RiverOak Strategic Partners

Appendices to Answers to First Written Questions

TR020002/D3/FWQ/Appendices

Examination Document

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Manston Airport Development Consent Order

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Thanet District Council

Economic Development in Thanet

(Employment Land Update and Economic Needs Assessment)

July 2018

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www.thanet.gov.uk

thanet
district council

Appendix G.1.3 (Part A)

Appendix G.1.3 (Part A)

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Appendix G.1.3 (Part A)

Introduction

1.1 This document draws together employment evidence and gives reasoning behind the level of growth to be planning for and the economic strategy to achieve this. It also updates the evidence in the Employment Land Review (ELR) that was published in 2010, identifying any areas of change, and reviewing the conclusions.

1.2 There have been a few significant changes since the publication of the ELR. The National Planning Policy Framework was published in March 2012 and there have been some potentially significant changes in local economic circumstances as well as the national and global picture.

1.3 The Council appointed Experian to carry out an assessment of job growth to 2031. The commission involved an assessment of business sectors, % of jobs in the B Use Classes, clusters or networks of knowledge driven creative or high tech industries, the rural economy and barriers and opportunities for growth. This work has helped to inform this document and in the light of the conclusions from the Economic and Employment Assessment 2012 the employment sites from the ELR 2010 have been revisited and reassessed.

Things that have changed since the 2010 ELR

<u>The National Planning Policy Framework (NPPF)</u>

1.4 One of the major changes since the ELR was carried out is the change in policy guidance at the National Level with the introduction of the National Planning Policy Framework.

1.5 The National Planning Policy Framework now requires that Local Planning Authority's

- set out a clear economic vision and strategy for their area which positively and proactively encourages sustainable economic growth;
- set criteria, or identify strategic sites, for local and inward investment to match the strategy and to meet anticipated needs over the plan period;
- support existing business sectors, taking account of whether they are expanding or contracting and, where possible, identify and plan for new or emerging sectors likely to locate in their area. Policies should be flexible enough to accommodate needs not anticipated in the plan and to allow a rapid response to changes in economic circumstances;
- plan positively for the location, promotion and expansion of clusters or networks of knowledge driven, creative or high technology industries;
- identify priority areas for economic regeneration, infrastructure provision and environmental enhancement; and
- facilitate flexible working practices such as the integration of residential and commercial uses within the same unit.

1.6 The NPPF also has the following requirements in terms of the evidence base, and Local Planning Authorities should assess:

- the needs for land or floorspace for economic development, including both the quantitative and qualitative needs for all foreseeable types of economic activity over the plan period, including for retail and leisure development;
- the existing and future supply of land available for economic development and its sufficiency and suitability to meet the identified needs. Reviews of land available for economic development should be undertaken at the same time as, or combined with, Strategic Housing Land Availability Assessments and should include a reappraisal of the suitability of previously allocated land;
- the role and function of town centres and the relationship between them, including any trends in the performance of centres;
- the capacity of existing centres to accommodate new town centre development;
- locations of deprivation which may benefit from planned remedial action; and
- the needs of the food production industry and any barriers to investment that planning can resolve.

1.7 The 2010 Employment Land Review took an in depth look at the quantitative and qualitative need for economic floorspace including a review of economic indicators, existing employment space and its quality, the commercial property market of Thanet, a review of business needs and an assessment of employment land requirements.

1.8 The changes in national policy along with changes in the economy since 2010 triggered the need to understand the latest forecasts in job growth, what the growth sectors are for the District and the likely employment floorspace requirements. This document revisits the ELR using this updated evidence along with other relevant information.

1.9 The Council has also had a Town Centre Retail, Leisure, Tourism and Culture Assessment carried out by Nathaniel Lichfield and Partners to understand the needs of the non B use class uses. The assessment carried out a completely new household telephone survey as well as in street surveys. In addition to purely retail uses the survey assesses leisure, tourism uses and looks at the role and function of the town centres, which further satisfies the requirements of the NPPF. The assessment was updated in 2016 and 2017 to incorporate changing housing forecasts.

1.10 The National Planning Policy Framework also requires Local Planning Authorities to specifically consider the needs of the rural economy, home working and the communications infrastructure.

<u>Rural Economy</u>

1.11 The NPPF says that planning policies should support economic growth in rural areas in order to create jobs and prosperity by taking a positive approach to sustainable new development. To promote a strong rural economy, local and neighbourhood plans should:

- support the sustainable growth and expansion of all types of business and enterprise in rural areas, both through conversion of existing buildings and well designed new buildings;

- promote the development and diversification of agricultural and other land-based rural businesses;
- support sustainable rural tourism and leisure developments that benefit businesses in rural areas, communities and visitors, and which respect the character of the countryside. This should include supporting the provision and expansion of tourist and visitor facilities in appropriate locations where identified needs are not met by existing facilities in rural service centres; and
- promote the retention and development of local services and community facilities in villages, such as local shops, meeting places, sports venues, cultural buildings, public houses and places of worship.

1.12 In the same year as the NPPF was published the Government (Defra) released the rural statement in September 2012. The Statement is based around three key priorities; Economic Growth and ensuring rural businesses make a sustainable contribution to national growth; Rural Engagement; and quality of life to ensure that rural people to have fair access to public services and to be actively engaged in shaping the places in which they live. This document is mainly aimed at remote rural communities of the UK and as recognised in the ELR 2010 Defra themselves categorise Thanet as "Other Urban" in the rural/urban land classification they use for policy making.

1.13 The Rural area in Thanet is very close to the urban area and centres of economic activity and these are highly accessible in comparison with other districts. They are not isolated settlements of economic inactivity as elsewhere in the country, particularly the 5 priority areas identified in the rural statement.

1.14 In Thanet there are two types of rural economic activity. One is economic activity that occurs in rural areas but is not dependent on the rural area for the economic activity and the other is economic activity that is dependent on the rural area for the economic activity such as agricultural and equestrian businesses. Due to the geography of Thanet both co exist successfully.

1.15 The ELR stated that the number of VAT registered enterprises within the rural area was less than 10% and this is still the most up date data, however a more detailed breakdown of these figures shows that 10% of the rural businesses in Thanet employ 20 persons or more compared with 5% in both the South East and England. The ELR also noted that much of Thanet's employment space is located in the rural area on sites such as Laundry Road and Hedgend Industrial Estates and it is important that these sites remain.

1.16 Village audits carried out by the Parish Councils suggest that there is a fairly even spread of businesses across the villages. Many service industry businesses exist to serve the local population and sit alongside large farming businesses and businesses that support the land based economy such as agricultural repair companies.

1.17 The Council has traditionally supported sustainable rural economic development through planning policy and permission has been granted for businesses in the rural area in the past. The NPPF also requires Local Planning Authorities to support the needs of the food production industry. The Council considers how to support the rural economy, rural communities in terms of service provision and quality of life and the needs of the food production industry in Part D of the Employment Topic Paper.

Working from home

1.18 The rising trend of live/work is an important consideration for the rural economy as well as the wider economy. It is a sustainable method of working and can be encouraged as a way to strengthen the rural economy. With the increasing level of home working and technical innovations in food production and farming it is vital that telecommunications infrastructure in the rural area is supported.

1.19 The publication Understanding Kent's Home Based Business sector shows that home based working is a growing trend and that nationally 63% of home based businesses were in the service sectors. As the service sector dominates Thanet's economy it is reasonable to assume that live/work is a growth opportunity for Thanet's economy and should be supported. Fundamental to the success of home based working is adequate communications infrastructure such as broadband.

1.20 Overall findings of the report include that most businesses in the UK are started from home, homeworking is more prevalent in rural areas than urban and that home is the main business or work premises for 41% of small to medium sized enterprises. Supporting home working can be a way of supporting Thanet's rural economy and new businesses which would support the aims of the national planning policy framework and Thanet's overall economy.

1.21 The report also concludes that workhubs should be used as a "tool" to grow the home based economy. Workhubs act as flexible office space with professional equipment and meeting space that can be hired and used in an ad hoc manner by home based workers. The Council has traditionally supported the growing trend of home working through planning policy and work hubs could be located in an accessible central location in the District.

Communications Infrastructure

1.22 The National Planning Policy Framework says that advanced, high quality communications infrastructure is essential for sustainable economic growth. The development of high speed broadband technology and other communications networks also plays a vital role in enhancing the provision of local community facilities and services.

1.23 In preparing Local Plans, local planning authorities are required to support the expansion of electronic communications networks, including telecommunications and high speed broadband. They should aim to keep the numbers of radio and telecommunications masts and the sites for such installations to a minimum consistent with the efficient operation of the network. Existing masts, buildings and other structures should be used, unless the need for a new site has been justified. Where new sites are required, equipment should be sympathetically designed and camouflaged where appropriate.

1.24 The NPPF also contains detail on determining planning applications for telecommunications.

1.25 Kent County Council has been campaigning for super fast broadband across Kent. Over the past 20 years Kent has seen a massive increase in growth, and to attract more business and economic growth to our communities we need to equip the county with a strong digital structure. Broadband is essential for regeneration, and therefore making

Kent the destination of business choice for the future is key. The aim of KCC's work is to attract business to smaller areas, benefitting communities in terms of regeneration and the economy. Kent County Council (KCC) is working with the Government's broadband agency Broadband Delivery UK (BDUK). The Making Kent Quicker programme covers a range of projects that KCC is leading to improve broadband infrastructure

1.26 The Employment Topic Paper considers how communications infrastructure and home working might be supported.

1.27 One of the provisions of the NPPF is to identify the Functional Economic Area to reflect the market geography within which the local economy sits. This has been addressed later on in the Floorspace Requirements section of the report.

Changes in the Economy

Recession

1.28 The macro economic situation of the country has had an affect on employment growth in Thanet. In 2008 the UK economy went into recession. Gross domestic product fell by 1.5% in the last three months of 2008 after a 0.6% drop in the previous quarter which meant two consecutive quarters of negative economic growth – the definition of recession. The figures, from the Office for National Statistics (ONS), showed that manufacturing made the largest contribution to the slowdown, contracting by 4.6%.With the exception of agriculture, all elements of the economy shrank in the first tear of recession.

1.29 Low wage growth and low consumer spend means that UK growth is expected to be 1.4% in 2018 (PWC 2018)

Public Sector Cuts

1.30 The political priority is to cut this fiscal deficit and the Government has responded to the situation with a series of austerity measures, which include public sector cuts including jobs. Thanet and East Kent relies heavily on the public sector. Thanet has the 2nd highest level of public sector dependence in the South East with 14,200 people or 35.3% of the total workforce. Thanet has a high proportion of public sector employees with 22.7% of total employment within the public sector. There is expected to be a gradual reduction in public sector employment as a result of budget constraints.

1.31 A report by Kent County Council into public sector dependency models 3 scenarios, a 5%, 10% and 15% cut in public sector jobs. The report concludes that there could be between a 1 and 5% reduction in employment growth between 2010 and 2025. Public sector job losses may mean a very different unemployment demographic. Public sector workers tend to be older, relatively highly qualified and the majority are women. This is different to the current unemployment trend of young workers just entering the job market. Public sector job losses and cuts in expenditure also impacts upon the private sector, particularly service providers.

1.32 The goal and challenge is clearly to grow the private sector. Between 2000 and 2008 Thanet's private sector jobs grew by 14% which is a positive direction of travel. The report suggests that in order to build on this Kent should take advantage of growing sectors such as the low carbon and environmental goods sector and the creative industries sector. The introduction of the High Speed One Domestic Rail Service could encourage the “London Effect” It suggests to take advantage of this potential growth that Kent should position itself in terms of relevant skills base and supporting business investment.

Closure of Pfizer Sandwich Campus

1.33 In February 2011 Pfizer announced that it was closing its Sandwich campus which employed approximately 2,400 people. The phased closure happened over a year and some staff have been retained. Indirect job losses such as those of security and delivery staff made the total even higher.

1.34 A report by DTZ in 2011 estimated that 9,900 FTE jobs could be lost in Kent or 6,100 in East Kent if all jobs on the Pfizer Sandwich campus are lost. It concluded that if 25% of current employees secure employment through other new employers on site, or in the East Kent area, the estimated job losses would be 7,400 FTE jobs in Kent and 4,500 in East Kent. Employment impacts appear most significant in Dover district where the Pfizer campus is located; however as a significant proportion of employees live in surrounding districts, the direct residence based impacts would be spread more evenly between districts. It is understood that around a third that of Pfizer employees came from Thanet.

1.35 Total combined job losses in East Kent were estimated to reach 7,800 in 2011, based on the loss of all jobs at the Pfizer Sandwich Campus, the closure of Dungeness A power station, the start of decommissioning on Dungeness A, and the first year of public sector cuts (25% of total reductions). Combined job losses in East Kent are estimated to increase to 12,200 by 2018, based on the loss of all jobs at the Pfizer Sandwich Campus, the closure of Dungeness A and B power station, the decommissioning of both power stations, and the full amount of public sector cuts. This may be a pessimistic assumption given measures that are being put in place to address this.

1.36 The report concluded that if 25% of current Pfizer employees secure employment through other new employers on site, or in the East Kent area, then employment growth would be expected to return to East Kent in 2014 and employment levels of 2009 attained in 2017. However, it should be noted that employment growth in the retail and hotel sectors will not necessarily provide equivalent employment opportunities for the highly skilled that remain unemployed following the closures of Pfizer and Dungeness and average salaries in these sectors are also likely to be lower than those achieved at Pfizer and Dungeness.

1.37 It is unclear from latest statistics whether these impacts have occurred especially as not all of Pfizers workforce lost their jobs. There have also been a number of positive interventions that will have benefitted and have future benefits for Thanet’s economy.

Discovery Park

1.38 The former Pfizer campus is under new ownership and the Government has designated Discovery Park at Sandwich, Kent an Enterprise Zone. This is a major opportunity for the workforce and supply chain businesses in Thanet and offers the potential for East Kent to maintain its position as a leader in life science and pharmaceutical production. Discovery Park Enterprise Zone covers 99.4 hectares on the

Pfizer site at Sandwich and was sold to a private consortium, Discovery Park Ltd, in August 2012.

1.39 The package of incentives on offer for businesses locating at the Enterprise Zone are attractive and include:

Business rate discounts:
The available discount is a maximum of £55,000 per year, for up to five years (i.e. a maximum discount of £275,000 over a five year period). There is no limit on the percentage discount, so a business paying rates of less than £55,000 per year could receive a discount of 100%, subject to European state aid rules which will not apply to most businesses.

Planning simplification:
The Enterprise Zone has a simplified planning regime. To achieve this, Dover District Council has developed a Local Development Order (LDO) in partnership with businesses in the Enterprise zone, Kent County Council, the Environment Agency, English Heritage, Natural England, Locate in Kent, Business Link, Sandwich Town Council and Thanet District Council. The LDO enables the conversion of existing buildings, the development of new buildings and changes of use, without the need for individual planning permissions, provided that it is within the scope of the Order.

Superfast broadband:
The Government's Enterprise Zone prospectus offers support to ensure that superfast broadband is available throughout the Zone, by guaranteeing the most supportive regulatory environment and if necessary public funding. Discovery Park already has good broadband access and it is not yet known what additional Government support will be required or available.

1.40 Thanet District Council has worked closely with Dover District Council on strategic projects along the Richborough corridor including developing a masterplan for Discovery Park which now includes 500 homes and a combined heat and power plant. Discovery Park is proving a success and leading the way in Enterprise zones. 650 Pfizer jobs remained on site and with new companies on site now employ around 2,400 people.

Thanet's Accessibility

Kent International Airport
1.41 Kent International Airport lies 2 km west of Ramsgate on a chalk plateau in the central part of the Isle of Thanet, North East Kent. It is approximately 110km east of London. The airport is 1.5 kilometres from the dual carriageways (A299 then M2) which provide fast road links to the M25 and London. Drive time to London is approximately 1 to 1.15 hrs. The airport is within half an hour drive of Dover and both Dover and Ramsgate ports have access to Europe. The airport was formerly an RAF base and became a passenger terminal in1964-65.

1.42 The former owners of the airport, Infratil, produced a Masterplan in 2009 which estimated passenger and freight numbers for the airport to 2033 along with details of future airport expansion and these projections are detailed in the ELR 2010. Estimates for growth proposed in that Masterplan have not happened.

1.43 Following the sale of the airport by Infratil in 2013 and its closure by new owners Lothian Shelf in May 2014 the Council has made significant efforts to explore its CPO powers to support a functioning aviation use in the site. The table below details the work of the Council in trying to secure this.

- July 2014 - Cabinet resolved to carry out a soft-market testing exercise to identify a CPO Indemnity Partner – a third party who could cover the costs of compulsory purchase of the Manston Airport site.
- December 2014 – Cabinet decided that no further action be taken at the present time on a CPO of Manston Airport, on the basis that the Council has not identified any suitable expressions of interest that fulfil the requirements of the Council for a CPO indemnity partner and that it does not have the financial resources to pursue a CPO in its own right.
- May 2015 - Extraordinary Council meeting agreed that to recommend to Cabinet that it reviews its position in relation to the Manston Airport site, taking account of all the surrounding circumstances relating to an indemnity partner for a possible Compulsory Purchase Order.
- July 2015 – Cabinet decides to authorise specialist advice to determine whether RiverOak are a suitable indemnity partner in relation to a CPO for Manston Airport.
- October 2016 - Cabinet decides to take no further action at the present time on a CPO of Manston Airport, on the basis that RiverOak do not fulfil the requirements of the Council for an indemnity partner
- December 2015 - Cabinet decides to undertake a further soft market testing exercise to identify any interest in becoming a CPO indemnity partner in relation to Manston airport
- June 2016 - Cabinet considered the assessment of the responses to the exercise and agreed that in terms of the key lines of enquiry, the market cannot deliver on the council's requirements; there is no established market which is able to deliver, or an adequate number of operators; the market has no capacity to deliver the requirements and there is no cost or other benefits in taking this matter further.

1.44 Following this the Council sought to understand whether an airport would be a viable operation for the site and whether there would be a reasonable prospect of that occurring within the plan period of the Local Plan (i.e. to 2031) so that it could fully consider the options for the site. The Council also needed robust evidence to inform the Local Plan. Accordingly the Council appointed Avia Solutions to carry out the study.

1.45 The Avia Solutions Report September 2016 concluded that it is most unlikely that Manston Airport would represent a viable investment opportunity even in the longer term (post 2040), and certainly not during the period of the Local Plan to 2031.
The owners of the airport site submitted a planning application in April 2016 for a mixed use development comprising 2,500 dwellings, 85,000sqm of employment floorspace, a 3,100sqm of retail floorspace, a 120 bedroom hotel and two primary schools known as Stone Hill Park.

1.46 RiverOak Strategic Partners are in the process of submitting a Development Consent Order (DCO) to the Secretary of State to acquire the site for aviation use as a Nationally Significant Infrastructure Project (NSIP). The proposal is to reopen Manston as a hub for international air freight which also offers passenger, executive travel and aircraft engineering services.

1.47 At the time of writing the application remains undecided and the DCO is yet to be accepted by the Planning Inspectorate.

<u>High Speed Rail</u>

1.48 Domestic services on the high speed Channel Tunnel link line began in December 2009, operated under a UK franchise agreement by Southeastern railway.

1.49 Since the service began, commuters from Kent using the service have been able to benefit from significant time savings. For example, commuting from Ashford to central London used to take 84 minutes and now takes just 37 minutes on the High Speed service. Journey times to London from Thanet are currently 76 minutes.

1.50 This has had potentially significant positive effects on Thanet's economy and perception. A report was published in January 2009 "Economic Impact of High Speed 1" carried out by Colin Buchanan for London and Continental Railways that assessed some of the effects.

1.51 Some broad conclusions were that the scheme brings about improvements to journey times between London and destinations in Kent as well as Paris and Brussels and also has significant regeneration impacts.

1.52 The report said the four main benefits of the scheme were:

- A financial impact (increase in rail revenues)
- Conventional transport benefits (e.g. journey time savings)
- Wider economic benefits (enabling workers to move to more productive jobs by increasing peak capacity to central London, and increasing the effective density of London and locations in Kent by reducing the generalised costs of travel)
- Regeneration (helping to deliver the regional growth strategy and thus providing the land that allows new investment)

1.53 With regards to regeneration, impacts of the scheme include:

- The value of the housing stock in the study area may increase by around £1.3bn, representing a capitalised value of HS1 benefits to current residents;

- Earnings per annum across the study area may increase by between £62m and £360m due to the commuting facilitated by HS1.

1.54 A later report prepared by the Local Strategic Partnership in March 2011 called “High Speed 1 Impact Analysis Year One Study” looks at satisfaction levels with the service and public perception. The report shows that there is a high level of satisfaction with users of the service but when looking at its impact on economic growth respondents to a survey were not aware that the High Speed services extended to east Kent suggesting that better marketing for the area is needed.

1.55 Some potential knock on benefits of the High Speed 1 scheme for Thanet include a high speed rail extension to Thanet and a potential new station.

High Speed Rail Extension to Thanet
1.56 KCC is working with Network Rail to investigate ways in which journey times on the existing Ashford to Ramsgate line could be reduced. A preliminary study found that there is the potential to reduce current journey times by up to 10 minutes. Thanet District Council continue to campaign for this line upgrade. Funding is in place for line improvements between Ashford and Canterbury and Canterbury and Ramsgate.

Thanet Parkway

1.57 Kent County Council’s Local Transport Plan “Growth without Gridlock” includes proposals for a new station on the High Speed 1 line.

1.58 KCC has been promoting the building of a new parkway station in Thanet on the existing rail line between Minster and Ramsgate since 2010. Long commuting times to London are often seen as a barrier for new business investment in the area. Thanet Parkway railway station will complement high speed rail, bringing Thanet to within about an hour’s journey time of London, thereby improving the perception of East Kent as a place for investment, particularly at Discovery Park Enterprise Zone, the former Manston Airport site and other development sites proposed in the draft Thanet Local Plan. The improved rail connectivity to London and across the County will allow local residents to access a wide range of job opportunities.

1.59 The proposed location of the Parkway Station is on the Ashford International to Ramsgate line, south of the former Manston Airport site and just to the west of the village of Cliffsend. It will be sited between Minster and Ramsgate railway stations, and will be served by both Mainline and High Speed trains. See map below:

1.60 The proposed parkway station will widen employment opportunities for Thanet residents by providing improved rail access to London and other locations in the county. Thanet Parkway will encourage growth in Thanet and East Kent, and will also cope with the growth in rail usage from existing and future communities.

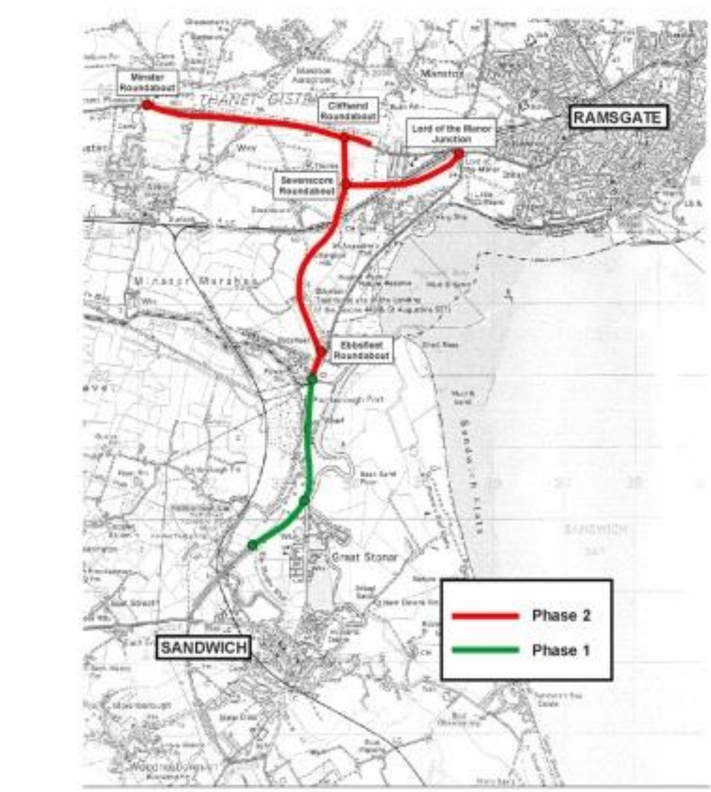
1.61 It was proposed the station will be part funded by the Local Growth Fund (LGF) through the South East Local Enterprise Partnership (SELEP) along with a contribution from KCC. An application has been made to Network Rail and the Department for Transport’s New Stations Fund for the remaining funding, Thanet Parkway Station

1.62 KCC are currently preparing a business case for a new station and are considering capacity at the existing stations. These improvements to rail infrastructure in Thanet are potentially very positive for Thanet’s economy and options for their development are discussed in the Employment Topic Paper.

<u>East Kent Access</u>

1.63 East Kent Access, a phased road improvement scheme for the Thanet and Dover Districts, opened in May 2012. The overall project cost £87 million funded by the Department of Transport with £5.75 million coming from Kent County council. Phase 1 of the scheme was designed to improve accessibility and safety. The scheme was designed to help the economy of East Kent and connect the ports of Dover and Ramsgate and Kent International Airport. Phase 2 was an improvement to dual carriageway standard and crosses roads and railway lines. The map below shows the route.

East Kent Access Phase 2



1.64 The local transport plan for Kent 2006-2011 states that the purpose of the East Kent Access scheme derives directly from the principal objectives of the first Local Transport Plan, namely to:

- stimulate economic activity and employment;
- integrate transport planning with the wider spatial planning of the area;
- improve safety and security in the transport system;
- influence and manage the demand for the type of transport used
- widen the choice of transport available to the area

1.65 The Local Transport Plan stated that Phase 1 alone would generate some 450 jobs, whilst Phases 1 and 2 together would generate some 8,000 jobs by 2016 and that the scheme is therefore a central and indispensable part of the regeneration of East Kent and its coastal towns and the re-balancing of the south east's economy. With the closure of Pfizer and the recessions these predictions may not be accurate but the road infrastructure improvements will be benefit the development of Discovery Park and Thanet residents. Other benefits of Phase 2 were stated as:

- To provide more efficient and rapid access from Sandwich and the Sandwich corridor to the major labour source in the Thanet towns.
- To provide more efficient access from the employment hub at Sandwich, westward to the A299 and the principal motorway route to domestic markets.

- To complete the high grade access of the Sandwich Corridor between the A2 at Dover and the A299/A253 Thanet Way and thereby capitalise on the provision of a wider and more mobile labour market in East Kent.
- To increase the mutual advantages of linking Kent International Airport to the Port of Dover, as an international port and cruise terminal.
- To improve the general accessibility of the former Kent coalfield sites.
- To provide for flexibility in the management and control of international freight between the Channel, and Ports of Dover and Ramsgate at times of disruption to the M2 and M20 corridors or French, Belgian and Dutch ports.
- To ensure good South Coast connections, avoiding Canterbury, between the regional airport at Manston and South Kent and Sussex.

Ramsgate Port

1.66 In 2000 the Royal Harbour Approach Road was built to improve access to the Port and service the then thriving ferry industry operating in and out of Ramsgate. The port has excellent ro ro facilities and excellent road connectivity although unfortunately TransEuropa ferries ceased operating form the port leaving Ramsgate with no ferry operator. The Port currently services 2678.4 MW of Wind Energy and with further planned increase in the UK's offshore energy capacity there is potential to grow the port's renewable energy support facilities and increase geographic reach.
The current Port Masterplan produced aspires to re introduce a roll on roll off passenger service to the port, support growth in commercial use of the port and support the tourism and leisure industry that surround the neighbouring Royal harbour and its key priorities are:

- Protecting and growing existing relationships with users of the port and harbour in order to assure service standards and secure future income streams;

- Implementing a Ro-Ro strategy described in this plan to restore the commercial port's market position and recover recent lost revenue;

- Making improvements to the Royal Harbour Marina (new marina management system, increasing visitor footfall and dredging) to significantly enhance the user experience and attract more visitors;

- Keep the re-launched website fresh to support the commercial port an Royal Harbour Marina in order to raise substantially their market profiles.

Cultural and Leisure Development

1.67 The Turner Contemporary gallery on Margate seafront opened in 2011. The project was part funded by Kent County Council, Thanet District Council and the South East England Development Agency and its purpose to trigger economic regeneration in the town.

1.68 A report into the economic impact of Turner after its first year was published in April 2012. The gallery received 495,000 visitors in the first year. The report concludes that the total economic benefit for 2011/2012 is £13.9 million and a total of 130 full time equivalent created jobs during its first year.

Number of visits	495,000
Gross effects (£)	
Visitor-related expenditure	5.4 million
Gallery expenditure on goods and services	0.9 million
Other gallery expenditure	0.7 million
	7.0 million
Net additional effects (£)	
Visitor-related expenditure	4.5 million
Gallery expenditure on goods and services	0.6 million
Other gallery expenditure	1.1 million
	6.3 million
Destination profile benefits (£)	
Press coverage	6.0 million
Broadcast media	0.7 million
	7.6 million
Total economic impact 2011/2012 (£)	13.9 million
(Net additional effects plus destination profile benefits)	
Direct employment (within the Gallery) (FTEs)	49
Indirect employment support by the Net Additional Effects (FTEs)	81
TOTAL	130

1.69 The report clearly shows that the Turner Contemporary has had a very successful first year. The success has continued and in August 2013 the gallery welcomed its one millionth visitor and it is evident that there have been knock on effects in Margate's Old Town with numbers of galleries, shops, cafes and restaurants opening recently. Between November 2012 and March 2013 there was a 59% increase in contacts to the Visitor Information Centre compared to the same winter period before the Turner Contemporary opened.

1.70 Dreamland also reopened in 2015 following a multi million pound revamp and created considerable interest in Thanet. In 2012 The Dreamland Trust appointed multi-disciplinary designer, Wayne Hemingway MBE and the HemingwayDesign team to bring forward the branding and design scheme for Dreamland.

1.71 In September 2013 Dreamland transferred into the council's ownership securing the future for Dreamland. After a long restoration project, Dreamland opened its doors to the public in June 2015. Work was carried out on the Scenic Railway, along with an Historic Rides Collection, internal spaces, archiving, learning and engagement programmes. The attraction saw bumper visitor numbers of 50,000 during the May bank holiday in 2017. Further phases of development are ongoing.

1.72 A report into the Economic Impact of Tourism by Visit Kent in November 2016 found that £293 million spent in the local area as result of tourism, taking into account multiplier effects. This is an increase of over 19% compared to 2013. This demonstrates how important tourism is to the public sector.

Growth and Funding Initiatives

Public Sector Finance

1.73 Public sector finance has been made available by Kent County Council to support new jobs and business growth which will help the private sector base in east Kent.

1.74 “Expansion east Kent” had funding of £35 million available from the Regional Growth Fund. They are offering 0% loans for businesses wishing to start up or expand in east Kent. The programme aims to unlock private sector finance, stimulating over £300million in associated investment over the course of the next three years and creating a major boost for the East Kent economy. Kent County Council, with the support of the Sandwich Task Force and the East Kent Districts, was successful in applying to the Government’s Regional Growth Fund (RGF). Over £30 million was taken up.

1.75 Work is ongoing under the Kent and Medway Business Fund offering 0% loans to small and medium sized businesses across Kent and Medway funded by loan repayments from previous Regional Growth Fund Schemes (Expansion East Kent, Tiger and Escalate).

Thanet’s Economic Growth Strategy

1.76 Thanet District Council’s Economic Growth Strategy was published in November 2016 and it identified key transformational initiatives to focus on to deliver employment growth. These are:

- Developing the Port at Ramsgate
- Investing in high value manufacturing and engineering across Thanet and east Kent
- Position Thanet as a global agritech hub
- Promoting Thanet’s broader cultural/leisure offer
- Cultivating the creative industries across Thanet
- Designing enterprise into new communities
- Long term feasibility modelling for Margate and Ramsgate

East Kent Growth Framework Report December 2017

1.77 The East Kent growth Framework (EKGF) has been prepared by the East Kent Regeneration Board (EKRB) to set out an overarching strategy and investment priorities for achieving long-term sustainable growth across East Kent between 2017 and 2027. The EKRB comprises the five East Kent authorities and Kent County Council.

1.78 Several projects were identified in Thanet:

- Port of Ramsgate
- Thanet Parkway Station
- Inner Circuit Improvement Strategy
- *Westwood Relief Strategy*
- Margate Junction Improvements
- Advanced Manufacturing Park (Margate Business Park)
- Creative Industries Workspace
- Feasibility Modelling for Ramsgate, Margate and Viking Bay
- *Ramsgate Heritage Action Zone*
- *Theatre Royal*
- *Dreamland and Sunshine Café Redevelopment*
- *Viking Bay*
- Eurokent Business Park
- Agri-tech Hub
- East Kent College Broadstairs Campus extension

(*italics* represent subsidiary projects which are linked to or required in order to deliver the heading project)

1.79 Spatial priorities for Thanet are Port of Ramsgate, Thanet Parkway Station and Inner Route Improvements, Advanced Manufacturing Park at Manston Business Park, Creative Industries workspace and developing out Eurokent Business Park.

Key Findings:

- Thanet has a high dependency on the public sector for employment.
- The closure of the Sandwich Campus of Pfizer was a set back for the local economy although measures to mitigate this have been successful.
- Infrastructure improvements such as the introduction of High Speed One and the opening of East Kent Access have significantly improved access to Thanet and are very positive for the economy
- The Turner Contemporary Gallery, Dreamland and other attractions are having a very positive economic effect
- Following the closure of Pfizer public sector finance has been made available to assist businesses wishing to start up in Thanet
- The Council's Economic Strategy and the East Kent Growth Framework have identified similar economic aims and objectives for the District that strategic partners will deliver

Socio economics, existing employees and space and additional economic considerations

2.1 The 2010 Employment Land Review concluded that Thanet suffers from severe socio economic problems and this is still the case.

2.2 In November 2017 the proportion of working age population claiming Job Seekers Allowance in Thanet was 2.4% compared to 0.7% in Kent and 1.1% in the South East. Unemployment is still significantly above Kent and the South East. The claimant rate peaked at 6.4% in February 2012 which is almost double the UK average. The figure was 5.6% in July 2013 which demonstrates an improvement.

2.3 The claimant count for Thanet in November 2017 was 3.8%. The South East average for all age groups is 1.2% and for Great Britain it is 1.9%. This shows Thanet has a significantly higher claimant count than the south east and national averages.

2.4 The employment rate is a measure of the proportion of the population of working age who are actually in work. It is reduced by the number of those of working age who are students but not also employed; those people who are unemployed; and the number of people of working age who are economically inactive. The rate for Thanet in 2009 was 63.5% but increased in 2016 to 75%.

2.5 The average earnings of those ***living*** in Thanet in 2009 was £426 per week. This compares to £520 per week for residents of Kent as a whole, and £537 per week for those living in the South East of England. In 2012 the average weekly earnings of those living in Thanet fell to £412.5 and rose to £478.6 in 2017. Resident earnings of those living in Kent and the South East of England are boosted by the significant numbers of residents who work in London where they command higher salaries than they would were they to work where they live.

2.6 The average earnings of those ***working*** in Thanet in 2009 was £383 per week. This compares to £479 per week for those working in Kent as a whole, and £514 per week for those working in the South East of England. In 2012 the average weekly earnings of those working in Thanet rose to £392 and again to £424.5 in 2017. The low workplace earnings of those working in Thanet reflect the relative low value added economic activities located in the district and the level of part time work although the figures show that this is improving.

2.7 The Index of Multiple Deprivation captures many of the above indicators and a range of additional indicators to give a relative ranking on the level of disadvantage of the authority. Thanet is the most disadvantaged District in Kent as measured by the IMD and within the top 10% of the most deprived authorities nationally. Thanet's overall ranking in the Index of Multiple Deprivation is attributable in large measure to the intense deprivation to be found in five wards within the District; the wards of Central Margate and Cliftonville West in Margate, and the wards of Newington, Northwood and Eastcliff in Ramsgate.

2.8 Educational attainment in Thanet has significantly improved since 2009 across all level with the amount of students achieving NVQ1 to 4 or equivalents and other qualifications rising by approximately 10%. This could in part be due to school leaving age being increased to age 17 in 2013 and age 18 in 2015.

2.9 GVA per head is a broad measure of the wealth of an area. Thanet's GVA per head in 2009 was £14,788. In 2012 GVA per head increased to £14,876 and again to £15,021 in 2015 The UK average GVA in 2015 was £25,351. A significant factor in Thanet's low GVA per head is the large numbers of retired people living in the area but also below average productivity.

2.10 One reason why GVA varies between areas is because they can have very different numbers of people in work relative to the population as a whole. In Thanet there are 310 people in work for every 1,000 people living in the area, compared to 390 in Kent and 450 in the South East. The low proportion of people in work per 1000 population in Thanet reflects the relatively large proportion of the population that is over retirement age, (13%), compared to 11% in Kent, and 10% in South East England and this is expected to increase.

2.11 The number of employee jobs from 2008 is 40,200 and fell to 38,621 in 2012 and increasing again to 41,000 in 2016. The breakdown of jobs per sector is as follows:

Table 2 – Employment in Thanet 2016

	Employees	%	Kent %	England %
Agriculture, forestry and fishing	-	0	0.1	0.7
Mining and quarrying	-	0	0	0.2
Manufacturing	3,300	7.9	6.6	8.1
Electricity, gas, steam, air conditioning supply	100	0.3	0.3	0.4
Water supply; sewerage, waste management and remediation activities	200	0.5	0.8	0.7
Construction	2,100	5.2	6.3	4.6
Wholesale and retail trade; repair of motor vehicles and motorcycles	7,500	18.3	17.7	15.2
Transportation and storage	1,900	4.6	6.4	4.8
Accommodation and food service activities	3,800	9.1	6.8	7.4
Information and communication	700	1.7	2.9	4.2
Financial and insurance activities	800	2.0	2.7	3.5
Real estate activities	700	1.7	1.9	1.6
Professional, scientific and technical activities	1,600	4.0	6.5	8.6
Administrative and support service	2,400	5.8	9.9	8.9

activities				
Public administration and defence; compulsory social security	1,100	2.7	3.8	4.3
Education	5,500	13.4	10.2	8.9
Human health and social work activities	8,000	19.5	13.0	13.2
Arts, entertainment and recreation	1,100	2.7	2.3	2.5
Other service activities	700	1.7	2.1	2.0
TOTAL				

(Source: 2016 BRES, KCC Business Intelligence, Research Evaluation) (figures are rounded)

2.12 This shows that strong sectors in the Thanet economy are retail, accommodation & food services, education and health

2.13 Evidence from the Economic and Employment Assessment 2012 (EEA) shows that the green and tourism sectors comprise a greater proportion of total employment than they do in South East and England and have been growing faster.

The Green Sector

2.14 The green sector in Thanet has experienced growth above the regional and England levels over the last two years demonstrating growth potential within this sector. When the primary and secondary green sector are combined this amounts to more than 10% of total employment in Thanet.

The Tourism Sector

2.15 Similarly the tourism sector within Thanet has enjoyed stronger growth over the last two years than the region or England. The tourism sector in Thanet accounts for 9% of total employment compared to just over 8% for the region and England. Over the last two years the sector has grown by over 2% year on year compared to declines in the region and for England. Since the EEA was published KCC looked at BRES industrial categories and found that tourism now (2016 figures) accounts for 13.4% of Thanet's economy. (KCC Business Intelligence, Research Evaluation)

2.16 The Economic and Employment Assessment 2012 states that whilst there has been a decline in manufacturing in line with trends seen across the UK there are elements that have been performing better, namely high tech manufacturing within which the Thanet and the UK as a whole retains a competitive advantage.

2.17 Thanet's Economic Growth Strategy 2016 seeks to encourage creative industries in Thanet. This currently accounts for 1.8% of Thanet's economy. According to "Thanets New Wave – The creative force regenerating out towns" published in March 2017 the number of creative businesses in Thanet increased by 84% in the last four years (according to analysis of the Mint List in 2013 and 2016).

Floorspace Developed for Employment Type (all sites in the District)

Table 3 – Commercial Information Audit 2016

	A2/B1 sq m	B2 sq m	B8 sq m	A2/B1-B8 sq m
Completed 2015-2016	2,594	8,102	1,600	12,296
Completed 2014-2015	3,227	2,884	2,594	8,705
Completed 2013-2014	3,032	1,230	210	4,472
Completed 2012-2013	786	1,210	1,998	3,994
Completed 2011-2012	1,490	1,730	549	3,769
Completed 2010-2011	342	300	2,144	2,786
Completed 2009-2010	1,156	343	144	1,643
Completed 2008-2009	16,731	523	4,765	22,019
Completed 2007-2008	4,269	150	3,875	8,294
Completed 2006-2007	3,860	1,889	13,031	18,780
Completed 2005-2006	3,523	9,797	4,585	17,905

2.18 This demonstrates employment completions have been growing year on year since the ELR was published in 2010.

Count of Active Enterprises

Table 4 – Count of Active Enterprises

2010	2011	2012	2013	2014	2015	2016	2017
3,120	2,985	3,045	2,995	3,085	3,490	3,655	3,795

(Source: Inter Departmental Register (ONS))

2.19 The above table shows that the amount of active enterprises decreased slightly 2010 but has increased since 2015 and has remained at a fairly constant rate over a 2 year period.

Key Findings:

- Very little has changed in terms of Thanet's socio economic situation since the 2010 Employment Land Review. Thanet's economic profile is improving but is still not comparable with Kent, the South East and England.
- Strong sectors in the Thanet economy are retail, accommodation & food services, education and health
- In line with the UK trend Thanet is relatively strong in high tech manufacturing
- A particular growth area in Thanet is the Tourism sector.

Commercial property market

3.1 The 2010 Employment Land Review looked at the perception of Thanets Commercial Property Market by surveying Agents and concluded that the main demand and growth is coming from the local market and that there is little interest in companies or large investors wishing to relocate to Thanet.

3.2 This same survey was carried out again in 2012 and conclusions drawn are that the main types of businesses wishing to locate in Thanet currently are retail operators and reasonable quality light industrial/workshop units for small to medium sized enterprises and some engineering, manufacturing, ICT and environmental technology.

3.3 Regeneration in the District, the availability of funding and grants and transport links were seen as a positive attraction to businesses, as was the availability of training opportunities. Distance from established commercial centres (or perception of), planning constraints and high business rates were identified as factors that deter investment.

3.4 When asked about the commercial property market over the next fifteen years and what type of property should be provided and in which location respondents indicated there is likely to be a shift towards more internet and remote based working/consumerism. They identified a need for greater flexibility on employment sites with short leases that are easily sub divisible and easier changes of use. Light industrial/workshop/storage should be provided in accessible out of town locations with good access to transport links and trunk roads.

3.5 Locate in Kent (LiK) have emphasised that perception is a real barrier in demand for commercial property in Thanet. There is a perception that the District is hours from London and that road and rail infrastructure is inadequate. This is a not a true assumption but the problem of perception is a difficult one to tackle.

3.6 In November 2011 LiK carried out a survey of 158 companies with 10 or more employees, excluding schools, supermarkets and the public sector, but was also sent out by Dover and East Kent Chamber to an unknown number of other companies. 34 responses were received including 6 from members of the Thanet Business Forum, 5 other large companies and 23 mainly SMEs including one hotel, one business centre and two visitor attractions.

3.7 The majority of companies expected that their companies still to be In Thanet in 3 years with many anticipating needing space over the next 5 years. Over a third of the companies export and a number more were planning to.

3.8 The main opportunities for growth in Thanet in the next 5 years were seen as Manston, wind power and green energy supply chains, high speed rail, Ramsgate Port, tourism and agribusiness. The main threats and barriers to the business community included attracting suitably qualified staff and lack of finances to support escalating business costs. Some cited transport connectivity and planning difficulties. A number selected the availability of development land.

3.9 Priorities for the area were considered to be improve transport and infrastructure, grants loans and support, better planning and training and education.

Supply and Demand

3.10 The 2010 Employment Land Review considered data provided by Locate in Kent that show the supply and demand of Commercial Property in East Kent. The information is calculated from the number of enquiries that Locate in Kent receive and the level of supply is derived from Locate in Kent's property database. The same data source was reviewed in October 2012 and the following conclusions were drawn.

3.11 Previously the ELR showed that in the smaller industrial premises ranging from 0-1000sqm the match between supply and demand was relatively even. This is now showing that supply is greater than demand. This is also the case in the larger premises + 1000sqm

3.12 In terms of office premises less than 1000sqm the gap between supply and demand is noticeable with supply being much greater than demand and this was the case in the ELR. With regard to larger offices they are evenly matched.

3.13 Demand for industrial premises is still higher than for offices premises

3.14 BBP SQW as part of the development of Thanet's Economic Growth Strategy identified the following regarding Thanet's commercial property market:

Strengths

- Significant recent investment in connectivity, both rail and broadband, which has positioned Thanet as a strong business location with good access to London and to the rest of Europe
- Opportunities to develop an Advanced Manufacturing Park, working collaboratively with local education providers and employers and taking advantage of the districts location to Discovery Park
- The confidence gained from recent increases in the number of enterprises in the District and the number of residents in employment
- A growing and successful cultural offer and presence linked to Turner Contemporary and other local galleries/outlets, and opportunities to build on this
- A relatively competitive location (in terms of land and labour costs) in the greater south east, which can act as an incentive to both business investment and residents
- A port that can, potentially, grow significantly further in terms of commercial throughput, offshore energy facilities, the development of an "off-site commercial hub" and leisure uses
- High quality environmental assets – with an outstanding coastline and natural light conditions that are a significant asset, and wider possibilities for agritech applications in this context
- A commitment to investment in STEM sectors within the District, from Canterbury Christ Church University and East Kent College, including the potential to develop the "green-tech" sector

- Growing business representation in the creative sector over recent years, and associated skills development through FE and HE institutions
- Substantial planned housing growth – and associated population growth, creating inherent economic potential
- Possibilities linked particularly to the work of the Thames Estuary Growth Commission
- A progressive and committed District Council, delivering award winning services for its residents and businesses

Weaknesses

- A need for further investment in workforce skills
- Viability and developer challenges in the successful delivery of new development or relocation of existing businesses on major employment sites
- A tourism sector which is important to the area, and where growth in private investment in recent years needs to be supported and developed further. Hotels are at capacity at peak times and a lack of high quality accommodation
- Towns in need of a more clearly defined economic purpose; within specific areas / zones
- Increased competition and market challenges are impacting upon town centres – which in the context of fastchanging public expectations requires a renewed focus
- Ongoing uncertainty surrounding the future of the former Manston Airport site
- Uncertainties linked to the process of Brexit
- Despite growing confidence within the area, there are still some external perception issues to be addressed
- A Local Enterprise Partnership that is becoming more complex and competitive and where Thanet needs to promote its priorities and justify its "asks"

Key Findings

- There is still little demand for office premises
- The main type of businesses locating in Thanet are retail operators and reasonable quality light industrial/workshop units for small to medium sized enterprises and some engineering, manufacturing, ICT and environmental technology.
- There is a need for flexibility on premises and employment sites with shorter leases and easier changes of use.

Appendix G.1.3 (Part A)

Functional Economic Area and Floorspace Requirements

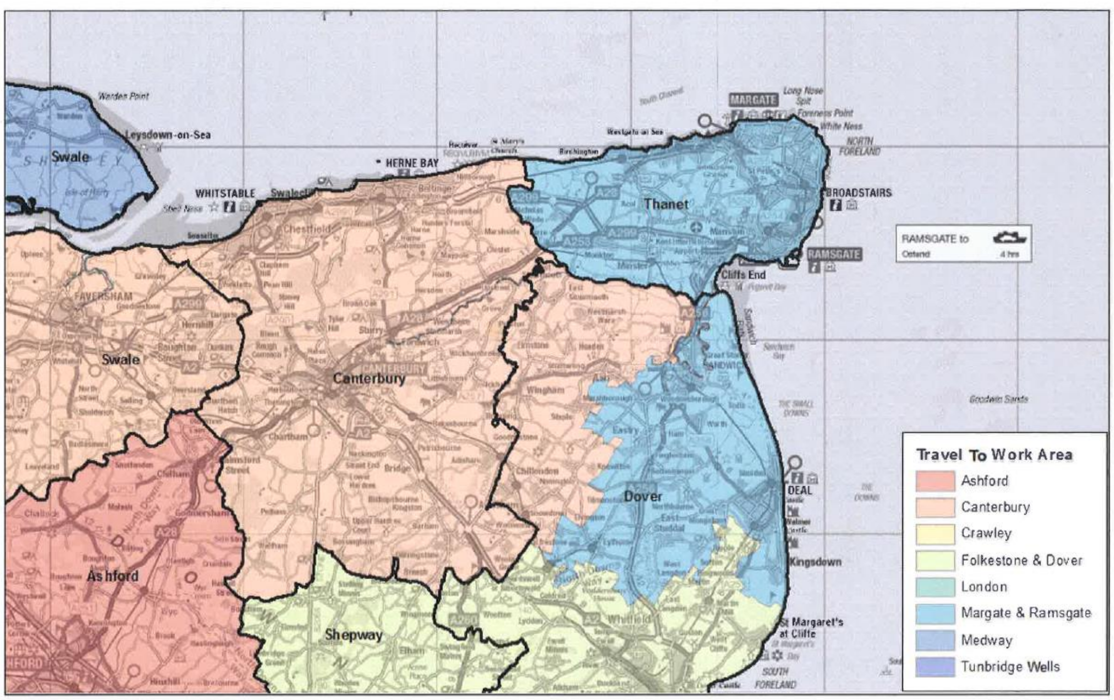
Functional Economic Area

4.1 National Planning Policy Guidance suggests that in order to establish functional economic areas we must take account of the extent of any LEPs operating in the area, travel to work areas, housing market area, the flow of goods, services and information within the local economy, service market for consumers, administrative area, catchment areas of facilities providing cultural and social wellbeing, and transport network.

4.2 The South East Local Economic Partnership (SELEP) covers East Sussex, Kent, Medway, Southend and Thurrock.

4.3 According to the census 2011 the travel to work area for Thanet is called the Margate & Ramsgate Travel to work area. It includes the whole of Thanet and extends southwards down the Richborough corridor and includes the towns of Sandwich and Deal. Recent improvements to the A256 have made travelling to work easier and quicker and have extended the travel to work area from the 2001 Travel to Work area. It is considered that much of this travel can be attributed to Discovery Park which attracts workers from Dover, Thanet and Canterbury and the types of business in zone since its designation has diversified whereas once it was more specialised science based research and development.

2011 Census Travel to Work Areas in East Kent



This map produced by Strategic Business Development & Intelligence, Kent County Council

4.4 Guidance also suggests that in order to understand your economic area you should also look at your housing market area. GL Hearn in the Strategic Housing Market Assessment January 2016 concluded that the best fit housing market area for Thanet included Canterbury and Dover. Collectively these authorities demonstrate a commuting self-containment level of between 79-87%. The report also concluded that there is an East Kent housing market area which includes the whole of the local authorities of Canterbury, Dover and Thanet, together with parts of adjoining authorities – including Faversham in Swale, Chilham in Ashford and Folkestone in Shepway. Evidence from Dover District Council's SHMA suggests that Dover shares a housing market area with Shepway and not Thanet and therefore Dover District Council object to their identification in the Thanet Housing Market Area. However, there is a clear economic relationship across East Kent and this is reflected in the east Kent Growth Framework.

4.5 Service facilities in the Westwood area have an element of cross boundary draw particularly from some centres located close to Thanet notably Canterbury, Dover, Deal, Herne Bay and Sandwich albeit small (Table 4B Comparison Shopping Penetration Rates 2012, Thanet District Council: Town centre Retail, Leisure, Tourism and Culture assessment. Appendices December 2012). And equally Canterbury is the principal service centre in east Kent and therefore Thanet has a strong economic relationship with the centre there. The Town Centre, Retail, leisure, Tourism and Culture Assessment for Thanet 2012 includes a survey of shoppers in Thanet Centres asked which other regular shopping destinations centres are regularly (Table 7.7 of the Appendices) used and this showed that a large amount of people shop in Herne Bay and Canterbury and some travel to Sandwich, Deal and Whitstable.

4.6 It is concluded therefore that in terms of defining the functional economic area for Thanet there is a strong relationship between the whole of Thanet, north eastern Canterbury District following the routes of the A28 and A299, along with the northern part of Dover District served by the A256 in particular Sandwich and Discovery Park.

Economic Forecasts

4.7 When evaluating economic forecasts the National Planning Policy Guidance states that plan makers should consider:

- Sectoral and employment forecasts and projections (labour demand)
- Demographically derived assessments of future employment needs (labour supply techniques)
- Analyses based on the past take-up of employment land and property and/or future property market requirements (past take up)

Labour Demand

4.8 Potential scenarios have been identified for the economic future of Thanet. These have been developed following a thorough review of the economic situation in Thanet, including identifying the potential threats and opportunities that exist, a review of the relevant policies, plans and strategies, as well as stakeholder input. Experian were commissioned to develop and test the following scenarios:

- Baseline (economy continues to perform in the way it has done in the past)

- Policy – on (assumes high growth especially in the green and tourism sectors)
- Risk Based (assumes that the economy returns to recession)

4.9 The different scenarios are discussed in more detail in the Employment Topic Paper 2013. The report also looked at growth scenarios for the airport. Due to uncertainty surrounding the airport this was done as a separate exercise. The airport high growth option assumes that the airport grows in line with the 2009 Airport Masterplan and this would result in 2,420 jobs. The airport low growth option was devised by Experian looking at similar sized airports and passenger numbers growing to 200,000. The low growth option resulted in a figure of 240 jobs in the district. Due to the level of uncertainty surrounding the airport including unachieved growth targets, the wider economic situation, the relatively peripheral location of the airport, uncertainty at the time over the Governments intended aviation policy and at the time the airport being up for sale it was considered that the low growth scenario should be planned for. This is still the case following closure of the airport as it is reasonable to assume that the site will deliver growth over the Plan period in some form.

4.10 Following consultation and Sustainability Appraisal at Issues and Options stage an overall job growth target of 5,000 jobs for Thanet was selected. This reflects a level of growth between baseline and policy on with an element of growth from the airport site.

4.11 Translating the labour demand method into floorspace the Economic and Employment Assessment concluded that Thanet need to plan for between -15 to 3 (ha) of B use class land during the plan period to 2031, see Table below. The range reflects the three scenarios, Baseline, Policy on and Risk based. It should be noted that this is a net figure and assumes the losses of B2 manufacturing uses would have already occurred; therefore in order to ensure that land would be available if the new development were to come forward prior to the loss of existing floorspace, it is considered necessary to plan for the gross increase required, which is in the region of 15 ha. The Assessment concludes that a margin of error will also need to be factored in.

Land and Floorspace requirements 2011-2031

Use Class	FTE Employment change 2011-31	Floorspace Need (sqm)	Land Need (ha)
B1	700 to 1,000	10,500 to 15,000	3 to 4
B2	-1,400 to -1,000	-63,000 to -45,000	-18 to -13
B8	0 to 600	0 to 42,000	0 to12
Total B Class	-700 to 600	-52,500 to 12,000	-15 to 3

Source: Experian Economic and Employment Assessment 2012

Labour Supply Technique

4.12 The East of England Forecasting Model (EEFM) was developed by Oxford Economics to project economic, demographic and housing trends in a consistent fashion to inform spatial strategies. The overall Model structure captures the interdependence of the economy, demographic change and housing at a local level, as well as reflecting the impact of broader economic trends on the East of England. The employment forecasts take account of the supply and demand for labour, the demographic forecasts reflect labour market trends as they are reflected in migration (and natural change indirectly), and the housing forecasts take account of both economic and demographic factors. This structure allows scenarios which test the impact of variables upon each other – for example, the impact of housing supply on economic variables (EEFM Technical Report January 2015).

4.13 The Thanet Strategic Housing Market Assessment produced by GL Hearn in January 2016 looked at the range of 1,200 – 5,100 additional jobs, with the latest forecasts from the East of England Forecasting Model (EEFM) projecting growth in employment of 4,800 (baseline) between 2011-31 (equivalent to 0.5% growth in jobs pa). Taking account of commuting dynamics and the potential for some people to hold down more than one job, it is anticipated that this would require an increase in the resident workforce of up to 5,600 persons over the 2011-31 plan period.

4.14 In addition Kent County Council's Economic and demographic forecasts for Thanet District Council from February 2013 suggest that under the Short Term Migration Trend projection suggests an additional 5,800 jobs could be supported by the population growth associated with this projection (Table 4). This level of growth is broadly comparable, though slightly above, the job growth driving the policy on scenario.

4.15 Taking in to account the range of labour supply forecasts about the amount of floorspace to provide for would approximately be between 12 and 15 hectares.

Past Take up of Land

4.16 The Guidance also suggests that we also have to look at the past take up of land when formulating the amount of land that has to be provided for. In order to do this we looked at the past ten years of employment land delivery from the adoption of the Thanet Local Plan 2006. This concludes that the past take up of land averages out 10,446sqm per annum and this multiplied by the remaining plan period (x15 years) gives a potential floorspace requirement of 15.7.

Projection to the end of the plan period (as at 2016)

	Change 2006-2016	Annual Average	Requirement to 2031 sqm/ha (x15 years)	
B1	41,010	4,101	61,515	6.2
B2	28,158	2,816	42,240	4.2
B8	35,495	3,550	53,250	5.3
TOTAL	104,663	10,466	156,990	15.7

(A2 completions average 168sqm per annum so this has a negligible effect of the overall figure equating to 0.25ha over the plan period. This is an average that comes from CIA Table 4A in the 2016 KCC document. Prior to 2008 A2 was included with B1 in monitoring)

4.17 It is significant to note that the period looked at for the past take up of land calculation (ie to the period of adoption of 2006 Local Plan) includes a period of national recession and therefore does not represent an overly ambitious forecast result.

Conclusion

4.18 The labour demand forecast suggests that the amount of land to be planned for in the district varies between 3 and 15 hectares. It is considered that to plan for the risk based scenario would not represent positive planning and therefore a level between ‘baseline’ and ‘policy on’ was chosen. Given the uncertainties surrounding economic forecasting two other forecasting methods were also assessed. Past trends and labour supply forecasts suggest that a figure towards the higher range of the 3 scenarios set out in the labour supply calculation is more appropriate therefore it is considered that the land supply to be planned for should be 15 hectares.

Key Findings:

- It is concluded that Thanet’s functional economic area is East Kent and particularly Canterbury and Dover districts.*
- In terms of Economic Forecasts the labour demand forecast suggests that the amount of land to be planned for in the district varies between 3 and 15 hectares. Past trends and labour supply forecasts suggest that a figure towards the higher level is more appropriate and therefore it is considered that the land supply to be planned for should be 15 hectares.

*Dover District Council objects to Dover’s identification within Thanet’s housing market area.

Appendix G.1.3 (Part A)

Review and appraisal of existing sites/floorspace update

5.1 The NPPF says at paragraph 22 that planning policies should avoid the long term protection of sites allocated for employment use where there is no reasonable prospect of a site being used for that purpose. Land allocations should be regularly reviewed. Where there is no reasonable prospect of a site being used for the allocated employment use, applications for alternative uses of land or buildings should be treated on their merits having regard to market signals and the relative need for different land uses to support sustainable local communities. Therefore it is appropriate to carry out a further review of employment sites based on the latest evidence. This derives from the Economic and Employment Assessment 2012, the Employment Land Review 2010 and the updates in this document.

5.2 The 2010 Employment Land Review looked at the Allocated Sites, Retained Sites and Additional Sites. An update of this follows:

Employment Land allocation strategy
5.3 This section of the document firstly looks at the conclusions of the 2010 Employment Land Review, outlines current circumstances and reviews the sites in accordance with new information available.

ELR Conclusions
5.4 The 2010 ELR suggested that based on projections that 51.6ha (including element of contingency) of employment land was needed to the end of the plan period which at the time was 2026. A generous supply was recommended due to the nature of the Thanet economy and the need to stimulate growth and ensure that no significant opportunities are lost.

5.5 Projections indicated that 37% of floorspace/land is required for B8 development,36% for B1 development, and 27% for B2 development. B1 development should exist close to town centres and urban areas. Sites for B8 uses should be available with good access to the strategic road network, and B2 uses should be provided away from residential areas. The report concluded that a range of sites which are suitable for both inward investment opportunities, and accessible to growth in existing markets should be considered. New development needs to be flexible and affordable to the local market, and in particular the provision of starter units and mid range property.

5.6 The ELR found there were 12 sites with land available for future development totalling approximately 85ha of undeveloped land plus an additional two sites with potential for future development – the latter which are the Fire Training School and the Northern grass airside development area at the airport. 74.5ha of land was considered good or excellent quality for future employment purposes and suitable for a mix of B1, B2 and B8 uses. The ELR also recommended that the 24 existing retained sites allocated in the Thanet Local Plan 2006 should remain retained. The sites were scored according to their marketability, sustainability, deliverability and strategic planning factors. Many of the sites scored good or excellent against these criteria however, it was noted that a number of the retained sites exhibited relatively poor building quality, and whilst they were currently functioning well as employment locations, the condition of the buildings could affect future functionality. The sites in greatest need for renewal/upgrade were:

- Dane Valley Industrial Estate, St Peters
- Princes Road Depot, Ramsgate
- Factories, Suffolk Avenue
- All Saints Industrial Estate
- Parts of Haine Road, Pysons Road and Westwood Industrial Estate

5.7 The ELR also scored a number of additional employment sites that were over the 0.25 ha threshold. These sites were considered for retention to avoid their loss to alternative uses.

5.8 Manston Business Park was considered to provide the ideal site for inward investors and potential development opportunities for growing existing businesses in the district to relocate. In view of their sustainable location, the slow take up by traditional employment uses and given the overall quantity of employment land both Eurokent Business Park and Thanet Reach Business Park were considered to have potential for partial release.

5.9 The ELR also concluded that there was demand for property from within the local market on a smaller scale. Despite the economic situation being poor, the vacancy levels for these types of property were low showing a demand. It concluded that the most crucial factor for the indigenous market is that the premises are affordable. The important role of start up space was also recognised, which provide small scale, flexible units with easy in/out arrangements – there are three innovation centres across the district which serve this important role (the Kent Innovation Centre, the Marlowe Innovation Centre and the Margate Media Centre).

5.10 Rural provision was also considered but with the proximity of Thanet's rural areas to the urban areas, the strategic sites and the existing allocation of Hedgend Industrial Estate in St Nicholas at Wade indicated no need for additional rural employment land allocations. The ELR concluded that the majority of rural space is provided through conversion of redundant agricultural buildings, and evidence suggests that these are popular types of accommodation for business in Thanet.

<u>Forecasted demand for employment space and current situation</u>

5.11 In December 2012 the Council commissioned an Economic and Employment assessment which looked at job growth forecasts to the end of the plan period (now 2031).The assessment looked at what sectors of the economy are likely to grow and what this means in terms of floorspace that will need to be planned for. The report looked at a range of job growth scenarios and concluded that between 3 and 15 hectares of employment land is needed over the plan period. (More detailed information on this is contained in parts A and B of the Employment Topic Paper and the Economic and Employment Assessment 2012). This report also explores other methods of economic forecasting and considers their results.

5.12 According to evidence in 2013 Thanet had approximately 74.64 hectares of allocated employment land currently available. In addition to this there is 86.41 hectares of established employment floorspace that is retained through saved policy EC12 from the Thanet Local Plan 2006. On these retained sites there is also a remaining developable area of 6.4 hectares.

5.13 While planning for a generous supply of employment land is important for Thanet there is clearly a current oversupply of land over the new plan period to 2031. The economic and employment assessment concludes that only 30% of employment growth is likely to be within the traditional B use classes that are found on business parks such as manufacturing, construction, and distribution. The major areas of growth over the plan period are within the green economy and tourism sectors. (Economic and Employment Assessment 2012)

5.14 The primary green sector includes green infrastructure activities such as landscape architecture and nature reserve activities and waste management activities such as recycling and wholesale of scrap. Secondary green sector activities include energy equipment manufacture and professional, scientific and technical activities. Tourism sector activities include hotel, restaurant and bar activities, travel agency and sports/recreation activities. Some, but not all green economy sector activities will need to be accommodated on employment land, however the majority of tourist uses will not.

5.15 Another area of predicted growth is the service sector which includes town centre uses such as retail, accommodation and food services, professional services such as legal and accountancy. Government services such as education, residential and social care and health services are also estimated to grow over the plan period. Sui generis uses are uses which do not fall into a particular use class and include such uses as petrol filling stations and motor car showrooms and clearly we will need to be flexible with employment land to ensure all types of growth are accommodated.

5.16 It is clear from the evidence that traditional employment sites are not as much in demand, and employment growth is occurring in other sectors. In order to respond to this we need to review our strategy in terms of the allocation of employment land and consider the need to be flexible with the land we have in order to support the employment sectors that are growing in the District.

The Allocation Strategy

5.17 The Employment land review concluded that we need 7.7ha (baseline) of employment land to 2026 which is not at odds with the findings of the Economic and Employment assessment 2012 which concluded that we need between 3 and 15 hectares. This is significantly below what is allocated in the current local Plan and given the latest policy position with the National Planning Policy Framework a review of the allocated sites with a view to deallocating those which are not fit for purpose was appropriate.

5.18 Many of the conclusions of the ELR are still relevant. There is still a need to provide land for potential inward investment that also provides opportunities for growing existing businesses to relocate to and there is also a need for affordable premises from the indigenous market and start up space also fulfils and important role.

5.19 Also since the ELR was written and as discussed earlier in this document the Pfizer pharmaceutical plant at Sandwich closed and the Discovery Park Enterprise Zone has taken its place. With the range of benefits offered by its enterprise zone status available just across the district boundary the park is likely to have an impact on the demand for employment land in Thanet. The proximity of the enterprise zone to Thanet is positive for employment and it is considered that Thanet should align its economic strategy in order to complement Discovery Park.

5.20 As an overall strategy we need to cater mainly for small to medium businesses and tourism and leisure related trade. We also need to make some land available for larger businesses although some of these businesses may be drawn towards Discovery Park. Thanet's employment allocations will complement this trend. Some of the poorer quality retained sites in the urban area will be released in order to trigger reinvestment in some of our larger established sites such as Pysons Road, Haine Road and Westwood Industrial Estate as parts of these sites were recognised as needing renewal/upgrade in the ELR. We will need to protect some sites to ensure they are not lost to higher value uses such as housing, small employment sites that are important to the local economy and located within residential areas are particularly vulnerable. Good quality sites that are within the urban and rural confines will be retained, and of particular importance are quality sites that support our SME's such as Manston Green. Where possible there should be a balance of sites across the District.

5.21 Discussions with stakeholders have revealed the need to keep a range of sites for cheap premises and business start ups. We also need to retain some sites that can accommodate "dirty uses" such as paint spraying and tyre recycling. Some sites are also needed in the rural area to support the rural economy in line with the National Planning Policy Framework. We need a "flagship" site for inward investment and that can accommodate growing indigenous businesses.

5.22 Evidence also shows that we need "flexible" sites on which we can accept alternative non B use class uses as there is potential demand for employment generating uses that are currently not provided for.

Sustainability Appraisal

5.23 The Interim Sustainability Appraisal published in May 2013 assessed options for determining the amount of employment land required, and continuing to protect existing employment sites. It concluded the following:

Amount of employment land

5.24 In relation to how much employment land is needed, the initial SA assessment looked at the following options:

- Employment growth forecasts (from Experian)
- Previous rates of take up of land
- Maintaining the existing supply of land
- Include contingency when determining the amount of land to allocate

5.25 The sustainability appraisal concluded that is difficult to assess the options in relation to the amount of employment land, due to uncertainties associated with the type of development, density and location. The only indicators where there were differences between the options were related to economic development.

5.26 Maintaining the existing supply of employment land and allowing for additional land to ensure flexibility and choice, performed the best.

5.27 The difficulty in assessing these will be overcome at the site allocations stage and potential development management policies will also help to mitigate against potentially adverse effects.

Location and Type of Employment Land

5.28 In relation to the location and type of employment land the sustainability appraisal considered the following options:

- Relax the uses permitted on some of the allocated employment sites to allow other employment generating uses outside of the B classes.
- Maintain a variety of sites in a range of locations across the district
- Provide all employment land in a single location or cluster in the district
- Use of allocated supply to select sites

5.29 The option to use the existing allocated supply from which to select sites is less likely to result in adverse effects and has the greatest opportunity to deliver beneficial effects. Concentrating employment sites in one area (at the single site or cluster) could disadvantage the rest of the District. The single site option could also result in residents having to commute longer distances to get to work and therefore they would be more reliant on the private car.

5.30 All of the options are likely to have a beneficial effect on economic growth within Thanet. In most cases potentially adverse effects can be mitigated against during the assessment of allocations.

Protection of existing employment sites

5.31 The two options assessed were whether to continue with policy protection for identified employment sites from the 2006 Thanet Local Plan. The option to continue with policy protection was predicted as having the potential to result in a significant positive effect, particularly in terms of job creation and supporting economic growth. The option to cease the policy protection performed better in terms of its potential to have indirect benefits for housing by potentially allowing a greater area of land for housing and other types of development. Neither option resulted in a significant adverse effect.

Individual site assessment and how the sites fit into the strategy.

5.32 This section reviews each employment site from the ELR individually. The sites have been scored using the same methodology as the Employment Land Review i.e. marketability, sustainability and deliverability. Strategic planning factors was removed as a category as the there is no strategic plan in place with the abolition of the south east plan. More information on scoring methodology can be found in the Employment Land Review 2010. This section also provides an update on circumstances, and assesses how successfully each site fits into the new allocation strategy before making recommendations.

5.33 It will be necessary to keep under review the portfolio of sites especially given the recent duty on commercial premises to have Energy Performance Certification. Measures may be expensive to retrofit and may have an impact on some of the older stock.

Manston Business Park

5.34 This is the largest area of employment land in Thanet. It is still considered to be ideally located for inward investment as it is centrally located adjacent to the airport and near the port. The site enjoys very good road infrastructure with access dual carriageway access to the M25 and the East Kent Access road to the south. The site is owned by East Kent opportunities which is a joint venture between Kent County Council and Thanet District Council to bring forward economic growth and regeneration, and is marketed by Savills.

5.35 Current occupiers of the sites are Summit Aviation, Invicta produce, and Cohline. There has been a recent completion of 3 business units 2,345 in size for B1, B2 and B8 use on the corner of Invicta Way and Columbus Avenue and one of the units will be occupied by Rowe Atlantic.

5.36 There has also been a large development by Manyweathers Property Ltd constructed on the corner of Columbus Avenue and Invicta Way.

5.37 There is also planning permission for a development of 46 industrial units and 4 office units on the opposite side of Columbus Avenue.

5.38 This site scored a high 12 out of 15 mainly due to its prime location with good/recently upgraded transport connections and recent developments indicating that the site is marketable.

5.39 This site is considered to be the flagship inward investment site for the district and its allocation should be carried forward. It is approximately half developed and there is some infrastructure in place. As this site is somewhat unique it is considered that a range of other employment sites should be allocated in the plan period to provide a range of sites

Eurokent Business Park

5.40 This site is well placed and situated roughly equidistant between the three main Thanet towns. It is located between the recently developed Westwood Town Centre, a retail and leisure hub, and the Royal Harbour Academy School. This is a highly accessible and sustainable site with the Eurokent, highway improvements and infrastructure are already in place for the site.

5.41 The most northern part of the site was developed for leisure uses in 2007, as part of the Westwood Cross development, and houses a multiplex cinema, restaurants and Casino. The Grupo Antolin building has been demolished and has been replaced by the new Sainsburys Store. The centre of the site remains undeveloped, with approximately 20 hectares of vacant land. At the south of the site lies the Marlowe Innovation Centre, which was completed in August 2008, and provides affordable accommodation for innovative small businesses, with a mix of light industrial and office space. Adjacent to this is the *Eurokent Business Park*, a joint venture by SEEDA in conjunction with Thanet

District Council, comprising a high quality scheme of imaginatively designed units, with flexible accommodation serving a mixture of B1, B2 and B8 uses. At the time of visiting three industrial units and one office unit were vacant although later information has revealed that two of the industrial units are due to be sold. Laleham School has also recently been relocated to the southern part of the site.

5.42 A planning application was submitted for a mixed-use development for up to 350 dwellings; up to 63,000sqm Class B1 business floorspace and sui generis use; a new local centre comprising up to 2,000sqm convenience retail (class A1, A2, A3), community facilities up to 5,000 sqm (class D1/D2) and community healthcare up to 1,200sqm (class D1). This was refused by the Council and the subsequent appeal upheld (APP/Z2260/A/14/2213265) allowing up to 550 dwellings, up to 54,550sqm class B1 floorspace, car showroom of up to 8,151sqm, a local centre comprising up to 2,000sqm Class A1 (Shops), Class A2 (Cafes and Restaurants), community facilities up to 5,000sqm (Class D1/D2) and community healthcare up to 1,200sqm (Class D1), and associated highway works. The permission contains a series of “up to” statements and the site cannot accommodate all of the aforementioned quantum’s.

5.43 The site scored 11 out of 15 in the rescoring exercise mainly because of prime location. Due to its location close to the commercial area in Westwood this site is considered suitable for flexible uses and should be allocated as such and it may be appropriate to de-allocate some of the site.

Thanet Reach Business Park

5.44 This site has good cycle and pedestrian links and is close to the Westwood area. It has been partially developed for Canterbury Christ Church College and the Kent Innovation Centres. A substantial part of the site is still undeveloped and as reported in the ELR the now East Kent College is no longer wishing to locate its campus at Thanet Reach. It is considered that the site is suitable for B1 business and education uses. It is considered that the Northern part of the site should be retained so that the expansion of the current uses which is high quality, managed workspace for start up and indigenous business is not stifled. There is also potential for expansion of the University and this should be encouraged on the Northern part of the site.

5.45 The site scored 11 out of 15 as the site is available and in a good location. Uses may be constrained by the predominantly residential location.

Manston Road, Ramsgate

5.46 The allocated parts of the site are split in two. On one of the sites is the Beacon Centre which accommodates the Thanet NHS Community Health Team. The remaining developable land and the other site to the south is vacant with poor accessibility. With regard to the retained parts of the site the Old Timber Yard is poorly maintained with no vacant units and the section containing the Flambeau Europlast building is in very poor condition.

5.47 The allocated parts of the site containing the NHS Beacon development and the remaining developable land scored 10 out of 15. The site is good quality and in a fairly sustainable location but has remained vacant. Given the downturn in the market and the availability of other land it is unlikely to be developed in the future.

5.48 The retained parts of the site incorporating the Old Timber yard and the Flambeau Europlast section scored 8 reflecting the poor quality of the sites and that redevelopment is likely to be unviable.

5.49 The retained site is not viable for business use to the end of the plan period and there is little demand for the allocated sites. Therefore it is considered that both the retained and allocated parts of the site should be de-allocated.

5.50 Flambeau had indicated that they wished to relocate so this should be deallocated. Outline consent for 120 houses was granted in 2017. The Old Timber Yard, despite being of poor quality was fully occupied and therefore retention in the short term is considered appropriate. It is recommended that the site be protected during the plan period to 2031 and reviewed thereafter.

Hedgend Industrial estate

5.51 The buildings at Hedgend are good quality and comprise a range of sizes. Hedgend is in a rural location with good access to the A299 Thanet way. The site is busy and appears suitable for general industrial use. The site is still considered ideal for distribution activities. The site is in an isolated location, well shielded from view and away from residential properties and it is therefore considered that this would be a suitable site for dirty uses which it is understood there is some demand for.

5.52 Land at McNab kennels previously had outline permission for the erection of three buildings for general industrial use B2 comprising 12 units.

5.53 The site scored 10 out of 15 as it is well located in terms of access to the primary road network rather than sustainability and that is proving a popular site with scope for further development.

5.54 As the site is functioning well, may be likely to expand in the near future and fulfils a role within the strategy for dirty uses it is considered that this site should continue to be allocated.

Westwood Industrial Estate

5.55 This is the largest retained site located on the main road network and it contains a mix of industries and uses including a church/community building. The site contains 3 retail units, and has partly been developed for residential. There is also the Thor Chemicals section of the site which has been decommissioned.

5.56 The site has many different sections containing both small and large units and these vary in quality. The greatest vacancy at the time of visiting was 2 or 3 units within the Goodwin Park section of the site with one unit actively being marketed.

5.57 Some sections of the site are in poor repair but overall the site functions well and there is a good turnover of units. It is considered that some reinvestment is needed in the site but it is a large strategic site and important to the overall economic strategy.

5.58 The site scores 11 out of 15 as the site is a popular vibrant site containing a range of employment uses of various sizes.

5.59 This site already caters for a range of uses and is an accessible location in Margate and therefore could be a suitable location for flexible business use and as such it should be retained. The site also has scope to accommodate future employment generating development.

Pysons Road Industrial estate
5.60 This is a large, important and well established site located on the main road network. It is occupied by a variety of businesses with a significant amount of heavy/specialist B2 industry such as Fujifilm. This site is split into many sections with varying quality and some are quite poor particularly the Lysander Close section with 4 buildings apparently vacant and parked vehicles over pavement and verges. The site as a whole appears to function well and has fairly low vacancy rates. The appearance of Pysons Road as a whole is pleasant with the largest business on the site, Fujifilm, being the main visual focus within attractive open landscaping.

5.61 The site scored 11 out of 15 as it is a large popular site with a range of premises. Like Westwood Industrial Estate, some sections of the site are in poor repair but overall the site functions well and there are a good turnover of units. It is considered that some reinvestment is needed in the site but it is a large strategic site and important to the overall economic strategy.

5.62 It was considered that parts of the site should be considered for de allocation because complaints had been received from the residents of Hopes Lane about the industrial units opposite. The buildings of the former Focus DIY also do not contribute positively to the Pysons Road Industrial Estate.

Dane Valley Industrial Estate
5.63 This is a large site occupied by a wide variety of business and industry but parts of the site are in extremely poor condition. It is very busy with only 2 or 3 apparent vacancies. The site layout is confusing and presentation generally poor and in parts parking is very bad. The Site contains St Peter's House, an office of Kent County Council.

5.64 The site was scored in two sections. The developed part of the site scored 9 as it has some access and parking difficulties. However the site proves extremely popular and is occupied by a range of business. The site also provides crucial cheap business accommodation that supports our local small to medium enterprises and the site is still expanding.

5.65 Since the ELR was completed a development of 7 industrial units has been erected. This is called the Copper Leaf Business Park.

5.66 The undeveloped part is owned by UK Power networks and does not form part of the business park. It is separated from the rest of the site by the railway line and access is poor. Given the downturn in the market, low demand and the constrained nature of this site the undeveloped part of the site is considered unsuitable for business use.

5.67 It is considered that undeveloped parts of the site should be de-allocated but the remainder of the site should be retained in order to trigger reinvestment in the poorer parts of the site.

Haine Road (Leigh Road) Industrial Estate

5.68 This is a large site on the urban edge of Ramsgate that is well located on the road network. The site has a mix of buildings of different ages and sizes that are in generally satisfactory condition. The site layout and presentation is good but parking is inadequate. There is a high take up of units with only 1 or 2 appearing vacant at the time of visiting. There is a large sign company presence on the site.

5.69 The site scored a high 13 out of 15 due to its sustainable location, proximity to the primary transport network and popularity.

5.70 The site caters well for an expanding medium sized offer and is therefore an important site to retain. Access to the site is currently limited but a right hand turn lane accessing the site is in the pipeline which will overcome the problem.

Laundry Road (Telegraph Hill) Industrial Estate

5.71 This site is in a good location close to the strategic road network. This access has been further improved by the new East Kent Access road. This is a good popular site in the rural area and units are in demand. A large proportion of the site is occupied by Whites Transport, a local haulage company and this has been recently extended. The site has good buildings, good layout and parking. There appeared to be only 2 vacant units on visiting.

5.72 This site scores 13 out of a possible 15 as it is a popular large site located in the rural area but close to the strategic road network and there is potential for expansion.

5.73 As this site is in good condition, in high demand, and in the rural area it should be considered for retention.

All Saints Industrial Estate

5.74 This site is in poor condition including buildings, external areas and the access road which is unmade. The site is bounded by the railway and some residential units. There was only one vacant unit at the time of visiting. There is plenty of undeveloped land around the site which is currently used as a dumping ground and constitutes a very poor use of the site. The site currently caters for some “dirty” uses but the Council has in the past received Environmental Health complaints related to this from the nearby residents.

5.75 The site scored 9 out of a possible 15 mainly due to the fact that the site is in a highly sustainable location in Margate Town Centre.

5.76 Planning permission for the erection of two industrial units had been granted on a derelict and unsightly part of the site. This has yet to be implemented.

5.77 The site is in poor condition but it caters for dirty uses. It is considered that the site should remain allocated in the short term pending review for the next plan period.

Tivoli Road Industrial Estate

5.78 This site is bounded by the railway line and residential properties. The site comprises three large buildings that are in good condition. Heavy parking in the residential roads surrounding the site is an access constraint for the site.

5.79 The site scored 8 out of a possible 15 as it is located in a constrained residential area and is incompatible with surrounding uses leading particularly to parking and access problems.

5.80 Although the site is currently functioning well it is not suitable for large scale commercial use given the town centre/residential location. Kent Highways have commented that the site is not conducive to large vehicle movements. The site is not suitable for dirty uses as it is not hidden and is in very close proximity to residential properties. The 3 large units represented here are better suited to one of Thanet's larger employment sites.

5.81 As this site is currently full and functioning well it is considered appropriate to protect it in the short term in the plan period to 2031 and reconsider this thereafter.

Cromptons Site

5.82 This site is located in the commercial area of Westwood. It is an excellent modern site occupied by two well established businesses. The high quality buildings are also considered suitable for occupation by other businesses. Poorhole Lane has recently been upgraded providing improved access to the site.

5.83 This site scored highly with 13 out of a possible 15 due to its good location and the overall quality of the site.

5.84 The site is inappropriate for other uses as it is located within the green wedge and therefore it is recommended that this site is retained.

Jentex

5.85 This is a single occupier site owned by Jentex Fuel Oils. The site comprises a mix of buildings, oil tanks and open storage. The owner has indicated that the use is no longer viable and the site is being decommissioned. Four tanks have been removed and the remaining use of the site is holding gas oil for ships which is increasingly being taken direct from the refinery to destination by road. In addition the main road into Ramsgate has now bypassed the Jentex site as part of planned road improvements. The existing buildings are unviable for re occupation by other businesses due to the cost of remediation.

5.86 The site scored 4 out of a possible 15 due to the redundant nature of the site and the site is undeliverable as part of Thanet's employment land portfolio.

5.87 The owner has indicated that their aspiration is to redevelop most and probably all of the site for extra care housing/community related use but there are contamination concerns on the site. For these reasons it is considered that the site should not be retained for employment use.

140-144 Newington Road

5.88 The site was originally occupied by Piper windows but they have since gone into receivership and the site has been redeveloped as a primary school to provide up to 420 school places.

5.89 The site scored 9 out of a possible 15 as it is in a fairly sustainable urban location however, the proximity to the residential areas is a constraint in itself. Access is poor through heavily parked up streets and opening hours have had to be restricted. Kent Highways Services have advised that the site has lorry routing issues and that it is incompatible with the surrounding uses.

5.90 It is recommended that this site is no longer protected for employment uses.

Princes Road Deport

5.91 This site contains a number of small businesses but is in poor condition. It is adjacent to a residential area with a railway line to the north. The site is disorganised and poorly maintained.

5.92 The site scored 9 out of a possible 15 largely to do with its sustainable location. There are a number of businesses operating from the cheap premises on site and one of the units is being upgraded.

5.93 The site is incompatible with the residential area opposite however it is adjacent to the Pioneer business park and is well located close to Ramsgate railway station. The ELR concluded that this site was in need of refurbishment and this is still the case but as this is beginning to happen and the site provides inexpensive units it is considered that the site should continue to be protected.

Pioneer Business Park

5.94 This site is well maintained and is in a sustainable location near to Ramsgate Railway Station. It is not suitable for intensification but caters well for small to medium sized enterprises.

5.95 It scored 12 out of a possible 15 in the assessment and therefore it is recommended that this site is protected.

Whitehall Road Industrial Estate

5.96 This site is located within a residential area and has a mix of B2 uses. It has two industrial buildings dating from the 1970's that are in satisfactory condition which accommodate a number of small to medium sized businesses There was one vacant unit at the time of visiting.

5.97 The site scores 10 out of a possible 15 as it is a sustainable site within the urban area. It is surrounded by residential uses which make it incompatible with the use of heavy goods vehicles. The site provides affordable premises for small to medium businesses and therefore it is recommended that protection of this site should continue.

Northdown Industrial Estate

5.98 This site contains a single industrial building split into 11 small office buildings. The buildings are in poor condition but the presentation is good. The site is functioning well with only one apparent vacancy.

5.99 The site scores 10 out of 15 as it is a popular site with planning permission. It provides cheap premises for small businesses and is compatible with the Dane Valley Business Park next door.

5.100 In 2011 permission was granted for the erection of a two story office/store building following demolition of garages which was implemented. This demonstrates demand on the site.

5.101 As this site is proving resilient to the economic downturn and provides vital affordable premises it is recommended that protection for the site should be protected.

Suffolk Avenue factories

5.102 This is a small site in a predominantly residential area. There are two large buildings on site, one is in poor condition.

5.103 The site scored 6 out of a possible as the site is wholly incompatible with the surrounding residential area. Access is very poor and the surrounding roads are heavily parked up, and Kent Highways have indicated that there are lorry routing issues. Furthermore, noise complaints have been received by TDC's Environmental Health Department.

5.104 The owner of the site has indicated that they wish to relocate elsewhere in Thanet and redevelop the site for housing. The site has been marketed for employment use and no interest has been shown. For these reasons and considering the low demand for employment land and the availability of higher scoring sites it is considered that this site should no longer be protected.

Manston Green

5.105 This is a small site within Manston village confines and is occupied by small cottage industries. There is currently a new office development underway demonstrating that the site in attractive and in demand.

5.106 The site scored 12 out of 15 as it is very well presented and is compatible with the rural area. At the time of visiting there were no vacancies. This site provides a unique offer in the rural area and is good for small to medium enterprises. It is recommended that the policy protection for this site should remain.

Magnet and Southern

5.107 This site contains a single building with an open forecourt to the front which is presentable. The site is within the Newington residential area and part of the site has been developed for 5 houses.

5.108 The site scored 9 out of 15 as despite its sustainable urban location it is incompatible with the surrounding residential area.

5.109 Given the low demand for employment land and the availability of better scoring sites it is considered that this site should no longer be protected.

St Lawrence Industrial Estate

5.110 This is a very small site with one building split into 5 units containing a mix of small businesses which appeared to be fully occupied. The buildings are in satisfactory condition but access, turning and parking is poor. The site is bounded by residential properties and a school.

5.111 The site scored 12 out of 15 mainly as it is located within a sustainable urban location. The scoring concludes that lorry routing is poor and that redevelopment of the site would be incompatible with surrounding uses but this is not necessarily at odds with the current use of the site which is characterised by small uses where the use of lorries would be unlikely. As the site provides small affordable units it is recommended that protection for the site should be continued.

Fuller's Yard

5.112 This site contains 12 units for office and light industry. The site is owned by TDC and most of the buildings are in good condition. The site is bounded by education facilities and residential. At the time of visiting 5 units were vacant and were being marketed.

5.113 The site scored 12 out of 15 as it is in a sustainable urban location that is well maintained and provides small affordable units.

5.114 Consultation revealed that the site is popular and caters well for small to medium enterprises. As the site is a small scale, town centre site that caters for SME's it is considered that the site should continue to be protected.

Manston Road Depot

5.115 The site comprises TDC's refuse and recycling depot. The majority of the site is open storage. The site has a poor visual appearance but is not visible from the road. The main building is in reasonable condition. There are proposals to erect a waste sorting and transfer building and extend the office and workshop building.

5.116 The site was not re-scored as the site does not contribute to the overall land allocation strategy however it is likely to remain in this use, is difficult to relocate and may need to expand in the future. The site importantly provides for waste uses in Thanet. If the site is de-allocated then it becomes a site in the open countryside and any expansion will be stifled. It is therefore recommended that the current allocation is retained but should not contribute to the employment land supply.

5.117 The Employment Land Review identified a further 13 sites from Kent County Council's Commercial Information Audit and the Business Rates Ratings List, which were considered for protection. These were in addition to those that were allocated and protected in the Thanet Local Plan 2006. The decision was taken not to re score these sites as the National Planning Policy Framework states at paragraph 22 that we should avoid the long term protection of sites for employment use where there is no reasonable prospect of an allocated site being used for that purpose. Thanet is currently oversupplied with employment land and the forecasted need to the end of the plan period along with a margin of error/buffer can be adequately accommodated from the current supply. It would be contrary to National Policy to protect more land for employment purposes to 2031.

5.118 A number of site submissions were received requesting employment land allocations. Consideration of these submissions can be found at Appendix 2.

Omission Site Submissions

5.119 A number of employment omission sites have been submitted during the various stages of Local Plan consultation and these are listed in appendix 2. The floorspace requirement identified can be accommodated by the existing employment allocations from the Thanet Local Plan 2006. In accordance with advice in the Sustainability Appraisal sites were selected for allocation from the current supply effectively meaning that omission sites were not needed as allocated sites have already been assessed for suitability and fitness for purpose. Selecting sites from our current supply (i.e. those allocated in the Thanet Local Plan 2006) was the most sustainable option.

5.120 The Manston airport site was submitted as an omission site in 2015. Given the advice from Avia Solutions report that the aviation use on the site is unlikely during the Local Plan period, and the increased need for housing following the 2016 sub national population projections the airport site was assessed alongside other suitable omission sites that either on their own or in combination were able to form a new settlement. Advice from the sustainability appraisal was that the airport site was considered most sustainable largely due to its brownfield element. The report concludes that sustainability considerations should be at the forefront when considering a new settlement and therefore it was considered that an element of employment use was needed in order for the site to be sustainable. It was concluded that employment land on the site should be allocated and it was considered that this could complement Manston Business Park. The planning application for the site was accompanied by a business plan which detailed that “advanced manufacturing” industrial units were in demand from developing businesses at Discovery Park. This element also complemented Thanet’s Economic Growth Strategy.

5.121 However, despite the identification of a potential new mixed use settlement the Council recognises that a DCO process is underway by RiverOak Strategic Partners to acquire the site for aviation use as an NSIP project.

5.122 The outcome of the process is still unknown and therefore it would be inappropriate to allocate the airport for an alternative use at this stage. This reflects the decision of Full Council in July 2018.

Key Findings and Recommendations

Having assessed the type of employment land needed in Thanet and scored the sites from the existing employment land supply the following conclusions were drawn:

The following sites should be de-allocated from the Local Plan

Manston Road (part)
Thanet Reach (part)
Eurokent (part)

Manston Road was not considered necessary to contribute to the employment land portfolio given the amount of land available and the nearby provision at Manston Business Park and Eurokent. The Southern part of this site was considered surplus to requirements and potential uses may be constrained by the predominantly residential location. The Northern part of the site is considered suitable for education uses and B1 uses. Again Eurokent is a large site and given the demand for employment land over the plan period to retain the whole of the site as an employment allocation was considered unnecessary. Eurokent remains an important site but it is considered that a mix of uses on the site would be more appropriate. A planning appeal has allowed mixed us development on the site. De allocated parts of Manston Road and Thanet Reach are also being considered through the SHLAA process.

The following sites should no longer be protected for employment purposes:

- Manston Road Industrial Estate
- 144 Newington Road
- Magnet and Southern
- Pysons Road (part)
- Dane Valley (part)
- Suffolk Road Factories
- Jentex

These sites were not considered to contribute positively to the employment land strategy and in many cases were incompatible with surrounding uses.

The following sites scored well in the assessments and provide a range of large and small sites at varying locations around the District. They allow flexibility of uses and cater for all types of business

Allocated sites

Site	Total Site Area (ha)	Remaining employment allocation (ha)
Manston Business Park	75.2	42.53
Eurokent	38.6	5.45
Thanet Reach	9.74	3.7
Hedgend	2.46	1.61
TOTAL	126	53.29

Retained Sites

Site	Size	Remaining developable Area
Cromptons	2.26	0

Haine Road	6.52	0.28
Manston Green	0.38	0
The Old Timber Yard	1.97	0
Pioneer	0.64	0
Fullers Yard	0.17	0
Laundry Road	3.68	0
Pysons Road	20.31	0.52
St Lawrence	0.19	0
Tivoli Road	2.45	0
Westwood Ind Est	25.9	0.75
Northdown	0.89	0
Princes Road	0.98	0.25
Whitehall Road	0.95	0
Dane Valley (developed)	5.04	0

Flexible Sites

It is recommended that the following sites be allocated all or partially as flexible sites as they already contain a strong element of non B uses and they are geographically spread around the District:

- Westwood Industrial Estate (part)
- Eurokent
- Dane Valley Industrial Estate

Appendix G.1.3 (Part A)

Appendix G.1.3 (Part A)

Employment Land Supply

6.1 The Council has allocated the following sites for employment generating purposes in the Local Plan to 2031. Acceptable uses will be B1 (business), B2 (general Industry) where appropriate, and B8 (storage and distribution) as well as education and flexible uses on some sites. The individual policies provide more detail.

Site	Total Site Area (ha)	Remaining employment allocation (ha)
Manston Business Park	75.2	42.53
Eurokent	38.6	5.45
Thanet Reach	9.74	3.7
Hedgend	2.46	1.61
TOTAL	126	53.29

6.2 It is acknowledged that the amount of land allocated represents a significant oversupply of employment land. However, it is considered that this is justified for the following reasons:-

- The Economic and Employment Assessment 2012 (EEA) Experian suggested that:
  Based on these figures it is evident that the requirement for employment land is relatively low. Clearly a margin of error would need to be factored in, but they do suggest that relatively new employment land is required under the baseline and an amount closer to the lowest end of the ELR projections would be required. Conversely positive planning will be required to consider how non B Class employment growth will be accommodated.
- The EEA concluded that only 30% of employment growth would be in the traditional B Use Classes suggesting that a flexible approach to employment generating development needs to be adopted on our employment sites. In response to this it has been decided that flexible uses will be allowed on some employment sites including Eurokent subject to the application of the sequential test. This will inevitably lead to a loss of B Use Class floorspace in order to allow for this.
  On certain sites, wider employment generating uses will be allowed in addition to traditional B1, B2 and B8 employment uses. The "flexible uses" include leisure, tourism and other town centre uses which, due to scale and format cannot be accommodated within town centres. They also include uses known as sui generis which do not fall into a category in the Use Classes Order. These include uses such as car showrooms and creches.
- The Eurokent appeal decision (APP/Z2260/A/14/2213265 allows up to 5.45 ha of employment land and up to 550 houses. The size of the site constrains the implementation of both of the "up to" figures and therefore it is unlikely that all of the 5.45 hectares will be delivered. Furthermore an early masterplan for the site indicated that 8 acres of the site would be dedicated to employment leaving 2.25 hectares of the permission unimplemented and not possible on the site in future.
- The majority of allocated land is at Manston Business Park. Approximately 42 hectares remains undeveloped although there have been a number of recent

developments following slow take up of the site. However, given deliverability problems and the history of slow land take up then it is considered that the delivery of site will progress beyond the 2031 horizon of the Local Plan. As the site is approximately half developed it would not represent positive planning to remove it from employment allocation and to do so would leave an undersupply of employment land especially given all of the justifications for maintaining an oversupply.

- Maintaining an oversupply facilitates the replacement of old stock. An element of vacancy on employment sites allows for the movement and expansion of firms as well as improvement. The ELR 2010 states that it is assumed that a vacancy rate of 10% allows this to occur successfully.
- The Town and Country Planning (General Permitted Development) (England) Order 2015 laws have changed putting the loss of B1(a) office use out of planning control.
- An element of sui generis uses takes up employment land. Between 2011 and 2016 there was 1237m2 of sui generis uses developed. The Eurokent appeal decision (APP/Z2260/A/14/2213265) includes permission for 8,151sqm car showroom.
- The Regulation 18 Consultation into the Issues and Options of the Local Plan looked at whether we should include a level of contingency when allocating employment land. Respondents generally agreed and the sustainability appraisal concluded that including contingency in the supply scored well in terms of economic development.
- Maintaining a high level of employment land also reflects the potential workforce growth from the housing requirement in the plan.

De-allocated Sites

6.3 The NPPF says at paragraph 22 that planning policies should avoid the long term protection of sites allocated for employment use where there is no reasonable prospect of a site being used for that purpose. Land allocations should be regularly reviewed. Where there is no reasonable prospect of a site being used for the allocated employment use, applications for alternative uses of land or buildings should be treated on their merits having regard to market signals and the relative need for different land uses to support sustainable local communities.

6.4 Therefore it was appropriate to carry out a further review of employment sites based on evidence from the Economic and Employment Assessment 2012, and the Employment Land Review 2010.

6.5 The sites have been scored using the same methodology as the Employment land Review i.e. marketability, sustainability and deliverability. Strategic planning factors was removed as a category as the there is no strategic plan in place with the abolition of the south east plan.

6.6 It was concluded that the following sites should no longer be protected for employment purposes as they were not considered to contribute positively to the employment land supply and in many cases were incompatible with surrounding uses.

• 144 Newington Road	1.12 ha

• Magnet and Southern	0.29 ha
• Pysons Road (part)	1.14 ha
• Dane Valley (part)	2.39 ha
• Suffolk Road Factories	0.45 ha
• Jentex	2.09 ha
• Manston Road Industrial Estate (Flambeau Europlast)	4.34 ha
TOTAL	11.82 ha

6.7 The employment sites from the Thanet Local Plan 2006 were reviewed in light of the Economic and Employment assessment 2012 which looked at job growth forecasts to the end of the plan period (2031).The assessment looked at what sectors of the economy are likely to grow and what this means in terms of floorspace that will need to be planned for.

6.8 It was concluded that the following sites should no longer be allocated for employment purposes as they were not considered to contribute positively to the employment land strategy.

• Manston Road Industrial Estate	1.53 ha
• Thanet Reach (south)	3.19 ha
TOTAL	4.72 ha

6.9 A large number of sites were considered for retention and assessed using the scoring method. A small range of sites have been retained that include those with cheap start up small premises, those containing un-neighbourly uses and those that are full or near fully occupied. More information can be found at the next chapter Review and appraisal of existing sites/floorspace update

6.10 The remaining developable area of Eurokent is 20.5 hectares. The Draft Local Plan allocated it for 15ha but reflecting the appeal decision only 5.45ha ha is allocated.
This means that 31.59 hectares have been deallocated from employment uses since the adopted Thanet Local Plan 2006 with many of the sites reallocated as housing sites.

Key Findings:

- There is strong justification in maintaining an employment land “oversupply”.
- 31.59 hectares have been deallocated from employment uses since the adopted Thanet Local Plan 2006 with many of the sites reallocated as housing sites.

Appendix G.1.3 (Part A)

APPENDIX 1 – Site Scoring

Site	Size	Market-ability	Comment	Score	Sustain-ability	Comment	Score	Deliver-ability	Comment	Score	Previous Total	Comment
Cromptons	2.26	5	This site has been recently developed with new good quality office buildings. The market for these types of premises has declined but they are above average in quality	4	5	The site is located in a sustainable location and access t o the road network improved with Westwood road improvements including with widening of Poorhole Lane	5	5	Occupied by two well established businesses. Any intensification on the site would need mitigation on the Westwood junctions	4	**20**	13: Despite a change in market conditions this is a site in good condition occupied by successful well established businesses. It is unlikely that intensification will occur on the site
Haine Road	6.52	4	This site is well located, has a mix of buildings, functions well and has very few vacancies. Those units that are vacant are being actively marketed. Having said that there is a general downturn in the market.	3	5	The sustainability of this site has not changed since the original scoring exercise	5	5	A right hand turn land is proposed for the site as part of planned road improvements which would make the site more accessible.	5	**19**	13: Despite a change in market conditions this site is still an attractive and popular employment site
Manston Green	0.38	5	The site is located within the village confine of Manston and is well presented with good facilities. The site is occupied by small cottage industries and currently has no vacancies. The site is function well despite a downturn in the market.	4	4	The sustainability of this site has not changed since the original scoring exercise.	4	5	The site is well established and has a unique offer but intensification will not be deliverable due to highway constraints	4	**19**	12: The site remains successful despite a change in market conditions
Manston Road (N)	1.67	5	The site is occupied by an NHS medical centre but the remainder of the site has remained undeveloped. With the downturn in the market demand for this type of	3	5	The sustainability of this site is fairly good with access to facilities for staff and it has reasonably good road access.	4	4	Apart from the medical centre the site has remained vacant. Mitigation would be needed at the Stanner Court junction if the site were to be developed.	3	**19**	10: The site has remained vacant and given the downturn in the market is unlikely to be developed in the future

			land has declined considerably						Other allocated sites are available in the area.			
Pioneer	0.64	5	This site is well maintained, in good condition and well occupied by small businesses	4	4	The sustainability of this site has not changed since the original scoring exercise.	4	5	The site is not suitable for intensification due to constraints on the road network but caters well for small to medium enterprises.	4	**19**	12: The site remains successful despite change in market conditions
Fullers Yard	0.17	5	The site is in good condition and is an ideal site on the edge of the town centre for small businesses. At the time of visiting 5 of the units were vacant but there is a high turnover of this type of unit that serves small industry and the site has proved popular.	4	4	The sustainability of this site has not changed since the original scoring exercise	4	5	The site is not suitable for intensification due to constraints on the road network but caters well for small enterprises.	4	**18**	12: The site is proving successful despite a change in market conditions
Jentex	2.09	5	There is no longer a commercial demand for fuel oil storage and therefore the use of this site is redundant and the owner has expressed a wish to redevelop the site	1	4	The main road into Ramsgate has now bypassed the Jentex site and therefore it is a site in a traffic calmed village location with relatively poor access to the main highway network.	2	4	Although the site is in single ownership it has constraints in terms of contamination and is now unsuitable for routing of heavy goods vehicles	1	**18**	4: This site contains a redundant use and redevelopment is not considered viable
Laundry Road	3.68	5	The site is in a good location close to the strategic road network. There are a range of units with good parking and layout. At the time there were only 2 vacancies and the site contains several well established companies. Planning permission has been granted for a change of use to a haulage yard to facilitate	4	3	The sustainability of this site has improved as it is now accessed off the new dualled A256 and there are now food/drink and shopping facilities within walking distance. A full score of 5 is not possible as the site is not accessible by public transport such as bus and rail	4	5	This site is owned by Whites transport (we think) and is popular with well established businesses on site and there are no constraints such as highways and there remaining developable land.	5	**18**	13: This is a large site in the rural area that has proved successful, is sustainable and has potential for future expansion.

			growth of White's transp ort									
Magnet and Southern	0.29	4	This is a single occupier site. It is in reasonable condition. The market downturn has significantly affected the marketability of sites such as these.	1	4	The sustainability of this site has not changed since the original scoring exercise	4	5	The site is located in a predominantly residential area and development of the site could be incompatible with the surrounding area and lorry routing is poor	4	**18**	9: This is a small single occupied site in a residential area and given the market downturn commercial redevelopment is unlikely
Manston Business Park	75.2	5	This site is the Districts largest employment site and is centrally located. There are a number of large occupiers. Currently there are 3 units being actively marketed and there are currently new units being built out	4	4	This site is located away from centres of population and facilities for staff but is well related to the primary road network and as this large site develops with a number of occupiers it is considered that staff facilities are likely to improve	4	4	The site is in a prime/accessible location which is compatible with business use and is therefore attractive to developers. Improvements to the road network makes the site more attractive. Some improvements to the spitfire junction may be required as development comes forward.	4	**18**	12: This is a strategic employment site is in the District which is centrally located and is showing signs of development
Pysons Road	22.7 9	4	This is a large popular site with many different sections of varying quality. There are a few vacant units but there is active marketing on the site	3	4	The sustainability of this site has not changed since the original scoring exercise.	4	5	Parts of the site have attracted complaints to environmental health. Parts of the site need investment	4	**18**	11: This is a popular site with a healthy turnover of businesses that is showing resilience to the market downturn on the whole. Some parts of the site are in need of upgrading and some reinvestment is needed.
St Lawrence	0.19	4	This is a small site in a predominantly residential area. There are 5 small units that are all occupied. The	3	4	The sustainability of this site has not changed since the original scoring exercise	4	5	The site is located in a predominantly residential area and development/intensifica tion of the site could be	4	**18**	12: This is a small site in a residential location next to a school. It is incompatible with surrounding uses, and given the downturn in the

			buildings are satisfactory but the access, turning and parking are poor. The downturn in the market will have an effect on the marketability of this site.						incompatible with the surrounding area and lorry routing is poor			market is unlikely to be redeveloped
Tivoli Road	2.45	5	This site is bounded by the railway line and residential properties. It is occupied by three large buildings which are in good repair. Access to the site and parking is poor. There has been a recent change of use allowed from storage and distribution to retail in one of the units. The downturn in the market may have an effect on the marketability of this site.	1	3	The sustainability of this site has not changed since the original scoring exercise	3	5	The site is in a residential location and has poor access through heavily parked up residential streets. It has lorry routing issues and is not suitable for large vehicle movements.	4	**18**	8: This site is in a constrained residential location. It is incompatible with surrounding uses and given the downturn in the market is unlikely to be redeveloped.
Westwood Ind Est	25.9	4	This site is a large site in Margate which is well established and has a varied mix of uses including retail. There are vacancies in some sections but they are being actively marketed. Some parts of the site are poor and in need of upgrading. The access and road networks to the site are good and there are few constraints to redevelopment	3	4	The sustainability of this site has not changed since the original scoring exercise	4	5	Redevelopment on a large site such as this is viable. It is a large accessible site within Margate's urban confines and attracts a range of uses of varying sizes.	4	**18**	11: This site is unconstrained in nature and is a popular vibrant employment site which could accommodate redevelopment.
140-144 Newington Road	1.12	4	This is a single occupier site located in a predominantly residential location.	1	4	The sustainability of this site has not changed since the original scoring exercise	4	5	The site is in a residential location and has poor access through heavily parked up	4	**17**	9: The site is located in a predominantly residential area and commercial redevelopment of the site

			Lorry routing to the site is poor. At the time of this review Piper Windows had gone into receivership and the site is vacant. The downturn in the market is likely to have an effect on the marketability of this site						residential streets. It has lorry routing issues and is not suitable for large vehicle movements.			could be incompatible with the surrounding area and lorry routing is poor
All Saints	3.16	4	This site is bounded by the railway line and residential properties. The site is in poor condition including buildings and external area. There is a large area of vacant land and poor use of the site. Given the market downturn it is unlikely that this will be developed.	1	5	The sustainability of this site has not changed since the original scoring exercise	5	4	The site is in a residential location and has poor access through heavily parked up residential streets. It has lorry routing issues and is not suitable for large vehicle movements. There have been complaints of noise and paint spraying to Environmental Health from nearby residents.	3	**17**	9: This site is in a constrained residential location. It is incompatible with surrounding uses and given the downturn in the market is unlikely to be redeveloped.
Eurokent	38.6	5	This is a large site in Ramsgate which is largely vacant. The Northern part of the site contains leisure uses and the southern part of the site has been developed for office and industrial units developed by SEEDA. The possibility of housing on the site is being investigated. The units have been actively marketed and most of them have been taken up. It is a well presented site with good access and centrally located.	3	5	The sustainability of this site has not changed since the original scoring exercise	5	3	The site is centrally located in the District with good road access although some mitigation may be required. The site has been the subject of a recent planning application for mixed use development.	3	**16**	11: This site has development potential, it is centrally located with good road access and is close to the amenities at Westwood.

Hedgend	2.46	4	This popular site is in a rural location but is well linked by road to the Thanet Way. Access and lorry routing is good There is a planning permission for 3 buildings housing 12 general industrial units. The market downturn does not seem to have affected the take up of units on this site.	3	3	The sustainability of this site has not changed since the original scoring exercise	3	4	The site is well located with good access to the road network for lorries. The site is popular with a remaining developable area with planning permission for 12 units.	4	**16**	10: This is a well located popular site with scope for further development.
Northdown	0.89	4	This is a single industrial building which is split into 11 units. The site is popular with all units occupied. The site appears unaffected by the downturn in the market but there is a planning permission for an office building.	3	3	The sustainability of this site has not changed since the original scoring exercise	3	4	The site has fairly poor access but is proving deliverable as redevelopment is occurring.	4	**16**	10: This is a popular site that is proving resilient to the economic downturn despite highway constraints
Princes Road	0.98	3	This site is in very poor condition within a predominantly residential area. The contains a number of small units and is well occupied but given the downturn in the market is less attractive and marketable	2	4	The sustainability of this site has not changed since the original scoring exercise	4	4	This site has poor lorry routing and is in a residential area complete redevelopment is needed	3	**16**	9: This site is in a constrained residential location. It is incompatible with surrounding uses and given the downturn in the market is unlikely to be redeveloped.
Whitehall Road	0.95	4	This site is located in a residential area. The building and site presentation are satisfactory. The site contains a number of small and medium sized units but given the downturn in the market	3	4	The sustainability of this site has not changed since the original scoring exercise	4	4	This site has poor lorry routing and is incompatible with the surrounding uses	3	**16**	10: This site is in a constrained residential location. It is incompatible with surrounding uses although does provide inexpensive premises for a number of small businesses.

			other sites are more attractive. At the time of visiting there was one vacant unit									
Manston Road (S)	6.8	2	The Flambeau site is poor and in need of redevelopment	1	5	The sustainability of this site has not changed since the original scoring exercise	4	4	The site has reasonably good access but mitigation may be required at Stannar Court. Complete redevelopment may be unviable	3	**15**	8: This poor quality site is in need of complete redevelopment.
Thanet Reach	9.74	3	This site is well presented and currently contains some education uses and the Kent Innnovation centre. Access to the site and parking are good. Large parts of the site remain undeveloped.	2	5	The sustainability of this site has not changed since the original scoring exercise	5	4	The site is attractive and deliverable but uses may be limited by the residential nature of the area.	4	**15**	11: The site is attractive and ready for development but uses may but uses may be constrained.
Factories, Suffolk Av	0.45	3	This is a small site in a residential area. There are 2 businesses operating from the site in poor unsuitable buildings. Access to the site and parking are very poor.	1	3	The sustainability of this site has not changed since the original scoring exercise	3	5	Redevelopment of this site for employment site is unsuitable and unrealistic. Lorry routing is particularly poor. Employment use is incompatible with the surrounding area and noise abatement notices have been served	2	**14**	6: The site is inadequate for employment use and is incompatible with surrounding uses. The owner has expressed a wish to locate to a different employment site in Thanet
Dane Valley (developed)	5.04	4	This is a large very popular site occupied by a range of businesses. Parts of the site vary in quality and access and parking is relatively poor. 5 spec units have recently been developed named copper leaf business park.	3	3	The sustainability of this site has not changed since the original scoring exercise	3	3	Lorry routing and access are poor and the area is heavily parked up, Despite this the site is popular with regular enquiries for new uses.	3	**13**	9: This site functions well despite having access and parking difficulties. Due to its popularity it may benefit from some reinvestment.

Dane Valley (undeveloped)	3.49	3	The undeveloped part of the site is constrained	1	3	The sustainability of this site has not changed since the original scoring exercise	3	2	Lorry routing and access are poor so development of the undeveloped part of the site is unlikely	2	**11**	6: The remainder of the site is unsuitable for development and this allows for reinvestment in parts of the developed site that need it.

APPENDIX 2 – Site Submissions

A number of site submissions have been received relating to employment land and these are outlined in the table below along with recommendations in the light of this report:

Site	Request	Recommendation/ Comment
Manston Business Park (four sections of)	A wider variety of uses should be allowed on site such as crèches to make the site more attractive [Employment generating uses within existing local plan designation but also other small scale uses which serve the employment use of the site]	Manston Business Park is Thanet's flagship employment site and should not be compromised by piecemeal development and uses that are not traditional B use employment. Ancillary development would be allowed to support the main use. Provision has been made for flexibility of uses on more appropriate sites
East Northdown Farm	The site owner requests that the site be allocated for employment and leisure uses [Submission indicates potential residential or mixed use including retail, nursery/farm shop/horticulture/agriculture/class B1/leisure and retail.]	This site is already in employment use and contains a number of small units. A number of similar sites which cater for SMEs in the District are protected for employment use and this is not considered a necessary addition. Road access to the site is also poor. Provision for leisure uses has been made within Thanet's town centres and on specific sites
Manston Riding Centre, Alland Grange Lane, Manston	The site owner has requested leisure and tourism and potentially light industrial employment/mixed	Adequate land is available on within the existing allocation on Manston Business Park. Provision for leisure uses has been made within Thanet's town centres and on specific sites
Ramsgate Garden Centre, Montefiore Avenue, Ramsgate	The site owner requests residential development or alternative uses such as retail, commercial employment, leisure or tourism e.g hotel	Sufficient land and varied sites are available on existing sites in Ramsgate to meet the identified need to the end of the plan period. The area is predominantly

		residential and employment uses may be incompatible with surrounding uses
Former railway track, Nash Road, Margate	Residential and/or employment/employees' housing	Employment uses are already provided in this area at Westwood Industrial Estate
Jentex Site, Canterbury Road west, Ramsgate	Residential/possible commercial or any suggested alternative	The site is currently allocated for employment use. The site now scores worse in terms of accessibility as the A256 road improvements have bypassed the site and has limited access to the primary road network
Jewson's site, Tivoli Brooks Industrial Estate, Margate	Mixed development including residential and employment uses	The site is already allocated for employment uses and the recommendation in this report is to continue this.
Land south of Manston Road, Ramsgate	Infrastructure-led mixed use including residential and employment land	The owner is now seeking purely residential allocation. The scoring exercise in this report concludes that the site is not necessary to the portfolio of sites that support the economic strategy for the area.
Land west of Cliff View Road, Cliffsend	Housing, employment, airfield and road related development	Employment uses are already provided for adequately in this area at Laundry Road Industrial Estate
Land West of Greenhill Gardens, Minster	Housing, employment, airfield and road related development	Employment uses are already provided for adequately in this area at Laundry Road Industrial Estate
Land west of prospect rd, Minster	Housing, employment, airfield and road related development	Employment uses are already provided for adequately in this area at Laundry Road Industrial Estate
Land south of Monkton rd, Minster	Housing, employment, airfield and road related development	Employment uses are already provided for adequately in this area at Laundry Road Industrial Estate
Land southeast of Mount Pleasant roundabout, Minster	Housing, employment, airfield and road related development	Employment uses are already provided for adequately in this area at

		Laundry Road Industrial Estate
Land east of laundry road, Minster	Housing, employment, airfield and road related development	Employment uses are already provided for adequately in this area at Laundry Road Industrial Estate
Land east of Wayborough Hill, Minster	Housing, employment, airfield and road related development	Employment uses are already provided for adequately in this area at Laundry Road Industrial Estate
Land east of Way Hill, Minster	Housing, employment, airfield and road related development	Employment uses are already provided for adequately in this area at Laundry Road Industrial Estate
Land south of A253, Minster	Business	Employment uses are already provided for adequately in this area at Laundry Road Industrial Estate
Land at Ramsgate Road, Margate IPA Smith R25-051	Either residential or mixed (residential with employment/commercial)	Employment uses are already provided in this area at Westwood Industrial Estate
Land at manor Road, St. Nicholas	Either primarily residential including some community facilities or mixed use including residential, employment and community facilities	Employment uses are already provided for adequately in this area at Hedge End Industrial Estate
Land west of Updown House, Ramsgate Road, Margate R25-57	Either residential with public open space or a mixed development including residential, commercial/employment, retail and a quality hotel.	Employment uses are already provided in this area at Westwood Industrial Estate
Land North of Manston Green Farm, Manston R25-059	Either all residential incorporating some community facilities and or employment (small business uses) or a business hotel.	Employment uses are already provided for adequately in this area at Manston Green
Land fronting (north side of) Westwood Road, Broadstairs R25-063	Either primarily residential but including some community facilities or a mixed development I.e. residential, commercial and leisure	Employment uses are already provided in this area at Cromptons site.
Land at Minster Road, Acol (northern part) R25-076-1&2	Extension to existing business park	Adequate land is available on within the existing allocation on Manston Business Park
Land at Richborough Power Station.	B1/B2/B3 employment and uses identified within 2006 Thanet Local Plan under Policy EP14	This area is being considered in the Kent Minerals and Waste

	(Renewable energy)	Local Plan for Waste to Energy uses. It is currently allocated in the Kent waste Local Plan for Waste Uses. Use of this Land for employment uses is surplus to requirements
Land at Manston Business Park (east of existing BP) 2018 submission Phase 1,2 and 4, Land at Manston Business Park, Manston Road, Manston, Ramsgate	Employment/Commercial Residential and commercial	Adequate land is available on within the existing allocation on Manston Business Park
Land to east of Grupo Antolin, Eurokent Business Park	Mixed use business	This area has been developed for retail.
Land at Dane Valley Road/Northdown Hill, Broadstairs R25-104	Employment	Copper Leaf extension has been built
Land at Haine Road & Spratling Street R25-119	Residential or mixed leisure/residential	Adequate land is available on within the existing allocation on Haine Road Industrial Estate and at Westwood Cross
Land at Nash & Haine Roads (Gleesons site), Westwood R25-133	Residential (inc element of commercial/community)	Adequate land is available on within the existing allocation on Eurokent and at Westwood Cross
Arlington House & 1-50 Arlington Sq, Margate R25-150	Mixed use for retail, superstore, hotel and refurbishment of existing residential	Site has extant permission for retail
Dane Valley Industrial Estate Extension EKC	Employment uses – extension to the Industrial Estate	Site lies in the green wedge
Manston Airport site GVA	Mixed Use Employment led Development	Awaiting outcome of DCO process

The Rt Hon James Brokenshire MP
Secretary of State for Housing, Communities and Local Government

Ministry of Housing, Communities and Local Government
4th Floor, Fry Building
2 Marsham Street
London SW1P 4DF

Tel: 0303 444 3450
Email: james.brokenshire@communities.gsi.gov.uk

www.gov.uk/mhclg

Councillor Robert W. Bayford
Leader, Thanet District Council

28 January 2019

LOCAL PLAN INTERVENTION

Following Thanet District Council's failure over many years to get a Local Plan in place, the former Secretary of State wrote to your Council, on 16 November 2017, to express his concerns. He offered an opportunity to explain any exceptional circumstances justifying the failure of your Council to produce a Local Plan and any measures you had taken or intended to take to accelerate plan publication. Following your letter of January 2018 outlining your exceptional circumstances, the former Secretary of State wrote again on 23 March 2018. He set out that he had considered your representations and the Government's Local Plan intervention policy criteria and had decided to continue with the intervention process by commissioning a team of experts led by Government's Chief Planner to provide advice on next steps.

I have carefully considered that advice on next steps and all the above matters. I have also considered correspondence sent to my Department since January 2018, including correspondence from Thanet District Council, which reported some positive actions and progress, including the publication of a Local Plan under regulation 19 of the Town and Country Planning (Local Planning) (England) Regulations 2012, the publication of a revised Local Plan production timetable[1] and the submission of a Local Plan under regulation 22 of the Town and Country Planning (Local Planning) (England) Regulations 2012.

Section 27(1) of the Planning and Compulsory Purchase Act 2004 ("the 2004 Act") provides:

[1] The Thanet Local Development Scheme (July 2018)

"This section applies if the Secretary of State thinks that a local planning authority are failing or omitting to do anything it is necessary for them to do in connection with the preparation, revision or adoption of a development plan document."

In view of your continuing failure to get a Local Plan in place I am satisfied that the requirements in section 27(1) of the 2004 Act are met; Thanet District Council (in its capacity as local planning authority):

- does not have an up-to-date Local Plan in place - the Council's last Local Plan was adopted in 2006 and covered a period up to 2011.
- has failed to meet the milestones in at least five Local Development Schemes since 2006.
- has failed to plan for and deliver the homes people need in Thanet.

Section 27(2) of the 2004 Act provides:

"The Secretary of State may—
(a) prepare or revise (as the case may be) the document, or
(b) give directions to the authority in relation to the preparation or revision of the document."

Pursuant to the powers in section 27(2)(b) of the 2004 Act I have decided to make a direction in relation to the preparation of the Thanet Local Plan:

Within four weeks of the date of this letter, I direct Thanet District Council to designate a lead Councillor and lead official to be responsible for progressing preparation of the Local Plan and to publish details of those designations.

In making this decision I have considered the following Local Plan intervention policy criteria[2]:

- **The least progress in plan-making has been made:** Out of 338 local planning authorities in England, Thanet are one of only circa 50 authorities who have not yet adopted a 2004 Act Local Plan under Regulation 26 of the Town and Country Planning (Local Planning) (England) Regulations 2012.

- **Policies in plans have not been kept up to date:** Thanet's last Local Plan was adopted in 2006 (not under the provisions of the 2004 Act), and covered a period up to 2011. Thanet have consistently failed to bring forward a Local Plan in accordance with its Local Development Scheme as legally required, having failed to meet Local Plan milestones in at least six Local Development Schemes since 2006.

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[2] Local Plan intervention policy criteria were consulted on in 2016 and confirmed in the 2017 housing White Paper and the 16 November 2017 Written Statement in the House of Commons

- **There is higher housing pressure:** Thanet is within the top third of Districts in England for high housing pressure, based on average affordability ratios[3]. Thanet lack of a five-year housing land supply further highlights the authority's failure to plan for and deliver the homes people need.

- **Intervention would have the greatest impact in accelerating Local Plan production:** Based on Thanet's revised Local Development Scheme, it is unlikely that Local Plan production would be accelerated by my Department taking over its production. In my judgement, given the authority's track record of persistent failure in plan-making, the intervention I have decided upon will provide more certainty and is the best way of ensuring that a Local Plan will be produced in accordance with the Local Development Scheme timetable.

- **The wider planning context in each area in terms of the extent to which authorities are working co-operatively to put strategic plans in place:** Several authorities in Kent have indicated interest in joint planning but no formal arrangements are in place.

- **The wider planning context in each area in terms of the potential impact that not having a plan has on neighbourhood planning activity**: at least six communities in Thanet are preparing neighbourhood plans: Birchington, Ramsgate, Margate, Broadstairs & St Peters, Westgate and Cliffsend. Communities can bring forward neighbourhood plans in the absence of an up-to-date Local Plan, but doing so can be more challenging for communities.

Having considered Thanet's performance against the Local Plan intervention criteria, I am satisfied that intervention action is justified.

Section 15(4) of the 2004 Act provides:

"The Secretary of State may direct the local planning authority to make such amendments to the [local development] scheme as he thinks appropriate for the purpose of ensuring full and effective coverage (both geographically and with regard to subject matter) of the authority's area by the development plan documents (taken as a whole) for that area."

Pursuant to my powers in Section 15(4) of the 2004 Act, I am also directing Thanet District Council to, within eight weeks of the date of this letter, amend its Local Development Scheme (dated July 2018) to provide for the completion of a review of their Local Plan within six months of its adoption.

[3] Ranked 98 least affordable of 324 English Districts (Housing Affordability Statistics, Office of National Statistics, 2017)

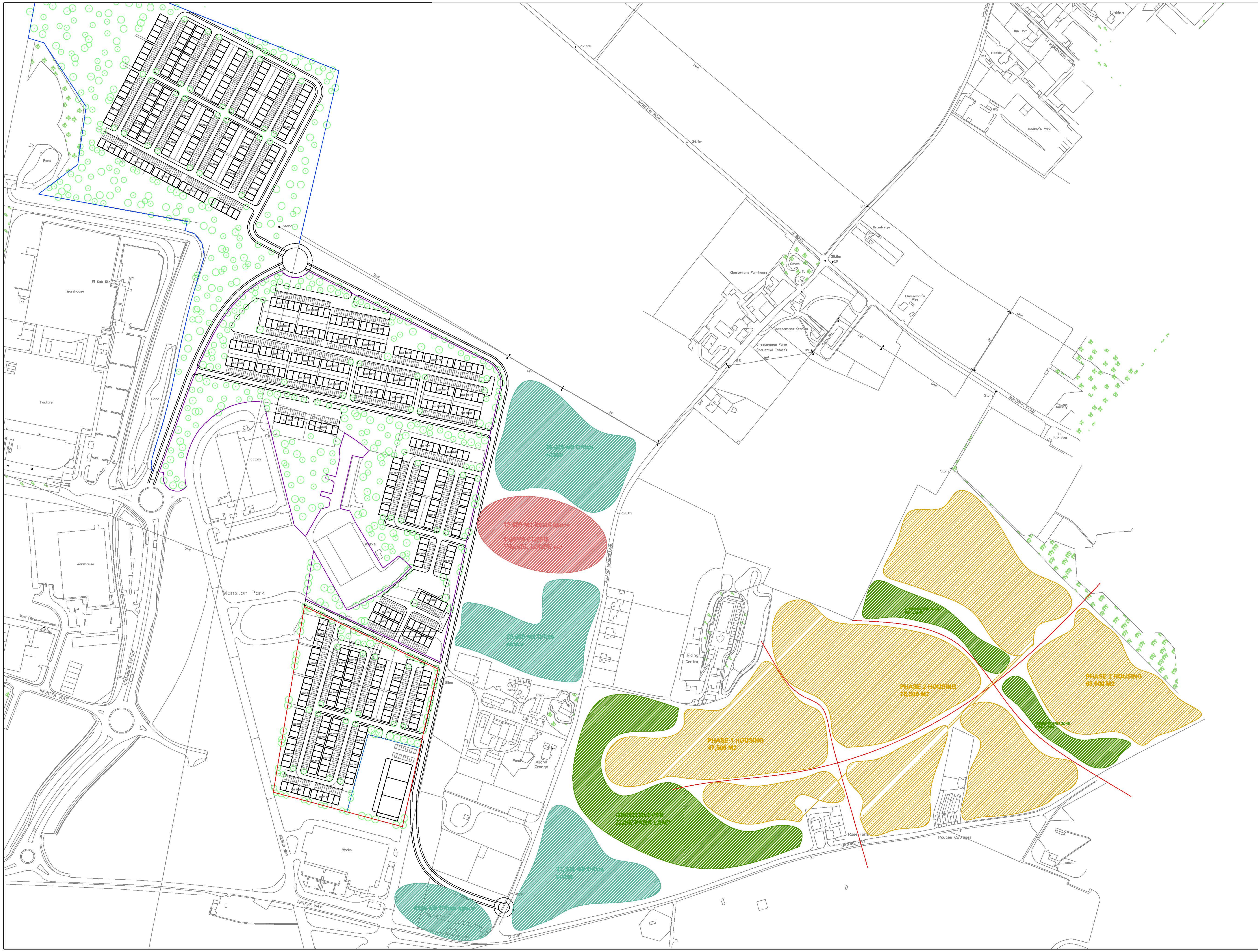
This course of action would ensure full and effective coverage of housing provision to give clarity to communities and developers about where homes should be built.

Having considered all of the above, in my judgement, there is a compelling case for the Local Plan intervention actions I have decided upon in Thanet, pursuant to powers in sections 15(4) and 27(2)(b) of the 2004 Act. Given your recent actions and progress in meeting the requirements in the Town and Country Planning (Local Planning) (England) Regulations 2012, I have decided not to prepare the Thanet Local Plan. However I will continue to closely monitor your Local Plan progress. Should a significant delay occur against the milestones set out in your July 2018 Local Development Scheme, should you fail to comply with the directions in this letter or should your draft Local Plan fail at examination, I will consider whether to take further action to ensure that a Local Plan is put in place.

I am also, for the avoidance of doubt, now putting on public record my concerns about the low level of housing supply and delivery in Thanet. I expect planning decision-takers to have regard to these concerns as a material consideration when deciding local planning applications.

I appreciate the constructive way Thanet District Council have engaged in this process so far and I trust that you and your officers will continue to engage positively. My officials will be in touch over the next few days to discuss next steps.

RT HON JAMES BROKENSHIRE



General Notes:

Use of this data acts as an agreement to the following. Do not use this data if you do not agree with the following:

Do not scale.

Use figured dimensions in all cases.

Report all errors, omissions and discrepancies in writing.

Verify all dimensions on site prior to commencing any works on site or preparing any shop drawings.

All materials, components and workmanship are to comply with the relevant current British Standards, Codes of Practice and appropriate manufacturer's recommendations that from time to time shall apply.

For all specialist work see relevant drawings.

All survey information is approximate and subject to clarification via a detailed topographical survey, statutory service enquiries and confirmation of legal boundaries.

Revisions :

Project :

Unity Park
Manston
Kent

Drawing Description :

Location Plan

Scale :

1:2500 @ A1

Date Drawn :

Sept 2017

Drawing No. **Revision.**

JD/AN/UP/01

Thanet District Council

Strategic Housing Land Availability Assessment

Review July 2018

Appendix G.1.7

Appendix G.1.7

Contents

Strategic Housing Land Availability Assessment UPDATE 2018

Executive Summary

This Strategic Housing Land Availability Assessment (SHLAA) assesses the individual and combined potential capacity of a pool of sites to accommodate additional dwellings over the period of the emerging Local Plan to 2031. It reflects the challenge of identifying sufficient sites to meet Objectively Assessed Need, and government guidance on land availability assessment.

The SHLAA itself does not allocate land for housing, and an indication that a site may have potential does not signify that planning consent would necessarily be granted for such development. It will be for the Local Plan making process (drawing on the information from the SHLAA) to determine which sites are appropriate to allocate for development.

The Councils Strategic Housing Market Assessment (SHMA) assesses housing need against projected population growth and determines the Objectively Assessed Need (OAN) for housing over the plan period. The SHMA was first undertaken in January 2016, and the review of September 2016 identifies an OAN for 17,140 new homes for Thanet over the plan period until 2031.
The SHLAA indicates that potential supply is sufficient to meet the target housing requirement across the Plan period.

The SHLAA process began in 2010 and has been on-going through various stages of the local plan process. The purpose of this document is to review, update and pull together all of the previous stages of the SHLAA into a single report.

1 Introduction

1.1 The new Local Plan will reflect a strategy for housing, which contributes to the achievement of sustainable development. This will need to be informed by evidence regarding the opportunities and options for the location of future housing provision. It is the purpose of this Strategic Housing Land Availability Assessment (SHLAA) to assess the potential availability of land for new homes in Thanet to provide this essential baseline information.

1.2 Government requires that Local Plans be based on adequate and up to date evidence. Its National Planning Policy Framework (NPPF), published in March 2012, maintains the requirement for local planning authorities to prepare a Strategic Housing Land Availability Assessment to establish realistic assumptions about the availability, suitability and likely economic viability of land to meet identified need for housing over the plan period. It also states that assessment of, and strategies for, housing and employment and other uses should be integrated and take full account of market and economic signals.

1.3 A separate Strategic Housing Market Assessment has been carried out to assess housing needs in the area and to inform a target level of housing to be provided for.

1.4 A Strategic Housing Land Availability Assessment for Thanet was published in 2010 and reviewed in 2013. This review provides an updated perspective on potential housing land in Thanet, following a higher housing requirement as identified in the SHMA (2016).

1.5 It is the role of the Local Plan to determine which sites are appropriate to be allocated for housing development, taking into account its strategy, higher level policy, plan targets and competing uses. It is therefore important to note that even if a site is assessed as deliverable or "developable" for housing in the SHLAA, this does not signify that the site will be allocated for such use in the Local Plan or that planning permission for residential development will or might be granted.

2 Previous versions of the SHLAA

2.1 The first SHLAA was prepared in 2010 and is an on-going and evolving process. A stakeholder partnership was initially established to participate in its preparation. While the Council took the lead role in drafting the work, the partnership participated by contributing expertise and knowledge to inform views on the deliverability and developability of sites and how market conditions may affect economic viability.

2.2 Stakeholder involvement and engagement in the process has evolved, including for example registered housing providers, builders and property agents participating in a number of workshops focusing on assessment of viability of development in the district.

2.3 The Council is now seeking to work with the market to encourage higher rates of house-building, and recently achieved accreditation to the Housing Business Ready Programme, run by the Housing & Finance Institute (HFI). The recent new involvement of the Homes & Communities

Agency (HCA) in development in the district, and their purchase of sites for development, is a positive indicator of commitment to delivery in the area.

2.4 The 2010 SHLAA assessed dwelling potential to 2026 against the benchmark target of 7,500 dwellings in accordance with the Regional Spatial Strategy (the 2009 South East Plan).
Since the 2010 SHLAA was carried out, the Government abolished the South East Plan and stated that decisions on future levels of housing will be decided by local planning authorities based on an objective assessment of need. The Government also introduced fundamental changes to the plan making system, including

- Introduction of the new National Planning Policy Framework (NPPF) to replace previous individual national policy statements,
- introduction of Planning Practice Guidance to amplify the NPPF and provide updated guidance on assessing land availability,
- greater emphasis on local authorities preparing single development plan documents to be known, again, as Local Plans.

2.5 The Council is now preparing a Local Plan for the District which is to cover the period to 2031. The changes referred to above have contributed to a deceleration of the plan preparation process, so the SHLAA was updated in 2013 in order to:

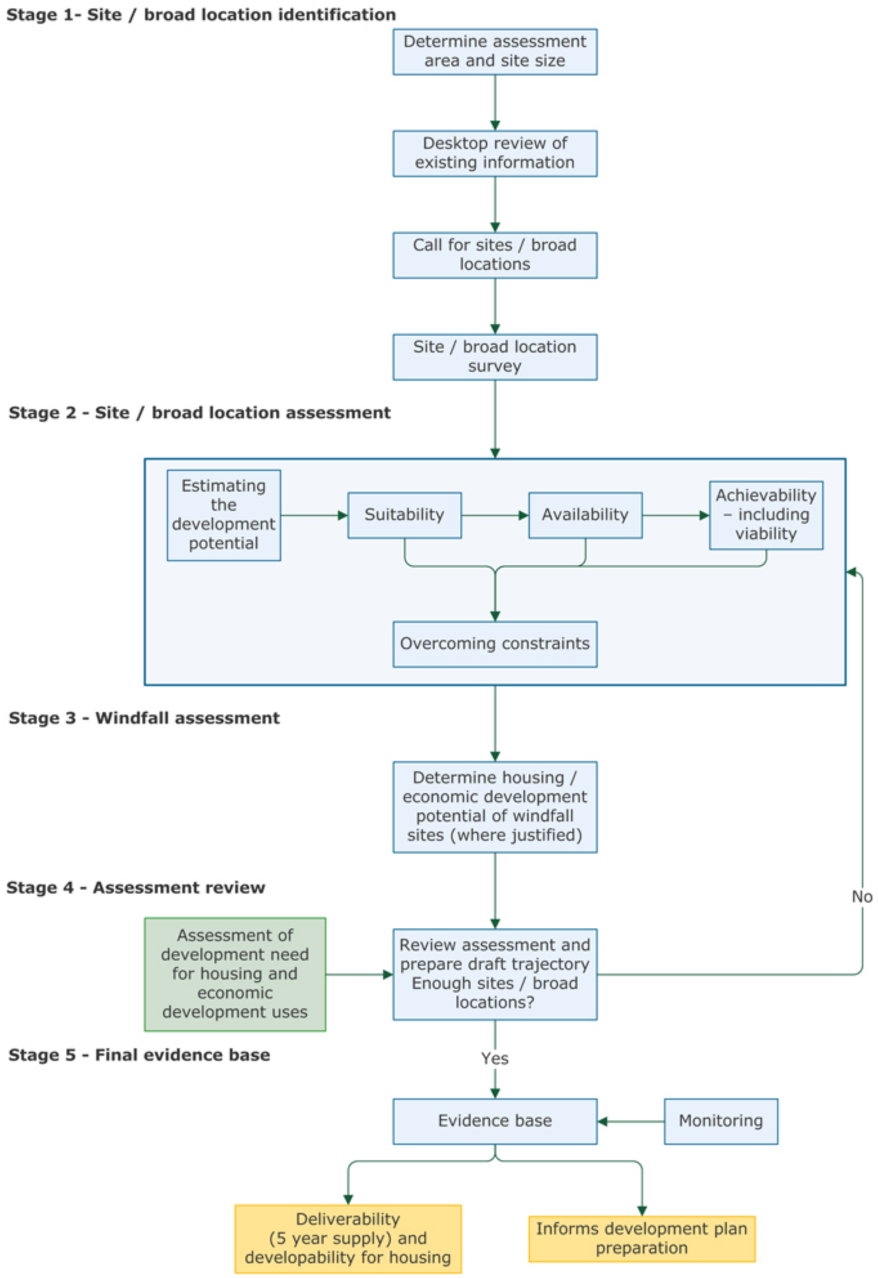
- Assess options for accommodating an alternative housing provision target (a total of 12,000 dwellings based on an in-house assessment)
- Reflect the longer term Local Plan period now proposed (2031)
- Review the portfolio of sites considered to have housing potential.

2.6 The process applied in the 2010 SHLAA was developed in light of the relevant government practice guidance applicable at that time, an agreed county-wide protocol (Appendix C) and in consultation with stakeholders. In the initial stages of preparing the SHLAA, involvement was sought to help assess current and future housing demand and provide feedback on the methodology. A range of representatives including local housebuilders and property agents, registered social landlords, the Homes and Communities Agency and Kent County Council participated. The 2013 review was undertaken on a similar basis and maintaining the principles established in the 2010 version but having regard to the draft Planning Practice Guidance on assessing land availability as it evolved.

2.7 This review has been carried out to demonstrate the availability of sites to accommodate a revised OAN (from the SHMA 2016), and includes sites proposed at Preferred Options and Preferred Options Review consultations. It is considered to be consistent with the PPG published in March 2014 and all of the sites submitted (see sources of sites below) have been assessed accordingly.

3 Methodology

3.1 This SHLAA has been prepared using the methodology set out in the National Planning Practice Guidance (PPG) and is illustrated on the diagram below.



3.2 Certain of the NPPF's core principles are particularly relevant to the context of the SHLAA . These include:

- Always seeking high quality design and a good standard of amenity for existing and future occupants of land and buildings.
- Preference in allocating land for development to land of lesser environmental value where consistent with the NPPF policies.
- Encouraging effective use of land by using land that has been previously developed provided that it is not of high environmental value.
- Promoting mixed use developments recognizing that some open land can perform many functions (including wildlife, recreation and food production).
- Managing patterns of growth to make fullest possible use of public transport, walking and cycling, and focusing significant development in locations which are or can be made sustainable.

3.3 The PPG states that assessing the suitability, availability and achievability of sites including whether the site is economically viable will provide the information on which the judgement can be made in the plan-making context as to whether a site can be considered deliverable over the plan period.

3.4 The level of housing provision to be provided over the period to 2031 is established through the SHMA which identifies Thanets housing requirement as 17,140 net additional homes over the period 2011-2031.

3.5 One of the aims of this SHLAA has been to identify sufficient deliverable and developable sites to meet the target requirement. The SHLAA process is resource intensive, and including every piece of land in the district would not be feasible. Nonetheless the extent of the search and survey needs to match the challenge of informing sustainable policy options for providing a land supply that is sufficient both in terms of meeting the numerical housing target as well as accommodating the type of homes required to meet policy objectives.

3.6 In order to keep the SHLAA exercise manageable, the PPG states that only sites with potential capacity of 5 or more dwellings should be considered as potential sites or broad locations. The PPG indicates that sites with planning permission for residential development will be suitable for housing unless circumstances have changed. Sites with planning permission that fall below the 5 dwelling threshold have therefore been included - the Housing Information Audit identifies a significant number of such sites and it is important that the cumulative contribution of these sites is not overlooked.

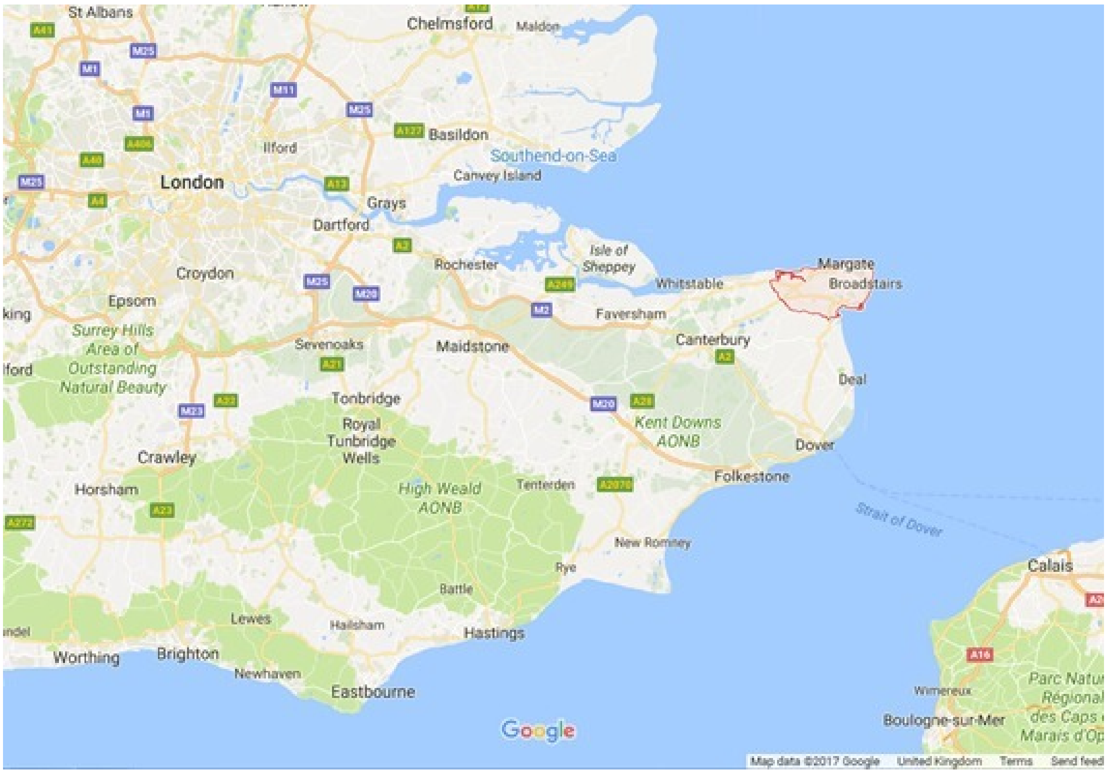
3.7 A principle applied in the 2010 SHLAA was for a lower than historic contribution from flatted development. The 2009 Strategic Housing Market Assessment identified a need to prioritise rebalancing of the housing stock to incentivise provision of family homes and control the expansion of flatting of larger homes. The 2016 SHMA confirms the over-provision of flatted accommodation therefore this SHLAA maintains the principle of assessing capacity in terms of new houses/bungalows unless flats are appropriate for good planning reasons (e.g. townscape) or where for example such development is anticipated as a result of a consented scheme

4 Methodology Stage 1 – Identification of Sites and Broad Locations

Study Area & Target Housing Requirement

4.1 The PPG states that the Strategic Housing Land Availability Assessment should cover the relevant housing market area. The PPG describes this as a geographical area defined by household demand and preferences for all types of housing, reflecting the key functional linkages between places where people live and work.

4.2 The Strategic Housing Market Assessment (SHMA) 2016 identifies a Housing Market Area of Thanet, Canterbury and Dover, but the housing requirement can be met by allocating sites within the Thanet district. Accordingly the geographical coverage of this SHLAA equates with the Thanet District, as illustrated on the map below.



Target Housing Requirement

4.3 The SHMA January 2016 identified Thanet's OAN as 15,700, however this was updated in September 2016 to take into account the 2014-based ONS Sub-National Population Projections and Thanet's OAN is now identified as 17,140.

Involvement of stakeholders

4.4 In the initial stages of the SHLAA process, stakeholder workshops were held in 2010 and 2014 to participate in establishing assessment methodology. The workshops were attended by neighbouring district councils, Kent County Council, parish councils, neighbourhood plan groups, planning agents, developers and Registered Social Landlords.

As part of the site assessment processes, the following stakeholders were contacted for comments on specific aspects of the potential allocation of sites:

- TDC Environmental Health Officer
- TDC Conservation Officer
- TDC Environmental Protection Manager
- Kent County Council Ecologist
- Kent County Council Highways
- Kent County Council Archeologist
- Southern Water

Sustainability Appraisal

4.5 A sustainability appraisal (SA) has been carried out to assess the draft policies of the local plan to determine whether or not they will have a positive or negative effect on sustainability. It is an iterative process that evolves alongside, and informs, the local plan.

It is important that site selection follows the broad principles emerging from the SA.

4.6 At the issues and options stage of the SA process, broad options were tested such as the amounts and location of housing including where the greenfield element should be accommodated. The option for accommodating development on brownfield sites within the urban area scored the best. The option for where best to locate the greenfield element favoured urban edge sites (based on the 2006 Local Plan Urban and Village Confines) which scored the best in sustainability terms. This informed the allocation strategy. The SHLAA further looked at sustainability criteria such as distance to public transport, healthcare provision, schools and shops.

4.7 At the early stages of the SHLAA process, sites that did not meet the locational principles in the Strategy for the Planned Location for Housing (SPLH) or emerging SA work were excluded from further detailed assessment – a list of these sites is attached at Appendix G. Any sites that do not appear in Appendix F should be listed in Appendix G and there may be some duplication between these lists.

<u>New Settlement</u>

4.8 The concept of a new settlement to address housing demand was put forward as an option of the Local Plan Issues and Options consultation in the summer of 2013. As limited details regarding a new settlement option and any mitigation were known at this time, the option performed poorly within the sustainability appraisal as there would be a high level of greenfield development requiring additional infrastructure and public transport investment in order to function. As such, the poorly performing option was discounted as a viable solution to addressing Thanet's housing demand.

4.9 Since the Issues and Options consultation, additional housing need has been identified within Thanet resulting in a need to review the preferred housing strategy. For completeness, it was decided that a review of a potential new settlement option should be undertaken, but exploring the opportunity to implement robust mitigation in order to facilitate as sustainable new settlement scenario as possible.

4.10 An assessment of possible new settlement sites due to their size and location, either on their own or adjoining other sites were appraised against the sustainability appraisal.

4.11 The study concluded that given the implementation of defined and robust mitigation (based on the content of exemplar planning policies from other authorities, which have progressed through the plan preparation process), sustainable implementation of a new settlement option could be achieved.

4.12 Based on SA assessment, option NS5 (the former airport site) was deemed the most likely opportunity to provide a sustainable new settlement due to its size, which would allow comprehensive provision of uses and facilities, and its unique status amongst options as a brownfield site.

4.13 However the former airport is currently subject to a Development Consent Order application and its current lawful use is for aviation activities. It has since been considered that the allocation of the site as a new settlement would not be appropriate if it might jeopardise any future aviation use.

4.14 The other potential new settlement sites were either unsustainable, or would not be appropriate for allocation due to their proximity to the airport site, if it is to return to active aviation uses. The housing sites required to accommodate the additional need were therefore identified in accordance with the original SA recommendations as sites at the urban edge.

Sources of Potential Sites

4.15 Planning Practice Guidance advises that all available types of sites and relevant sources of data should be considered in the SHLAA assessment process. Key sources used in assembling the pool of sites for this SHLAA are listed below.

- The 2002 Urban Capacity Study
  This provided a thorough survey and assessment of potential housing sites. The Study was based on a Kent Protocol which included guidance from PPG3 and Governments Good Practice Guidance on Urban Capacity Studies 'Tapping the Potential Assessing Urban Capacity'. The Protocol identified the following potential sources of housing capacity:
    - Sub-division of existing housing
    - Flats over shops
    - Empty Homes
    - Previously developed vacant and derelict land and buildings (non-housing)
    - Intensification of existing areas
    - Redevelopment of existing housing
    - Redevelopment of car parks
    - Conversion of commercial buildings
    - Review of existing housing allocations in plans
    - Review of other existing allocations in plans
    - Vacant land not previously developed

  The SHLAA exercise reviewed and re-assessed the sites identified in the study. This included a review of capacity assumptions, including concerns about the need to safeguard residential amenity and avoid developments which would worsen the existing imbalance in the make-up of the district's housing stock which has a high proportion of flats. Many of these sites included back gardens – these have not been carried forward as potential sites as they are contrary to the NPPF.

- Sites allocated for development in the adopted (2006) Local Plan, but not yet developed

- Brownfield Land Register

- Sites granted planning permission (including those not started and under construction) sourced from annual Housing Information Audits.
  The base date for this SHLAA is 31 March 2018 - this coincides with the annual Housing Information Audits (HIA) carried out by the Council. These HIA's assess the status of housing sites with planning permission (ie not started, under construction or complete). Sites that were submitted in earlier calls for sites that have since been granted planning permission have been listed in Appendix E, however a further 2182 residential units have been granted planning permission and identified through the most recent HIA.

- Potential sites subject of pre-application discussions.

- Council owned land with potential availability.

- Sites to be the subject of development briefs/master plans (for example due to their recognised potential for area regeneration).

- Sites requested for allocation in the development plan by landowners and developers. (Such submissions included requests to consider allocation of sites for housing and some sites for other purposes)
  As part of the Local Plan preparation process, land owners and developers have been invited through several “calls” to put forward any sites they felt should be assessed for development potential and possible allocation. The first ‘call for sites’ was carried out in 2005 as part of the (then) Core Strategy process. Subsequent calls have coincided with stages in the plan preparation process, the most recent being January 2018. Many such submissions involve larger sites on greenfield land. Sites have also been submitted as responses to the Issues and Options, Preferred Options and Preferred Options Review local plan consultations. A map at Appendix A illustrates the distribution of all of the sites submitted.

- Land allocated or protected for employment use.
  Certain sites have been used for employment purposes and may be available and suitable for residential development. Assessment of such sites has been informed by specific survey and review as part of an Employment Land Review of the district, which has effectively been carried out in parallel with the SHLAA. This has resulted in some 30ha of older, less suitable employment land being re-allocated for housing.

- Empty Property
  There are some 4,325 properties in Thanet identified as empty in the Council Tax records. However, this includes properties which are temporarily empty for various reasons (Armed Forces; people in prison; etc), or second homes, and other similar categories. This means that there are in fact about 1,450 properties that are actually vacant. Of these, just under 1,000 are long-term empty (within the Council Tax definition).
  Some empty properties can be considered as contributing to land supply, but only when the following criteria are met:
    - The properties in question have been empty for a period of 4 years or more. (This is based on the position that over that period it can be argued that those properties have been vacant and unused for such a long period that they are no longer available in the housing market and therefore not part of the active housing stock); And
    - The Council has an active and robust programme for bringing those properties back into use.

  This is based on the position that such housing is returned to the market, almost as if it were new housing stock and is a rolling 4 year programme. The Council does have an Empty Homes programme which it is calculated has, over the last few years, brought about 110 dwellings back into use each year.

  In May 2017, Thanet District Council committed additional resources to its empty homes work by appointing a new Empty Property Officer. The existing Empty Property Support Officer will continue to focus on offering advice and support to the owners of empty homes, together with facilitating empty homes loans in partnership with Kent County Council. The new Empty Property Officer will be tackling the most difficult and dilapidated properties with a view to taking robust action to bring these back into use. The outcomes from this programme will need to be regularly monitored, and is dependent on the Council’s Empty Homes programme continuing through at least the Plan period.
  There are a number of steps required to provide a robust calculation of the empty homes contribution to housing land supply:

1	Identify the number of properties in the stock that have been vacant for 4 years or more
2	Identify the number of properties in the stock that are likely to become vacant for 4 years or more during the Local Plan period
3	Identify the number of empty properties that the Council (through its Empty Homes programme) has brought back into use so far in the Local Plan period
4	Identify the number of empty properties that the Council is expecting to bring back into use during the rest of the Plan period (through its Empty Homes programme)

The calculation below is the result of combined work between Strategic Planning; Housing (Empty Homes) and Council Tax bringing together the relevant information. In order to be eligible to be counted towards housing land supply, properties must meet BOTH the criteria set out above.

Council Tax produces data for properties which have been empty 4+ years.
Secondly, identify the number of empty properties that the Council is intending to bring back into use that fall within the 4+ years empty category, as these are the only ones that would count towards the housing supply.

Of the properties that have been brought back into use, the figure that can be used for the Local Plan housing figures must exclude any properties with planning permissions in order that they are not double counted as these would be included in the Housing Information Audit. The number of empty properties that have been brought back into use that have not required planning permission is 89 from 2016/17 and 84 2017/18.

By projecting these figures to the end of the plan period, it can be assumed that 357 empty properties (27 per annum) can be brought back into use, and therefore subtracted from the number of dwellings to be provided for in the local plan. Discussions with Council Tax and Housing will enable these trends to be monitored throughout the plan period and reported each year in the Annual Monitoring Report.

5 Methodology Stage 2 - Assessment of Sites

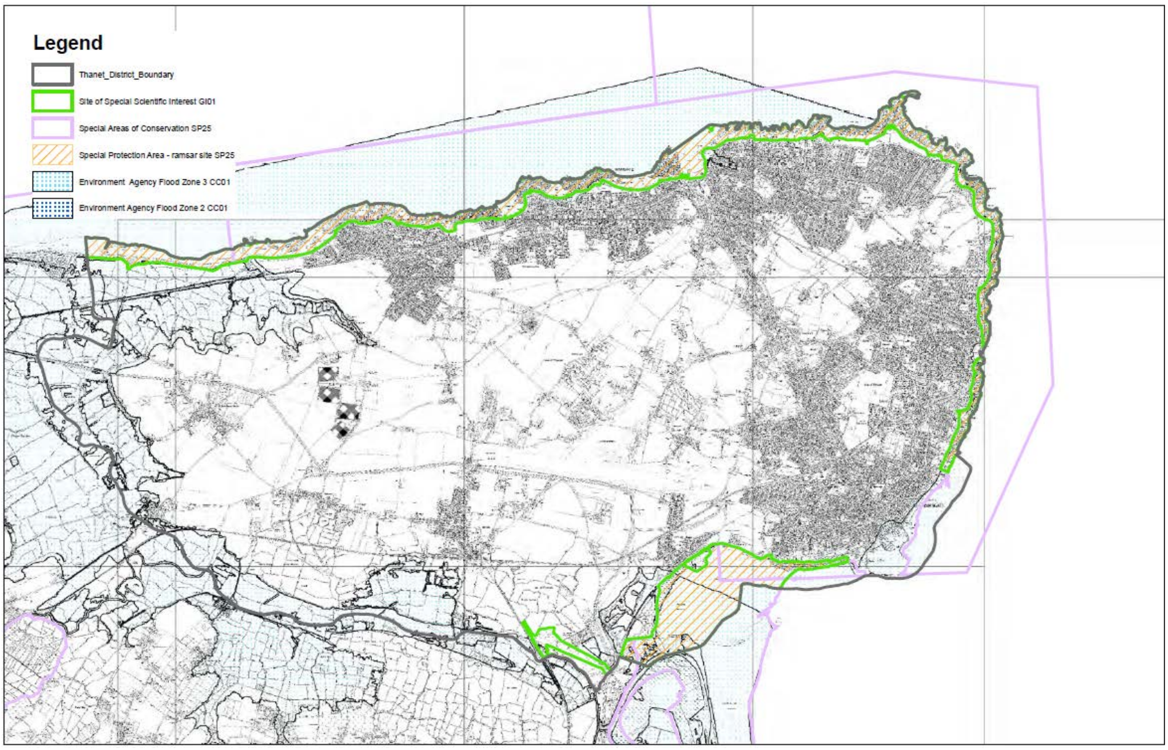
5.1 All sites have been assessed for their suitability, availability and achievability. Sites were surveyed to assess their general characteristics including existing use, obvious constraints and initial observations on suitability for housing or mixed-use development. All of the sites have been re-assessed against criteria that conform with that in the National Planning Guidance. The Stage 1 Assessment is the initial screening and raises the following considerations:

Category 1: National and Regional

5.2 Relevant policies include Flood Risk Areas and SPA, Ramsar, SAC, SSSI, NNR, AONB, Ancient Woodlands, Local Green Spaces, Flood Risk Areas – sites located within these areas, or in close proximity could cause a detrimental impact to the designated site.

5.3 The majority of Thanet’s coastline is designated as a Special Protection Area. The potential for additional recreational pressure on the SPA as a result of the proposed amount of housing has been identified as a risk to the SPA. This can be addressed by a Strategic Access Monitoring and Mitigation Strategy (SAMM) which is the method agreed with Natural England. New residential developments will be required to contribute towards the SAMM via a S106 agreement. This applies to all new residential development in the district, since development anywhere in the district is close enough to the coast to increase recreational pressure. As this is an issue applicable to all sites, there has not been a specific reference to it in the assessments.

Map A - Location of Sites of Special Scientific Interest, SPA, Ramsar, SAC and National Nature Reserve, Flood Risk Area



Category 2: Local

5.4 Relevant policies include Urban/Village confines, Green Wedges, Local Wildlife Sites, Landscape Character Areas – sites that fall within local designations would still be assessed but may not be allocated if there are sufficient sites that do not fall within locally designated areas.

5.5 Green Wedge boundaries have been assessed as part of the SHLAA process where sites have been proposed within them. The Council considers the boundaries to be robust, and has identified sufficient sites outside of the Green Wedges, therefore no sites have been allocated within them. (A planning application for residential development on one of the sites in the Green Wedge was granted planning permission on appeal, and the site has since been allocated. This will have an adverse impact on the Green Wedge, so the boundary has been amended to exclude the site from the Green Wedge).

5.6 The NPPF states that sites should be allocated on land with the least environmental or amenity value, and that account should be taken of the economic and other benefits of best and most versatile agricultural land. However the majority of Thanets agricultural land is either Grade 1 or Grade 2 so allocating high quality land for housing has been unavoidable.

B - Is the site currently in use or allocated for employment or other use and remains suitable and required for that use or is protected by a current development plan policy from development for other uses?

5.7 The NPPF states that planning policies should avoid the long term protection of allocated employment sites where there is no reasonable prospect of a site being used for that purpose. A separate Employment Land Review has been carried out, and about 30 hectares of older employment land has been allocated for housing development.

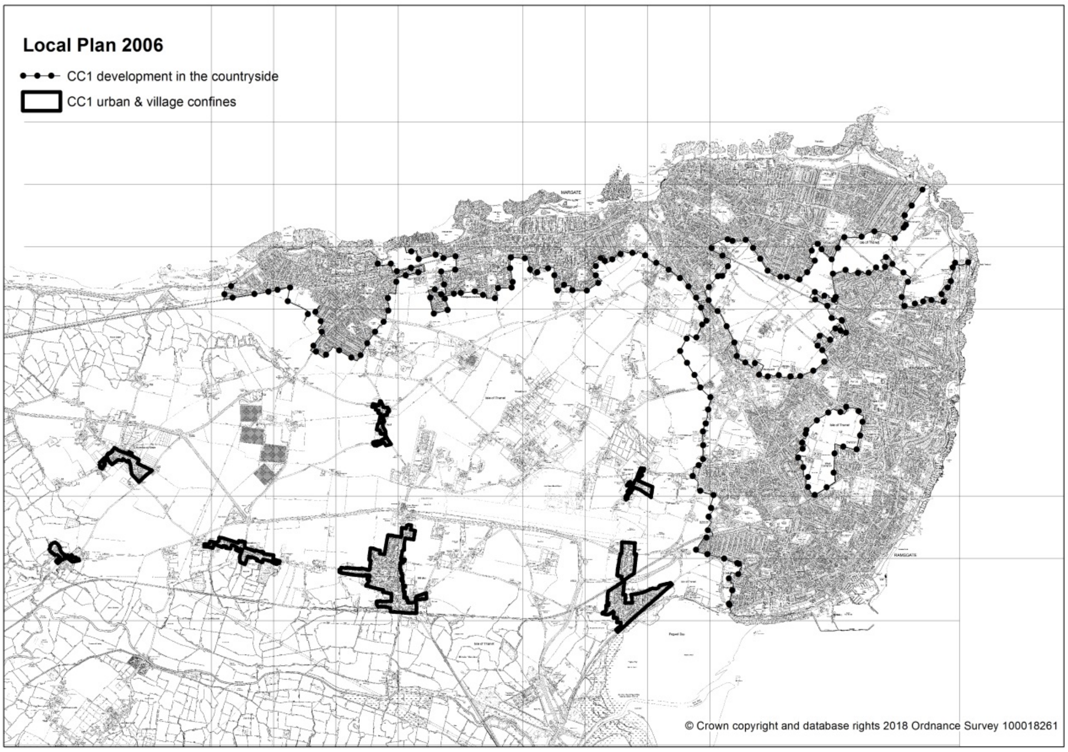
C - Is the site in or adjacent to a settlement?

5.8 Sites within or adjacent to existing settlements will be more sustainable than those which are not. There is some merit in considering allocating houses in rural settlements not only in meeting local housing need but also in providing a degree of locational choice.

D - Does the site fall within or adjacent to a settlement which has been identified in a development plan document as being suitable for future housing development?

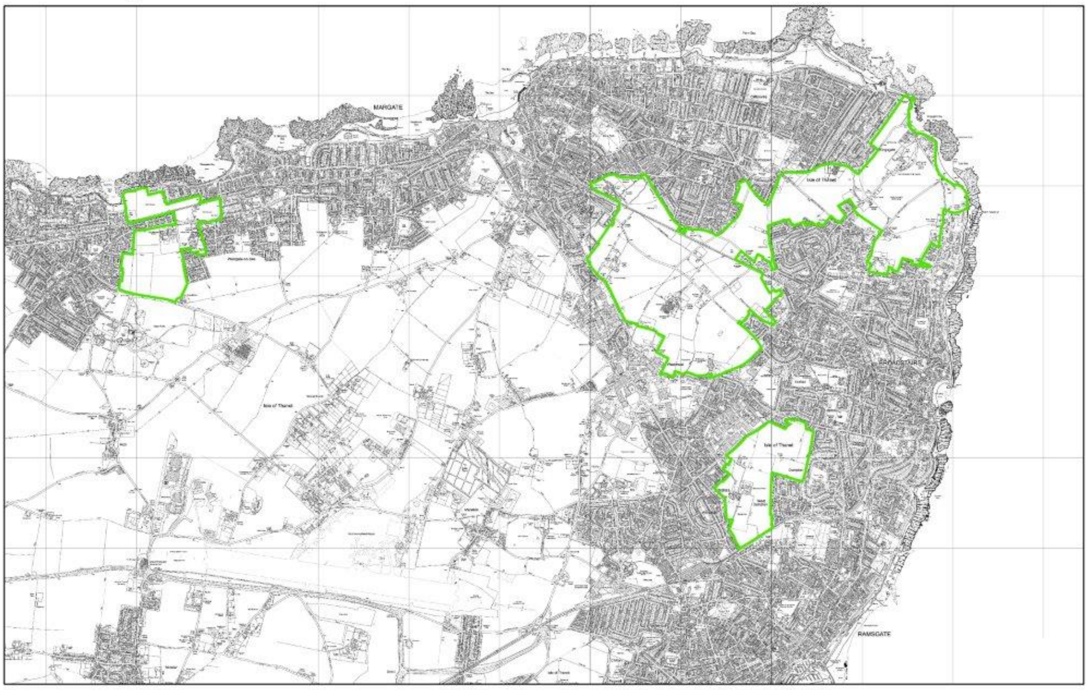
5.9 There is potential for any sites within or adjacent to a site already allocated for housing development to be considered as part of the wider allocation and make more positive contributions to the area as a whole.

Map B – Urban and Village Confines



Map C - Location of designated Green Wedges

Green Wedges



Housing Capacity

5.10 The potential number of dwellings for a site have been included for site submissions based on a broad requirement of 35 dwellings per hectare. However alternative capacities have been applied in circumstances where it is more realistic or desirable, for example where particular dwelling types, density or layout would be more appropriate in the area. Where a valid and detailed planning permission existed then the relevant capacity was applied unless site assessment or other circumstances indicate otherwise

Sites that passed the above criteria were assessed under 'Stage 2' in more detail.

Stage 2 Assessment

A. Is the site allocated for housing in an existing development plan or does it have planning permission for housing?
If yes, the site was considered to be suitable unless circumstances had changed to render it unsuitable.
If no, the site was assessed against the questions set out in B to E as follows

B. Is the site in a suitable location when measured against the following criteria?

- Within 800m walking distance of a bus stop or railway station providing two or more services per hour.
- Within 800 m walking distance of a convenience store, a primary school and a GP surgery (some GP surgeries have closed and being replaced with 'hubs' which provide more services than a GP to a wider area which may make this criteria less consistent)
- Within 30 minutes public transport time of a hospital/health centre, secondary school, employment area, town or district centre

5.11 These criteria were applied via discussions with KCC Highways, including whether or not the criteria were already able to be met, or could be met through contributions from new developments. This included considering the potential of adjacent sites to deliver services and/or infrastructure. If a site failed to meet any of these criteria it was not considered suitable for allocation, unless the constraints could be overcome as a result of the development of the site (and potentially other nearby sites)

C. Technical consultations were then carried out relating to the following issues and involving input from other departments and organisations where appropriate:

- Access (KCC Highways)
- Highway capacity (KCC Highways)
- Infrastructure:
  - Water Supply (Southern Water)
  - Sewerage/Drainage (Southern Water)
  - Electricity supply
  - Gas Supply
- Electricity pylons
- Contamination/pollution (TDC Environmental Health)
- Ecology (KCC)
- Adverse Ground conditions
- Hazardous Risk (TDC Environmental Health)
- Topography
- Flood zone (Environment Agency)
- Other eg Archaeology, conservation area local landscape area (KCC)

Comments on ecological issues were provided by Kent County Council based on the following scoring:

KEY	Ecological constraint level (protected/notable species impacts, habitat loss)	Description
1	potential for significant ecological impacts	Suitable habitats and features for protected/notable species present on or near site. Site is on or near to designated area (including international, national, local sites and BAP habitat) with potential impact pathways
2	potential for moderate ecological impacts	Suitable habitats and features for protected/notable species present on or near site. Near to designated site (including international, national, local and BAP habitat) with potential impact pathways. Likely level of significance is lower than (1) due to factors such as location (e.g. in relation to protected species ranges) and the extent of adjacent natural/semi-natural habitats.
3	potential for minor ecological impacts	Some suitable habitats and features for protected/notable species present on or near site.
4	Minimal potential for ecological impacts	No obvious habitats or features on or near site with potential for protected/notable species

The assessment requires details of how any constraints identified can be overcome. If they cannot be overcome the site should not proceed as a potential housing allocation.

D Would development have a detrimental impact on the following, either within or adjacent to the site or in its vicinity?

- Townscape
- Landscape
- Trees
- Conservation Areas
- Historic Parks and Gardens
- Listed Buildings
- Scheduled Ancient Monuments

5.12 The assessment requires details of how any impact can be mitigated through the design process, the imposition of a condition or a legally binding agreement. If it cannot be mitigated, the site should not proceed as a potential housing allocation.

E. Would the amenity of residents be adversely affected by any external, environmental factors?

5.13 If yes, could the impact be mitigated to such an extent that the residents' living conditions would be acceptable? If the nature and scale is such that it cannot be mitigated, the site should not proceed as a potential housing allocation

Availability Criteria - Do any of the following legal or ownership factors apply to the site?

- Multiple ownership likely to result in protracted site assembly, part of the site being unavailable for development or a ransom strip situation

- Existing tenancy or lease agreement, which could affect the timing of the release of the site for development
- The willingness of an owner to sell
- The willingness of an owner with control of the site to develop

5.14 Whilst a site may be considered suitable when assessed against physical constraints, its availability may render a site unsuitable for a local plan allocation.

Achievability Criteria - Can development of the site be achieved during the plan period having taken into account the following market, cost and delivery factors?

Market
- Compatibility of adjacent uses
- Land values compared with alternative uses
- Market demand
- Projected rate of sales

Cost
- Site preparation to overcome physical constraints
- On-site and off-site planning and infrastructure requirements
- Availability of funding

Delivery
- Developers' phasing
- Build-out rates
- Number of developers
- Size and capacity of developer

If the site is deliverable and developable, in which of the following periods would development take place?

- During the next five years
- During years six to ten
- During years eleven to fifteen
- Beyond year fifteen and a) within plan period or b) beyond plan period, if known

5.15 Assessment of the achievability criteria has helped with indicative phasing of allocated sites, where this information has been available.

5.16 Since the beginning of the assessment process, some of the assessment considerations may have varied as a result of changes in circumstances; changes in Government guidance and other factors.

6 Methodology Stage 3 - Windfall Assessment

6.1 Historically, a significant proportion of the new homes delivered in Thanet has been by way of "windfall" sites, which the National Planning Policy Framework (NPPF) defines as

“Sites which have not been specifically identified as available in the Local Plan process. They normally comprise previously-developed sites that have unexpectedly become available.”

6.2 There is a long history of such sites coming forward in Thanet, and the NPPF allows a reasonable calculation of such sites to be included in the Local Plan housing land supply. An allowance of 2,250 “windfall” permissions is identified on the basis of the history of windfall housing delivery over the last 8 years.

6.3 The calculation of windfall sites only applies to “small sites” (defined as up to and including 9 units in this SHLAA to reflect the historic provision at this scale, and that there are few sites allocated at this scale). Small windfall sites make a significant contribution towards Thanets housing supply. Historically, Thanet has also seen larger windfall sites making a significant contribution to housing land supply, and they were at one stage a sizeable proportion of housing completions. However, this trend has been entirely discounted from the calculation of future housing supply, to ensure the robustness of the housing land supply position. Furthermore, the first three years of the remainder of the Local Plan period have been discounted to ensure that there is no double-counting of potential housing land supply.

Table 1: Summary of Windfall Completions

	Windfall and allocated (all comps)	Allocated	Windfalls	Windfall sites <10	Windfall sites of 10 or more	All windfalls as % of comps	Windfalls <10 as % of all comps
2006-07*	651		564			86.64	N/A
2007-08*	606		551			90.92	N/A
2008-09	726	97	629	367	274	86.64	50.55
2009-10	520	30	490	182	312	94.23	35.00
2010-11	788	46	742	496	386	94.16	62.94
2011-12	307	30	277	214	63	90.23	69.71
2012-13	217	26	191	76	115	88.02	35.02
2013-14	322	73	249	123	126	77.33	38.20
2014-15	380	128	252	120	132	66.32	31.58
2015-16	350	20	330	151	179	94.29	43.14
2016-17	389	79	310	183	127	79.69	47.04
2017-18	322	58	264	229	35	81.99	71.12
TOTALS	**5578**	**587**	**4849**	**2141**	**1749**		

Table 2: Summary of completions from 2008/9 to 2016/17 to determine windfall allowance

	Windfall sites <10
2008-09	367
2009-10	182
2010-11	496
2011-12	214
2012-13	76
2013-14	123
2014-15	120

Total	1578
Annual average	**225**

6.4 The windfall allowance is based on data that was available at the time of the preferred options draft and is therefore an average of windfall sites of less than 10 units over the 7 year period (2008/9 to 2014/15).

7 Methodology Stage 4 - Assessment Review

7.1 The SHLAA indicates that potential supply is sufficient to meet the total target housing requirement. Table 3 summarises the SHLAA's conclusions regarding potential housing capacity. The figures represent single dwelling units and include potential arising from dwelling houses and flats.

Table 3 - Potential Housing Capacity

Local Plan requirement 2011-31 (857pa)	**17,140**
Completions from 01/04/11 to 31/03/18	2182
Empty homes brought back into use 2016/17 Empty homes brought back into use 2017/18	89 84
Total allocations	8939
Planning permissions supply as at 31/03/18	4294
Empty homes 27pa (27x13)	351
Windfall allowance of 225 units pa 225x10*	2250

5 Year Supply

7.2 The NPPF requires local authorities to be able to demonstrate that it has a rolling 5 year supply of housing land that is available, sustainable and achievable.
Table 4 demonstrates that the Council has sufficient sites that meet this requirement.

Table 4 – Land Supply for 2018-23

Local Plan requirement 2011-31 (857pa annualised)	**17140**
Stepped requirement for 15 years from 2016-31 (Pre-Submission publication July 2018)	
2016-21	4500
2021-26	5500
2026-31	5585
Requirement for rolling 5 year period 2018-23	**4900**
Land Supply	
Planning permissions as at 31/03/18	2233
Allocations as at 31/03/18	3527
Empty Homes (5years @27 units)	135
Windfall Allowance (225x2)	450
Total Land Supply	**6345**

7.3 A “stepped” approach to the housing target has been adopted; ie. that a lower target is set for the first five years, with higher targets for the following 10 years to make good the total housing requirement for the Plan period. This is for two main reasons:

- There are significant infrastructure requirements that need to be delivered to support new development. If the Council were required to allocate more sites to cover average requirement for the first five-year period, this might undermine the delivery of that infrastructure, and therefore the wider Local Plan strategy; and
- Thanet has an emergent development market, but there is a real possibility that driving high levels of requirement in the early years might undermine the viability of some sites, or result in lowered viability, which again could affect the delivery of services and infrastructure, as well as affordable housing.

7.4 Taking a “stepped approach” to the housing target is considered to be realistic and deliverable, consistent with the known intentions of developers and house builders, and does not place unrealistic expectations on the house building industry to deliver much higher levels of housing in a relatively short space of time. It also means that the Council can demonstrate a 5-year housing land supply, and seek to ensure the delivery of sustainable development, supported by services and infrastructure. There has been a shortfall in delivery over the early years of the formal Plan period – the Council has adopted the ‘Liverpool’ methodology to address this, by spreading the shortfall in the early years across the plan period. The Council has phased more of the smaller allocated sites in the early phases of the plan period since delivery of the larger Strategic sites is more likely to happen later in the phasing periods. The indicative phasing for delivery is shown in Table 5 (this is proposed phasing of sites – the council is currently consulting with developers regarding this)

Table 5 - Phasing of Delivery

	Phasing 2018/19	**Phasing 2019/20**	**Phasing 2020/21**	**Phasing 2021/22**	**Phasing 2022/23**	**Phasing 2023/24**	**Phasing 2024/25**	**Phasing 2025/26**	**Phasing 2026/27**	**Phasing 2027/28**	**Phasing 2028/29**	**Phasing 2029/30**	**Phasing 2030/31**	**Phasing 2031/32**	**totals**
Planning permissions	229	379	555	530	540	500	354	353	293	225	124	74	74	64	4294
Allocations		270	675	1107	1475	786	670	670	752	742	642	630	470	50	8939
windfalls	0	0		225	225	225	225	225	225	225	225	225	225		2250
empty homes	27	27	27	27	27	27	27	27	27	27	27	27	27		351
total	256	676	1257	1889	2267	1538	1276	1275	1297	1219	1018	956	796	114	15834

7.5 The target housing requirement applied at the time of undertaking this SHLAA update was 17,140 net additional dwellings to 2031. The SHLAA has identified more than sufficient capacity to allow a degree of choice, acknowledging that even where sites appear deliverable/developable there is a risk that they will not come forward.

7.6 The sites are listed in Appendices D, E and F. Appendix D lists the sites that have been allocated in the emerging local plan, appendix E lists the sites that have been granted planning permission for residential development and appendix F lists the sites that have not been carried forward for allocation. The sites are based on those included in the 2013 SHLAA with the additions of those submitted at the Preferred Options Consultation (2015), Preferred Options Revisions Consultation (2017) and the Call for Sites (2018).

Developability and Deliverability of Sites

7.7 As a result of the SHLAA process, the Council has allocated the sites set out in Appendix D based on their conformity with the following requirements:

(1) consistent with the advice from the SA process;

(2) broadly meet the criteria set out in the SHLAA assessment;

(3) consistent with national planning guidance;

(4) consistent with advice from technical consultees

7.8 A number of strategic sites have been allocated as urban extensions, in line with the advice set out in the Sustainability Appraisal. Site specific policies have been included in the local plan for each of these sites. The sites allocated in the local plan will also contribute towards the delivery of the proposed transport infrastructure ('inner circuit') identified as necessary to accommodate the additional traffic that will be generated from the additional housing requirements. Phasing of the housing delivery has been considered in conjunction with delivery of the transport strategy.

7.9 There are site promotors and/or developer for all of the strategic sites – one of the sites has already been granted planning permission. The Council has had frequent meetings with the promoters and developers of the strategic sites, including a meeting with all parties to discuss delivery of the transport strategy. Meetings with individual parties have been held to address the policy requirements for each site, constraints and any other issues arising that may be a barrier to their delivery. Meetings and pre-application discussions have also taken place with parties concerned with some of the non-strategic sites allocated in the plan.

7.10 Other sites have not been carried forward and allocated in the Local Plan for the following reasons:

- The site lies in the open countryside/within the green wedge, in an unsustainable location, contrary to local and national policy
- Site is not consistent with the SA Strategy
- Falls below SHLAA site threshold
- Deliverability unrealistic due to multiple ownership
- No owner intention to develop site for housing
- Site is in alternative use
- The site has major highways/archaeological/ecological/environmental/historical issues that cannot be mitigated by condition
- The site is designated employment land, contrary to local policy
- Site has been developed

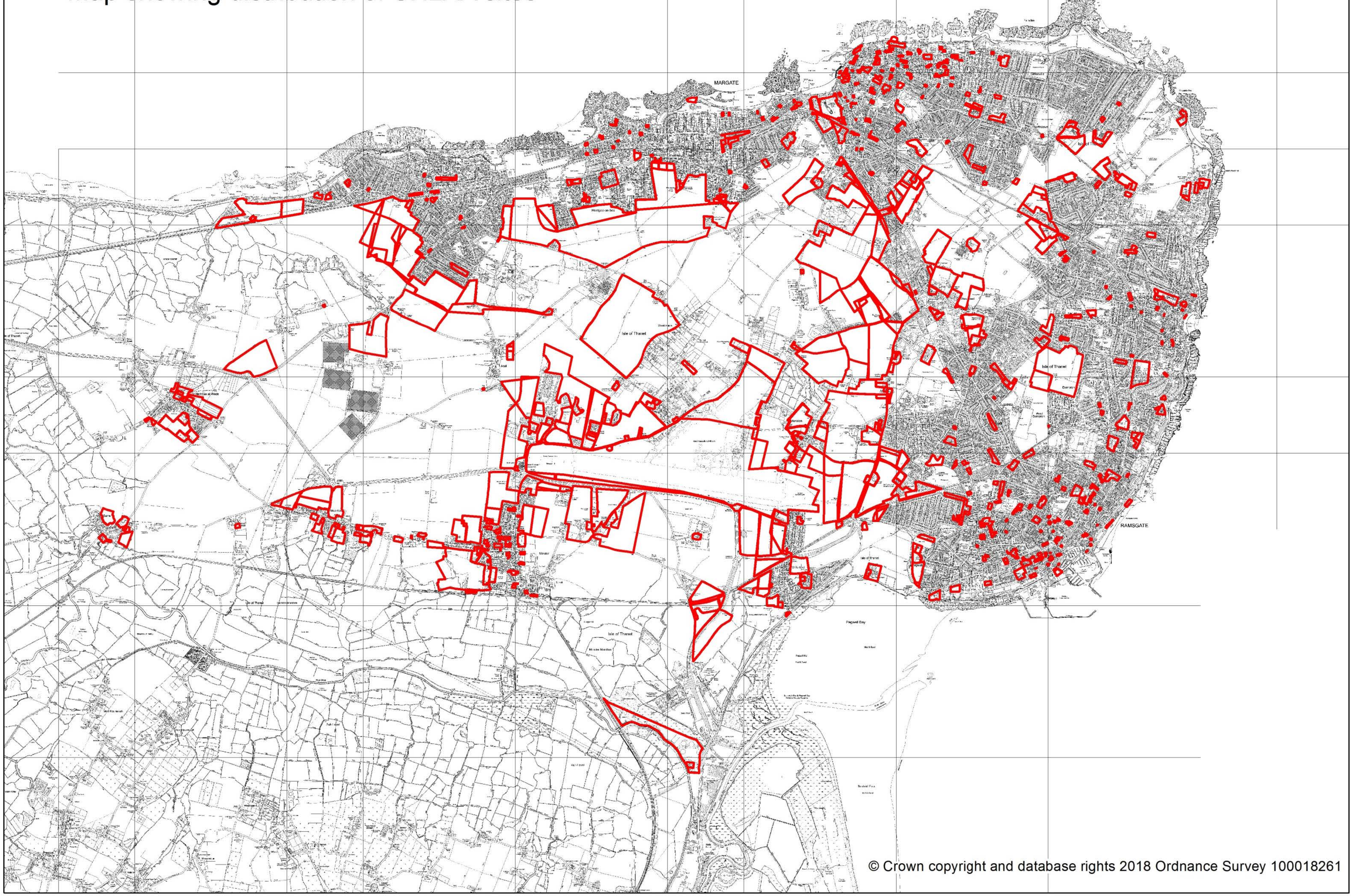
8 Methodology – Stage 5: Final Evidence Base

8.1 Appendices D, E and F of this report include lists of the SHLAA sites – those allocated, those with planning permission and those not allocated. Summaries are available for each site in Appendices D-F. Indicative phasing of anticipated development of the sites is available in Appendix B of the Local Plan.

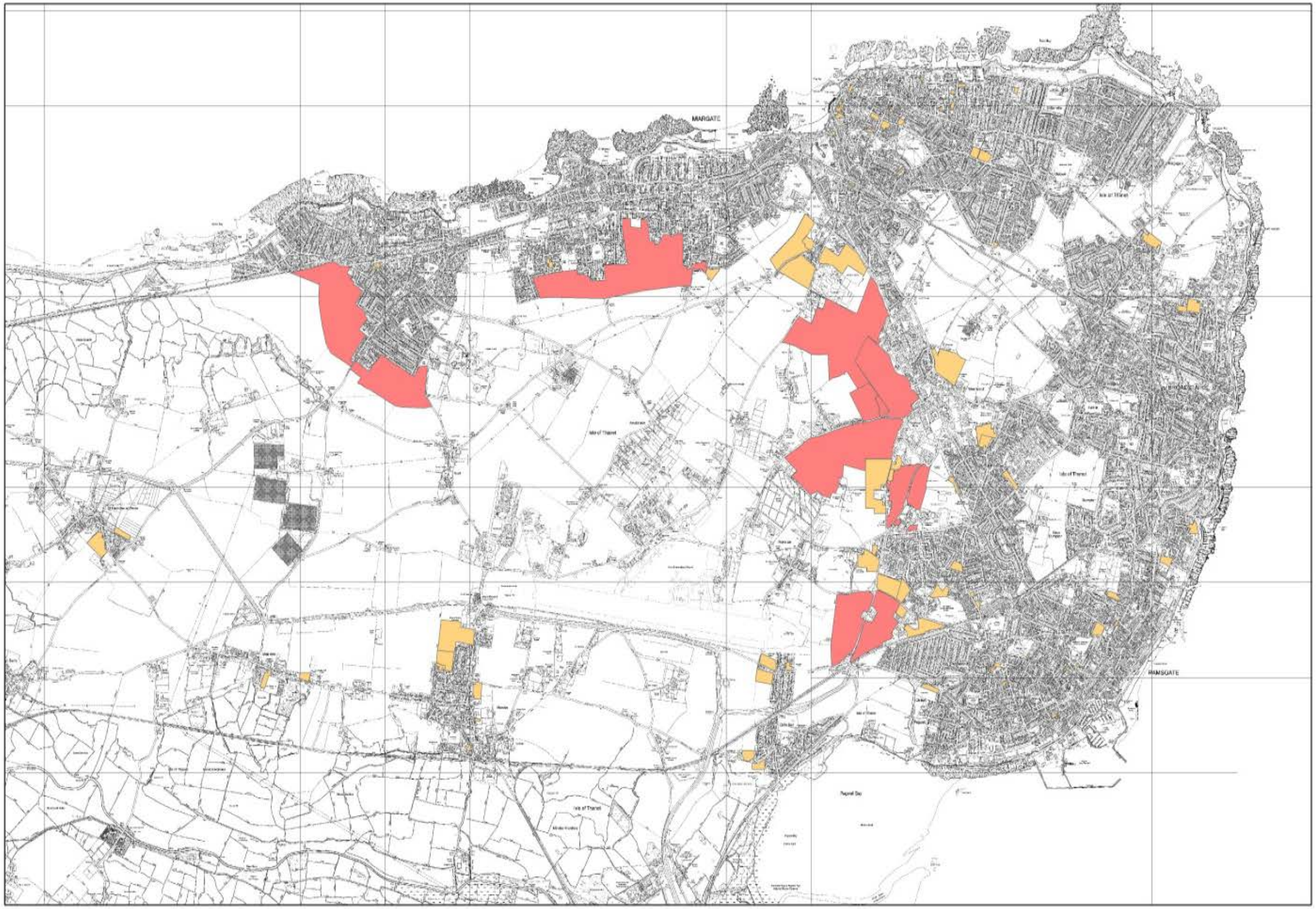
Reviewing the Assessment
8.2 The number of homes delivered will continue to be monitored annually through the Council's established monitoring process, and in particular to assess the availability of a rolling 5 year land supply and published in the Annual Monitoring Report.

Appendix A - Map showing all sites submitted

Map showing distribution of SHLAA sites



Appendix B - Map showing all sites allocated



Appendix G.1.7

Appendix C - Kent & Medway Protocol

The process applied in this Thanet SHLAA generally reflects that established in the Kent & Medway Protocol, as set out for information below. Some local interpretation has been applied to reflect Thanet's circumstances.

POLICY CONSTRAINT CRITERIA (PC)

PCA - Is the site within any of the following Areas?
Category 1: National and Regional

SPA, Ramsar, SAC, SSSI, National Nature Reserve, AONB, Ancient Woodlands.

Category 2:

Metropolitan Green Belt

Category 3: Local

To be determined by each individual Authority in the light of local policies and local circumstances (***In respect of Thanet this might include the designated Green Wedges)***

PCB - Is the site currently in use or allocated for employment or other use and remains suitable and required for that use or is protected by a current development plan policy from development for other uses?

PCC - Is the site neither in nor adjacent to a settlement?

PCD - Does the site fall within or adjacent to a settlement which has not been identified in a development plan document as a settlement/settlements suitable for future housing development with sufficient capacity to meet future housing requirements?

IF A SITE FALLS WITHIN ANY OF THESE CATEGORIES IT SHOULD BE EXCLUDED FROM THE ASSESSMENT AT THIS STAGE.

SUITABILITY CRITERIA (S)

SA Is the site allocated for housing in an existing development plan or does it have planning permission for housing?
If yes, the site will be suitable unless circumstances have changed to render it unsuitable. If no, the site should be assessed against the questions set out in B to E as follows.

SB Is the site in a suitable location when measured against the following criteria?

- Within 800m. walking distance of a bus stop or railway station providing two or more services per hour.
- Within 800 m. walking distance of a convenience store, a primary school and a GP surgery.

- Within 30 minutes public transport time of a hospital/health centre, secondary school, employment area, town or district centre.

In the case of Thanet the criterion applied is whether the site falls within a corridor where a range of services is accessible by public transport within 30 minutes.

IF A SITE FAILS TO MEET ANY OF THESE CRITERIA IT SHOULD BE EXCLUDED FROM THE ASSESSMENT AT THIS STAGE UNLESS THE SITE IS OF SUCH A SCALE THAT THESE CONSTRAINTS COULD BE OVERCOME AS A RESULT OF ITS DEVELOPMENT.

SC Does the site have any of the following physical or infrastructure constraints?[1]

- Access
- Highway capacity
- Infrastructure
  - Water Supply
  - Sewerage/Drainage
  - Electricity supply
  - Gas Supply
  - Electricity Pylons
- Contamination/Pollution
- Adverse Ground Conditions
- Hazardous Risk
- Topography
- Flood Zone

If yes, how and when can the constraint be overcome?

IF THE NATURE AND SCALE OF THE CONSTRAINT IS SUCH THAT IT CANNOT BE REMOVED DUE TO COST OR TIMESCALE OR BOTH, IT SHOULD BE DELETED FROM THE ASSESSMENT AT THIS STAGE.

SD Would development have a detrimental impact on the following, either within or adjacent to the site or in its vicinity?

- Townscape
- Landscape
- Trees
- Conservation Areas
- Historic Parks and Gardens
- Listed Buildings
- Scheduled Ancient Monuments
- Sites of Nature Conservation Interest/Protected Species

If yes, could the impact be mitigated through the design process, the imposition of a condition or a legally binding agreement?

IF THE NATURE AND SCALE OF THE IMPACT IS SUCH THAT IT CANNOT BE MITIGATED, THE SITE SHOULD BE EXCLUDED FROM THE ASSESSMENT AT THIS STAGE.

SE Would the amenity of residents be adversely affected by any external, environmental factors?

If yes, could the impact be mitigated to such an extent that the residents' living conditions would be acceptable?

IF THE NATURE AND SCALE OF THE IMPACT ON AMENITY IS SUCH THAT IT CANNOT BE SATISFACTORILY MITIGATED, THE SITE SHOULD BE EXCLUDED FROM THE ASSESSMENT AT THIS STAGE.

AVAILABILITY CRITERIA (AV).

AVA Do any of the following legal or ownership factors apply to the site?

- Multiple ownership likely to result in protracted site assembly, part of the site being unavailable for development or a ransom strip situation.
- Existing tenancy or lease agreement, which could affect the timing of the release of the site for development.
- The willingness of an owner of owners to sell.
- The willingness of a developer with control of the site

If yes, how and when can the constraint be overcome?

IF THERE ARE ANY CONSTRAINTS TO THE DEVELOPMENT OF THE SITE WITHIN THE RELEVANT TIMESCALE WHICH CANNOT BE OVERCOME, (i.e. IT IS NOT AVAILABLE), THE SITE WILL NOT SUBSEQUENTLY BE ASSESSED FOR ITS ACHIEVABILITY.

ACHIEVABILITY CRITERIA (AC)

Can development of the site be achieved during the plan period having taken into account the following market, cost and delivery factors?

ACA Market

- Compatibility of adjacent uses
- Land values compared with alternative uses
- Attractiveness of locality
- Market demand
- Projected rate of sales.

ACB Cost

- Site preparation to overcome physical constraints
- On-site and off-site planning and infrastructure requirements
- Availability of funding

ACC Delivery

- Developers' phasing
- Build-out rates
- Number of developers
- Size and capacity of developer.

If the site is deliverable and developable, in which of the following periods would development take place?

- During the next five years
- During years six to ten
- During years eleven to fifteen
- Beyond year fifteen and a) within plan period or b) beyond plan period, if known.

Information on the timing of overcoming physical, infrastructure, and legal constraints, identified under "Suitability" and "Availability", will be taken into account, together with the "Achievability" criteria when determining the time of development.

Appendix D – List of sites allocated in the emerging local plan

All sites included in the table below meet the criteria relating to suitability, availability and achievability set out within National Planning Practice Guidance and the Kent Protocol. We have considered sites as they might relate to a larger allocation. The sites included are based on the 2013 SHLAA - these have previous reference numbers. Other sites were added from:
Preferred Options Consultation (2015 sub)
Preferred Options Revisions Consultation (2017 sub)
Call for Sites (2018 sub)
Coding in the SA column - UE = Urban Edge, UE* = Urban Edge if other sites are allocated, URB = Urban, VE = Village Edge, GW = Green Wedge, Open Countryside = remote from/poorly related to any existing settlements

New Reference No.	Previous References	Site Name	Town/ Village	Capacity	PDL Land (y/n/part)	SA	Note
SHLAA 001	S511 2015 sub	Land at Nash Court Road	Westwood/Margate	1450	n	UE*	Now forms Strategic Westwood Allocation The site is located at the urban edge, consistent with the findings and recommendations of the Sustainability Appraisal, and is consistent with other environmental and planning policy and guidance. Also assists in the delivery of the Inner Circuit relief scheme.
SHLAA 002	S553	Land West of Red House Farm	Westwood		n	UE*	
SHLAA 003	S447	Red House Farm, Manston Court Road	Westwood		n	UE	
SHLAA 004	S515 2015 sub	Land at Gore End Farm	Birchington	1600	n	Partial UE	Now forms Strategic Birchington Allocation - The site is located at the urban edge, consistent with the findings and recommendations of the Sustainability Appraisal, and is consistent with other environmental and planning policy and
SHLAA 005	S498	Land at Street Farm	Birchington		n	UE	

Appendix G.1.7

New Reference No.	Previous References	Site Name	Town/ Village	Capacity	PDL Land (y/n/part)	SA	Note
SHLA 006	S499	Land at Court Mount	Birchington		n	UE	guidance. Also assists in the delivery of the Inner Circuit relief scheme.
SHLAA 007	2015 sub	Land to west of Minnis Road/South of Railway Line and Ingoldsby Road	Birchington		n	UE	
SHLAA 008	2017 sub 2018 sub	Additional land at Birchington	Birchington			UE*	
SHLAA 009	ST3	Land West Park Lane	Birchington		n	Partial UE	
SHLAA 010	ST1	Land South of Canterbury Road	Westgate	2000	n	UE	Now forms Strategic Westgate Allocation - The site is located at the urban edge, consistent with the findings and recommendations of the Sustainability Appraisal, and is consistent with other environmental and planning policy and guidance. Also assists in the delivery of the Inner Circuit relief scheme. Not all of the site proposed in SHLAA12 has been allocated.
SHLAA 011	ST2	Land South of Linksfield Road	Westgate		n	UE	
SHLAA 012	2018 sub	Additional land at Westgate	Westgate			UE*	
SHLAA 013	2015 sub	Land at Manston Court Road/Haine Road	Ramsgate	1200	n	UE*	Now forms strategic allocation. The site is located at the urban edge, consistent with the findings and recommendations of the Sustainability Appraisal, and is consistent with other environmental and planning policy and guidance. Also assists in the delivery of the Inner Circuit relief scheme.
SHLAA 014	2018 sub	Additional land submitted in call for sites 2018 (Westwood Village)					

Appendix G.1.7

New Reference No.	**Previous References**	**Site Name**	**Town/ Village**	**Capacity**	**PDL Land (y/n/part)**	**SA**	**Note**
SHLAA 016	S415	South of Canterbury Road	Ramsgate	27	n	UE	The site is located at the urban edge, consistent with the findings and recommendations of the Sustainability Appraisal and is consistent with other environmental and planning policy and guidance
SHLAA 017	S505	Land South East of Brooke Avenue	Garlinge	34	n	UE	The site is located at the urban edge, consistent with the findings and recommendations of the Sustainability Appraisal and is consistent with other environmental and planning policy and guidance
SHLAA 018	SR60	Land at Haine Road & Spratling Street	Ramsgate	85	p	UE	The site is located at the urban edge, consistent with the findings and recommendations of the Sustainability Appraisal
SHLAA 019	S540	Land off Nash/Manston Road	Margate	250	n	UE	The site is located at the urban edge, consistent with the findings and recommendations of the Sustainability Appraisal and is consistent with other environmental and planning policy and guidance Consistent with the emerging Transport Strategy for the district

New Reference No.	Previous References	Site Name	Town/ Village	Capacity	PDL Land (y/n/part)	SA	Note
							The site is well-related to the road network improvements proposed in the draft Transport Strategy, including the Inner Circuit
SHLAA 020	S535 & S549 2015 sub	Land West of Haine Road (adjacent to Eurokent Business Park)	Ramsgate	250	n	UE	The site is located at the urban edge, consistent with the findings and recommendations of the Sustainability Appraisal and is consistent with other environmental and planning policy and guidance
SHLAA 021	S160 2018 sub	Former Allotment Gardens, Manston Road	Ramsgate	64	n	UE	The site is located at the urban edge, consistent with the findings and recommendations of the Sustainability Appraisal and is consistent with other environmental and planning policy and guidance
SHLAA 022		Land at Manston Road/Shottendane Road	Margate	550	n	UE*	Now forms strategic allocation – Land north and south of Shottendane Road
SHLAA 023	2018 sub	Land between Shottendane Road/Hartsdown Road	Margate		n	Partial UE	
SHLAA 024	S189	Land at Queens Arms Yard Duke Street/Market Street	Margate	24	y	URB	Site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal and is consistent with other environmental and planning policy and guidance
SHLAA 025	S411	Cottage Car Park, New Street	Margate	32	p	URB	The site is located in the urban area, consistent with the findings and recommendations of the

New Reference No.	Previous References	Site Name	Town/ Village	Capacity	PDL Land (y/n/part)	SA	Note
							Sustainability Appraisal and is consistent with other environmental and planning policy and guidance
SHLAA 026	S412	Margate Town Centre (South of New Street)	Margate	27	p	URB	Site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal and is consistent with other environmental and planning policy and guidance
SHLAA 027	S019	Adjacent to 9 Minnis Road	Birchington	11	y	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal
SHLAA 028	S106	End of Seafield Road	Ramsgate	16	y	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal
SHLAA 029	S112	Adjacent to 8 Chapel Place	Ramsgate	6	p	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal
SHLAA 030	S113	Adjacent to 21 Royal Road & 9 Townley Street	Ramsgate	18	y	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal
SHLAA 031	S141	Land adjacent Westwood Centre	Margate	1020	n	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal
SHLAA 032	S158	R/o 7-10 Marine Gardens	Margate	6	n	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal, and is consistent with other environmental and planning policy and

New Reference No.	Previous References	Site Name	Town/ Village	Capacity	PDL Land (y/n/part)	SA	Note
							guidance
SHLAA 033	S168	British Gas Site Boundary Rd	Ramsgate	96	y	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal, and is consistent with other environmental and planning policy and guidance
SHLAA 034	S174	Land at junction Wilderness Hill & Dane Road	Margate	14	n	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal, and is consistent with other environmental and planning policy and guidance
SHLAA 035	S186a	79-85 High Street	Ramsgate	10	y	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal, and is consistent with other environmental and planning policy and guidance
SHLAA 036	S196	Gas Holder Station, Addington Street	Margate	22	y	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal. Possible need for decontamination due to previous use
SHLAA 037	S200	100 Grange Road	Ramsgate	16	y	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal, and is consistent with other environmental and planning policy and guidance.
SHLAA	S215	WW Martin, Dane	Ramsgate	14	y	URB	The site is located in the urban area, consistent

New Reference No.	Previous References	Site Name	Town/ Village	Capacity	PDL Land (y/n/part)	SA	Note
038		Park Road					with the findings and recommendations of the Sustainability Appraisal, and is consistent with other environmental and planning policy and guidance
SHLAA 039	S230	10 Cliff Street	Ramsgate	11	y	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal, and is consistent with other environmental and planning policy and guidance
SHLAA 040	S276	Complete Car Sales, Willsons Road	Ramsgate	10	y	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal, and is consistent with other environmental and planning policy and guidance
SHLAA 041	S295	38, 38a and 42 St Peters Road	Broadstairs	5	y	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal, and is consistent with other environmental and planning policy and guidance
SHLAA 042	S322	Units 1-4 Monkton Place	Ramsgate	5	y	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal, and is consistent with other environmental and planning policy and guidance
SHLAA 043	S339	3 & 7 Northumberland	Margate	5	p	URB	The site is located in the urban area, consistent with the findings and recommendations of the

New Reference No.	Previous References	Site Name	Town/ Village	Capacity	PDL Land (y/n/part)	SA	Note
		Avenue					Sustainability Appraisal
SHLAA 044	S393	Highfield Road Land	Ramsgate	25	n	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal, and is consistent with other environmental and planning policy and guidance.
SHLAA 045	S410	Fort Hill/ Arcadian	Margate	28	y	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal, and is consistent with other environmental and planning policy and guidance
SHLAA 046	S429	Safari House, Haine Road	Ramsgate	6	n	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal, and is consistent with other environmental and planning policy and guidance
SHLAA 047	S467	Furniture Mart, Booth Place, Grotto Hill	Margate	9	y	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal, and is consistent with other environmental and planning policy and guidance
SHLAA 048	S522	Eurokent, New Haine Road	Ramsgate	550	n	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal, and is consistent with other environmental and planning policy and guidance
SHLAA	2018 sub	Laleham School,	Ramsgate	70	y	URB	The site is located in the urban area, consistent

New Reference No.	Previous References	Site Name	Town/ Village	Capacity	PDL Land (y/n/part)	SA	Note
049	S527	Northdown Park Road					with the findings and recommendations of the Sustainability Appraisal, and is consistent with other environmental and planning policy and guidance
SHLAA 050	S529	Land at Victoria Road & Dane Road & Thanet Road & Danesmead Terrace	Margate	35	y	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal and is consistent with other environmental and planning policy and guidance
SHLAA 051	S534	Haine Farm, Haine Road (adjacent to Eurokent Business Park)	Ramsgate	35	n	URB	This site has been allocated in the Local Plan as it is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal.
SHLAA 052	S536	Land off Northwood Road	Ramsgate	45	n	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal
SHLAA 053	SR9	Dane Valley Arms, Dane Valley Road	Margate	13	y	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal
SHLAA 054	SR16	Builders Yard, The Avenue	Margate	10	y	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal
SHLAA 055	SR45	1 Thanet Road	Margate	5	y	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal
SHLAA 056	SR51	3-7 Surrey Gardens	Birchington	5	y	URB	The site is located in the urban area, consistent with the findings and recommendations of the

New Reference No.	Previous References	Site Name	Town/ Village	Capacity	PDL Land (y/n/part)	SA	Note
							Sustainability Appraisal
SHLAA 057	SR65	Land at Waterside Drive	Westgate	12	n	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal
SHLAA 058	SR67	14 Suffolk Avenue	Westgate	14	y	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal.
SHLAA 059	SR69	R/O Cecilia Road	Ramsgate	23	y	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal
SHLAA 060	SS16	Margate Delivery Office, 12-18 Addington Street	Margate	10	y	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal
SHLAA 061	SS20	Industrial Units, Marlborough Road	Margate	10	y	URB	This site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal.
SHLAA 062	SS22	Former Newington Nursery & Infants School, Melbourne Avenue	Ramsgate	49	y	URB	This site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal.
SHLAA 063	SS23	Gap House School, 1 Southcliff Parade	Broadstairs	10	p	URB	This site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal.
SHLAA 064	SS24 2018 sub	Foreland School, Lanthorne Road	Broadstairs	14	p	URB	This site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal.
SHLAA	SS34	Thanet Reach	Broadstairs	80	n	URB	This site is located in the urban area, consistent

New Reference No.	Previous References	Site Name	Town/ Village	Capacity	PDL Land (y/n/part)	SA	Note
065		Southern Part					with the findings and recommendations of the Sustainability Appraisal.
SHLAA 066	SS35	Manston Road Industrial Estate (2 sites North and South) (including S443)	Ramsgate	170	y	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal, and is consistent with other environmental policy and guidance.
SHLAA 067	SS36	Part of Pysons Road Industrial Estate	Broadstairs	26	y	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal, and is consistent with other environmental policy and guidance.
SHLAA 068	SS43	Magnet & Southern, Newington Road	Ramsgate	8	y	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal, and is consistent with other environmental policy and guidance.
SHLAA 069	2017 sub	Shottendane Farm	Margate	8	n	Partial UE	The site is located at the urban edge, consistent with the findings and recommendations of the Sustainability Appraisal, and is consistent with other environmental policy and guidance.
SHLAA 070	2017 sub	Lanthorne Court	Broadstairs	56	y	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal, and is consistent with other environmental policy and guidance.
SHLAA 071	SR61	Former Club Union Convalescent Home, north of Reading Street	Broadstairs	24	y	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal, and is consistent with other environmental policy and guidance.

New Reference No.	Previous References	Site Name	Town/ Village	Capacity	PDL Land (y/n/part)	SA	Note
SHLAA 072	S512 2015 sub	Land at Tothill Street	Minster	250	n	VE	All part of same allocation The site is located at the urban edge/larger villages, consistent with the findings and recommendations of the sustainability appraisal, and is consistent with other environmental planning policy and guidance
SHLAA 073	S436	Land West of Greenhill Gardens	Minster		n	VE	
SHLAA 074	S85	End of Prospect Road	Minster		p		
SHLAA 075	ST4	Adjacent Foxborough House, Foxborough Lane	Minster	35	n	VE	The site is located at the larger village edge, consistent with the findings of the sustainability appraisal, and is consistent with other environmental planning policy and guidance.
SHLAA 076	S509 2015 sub	Land at The Length	St Nicholas	25	n	VE	The site is located at the village edge, consistent with the findings of the sustainability appraisal and is consistent with other environmental planning policy and guidance.
SHLAA 077	ST6 2017 sub	Land at Walter's Hall Farm	Monkton	18	n	VE*	The site is located at the village edge, consistent with the findings of the sustainability appraisal and is consistent with other environmental planning policy and guidance.
SHLAA 078	S488 2015 Sub	Land at Manor Road	St Nicholas	36	n	VE	The site is located at the village edge, consistent with the findings of the sustainability appraisal and is consistent with other environmental planning policy and guidance.
SHLAA 079	S543 (18) R25-135 & R25-102 (20)	Builders Yard South of 116-124 Monkton Street	Monkton	20	p	VE	The site is located at the village edge, consistent with the findings of the sustainability appraisal and is consistent with other environmental planning policy and guidance.

Appendix G.1.7

New Reference No.	Previous References	Site Name	Town/ Village	Capacity	PDL Land (y/n/part)	SA	Note
SHLAA 080	S468	Site ‘A’ South Side of A253	Cliffsend	40	n	VE	All part of same allocation The site is located at the urban edge/larger villages, consistent with the findings and recommendations of the sustainability appraisal, and is consistent with other environmental planning policy and guidance. Site partially allocated. Land at S470 allocated for Parkway Station.
SHLAA 081	S435 S469 S470 R25-043 R25-020/1	Land West of Cliff View Road	Cliffsend		n	VE	
SHLAA 082	S416 S561	South Side Cottington Road	Cliffsend	30	n	VE	All part of same allocation The site is located at the larger villages, consistent with the findings and recommendations of the Sustainability Appraisal and is consistent with other environmental and planning policy and guidance The site is not located in the vicinity of the Airport
SHLAA 083	S46	Rear of 59-65 Harold Road	Cliftonville	9	p	URB	This site has been allocated in the Local Plan as it is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal
SHLAA 084	S47	Adjacent to 60 Harold Road and rear of 40-56 Harold Road	Cliftonville	14	y	URB	This site has been allocated in the Local Plan as it is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal.
SHLAA 085	S48	Adjacent to 14 Harold Road	Cliftonville	10	y	URB	This site has been allocated in the Local Plan as it is located in the urban area, consistent with the findings and recommendations of the

New Reference No.	Previous References	Site Name	Town/ Village	Capacity	PDL Land (y/n/part)	SA	Note
							Sustainability Appraisal.
SHLAA 086	S165	St George's Hotel, 61-75 Eastern Esplanade	Cliftonville	87	y	URB	The site is located in the urban area, consistent with the findings and recommendations of the Sustainability Appraisal, and is consistent with other environmental and planning policy and guidance
SHLAA 087	S452	Part of allotment gardens, Manston Road	Ramsgate	61	N	UE	The site is located on the urban edge, consistent with the findings and recommendations of the sustainability appraisal, and is consistent with other environmental planning policy and guidance.

Appendix E – List of SHLAA sites with planning permission for residential development

New reference no	Previous References	Site Name	Town/Village	Capacity	PDL Land (y/n/part)	SA	Planning Application Reference	Status (HIA 2018) C – Complete UC – Under Construction NS – Not Started
SHLAA 088	S1	Corner of Dumpton Park Drive & Honeysuckle Road	Ramsgate	12	Y	URB	(OL)14/1024 (F)15/0311	NS
SHLAA 089	S107	Land adjacent to 12 Kings Road	Ramsgate	89	Y	URB	11/0288	C
SHLAA 090	S159	Royal Seabathing Hospital	Margate	272	Y	URB	04/0700	UC
SHLAA 091	2015 sub R25-026 R25-027	Westwood Lodge, Poorhole Lane	Broadstairs	153	N	GW	OL/TH/15/0788	NS
SHLAA 092		Pleasurama Amusement Park, Marina Esplanade	Ramsgate	107	Y	URB	03/1200	UC
SHLAA 093	S164	Former Police Station & Former Magistrates Court Cavendish Street	Ramsgate	82	Y	URB	TH10/0573	UC
SHLAA 094	S172	Granville House, Victoria Parade	Ramsgate	38	Y	URB	TH14/0083	Expired
SHLAA 095	S179	6 North Foreland Road	Broadstairs	14	P	URB	NS – 12/0941	S/S
SHLAA 096	S209	44 Canterbury Road	Margate	13	Y	URB	15/0278	UC
SHLAA 097	S216	131-141 King Street	Ramsgate	15	Y	URB	13/0230	UC
SHLAA 098	S227	139-141 High Street	Ramsgate	12	Y	URB	15/0087	UC
SHLAA 099	S228	See SR12 237 Ramsgate Road	Margate	9	Y	URB	12/0313	Expired
SHLAA 100	S234	9 & 30-32 Cavendish Street & High	Ramsgate	12	Y	URB	12/0765	UC

New reference no	Previous References	Site Name	Town/Village	Capacity	PDL Land (y/n/part)	SA	Planning Application Reference	Status (HIA 2018) C – Complete UC – Under Construction NS – Not Started
		Street, Land adj						
SHLAA 101	S243	Court Stairs Lodge Pegwell Road	Ramsgate		Y	URB	14/0447	C
SHLAA102	S258	6-8 Cliff Street	Ramsgate	9	Y	URB	13/0063	C
SHLAA 103	S263	56,56A&58 Station Road	Birchington	6	Y	URB	12/0912	C
SHLAA104	S272	69 West Cliff Road	Ramsgate	8	Y	URB	11/0096	C
SHLAA 105	S290	Land to rear of 28 High Street	Broadstairs	4	Y	URB	14/0636	NS
SHLAA 106	S293	10-14 Vicarage Crescent	Margate	6	Y	URB	10/0041	UC
SHLAA 107	S297	Cliff Cottage Herschell Road	Birchington	6	P	URB	10/0248	UC
SHLAA 108	S301	27-29 Alexandra Road	Margate	5	Y	URB	08/0904	C
SHLAA 109	S309	The Lodge Canterbury Road	Margate	8	P	URB	15/0373	UC
SHLAA110	S318	Brown & Mason Ltd, Canterbury Road, Court mount	Birchington	5	Y	URB	14/0612	Expired
SHLAA111	S321	167 Pegwell Road	Ramsgate	7	N	URB	12/0537	UC
SHLAA 112	SR2	45-49 and 51. Sea Road	Westgate	29	Y	URB	16/0280	UC
SHLAA 113	SR4	Land at 57 59 61 63 and 67 Eaton Road	Margate	6	Y	URB	13/0888	S/S
SHLAA114	SR11	100 South Eastern Road	Ramsgate	12	Y	URB	14/0902	C
SHLAA 115	SR14	69-73 King Street	Ramsgate		Y	URB	14/0660	C
SHLAA 116	SR15	8-12 High Street	Broadstairs	12	Y	URB	14/0480	UC
SHLAA 117	SR17	Emmanuel Church, Victoria Road	Margate	10	Y	URB	17/1271	NS
SHLAA 118	SR18	Lockwoods Yard, The Grove	Westgate		Y	URB	09/0784	C
SHLAA 119	SR20	43-49 High Street	Margate		Y	URB	05/0204	C
SHLAA 120	SR22	Land adjoining 34 Seafield Road &	Ramsgate	6	Y	URB	16/0377	NS

New reference no	Previous References	Site Name	Town/Village	Capacity	PDL Land (y/n/part)	SA	Planning Application Reference	Status (HIA 2018) C – Complete UC – Under Construction NS – Not Started
		121, 121A & 121B Southwood Road						
SHLAA 121	URB	2A Park Road	Ramsgate	8	Y	URB	14/0976	C
SHLAA 122	SR25	33 Belmont Road	Ramsgate	3	Y	URB	13/0254	UC
SHLAA 123	SR26	41-43 Victoria Road	Margate	8	Y	URB	15/0291	NS
SHLAA 124	SR31	2&3 St Marys Road	Broadstairs	7	Y	URB	08/0929	C
SHLAA 125	SR34	Dane Valley Filling Station, Millmead Road	Margate	4	Y	URB	15/0642	C
SHLAA 126	SR37	125 High Street	Margate		Y	URB	15/0383	C
SHLAA 127	SR39	29 Athelstan Road	Margate		Y	URB	14/0476	C
SHLAA 128	SR42	Abbey Lodge, Priory Road	Ramsgate	5	P	URB	16/1442	C
SHLAA 129	SR44	Sheridan, Cliff Road	Broadstairs	14	P	URB	16/0424	UC
SHLAA 130	SR48	140 King Street	Ramsgate	6	Y	URB	14/0847	NS
SHLAA 131	SR50	25-27 Turner Street	Ramsgate		Y	URB	13/0852	C
SHLAA 132	SR52	38 Sweyn Road	Margate		Y	URB	14/0996	C
SHLAA 133	S426	Jentex Site, Canterbury Road West	Cliffsend	56	Y	UE	15/0020	NS
SHLAA 134	S455	Youngs Nursery, Arundel Road	Cliffsend	12	Y	URB	13/0426	UC
SHLAA 135	SS33 2018 sub	Land at Haine Road (Manston Green	Ramsgate	785	N	Open Countryside	14/0050	NS
SHLAA 136	S429	Safari House, Haine Road	Ramsgate	28	P	URB	16/0731	C
SHLAA 137	S522	Eurokent Business Park, Haine Road	Ramsgate	550	N	URB	11/0910	NS

New reference no	Previous References	Site Name	Town/Village	Capacity	PDL Land (y/n/part)	SA	Planning Application Reference	Status (HIA 2018) C – Complete UC – Under Construction NS – Not Started
SHLAA 138	S527	Laleham School, Northdown Park Road	Margate	72	Y	URB	14/0518	UC
SHLAA 139	S488 R25-146	Land at Manor Road	St Nicholas at Wade	17	P	VE	15/0770	UC
SHLAA 140	S531	Land south of Cliffsend railway crossing	Cliffsend	31	N	VE	16/0483	UC
SHLAA 141	2017 sub	Land at Summer Road	St Nicholas at Wade	6	N	Open countryside	OL/TH/17/0314	NS
SHLAA 142	R25-123	Land at 66 Monkton Rd	Minster	34	P	VE	OL/TH/16/0654 |	

Appendix F – List of sites not being carried forward for allocation in the Local Plan

New Reference no	**Previous References**	**Site Name**	**Town/Village**	**Capacity**	**PDL LAND (Y/N/Part)**	**SA**	**Assessment** Suitability, Availability, Achievability
SHLAA 143	S417	Land at Kingsdown Farm	Broadstairs	500	N	GW Partial UE	The site lies in the open countryside within the Green Wedge, in an unsustainable location, contrary to local and national policy
SHLAA 144	S421	Land West Side of Northdown Hill	Broadstairs	45	N	GW UE	The site lies in the open countryside within the Green Wedge, in an unsustainable location, contrary to local and national policy
SHLAA 145	S428	Focus Store and Land Rear, Pyson's Road	Ramsgate	20	P	GW UE	The site lies in the open countryside within the Green Wedge, in an unsustainable location, contrary to local and national policy
SHLAA 146	S434 SS18 S434 2015 sub 2018 sub	Land Adj Stella Maris Convent, North Foreland Rd	Broadstairs	8	N	GW UE	The site lies in the open countryside within the Green Wedge, in an unsustainable location, contrary to local and national policy
SHLAA 147	S450	Part of Former Gas Works Site, Northdown Rd	St Peters	60	N	GW UE	The site lies in the open countryside within the Green Wedge, in an unsustainable location, contrary to local and national policy
SHLAA 148	S460	Land North of Park Rd	Birchington	70	N	GW UE	The site lies in the open countryside within the Green Wedge, in an unsustainable location, contrary to local and national policy

New Reference no	Previous References	Site Name	Town/Village	Capacity	PDL LAND (Y/N/Part)	SA	**Assessment** Suitability, Availability, Achievability
SHLAA 149	S475	Land at Draper's Mill Primary School	Margate	60	N	GW UE	The site lies in the open countryside within the Green Wedge, in an unsustainable location, contrary to local and national policy
SHLAA 150	S481	Land at Ramsgate Road	Margate	30	N	GW UE	The site lies in the open countryside within the Green Wedge, in an unsustainable location, contrary to local and national policy
SHLAA 151	S489	Land West of Updown House, Ramsgate Rd	Margate	180	N	GW Partial UE	The site lies in the open countryside within the Green Wedge, in an unsustainable location, contrary to local and national policy
SHLAA 152	S496	Land fronting (north side) of Westwood Rd	Broadstairs	290	N	GW Partial UE	The site lies in the open countryside within the Green Wedge, in an unsustainable location, contrary to local and national policy
SHLAA 153	S545 SS37 2015 sub	Land at Hopeville Farm	Broadstairs	80	N	GW UE	The site lies in the open countryside within the Green Wedge, in an unsustainable location, contrary to local and national policy
SHLAA 154	S546	Land at Northdown Rd	Broadstairs	83	N	GW Partial UE	The site lies in the open countryside within the Green Wedge, in an unsustainable location, contrary to local and national policy
SHLAA 155	SR75	Brazil Brothers, Sackett's Hill	Broadstairs	9	Y	GW	The site lies in the open countryside within the Green Wedge, in an unsustainable location, contrary to local and national policy
SHLAA 156	SS25 2015 sub 2018	Land North of Albert Rd & East of Victoria Avenue	Broadstairs	40	N	GW UE	The site lies in the open countryside within the Green Wedge, in an unsustainable location, contrary to local and national policy

New Reference no	Previous References	Site Name	Town/Village	Capacity	PDL LAND (Y/N/Part)	SA	Assessment Suitability, Availability, Achievability
	sub						
SHLAA 157	SS26 2015 sub 2018 sub	Land North East of Reading St and North West of Convent Rd (Parcel B)	Broadstairs	30	N	GW UE	The site lies in the open countryside within the Green Wedge, in an unsustainable location, contrary to local and national policy
SHLAA 158	SS27	Land North of Reading St and South of George Hill Rd (Parcel C)	Broadstairs	55	N	GW	The site lies in the open countryside within the Green Wedge, in an unsustainable location, contrary to local and national policy
SHLAA 159	SS6	Land off Newlands Lane	Broadstairs	110	N	GW	The site lies in the open countryside within the Green Wedge, in an unsustainable location, contrary to local and national policy
SHLAA 160	2018 sub	Field adjacent to St Peters Road/Land adj QEQM hospital, Land adj Yoakley House	Margate	80	N	GW	The site lies in the open countryside within the Green Wedge, in an unsustainable location, contrary to local and national policy
SHLAA 161	S3	25-32 Royal Close	Broadstairs	0	N	URB	Site is in alternative use No owner intention to develop site for housing
SHLAA 162	S4	Rear 14-42 Fair Street	Broadstairs	0	N	URB	Site is in alternative use No owner intention to develop site for housing
SHLAA 163	S5	R/O 4-28 St Peters Park Road	Broadstairs	0	Y	URB	Site is in alternative use No owner intention to develop site for housing
SHLAA	S7	78-92 Bromstone	Broadstair	2	N	URB	Falls below SHLAA site threshold

New Reference no	Previous References	Site Name	Town/Village	Capacity	PDL LAND (Y/N/Part)	SA	**Assessment** Suitability, Availability, Achievability
164		Road	s				
SHLAA 165	S8	R/O 2-24 Brassey Avenue & 67-87 Ramsgate Road	Broadstairs	0	N	URB	Site identified as part of the Halcrow urban capacity study. No owner intention to develop land for housing. Multiple gardens and ownership and therefore unlikely to come forward.
SHLAA 166	S11	R/O 1-15 Catherine Way & 9-15 Lindenthorpe Road	Broadstairs	0	N	URB	Site identified as part of the Halcrow urban capacity study. No owner intention to develop land for housing. Multiple gardens and ownership and therefore unlikely to come forward.
SHLAA 167	S12	Corner of Reading Street and Elmwood Close	Broadstairs	1	N	URB	Falls below SHLAA site threshold
SHLAA 168	S13	R/O 3-213 Beacon Road	Broadstairs	0	N	URB	Site identified as part of the Halcrow urban capacity study. No owner intention to develop land for housing. Multiple gardens and ownership and therefore unlikely to come forward.
SHLAA 169	S14	R/O 30-61 Northdown Road	Broadstairs	0	N	URB	Site identified as part of the Halcrow urban capacity study. No owner intention to develop land for housing. Multiple gardens and ownership and therefore unlikely to come forward.
SHLAA 170	S20	East of Birchington Station car park	Birchington	0	N	URB	Falls below SHLAA site threshold
SHLAA 171	S23	Rear of 10-30 Shakespeare Road	Birchington	0	N	URB	Site identified as part of the Halcrow urban capacity study. No owner intention to develop land for housing. Multiple gardens and ownership and therefore unlikely

New Reference no	Previous References	Site Name	Town/Village	Capacity	PDL LAND (Y/N/Part)	SA	Assessment Suitability, Availability, Achievability
							to come forward.
SHLAA 172	S24	Rear of 6-12 Queens Avenue	Birchington	3	N	URB	Falls below SHLAA site threshold
SHLAA 173	S25	Rear of 14-26 Daryngton Avenue	Birchington	0	Y	URB	Site is in alternative use No owner intention to develop site for housing
SHLAA 174	S26	Rear of 61-97 Quex View Road & 68-116 Park Avenue	Birchington	0	N	URB	Site identified as part of the Halcrow urban capacity study. No owner intention to develop land for housing. Multiple gardens and ownership and therefore unlikely to come forward.
SHLAA 175	S27	53 High Street	Broadstairs	0	*Y*	URB	Falls below SHLAA site threshold Site is in alternative use
SHLAA 176	S30	Rear of 11-25 Canterbury Road	Margate	5	P	URB	Site identified as part of the Halcrow urban capacity study. No owner intention to develop land for housing. Multiple gardens and ownership and therefore unlikely to come forward.
SHLAA 177	S31	Rear of 40-115 Westbrook Avenue	Margate	0	N	URB	Site identified as part of the Halcrow urban capacity study. No owner intention to develop land for housing. Multiple gardens and ownership and therefore unlikely to come forward
SHLAA 178	S32	Rear of 16-52 Bird's Avenue	Margate	0	N	URB	Site identified as part of the Halcrow urban capacity study. No owner intention to develop land for housing. Multiple gardens and ownership and therefore unlikely to come forward.
SHLAA 179	S33	Rear of 6-22 Craven Close	Margate	3	N	URB	Site unrealistic due to multiple ownership

New Reference no	**Previous References**	**Site Name**	**Town/Village**	**Capacity**	**PDL LAND (Y/N/Part)**	**SA**	**Assessment** Suitability, Availability, Achievability
SHLAA 180	S34	Adjacent to 146 Canterbury Road & rear of 128-146 Canterbury Road	Margate	20	P	URB	Site identified as part of the Halcrow urban capacity study. No owner intention to develop land for housing. Multiple gardens and ownership and therefore unlikely to come forward.
SHLAA 181	S42	Rear of 18-36 St Peter's Road	Margate	5	N	URB	Site identified as part of the Halcrow urban capacity study. No owner intention to develop land for housing. Multiple gardens and ownership and therefore unlikely to come forward.
SHLAA 182	S43	Opposite 4 Victoria Road	Margate	0	Y	URB	Site identified as part of the Halcrow urban capacity study. No owner intention to develop land for housing. Multiple gardens and ownership and therefore unlikely to come forward.
SHLAA 183	S50	Adjacent 6 Second Avenue	Margate	0	P	URB	Falls below SHLAA site threshold Site is garden land
SHLAA 184	S59	Adjacent to 15 Dalby Square	Margate	12	Y	URB	Site has been developed
SHLAA 185	S61	Adjacent to 32 Fort Crescent	Margate	10	Y	URB	Site has been developed
SHLAA 186	S65	Rear of 2-22 Ethelbert Road	Margate	8	Y	URB	Site largely developed with a mixture of new-build and conversions. No further scope for significant additional development.
SHLAA 187	S69	Rear of 46-78 Northdown Park Road & 44-48 Holly Lane	Margate	0	N	URB	Site unrealistic due to multiple ownership
SHLAA	S71	Between 36-42	Margate	4	N	URB	Falls below SHLAA site threshold

New Reference no	**Previous References**	**Site Name**	**Town/Village**	**Capacity**	**PDL LAND (Y/N/Part)**	**SA**	**Assessment** Suitability, Availability, Achievability
188		Star Lane					
SHLAA 189	S72	Rear of 2-36 Farley Road & 1-21 Nash Lane	Margate	0	P	URB	Site unrealistic due to multiple ownership
SHLAA 190	S73	Rear of 15-70 Nash Road	Margate	0	N	URB	Site unrealistic due to multiple ownership
SHLAA 191	S77	Rear of 3-47 Marlowe Road & 2-48 Hertford Road	Margate	0	N	URB	Site unrealistic due to multiple ownership
SHLAA 192	S78	Rear of 1-59 Invicta Road & 2-41 Kent Road	Margate	0	N	URB	Site unrealistic due to multiple ownership
SHLAA 193	S100	Back gardens of 3-9 Nethercourt Farm Rd & 4-12 Helvellyn Ave	Ramsgate	0	N	URB	Site unrealistic due to multiple ownership
SHLAA 194	S108	Corner of Eagle Hill	Ramsgate	0	Y	URB	Site now largely developed for retail use and housing
SHLAA 195	S111	Rear of 2-26 Ellington Road	Ramsgate	5	Y	URB	Public car park, no intention to develop for housing
SHLAA 196	S116	Rear of 2-50 Queens Gate Road & 1-51 Wilfred Road	Ramsgate	38	N	URB	Site unrealistic due to multiple ownership
SHLAA	S117	Rear of 1-23 West	Ramsgate	0	N	URB	Development could have a significant impact of the

New Reference no	Previous References	Site Name	Town/Village	Capacity	PDL LAND (Y/N/Part)	SA	Assessment Suitability, Availability, Achievability
197		Cliff Terrace					Listed Building and its setting
SHLAA 198	S119	Rear of 12-86 Manston Road	Ramsgate	0	N	URB	Site unrealistic due to multiple ownership
SHLAA 199	S128	Rear of 1-13 Beaufort Avenue	Ramsgate	0	Y	URB	Site unrealistic due to multiple ownership
SHLAA 200	S129	Adjacent to 63 Spratling Street	Ramsgate	0	P	UE	Site unrealistic due to multiple ownership
SHLAA 201	S130	Along Spratling Lane	Ramsgate	13	P	Partial UE	Site unrealistic due to multiple ownership
SHLAA 202	S132	52-64 Park Road	Ramsgate	8	Y	URB	Development of whole site unrealistic due to multiple ownership, but part of site has been developed.
SHLAA 203	S140	Corner of Cedric Road & Cuthbert Road	Westgate	7	P	URB	Any redevelopment likely to fall below SHLAA site/allocation threshold
SHLAA 204	S145	St Augustine's College Canterbury Road	Westgate	97	Y	URB	Site has been developed
SHLAA 205	S146	St Augustine's Abbey	Ramsgate	45	N	URB	Significant heritage asset – the site has high historical/cultural value and the development of any part of this site for residential purposes would cause “material harm” to the setting of the main listed building.
SHLAA 206	S149	29 Ethelbert Crescent, Cliftonville	Margate	29	Y	URB	Suitable for residential use, but no owner intention to develop land for housing. Planning consent granted for hotel use.
SHLAA 207	S150	17-23 Dalby Square	Margate	12	N	URB	Development completed

New Reference no	**Previous References**	**Site Name**	**Town/Village**	**Capacity**	**PDL LAND (Y/N/Part)**	**SA**	**Assessment** Suitability, Availability, Achievability
SHLAA 208	S151	16/17 Marine Terrace	Margate		Y	URB	Some physical/structural constraints. Owner intentions not known. Could come forward as "windfall".
SHLAA 209	S152	Church, St Lukes Avenue	Ramsgate	0	P	URB	No owner intention to develop land for housing
SHLAA 210	S154	65 Hereson Rd & Thanet Road	Ramsgate		*Y*	URB	Site developed
SHLAA 211	S155	7 Market Place	Margate	2	Y	URB	Falls below SHLAA site threshold
SHLAA 212	S156	7/11 Addington Road	Margate		Y	URB	Falls below SHLAA site threshold
SHLAA 213	S157	67/73 Northdown Rd	Margate		Y	URB	Falls below SHLAA site threshold
SHLAA 214		Land at Hundreds Farm, Canterbury Road	Westgate	0		URB	Site has planning permission for alternative use
SHLAA 215	S250	Station Approach Yard, Station Approach	Birchington	9	Y	URB	Development completed
SHLAA 216	S282	Regency School of English & Hotel St Augustines Road	Ramsgate	0	Y	URB	Planning consent granted, but not implemented. No clear owner intention to develop land for housing
SHLAA 217	S289	2a Dane Hill	Margate	2	Y	URB	Falls below SHLAA site threshold, may come forward as a windfall
SHLAA	S291	30 Albion Road	Broadstair	3	Y	URB	Falls below threshold, may come forward as a windfall

Appendix G.1.7

New Reference no	**Previous References**	**Site Name**	**Town/Village**	**Capacity**	**PDL LAND (Y/N/Part)**	**SA**	**Assessment** Suitability, Availability, Achievability
218			s				
SHLAA 219	S324	5&1-11 (land rear of Albion Road)	Margate	5	P	URB	Falls below threshold, may come forward as a windfall
SHLAA 220	S330	7C Market Place	Margate	5	Y	URB	Falls below SHLAA threshold, may come forward as a windfall
SHLAA 221	S333	The Surgery, Mildmay Court Bellevue Road	Ramsgate	5	Y	URB	The current use of the building for healthcare purposes would be supported by Local Plan policy. Unlikely to come forward for development.
SHLAA 222	S344	43 Ethelbert Square	Westgate	2	Y	URB	Falls below SHLAA threshold, may come forward as a windfall
SHLAA 223	S347	15 Approach Road	Margate	5	P	URB	Falls below SHLAA threshold, may come forward as a windfall
SHLAA 224	S348	6 Surrey Road	Cliftonville	5	Y	URB	Falls below SHLAA threshold, may come forward as a windfall
SHLAA 225	SR10	St Benedicts Church, Whitehall Road	Margate	12	Y	URB	The Community Centre is a relatively new bespoke building and its long-term use for community purposes would be supported by Local Plan policy. No owner intention to develop land for housing.
SHLAA 226	SR21	86-88 Ellington Road,	Ramsgate	9	Y	URB	No clear owner intention to develop site
SHLAA 227	SR29	Fairlight and Seascape, Reading Street	Broadstairs	0	P	URB	Site partially developed with single dwelling. Outline consent not capable of implementation.
SHLAA 228	SR30	13 Canterbury Road	Margate	6	Y	URB	No clear owner intention to develop land for housing.
SHLAA	SR36	110 Minnis Road	Birchingto	6	Y	URB	Planning permission has lapsed. No reasonable

New Reference no	Previous References	Site Name	Town/Village	Capacity	PDL LAND (Y/N/Part)	SA	Assessment Suitability, Availability, Achievability
229			n				prospect of implementation.
SHLAA 230	SR38	25 Royal Esplanade	Margate	0	Y	URB	No owner intention to develop land for housing
SHLAA 231	SR40	3-4 Royal Esplanade	Margate	6	Y	URB	No owner intention to develop land for housing
SHLAA 232	SR41	62A Addiscombe Road	Margate	6	Y	URB	No reasonable prospect of delivery
SHLAA 233	SR43	Old School Lodge, New Cross Street	Margate	6	Y	URB	No reasonable prospect of delivery
SHLAA 234	SR46	11 Elms Avenue	Ramsgate	0	P	URB	No owner intention to develop land for housing
SHLAA 235	SR53	38-40 High Street	Margate	5	Y	URB	No owner intention to develop land for housing
SHLAA 236	SR54	41 Royal Road	Ramsgate	5	Y	URB	Site has been developed
SHLAA 237	S355	Land adjacent Media Centre	Margate	0	Y	URB	No owner intention to develop land for housing
SHLAA 238	S357	45 Hawley Square	Margate	1	Y	URB	Falls below SHLAA threshold, may come forward as a windfall (1 unit)
SHLAA 239	S445	Rose Farm House, Haine Road	Ramsgate	0	P	URB	No owner intention to develop land for housing
SHLAA 240	S446	Beerlings Farm, Haine Road	Ramsgate	0	P	URB	Previously no owner intention to develop land for housing. Outline application now in for 17 houses. If planning permission is approved could come forward as

New Reference no	Previous References	Site Name	Town/Village	Capacity	PDL LAND (Y/N/Part)	SA	Assessment Suitability, Availability, Achievability
							a windfall
SHLAA 241	S349a	Thanet Technical College, Ramsgate Road	Broadstairs	0	Y	URB	No owner intention to develop land for housing
SHLAA 242	S407	Dreamland amusement park site	Margate	0	Y	URB	No owner intention to develop land for housing
SHLAA 243	S408 2015 sub	Arlington	Margate	0	Y	URB	No owner intention to develop land for housing
SHLAA 244	S409	Rendezvous	Margate	0	Y	URB	No owner intention to develop land for housing
SHLAA 245	S413	The Lido	Margate	80	Y	URB	No owner intention to develop land for housing
SHLAA 246	S414 & 102 2015 sub	Nethercourt Estate (N of Canterbury Road)	Ramsgate	41	P	URB	The site has major archaeological issues that cannot be mitigated by condition
SHLAA 247	S422	Land at Margate Station	margate	20	Y	URB	No owner intention to develop land for housing
SHLAA 248	S451	Montefiore Site	Ramsgate	0	N	URB	No owner intention to develop land for housing
SHLAA 249	S459	Land off Northdown Road, St Peters	Broadstairs	2	N	UE	Falls below threshold, may come forward as a windfall (2 unit)
SHLAA	S462	Warten Road	Ramsgate	0	N	URB	No owner intention to develop land for housing

New Reference no	**Previous References**	**Site Name**	**Town/Village**	**Capacity**	**PDL LAND (Y/N/Part)**	**SA**	**Assessment** Suitability, Availability, Achievability
250		playing field, Warten Road					
SHLAA 251	S463	Land at East Northdown Farm	Margate	0	P	URB	Site in multiple ownership
SHLAA 252	S465	Bromstone School, Rumfields Road	Broadstairs	0	Y	URB	No owner intention to develop land for housing
SHLAA 253	S473	31 Victoria Road	Ramsgate	2	Y	URB	Falls below threshold, may come forward as a windfall
SHLAA 254	S476	Land adj Hartsdown & Garlinge schools	Margate	0	N	UE	Site in alternative use
SHLAA 255	S497 2015 sub	Land east of Harbour approach road,	Ramsgate	174	N	UE	The site has major archaeological/ecological/environmental/historical issues that cannot be mitigated by condition
SHLAA 256	S516	Wolseley UK, Westwood Road	Broadstairs	0	Y	URB	Site in alternative use
SHLAA 257	S524	Davenport House, 479 Margate Road	Broadstairs	0	Y	URB	Site in alternative use
SHLAA 258	S548	Land at Birchington medical centre	Birchington	0	Y	UE	No owner intention to develop land for housing
SHLAA 259	S532	Land at 169 Minnis Rd, 42	Birchington	0	P	URB	The site has major archaeological/ecological/environmental/historical

Appendix G.1.7

New Reference no	Previous References	Site Name	Town/Village	Capacity	PDL LAND (Y/N/Part)	SA	Assessment Suitability, Availability, Achievability
		Arthur Rd, Viking Close					issues that cannot be mitigated by condition
SHLAA 260	SR64	Land at Surrey Gardens	Birchington	2	Y	URB	Falls below threshold, may come forward as a windfall
SHLAA 261	SS14	Adj 9 & 11 Helvellyn Avenue	Ramsgate	3	N	URB	Falls below threshold, may come forward as a windfall
SHLAA 262	SS15	Broadstairs Delivery Office, 20 The Broadway	Broadstairs	4	Y	URB	No owner intention to develop the site for housing
SHLAA 263	SS17	Ramsgate Delivery Office ,42 Wilfred Road	Ramsgate	4	Y	URB	No owner intention to develop the site for housing
SHLAA 264	SS28	Land between 296 & 284 Canterbury Road	Birchington	4	N	URB	Falls below threshold, may come forward as a windfall
SHLAA 265	S420 2017 sub	Land west of Dane Road/Pudding Mill Lane	Birchington	75	N	Open Countryside	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy. Close proximity to multiple international wildlife designations. Not well related to urban edge.
SHLAA 266	SR71	Stroud & Stylecast	Westwood	27	Y	URB	Site in alternative use. No owner intention to develop for housing
SHLAA 267	SR72	Dane Valley Industrial Estate (developed and undeveloped	St Peters	255	P	UE GW	The developed part of the site is designated employment land, contrary to local policy. The undeveloped part of the site lies within the Green Wedge, in an unsustainable location, contrary to local

New Reference no	**Previous References**	**Site Name**	**Town/Village**	**Capacity**	**PDL LAND (Y/N/Part)**	**SA**	**Assessment** Suitability, Availability, Achievability
		parts)					and national policy.
SHLAA 268	SR73	K Laundry	Ramsgate	16	Y	URB	Site in alternative use. No owner intention to develop for housing
SHLAA 269	SS38	All Saint's Industrial Estate,	Margate	60	Y	URB	The site is designated employment land, contrary to local policy No owner intention to develop site for housing
SHLAA 270	SS39	Tivoli Road, Industrial Estate,	Margate	100	Y	URB	The site is designated employment land, contrary to local policy
SHLAA 271	SS40	140-144 Newington Rd	Ramsgate	50	Y	URB	Circumstances have changed as site is now a primary free school.
SHLAA 272	SS41	Princes Road Depot	Ramsgate	35	Y	URB	The site is designated employment land, contrary to local policy.
SHLAA 273	SS42	Whitehall Road Industrial Estate	Ramsgate	30	Y	URB	The site is designated employment land, contrary to local policy
SHLAA 274	SS44	St Lawrence Industrial Estate	Ramsgate	11	Y	URB	The site is designated employment land, contrary to local policy
SHLAA 275	S83	Rear of 45-47 Monkton Road & 1-19 Prospect Road	Minster	8	N	URB	Site is garden land. Site identified as part of the Halcrow urban capacity study. No owner intention to develop land for housing. Multiple gardens and ownership and therefore unlikely to come forward.
SHLAA 276	S84	Rear of 45-47 Prospect Road	Minster	0	N	URB	Site is garden land. Site identified as part of the Halcrow urban capacity study. No owner intention to develop land for housing. Multiple gardens and ownership and therefore unlikely to come forward.
SHLAA 277	S86	Rear of 31 Freemans Road	Minster	8	N	URB	Site is garden land. Site identified as part of the Halcrow urban capacity study. No owner intention to develop

New Reference no	**Previous References**	**Site Name**	**Town/Village**	**Capacity**	**PDL LAND (Y/N/Part)**	**SA**	**Assessment** Suitability, Availability, Achievability
							land for housing. Multiple gardens and ownership and therefore unlikely to come forward.
SHLAA 278	S87	Garden of 20 High Street	Minster	0	N	URB	Site is garden land. Site identified as part of the Halcrow urban capacity study. No owner intention to develop land for housing and therefore unlikely to come forward.
SHLAA 279	S88	Rear of 28-36 Station Road	Minster	5	N	URB	Site is garden land. Site identified as part of the Halcrow urban capacity study. No owner intention to develop land for housing and therefore unlikely to come forward
SHLAA 280	S89	Corner of Conyngham Road & Station Approach	Minster	3	Y	URB	Site has major archaeological issues that cannot be mitigated by condition. Site identified as part of the Halcrow urban capacity study. No owner intention to develop land for housing and therefore unlikely to come forward
SHLAA 281	S91	Rear of 94-100 Tothill Street & 2-22 Fairfield Road	Minster	4	N	URB	Falls below SHLAA site threshold. Site is garden land. Site identified as part of the Halcrow urban capacity study. No owner intention to develop land for housing. Deliverability unrealistic as multiple gardens and ownership and therefore unlikely to come forward.
SHLAA 282	S92	Rear of 1-45 Augustine Road	Minster	14	N	URB	Site is garden land. Site identified as part of the Halcrow urban capacity study. No owner intention to develop land for housing. Deliverability unrealistic due to multiple gardens and ownership and therefore unlikely to come forward. No owner intention to develop site for housing.
SHLAA 283	S93	Rear of 19-43 Monkton Road &	Minster	12	N	URB	Site is garden land. Site identified as part of the Halcrow urban capacity study. No owner intention to

New Reference no	Previous References	Site Name	Town/Village	Capacity	PDL LAND (Y/N/Part)	SA	Assessment Suitability, Availability, Achievability
		16-32 Augustine Road					develop land for housing. Deliverability unrealistic due to multiple gardens and ownership and therefore unlikely to come forward. No owner intention to develop site for housing.
SHLAA 284	S94	Rear of 2-14 Augustine Road & 4-12 Tothill Street	Minster	2	N	URB	Site is garden land. Falls below SHLAA site threshold. Site identified as part of the Halcrow urban capacity study. No owner intention to develop land for housing. Deliverability unrealistic due to multiple gardens and ownership and therefore unlikely to come forward. No owner intention to develop site for housing.
SHLAA 285	S96	Rear of 10-20 Monkton Road	Minster	4	N	URB	Falls below SHLAA site threshold could come forward as a windfall. Expired permission for 3 units.
SHLAA 286	S368	Land at Beech Grove	Cliffsend	0	N	VE	Site is garden land. Falls below SHLAA site threshold. No owner intention to develop site for housing. There is no obvious vehicular access from site to existing highway. TPOs on site restrict the number of units.
SHLAA 287	S423	Minster Station	Minster	4	Y	URB	Falls below SHLAA site threshold. The site has archaeological, historical, ecological and environmental issues that cannot be mitigated by condition. The site lies in the open countryside.
SHLAA 288	S427 2015 sub	Land north of Monkton Road	Monkton	17	N	VE/open countryside	The site lies in the open countryside in an unsustainable location, contrary to local and national policy. The site has major highways and ecological issues that cannot be mitigated by condition.
SHLAA 289	S518 2015	Land north of Monkton Road	Monkton	81	N	VE/open countrys	The site lies in the open countryside in an unsustainable location, contrary to local and national policy. The site

New Reference no	Previous References	Site Name	Town/Village	Capacity	PDL LAND (Y/N/Part)	SA	Assessment Suitability, Availability, Achievability
	sub					ide	has major highways and ecological issues that cannot be mitigated by condition.
SHLAA 290	S437 R25-020/4	Land west of Prospect Rd	Minster	179	N	Open countryside	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy The site has major access constraints that cannot be mitigated by condition.
SHLAA 291	S438 R25-020/5	Land south of Monkton Rd	Minster	400	N	Open countryside	The site lies in the open countryside, in an unsustainable location, contrary to local and national policy. The site has major highways/archaeological/ ecological/environmental/historical issues that cannot be mitigated by condition. TPOs on woodland. Local wildlife sites within the site.
SHLAA 292	S470	Site B South of A253	Cliffsend	226	N	Open countryside	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy. Site now proposed for allocation as site for new Parkway Station.
SHLAA 293	S474 2018 sub	Adj Vicarage, Monkton St	Monkton	15	P	VE/open countryside	The site lies in the open countryside in an unsustainable location, contrary to local and national policy. Loss of undeveloped frontage affording view over countryside. TPOs on boundary of site.
SHLAA 294	S487	East of Tothill Street	Minster	295	N	VE/open countryside	The site lies in the open countryside, contrary to local and national policy. The site has major highways issues that cannot be mitigated by condition.
SHLAA 295	S510 2015	Land at Shuart Lane	St Nicholas	6	N	VE/open countrys	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to

New Reference no	Previous References	Site Name	Town/Village	Capacity	PDL LAND (Y/N/Part)	SA	Assessment Suitability, Availability, Achievability
	sub					ide	local and national policy. Likely highway objection to principle of development.
SHLAA 296	SS30	Land at south of The Street, Monkton	Monkton	36	N	VE/open countryside	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy. Likely highway objection to principle of development. The site has highways and ecological issues. (See also S521).
SHLAA 297	S519	Land at Millers Lane	Monkton	267	N	VE/open countryside	The site lies in the open countryside in an unsustainable location, contrary to local and national policy. The site has major highways issues that cannot be mitigated by condition.
SHLAA 298	S520 2015 sub 2018 sub	Land at Willetts Hill	Monkton	149	N	Open countryside	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy
SHLAA 299	S521 2015 sub	Land at (south of) The Street	Monkton	5	N	VE/open countryside	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy.
SHLAA 300	S523	Rear of 59A High Street	Minster	2	N	VE	Falls below SHLAA site threshold. Site is garden land
SHLAA 301	S539	The Royal Exchange, Millers Lane	Monkton	0	N	VE	Falls below SHLAA site threshold.
SHLAA	R25-	Adj Chapman's	Cliffsend	1	N	URB	The site has major archaeological/

New Reference no	Previous References	Site Name	Town/Village	Capacity	PDL LAND (Y/N/Part)	SA	Assessment Suitability, Availability, Achievability
302	131	Fields					ecological/environmental/ historical issues that cannot be mitigated by condition. Falls below threshold. Site is garden land with TPOs.
SHLAA 303	R25-136 2018 sub	Walled Garden, Sun Lane	St Nicholas	8	N	Open countryside	The site lies in the open countryside in an unsustainable location, contrary to local and national policy. Site has highways issues with the junction at The Street, high archaeological potential, contamination issues associated with former use and TPOs on boundary of site.
SHLAA 304	SS8 2017 sub	Land adj Little Orchard, Canterbury Rd/Corner of Manor Road and Canterbury Road	St Nicholas	33	N	Open countryside	The site lies in the open countryside in an unsustainable location, contrary to local and national policy. Site has highway issues.
SHLAA 305	SS31	Land east of Shuart Lane	St Nicholas	20	N	VE/open countryside	The site lies in the open countryside in an unsustainable location, contrary to local and national policy. The site has highway issues that cannot be mitigated by condition.
SHLAA 306	SS32	Land off Sun Lane	St Nicholas	5	N	VE/open countryside	The site lies in the open countryside in an unsustainable location, contrary to local and national policy. The site has major highways issues that cannot be mitigated by condition.
SHLAA 307	S300	P&B Metals, Hartsdown Road	Margate	9	Y	URB	The site is in employment use, may come forward as a windfall. Deliverability unrealistic due to multiple ownership. Difficult site as differences in land level. No

New Reference no	**Previous References**	**Site Name**	**Town/Village**	**Capacity**	**PDL LAND (Y/N/Part)**	**SA**	**Assessment** Suitability, Availability, Achievability
							recent interest in bringing the site forward since expired planning permission in 2010.
SHLAA 308	S167	69 Eaton Road	Margate	78	Y	-	Site has been developed
SHLAA 309	S183	Newington Library, Newington Road	Ramsgate	9	Y	-	Site has been developed
SHLAA 310	S203	Munro Cobb Ltd, 223-229 Northdown Road	Margate		Y	-	Site has been developed
SHLAA 311	S211	25-27 Sweyn Road	Margate		Y	-	Site has been developed
SHLAA 312	S217	Pierremont Garage, 94 High Street	Broadstairs		Y	-	Site has been developed
SHLAA 313	S219	1&2 & 96-98 Harbour Parade Kent Terrace	Ramsgate	14	Y	-	Site has been developed
SHLAA 314	S221	67 Victoria Road	Margate	5	Y	-	Site has been developed
SHLAA 315	S231	9 Dalby Square	Margate		Y	-	Site has been developed
SHLAA 316	S238	24-25A Park Place	Margate		Y	-	Site has been developed
SHLAA 317	S239	Beaconsfield House St Peters	Broadstairs		Y	-	Site has been developed

New Reference no	Previous References	Site Name	Town/Village	Capacity	PDL LAND (Y/N/Part)	SA	**Assessment** Suitability, Availability, Achievability
		Road 25					
SHLAA 318	S241	14&28 Hatfield Road & Canterbury Road	Margate		Y	-	Site has been developed
SHLAA 319	S252	25-27 Godwin Road	Margate		Y	-	Site has been developed
SHLAA 320	S262	77 site adj Hereson Road	Ramsgate		P	-	Site has been developed
SHLAA 321	S272	69 West Cliff Road	Ramsgate	8	Y	-	Site has been developed
SHLAA 322	S308	234-236 Northdown Road	Margate	5	Y	-	Site has been developed
SHLAA 323	S331	19 Addiscombe Road	Margate		Y	-	Site has been developed
SHLAA 324	S334	23 Western Esplanade	Broadstairs	5	P	-	Site has been developed
SHLAA 325	S335	Hainault Haine Road	Ramsgate	5	Y	-	Site has been developed
SHLAA 326	S336	Haven Leisure, 42 Hawley Square	Margate		Y	-	Site has been developed
SHLAA 327	SR3	Capital House, Northdown Road	Margate		Y	-	Site has been developed
SHLAA 328	SR5	Ellington High School, Ellington Place	Ramsgate		Y	-	Site has been developed
SHLAA	SR6	Land adj the	Margate		N	-	Site has been developed

New Reference no	Previous References	Site Name	Town/Village	Capacity	PDL LAND (Y/N/Part)	SA	Assessment Suitability, Availability, Achievability
329		Promenade, All Saints Avenue					
SHLAA 330	SR13	56 Dumpton Park Drive	Broadstairs		Y	-	Site has been developed
SHLAA 331	SR27	58 Maynard Avenue	Margate		Y	-	Site has been developed
SHLAA 332	SR28	69 Sea Road	Westgate		Y	-	Site has been developed
SHLAA 333	SR35	10-14 The Square	Birchington		Y	-	Site has been developed
SHLAA 334	SR47	112 High Street	Ramsgate		Y	-	Site has been developed
SHLAA 335	SR49	19 Royal Esplanade	Margate		Y	-	Site has been developed
SHLAA 336	SR62	Culmers Lane, Vere Road	Broadstairs		N	-	Site has been developed
SHLAA 337	SS37	Dane Valley Industrial Estate – Part of national grid land, Northdown Road	St Peters	60	Y	URB	Planning application submission stated site was not viable in isolation. (See S545)
SHLAA 338	S513/S514 2015 sub	Land adjacent Manston Park	Acol		N	Open countryside	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy. Located in close proximity to the airport.
SHLAA	2015	Crumps Farm	St		N	Open	The site lies outside the village confines within the open

New Reference no	Previous References	Site Name	Town/Village	Capacity	PDL LAND (Y/N/Part)	SA	Assessment Suitability, Availability, Achievability
339	sub 2018 sub		Nicholas at Wade			countryside	countryside, in an unsustainable location, contrary to local and national policy.
SHLAA 340	2015 sub	Land off Margate Hill	Acol		N	VE	The site lies outside the village confines within the open countryside, in an unsustainable location, contrary to local and national policy.
SHLAA 341	2015 sub 2017 sub 2018 sub	Monkton Street (adjacent Foxhunter Park)	Monkton	60	N	VE	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy.
SHLAA 342	2015 sub- part of site has pp	Cliffsend (Foads Lane and Cliffsend Road)	Cliffsend		N	VE	Southern part of site has planning consent.
SHLAA 343	2017 sub	Sarre Windmill	Sarre		N	Open Country side	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy
SHLAA 344	2017 sub	Land adj Manston Park Bungalows and Esmonde Drive		20	N	Open Country side	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy
SHLAA 345	2017 sub	Land at Woodchurch		1500	N	Open Country	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to

New Reference no	Previous References	Site Name	Town/Village	Capacity	PDL LAND (Y/N/Part)	SA	**Assessment** Suitability, Availability, Achievability
	2018 sub					side	local and national policy.
SHLAA 346	2017 sub	Land between Manston Road/Preston Road	Manston	180	N	Open Countryside	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy
SHLAA 347	S419 2017 sub	South West of Sarre Business Park, Canterbury Road	Sarre	20	N	Open Countryside	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy
SHLAA 348	2017 sub	Former Manston Court Garage and Worlds Wonder	Manston	90	Y	Open Countryside	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy. Site is located in the vicinity of the airport.
SHLAA 349	north was 2017 sub 2018 sub	Land north and south of Millennium Way		225	Y	URB	The north is designated employment land, contrary to local policy. Peak capacity constraints unless new link roads are provided.
SHLAA 350	2018 sub	Eccleston, 4 The Grove	Westgate	8	PART	URB	The site has major highways issues that cannot be mitigated by condition.
SHLAA 351	2018 sub	Former Fuel Depot, Spitfire Way	Manston	8-20	Y	Open Countryside	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy
SHLAA	2018	Havisham House,	Broadstair		Y	GW	The site lies within the Green Wedge, in an

New Reference no	**Previous References**	**Site Name**	**Town/Village**	**Capacity**	**PDL LAND (Y/N/Part)**	**SA**	**Assessment** Suitability, Availability, Achievability
352	sub	Northdown Hill	s				unsustainable location, contrary to local and national policy
SHLAA 353	2018 sub	Land adj Doris Villa and Fairfield, Flete Road	Margate	4	N	Open countryside	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy Falls below threshold, may come forward as a windfall
SHLAA 354	2018 sub	Land adjacent to The Leys	Manston		N	VE	The site lies outside the village confines within the open countryside, in an unsustainable location, contrary to local and national policy. The site has highways issues that cannot be mitigated by condition
SHLAA 355	2018 sub	Land at junction of Monkton Street and Sheriffs Court Lane	Monkton	10	N	Open countryside	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy
SHLAA 356	2018 sub	Land at Little Brooksend Farm	Birchington	450	N	Open countryside	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy
SHLAA 357	2018 sub	Land at Manston Business Park	Ramsgate		N	Open countryside	Site is located in the vicinity of the airport.
SHLAA 358	2018 sub	Land at Manston Village	Ramsgate		N	VE	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy
SHLAA 359	2018 sub	Land at Monkton Road	Minster	10	N	Partial village edge	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy

New Reference no	Previous References	Site Name	Town/Village	Capacity	PDL LAND (Y/N/Part)	SA	Assessment Suitability, Availability, Achievability
SHLAA 360	2018 sub	Land at Ramsgate Road	Margate	208-242	N	Open countryside	The site lies within the Green Wedge, in an unsustainable location, contrary to local and national policy
SHLAA 361	2018 sub R25-043	Land between north of Hengist Way and south of Canterbury Road West	Cliffsend	350-450	N	Open countryside	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy
SHLAA 362	2018 sub	Land east of Ebbsfleet Lane	Ramsgate		Y	Open countryside	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy
SHLAA 363	2018 sub R25-020/2	Land north of Cottington Road, south of railway line	Cliffsend	80-150	N	VE	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy. The site has highways issues that cannot be mitigated by condition
SHLAA 364	2018 sub	Land north of Foxborough Lane	Minster	130-140	N	VE	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy. The site has highways issues that cannot be mitigated by condition
SHLAA 365	2018 sub	Land north of Monkton Road	Minster	120	N	VE	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy. The site has highways issues that cannot be mitigated by condition
SHLAA 366	2018 sub	Land north of The Length	St Nicholas	115	N	VE	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to

New Reference no	Previous References	Site Name	Town/Village	Capacity	PDL LAND (Y/N/Part)	SA	Assessment Suitability, Availability, Achievability
			at Wade				local and national policy. The site has highways issues that cannot be mitigated by condition
SHLAA 367	2018 sub	Land north of Westwood Road	Broadstairs		N	UE	The site lies within the Green Wedge, in an unsustainable location, contrary to local and national policy. The site has highways issues that cannot be mitigated by condition
SHLAA 368	2018 sub	Land north west of Down Barton Road	St Nicholas at Wade	9	N	Open countryside	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy
SHLAA 369	2018 sub	Land rear of Flete Lodge, Vincent Road	Margate	13	N	Open countryside	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy
SHLAA 370	2018 sub	Land south of Birchington, east and Canterbury Road	Birchington	455	N	Open countryside	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy
SHLAA 371	2018 sub	Land south of Canterbury Road east	Ramsgate		N	Partial UE	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy
SHLAA 372	2018 sub R25-014	Land south of Chilton School	Ramsgate		N	UE	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy
SHLAA 373	2018 sub R25-	Land west of Chilton School	Ramsgate		N	UE	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy

New Reference no	**Previous References**	**Site Name**	**Town/Village**	**Capacity**	**PDL LAND (Y/N/Part)**	**SA**	**Assessment** Suitability, Availability, Achievability
	031						
SHLAA 374	2018 sub R25-100, 003 and 400	Land south of Cottington Road	Cliffsend	60	N	Open countryside	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy
SHLAA 375	2018 sub	Land west of Allen Avenue	Westgate	130-140	N	UE GW	The site lies within the Green Wedge, in an unsustainable location, contrary to local and national policy
SHLAA 376	2018 sub	Land west of Egerton Manor	Acol	30	N	Open countryside	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy.
SHLAA 377	2018 sub 2017 sub	Land west of Preston Road	Manston	150	N	Partial VE Not well related	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy.
SHLAA 378	2018 sub	Land west of Willets Hill	Monkton	70	N	VE	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy. The site has highways issues that cannot be mitigated by condition
SHLAA 379	2018 sub	Little Cliffsend Farm	Ramsgate		PART	Open countryside	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy. The site has highways issues that cannot be mitigated by condition

Appendix G.1.7

New Reference no	Previous References	Site Name	Town/Village	Capacity	PDL LAND (Y/N/Part)	SA	**Assessment** Suitability, Availability, Achievability
SHLAA 380	2018 sub	Pendell, Broadley Road	Margate		Y	UE GW	The site lies within the Green Wedge, in an unsustainable location, contrary to local and national policy. The site has highways issues that cannot be mitigated by condition
SHLAA 381	2018 sub	Two plots adj Kingsgate and Kenver Nursery	Broadstairs	48	N	UE GW	The site lies within the Green Wedge, in an unsustainable location, contrary to local and national policy.
SHLAA 382	2018 sub	20 Clive Road	Ramsgate	5	N	VE	The site lies outside the urban confines within the open countryside, in an unsustainable location, contrary to local and national policy.
SHLAA 383	2018 sub	382 Northdown Road (former Holly Tree Public House)	Margate	50	PART	URB	Live application. Could come forward as windfall
SHLAA 384	2018 sub	123 Sandwich Road	Cliffsend	9	Y	URB	Could come forward as windfall
SHLAA 385	2018 sub	Ethelbert Crescent/Edgar Road/Dalby Square	Cliftonville	20	Y	URB	Could come forward as windfall
SHLAA 386	2018 sub	Hereward Motors, 17 Birds Avenue	Margate	5	Y	URB	Could come forward as windfall
SHLAA 387	2018 sub	Former Laleham Gap School, 1 South Cliffe Parade	Broadstairs	20	Y	URB	Could come forward as windfall

New Reference no	**Previous References**	**Site Name**	**Town/Village**	**Capacity**	**PDL LAND (Y/N/Part)**	**SA**	**Assessment** Suitability, Availability, Achievability
SHLAA 388	2018 sub	Ramsgate Social Club CIU Institute, Elms Road	Ramsgate	5	Y	URB	Could come forward as windfall
SHLAA 389	2018 sub	Land adjacent to Yoakley House, Drapers Close and north and south of St Peters Road O(A255), Margate				GW	The site lies within the Green Wedge, in an unsustainable location, contrary to local and national policy
SHLAA 390	2018 sub	Laurensfield, Tothill Street	Minster		N	URB	Falls below SHLAA site threshold
SHLAA 015	2015 sub 2018 sub	Airport site	Manston	2500	p	Potential NS	The site is sustainable subject to mitigating criteria, is located on brownfield land and is consistent with other environmental policy and guidance. However, it was agreed at Full Council that the airport site should not be considered for allocation until the DCO process is concluded.

Appendix G - Sites excluded at the early stages of the SHLAA process

Site Reference	Site Name & Address	Town	Reason on reserve list
S10	Adjacent 363 Margate Road & opposite 53-25 Northwood Road	Ramsgate	In employment use and no reason not to assume continued operation of this very longstanding business from these premises
S163	Land At Molineux Road Molineux Road & Thorne Road Monkton Road	Minster	Site complete/near complete
S175	Manston Park Bungalows, Manston Road	Manston	Not in or adjoining urban/village confines.
S197	Cliffs End Farm, (Land at) Cliffs End Road	Ramsgate	Largely built out. Superseded by site ref R25-131 (an assessed site).
S207	Castle Keep Hotel, Joss Gap Road	Broadstairs	Identified from old planning consent. No evidence of intention to seek to develop.
S314	Gore Street Farm House, Gore Street	Monkton	Not in or adjoining urban/village confines.
S359	Land adj 208 High Street	Margate	capacity likely less than 5 net
S368	Land at Beech Grove	Ramsgate	Identified from old audit. No evidence that owner wishes to seek development.
S369	Land west side of Fairfield Road	Ramsgate	Identified from old planning consent. Site likely too small for SHLAA threshold
S370	Land at Dumpton Park Drive	Ramsgate	capacity likely less than 5 net

Site Reference	Site Name & Address	Town	Reason on reserve list
S371	Garage 3 Colemans Yard	Ramsgate	capacity likely less than 5 net
S372	Closed PC's Boundary Road	Ramsgate	capacity likely less than 5 net
S373	Land at Greenfield Road	Ramsgate	capacity likely less than 5 net
S385	King Street opposite Tudor House	Margate	capacity likely less than 5 net
S400	1-6 Covells Row	Margate	capacity likely less than 5 net
S418	Former Chalk pit, Sarre	Sarre	Not identified as sustainable settlement
S419	Land south of Canterbury Road, Sarre	Sarre	Not identified as sustainable settlement
S420	Land west of Birchington	Birchington	Part of site assessed . However, entire site as submitted would not represent a proportionate urban extension
S428	Focus Store & land Rear, Pyson's Road, Ramsgate	Ramsgate	Part of site in Green Wedge assessed. Remainder not assessed as on allocated employment land.
S430	Jewson's Site, Tivoli Brooks Ind Estate, margate	Margate	Safeguarded employment site
S439	Land southeast of Mount Pleasant roundabout, Minster	Minster	Site would not represent proportionate extension to urban area. In addition, part of site closest to confines largely built out with alternative development.
S440	Land east of laundry road, Minster	Minster	Not in or adjoining urban/village confines.
S441	Land east of Wayborough Hill, Minster	Minster	Not in or adjoining urban/village confines.

Site Reference	Site Name & Address	Town	Reason on reserve list
S442	Land east of Way Hill, Minster	Minster	Not in or adjoining urban/village confines.
S444	Land adjoining Ebbsfleet Lane	Sevenscore	Not in or adjoining urban/village confines.
S454	land adj Sevenscore Farm Cottages, Sevenscore	Sevenscore	Not in or adjoining urban/village confines.
S461	Lord of the Manor, Ramsgate	Ramsgate	Not in or adjoining urban/village confines.
S471	Land south of A253, Minster	Minster	Not in or adjoining urban/village confines.
S492	Land North of Manston Green Farm, Manston	Manston	Not classified as sustainable settlement
S493	Land fronting Preston Road, Manston Green farm, Manston	Manston	Not classified as sustainable settlement
S494	Land rear of Manston Green Farm Bungalow, Manston	Manston	Not classified as sustainable settlement
S495	Land rear of Jubilee Cottages, Manston Road, Manston	Manston	Not classified as sustainable settlement
S500	Manston park, mansion (1.73ha)	Manston	Allocated employment land. Not in or adjoining urban/village confines
S501	Manston park, manston (0.65ha)	Manston	Allocated employment land. Not in or adjoining urban/village confines
S502	Manston park, manston (2.08ha)	Manston	Allocated employment land. Not in or adjoining urban/village confines

Site Reference	Site Name & Address	Town	Reason on reserve list
S503	Manston park, manston (10.5ha)	Manston	Allocated employment land. Not in or adjoining urban/village confines
S506	Land adj. pumping station, Canterbury Rd West, Ramsgate	Ramsgate	Not in or adjoining urban/village confines
S507	Land north of St Nicholas Roundabout.	St Nicholas	Not in or adjoining urban/village confines
S508	Land West of Haine Road, Ramsgate	Ramsgate	Part of site assessed under ref SS33. Rest of site Poor and disproportionate relationship to urban confines.
S513	Land at Minster Road, Acol	Acol	Not in or adjoining urban/village confines. Submission not seeking residential allocation
S514	Land at Minster Road, Acol	Acol	Not in or adjoining urban/village confines. Submission not seeking residential allocation
S517	Land at Richborough Power Station.	Sevenscore	Part within and part adjoining Site of Special Scientific Interest. Not in or adjoining urban/village confines
S526	Land at Manston Business Park (east of existing BP)	Manston	Not in or adjoining built confines. Submission not seeking residential allocation
S533	Land to east of Grupo Antolin, Eurokent Business Park	Ramsgate	Partly allocated employment land. Submission not seeking residential allocation
S538	40 Canterbury Road West, Cliffsend	Cliffsend	Not in or adjoining urban/village confines. Likely too small for SHLAA threshold
S547	Land at Ebbsfleet	Sevenscore	Not in or adjoining urban/village confines

Site Reference	Site Name & Address	Town	Reason on reserve list
R25-116 & R25-132	Land next to church Plumstone Road	Acol	Not identified as sustainable settlement.
R25-117	Old Village hall	Manston	Not identified as sustainable settlement.
R25-120	Hydrophone Site	Cliftonville	Promoter not seeking residential. Submission abandoned.
R25-122	Land north of A299	Minster	Not adjoining urban/village confines and seeking non residential development
R25-128	Chapel Farm	Manston	Not identified as sustainable settlement.
R25-129	South of Manston Green farm	Manston	Not identified as sustainable settlement.
R25-134	Grenham Lodge, Manston Rd	Manston	Not identified as sustainable settlement.
R25-138	Hoverspeed Social Club	Manston	Not identified as sustainable settlement.
R25-142	Land west of Manston Green Bungalow	Manston	Not identified as sustainable settlement.
R25-147	Attwells Yard, Queensdown Rd	Manston	Not in or adjoining urban/village confines
R25-148	Land at 151 Monkton Street	Monkton	Not in or adjoining urban/ village confines.
R25-153	Site at 129 Manston Rd	Manston	Not in or adjoining urban/ village confines
SS2	Land at Chantry Park, Sarre	Sarre	Not identified as sustainable settlement.
SS3	Land East of Sarre Court, Sarre	Sarre	Not identified as sustainable settlement.
SS4	Land adj Jolly farmer PH, Manston	Manston	Not identified as sustainable settlement.

Appendix G.1.7

Site Reference	Site Name & Address	Town	Reason on reserve list
SS5	Land at Watchester Lane, Minster	Minster	Not in or adjoining urban/village confines
SS7	Land adjacent to Upper hale, Canterbury Road, St. Nicholas at Wade	St Nicholas	Not in or adjoining urban/village confines
SS9	Rear of 4 Ramsgate Road & 8 Vicarage Crescent, Margate	Margate	Too small for SHLAA threshold
SS10	Rear of 11-13 Quex View Road, Birchington	Birchington	Too small for SHLAA threshold
SS11	Rear of 52 Invicta Road, Margate	Margate	Too small for SHLAA threshold
SS12	Manston Riding centre, Alland Grange Lane, Manston	Manston	Not in or adjoining urban/village confines
SS13	Land adjacent to The Leys, Manston	Manston	Not identified as sustainable settlement.
SS29	Land adjacent to Manston park, Acol	Acol	Not in or adjoining urban/village confines. Submission not seeking residential
SS33 (R25-188)	Land between 46 Monkton Street and Walters Hall Oast, Monkton	Monkton	capacity likely less than 5 net
ST5	Airport land north of B2050	Manston	Not in or adjoining urban/village confines

Appendix G.1.7

WhatDoTheyKnow

Extension to planning application OL/TH/18/0660

Andrew McCulloch made this Freedom of Information request to Thanet District Council

Follow 3 followers

The request was **partially successful**.

Andrew McCulloch 3 September 2018
Delivered

Dear Thanet District Council,

Planning application OL/TH/18/0660 was submitted on 4th May and validated on the 9th May. A Statutory Expiry Date of 15th August 2018 was confirmed.

Sometime after the end of July 2018 the applicants were granted an extension and an Agreed Expiry Date of 31st December 2018 was established. No reason for the granting of this extension was posted on the planning portal.

Please send me copies of all correspondence relating to the request for and granting of this extension to OL/TH/18/0660

Thank you.

Yours faithfully,

Andrew McCulloch

Andrew McCulloch 7 September 2018
Delivered

Dear Thanet District Council,

Appendix G.1.9

This request was filed on the 3rd September. It is now the 7th and I have yet to receive an acknowledgement.

Yours faithfully,

Andrew McCulloch

Andrew McCulloch 2 October 2018
Delivered

Dear Thanet District Council,

A response to this request was due on 1st October. To date I have not even received an acknowledgement. I shall therefore refer the matter directly to the Information Commissioner.

Yours faithfully,

Andrew McCulloch

TDC FOI, Thanet District Council 2 October 2018

Dear Mr. McCulloch

Thank you for your Freedom of Information request, in which you requested for:

"copies of all correspondence relating to the request for and granting of this extension to OL/TH/18/0660"

Firstly, I sincerely apologise on behalf of the Council for the slight delay in sending you the requested information. This is due to a combination of administrative issues and a significant increase in requests in recent months.

Our response is as follows:

The information you have requested is exempt under Section 21 of the Freedom of Information Act (FOIA) - information already reasonably accessible to the applicant.

This information is available on our website via the following link:

Appendix G.1.9

[1]https://planning.thanet.gov.uk/online-ap...
The advanced search can be utilised to search for certain descriptions of development, such as 'annexes'.

Put the first line of the address in the search box and press enter. Once the search results are collated they are shown the 'search/Clear' buttons, even though the result figure may show zero.

By clicking on the application reference you should be able to see the information you require.

It is advisable to go back to the search page again before inputting another address.

If you have any difficulties with this please contact us.

Next Steps

If you are unhappy with the way your enquiry has been dealt with, you may ask for an internal review by submitting a request within two weeks of the date of this response. Further information on the internal review process is can be found here:
[2]https://www.thanet.gov.uk/your-services/...
Your request should be addressed to the Information Governance Manager, Thanet District Council, PO Box 9, Cecil Street, Margate, CT9 1XZ or by emailing [3][email address].

If you are still dissatisfied after an internal review, you may appeal to the Information Commissioner, Wycliffe House, Water Lane, Wilmslow SK9 5AF.

Best regards

Information Governance Officer

Thanet District Council

Margate

Appendix G.1.9

CT9 1XZ

01843 577620

References

Visible links
1. https://planning.thanet.gov.uk/online-ap...
2. https://www.thanet.gov.uk/your-services/...
3. mailto:[email address]

Andrew McCulloch 2 October 2018
Delivered

Dear Thanet District Council,

Please pass this on to the person who conducts Freedom of Information reviews.

I am writing to request an internal review of Thanet District Council's handling of my FOI request 'Extension to planning application OL/TH/18/0660'.

This request has been handled in a thoroughly disgraceful manner and the last straw is to not answer the question posed.

The last sentence of my request was:

"Please send me copies of all correspondence relating to the request for and granting of this extension to OL/TH/18/0660".
I am perfectly capable of finding this application on the planning portal; I have just checked again and there is not a single document referring to " the request for and granting of this extension to OL/TH/18/0660"

This matter is now in the hands of the ICO, who will doubtless be in touch over your inability to comply with the law yet again. In the meantime please don't treat me as an idiot and this time answer the question put.

A full history of my FOI request and all correspondence is available on the Internet at this address: https://www.whatdotheyknow.com/request/e...

Yours faithfully,

Andrew McCulloch

Andrew McCulloch left an annotation (2 October 2018)

At 08:48 I informed TDC on this site that I had received nothing from them, not even an acknowledgement, and that I had therefore referred the matter to the ICO.
At 09:03 on 2nd October I referred this matter to the ICO, receiving an acknowledgement from them at 09:05.
At 09:29 I received a response from TDC, doubtless as a result of my 08:48 posting here. It completely failed to answer my request.

Thanet District Council 9 October 2018

1 Attachment

FOI 2113.Additional Information..pdf

137K Download View as HTML

Dear Mr. McCulloch

Further to your Freedom of Information request, and our email of 2 October 2018, we herewith disclose additional information, which is attached to this email.

We apologise on behalf of the Council for not sending this additional information earlier.

You may notice that material in your file is blacked out (also known as redacted). In order to ensure that you receive as much information as possible we have provided you with your entire file, however, all third party information (for example information about other people) have been blacked out pursuant to the Section 40 of the Freedom of Information Act 2000.

Section 40

Section 40(2) of the Act says that, the personal data of a 3^rd party may be withheld if its disclosure would be to someone other than the third party; and the disclosure would contravene any of the data protection Principles of the Data Protection Act 2018 especially the first data protection principle that, disclosure of third party information must be fair and lawful.

Under the Act, we are required to consider the impact of 3^rd party disclosure in the widest possible sense.

Next Steps

If you are unhappy with the way your enquiry has been dealt with, you may ask for an internal review by submitting a request within two weeks of the date of this response. Further information on the internal review process is can be found here:
[1]https://www.thanet.gov.uk/your-services/...
Your request should be addressed to the Information Governance Manager, Thanet District Council, PO Box 9, Cecil Street, Margate, CT9 1XZ or by emailing [2][email address].

If you are still dissatisfied after an internal review, you may appeal to the Information Commissioner, Wycliffe House, Water Lane, Wilmslow SK9 5AF.

Best regards

Information Governance Officer

Thanet District Council

Margate

CT9 1XZ

show quoted sections

References

Appendix G.1.9

Visible links
1. https://www.thanet.gov.uk/your-services/...
2. mailto:[email address]

Andrew McCulloch 6 November 2018
Delivered

Dear Thanet District Council,

Further to my Freedom of Information request regarding the extension to SHP's planning application OL/TH/18/0660 (for your information this can be found on (http://bit.ly/2�1Z6Ca) I wish to make the following points.

In your official letter to GVA (which I assume is a poorly worded version of the formal letter prescribed in Regulation 25(1) of the Town and Country Planning (Environmental Impact Assessment) Regulations 2017) you state that the reason that TDC are requesting the extension is that you require further information. �Further information�is clearly defined at the end of Regulation 25(1); I assume that you are using the term in the same way as the Regulations.

In your accompanying email you expand on this by saying that �the extension is requested to allow for further information on highways and environmental matters and any potential revisions to parameter plans, heads of terms negotiations and reporting the application to the Planning Committee.�
Presumably GVA know exactly what further information is required;
�I think that these requirements should have been posted on the planning portal?
�Your rather vague email leaves open the probability that GVA/SHP have told you that they propose to amend one or all of the parameter plans - such amendment would surely require a full review of the Environmental Statement under Regulation 25 of the EIA Regulations.
�Since it is clear that this was a Regulation 25(1) request the applicant has to publish a notice in a local paper containing a lengthy list of obligations under Regulation 25(3). I have not seen such a notice.

A look at the TDC website shows me that the two remaining Planning Committee meetings this year are on the 21st November and 12th December; the latter is five weeks away as I write.
�Regulation 25(f) requires that a copy of the further information or any other information and of any environmental statement which relates to any application for planning permission or subsequent application may be inspected by members of the public at all reasonable hours;
�Regulation 25(l) requires that any person wishing to make representations about the further information or any other information should make them in writing, before the latest date specified in accordance with sub-paragraph (g) or (h), to the relevant planning authority, the Secretary of State or the inspector (as the case may be), and
�Regulation 25(9) requires that the relevant planning authority must make the further information or any other information available for inspection on a website maintained by or on its behalf.

If there is still an intention to publish a Regulation 25(3) notice then there is certainly not enough time before the expiry of the extension; 25(g) and 25(h) both require a representation deadline not less than 30 days later than the date on which the notice is published. In six days from now that deadline will fall after the meeting on 12th December.

As a resident with an interest in this proposed large-scale development I think it not unreasonable for the public to have answers to the following questions.

1. Is your letter of 14th August to GVA intended to serve as the notification required by Section 25(1) of the Town and Country Planning (Environmental Impact Assessment) Regulations 2017?
2. If it was not intended to be such a notification please explain why not. Your accompanying email lists highways and environmental mattersas criteria; criteria covered by the requirements of Regulation 25 (1)
3. Have GVA/SHP published a notice as required by Section 25(3) of the Town and Country Planning (Environmental Impact Assessment) Regulations 2017? If so, when and in which publication. Please provide a copy of this notice, if it really exists.
4. If GVA/SHP have published such a notice, why has it not appeared on the planning portal site?
5. Do you still intend to place this application on the agenda for the 12th December Planning Committee meeting?
6. If you are not intending to place it on the 12th December agenda have you informed GVA of this fact?
7. Why has it taken a Freedom of Information request to obtain this exchange of correspondence? Council officers are frequently complaining of the costs incurred in complying with the requirements of the Act; this documentation, and any others relating to this planning application should have been placed on the planning portal. Please explain for the benefit of Thanet council tax payers why you have caused them to incur this extra expense.

I don't require a reply to this but wish to ensure that the text - which is an email to the relevant planning applications manager - reaches a wider audience and is not lost in the system.

Yours faithfully,

Andrew McCulloch

Appendix G.1.9

Nick Hilton
Technical Director – EIA Lead / Project Director

wood.

Summary

Years of Experience

20

Sectors

- Aviation and Transport
- Power (including renewables)
- Industry
- Infrastructure
- Property
- Minerals and mining

Areas of Expertise

- Project Management
- Environmental appraisals for planning applications
- Environmental Impact Assessment

Languages

- English

Professional Summary

Nick is Wood's UK EIA service lead with 20 experience working to bring forward major infrastructure and development projects. He brings over 20 years of experience working as an environmental planner and project manager/director for transport projects including rail, road and airport developments. Nick has led the environmental assessment teams on multi-modal transport studies for local and transport authorities as well as public and private sector developers including the DCO application for Manston Airport. He is currently leading the environmental workstreams for two other UK airports both of which involve the provision of significant surface transport improvements as well as complex aviation components. Nick also has experience in public sector business case preparation, stakeholder consultation and project management. He is a full member of the Institute of Environmental Management and Assessment, a Chartered Environmentalist and holds an MBA from the well regarded Henley Business School.

Qualifications

Education

BSc, Environmental and Life Science with Geography

MA, Business Administration

LLM International Law

Registrations / Certifications / Licenses

Member of the Institute of Environmental Management and Assessment

Chartered Environmentalist

Projects Highlights

EIA and Project Director

RiverOak Strategic Partners Limited, Manston Airport Development Consent Order, Kent

Nick is currently leading the Environmental workstream for this DCO Application and Nationally Significant Infrastructure Project (NSIP). After joining Wood in 2017 Nick took on the role of Project Director closely managing all of the workstreams associated with this large and technically complex multidisciplinary project. Following a second round of PEIR consultation in late 2017 the ES was completed in 2018 with the DCO application being submitted shortly afterwards. The project has been accepted for examination by the Planning Inspectorate and Wood continue to work alongside RiverOak, their lawyers BDB and the rest of the consultant team in preparation for the 2019 examination.

EIA Lead and Technical Director

Bristol Airport 12mppa Planning Application

Bristol Airport Limited are currently in the process of consulting on a masterplan to expand operations to cater for up to 20million passengers per annum. The first phase of this process is the submission of a planning application for an initial expansion of 2mppa as well as supporting infrastructure and facilities including terminal buildings. Nick is currently the Technical Director for the EIA workstream.

EIA Lead and Technical Director

Luton Airport Variation of Condition 12 relating to Noise

Nick is the technical lead for the preparation of an ES to reflect EIA regulatory changes for Luton Airport. His role has involved providing legal advice to the client on a section 73 application and discussing implications for the EIA process.

EIA Lead and Project Director

Dunsfold Aerodrome

Project director for the EIA and planning application for this major mixed use development in Surrey. Working closely with the client over a three year period to bring forward development on an operation airfield and test track including an application for a masterplan for a mixed use development of 1800-3400 homes in Surrey and a number of related applications. The development also included transport works on the A281, bridge works, the integration of a country park and other public open space and 68,000m^2 of employment space to complement an existing business park. Consent was granted for the development in December 2016 however the application was subsequently called in by the Secretary of State and a public inquiry held which reported favourably with the grant of planning consent upheld.

Project Director

Shoreditch High Street Mixed Use Development

Nick acted as project Director and EIA lead for a major mixed use development on Shoreditch High Street in Hackney. The client for this project was a US based investment house that sought to bring forward a hotel led mixed-use development comprising a 30-storey tower with hotel, office and commercial space, retail and leisure facilities. Significant issues included those typically associated with high-rise tower schemes in urban environments: townscape and visual impact; microclimate including wind modelling, daylight/sunlight and overshadowing; archaeology; ground conditions and noise and vibration; and construction method and logistics. The EIA was delivered in just three months and the scheme was granted planning consent.

Project Director

Tavistock to Bere Alston Railway DCO Application

Nick was the Project Director, leading the EIA and DCO Application for this NSIP being promoted by Devon County Council. The project involved the reinstatement of a redundant rail link between Tavistock and Bere Alston as well as a number of cycle and pedestrian trails linking existing leisure assets in East Devon.

Project Director

Central Bedfordshire and Luton HMA Growth Options Studies

Nick was the Project Director leading two major studies that evaluated potential spatial strategies for the provision of housing within the Luton Housing Market Area and the Central Bedfordshire administrative area. Following the development and agreement of a GIS based methodology some 40 strategic housing sites in the central Bedfordshire area were evaluated.

Project Director

Malawi Strategic Environmental and Social Assessment (SESA)

As part of the World Bank's Support for Malawi's Mining Governance, Growth and Support Project (MGGSP) it was necessary to conduct a Strategic Environmental and Social Assessment in order to comply with the Bank's safeguarding Procedures. The project involved extensive stakeholder consultation as well as detailed scenario planning for the anticipated growth of Malawi's mining industry. The project was closely aligned with the delivery of a new Mining Act with the SESA seeking to anticipate the impacts of that act as well as ensuring that the act itself contained appropriate environmental and social protections. Nick oversaw the delivery of the SESA report, presenting the findings to the panel of ministries and the Inter-governmental stakeholder panel at a conference in Llilongwe in January 2016.

Project Director

Roodepoort Strengthening Project EIA

Nick oversaw the EIA and stakeholder consultation exercise examining six route options for a controversial 750kV transmission line and associated substation running from the Cradle of Humankind, north of Johannesburg into the urban area. Although the length of the line itself was, by south African standards relatively short the complexity of bringing large scale infrastructure into the urban environment brought significant challenges both in terms of the scale of the consultation exercise itself and the technical challenges of undergrounding (or otherwise) both within the Cradle UNESCO site and within the urban area itself. Much of the consultation and baseline EIA data was managed through a GIS system allowing the database to be used for precise tower placement following the grant of consent. The EIA was completed between 2012 and 2014 and consent granted for the development later that year.

Project Director

Le Morne, Mauritius

The Le Morne Development on Mauritius lay within the buffer zone of a candidate UNESCO World Heritage Site and therefore sought to be a light touch, high value development of 30-40 exclusive villas as well as a spa style resort centre including restaurant. The nature of the scheme was such that in addition to the EIA, it was necessary to undertake extensive consultation with numerous government ministries and international organisations as well as local interest groups. Nicks role was as UK lead for the EIA and planning phase of the development working with a multi-disciplinary team of engineers, environmental planners and technical specialists.

Project Director

Kennett Valley Park Project

Nick was the project manager for the Kennet Valley Park Project close to Junction 12 of the M4. This was a long term land development project being bought forward by Prudential Property Investment Management and involving the delivery of 8500 homes, employment and community facilities including country parks, schools, district heating and retail. The project also involved two major infrastructure schemes. First the construction of a large storage reservoir at Theale Lake as a flood risk mitigation scheme and second a package of transport upgrades including a major upgrade to Junction 12 of the M4.

Key Account Manager

Reading Borough Council Transport Framework Contract- Project Management

As part of his role, leading the development of internal project management capability at PBA, Nick managed a £5m transport framework contract involving transport planning, engineering and environmental works. The contract included extensive modelling using Saturn and various other transport modelling packages as well as local schemes and major developments. The contract also involved secondment of staff for development control roles. The critical success factor in this role was relationship management in terms of building a partnership with council officers and in particular the head of transport at the Borough. During the time that Nick was engaged in this role the LTP was prepared and several schemes were put forward for major scheme and TIF funding.

Project Manager

Reading Borough Council State of the Environment Report and SEA

With the Strategic Environmental Assessment (SEA) Directive fresh to everyone, Reading Borough Council decided to take a long term view of the environment in which LTP2 was to be delivered. Nick led the creation of a GIS based state of the environment report which also included noise and air quality modelling for the urban area, feeding into the review and assessment process and other statutory requirements. The SEA (SA) was delivered successfully and LTP2 was accepted without question and the SEA being complemented on its thoroughness and fitness for purpose.

EIA Project Manager

M4 Junction 11, Reading

As Reading Borough Council’s only access onto the motorway network, the bottleneck created by the then outdated infrastructure was considered to be a significant constraint to further growth in the Thames valley and particularly Reading’s reputation as a hi-tech hub in the south east. The multi-modal scheme proposed not only sought to increase capacity for private car users but also facilitated bus priority via dedicated bus lanes, safer pedestrian and cycle access.

The scheme went to Public Inquiry in 2004 as a result of Compulsory Purchase Order (CPO) Objections and consent granted following that public inquiry. Following agreement of the £68m funding package, the development was built between 2006-2008.

Professional History

2017, Technical Director, Wood

2014 – 2017, Director, Land Use Consultants

2012 – 2014, Director, PBA South Africa (4th Element Consulting)

2001-2011, Various, PBA UK and International

1998-2001- Contractor undertaking various transport and environmental consultancy contracts

Martin Peirce
Principal Consultant - Air Quality

wood.

Summary

Years of Experience

28

Areas of Expertise

- Air quality assessment
- Atmospheric emission inventories, including greenhouse gases

Industries

- Aviation
- Power generation
- Nuclear

Professional Summary

Martin has performed many assessments of air quality around major airports over the last 20 years. Some of these are aimed at allowing the airport operator to understand its current impacts, help inform the local community under Section 106 agreements, and develop action plans; others are to assess the impacts of proposed developments ranging from a new heating plant, a reconfiguration of the airfield, or new terminals and runways. Still others provide a strategic comparison of the effects of different aviation expansion options across a range of airports.

Martin has expertise at calculating emissions from a wide range of sources on and near the airport, including aircraft, ground support equipment, landside roads, heating plant, and other local sources. He then uses dispersion modelling, featuring specialised techniques for modelling plume rise from aircraft engines, to calculate concentrations of pollutants at sensitive receptors, and assesses them against regulatory limits and standards.

Projects support an understanding of both local air quality and emissions of greenhouse gases.

Qualifications

Education

MSc, Nonlinear Mathematics, University of Bath

BSc (Hons), Mathematics with Astronomy, University of Leicester

Software

ADMS, ADMS-Airport, ADMS-Roads

Current Project

Air quality assessment

RiverOak Strategic Partners Limited, Manston Airport Development Consent Order, Kent

Martin led the air quality assessment of the proposed Airport, including the associated road traffic. The assessment examined the air quality impacts on human and ecological receptors and compared them against regulatory standards.

He also contributed to the ecology, health and climate change assessments, and carried out assessments of odour and construction dust. These formed key parts of the Environmental Statement and of the Development Consent Order application.

Martin Peirce
Principal consultant, air quality

Experience

Air quality and greenhouse gas assessments

Heathrow Airport Expansion and other projects, Heathrow Airport, London

Martin has provided considerable support to Heathrow Airport over many years. He is currently working on the air quality assessment for the Development Consent Order (DCO) application for the third runway, focussing on the methodology for calculating the impacts of aircraft emissions, for both air quality pollutants and greenhouse gases. This builds on his work for Heathrow's submission to the Airports Commission, where he carried out the development of the emissions inventory and dispersion modelling for three-runway and two-runway scenarios, as well as appraising many masterplanning options. His other air quality work has included regular emission inventories, including detailed evaluations of the models' performance against monitoring data; support for Heathrow's air quality action plan to reduce the airport's air quality impacts; assessment of the introduction of full runway alternation in easterlies in support of the planning application; assessment of the reconfiguration of the eastern apron; and work on the public inquiry into the Terminal 5 development.

Air quality assessments

Heathrow Airport Expansion and other airport projects, Department for Transport (DfT), London

Martin was a key technical member of the team that carried out the air quality assessment of a proposed third runway at Heathrow (the northeast runway scheme) for DfT. He assessed a wide variety of baseline and development scenarios, and attended public exhibitions of the proposals.

He worked with the Project for the Sustainable Development of Heathrow, helping create a best-practice methodology for airport air quality assessments, with regard to both emissions calculation and dispersion modelling techniques.

Martin performed air quality assessments as part of optioneering for the DfT's white paper on aviation, looking at a wide range of options for expansion of airports across the UK.

Air quality assessment

Bristol Airport 12 mppa, Bristol Airport, Somerset

Martin led the air quality assessment for the proposed expansion of Bristol Airport to support 12 million passengers per annum (mppa), in support of the planning application. The air quality impacts include those due to aircraft and road traffic during the operational phase, as well as construction activity. Martin assessed impacts on both human and sensitive ecological receptors, and compared them against regulatory standards.

Air quality assessments

Generation 2 and other projects, Stansted Airport and Gatwick Airport, UK

Martin was a key technical member of the team that carried out the air quality assessment for the proposed second runway at Stansted (the Generation 2 project) for a planned public inquiry, subsequently withdrawn. He has also carried out regular emission inventory and dispersion modelling studies for both Stansted Airport and Gatwick Airport, as well as performing air quality assessments of other developments such as the reconfiguration of Gatwick's northwest apron.

Professional History

- Wood (2015 – Present) Principal Consultant
- Ricardo (1990 – 2014) Senior Consultant

Dr Mark Linsley
Associate Director – Biodiversity (Lead Response)

wood.

Summary

Years of Experience

20+ years

Areas of Expertise

- Ecological Appraisal
- Ecological Impact Assessment
- Ornithology
- Habitat restoration and creation
- Protected species survey and mitigation
- Project Management/Direction

Types of Facilities

- Airports
- Transmission (OHL)
- Power Plants
- Landfill

Industries

- Property
- Waste
- Transport
- Energy

Professional Summary

Mark has extensive experience of project managing and directing a wide range of ecological and environmental projects many from initial risk assessment and appraisal through to the post-consent stage. His project management and director capabilities, especially in consent related projects, has given Mark experience of the development process, UK and European wildlife legislation, and Habitats Regulations Assessment (HRA).

In addition to significant experience in the property sector, Mark has also carried out significant work in power, particularly on overhead lines and in nuclear, on both new build and decommissioned sites.

Furthermore, Mark has extensive waste sector experience, particularly in the restoration (habitat creation) and monitoring of closed landfill sites and has specialist skills in ornithology, protected species survey as well as the development of appropriate mitigation.

Qualifications

Education

BSc Terrestrial and Freshwater Ecology

PhD Farmland Bird Ecology

Professional Registration / Certification

CENV, MCIEEM

Current Projects

- Manston Airport, Biodiversity Lead
- Chilton Woods Delivery, Biodiversity Lead
- Ipswich Garden Suburb, Project Director
- Rainham Landfill Restoration Masterplan, Project Director
- Pitsea Landfill Restoration, Project Director
- Holehaven Creek SSSI Barge Disturbance Study, Project Director

RiverOak Strategic Partners Limited, Manston Airport Development Consent Order, Kent

Mark has led the Biodiversity work to date, assisting with Site access arrangements, developing the Site baseline survey programme and administering field survey sub-contractors and Associates. This has included coordinating all baseline surveys and reviews of all outputs and reports. As technical lead, Mark has been principal point of contact on all consultation, including with Natural England and other non-statutory consultees. He also drafted the Biodiversity chapters of the PEIRs and the ES and undertook the technical review of the Report to Inform the Appropriate Assessment (RIAA). He will lead the examination work for Biodiversity.

Experience

Project Director

Ipswich Garden Suburb, Mersea Homes CBRE SP UK III,

Wood was commissioned by Mersea Homes on behalf of CBRE SPUK III (No.45) to conduct ecological studies of a 50 hectare area of land (part of the Ipswich Garden Suburb) on the northern fringe of Ipswich, Suffolk. The studies were required to provide ecological information to inform an Environmental Impact Assessment for a planning application made in spring 2014. Work included a preliminary ecological assessment (extended Phase 1 habitat survey) with subsequent surveys for great crested newts, reptiles, badgers dormouse, breeding birds and bats. Following on from this Wood prepared the Biodiversity Chapter of the Environmental Statement. In addition, a Habitats Regulations Assessment screening report was prepared due to the proximity of the application site to a Special Protection Area. As Project Director, Mark was technical lead and reviewed all output plus lead in consultation with Natural England and Ipswich Borough Council (the LPA) in regard of the HRA and European protected species.

Project Director

Pitsea Landfill Restoration, Veolia, Pitsea, Essex

Mark prepared the Restoration Masterplan and subsequently the Restoration Management Plan for Veolia's waste facility at Pitsea. Since 2012 Mark has directed the annual monitoring of the restored phases of the landfill to determine that the composition of the sward establishment accords with the targeted restoration habitat type. Monitoring involves the sampling of vegetation and soil at a number of points with results compared to a series of attributes or characteristics developed in the Management Plan. Recommendations are made on the strength of the annual monitoring maintaining progress towards desired outcomes. Management techniques are agreed at review meetings involving a series of stakeholders including Natural England, Essex County Council, the RSPB, Basildon Borough Council and the Environment Agency.

HRA Technical Lead

Whitehill & Bordon Regeneration, Hampshire, DIO

Wood was commissioned to take forward the design and planning aspects of a 4,000 home new community within Whitehill & Bordon - one of the four communities selected for Eco-town status in 2008. Mark prepared the Habitats Regulations Assessment (HRA) required to assess any potential effects of the new development against the conservation objectives of nearby European designated sites. In view of the likely significant effect of the development proposals, principally from increased recreation and urban edge impacts, on the designated features of the local heathland European sites, suitable mitigation, in the form of Suitable Alternative Nature Greenspace (SANG),was required, in addition to improved access management and monitoring of the European sites. Mark was Wood's liaison on the Eco-town project HRA Working Group, which became the Natural Environment Working Group, and worked on the design of the SANGS and access management measures and monitoring.

Professional History

- Associate Director, Wood (2017 – Present)
- 2015-2017, Associate Director, Amec Foster Wheeler
- 2011-2015, Associate Director, AMEC Environment & Infrastructure UK
- 2007-2011, Associate Director, AMEC Earth & Environmental
- 2002-2007, Principal Ecologist, AERC Ltd
- 2002, Senior Ecologist, Just Ecology Ltd
- 1999-2002, Ecologist, MDL Ecology
- 1982-2002, Multiple ecological research and consultancy contracts and university lecturer, Various.

Mike Raven
Principal Consultant – HRA Lead

wood.

Summary

Years of Experience

21

Areas of Expertise

- Ornithology
- HRA
- Ecological Assessment
- Terrestrial Ecology
- EIA

Industries

- Airports
- Nuclear
- Renewables
- Defence
- Government and Agencies
- Transmission & Distribution
- Property

Professional Summary

Mike has particular expertise in the collection and interpretation of ornithological survey data relating to large proposed development sites (including for DCO applications for nuclear new build, renewable energy and aviation industries), for which he has prepared technical reports and ornithological chapters/text for inclusion in Environmental Statements.

Mike has also undertaken Habitat Regulations Assessments (HRA) for a proposed airport and residential developments, and managed a number of projects for proposed wind farm sites, mixed-use residential development and landfill restoration that have involved a wide range of ecological survey work and liaison with consultees such as Natural England and RSPB. This work is supported by his in-depth knowledge of avian ecology, fieldwork design, population trends and distribution.

Mike has a wide range of other ecological experience including managing and undertaking extended Phase 1 habitat surveys, and surveys for reptiles, bats, water vole, badgers and great crested newt.

Qualifications

Education

BSc (Hons), Environmental Protection, University of Surrey

Professional Registration / Certification

Chartered Institute of Ecology and Environmental Management - Member

Publications / Presentations

Raven, M.J. & Noble, D.G. (2006). The Breeding Bird Survey 2005. BTO Research Report 439. British Trust for Ornithology, Thetford.

Experience

HRA Lead

Manston Airport Development Consent Order, RiverOak Strategic Partners Limited, Kent

Mike is the lead for the Habitat Regulations Assessment (HRA) for the proposed re-opening of Manston Airport, for which he has prepared an HRA Report to inform an Appropriate Assessment (RIAA) to support the DCO application. This report covers the potential effects of air quality, water runoff and noise, particularly in relation to disturbance to the qualifying bird species of the Thanet Coast and Sandwich Bay SPA/ Ramsar site, and the effects of air quality on the sand dune habitats of the Sandwich Bay SAC.

Appendix G.1.10

Mike Raven
Principal Consultant – HRA Lead

wood.

Experience

Ornithological Consultant

Heathrow Airports Limited, Heathrow, London

Mike has managed a team of surveyors to undertake a programme of waterbird surveys from 2014-18 the results of which will inform the EIA and HRA for the proposed expansion of Heathrow Airport. Mike has also been the lead author to the technical report summarising the results of these surveys, focussing on the importance of the waterbodies close to the proposed development to waterfowl, in relation to the South West London Waterbodies SPA.

HRA Lead

Taylor Wimpey & Barratt and David Wilson Homes, Rushden East SUE, Rushden, Northamptonshire

Mike is the HRA lead for a large (c.2,500 units) proposed mixed-use (primarily residential) development in Northamptonshire. Mike has designed and undertaken bird disturbance studies, liaised with Natural England, and is writing the HRA Report to Inform Appropriate Assessment for the project, based on this work. The HRA is focussed on assessing the effects of increased recreational disturbance on waterbirds using the SPA.

Project Manager

Vattenfall Wind Power Ltd , Nocton Fen Wind Farm, Lincoln, UK

Mike was the project manager for a large proposed onshore wind farm (which qualified as a Nationally Significant Infrastructure Project) at Nocton in Lincolnshire. Mike was responsible for organising a programme of winter and breeding season bird surveys undertaken by himself and a team of associate bird surveyors from 2012-14. The surveys have included vantage point surveys, walkover surveys and specific surveys for breeding wildfowl and marsh harriers. Mike also undertook detailed consultation on the bird issues and potential mitigation for the scheme with RSPB and Natural England, and was lead contributor to the baseline ornithology reports and Ornithology Environmental Chapter for the Scheme.

Ornithology Task Manager

EDF Development Company, Sizewell Ecological Studies, UK

Mike was the lead ornithologist in the design and organisation of a detailed programme of baseline bird survey work at the proposed site for new nuclear build at Sizewell in Suffolk from 2009-12. The programme included generic surveys for breeding and wintering birds, and more species-specific surveys for terns, divers, black redstart, nightjar, bittern and harriers. Mike has been involved with the design of the survey programme through discussion and meetings with consultees and has organised a team of staff and freelance contract surveyors to complete the work as well as undertaking some of the surveys himself. Mike has presented the results from the work in the form of a number of stand-alone baseline reports.

Professional History

- Wood (2007 – Present) Principal Consultant Ecologist
- British Trust for Ornithology (1999 – 2007) BTO/JNCC/RSPB Breeding Bird Survey, National Organiser
- RSPB (1998 – 1999) Visitor Centre Assistant at Pulborough Brookes RSPB Nature Reserve, Sussex
- Kvismere Bird Ringing Station, Sweden (1997) Bird Ringing Warden

Ben Fretwell
Associate Director – Hydrogeology & Flood Risk

wood.

Summary

Years of Experience

25 years

Areas of Expertise

- Groundwater quality
- Groundwater remediation
- Quantitative risk assessment
- Groundwater resources

Types of Facilities

- Production Facilities
- Power Plants
- Refineries
- Water Treating and Injection

Industries

- Transport
- Government
- Oil and Gas
- Industry
- Property
- Waste Management

Professional Summary

Ben is a highly experienced hydrogeologist. He specialises in understanding the behaviour of contaminants in groundwater through: investigation and monitoring; the development of robust conceptual models and modelling of contaminant transport; detailed quantitative risk assessment; and groundwater remediation. His experience includes hydrogeological site characterisation for a wide range of projects across a range of scales.

Ben was principal author or co-author of European Commission, Environment Agency, CL:AIRE UK Water Industry Research, Irish Environmental Protection Agency and Nuclear Decommissioning Authority guidance documents, including guidance on permeable reactive barriers, groundwater monitoring point design and the use of hydrocarbon analysis in hydrogeological risk assessment. Ben has acted as project manager or project director on many projects.

Ben has undertaken successful Environmental Impact Assessments on a number of large projects including: airports; open pit mines; built development; and integrated waste facilities.

Qualifications

Education

1987, BSc (Hons), Geology, University of Newcastle Upon Tyne

1991, MSc, Engineering Geology, University of Durham

1999, PhD, Hydrogeology, University of London

Professional Registration / Certification

Geological Society - Fellow

Geological Society - Chartered Geologist

Sobra – accredited (controlled waters)

Selected Publications

Brown, D, Fretwell, B, Harries, N, Johnstone, K, Smith J, Sweeney, R and Thomas L. 2017. Petroleum Hydrocarbons in Groundwater: Guidance on assessing petroleum hydrocarbons using existing hydrogeological risk assessment methodologies. CL:AIRE, London. ISBN 978-1-905046-31-7.

Software

Aquachem, AquiferWin32, ArcGIS

Languages

Spanish

Appendix G.1.10

Current Projects

Technical lead – flood risk assessment, Technical Reviewer – hydrogeological risk assessment

Manston Airport Redevelopment Development Consent Order (DCO), Kent, UK, RiverOak Strategic Partners

Ben prepared the flood risk assessment (FRA) to support the freshwater chapter of the Environmental Statement; supported consultations with environmental regulators; and was technical reviewer for a hydrogeological impact assessment (HIA). Manston Airport lies in a sensitive hydrogeological setting, over a Principal Aquifer and within a source protection zone for a public water supply (PWS). An adit connects the PWS to the aquifer beneath the runway. The potential for rapid movement of contamination into aquifer and the PWS was a major concern for regulators that needed to be addressed in the FRA, HRA and drainage strategy.

Technical lead - groundwater

Bristol Airport Environmental Statement for expansion to 12 mppa

Bristol Airport plan further development to support growth to 12 million passengers per annum (mppa). The Environmental Statement (ES) supports this development. Bristol Airport overlies a Principal Aquifer and is within a Source Protection Zone (SPZ) for a public water supply. Groundwater beneath the site is, therefore, sensitive. To address potential impacts on groundwater, the ES included a separate groundwater chapter, which Ben wrote. The work built on Ben's earlier work on the ES for expansion to 10 mppa, which was granted in 2010.

Technical reviewer – hydrogeological risk assessment

North London Heat and Power Project Development Consent Order (DCO), London, UK, North London Waste Authority (NLWA)

The Project consists of an Energy Recovery Facility (ERF) to serve North London. To support the DCO application, an Environmental Impact Assessment (EIA) was undertaken. A hydrogeological risk assessment was provided to support the EIA. The project will change groundwater levels and flow directions in the shallow Kempton Park Gravels due to the construction of an impermeable bunker for storage of waste. In addition, the risk assessment was required to demonstrate that underlying sensitive aquifers would continue to be protected by the low permeability London Clay. It was also necessary to demonstrate that the potential for foundation piles to create new pathways for contaminant migration from the surface to sensitive deep aquifers could be mitigated.

Professional History

- 2014, Associate Director, Wood Environment & Infrastructure Solutions UK (formerly Wood)
- 2005, Principal Consultant, Wood Environment & Infrastructure UK (formerly Entec UK Ltd.)
- 2001, Senior Hydrogeologist, Entec UK Ltd
- 1998, Consultant Hydrogeologist, Entec UK Ltd
- 1995, Senior Engineer, Delft Geotechnics
- 1991, Engineering Geologist, Golder Associates
- 1989, Geologist, Wardell Armstrong

Liz Buchanan
Associate Director, Water Management

wood.

Summary

Years of Experience

15

Sectors

- Transport and infrastructure
- Nuclear
- Transmission and distribution
- Renewables
- Commercial and industrial
- Environmental regulation
- Water

Areas of Expertise

- Environmental impact assessment (EIA) for the water environment
- Water Framework Directive
- Water resources policy and regulation

Professional Summary

Liz is a hydrologist and hydrogeologist with 15 years' experience in water resources assessment, environmental impact assessment (EIA), Water Framework Directive assessment (WFD) and strategic environmental assessment.

Liz has been lead author or technical reviewer of EIAs for a variety of sites throughout the British Isles. Specific projects have included windfarms, grid connection corridors, nuclear power stations, urban regeneration areas and transport infrastructure. This has involved the development of mitigation measures for the protection of a wide variety of surface and groundwater environments including heavily urbanised environments, salmonid spawning streams in Scotland, groundwater source protection zones and Internal Drainage Board controlled areas.

In addition to her EIA work Liz also has experience in catchment management, water resources assessment and WFD assessment. She has managed a suite of work under these headings for a number of clients including water companies, the Environment Agency (EA), Department for Environment, Food and Rural Affairs (DEFRA) and the European Commission (EC). Work has included the authoring of environmental monitoring requirements for water company Drought Orders, work on developing the Source Apportionment GIS (SAGIS) which is a spatially distributed water quality assessment tool, development of excel/GIS systems for water resources regulation and WFD compliance for the Environment Agency, advising the Environment Agency and Defra on the future of water resources regulation and the reform of water abstraction licensing and managing a project for the EC on the Integrated Assessments of the 2015 WFD River Basin Management Plans to understand WFD implementation in all Member States.

Liz is also a project manager on a wide variety of projects with a value between £2K-£1million and has an APMP qualification in project management, which is equivalent to an IPMA Level D.

Qualifications

Education

2000, MSci, Physics, University of Durham

2002, MSc, Water Management, Cranfield University

2007, APMP Examination, Project Management, Association for Project Management

2011, PG Cert (Development Management), Open University

Professional History

- Wood (2002 – Present) – Assistant Consultant/ Consultant/ Principal Consultant/ Associate Director

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Liz Buchanan
Associate Director, Water Management

wood.

Selected Experience

RiverOak Strategic Partners, Manston Airport (DCO), UK – Water Environment EIA

Liz was the EIA water chapter (surface and groundwater) lead author for the Manston Airport DCO application, and also co-wrote the supporting WFD summary report. Liz was involved in this project from Scoping stage to DCO submission to PINS in 2018.

Heathrow Airport Limited, Heathrow Expansion Project (DCO), UK - Water Environment EIA

Liz is the water environment (surface and groundwater) EIA lead for the 3rd runway DCO application at Heathrow. This project is in the early stages of the DCO process and the scoping report was sent to PINS in May 2018. Liz was co-author of the scoping report, has lead a number of different aspects of stakeholder engagement with the Environment Agency, local NGOs and local authorities. She also represented Heathrow during the public consultation events in February/March 2018. Her role also includes the oversight of the Water Framework Directive (WFD) assessment and co-ordination of water teams interactions with the engineers and master planners responsible for the final design.

NuGeneration Ltd, Moorside Nuclear Power Station (DCO), Cumbria, UK – Hydrology and Flood Risk EIA

Liz was the surface water EIA lead for the post-PEIR surface water assessment work at Moorside and led on the production of the surface water baseline report and other aspects of the surface water EIA assessment until the project was put on hold. This role also included engagement with the Environment Agency, local councils and other key stakeholders on the progression of the surface water assessment.

National Grid, North Wales Connection (DCO), Gwynedd, UK – Surface Water EIA

Liz is the Wood Project Director and EIA technical reviewer for the surface water EIA chapter, FRA and WFD Assessment for the National Grid connection from the proposed Wylfa Newydd nuclear power station. The connection stretches across the Isle of Anglesey to connect with National Grid infrastructure on the Welsh mainland. Liz has been involved with the project since the PEIR stage and the project is now in the final stages of preparation for DCO submission.

Vattenfall, Thanet Offshore Windfarm Connection (DCO), UK – Land quality and water environment EIA

Liz was the water environment technical reviewer for the scoping and PEIR stages of the Thanet Offshore Windfarm Extension grid connection, which constituted the cable from landfall to grid connection at the Richborough substation. The PEIR was submitted in November 2017.

NNB Genco Ltd., Sizewell C, Suffolk, UK – Environmental Permitting for Replacement Wetland Habitat Creation

Liz was responsible for the water environment permitting applications for new wetland extension to the Sizewell Marshes Site of Special Scientific Interest (SSSI), adjacent to Sizewell nuclear power station. This constituted the development of 67ha of new wetland habitat required to replace areas of the SSSI that could be lost as a consequence of the construction of Sizewell C. The role included the authoring of the permitting applications for new abstractions and discharges associated with the construction and operation of the site and meeting with the Environment Agency to agree the permit applications. Planning consent was granted in March 2015, and construction of the wetland is now complete.

Appendix G.1.10

Dr Tim Haines
Technical Director - Hydrogeology

wood.

Summary

Years of Experience: 34

Areas of Expertise:

- Water resource assessments
- Hydrogeological Impact assessments
- EIA
- Groundwater control
- Mining hydrogeology
- Hydrochemistry and water quality
- Groundwater protection
- Aquifer Storage and Recovery

Experience in the following industries:

- Major infrastructure developments
- Extractive industry (quarrying/coal)
- Environment Agency
- Water utilities
- International water resources
- Nuclear power
- Food and drinks industry

Professional Summary

A hydrogeologist with worldwide experience including water resource management and protection, abstraction licensing, water engineering and groundwater control for infrastructure and engineering projects.

His current work includes providing expert advice to the UK quarrying industry relating to planning developments and EIA's and including support on their response to recent (2017) changes to abstraction license regulations. He is part of the team delivering a ES for a DCO development in Kent and provides a review role on aspects of the current Heathrow development.

Tim has proven management experience in successfully delivering multi-disciplinary projects linked to the collation and assessment of hydrogeological and engineering data, including regional studies for major infrastructure developments, studies in support of planning developments, groundwater protection, and hydro-ecological assessments.

He recently successfully delivered a major water resource project in Qatar managing inputs from drilling and geophysical contractors, chemists, design engineers and EIA specialists.

Qualifications

Education

1984, PhD, Geological Science, University of Birmingham, UK

1980, BSc (Hons), Geology, University of Bristol, UK

Professional Registrations

Geological Society – Fellow

Geological Society - Chartered Geologist

Chartered Institution of Water and Environmental Management - Member

International Association of Hydrogeologists – Member (past UK Committer Member)

Institute of Quarrying – Member

Recent Project Experience

RiverOak Strategic Partners Limited, Manston Airport Development Consent Order, Kent
Expert Advice – ongoing

Tim is the lead hydrogeological advisor undertaking the hydrogeological impact assessment of the development and operational phases of the airport. He prepared the hydrogeological impact assessment work relating to the potential effects off the development on the underlying Chalk aquifer system and nearby public water supply abstractions. The assessment was undertaken following consultation with the Environment Agency and Southern Water.

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Derbyshire CC/High Peak Borough Council -ongoing

Technical advisor to Derbyshire CC and High Peak Borough Council who are owners of a Grade 1 building in Buxton which is being re-developed as a thermal spa hotel. This £35m Heritage Lottery Funded project requires close liaison between the developer and the owners and Nestle who bottle the Buxton Mineral Water to ensure the thermal groundwater resources are protected and safeguarded for future use.

Nexperia Abstraction Licence support - ongoing

Nexperia have a borehole supply for their manufacturing facility and Wood were commissioned to undertake the necessary work and liaison with the Environment Agency in order to obtain an increase in their abstraction licence required to meet growing water demand. This work entailed undertaking the required pumping tests and completing the application process. The increase in the license amount was approved. Subsequently we are advising Nexperia on aspects of water security, borehole engineering and future changes to their abstraction licence.

Hanson UK and Aggregate Industries: Technical Advice to UK Quarrying Industry – ongoing

Tim is providing advice on how they meet the requirements of The Water Resources (Transitional Provisions) Regulations 2017 whereby all they dewatering operation require a transfer or full licence. This Act amends the 1991 Water Resources Act whereby all previous exempt abstractors will require an abstraction licence (New Authorisation) to continue to lawfully abstract water.

He also provides hydrogeological advice and direction to a range of projects addressing the requirements of the quarrying industry to ensure their dewatering activities do not have an adverse effect on the groundwater environment. Work for Hanson's includes at their flagship limestone quarry and at an important sand quarry in Cheshire. Work for Aggregate Industries is ongoing at three major limestone quarries including ROMP reviews and at two proposed new sand quarries in the south west of England with accompanying input to the planning application and EIA.

Highland Spring, water security - ongoing

Tim is the project director for the ongoing technical support we provide to Highland Spring one of the UK's largest producers of bottle water. Advice is on the development and management of their wellfield the design and construction of new wells and long-term planning to ensure wellfield growth together with obtaining the relevant abstraction license from SEPA is in line with growth forecasts.

International Experience

Tim has worked on a range of water resource projects globally over the last thirty years. He has worked in several countries in the Middle East with recent work in Qatar and Saud Arabia. The latter (2016/17) involved assessing the risk to groundwater resources for a proposed new waste facility for Al-Riyadh Development Corporation. Other work for the food and drink industry has involved work in China and North Korea and technical advice to water companies has led to work across Europe and in Brazil.

Professional History

1993 – date - Technical Director, Wood Environment & Infrastructure Solutions (UK) Ltd

1990 -1992 – Company Hydrogeologist Tarmac Quarry Products Ltd

1987-1990, Principal Hydrogeologist, Hydrotechnica Ltd

1984 -1986, Hydrogeologist, Sir M MacDonald and Partners Oman

Dr John Mabbitt
Associate Director - Historic Environment

wood.

Summary

Years of Experience

23

Areas of Expertise

- Archaeology
- Historic Environment
- Environmental impact Appraisal

Industries

- Aviation
- Renewables
- Water and Utilities
- Nuclear
- Property
- Regeneration
- Waste

Professional Summary

John has substantial experience of professional historic environment practice and project management on a wide variety of projects. He has particular expertise in Environmental Impact Assessment, supported by extensive experience of archaeological fieldwork management, buildings recording and documentary research. He has experience of working across the UK and Ireland. John manages historic environment support and multidisciplinary projects, providing advice to a wide variety of clients within the public and private sectors and managing archaeological services on behalf of clients, with an established record of completion to time and budget. He has developed effective working relationships with regulators and archaeological contractors across the UK. John has particular experience of the production of EIAs for planning and DCO applications. John's project experience includes involvement in property, industrial, urban regeneration and major infrastructure development schemes. He was project manager for the historic environment support to the Richborough Connection and Sizewell C DCO application, has been historic environment lead on other DCO applications including Manston Airport and has provided support to LPAs on DCO consultations for York Potash and Wylfa Newydd.

Qualifications

Education

PhD Historical Archaeology, Newcastle University (2012)

MA Field Archaeology, University of York (1999)

BA (Hons) Ancient and Modern History, Oxford University (1996)

Professional Registration / Certification

Chartered Institute for Archaeologists, Member (2007)

Technical Lead

Manston Airport, RiverOak Strategic Partners, Kent, England

John is historic environment technical lead to the production of inputs to the Manston Airport DCO Application and Examination. John advised on and reviewed the production of a detailed desk-based assessment and Environmental Statement chapter. In addition to considering disturbance of archaeological remains and change to setting arising from visibility of the proposed development, the ES also used the Historic England Aviation Noise Metric to understanding change to setting of heritage assets, particularly listed buildings in nearby conservation areas at St Nicholas at Wade, Ramsgate, Manston, Minster and Acol.

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Dr John Mabbitt
Associate Director - Historic Environment

Experience

Acting Technical Lead

Heathrow Third Runway, Heathrow Airport Limited, England

John acted as historic environment technical lead to the initial delivery of the Heathrow Third Runway PEIR. He developed the plan for the deployment of a technical team comprising staff from Wood and Mott MacDonald to produce technical studies supporting the development of the EIA baseline and managed the delivery of these inputs in the absence of the identified historic environment lead.

Technical Lead and Project Manager

Richborough Connection Project, National Grid, Kent, England

John was project manager and technical lead for historic environment support to the DCO application and examination for a 400kV OHL, leading this element of the work from options appraisal stage in October 2013, through EIA and examination in summer 2016. John developed an assessment methodology to ensure the provision of robust advice and information and led consultation with LPA officers and Historic England, ensuring that archaeological and built heritage concerns were identified and addressed. John was principal author of the PEIR and ES, and was lead response provider through the DCO examination.

Following consent, John was lead Archaeological Clerk of Works for the delivery phase, monitoring the main contractor's specialist archaeologist for compliance with the agreed written scheme of investigation.

Technical Lead and Project Manager

Sizewell C Stage 3 Consultation, EDF Energy – New-Build Nuclear, Suffolk, England

John was project manager and technical lead for archaeology and cultural heritage elements of the Stage 3 consultation for the construction of the proposed Sizewell C Nuclear Power Station, having led desk-based research and settings assessment for the Stage 2 consultation. At Stage 3, John led the production of further consultation and baseline documents and carried out consultation with English Heritage, Suffolk County Council, Waveney District Council and Suffolk Coastal District Council.

Technical Lead

Thanet Offshore extension wind farm, Vattenfall, Thanet, Kent

John was historic environment lead for the production of the PEIR for the Thanet Offshore extension wind farm. John reviewed the PEIR chapter and supporting desk-based assessment and led consultation with English Heritage, Kent County Council and Thanet District Council.

Professional History

• Wood (2008 – Present)	Associate Director
• Tyne and Wear Museums (1999-2007)	Keeper of Field Archaeology
• Colchester Archaeological Trust (1999)	Site Assistant
• Carlisle Archaeology (1998-1999)	Archaeologist
• Field Archaeology Specialists (1997)	Archaeologist
• Colchester Archaeological Trust (1996-1997)	Site Assistant
• Oxford Archaeological Unit (1995-1996)	Site Assistant

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Barry Mitcheson
Principal Consultant

wood.

Summary

Years of Experience

20 years

Industries

- Defence
- Utilities
- Development
- Waste management
- Public Sector

Types of Facilities

- Defence
- Residential sites
- Former Gasworks
- Landfills
- Manufacturing plants
- Energy from waste facilities

Areas of Expertise

- Human Health Risk Assessment
- Environmental Chemistry
- Land quality assessment
- Remediation

Professional Summary

Barry is a principal consultant with over 20 years' experience in land quality consultancy. He has project managed and provided technical support for all aspects of land quality assessment ranging from phase 1 and 2 land quality assessments to remediation projects and has extensive knowledge and experience of all stages of contaminated land assessment as well as supporting Environmental Statement and baseline assessments under Environmental Permitting regulations. He has works for a wide range of clients including the MoD, the Environment Agency, Local Authorities, developers, contractors, lawyers and from the food and drink, chemical, transport and waste industries.

Barry's has particular expertise in environmental chemistry and detailed quantitative human health risk assessment techniques and its application to support remediation design and regulatory decision making. These have included assessment for redevelopment for housing and commercial end use to support planning and as well as assessment of existing service family accommodation and of housing estate assessment under Part 2A under Part 2A of the Environmental Protection Act. Site have included assessment of MOD airfields, firing ranges, GPSS fuel storage sites, barracks, former chemical weapons disposal sites, vehicle maintenance sites, laundries, fragrance factories, coating manufacturers, a former Coalite manufacturing plant, plating works, gas works, sewage treatment works and engineering works..

Barry has been involved in a range of industry initiatives including active participation on the steering group for the 2011 major revision to BS10175 on the Investigation of potentially contaminated sites, CIRIA VOCs handbook and the recent CIRIA Guidance on the use of plastic membranes vapour barriers. He currently chairs the SoBRA subgroup on acute risks to human health, is a member of the SoBRA subgroup on asbestos and has been appointed as one of the Tier 2 toxicologist for the Phase 2 C4SL project will develop 20 C4SLs

Qualifications

Education

1998, BA (Hons), Natural Sciences - Chemistry, University of Cambridge

1997, MSc, Pollution & Environmental Control, University of Manchester

Certifications

2015 Specialist in Land Condition (SiLC)

2016 Society of Brownfield Risk Assessment
ASoBRA Human Health and Vapour Intrusion
RSoBRA Controlled Waters and Permanent Gases

Security Clearance level

SC Clearance and WWW card

Languages

- English

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Experience

Manston Airport Development Consent Order, Kent RiverOak Strategic Partners Limited,

- Barry was a technical reviewer for the Land Quality Chapter of the Environmental Statement to support the Manston Airport Development Consent Order.

Assessment and remediation of lead in residential area in Uxbridge, Ministry of Defence

- This project initially involved site investigation and detailed quantitative risk assessment at this former firing range which is now a housing estate and informal play area. Barry Mitcheson was the project manager, human health risk assessor and main report author. The project included calibration and use of a hand held XRF to delineate the areas where elevated concentrations of lead were identified. Risk assessment was carried to produce levels to determine which areas of open space and gardens required clean-up for on-going use. These were agreed with the Local Authority and the Health Protection Agency. Barry subsequently carried out the remediation options appraisal and the detailed design. Finally Barry project managed the CQA supervision for the successful remediation of the site including attendance at site meetings and response to queries.

St Raphael's Estate Part 2A assessment and remediation, Brent Council

- Barry managed and provided technical support for the Staged Investigation and Detailed Quantitative Risk Assessment at this former sewage treatment works which is now a large housing estate. The project included detailed assessment of data for polycyclic aromatic hydrocarbon concentrations and calculated the risks to human health. Barry was also project manager the remediation options appraisal, design and tender support provided to the council. He also project managed the supervision of the remediation on behalf of the council. This included technical input during work to resolve conflicts in CQA arising from failures of source material and potential cross contamination from handling procedures when the imported material was brought to site. He oversaw validation work including validation reporting. Barry was also involved in stakeholder engagements throughout the project and reviewing leaflet and letters and attended meetings with the council, local councillors and the residents steering group.

Kenilworth Gasworks, Environment Agency

- This was a Part 2A detailed inspection of a residential housing estate built over a former gasworks. Barry was the human health risk assessor reviewing of unresolved contaminant linkages identified from the earlier phases of inspection; intrusive investigations combined with soil, and soil gas sampling;. Based on the Human Health Risk Assessment seven properties were identified to have shallow soil contamination that may present the significant potential of significant harm. Based on the assessment, the site was formally determined as "Contaminated land" by the local council.

Professional History

- Wood, Principal Consultant (2015 – Present)
- Enviros / SKM Enviros / SKM / Jacobs, Consultant to Principal Consultant (1998 – 2015)
- BNFL Environmental, Risk Section, Warrington (1997 – 1998)

Ian Gates
Associate Director Landscape Architect

Summary

Years of Experience

29

Areas of Expertise

- Landscape and Visual Impact Assessment (LVIA)
- Townscape and Visual Impact Assessment (TVIA)
- Landscape Sensitivity and Capacity Studies (LSCA)
- Landscape design

Industries

- Transport
- Power
- Residential
- Industry
- Waste
- Minerals

Professional Summary

Ian is a chartered landscape architect (CMLI) with experience in landscape planning and landscape design. Since 2000 he has focused upon landscape and visual impact assessment (LVIA) and has undertaken over 250 appraisals and assessments, using bespoke methodologies based upon current best practice.

These appraisals and assessments have been for a wide variety of developments including airports, residential developments, power stations, pipelines, hospitals, windfarms, business parks, infrastructure improvements, quarrying, industrial developments, landfills, mineral extraction and overhead power lines. These LVIAs have ranged in location from AONBs to major cities with the latter frequently requiring townscape assessments to be undertaken.

He leads Wood's landscape team in Shrewsbury. He also frequently provides technical reviews for LVIAs produced by other Wood landscape architects. He has experience in undertaking landscape character assessments and landscape sensitivity and capacity studies. He acted as an expert witness at informal public hearings and public inquiries.

Qualifications

Education

M. LD, Landscape Architecture, Manchester University.

BA (Hons), Geography, University of Southampton

Professional Registration / Certification

Landscape Institute - Chartered Member

Current Project

Technical Specialist (LVIA)

Isle of Anglesey County Council, Wylfa Newydd Nuclear Power Station, Anglesey

Ian has been providing advice to IACC since early 2018 on visual matters for the ongoing DCO application for a new nuclear power station on the north coast of Anglesey. This role has required review of the LVIA and a wider range of supporting documentation submitted by the developer on the power station site and several associated development sites.

Outputs have included commentaries on the visual impacts for each site; inputs on visual issues into a series of Local Impact Reports; responding to questions provided by the Examining Authority; liaison with the developer’s technical specialists; and advising IACC on additional on-site and off-site mitigation measures.

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Selected Experience

Technical Specialist (LVIA)

Bristol Airport 12 million passengers per annum development, Bristol Airport Limited (BAL), Somerset

Building upon a long-standing role providing LVIA support to BAL, Ian undertook scoping, liaison with consultees and wrote the LVIA for this complex proposal consisting of a number of dispersed individual developments at a major regional airport. Key issues included proximity to an AONB; working with the ecological consultants and BAL's operations team to develop a mitigation masterplan, taking into account a variety of future baseline scenarios and working with the architecture consultants to provide photomontage visualisations.

Technical Specialist (LVIA)

Manston Airport Development Consent Order, RiverOak Strategic Partners Ltd, Kent

Ian undertook the scoping study for the LVIA, including initial desktop surveys and a day and night-time site visit, and undertook consultations including for the selection of viewpoints. Subsequently he contributed to the PEIR and the complex LVIA. The compilation of the LVIA involved extensive liaison with the design engineers including development of the visualisations and the landscape masterplan.

Technical Specialist and Expert Witness (LVIA)

Mid Wales Wind Farms Conjoined Public Inquiry, Vattenfall, Powys

As the author of the LVIA for Llanbadarn Fynydd Wind Farm Ian was appointed by Vattenfall as their LVIA expert witness this Public Inquiry at which five wind farm proposals were considered. The public inquiry was the largest public inquiry ever held in Wales. Landscape and visual issues were crucial. Ian worked in tandem with the four other landscape expert witnesses upon the production of joint SEI information and to agree overarching methodological approaches. Llanbadarn Fynydd was the only one of the wind farms completely opposed by Powys County Council. Hence evidence had to be especially robust as it was closely examined by Powys County Council's barrister and LVIA witness as well as by highly motivated opposition groups at Session 1 concerning LVIA issues specific to Llanbadarn Fynydd and also at Session 4 upon cumulative LVIA issues.

Technical Specialist and Expert Witness (LVIA)

Land at Barrow Farm, Chippenham, Robert Hitchens Group, Wiltshire

The Barrow Farm development was a mixed use greenfield site on the edge of Chippenham. Having technically reviewed the initial LVIA and authored several amendments, Ian was engaged for the public inquiry prompted by the non-determination of the application. Landscape and visual reasons were one of the main putative reasons for refusal and as such were a key issue for both the planning authority and the Rule 6 party (local residents' groups). Ian was involved in meetings to secure a Statement of Common Ground, conferences with the client's barrister resulting in the production of a Proof of Evidence and various briefing notes prior to presenting evidence and being cross examined. Key LVIA considerations were tranquillity, landscape history and landscape capacity.

Professional History

- Wood (1995 – Present) Associate Director Landscape Architect
- Freelance Landscape Architect (1992 – 1995)
- Appleton Deeley Partnership (1989 – 1992) Landscape Architect

Steve Wright
Associate Director, Landscape

wood.

Summary

Years of Experience

22

Industries

- Transport
- Power generation
- Power transmission and distribution
- Industrial/commercial

Areas of Expertise

- Opportunities and constraints assessment
- Routeing and siting studies
- Co-ordination of iterative design and assessment processes
- Landscape and Visual Impact Assessment (LVIA)
- Cumulative Impact Assessment
- Visualisation requirements

Professional Summary

Steve is an Associate Director with over 20 years' experience in environmental consultancy. He is responsible for the management and co-ordination of a wide range of landscape inputs to projects, including feasibility studies, opportunity and constraints analysis, routeing and siting studies, mitigation design and Landscape and Visual Impact Assessment (LVIA).

His experience has been gained across a range medium and large scale developments across a number of sectors, particularly power generation, distribution and transmission. Since 2014 he has developed considerable expertise in nuclear new build as a result of his involvement in the Moorside Nuclear Power Station. During the same period, he has also acquired substantial experience in relation to airport redevelopment and expansion.

Successful stakeholder engagement has played a major role in achieving positive outcomes for clients in the vast majority of the projects Steve has managed or contributed to. This has included contributions to project screening and scoping, and to formal consultation documents (e.g. Preliminary Environmental Information Reports) for DCO. He has also taken part in technical working groups (involving both statutory and non-statutory consultees) and public exhibitions. He has considerable experience of engagement with Local Planning Authorities (including National Parks), AONB management partnerships, Natural England, Natural Resources Wales and other specific interest groups (e.g. National Trust).

Qualifications

Education

2010, BA (Hons), Landscape Architecture, Birmingham City University

Software / Skills

- GIS analysis, Zones of Theoretical Visibility, Visualisation

Experience

Technical specialist (LVIA coordinator)

RiverOak Strategic Partners, Manston Airport, Kent, UK

Steve coordinated landscape and visual inputs to Stage 1 and 2 Consultation PEIRs and ES LVIA to support a DCO submission for the reopening of the airport. The DCO was submitted in 2018.

Technical specialist (Recreation and Amenity)

Heathrow Expansion Project, Heathrow Airport Limited, London, UK

Steve is jointly responsible for the coordination and delivery of Wood's inputs to the Recreation and Amenity Impact Assessment and Open Space Assessment being undertaken as part of the Heathrow Expansion Project. This has entailed close liaison with the masterplanning workstream in order to inform design

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decisions and identify appropriate mitigation measures. Preliminary Environmental Information to support the impact assessment is currently in preparation.

Technical specialist (LVIA coordinator)

Nugeneration Ltd, Moorside Nuclear Power Station, Cumbria, UK

Wood provided a range of landscape and visual services to inform and support the emerging plans for a new nuclear power station close to the existing Sellafield site. These included consultation with statutory and non-statutory bodies, developing the scope of the EIA, inputs to landscape and mitigation design and baseline data collation. Steve was project manager for all aspects of the landscape and visual work, responsible for programme, staff and budget management. This included deploying multiple survey teams (onshore and offshore) drawn from several of our UK offices and coordinating the various strands of work including design inputs to the main site and associated developments. Steve was responsible for producing and submitting LVIA inputs to the Preliminary Environmental Information Report (PEIR), part of the Development Consent Order (DCO) Stage 2 Consultation (May-July 2016). He coordinated the landscape mitigation measures in the emerging project design, in close liaison with planners, engineers, landscape designers, architects and masterplanners to ensure that emerging designs reflected the requirements of numerous, sometimes conflicting, design imperatives. The schedule for the submission of a draft DCO for the Moorside Project is currently under development.

Technical specialist (Landscape and Visual)

National Grid, Review of Hinkley Point C Connection Options, Somerset, UK

Following a request for information from Ofgem, Wood was appointed to undertake a review of the options work completed for the Hinkley Point C Grid Connection project and specifically to review a transmission route option that had been 'parked' following strategic optioneering. Wood conducted a high-level, strategic environmental appraisal, Route Corridor Study (RCS) for the previously 'parked' option to provide National Grid with an understanding of the key environmental constraints and opportunities associated with this option and to verify the decision to park this option. The presence of locally and nationally designated landscapes along the route was a key consideration. Steve was the landscape and visual technical lead responsible for assessing potential landscape and visual effects using National Grid's Optional Appraisal process. In addition, he was responsible for several overarching tasks including the definition of the study area and draft route corridors and the drafting of the overall, multidisciplinary conclusions.

Technical specialist (Landscape and Visual)

National Grid, Methodologies for Landscape & Visual Strategic Options Appraisal

Steve co-authored the landscape and visual methodologies intended to be used by National Grid as part of its process of Strategic Options Appraisal of new high-voltage electricity transmission connections. The methodologies apply to strategic connections options that have already passed technical and financial filters and enable a high-level appraisal of the landscape and visual impacts likely to be associated with connection options in different geographical areas and employing various technologies. The methodologies drew upon Steve's previous experience of transmission and distribution routeing as well as emerging best practice.

Professional History

- Wood (2003 – Present)
- Self-employed (2002 – 2003)
- Enviros Ltd (1996 - 2002)

John Cookson
Principal Consultant – Noise and Vibration

wood.

Summary

Years of Experience

11

Areas of Expertise

- Noise & Vibration EIAs
- Aviation
- Sound propagation modelling
- Mitigation design

Professional Summary

John Cookson is an environmental consultant who has worked in the aviation sector for over 11-years. He is a member of the Institute of Acoustics (IoA) and provides technical support and advice to military and commercial airports in the UK and Europe. He has valuable experience of working for an airport operator and he has gained an appreciation of the numerous airport activities and stakeholders.

John's key expertise is in aircraft noise modelling and impact assessment. He has worked on a number of high profile projects including airspace change proposals, airport expansions and planning condition addendums. His experience in the aviation industry has also included a number of other environmental disciplines, including emission inventories and carbon footprinting.

Qualifications

Education

2007, BSc (Hons), Human Geography, Manchester Metropolitan University

2010, PgDip, Institute of Acoustics Diploma in Acoustics & Noise Control, University of Salford

Professional Registration / Certification

Institute of Environmental Management and Assessment (IEMA) – Practitioner (PIEMA)

Institute of Acoustics (IoA) - Corporate Member (MIOA)

Current Project

RiverOak Strategic Partners Limited, Manston Airport Development Consent Order, Kent

John has been working with RiverOak Strategic Partners Limited on the Manston Airport Development Consent Order (DCO) since 2016, including contributing to the relevant noise chapters for the Scoping Report, PEIR 1, PEIR 2 and DCO Environmental Statement. As part of the project, John has undertaken aircraft noise modelling and provided advice to the Client on the development of a Noise Strategy, including the introduction of noise mitigation, operational restrictions and noise abatement procedures.

John Cookson
Principal Consultant – Noise and Vibration

Experience

Project Manager
Noise Consultancy Services in Relation to Dublin Airport Second Runway Application, Fingal County Council

John has provided support to Fingal County Council in its role as Noise Regulator for Dublin Airport Authorities Second Runway Application, including review of and recommendations for a number of noise conditions, including Schools Noise Insulation Scheme, Dwelling Insulation Scheme, Voluntary Purchase Scheme and Engine Testing.

Noise Technical Lead
Section 73 Noise Condition Addendum, London Luton Airport

John is leading the noise input for the assessment of aircraft noise with regards to a Section 73 addendum to the airport's 2012 airport expansion Environmental Statement

Integrated Design Team Member
Heathrow Expansion Project, Heathrow Airport

John is working as part of the noise team providing support to the Heathrow Expansion Project. His work to date has included modelling of the runway and airspace options and noise abatement procedures. John has also represented the airport during public consultation and outreach events.

Project Manager
CAP 725 Airspace Change Proposal, Leeds Bradford Airport

John was project manager and responsible for the environmental assessments required by CAP725 in support of Leeds Bradford's proposed changes to airspace. As part of the work, a validated aircraft noise model was created, and a number of future airspace scenarios were simulated.

Noise Technical Lead
The Environmental Noise Directive Round 3 Noise Mapping, DAERA

John undertook noise mapping for a number of UK airports as part of the Round 3 Environmental Noise Directive, including Belfast International Airport and Belfast City Airport.

Professional History

- Wood (2017 – Present) Principal Consultant
- Wood (2014 – 2017) Senior Consultant
- Ricardo-AEA (2012 – 2014) Senior Technical Consultant - Aviation
- Manchester Airport (2007 - 2012) Environment Advisor

Oliver Bewes
Associate Director – Noise and Vibration Lead

wood.

Summary

Years of Experience

16

Office of Employment

London

Industries

- Major infrastructure DCO/EIA
- Transportation

Areas of Expertise

- Noise & vibration Assessment
- Noise & vibration mitigation design
- Noise & vibration policy
- Public Inquiries & Hearings

Languages

- English

Software

- Microsoft Office Applications
- 3-dimensional noise modelling;
- Signal processing
- Geographical Information Systems (GIS)

Professional Summary

Oliver is an Associate Director with more than 15 years of experience working in the field of noise and vibration control. He is Operational Lead of the Wood E&IS noise and vibration team. Oliver is a specialist in the control of noise and vibration from infrastructure and has experience of the planning, design and implementation phases of major aviation, road and rail schemes. He has worked in multidisciplinary design teams delivering schemes such as Heathrow, Manston Airport, High Speed 2, Crossrail and Thameslink. He has undertaken noise mitigation design and led noise and vibration measurement campaigns on projects in the UK, Europe, US, Scandinavia and Asia. He has experience preparing environmental impact assessments for major DCO aviation, road and rail schemes as well as new developments close to existing noise sources. He has represented promotors and stakeholders and prepared expert evidence during the Transport and Works Act Order (TWAO) process. In 2014 Oliver was awarded the Acoustics and Noise Consultants prize for excellence in transportation noise control for work related to the prediction of groundborne noise and vibration from high speed railways.

Qualifications

Education

2005, Engineering Doctorate, Transport Infrastructure Engineering, University of Southampton

2001, BEng, Acoustical Engineering, University of Southampton

Registrations / Certifications / Licenses

Chartered Engineer (Institute of Acoustics)

Member of the Institute of Acoustics

Current Project

Noise and vibration Lead

River Oak Service Partners, Manston Airport DCO Application

Oliver is a noise and vibration specialist for the Development Consent Order (DCO) in relation to the reopening of Manston Airport as a major freight hub. Oliver is the author of the noise and vibration chapter for the environmental statement. He is responsible for ensuring the quality of the assessment by reviewing and supervising the technical work undertaken to predict aircraft noise, construction noise and noise from plant required to operate the airport. Oliver also attended all public consultation events as a noise and vibration expert.

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Oliver Bewes
Associate Director – Noise and Vibration Lead

Experience

Noise and Vibration Manager

Heathrow Airport Limited, Heathrow Expansion Project DCO Application

Oliver is working as a noise and vibration manager for the joint venture team appointed as an Integrated Design Team partner to provide a suite of services to support HAL in its application for a Development Consent Order to expand the airport. He is currently involved in optioneering exercises to support the Masterplan and is also leading the construction noise assessment work required to obtain Section 61 Consent for geotechnical investigation works on the proposed site.

Technical Author

High Speed Two Limited, Hybrid Bill Applications for Phases 1 and 2a

For HS2 Phase 1 Oliver was discipline lead responsible for delivering the routewide groundborne noise and vibration sections of the environmental statement for the section of the route that runs between London and the West Midlands. The innovative prediction methods developed during the project won the Acoustics and Noise Consultants award for transportation noise control in 2014. For Phase 2a Oliver Co-author of the noise and vibration chapters and supporting technical appendices for the section of the route will run between the West Midlands and Crewe.

Project Manager

Network Rail, Werrington Grade Separation Hybrid Bill Application

Oliver was project manager and author of noise and vibration chapter for the Werrington grade separation TWAO. Prior to the TWAO submission local residents in the vicinity of the scheme highlighted noise as their main concern. Network Rail considered noise to be a key risk to the TWAO. As a result of the robust assessment undertaken the EIA received minimal objections on the grounds of noise and key stakeholders such as Peterborough City Council did not object to the scheme.

Public Consultation

High Speed Two Limited, Public Consultation Events for Phase 2a

Oliver attended multiple public consultation events as a noise and vibration specialist at various venues across the proposed route for HS2 phase 2a.

Professional History

- 2017, Associate Director, Wood
- 2005, Acoustic consultant, Ove Arup and Partners Limited
- 2001, Research Engineer, Pandrol Railway Fastenings Limited

Colin Carter
Associate Director

Summary

Years of Experience

20

Areas of Expertise

- Socio-economic analysis
- Policy analysis
- Financial analysis

Industries

- Airports
- Government (and various regulated sectors)

Languages

English

Professional Summary

Colin has 20 years' experience providing policy, socio-economic and financial advice often related to major developments or changes in markets and regulatory controls. His work covers appraisal, environmental valuation and analysis of technical, commercial and financial feasibility. He has provided investment and market intervention studies at strategic and local levels and contributed standard assessment methodologies to government and industry. He leads the economic function at Wood and his public sector clients include the World Bank, UK central government departments, and local planning authorities.

Colin is a key member of Wood's team addressing the planning challenges in the UK's priority areas for major housing developments, with recent work in the Midlands and East London. He has recently completed a detailed assessment of borough-wide education, health and social needs supporting the submission of an application for 1,700 housing units with cumulative effects from a further 11,000 units requiring major changes to services for Nuneaton and Bedworth Borough Council. Currently, he is lead author for the socio-economic assessment for the application to re-open Manston airport in Kent. His other planning work includes expert review of EIA submissions for local authorities in Hackney and Newham, of a quarry extension in the Dartmoor National Park, and socio-economic chapters for a wind park in a sensitive area of the Scottish Highlands as well as other housing development work in the Midlands.

At Wood, Colin covers overarching strategic themes of increasing importance to strategy and planning of infrastructure. He is currently advising the Environment Agency on assessing risks to natural capital and is leading the economic valuation of natural capital impacts for London's new Heathrow airport extension. He provided the economics support for the Circular Economy Route Map for the city of London and has recently worked with the Rockefeller Foundation 100 Resilient Cities project on assessing the investment value of infrastructure assets.

Previously, Colin led the quantitative methods department for a leading general economics consultancy (London Economics) and was Head of Operations Research at the Hatfield site of British Aerospace.

Qualifications

Education

1988, MA, Engineering, University of Cambridge

1984, BA, Engineering, University of Cambridge

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Selected Experience

Manston Airport EIA
(River Oak Strategic Partners)

Colin was the lead author for the socio-economic chapter in an Environmental Statement in an EIA for the reopening of Manston Airport, Kent.

EIA for Housing Developments in the Midlands
Milton Keynes Development Partnership & Warwick County Council

Colin is the lead author on the socio-economic chapters in an Environmental Statement in an EIA in support of two major housing developments in the Midlands (Top Farm, Nuneaton and Tattenhoe Park, MK), of 60 and 94 hectares.

Socio-economic expert review of Environmental Statements
Hackney and Newham Borough Councils, London

Colin is providing expert review of the socio-economic chapters of EIA submissions to Hackney and Newham councils for a number of developments across the boroughs in one of the fastest growing areas in the UK.

Response to government proposals for Marine Conservation Zones in the Isle of Wight
Lymington and Yarmouth Harbour Commissioners, IOW

Colin directed a detailed assessment of socio-economic impacts and a community survey regarding potential designation of Marine Conservation Zones near the Needles in the Isle of Wight submitted by the harbour commissioners in response to a government consultation.

Socio-economic advice for a quarry extension
Dartmoor National Park

Colin is developing the socio-economic arguments in an ongoing planning assessment of a potential quarry extension in a sensitive area on the edge of one of the UK's major national parks.

Performance-based design framework to integrate and demonstrate value within infrastructure projects
100 Resilient Cities - Rockefeller Foundation

Colin worked with an in-house expert team on a methodology to include the effects of resilience when assessing the investment value of infrastructure assets.

Current approaches for assessing risks to Natural Capital
Environment Agency

The Environment Agency is currently seeking to assess the practicalities of the possible approaches for local, regional and national environmental planning and management over a range of time horizons. Colin is directing the project which includes an international literature review and PESTLE analysis.

Natural Capital Assessment
London Heathrow Airport

The development of natural capital estimates is part of the integrated approach to investment in the new extension to London's Heathrow airport. Colin is leading the specification and implementation of the economic valuation of new and existing natural assets affected by the design options.

Upper Sonachan Wind Park EIA
Ecotricity

Colin was lead author for the socio-economic chapter in an Environmental Statement in an EIA for a large scale wind park planning application in Argyll and Bute in a sensitive landscape area.

Technical Assistance on Development of Circular Economy Route Map for London and the Interreg CircE Tool
London Waste and Recycling Board (LWARB) (2015-2017)

LWARB is required to provide a business plan on a yearly basis which incorporates the Mayor of London's ambition for London to become a world leader in circular economy (CE). In the first phase, Colin led the economic development of the first estimates of the potential value to London of adopting CE. In the second phase, the financial potential of a set of possible new CE incentives route map was assessed. In support for the European Interreg CircE programme, he led the collation of information on the circular economy landscape in London, including the policy framework, innovation strategies, a brief SWOT analysis, key sector statistics and a list of the most relevant stakeholders.

Tourism Assessment
North York Moors National Park Authority

Colin led the socio-economic assessment of potential impacts of a new potash mine in the Park on the tourist economy of Whitby.

Economic benefits of flood (FCRM) investment on recreation, tourism and health
Environment Agency (UK)

Wood (formerly Amec Foster Wheeler) is assisting the Environment Agency in a review and update of existing methods for valuing economic and financial benefits of flood defence schemes including impacts at national scale in the areas of recreation, tourism and public health. Colin is directing the project.

Generic assessment of socio-economic impacts of oil-spills worldwide
ENI (The Italian State Oil Company)

Colin directed a major study valuing the potential costs of socio-economic impacts on business, tourism, the community and the environment of onshore and offshore oil spills in 43 countries worldwide. This work is ongoing and being extended to 11 further countries.

A Strategic Level Approach to Cumulative Effects
Marine Management Organisation

In a project led by NIRAS, Colin directed the socio-economic analysis for assessing cumulative impacts in the UK marine environment.

Socio-economic impacts of a hypothetical oil spill in the Irish Sea
ENI

Colin directed an assessment of the socio-economic impacts on business, tourism, the community and the environment from an oil spill affecting the coastline of North West England.

Costs of pollution incidents
Environment Agency

Colin directed a project to provide a generic methodology for assessing socio-economic costs from pollution incidents which includes the integration of valuation frameworks in daily use by different stakeholders.

Financial Mechanisms for Industrial Resource Efficiency
World Bank (2014)

Colin managed the development of a generic toolkit to allow countries to identify resource efficiency opportunities and design well-matched financial support and enabling tools. The first application was in Jordan.

Circular Economy Economic Opportunity (Construction Excellence Wales)

Colin is leading the assessment of the economic impact of the Circular Economy arising from the introduction of new approaches throughout the supply chain and in the subsequent use of buildings.

Economic benefits of FCRM investment on recreation, tourism and health
(Environment Agency)

Colin is directing a project to provide the national approach for assessing recreation, tourism and health benefits arising from investment in flood and coastal erosion risk management infrastructure.

Options for a Strategy for Economic Assessment of the Benefits of Contaminated Land Remediation
Defra

Colin directed a project to provide the UK government with a generic methodology for assessing the economic value of the different types of benefits arising from the remediation of contaminated land. The extensive study included an assessment of the use of the ecosystem services approach in comparison with more traditional approaches.

Financial Assessment of options for Energy from Waste (EfW) Plant
Private Developer

Colin led a team advising on commercial options for electricity sales from a new on-site anaerobic digestion plant. This included assessing revenue options under government support schemes (Feed In Tariffs and Renewable Obligation Certificates), negotiating with electricity offtakers, and estimating costs of connection and distribution.

Commodity Market Feasibility Study for Waste Markets
Environment Agency

Colin directed a project funded under the LIFE programme considering the reasons for current market failures and the development of new commodity markets for materials made available through changes in waste regulation. In a study with substantial theoretical content, issues such as state aid, economies of scale and scope and barriers to entry were assessed for four materials with different intrinsic characteristics.

Market analysis of Isle of Wight ferry services
Wightlink

Colin advised on the market dynamics and pricing of ferry services to the Isle of Wight, drawing on previous work for Eurotunnel on competitor analysis.

Bev Coupe
Technical Director - Transport Planning

wood.

Summary

Years of Experience

24+

Office of Employment

Leamington Spa, Warwickshire

Industries

- Transport infrastructure
- Power
- Local and central government
- Property and development
- Travel Demand Management

Areas of Expertise

- DCO
- Transport Planning
- Development Planning
- Sustainable Transport

Professional Summary

Bev is a Technical Director with over 24 years' experience in transport planning.

She is an experienced Project Manager and Project Director, dealing with Transport Assessments, Travel Plans, sustainable transport schemes and multi modal strategies, parking studies and accessibility assessments for a variety of developments, including NSIPs and DCO applications. She is skilled in working with stakeholders during the project lifecycle to identify sustainable opportunities and develop solutions and has participated in numerous public consultation events.

Bev is a specialist in transport, but works closely with planning, design and environmental teams, looking at the holistic environmental impact of development with the aim of identifying sustainable design and access solutions.

Bev has appeared as expert witness at Public Inquiry and has made representations at Local Plan Examination in Public.

Qualifications

Education

MSc, Transport Engineering and Operations, University of Newcastle

BA (Hons), Planning Studies, Oxford Polytechnic

Diploma, Planning, Oxford Polytechnic

Registrations / Certifications / Licenses

Member Royal Town Planning Institute

Languages

English

Experience

Transport Lead

RiverOak Strategic Partners Limited, Manston Airport DCO, Kent, UK

Through a phased approach between 2020 and 2038, the proposals are for 350,000 tonnes of air freight and 1.5 million passengers per year. In addition, a business park is proposed to the north of the airport site. Bev is technical lead on the transport submissions which has included the development of a transport model, airport access strategy and parking strategy and production of a transport assessment, travel plans, construction traffic management plan, public rights of way management, as well as PEIR chapter and ES chapter and section 42 consultation.

Technical Reviewer

National Grid, North West Coast Connections Project (NWCC) DCO, Cumbria, UK

Wood was commissioned to deliver highways and transport services to support the DCO for the NWCC which is a major upgrade of electricity infrastructure in the north west of England as part of the Moorside New Nuclear Build scheme. The NWCC project involved a 22km tunnel under Morecombe Bay, 140km of a new power corridor and 5 new / upgraded substations. Bev undertook technical reviews of transport

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documents that were being produced to support the DCO application, including the Construction Traffic Management Plan and the Transport Strategy.

Technical Lead

Vattenfall, Nocton Fen Wind Farm DCO, Lincolnshire, UK

Wood was commissioned to undertake the Environmental Statement for the project which consisted of 20 wind turbines with a total installed capacity of up to 69MW (on the basis of 20 x 3MW wind turbines), and was therefore a Nationally Significant Infrastructure Project (NSIP). Bev led the Traffic and Transport assessment work, which included access studies to determine routing to the site and the point of ingress and egress for general construction HGV traffic and for Abnormal Indivisible Loads (AILs).

Technical Lead

Bristol Airport, 10mppa Expansion Project

Wood has extensive experience of working for Bristol Airport over many years, including the planning and environmental work which resulted in the granting of outline planning permission for expansion to 10 MPPA. Bev was the technical lead on the Traffic and Transport chapter for the Environmental Statement.

Technical Lead

Warwickshire County Council, Sites in SW Rugby

WCC has sites as part of a wider SW Rugby consortium which will deliver around 5,000 dwellings, major employment, an all through primary and secondary school site, two other primary schools, district centre and associated infrastructure, including a relief road to address congestion and air quality issues at signal crossroads in Dunchurch. The work has included working closely with the consortium members and their transport consultants, and with the local planning authority, Rugby Borough Council, and highway authority, Warwickshire District Council. Bev is leading the transport work to support the promotion of the WCC sites and the wider consortium.

Technical Lead

Robert Hitchins Ltd, Land and North & East of Barrow Farm, Chippenham, Wiltshire

Wood was commissioned to provide multi-disciplinary services to undertake the planning and technical support work for a proposed development of 500 units and primary school on a Greenfield, non-allocated site on the northern periphery of Chippenham, south of J17 M4. Bev led the transport planning work. The planning application was refused and Wood was commissioned to provide expert witnesses in planning, transport, landscape and heritage in support of the appeal. Bev successfully negotiated withdrawal of the highway authority's reasons for refusal prior to the Inquiry, achieving a comprehensive Statement of Common Ground. The planning appeal was unsuccessful on planning, landscape and visual grounds.

Professional History

- Wood (2017 – Present)
- Amec Foster Wheeler (2014 – 2017)
- AMEC (2011 – 2014)
- Entec (2006 – 2011)
- Atkins (2000 – 2006)
- Arup (1998 – 2000)
- Ove Arup & Partners (HK) (1994 – 1997)

Glyn Price
Associate Director – Transport Planning

Summary

Years of Experience

15

Areas of Expertise

- Transport Assessments
- Complex Junction Modelling
- Highways Design
- Travel Plans
- Gravity Models
- Traffic Management Plans

Types of Facilities

- Airports
- Power Infrastructure
- Residential Developments
- Commercial Developments
- Mixed Use Developments

Professional Summary

Glyn is a Transport Planner with over 15 years' experience.

Glyn's experience spans 15 years in transportation planning in both public and private sectors, and includes Transport Assessments (TA), Transport Statements (TS), Traffic Management Plans (TMP), environmental assessment relative to highways and transport, and Travel Plans (TP).

His key strength is in preparing and developing traffic management solutions for permanent developments and for the construction period of large infrastructure projects. He has been project manager for the transport element of the works required to support the DCO application for the Northwest Connection Project for National Grid and more recently Manston Airport. Another key strength is in transport modelling where he has been trained to an advanced level on many tools such as PICADY, ARCADY and TRANSYT and LinSig.

He is experienced in project and finance management on a range of projects such as marina developments, quarry extensions, new overhead and underground power cables, new underground water pipes, wind farms, mixed use industrial estates and residential developments. His focus in the last four years has been managing and delivering the relevant transport inputs to support a major planning application for OHL and underground cables in the power sector.

Qualifications

Education

2003, BA (Hons), Geography/Planning, Coventry University

Software

- Junctions 9
- LinSig V3 – Complex linked junction modelling
- TRANSYT
- Advanced Excel – complex gravity model spreadsheets
- CAD/GIS

Current Project

Transport Advice for junction modelling

RiverOak Strategic Partners Limited, Manston Airport Development Consent Order, Kent

Glyn has managed the traffic and transport support for the Manston Airport DCO. Glyn has liaised with the client, key stakeholders and internal project team to deliver the transport documents and figures for the DCO Submission.

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Experience

Transport Planner

National Grid, Northwest Connection Project DCO, Cumbria/Lancashire (2015 – 2017)

Glyn was the project manager for the traffic and transport element of a wider in-house team for the Northwest Coast Connection project DCO submission. This project is a mixture of overhead line and underground cables linking the existing National Grid in the northwest and the proposed new nuclear power station at Moorside. Glyn was heavily involved in all stages of the project from bidding to delivery, managing the project at the same time. This project has focused on the production of numerous documents to support various planning applications such as a CTMP, TA and EIA chapters, as well as various technical reports. Glyn has led consultation with the local authorities, led teams on site, and has worked closely with the client via weekly update meetings. Glyn worked within the designs teams and was seconded to Kendal. Glyn worked through change control processes and was an integral part of the evolving design solution. Glyn also played a key role in the development of a wide ranging multi modal Transport Strategy for the project.

Transport Planner

National Grid, Mid Wales Connection Project DCO, Shropshire/Powys (2013 – 2015)

Glyn was the project manager for the traffic and transport element of a wider project team for the Mid Wales Connection DCO project. This project is a mixture of OHL and underground cable linking up the TAN 8 area to the existing National Grid line in Shropshire. Glyn was heavily involved in all stages of the project from bidding through to delivery, managing the project at the same time. The project was delivered on time and budget until government policy resulted in the project bring cancelled. This project has focused on the production of several documents to support a DCO application such as a TMP, TA and EIA chapters, as well as various technical reports. Glyn has been involved with consultation with the local authorities, led teams on site, and been working closely with the client via weekly update meetings. Glyn worked within the designs teams and regularly worked out of the project office. Glyn worked through change control processes and was an integral part of the evolving design solution. Glyn also played a key role in the development of a wide ranging Transport Strategy for the project.

Transport Planner

Western Power Distrbution, Brechfa Forest Connection DCO, Brechfa (Wales) (2015)

Glyn was the project management for the traffic and transport element of a wider Wood team for the Brechfa Forest Connection project. This project is a mixture of OHL and underground cable linking up the wild farms of the Brechfa Forest to an existing OHL south of Carmarthen. Glyn was been heavily involved in all stages of the project from bidding through to delivery. This project has focused on assessing the access points to over 100 locations for the OHL. This has focused on how to manage HGV trips when the network is predominately thin rural roads which are unsuitable. The DCO was granted in September 2016.

Professional History

- Wood (2007 – Present)
- Faber Maunsell (2005 – 2007)

RPS

[redacted]

Andrew Buroni

Technical Director of Health

PhD, MSc, BSc (Hons), Fellow of the Royal Society of Medicine, Fellow of the Royal Society for Public Health, HIA Framework Advisor to Public Health England, HIA advisor to EPA Ireland and Public Health Wales, Temporary Advisor to the WHO on the Health Effects of Waste Management and sits on the IEMA Health in EIA Writing Group.

Dr Buroni is RPS' Health and Social Impact Assessment Practice Leader with 18 years of project experience on leading international Health Impact Assessment in the energy, oil and gas, transport, regeneration, spatial planning, sustainable development, civil aviation and waste management sectors.

Experience

Andrew is the market leader for planning focussed HIA in the UK. He has designed, delivered and presented evidence at public inquiry and issue specific hearing for some of the most complex planning focused examples of Health Impact Assessment (HIA), and has an unmatched catalogue of HIA project experience ranging from local planning through to DCO and Hybrid Bill.

Andrew provides clients with specialist advice on clarifying potential health, social and wellbeing outcomes, and separating perceived impacts from actual risk. He assesses the distribution, significance and likelihood of potential health outcomes, and provides bespoke Health Action Plans geared to addressing existing burdens of poor health, inequality and improving community health.

Andrew's experience is as extensive as it is varied, including surface mines, oil and gas projects, new nuclear power stations, regeneration strategies, urban expansions, through to windfarms and their grid connections, new national grid road and rail infrastructure, and national waste strategies.

A small sample of Andrew's aviation experience includes:

- Gatwick 2nd runway;
- Birmingham Runway Extension, Masterplan and ongoing technical advisor;
- London City Airport Interim, Main and CADP applications, including expert witness;
- Belfast City Airport runway extension, change in planning condition, expert witness and ongoing technical advisor;
- Dublin change in planning conditions and ongoing technical advisor;
- Stansted G1, optioneering of G2 and increased capacity applications; and
- Western Sydney Airport Expansion; and
- Melbourne Airport Expansion.

Key Projects

HS2 (Phase 2b Lot 3), Midlands Mainline Electrification, Northern Powerhouse Rail, Crossrail

Sizewell C, Bradwell B, Moorside, Hinkley Point C and Oldbury New Nuclear Power Stations

Sellafield Transformation Plan

The UK Geological Nuclear Waste Repository

Runcorn; Rufford; Lostock, Suffolk, Exeter, Norfolk, Belfast, Cheshire, Brig y Cwm, Tipperary and Public Health England Science Hub EfW's,

South Hook Gas Fired Power Station, Green Hills, Cardenden and Roosecote Biomass facilities

Nant Llesg Surface Mine, Bry Defaid Surface Mine, Curraghinalt Gold Mine, Ffos y Fran Opencast Mine

Falkirk Coal Bed Methane and shale gas exploration in Lancashire and Yorkshire

Health in EIA Best Practice Guidance for the entire UK Onshore Oil and Gas Industry and ongoing technical advisor

Environmental Social and Health Impact Assessment (ESHIA) projects in Algeria, Albania, Papua New Guinea, Ethiopia, Kurdistan, Sakhalin, Salym and the Arctic Circle;

EirGrid, Grid Link, Tamnamore to Omagh, Brockaghboy, Curraghmulkin Power Lines and the FAB Interconnector

Hornsea (One, Two and Three), the Atlantic Array, Burbo Bank, Moray Firth, Inch Cape, Kildare and Tyrone Windfarms

Irelands potable water Lead management treatment

Kent, Ipswich, Cambourne, Drayton Park, Leiston, Backwell, Green End, Brighton General Hospital, Uttlesford, Denny End and Chequers Road urban developments

Wales, Brighton & Hove, East Sussex Lancashire and Buckinghamshire Waste Strategies

WRAP Waste Management and Health Guidance

WHO Temporary Technical Advisor on the health effects of Waste Management

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Dr Christopher Harris
Principal Consultant – Climate

Summary

Years of Experience

8

Office of Employment

London (Canary Wharf), UK

Industries

- Airports
- High-speed rail
- Water resources
- Major infrastructure projects
- Refining
- Built environment

Areas of Expertise

- Climate adaptation and resilience
- Greenhouse Gas (GHG) assessment and climate change mitigation
- Environmental Impact Assessment (EIA) – DCO and TCPA
- Circular economy and low carbon design
- Sustainability and waste policy development

Professional Summary

Dr Christopher Harris has 8 years of experience specialising in climate change adaptation, the resilience of infrastructure systems, climate change mitigation and sustainability. He has experience on some of the largest infrastructure projects in the UK, and is a qualified project manager with experience of co-ordinating multi-disciplinary teams on complex projects across a range of sectors.

As well as his focus on climate change, Dr Harris has previously run major projects on circular economy, eco-design, water resources, environmental policy and applied academic innovation. Christopher has a PhD from the University of Birmingham (Civil Engineering) which focussed on increasing the resilience of water resource networks to drought under projections of climate change. He is a peer reviewer for two academic journals focussing on climate change.

Qualifications

Education

PhD. Civil Engineering. University of Birmingham

MSc. Climate Change. University of East Anglia (Distinction)

BSc. Marine Geography. Cardiff University

Registrations / Certifications / Licenses

Member of the UK working group for ISO 14090 and ISO 14091

PRINCE2 Practitioner (project management)

Life-cycle Assessment (LCA) Practitioner (SimaPro)

Current Projects

Climate Resilience and GHGs Lead

RiverOak Strategic Partners Limited, Manston Airport Development Consent Order, Kent

Christopher is responsible for the management and delivery of the climate change resilience and mitigation aspects of the Manston Airport redevelopment DCO application and the TCPA applications for Bristol Airport interim expansion and Fawley Refinery expansion. He is also the client representative for climate change throughout the Manston Airport redevelopment DCO examination process and has also managed the development of tasks covering water efficiency, waste, circular economy and energy efficiency.

Dr Christopher Harris
Principal Consultant – Climate

Experience

EIA Climate Change Director (Climate Resilience and GHGs)

Heathrow Airport Ltd, Heathrow Expansion Programme, UK. 2018 - present

Christopher is the topic director and manager for Heathrow Expansion Programme EIA for climate change resilience and mitigation, and technical reviewer for Major Accidents and Disasters. He is responsible for the technical development (including masterplan development) and delivery of the climate change EIA chapter and all associated tasks. This role includes extensive stakeholder engagement and the development of best practice in the consideration of climate change in EIA and the wider DCO process.

Climate Change (Resilience) and Major Accidents and Disasters Specialist

High Speed Two (HS2) Ltd, UK. 2015 - 2017

For two years Christopher was responsible for the development of the design of HS2 for resilience to future climates. This role included the production of technical standards, strategies and policies relating to climate change resilience including co-development with environmental, engineering and asset management discipline leads. Christopher managed input from a number of consultancies and research bodies feeding into the cutting edge environmental assessment and design of the scheme.

Christopher led the Climate Change Adaptation and Resilience Focus Group, responsible for developing and executing technical design changes related to climate resilience. He developed research projects with academic partners relating to the resilience of HS2 to climate change and natural disasters, including direct impacts of extreme weather on infrastructure, assessment of multiple environmental hazards.

Lead Research Officer (Circular Economy and Sustainable Design)

PDR / Welsh Government / Zero Waste Scotland / Riversimple, UK. 2014 – 2015

Christopher led the development and direction of ecodesign at PDR which facilitated sustainable and low carbon development in Wales and Scotland. This role included the production of key policy documents for the Welsh Government, 'Design for a Circular Economy' for Zero Waste Scotland. This role also included the development of sustainable business models with SMEs across Wales, including a value network through supplier adoption of sale-of-service business models with Riversimple Engineering Ltd.

Professional History

- Wood (2017 – Present). Principal Consultant, Climate Resilience and Sustainability
- High Speed Two (HS2) (2015 – 2017). Climate Change Resilience Specialist
- Ecodesign Centre / PDR (2014 – 2015). Lead Research Officer
- University of Birmingham (2010 – 2014) Doctoral Researcher

Publications / Presentations

- Whicher, A., Harris, C., Beverley, K., Swiatek, P. 2017. Design for circular economy: Developing an action plan for Scotland. Journal of Cleaner Production. https://doi.org/10.1016/j.jclepro.2017.11.009
- Harris, C.N.P., Quinn, A.D., Bridgeman, J. 2014. The use of probabilistic weather generator information for climate change adaptation in the UK water sector. Meteorological Applications. 21 (2) 129-140. DOI: 10.1002/met.1335
- Harris, C.N.P., Quinn, A.D., Bridgeman, J. 2013. Quantification of uncertainty sources in a probabilistic climate change assessment of future water shortages. Climatic Change. 121 (2) 317-329
- Harris, C.N.P., Sanders, C., Harfield, P. 2014. Mapping Critical Resources for Wales. Prepared for the Welsh Government Waste Strategy Branch.

Kate Duff

Technical Director – Major Accidents and Disasters

Summary

Years of Experience

25+

Areas of Expertise

- Risk Assessment & Management
- Major Accidents and Disasters
- Major Accident Regulation

Types of facility

- Airport
- Oil and gas: onshore/offshore
- Chemical
- Mine support facilities
- Marine and road offloading
- Waste

Industries

- Oil & Gas
- Chemical
- Nuclear
- Mining

Professional Summary

Kate leads the safety and risk team of Wood E&I and is a Chartered Physicist with almost 30 years of international experience in safety and risk management. Her expertise covers a wide range of industrial sectors, including oil and gas, petrochemical, chemicals, nuclear and mining industries. She has applied her expertise to all stages of facility life-cycle; from concept design, through FEED/EPC, to normal operations and final decommissioning.

Particular expertise includes:

- Major Accidents and Disasters
- Risk assessment and management
- ALARP demonstration Supporting safety studies
- Technical design safety
- Safety Report preparation
- Occupied Building Risk Assessment
- Escalation Assessment
- Business Risk Assessment and Cost Benefit Analysis

Qualifications

Education

1986, BSc (Hons), Applied Physics, Sunderland Polytechnic

Current Projects

Major Accidents and Disasters Lead

RiverOak Strategic Partners Limited, Manston Airport Development Consent Order, Kent

Technical lead for the Major Accident and Disaster aspect of the 2018 Manston evaluations for the purposes of the 2017 EIA regulatory submission for DCO. Technical method development and assessment, including detailed consideration of fuel storage.

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Kate Duff
Technical Director – Major Accidents and Disasters

Experience

Heathrow 3rd Runway EIA – Major Accident and Disasters
Aspect Director for Major Accident and Disaster Aspect of the Heathrow 3rd Runway Project EIA. Technical method development, assessment, stakeholder engagement. Supporting the project in meetings its requirements for major accident and disaster evaluation as part of the EIA 2017 regulatory requirements.

LNG Tank Storage - Quantitative Studies
TGE
Project Manager and lead engineer for frequency, consequence and risk based design evaluations associated with a Chinese LNG tank storage facility. The assessment included consideration of tank roof events and design considerations for safe guarding provisions such as the impoundment basin and PSVs.

COMAH Predictive Studies
Nalco
Detailed risk assessment for Upper Tier Chemical manufacturing establishment, including risk /HAZID/ENVID workshops and quantitative evaluation (consequence, frequency and risk) of toxic, flammable, VCE and Major Accident to the Environment (MATTE) hazards associated with storage and processing at the facility, chemicals and oil. Supporting studies were also undertaken including Occupied Building Risk Assessment.

Risk Assessment/HAZOP – CHP facility
Fingleton White
Facilitator for HAZOP considering modifications to the operation and design of a feed system relating to a CHP facility. The assessment considered business, asset, safety and environmental risks associated with changed to the facility.

Offshore sub- Arctic QRA and Safety Studies
International Offshore Operator and Design EPC Contractors
An update of studies performed for a sub- Arctic Sakhalin 1 Development. The 2012 commission was a selected update of activities performed at FEED stage. FEED activities included detailed fire risk analysis, temporary refuge assessment, platform escalation studies and detailed escape/evacuation/platform abandonment analysis. Full consideration was given for the extreme nature of the environment, which involves sea-ice for a significant proportion of the year.

Professional History

- 2015, Technical Director, Wood
- 2012, Technical Director - Safety and Risk, Amec E&I
- 2005, Managing Consultant - Safety and Risk, ESR Technology
- 1997, Principal Consultant - Safety and Risk, AEA Technology
- 1991, Senior Consultant - Safety and Risk, AEA Technology
- 1987, Safety and Risk Consultant, Safety and Reliability Directorate (SRD)

Emma North
Principal Consultant

Summary

Years of Experience

9 years

Industries

- Airport
- Nuclear
- Residential and mixed use
- Infrastructure
- Transport
- Oil & gas

Areas of Expertise

- Environmental Impact Assessment
- Ecology and habitat restoration

Professional Summary

Emma has over 9 years consultancy experience specialising in Environmental Impact Assessment (EIA) and environmental appraisal. Her experience includes the preparation, co-ordination and technical delivery of EIAs and environmental deliverables to support a wide range of planning applications. Emma's experience includes nuclear, highway, rail, airport, mixed-use and residential sectors among others.

Emma is experienced in the day-to-day running of EIA projects ensuring effective management of and liaison with both internal and external multi-disciplinary team members. She has provided screening and scoping advice in support of planning applications, written and reviewed Environment Statements and has extensive experience of undertaking consultation with a range of stakeholders. Emma is particularly experienced in planning and undertaking cumulative environmental effects assessments, having led the assessment for the Manston Airport EIA and a number of smaller EIA projects. Emma is proficient in the management and delivery of environmental work streams to both challenging deadlines and meeting budget expectations.

Having previously worked in the ecology field, Emma also has extensive experience of undertaking ecological impact assessment for a number of major projects in the UK.

Qualifications

Education

2009, MEnvSci, Environmental Science, University of Southampton

Registrations / Certifications / Licenses

Chartered Institute of Ecology and Environmental Management – Full member

Experience

EIA Task Lead

ExxonMobil, Fawley Oil Refinery, Hampshire, UK

The Fawley Oil Refinery, located on Southampton Water and operated by Esso Petroleum Company Ltd, is the largest oil refinery in the UK and one of the most complex in Europe. Wood was commissioned by ExxonMobil (Esso's parent company) to provide planning and permitting support for a number of developments at the site. As EIA and planning lead, Emma coordinated the EIA technical work, including preparing the screening requests, scoping requests and Environmental Statement. Emma was responsible for ensuring the EIA and planning element of the project was delivered on time and to budget.

EIA Project Manager

Marshall Properties Ltd, Cambridge Airport, Cambridge, UK

Wood were commissioned by Marshall Properties Ltd to provide consultancy services to discharge planning conditions in connection with an application to construct a ground engine testing facility at Cambridge

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Airport. Emma worked closely with the client, designers and contractors, enabling the production of a Materials Management Plan, Construction Environmental Management Plan and working methodologies to reduce environmental impacts associated with spoil management. She also reviewed a range of environmental reports produced by external consultants, coordinated production of public consultation material and she produced an Environmental Statement Addendum in support of the application to discharge the planning conditions. Emma was responsible for ensuring the timely delivery of the deliverables and managed the financial aspects of the project.

EIA Task Lead

RiverOak Operations Ltd, Manston Airport, Kent, UK

Wood were commissioned to produce the Environmental Statement for the Manston Airport project, which aims to bring the airport back into operation. This development is considered to be a Nationally Significant Infrastructure Project (NSIP) for which a Development Consent Order (DCO) is required. Emma was responsible for planning, coordinating and producing the cumulative effects assessment within the Environmental Statement and the inter-related effects assessments within each technical topic chapter. The project involved working closely with external and internal parties to identify and shortlist cumulative developments and to produce proportionate cumulative effects assessments.

Land Access Manager

Heathrow Airport Limited, Heathrow Expansion Programme, UK

The Heathrow Expansion Programme involves the construction and operation of a third runway at Heathrow Airport. Wood are leading on Land Access for the project and Emma provided early support, reviewing and improving the protocol for arranging baseline data collection for the EIA. This involved refining land access request procedures within the Interdisciplinary Design Team, which encompasses consultants from numerous consultancies in the UK and who require land access to undertake a wide range of surveys. Emma took a lead in reviewing and improving health and safety processes and procedures and also improved the process for landowner communications; having particular regard to sensitive landowners whose positive engagement is crucial to the project.

EIA Project Manager

NuGeneration Ltd, Moorside Project, Cumbria, UK

Emma was an active member of the Amec Foster Wheeler Environmental Impact Assessment (EIA) core project management team for the proposed Moorside Nuclear New Build Project in West Cumbria. The Moorside Project involves the construction and operation of a new three generator nuclear power station adjacent to the existing Sellafield nuclear facility. This development is considered to be a Nationally Significant Infrastructure Project (NSIP) for which a Development Consent Order (DCO) is required. As an EIA Project Manager, Emma reviewed and coordinated the baseline reporting and Environmental Statement workstream to support the DCO application. Emma was responsible for coordinating statutory and non-statutory consultation exercises and led the production of Statements of Common Ground.

Professional History

- Wood (previously Amec Foster Wheeler) (2015 – Present) Senior and Principal Consultant
- Middlemarch Environmental Ltd (2015 – 2015) Senior Ecologist
- Middlemarch Environmental Ltd (2014 – 2015) Wetland Habitat Consultant
- Jacobs UK (2011 – 2014) Aquatic Ecologist
- Enims Ltd (EnterpriseMouchel) (2009 – 2011) Consultant

Sally Dixon MBA PhD MRAeS

17 Island Wall, Whitstable, Kent, CT5 1EP   01227 772086   07973 523898

sally@azimuthassociates.co.uk   https://uk.linkedin.com/in/sally-dixon-2462041

PROFILE

As a skilled strategist with extensive Board-level capability, Dr Sally Dixon has a wealth of experience, particularly in airport-related projects. Sally is Reuters trained, MBA and PhD-qualified and adds value to projects where creating knowledge from scattered information sources and exposing the drivers for business and economic success are key. Sally has a track record for delivering workable, innovative solutions to the issues faced by organisations today.

KEY SKILLS

- Strategy development as a collaborative, innovative process
- Stakeholder engagement and management particularly in situations where managing stakeholder considerations are vital to success
- Airport acquisitions, specialising in regional and ex military airfields
- Institutional analysis to identify the taken-for-granted assumptions and corporate cultures that create barriers to innovation
- Business planning across a wide range of public and private sectors
- Business and economic analysis particularly collating information from scattered sources to provide organisations with actionable business intelligence
- Skills and capacity building at strategic and operational levels in the UK and Europe
- Quantitative and qualitative research using a wide range of methodologies

WORK EXPERIENCE

Aviation Consultant — Azimuth Associates — 2016 to date
Freelance Consultant focused on airfreight forecasting and the economic impact of airports.

Specialist lecturer — Cranfield University — 2012 to date
Specialist lecturer on stakeholder involvement in master planning, MSc in Airport Strategic Planning.

Principal Aviation Consultant — Ricardo AEA Ltd. — 2015
Providing expertise in the economic and social impacts of aviation, airport business and master planning, and in stakeholder involvement in decision-making. Developing Ricardo's aviation offering and promoting aviation services at technical meetings and in academic and trade papers. Sally was instrumental in winning high value work from the EU and British Government.

Business Consultant and Interim Manager — Azimuth Associates — 2002-2014
Freelance Consultant with a wide range of private and public sector clients. Many years spent in property development, lettings, and block management.

Head of Strategic Information — Wiggins Group/PlaneStation plc — 2000-2001
Responsible for acquisition proposals, strategic development and master planning for a network of regional airports.

Business Consultant — Azimuth Associates — 1998-2000
Freelance Consultant with a wide range of private and public sector clients.

Business and Economic Analyst — Kent Training & Enterprise Council — 1996-1998
Delivering a large portfolio of projects to support business and economic activity in the County.

Interim Manager — Various - Spain — 1991-1995
Working for a range of organisations including start-ups in travel, tourism, and import and distribution.

Senior Planning Analyst — Reuters plc — 1981-1990
Responsible for forecasting Reuters' global equipment requirements for external installations.

EDUCATION AND TRAINING

PhD — Cranfield University, United Kingdom — 2007-2014
Jointly supervised through School of Engineering, Department of Air Transport and School of Management

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- Investigated how airport managers take account of stakeholder opinion in their master planning
- As part of the agency-structure debate, developed a model Integrating the stakeholder framework within institutional theory
- Added to the body of work with a critical realist perspective

MBA University of Kent, United Kingdom 1996-1999
Distinction for dissertation on the effect of e-commerce on the manufacturing sector

PROFESSIONAL TRAINING

- Research Methodology Course (2007-8) Cranfield University School of Management
- MBA from Kent Business School (1996-1999) with distinction for dissertation on the impact of e-business on the manufacturing sector
- Kent Partners Skills Programme (developing and managing strategic partnerships)
- Reuters Management Training (Residential course)
- Reuters Report Writing Skills
- Coverdale Project Management

PERSONAL SKILLS

Mother tongue	English	
Other languages	Spanish (near fluent)	French (basic)

PUBLICATIONS

Dixon, S., 2014, 'Managing the Master Planning Process: How do airport managers incorporate stakeholder contribution in their final master plans?' PhD thesis, Cranfield University.

PROJECTS

Development Consent Order (DCO) for Manston Airport in Kent
Part of a team working on the first DCO application for a nationally significant airport project to be accepted for examination by the Planning Inspectorate (PINS). Production of a four-part report, The Azimuth Report, submitted to PINS as part of the 11,000 page, 63-document proposal. Responding to queries from PINS and preparing to provide further detail during examination.

Air traffic forecasting for Manston Airport in Kent

Providing air freight and passenger traffic forecasting consultancy to RiverOak Strategic Partners (RSP). Defining an airfreight forecasting methodology and undertaking interviews with key market players including government departments, cargo airlines and users, integrators and forwarders.

Building the case for Nationally Significant Infrastructure Project (NSIP) status

On behalf of RSP, providing justification that Manston Airport is an NSIP, including analysing the UK's current airport capacity and reviewing shortfall, particularly for dedicated freighters. Engaging with key stakeholders including government departments, MPs, local authorities.

Job creation and economic impact forecasting for Manston Airport

Forecasting direct, indirect, induced and catalytic jobs for the operation of a freight hub at Manston Airport.

Stakeholder consultation for Manston Airport

Providing professional services to three stakeholder consultations for RSP. Consultations included drop-in events and presentations to local people, Kent County Council, Thanet District Council, MPs, special interest groups and local business representatives.

Professional witness

Part of a small successful team that gave evidence to the Planning Inspectorate with regard to an appeal against the rejection of an application for change of use from aviation only to general commercial.

Passenger forecasting methodology for Gibraltar Airport
Providing a forecasting methodology to the Government of Gibraltar in response to their aim to increase use of the new Gibraltar Airport.

Development of a network of airports, PlaneStation plc
Supporting the strategic intention of the organisation to develop a network of regional airports. Preparing Acquisition Proposals for airports in Europe, and North and South America. Close liaison with Economic Development Agencies and other key internal and external stakeholders. Economic analysis of regions where the company was active. Assisting with traffic forecasting. Preparation and presentation of Board papers. Managing research projects covering a wide range of aviation, economic development, regional and property development-related subjects.

Business planning, PlaneStation plc
Researching and writing Business Plans for all seven airports in the PlaneStation network. These included Manston Airport, Black Forest Airport Germany, Baltic Airport Germany, Odense Airport Denmark, Plzen Airport Czech Republic, Cuneo Airport Italy, and Smyrna County Airport US.

Master planning, PlaneStation plc
Close liaison with internal and external stakeholders. Working with colleagues to produce the Master Plan for Manston Airport. Responsibility for the strategy for e-business for PlaneStation airports. Setting and writing the marketing strategy for PlaneStation airports and supporting marketing activities.

SciPark project, PlaneStation plc
Key role in the SciPark project, a technology park to be located in Newquay, Cornwall. The project was intended to develop airport security and other systems using new technologies, particularly face recognition technologies. Development of the business proposal and strategy for SciPark as well as responsibility for establishing a partnership with HE/FE in Cornwall.

BSc in Business Studies with Airport Operations, Christ Church University
Working with the Head of Campus to develop a BSc in Business Studies with Airport Operations. Enrolling students for three consecutive years for bursaries provided by PlaneStation plc. Providing specialist lectures on airport strategy.

Projektkontor2 (Germany), Thanet District Council
On behalf of six regional airports from the UK, Germany, Greece and Poland and with the aid of Interreg IIIC funding, developed a design concept for a European Airport Training Academy.

MAVRIC, East Kent Partnership
As part of efforts to reduce unemployment and bring sustainable jobs and increased economic prosperity to East Kent, developed a concept for a marine and aviation support framework (MAVRIC). Worked in partnership with all local, regional and national stakeholders including SEEDA, local businesses and academic institutions to deliver on time and on budget including a well-attended presentation to key stakeholders at the conference facilities at Canterbury Cathedral.

Strategy for e-business, Pfizer Ltd
Pfizer required a strategy for e-business in the UK. Undertook extensive research with Pfizer departments and external sources in the UK, Europe and US. Used scenario planning to make recommendations at Board level, providing a final report and series of well-received presentations.

Master's degree module, University of Kent
Research for and production of the supply chain management module for a Master's degree in e-business delivered by Kent Business School.

Master's degree in e-business, Bridge Wardens' College, University of Kent
Advising on the content and development of a Master's degree in e-business for the University of Kent at Chatham Historic Dockyard. Project involved extensive market research with businesses in the region including Caterham Cars.

Pfizer Pharmaceuticals Group, Strategic Development Department
Provision of consultancy to support the business case and strategic plan for a specific geographic region. Use of economic and institutional analysis. Preparation a report setting out the challenges to doing business in this particular environment with reference to past drug launch profiles. The work supported the production of a strategic plan for the region as well as providing substantiating evidence for the establishment of a sub-regional office.

Centre for Enterprise and Development, Canterbury Christ Church University College
Provision of consultancy and project management services for several ESF funded e-business and e-learning projects. Included re-design and update of project websites and management of communication strategies with all project stakeholders.

Interim management, Learning and Skills Council Kent & Medway
Interim manager (3-month contract extended to 7-months) bringing together two teams – Management Information and Analysis with the Research team – to form a new Information & Intelligence team.

Ofsted Inspection, Learning and Skills Council Kent & Medway
Managed the preparation of the self-evaluation report for the Ofsted Medway Area Inspection project. Liaising with key partners in the area to pull together all information to support a successful outcome.

EU project management training, Surrey Institute of Art
Providing training for all managers involved in bidding for and managing EU funded projects at the university.

MEMBERSHIPS AND VOLUNTARY WORK

Member of the Royal Aeronautical Society
LEA appointed governor, St Alphege Infant School and Sunbeams Nursery (since 2011)

wood.

Manston Airport:
Examples of similar airport developments where PSDH has been used to inform the approach to assessment

1. Response to ExA's question AQ.1.8

This technical note has been produced in response to Question AQ.1.8 of the First Written Questions issued by the Examining Authority (ExA) on the 18 January 2019.

The ExA requests that the applicant point to other similar airport developments where the Project for the Sustainable Development of Heathrow (PSDH) has been used to inform the approach to assessment. Six examples have been identified. Supporting evidence is available in documents produced for the respective assessments. Most of these are available on the web, but one which is currently less easily available has been attached to this document as an example. The six examples are:

- Heathrow's submission to the Airports Commission for third and fourth runways (https://your.heathrow.com/takingbritainfurther/wp-content/uploads/2014/07/02-Heathrow-3RNW-Air-Quality-Assessment.pdf);
- Gatwick's submission to the Airports Commission for a second runway (https://www.gatwickairport.com/globalassets/publicationfiles/business_and_community/all_public_publications/second_runway/airports_commission/gatwick_appendix_a9_air_quality.pdf);
- The Airports Commission's assessment of the three schemes it shortlisted (https://www.gov.uk/government/consultations/airports-commission-air-quality-assessment);
- Farnborough Airport's application for an increase from 28,000 to 50,000 movements per annum (http://publicaccess.rushmoor.gov.uk/online-applications/applicationDetails.do?activeTab=documents&keyVal=KKYXA5NM07W00);
- London City Airport's Development Programme — see attached document; and
- Bristol Airport's application for expansion to 12 million passengers per annum (https://planning.n-somerset.gov.uk/online-applications/applicationDetails.do?keyVal=PJML85LPMKI00&activeTab=summary).

The ExA also requests any further documentation for PSDH. The original documents produced by the PSDH are no longer available online. For the reports of the expert panels, which have been reformatted but contain the original content, see attached document.

As an alternative, a very detailed description of the implementation of the PSDH recommendations in an air quality assessment is given in the technical reports for Heathrow's 2008/9 emissions inventory and dispersion modelling study; see attached documents.

2. London City Airport's Development Programme: Air quality assessment for the Updated Environmental Statement.

9 Air Quality

Introduction

9.1 This chapter of the Updated Environmental Statement (UES) describes the likely significant effects of the proposed CADP (CADP1 and CADP2) with respect to local air quality, during both the construction and operational phases. The study has been carried out by Air Quality Consultants Ltd (AQC) on behalf of the Airport. This Chapter provides an update to the previous version presented in the Consolidated Environmental Statement (CES) submitted in November 2014, and takes account of the availability of baseline data for 2014 and the revised forecasts.

9.2 A detailed description of the proposed CADP is provided in Chapter 2: Site Context and Scheme Description, of this UES. In terms of this air quality assessment, the most pertinent features of the proposals are:

a) The construction of seven new aircraft stands, parallel taxiway, and associated infrastructure to the east of the existing terminal building, with associated dust and pollutant emissions during the construction works, and changes in the spatial distribution of pollutant emissions during operation;

b) Increased passenger numbers and associated changes to surface access (road traffic movements);

c) Changes in aircraft emissions during operation due to predicted changes in fleet mix and the introduction of a new type of aircraft; and

d) The construction of new passenger facilities, hotel, surface-level and decked car parking facilities and a taxi feeder park.

9.3 The Airport lies outside of, but adjacent to, an Air Quality Management Area (AQMA) which has been designated by the London Borough of Newham (LBN) for exceedences of the annual mean objective for nitrogen dioxide and the daily mean objective for PM_{10} (see Figure 9.1). Developments within or close to AQMA's require particular attention to be paid to any potential air quality effects. The extent to which the proposed CADP could affect measures within the local authority's Air Quality Action Plan (AQAP) also needs to be considered.

9.4 The assessment focuses on two pollutants with respect to potential human health effects, namely nitrogen dioxide (NO_2) and fine particles (PM_{10} and $PM_{2.5}$), as these pollutants are of greatest concern within LBN. Consideration is also given to the potential for odour nuisance.

9.5 There are unlikely to be any significant effects arising from emissions of benzene, 1,3-butadiene, carbon monoxide, lead or sulphur dioxide. It is widely acknowledged that problems with these pollutants are only likely to occur in the vicinity of specific industrial processes, and exceedences of the health-based standards do not occur even in the vicinity of major airports such as Heathrow [(1).] They have therefore been scoped out of the assessment.

9.6 This assessment takes into account all relevant local and national guidance and regulations, and takes into account comments received from LBN through the formal EIA Scoping process.

1 Department for Transport (2006). Project for the Sustainable Development of Heathrow. Final Report.

Figure 9.1 – LB Newham AQMA Boundary.

Legislative Context and National Planning Policy

European Legislation

9.7 Directive 2008/50/EC [2] *Ambient Air Quality and Cleaner Air for Europe*, entered into force on 11 June 2008, with Member States required to incorporate the provisions into national legislation before 11 June 2010. The principal aim of the Directive is to protect human health and the environment by avoiding, reducing or preventing harmful concentrations of air pollutants, by the establishment of limit and target values; by the assessment of air quality in a uniform manner; by making air quality information available to the public; and by setting out plans and programmes to maintain or improve ambient air quality conditions.

2 European Union (2008). Ambient Air Quality and Cleaner Air for Europe (2008/50/EC).

National Regulations

Air Quality Strategy

9.8 The 2007 Air Quality Strategy [3] provides the policy framework for air quality management and assessment in the UK. It provides air quality standards and objectives for key air pollutants, which are designed to protect human health and the environment. It also sets out how the different sectors, industry, transport and local government, can contribute to achieving the air quality objectives. Local authorities are seen to play a particularly important role. The Strategy describes the Local Air Quality Management (LAQM) regime that has been established, whereby every authority has to carry out regular Reviews and Assessments of air quality in its area to identify whether the objectives have been, or will be, achieved at relevant locations, by the applicable date. If this is not the case, the authority must declare an Air Quality Management Area (AQMA), and prepare an action plan that identifies appropriate measures that will be introduced in pursuit of the objectives.

9.9 The objectives defined in the Strategy are linked to the air quality Limit Values set at a European level in the Ambient Air Quality Directive.

Aviation Policy Framework (2013)

9.10 The Aviation Policy Framework [4] sets out the Government's high level strategy and overall objectives for aviation, and replaces the 2003 Air Transport White Paper [5]. With regards to air quality, the policy is to seek improved international standards to reduce emissions from aircraft and vehicles, and to work with airports and local authorities to improve air quality, including encouraging transport operators to introduce less polluting vehicles. The Framework places a particular importance on areas where the EU limit values and air quality objectives are exceeded, but recognises that nitrogen oxides (NOx) concentrations from aviation-related activities reduce rapidly beyond the immediate area of the runway, and places emphasis on reducing emissions associated with surface access. In particular, the preparation of Airport Surface Access Strategies (ASASs) is strongly encouraged, together with the development of targets to reduce the air quality impacts of surface access.

National Planning Policy

9.11 The National Planning Policy Framework (NPPF) [6] introduced in March 2012 sets out planning policy for the UK in one document. It replaces the majority of previous Planning Policy Statements, including PPS23 on Planning and Pollution Control. The NPPF contains advice on when air quality should be a material consideration in development control decisions. Existing, and likely future, air quality should be taken into account, as well as the EU limit values and national objectives, the presence of any AQMAs, and the appropriateness of both the development for the site, and the site for the development.

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3 Defra (2007). The Air Quality Strategy for England, Scotland, Wales and Northern Ireland, July 2007.
4 The Stationery Office (2013). Aviation Policy Framework
5 DfT (2003) The Future of Air Transport
6 CLG (2012) National Planning Policy Framework

9.12 The NPPF places a general presumption in favour of sustainable development, stressing the importance of local development plans, and states that the planning system should perform an environmental role to minimise pollution. One of the twelve core planning principles notes that planning should *"contribute to…reducing pollution".*

9.13 To prevent unacceptable risks from air pollution, planning decisions should ensure that new development is appropriate for its location. The NPPF states that the effects of pollution on health and the sensitivity of the area and the development should be taken into account.

9.14 The need for compliance with any statutory air quality limit values and objectives is stressed, and the presence of AQMAs must be accounted for in terms of the cumulative impacts on air quality from individual sites in local areas. New developments in AQMAs should be consistent with local air quality action plans.

The NPPF is supported by National Planning Practice Guidance (NPPG) [(7)], which includes guiding principles on how planning can take account of the impacts of new development on air quality. The NPPG states that "*Defra carries out an annual national compliance assessment of air quality using modelling and monitoring to determine compliance with the EU Limit Values"* and *"It is important that the potential impact of new development on air quality is taken into account….where the national assessment indicates that relevant limits have been exceeded or are near the limit*". The role of local authorities is covered by the LAQM regime, and NPPG states that local authority Air Quality Action Plans "*identify measures that will be introduced in pursuit of the objectives".* In addition, the NPPG makes clear that *"odour and dust can also be a planning concern, for example, because of the effect on local amenity".*

9.15 NPPG states that *"whether or not air quality is relevant to a planning decision will depend on the proposed development and its location. Concerns could arise if the development is likely to generate an air quality impact in an area where air quality is known to be poor. They could also arise where the development is likely to adversely impact upon the implementation of air quality strategies and action plans and/or lead to a breach of EU legislation".*

National Networks National Policy Statement

9.16 The National Networks National Policy Statement (NN NPS) [(8)] sets out Government's policies on the development of nationally significant infrastructure projects on the national road and rail networks in England. CADP is neither a nationally significant infrastructure project, nor a road or rail project, but the provisions of the NN NPS are considered to be helpful in assessing the significance of air quality impacts as part of the decision-making process. Where relevant, the NN NPS states:

"The Secretary of State must give air quality considerations substantial weight where, after taking into account mitigation, a project would lead to a significant air quality impact in relation to EIA and/or where they lead to a deterioration in air quality in a zone/agglomeration"; and

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7 DCLG (2014) Planning Practice Guidance.
8 DfT (2014) National Policy Statement for National Networks

"The Secretary of State should refuse consent where, after taking into account mitigation, the air quality impacts of a scheme will:

- *Result in a zone/agglomeration which is currently reported as being compliant with the Air Quality Directive becoming non-compliant; or*
- *Affect the ability of a non-compliant area to achieve compliance within the most recent timescales reported to the European Commission at the time of the decision".*

Airports Commission

9.17 The Government established the Airports Commission in 2012 to propose measures to maintain the UK's status as a global hub for aviation. The focus was on delivering new capacity by 2030 and the Final report issued in July 2015 examined three options for new capacity: two separate runway options at Heathrow and one at Gatwick. A detailed Air Quality report [(9)] was produced that supported the analysis of the three options. This focussed on nitrogen dioxide, with some attention also given to particulate matter (PM_{10} and $PM_{2.5}$). For nitrogen dioxide a clear distinction was made between an assessment against the objectives and the limit values, following the methodology set out in the NN NPS (see above).

Regional Planning Policy and Guidance

The London Plan (2015)

9.18 The London Plan 2015 [(10)] consolidates the London Plan 2011 with the Revised Early Minor Alterations to the London Plan (2013) and the Further Alterations to the London Plan (2015). It sets out the spatial development strategy for London and brings together all relevant strategies, including those relating to air quality.

9.19 Policy 7.14, 'Improving Air Quality', addresses the spatial implications of the Mayor's Air Quality Strategy (described below) and how development and land use can help achieve its objectives. It recognises that Boroughs should have policies in place to reduce pollutant concentrations, having regard for the Mayor's Air Quality Strategy. With respect to planning decisions, it states that:

"Development proposals should:

a) minimise increased exposure to existing poor air quality and make provision to address local problems of air quality (particularly within AQMAs or where development is likely to be used by large numbers of those particularly vulnerable to poor air quality, such as children or older people) such as by design solutions, buffer zones or steps to promote greater use of sustainable transport modes through travel plans (see Policy 6.3);

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9 Jacobs (2015 Module 6: Air Qualtiy Local Assessment, Available at: www.gov.uk/government/uploads/system/uploads/attachment_data/file/426241/air-quality-local-assessment-report.pdf

10 GLA (2015) The London Plan: The Spatial Development Strategy for London Consolidated with Alterations Since 2011.

b) promote sustainable design and construction to reduce emissions from the demolition and construction of buildings following the best practice guidance in the GLA and London Councils "The control, of dust and emissions form construction and demolition";

c) be at least "air quality neutral" and not lead to further deterioration of existing poor air quality (such as areas designated as Air Quality Management Areas (AQMAs);

d) ensure that where provision needs to made to reduce emissions from a development, these usually are made on site. Where it can be demonstrated that on-site provision is impractical or inappropriate, and that it is possible to put in place measures having clearly demonstrated equivalent air quality benefits, planning obligations or planning conditions should be used as appropriate to ensure this, whether on a scheme by scheme basis or through joint area-based approaches;

e) where the development requires a detailed air quality assessment and biomass boilers are included, the assessment should forecast pollutant concentrations. Permission should only be granted if no adverse air quality impacts from the biomass boiler are identified."

Supplementary Planning Guidance on Sustainable Design and Construction (2014)

9.20 The GLA's revised SPG on Sustainable Design and Construction ([11]) provides guidance on when an air quality assessment will be needed to support a planning application, and what the assessment should address. It also sets new emissions standards for gas boilers, biomass plant and Combined Heat and Power (CHP) plant and provides guidance on the implementation of the "air quality neutral" policy as defined in the 2011 London Plan.

Supplementary Planning Guidance on the Control of Dust and Emissions from Construction and Demolition (2014)

9.21 The GLA has also published a SPG on the Control of Dust and Emissions from Construction and Demolition ([12]). The SPG outlines a risk-based approach for construction dust assessment and helps to determine the mitigation measures that will be required, and essentially follows the approach recommended by the Institute of Air Quality Management (IAQM) which is referred to in this Chapter.

The Mayor's Air Quality Strategy (2010)

9.22 The revised Mayor's Air Quality Strategy (MAQS) was published in December 2010 [(13)]. The overarching aim of the Strategy is to reduce pollution concentrations in London to achieve compliance with the EU limit values

11 GLA (2014) Supplementary Planning Guidance on Sustainable Design and Construction.
12 GLA (2014) Supplementary Planning Guidance on The Control of Dust and Emissions from Construction and Demolition.
13 GLA (2010). The Mayor's Air Quality Strategy. [Online] Available at: http://www.london.gov.uk/mayor/environment/air_quality

as soon as possible. The Strategy commits to the continuation of measures identified in the 2002 MAQS and sets out a series of additional measures, including:

Policy 1: Encouraging smarter choices and sustainable travel;

- Measures to reduce emissions from idling vehicles focusing on buses, taxis, coaches, taxis, PHVs and delivery vehicles;
- Using spatial planning powers to support a shift to public transport; and
- Supporting car free developments.

Policy 2: Promoting technological change and cleaner vehicles:

- Supporting the uptake of cleaner vehicles.

Policy 4: Reducing emissions from public transport:

- Introducing age limits for taxis and PHVs.

Policy 5: Schemes that control emissions to air:

- Implementing Phases 3 and 4 of the LEZ from January 2012
- Introducing a NOx emissions standard (Euro IV) into the Low Emission Zone (LEZ) for HGVs, buses and coaches, from 2015.

Policy 7: Using the planning process to improve air quality:

- Minimising increased exposure to poor air quality, particularly within AQMAs or where a development is likely to be used by a large number of people who are particularly vulnerable to air quality;
- Ensuring air quality benefits are realised through planning conditions and section 106 agreements and Community Infrastructure Levy.

Policy 8: Creating opportunities between low to zero carbon energy supply for London and air quality impacts:

- Applying emissions limits for biomass boilers across London;
- Requiring an emissions assessment to be included at the planning application stage.

Low Emission Zone (LEZ) (2008)

9.23 A Low Emission Zone (LEZ) for London was introduced under the Strategy on 4th February 2008. All roads within Greater London, excluding those parts of the M25 located within the Greater London boundary, are included within the LEZ. This entails charges for vehicles entering Greater London not meeting certain emissions criteria, and affects older, diesel-engine lorries, buses, coaches, large vans, minibuses and other specialist vehicles derived from lorries and vans.

9.24 The timescale for implementation of the LEZ was 2008 for diesel heavy goods vehicles (HGVs), coaches and buses; and 2010 for the heaviest, most polluting large vans and minibuses (a standard of Euro III). From January 2012, a standard of Euro IV was implemented for lorries over 12 tonnes, buses and coaches, with larger vans and minibuses also brought into the scheme. Cars and lighter goods vehicles (LGVs) are excluded. A NOx emissions standard (Euro IV) has been included into the LEZ for TfL operated buses from 2015.

Local Policies and Plans

9.25 The Newham Core Strategy was adopted in January 2012 (14). This forms part of the Local Development Framework (LDF) that will replace the Unitary Development Plan. Policy EQ46 of the UDP which had previously been saved, and which related to air quality, has now been superseded by the Core Strategy.

9.26 Core Strategy, Policy SP2: Healthy Neighbourhoods states that:

"The Council supports health care partners' efforts to promote healthy lifestyles and reduce health inequalities and recognises the role of planning in doing so through the creation of healthy neighbourhoods and places. To this end, development proposals which respond to the following contributors to health and well-being will be supported:

The need to improve Newham's air quality, reduce exposure to airborne pollutants and secure the implementation of the Air Quality Action Plan having regard to national and international obligations."

Air Quality Action Plans

9.27 Following the declaration of the Air Quality Management Area in the London Borough of Newham, a consultation Air Quality Action Plan (15) was published in 2003. A number of measures relate specifically to the Airport's operations – a summary of these and the progress made to date is summarised in Table 9.1 below.

Table 9.1 - Summary of Progress on Airport-Related Measures in LBN Action Plan

Measure	Progress
The Airport to carry out a detailed study of the impact of the airport on local air quality conditions.	As part of the 2007 planning application (07/01510/VAR) for expansion of operations to 120,000 'noise factored' movements per annum, a detailed air quality assessment was undertaken by the Airport to quantify the impact of Airport operations. Subsequent detailed assessments have been undertaken to support the CADP proposal (including this UES Chapter)
Green Transport Plan to be regularly updated	The Airport's Travel Plan 2011 has been updated in 2015 through an interim Travel Action Plan for both staff and passengers. This has been discussed and agreed through the Airport Transport Forum. Detailed Travel Plans will be prepared to consider passenger and staff travel in conjunction with CADP and the new Surface Access Strategy.
LBN to liaise with the Airport for the Vehicle Inspectorate to carry out random emission checks of queuing taxis at the Airport.	The Airport has indicated its willingness to support emissions testing. LBN is still in discussions with the Vehicle Inspectorate.
The Airport to meet its commitments under the s106 agreements to carry out a programme of air quality monitoring.	The Airport carries out an extensive Air Quality Monitoring Programme that goes above and beyond the previous and existing legal obligations.

14 LB Newham (2012). Planning Newham – The Core Strategy. Adopted January 2012 (Interim Version)(2).
15 LB Newham (2003). Consultation Report Air Quality Action Plan.

Measure	Progress
LBN and the Airport to continue to lobby for a Crossrail proposal that includes access to the Airport.	The Airport continues to lobby for appropriate facilities to be provided at Custom House station to accommodate a shuttle bus service to the Airport.

9.28 In June 2012, the Airport published its Air Quality Action Plan that sets out a range of measures to minimise pollutant emissions over the next three years [16]. The Action Plan has been approved by LBN, and the Airport is required to report on progress each year. The Action Plan focuses on measures to reduce emissions of NOx from Airport-related sources, including:

a) Aircraft operations;

b) Ground Support Equipment (e.g. Mobile Ground Power Units);

c) Airside vehicles; and

d) Black cabs (taxis).

9.29 The Airport's 2012-2015 AQAP is now in its final year, and a new version of the Action Plan, covering the period 2016 to 2018 has been developed and submitted to LBN for initial comments. The final updated Action Plan for this period will be submitted to LBN for approval before the end of 2015. At this stage, it is intended that the existing measures will be consolidated but, in general terms, all relevant measures will be retained.

Summary of Regulations and Policies Relating to Air Quality

9.30 The key message arising from national, regional and local regulations and policies is that considerable care needs to be taken with developments that have potential to materially affect air pollution at locations that are within, or close to, Air Quality Management Areas (AQMAs). It is necessary to ensure that new developments do not cause existing poor air quality conditions to deteriorate further. It is also important to ensure that new development does not conflict with or hinder any measures that are introduced to improve local air quality conditions.

Assessment Criteria

Health Criteria

9.31 The Government has established a set of air quality standards and objectives to protect human health. The 'standards' are set as concentrations below which effects are unlikely even in sensitive population groups, or below which risks to public health would be exceedingly small. They are based purely upon the scientific and medical evidence of the effects of an individual pollutant. The 'objectives' set out the extent to which the Government expects the standards to be achieved by a certain date. They take account of economic

16 London City Airport (2012). Air Quality Action Plan 2012-2015. [Online], Available: http://www.londoncityairport.com/AboutAndCorporate/page/AirQuality

efficiency, practicability, technical feasibility and timescale. The objectives for use by local authorities are prescribed within the Air Quality Regulations 2000 [(17)] and Amending Regulations 2002 [(18)].

9.32 Local Air Quality Management Technical Guidance *LAQM.TG(09)* [(19)] provides evidence that the 1-hour nitrogen dioxide objective is unlikely to be exceeded where the annual mean concentration is below 60 µg/m^3. Therefore, 1-hour mean nitrogen dioxide concentrations need normally only be considered if the annual mean concentration is above this level.

9.33 More recently, health criteria have been introduced for $PM_{2.5}$. The 2007 Air Quality Strategy sets out both an exposure-reduction approach and a "backstop" annual mean objective for $PM_{2.5}$. The former is an objective focused on reducing average exposures across the most heavily populated areas of the country, and is not directly applicable to individual schemes. It is supported by the "backstop objective" or concentration cap to ensure a minimum environmental standard.

9.34 The objectives apply at locations where members of the public are likely to be regularly present and are likely to be exposed over the averaging period of the objective. Defra explains where these objectives will apply in its Local Air Quality Management Technical Guidance. The annual mean objectives for nitrogen dioxide and PM_{10} are considered to apply at the façades of residential properties, schools, hospitals etc.; they do not apply at hotels. The 24-hour objective for PM_{10} is considered to apply at the same locations as the annual mean objective, as well as in gardens of residential properties and at hotels. The 1-hour mean objective for nitrogen dioxide applies wherever members of the public might regularly spend 1-hour or more, including outdoor eating locations and pavements of busy shopping streets.

9.35 The European Union has also set limit values for nitrogen dioxide, PM_{10} and $PM_{2.5}$ which are defined in the Ambient Air Quality Directive. These limit values have been incorporated into UK legislation via the Air Quality Standards Regulations 2010 [(20)]. Achievement of these values is a national obligation rather than a local one. In the UK, only monitoring and modelling carried out by the UK Government meets the specification required to assess compliance with the limit values. Defra does not recognise local authority monitoring or modelling studies in determining whether the limit values are exceeded, and in reporting compliance to the European Commission. The limit values for nitrogen dioxide are the same levels as the UK objectives, and were to be achieved by 2010. The limit values for PM_{10} are also the same level as the UK statutory objectives, and were to be achieved by 2005. The Directive also includes a national exposure reduction target, a target value and a limit value for $PM_{2.5}$.

9.36 The relevant objectives and limit values for this assessment, as defined within the Regulations, are provided in Table 9.2.

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17 The Stationery Office (2000). Air Quality Regulations, 2000, Statutory Instrument 928.
18 The Stationery Office (2002). Air Quality (England) (Amendment) Regulations, 2002, Statutory Instrument 3043.
19 Defra (2009). Local Air Quality Management, Technical Guidance TG(09).
20 The Stationery Office (2010). Air Quality Standards Regulations (No. 1001)

Table 9.2 - Air Quality Objectives and European Directive Limit Values

Pollutant	Concentration Measured As	Obligation	To Be Achieved By
Air Quality Objectives			
Nitrogen dioxide	Annual mean	40 µg/m^3	31 December 2005
	1 hour mean	200 µg/m^3	31 December 2005
PM_{10}	Annual mean	40 µg/m^3	31 December 2004
	1 hour mean	200 µg/m^3	31 December 2004
$PM_{2.5}$	Annual mean	25 µg/m^3	2020
	3 year running annual mean	15% reduction in concentrations measured at urban background sites	Between 2010 and 2020
European Directive Limit and Target Values			
Nitrogen dioxide	Annual mean	40 µg/m^3	01 January 2010
	1 hour mean	200 µg/m^3	01 January 2010
PM_{10}	Annual mean	40 µg/m^3	01 January 2005
	1 hour mean	200 µg/m^3	01 January 2005
$PM_{2.5}$	Annual mean	Target value of 25 µg/m^3	2010
	Annual mean	Limit value of 25 µg/m^3	2015
	Annual mean	Stage 2 indicative Limit value of 20 µg/m^3	2020
	3 year Average Exposure Indicator (AEI)	Exposure reduction target relative to the AEI depending on the 2010 value of the 3 year AEI (ranging from a 0% to a 20% reduction)	2020
	3 year Average Exposure Indicator (AEI)	Exposure concentration obligation of 20 µg/m^3	2015

Construction Dust Criteria

9.37 There are no formal assessment criteria for dust arising from construction activities. In the absence of formal criteria, the approach developed by the Institute of Air Quality Management [(21)] (IAQM) has been used [(22)], on which the assessment methodology outlined in the 2014 GLA Supplementary Planning Guidance[23] is based. This approach divides the activities on construction sites into four types to reflect their different potential impacts (i.e. demolition, earthworks, construction and trackout [(24)] and then takes a phased approach to the assessment:

a) **STEP 1**: Screen the need for a detailed assessment.

b) **STEP 2**: Assess the risk of dust effects occurring.

c) **STEP 3**: Identify the need for site specific mitigation.

d) **STEP 4**: Define effects and their significance.

21 The Institute of Air Quality Management (IAQM) is the professional body for air quality practitioners in the UK.
22 Institute of Air Quality Management (2014) *Guidance on the assessment of dust from demolition and construction*
23 The Control of Dust and Emissions During Construction and Demolition Supplementary Planning Guidance (Greater London Authority, 2014)
24 This refers to dust that is transported outside of the site by way of vehicles on the local road network.

9.38 The IAQM does not provide a method for assessing the significance of effects before mitigation, and advises that pre-mitigation significance should not be determined.

9.39 Full details of this approach are provided in Appendix 9.1 to this UES.

Descriptors for Air Quality Impacts and Assessment of Significance of Operational Heath-Based Effects

9.40 There is no official guidance in the UK on how to describe the nature of air quality impacts, nor how to assess their significance. The approach developed jointly by Environmental Protection UK (EPUK) and the Institute of Air Quality Management (IAQM) [(25)] has therefore been used. This includes defining descriptors of the impacts at individual receptors which take account of the percentage change in concentrations relative to the air quality objective, rounded to the nearest whole number, and the absolute concentration relative to the objective. The overall significance of the air quality impacts is determined using professional judgement taking into account the impact descriptors. In this regard it is important to recognise the difference between the terms "impacts" and "effects"; the term impact is used to describe a change in pollutant concentration at a specific location, whereas the term effect is used to describe an environmental response resulting from an impact, or series of impacts.

9.41 The impact descriptors express the magnitude of incremental change as a proportion of the relevant assessment level, and then examining this change in the context of the new, total concentration, and its relationship to the assessment criterion. Table 9.3 sets out the method for determining the impact descriptor for annual mean concentrations at individual receptors, and has been adapted from the table in the guidance document. The Air Quality Assessment Level (AQAL) refers to the annual mean objectives. Impacts may be adverse or beneficial, depending on whether the change in concentration is positive or negative.

Table 9.3 - Air Quality Impact Descriptors for Individual Receptors[a]

Long -Term Average Concentration at Receptor in Assessment Year [b]	Change in concentration relative to AQAL [c]				
	0%	1%	2-5%	6-10%	>10%
75% or less of AQAL	Negligible	Negligible	Negligible	Slight	Moderate
76-94% of AQAL	Negligible	Negligible	Slight	Moderate	Moderate
95-102% of AQAL	Negligible	Slight	Moderate	Moderate	Substantial
103-109% of AQAL	Negligible	Moderate	Moderate	Substantial	Substantial
110% or more of AQAL	Negligible	Moderate	Substantial	Substantial	Substantial

a Values are rounded to the nearest whole number
b This is the "without scheme" concentration where there is a decrease in concentration, and the "with scheme" concentration where there is an increase
c AQAL = Air Quality Assessment Level (e.g. the air quality objective).

25 Moorcroft and Barrowcliffe et al (2015). Land-use Planning and Development Control: Planning for Air Quality. Institute of Air Quality Management, London.

9.42 The potential significance of effects is based on the frequency, duration and magnitude of the predicted impacts and their relationship to the relevant air quality objectives, taking into account the following factors:

a) the existing and future air quality in the absence of the development;

b) the extent of current and future population exposure to the impacts;

c) the influence and validity of any assumptions adopted when undertaking the prediction of impacts;

d) the potential for cumulative impacts to occur. Several impacts that are described as "slight" individually could, taken together, be regarded as having a significant effect. Conversely, "moderate" or "substantial" impacts may be regarded as having no significant effect if confined to a very small area and where they are not obviously the cause of harm; and

e) the judgement of significance relates to the consequences of the impacts. Will they have an effect on human health that could be considered as significant? In the majority of cases the impacts from an individual development will be insufficiently large to result in measurable changes in concentrations in health outcomes that could be regarded as significant by health care professionals.

9.43 The guidance notes that the judgement of significance should be made by a competent professional who is suitably qualified. A summary of the professional experience of staff contributing to this assessment is provided in Appendix 9.2 of this UES.

9.44 Guidance on how a local authority might determine whether an application is significant in terms of air quality was issued by the London Councils in 2007 (26). Although the London Councils guidance precedes that issued by IAQM/EPUK by a number of years, LBN specifically requested within its Scoping Opinion that reference be made to it (see Appendix 3.2 of this UES). The guidance notes that it is important that an air quality assessment evaluates modelled air quality in terms of "*changes in pollution concentrations"* where there is relevant public exposure.

9.45 The guidance is founded on the use of a flowchart which is intended to determine the significance of a development, based on the professional judgement of a local authority officer. Reference is also made to Air Pollution Exposure Criteria (APEC) with regard to the determination of significance and the level of mitigation required; however, there is no clear link between the flowchart and the APEC table. In addition the APEC values are predicated on the assumption that a downward trend in pollutant concentrations has been established. As discussed later within this Chapter, there is no strong evidence to support a downward trend in pollutant concentrations at some locations. A summary of the London Councils' guidance is provided in Appendix 9.3.

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26 London Councils (2007). Air Quality and Planning Guidance.

Health Effects and Air Pollution

9.46 The health effects associated with increased exposure to particulate matter are well-recognised, and there is no safe threshold below which it can be assumed that there would be no adverse effect. The greatest impact is believed to be associated with long-term exposure to $PM_{2.5}$ which increases the age-specific mortality risk, particularly for cardiovascular diseases. In 2010, the Committee on the Medical Aspects of Air Pollution (COMEAP) reported on the mortality effects of long-term exposure to $PM_{2.5}$ [(27)]. It recommended a risk coefficient for all-cause mortality of 1.06 (6%) per 10 µg/m^3 change in exposure to annual average $PM_{2.5}$ concentrations, with sensitivities at 1% and 12%.

9.47 More recently, evidence has emerged that exposure to nitrogen dioxide can, independently of particulate matter, play a role in reducing life expectancy. In March 2015, COMEAP [(28)] published a statement on the evidence of the effects of nitrogen dioxide on health, drawing upon evidence published by the World Health Organisation's (WHO) Review of Evidence on Health Aspects of Air Pollution (REVIHAAP) [(29)]. COMEAP concluded that the evidence of associations of ambient concentrations of nitrogen dioxide with a range of effects on human health had strengthened in recent years, and that it would be sensible to regard nitrogen dioxide as causing some of the health impact found to be associated with it in epidemiological studies. At this time, COMEAP did provide any recommendations for concentration-response functions, but indicated that it intended to do so by the end of 2015. Coefficients have been recommended in the WHO's Health Risks of Air Pollution in Europe (HRAPIE) report [(30)], and have recently been applied by King's College London to estimate the mortality burden on nitrogen dioxide exposure in London [(31)]. This approach assumes a 30% overlap in effect with $PM_{2.5}$, and is based upon a 3.9% increase in mortality per 10 µg/m^3 change in exposure to annual average nitrogen dioxide concentrations, with 95% confidence intervals at 2.2% and 5.6%.

Criteria for the Assessment of Odours

9.48 In considering the potential for odour effects, an important distinction should be drawn between the occasional detection of an odour and a loss of amenity due to odour, the latter generally being associated with persistent and long-lived problems.

9.49 Guidance note H4 Odour Management, published by the Environment Agency, provides a useful approach to quantifying odour effects [(32)]. Odour concentrations are measured in European odour units (OU_E/m^3). The odour concentration at the detection threshold is 1 OU_E/m^3.

9.50 Guidance Note H4 suggests that there is a likelihood of unacceptable odour pollution occurring where the 98^{th} percentile of 1-hour mean odour concentrations exceeds 1.5 OU_E/m^3 for the most offensive odours, 3 OU_E/m^3 for moderately offensive odours and 6 OU_E/m^3 for less offensive odours.

[27] COMEAP (2010) The Mortality Effects of Long-Term Exposure to Particulate Air Pollution in the United Kingdom
[28] COMEAP (2015) Statement on the Evidence for the Effects of Nitrogen Dioxide on Health
[29] WHO (2013) Review of evidence on health aspects of air pollution – REVIHAAP project: final technical report.
[30] WHO (2013) Health risks of air pollution in Europe (HRAPIE): Recommendations for concentration-response functions for cost-benefit analysis of particulate matter, ozone and nitrogen dioxide.
[31] King's College London (2015) Understanding the Health Impacts of Air Pollution in London.
32 Environment Agency (2011) *H4 Odour Management*

9.51 The perception of the offensiveness of odours is highly subjective, but airport-related odours cannot reasonably be classified as most offensive (a category which includes decaying animal remains and septic effluent). For the purpose of this assessment it is assumed that airport-related odours fall within the less to moderately offensive categories (which includes breweries, livestock rearing and food processing).

Assessment Methodology

Study Area

9.52 The study area is effectively defined by an approximately 1km radius around the runway (beyond which any effects are unlikely to be discernible) and the extent of the road transport network considered within the Transport Assessment (as shown in Figure 9.3).

Baseline Conditions

9.53 Information on existing air quality has been obtained by collating the results of monitoring carried out by both the Airport and the local authorities. This covers both the study area and nearby sites, the latter being used to provide context for the assessment. The background concentrations across the study area have been defined using the national pollution maps published by Defra (33). These cover the whole country on a 1x1 km grid. Current exceedences of the annual mean EU limit value for nitrogen dioxide have been identified using the maps of roadside concentrations published by Defra (34). These are the maps, presently based on 2012 data used by the UK Government, together with the results from national AURN monitoring sites that operate to EU data quality standards, to report exceedences of the limit value to the EU. There are no equivalent maps for 2013, 2014, or any other future year.

9.54 Records of complaints related to local air quality issues (odours, smoke and black smut deposits) are maintained by the Airport and reported annually to LBN. These complaint records have been reviewed to inform the assessment.

Construction Effects

9.55 Potential effects during construction may arise from emissions from construction traffic and on-site plant, and emissions of dust associated with the construction activities.

9.56 Locations sensitive to dust emitted during construction will be places where members of the public are regularly present. Residential properties and commercial operations close to the construction works will be most sensitive to construction dust. Any areas of sensitive vegetation or ecology that are very close to the dust sources may also be susceptible to some negative effects.

9.57 As discussed above, it is very difficult to quantify emissions from construction activities and it is thus common practice to provide a qualitative assessment of potential effects, making reference to the assessment criteria set out in Appendix 9.1.

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33 Defra (2011a) *Defra Air Quality Website*, [Online], Available: http://www.defra.gov.uk/environment/quality/air/airquality/
34 Defra (2015) UK Ambient Air Quality Interactive Maps [Online] uk-air.defra.gov.uk/data/gis-mapping

Sensitive Receptors

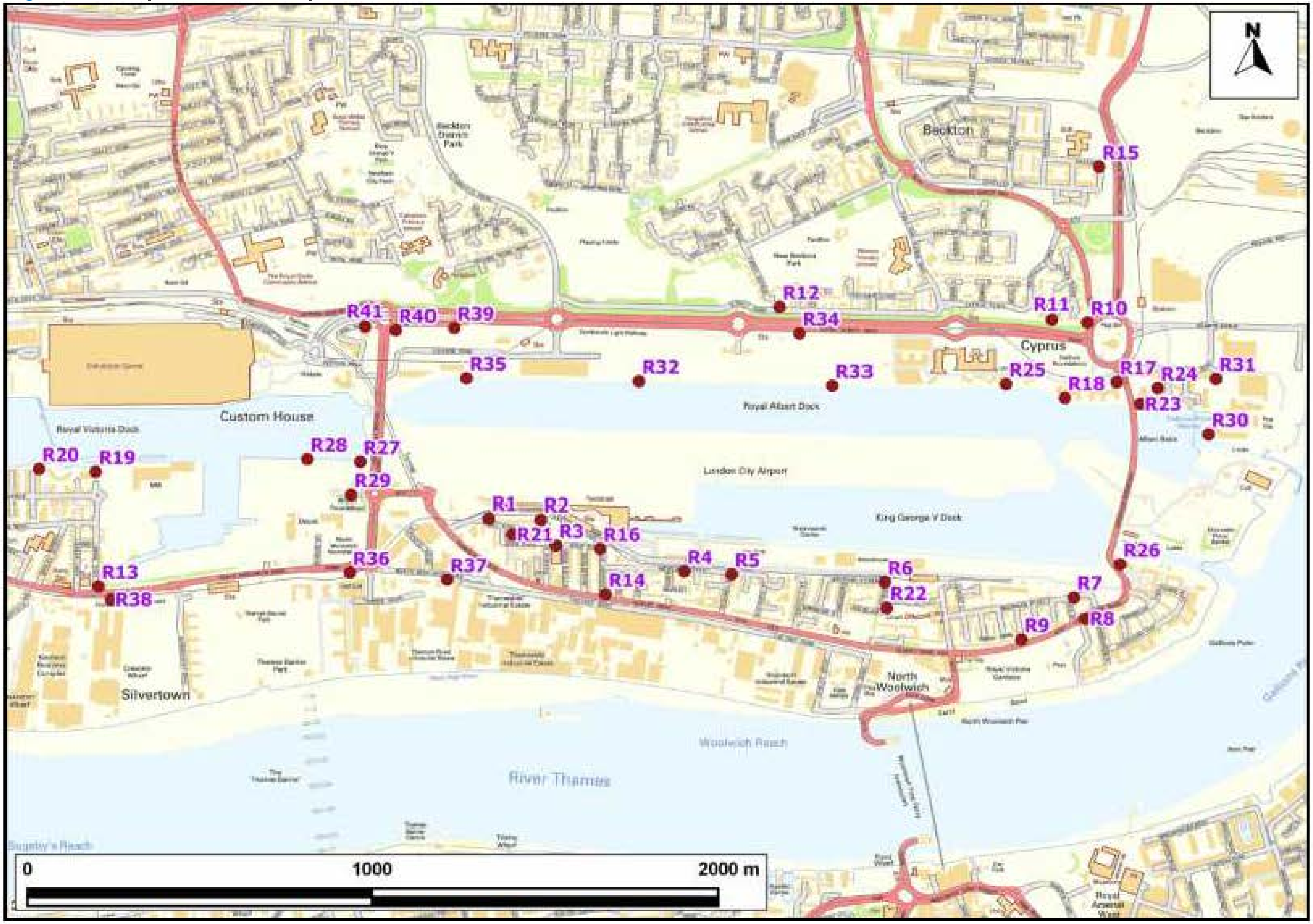
9.58 Sensitive receptors during the construction phase will be restricted to properties within the appropriate distance bands as set out in Appendix 9.1. Receptors at greatest risk of being affected by dust emissions are those residential properties that lie immediately to the south of Newland Street and Brixham Street, and the community facilities (The Storey Centre, Woodman Community Centre and Fight for Peace) which lie just to the south of the construction compound at the eastern end of the site. There are no sensitive ecological receptors that might be adversely affected, as described in Chapter 13: Ecology and Biodiversity.

9.59 Sensitive receptors during the operational phase are places where members of the public might be expected to be regularly present over the averaging periods of the objectives/limit values. For the annual mean and daily mean objectives/limit values, that are the principal focus of this assessment, sensitive receptors will generally be residential properties, schools, nursing homes etc.

9.60 A total of 26 existing sensitive receptors have been selected for the operational assessment. Where appropriate, these include additional receptors at height to account for blocks of flats. Additional receptor locations have been included for all future scenarios to account for proposed developments at Silvertown Quays, Barrier Park East, Minoco Wharf, Royals Business Park Hotels, North Side of Albert Dock, UEL, Gallions Roundabout, Gallions Quarter, Royal Albert Basin and Land at Gallions Reach (as described in UES Table 18.2, Chapter 18: Cumulative Effects). These have been selected to coincide with new developments within 1km of the Airport runway, and along the road network potentially affected by the proposed CADP. As the design details for many of these new developments are not yet finalised, it has been necessary to make assumptions regarding the likely heights of the buildings in the new developments.

9.61 The operational receptor locations are shown in Figure 9.2 and described in Table 9.6 below.

Figure 9.2 – Operational Receptor Locations



Appendix AQ.1.8

Table 9.6 – Sensitive Operational Receptor Locations (1.5m elevation unless stated)

Receptor ID	Description	OS Grid Ref
Existing Locations		
R1	Camel Road/Hartmann Road	541982, 180307
R2	Camel Road/Parker Street	542133, 180304
R3	Parker Street (Portway Primary School)	542177, 180229
R4	Newland Street (opposite entrance to LCY car park)	542549, 180153
R5	Newland Street/Kennard Street	542687, 180145
R6	Brixham Street/Dockland Street	543127, 180121
R7	Platterns Court/Billingway Dock Head	543676, 180077
R8	Albert Road/Woolwich Manor Way	543709, 180015
R9	Robert Street adj Albert Road (north side)	543523, 179954
R10	Collier Close adj Gallions Way Roundabout (eastern side)	543715, 180875
R11	Yeoman Close adj Royal Albert Way	543612, 180883
R12	Straight Road/Campton Close	542826, 180920
R13	Mill Rd adj North Woolwich Road (west)	540854, 180110
R14	Connaught Road/Leonard Street	542321, 180086
R15	Gallions Primary School adjacent to Royal Docks Road	543749, 181324
R16	Drew Road/Leonard Street	542306, 180219
R17	Woolwich Manor Way (UEL)	543800, 180701
R18	Woolwich Manor Way (UEL)	543650, 180655
R19	West Silvertown 1	540846, 180439
R20	West Silvertown 2	540681, 180448
R21	Flats on Drew Road	542050, 180261
R22	Flats on Docklands Street	543133, 180047
R23	Gallions Quarter	543868, 180637
R24	Gallions Quarter	543919, 180684
R25	University of East London Student Accommodation	543478, 180695
R26	Felixstowe Court	543810, 180174
Proposed/Committed Developments		
R27	Silvertown Quays 1	541614,180468
R28	Silvertown Quays 2	541460,180476
R29	Silvertown Quays, 30 m from Connaught Bridge	541587,180372
R30	Royal Albert Basin	544067,180548
R31	Royal Albert Basin	544088,180710
R32	North Side of Royal Albert Dock	542418,180704
R33	North Side of Royal Albert Dock	542979,180691
R34	North side of Royal Albert Dock (10m from Royal Albert Way)	542884,180843
R35	North Side of Royal Albert Dock	541917, 180713
R36	Barrier Park East	541583, 180149
R37	UNEX	541862, 180129
R38	Royal Wharf	540890, 180071
R39	Royals Business Park Hotel Site 2.3	541882, 180859
R40	Royals Business Park Hotel Site 2.2	541716, 180852
R41	Fox & Connaught Hotel, Lynx Way	541627, 180863

Appendix AQ.1.8

Operational Effects – Airport Operations and Road Traffic

Assessment Years and Scenarios

9.62 Predictions of nitrogen dioxide, PM_{10} and $PM_{2.5}$ concentrations have been carried out for the Baseline Year (2014) and three future assessment years, 2020, 2023 and 2025, in accordance with the assumptions set out in Chapter 3: EIA Methodology. For the future year assessments, predictions have been made both assuming that the proposed CADP does proceed ('With CADP') and does not proceed ('Without CADP') so that the incremental effects can be quantified.

9.63 For the 2020 Transitional Year, the assessment has been carried out using forecasts based on the two phase construction of the CADP under the *Updated Construction Programme,* as described in Chapter 6: Development Programme and Construction. For both 2023 (Design Year) and 2025 (Principal Assessment Year), the With CADP Core Case is also considered.

9.64 A number of sensitivity tests have also been carried out to evaluate the implications of the different 'With CADP' scenarios on air quality. For the 2023 With CADP Core Case, a sensitivity test has been considered which assumes a higher passenger load factor of 67% (the 'Higher Passenger Sensitivity Test'). As described in UES Chapter 3, this does not affect the aircraft movements, but increases the surface access movements in line with the greater number of passengers. For both 2023 and 2025, a further sensitivity test has been undertaken which assumes a faster re-fleeting ('With CADP Faster Move to Jets'). Lastly, an assessment based on forecasts for the 'With CADP Single Phase Development (Accelerated Construction) Sensitivity Test' is provided in Appendix 6.6 of the UES.

9.65 For 2025, an assessment has also been carried out for the Without CADP Higher Jet Centre Case.

9.66 A summary of the sensitivity test scenarios considered is provided below:

a) 2020 With CADP Single Phase Development

b) 2023 With CADP Higher Passenger Case

c) 2023 With CADP Faster Move to Jets

d) 2025 With CADP Higher Passenger Case

e) 2025 With CADP Faster Move to Jets

f) 2025 Without CADP Higher Jet Centre Growth

9.67 Further sensitivity checks for the 2020 scenarios have been carried out for nitrogen dioxide that involve assuming no reduction in emission factors for road traffic from the Baseline Year (2014). This is to address the issue identified by Defra [35] that road traffic emissions have not been declining as expected (see later section on Uncertainty). Nitrogen dioxide concentrations in 2020, with and without the proposed CADP, are thus presented for two scenarios: 'With Emissions Reduction' and 'Without Emissions Reduction'. In 2023 and 2025 it is assumed that emissions controls on new vehicles will be effective and thus only 'With Emissions Reduction' predictions are presented (see section on Uncertainty).

9.68 Predictions have been carried out for all scenarios to quantify potential odour effects from ground-based aircraft operations.

Air Quality Model

9.69 The predictions have been carried out using the ADMS-Airports model. This model incorporates a jet module specifically designed to represent the dispersion of emissions from moving aircraft, and was selected by the Project for the Sustainable Development of Heathrow (PSDH) for use at Heathrow airport.

9.70 The model requires the user to provide a variety of input data, which describe the pollutant emissions arising from the proposed development, the meteorological conditions, and the background contribution (i.e. the contribution to pollutant concentrations from all sources not explicitly included in the model).

9.71 Pollutant emissions arise from a number of Airport-related sources, and the following were taken into consideration in this assessment:

a) Aircraft main engines operating within the Landing and Take-off (LTO) Cycle, Auxiliary Power Units (APUs) and engine testing;

b) Airside support vehicles and plant (e.g. Mobile Ground Power Units);

c) Airport boiler plant and CHP;

d) Fire training ground;

e) Staff and passenger vehicle movements within the car parks; and

f) Road traffic on Airport landside roads and on the local road network.

9.72 The approach to quantifying emissions from the Airport sources has been based on generally accepted methodologies, and, as far as was practicable, follows the sophisticated or advanced approach recommended by the International Civil Aviation Organisation (ICAO) in its *Airport Air Quality Manual* [36]. For all airside sources, emissions of PM were assumed to represent both the PM_{10} and $PM_{2.5}$ fractions, based on the expected size distributions.

35 Carslaw, D., Beevers, S., Westmoreland, E. and Williams, M. (2011) *Trends in NOx and NO_2 emissions and ambient measurements in the UK*, [Online], Available: uk-air.defra.gov.uk/reports/cat05/1108251149_110718_AQ0724_Final_report.pdf.

36 ICAO (2011). *Airport Air Quality Manual.* [Online], Available: http://www.icao.int/icao/en/env2010/Publications.htm

Aircraft Operations – Landing and Take-off Cycle (LTO)

9.73 The emissions arising from each aircraft movement have been calculated as the sum of the emissions for each part of the LTO cycle. Records of Baseline Year aircraft mix and numbers of aircraft movements were derived from the 2014 Annual Performance Report [(37)]. Forecast movements and aircraft mix for all future scenarios were derived from the Update to the Need Statement (York Aviation, September 2015). A summary of the aircraft data used in this assessment is provided in Tables A4.1 to A4.5 (Appendix 9.4).

9.74 All turbofan-type aircraft jet engines with a rated power greater than 26.7 kN are certified by the International Civil Aviation Organisation (ICAO) for emissions of NOx, HC and Smoke Number. In addition, a database of emissions indices for all commercially operational turboprop aircraft engines is kept by the Swedish Defence Research Agency (FOI). For each type of aircraft, emissions per aircraft movement have been calculated using emission factors in grammes of pollutant per kilogram of fuel burnt, together with fuel flow in kilogrammes per second, based on the following equation:

$$E_{ij} = \sum (TIM_{jk}*60) * (FF_{jk}) * (EI_{jk}) * (NE_j) \qquad \text{Equation [1]}$$

Where:

E_{ij} = Emissions of pollutant *i* in grammes, produced by aircraft type *j* for each LTO cycle;

TIM_{jk} = Time-in-mode for mode *k* (e.g. idle, approach, climb-out or take-off) in minutes for aircraft type j

FF_{jk} = Fuel flow for mode *k* (e.g. idle, approach, climb-out or take-off) in kg/sec for each engine on aircraft type *j*

EI_{jk} = Emissions index for each pollutant *i* in grammes per kilogram of fuel, in mode k, for each engine used on aircraft type *j*

NE_j = Number of engines on aircraft type *j*

9.75 The emissions indices have been obtained from either the International Civil Aviation Organisation (ICAO) *Engine Exhaust Emissions Databank* [(38)] or the FOI *Aircraft Engine Emissions Database* [(39)] for turbofan (jet) engines and turboprop engines respectively. Airframe/engine assignments in 2014 were based on actual data for all aircraft.

9.76 Smoke number emissions indices are not available for all aircraft engines in all of the four ICAO standard thrust settings (100%, 85%, 30% and 7%). Where Smoke Number indices for an engine in a particular mode or modes are missing from the ICAO databank, the Smoke Number indices have been estimated based on the maximum Smoke Number for the engine, and the recommended scaling factors presented in Table D-1 of the ICAO *Airport Air Quality Manual*.

37 London City Airport (2015). 2014 Annual Performance Report, [Online], Available: http://www.londoncityairport.com/AboutUs/OurEnvironment.aspx.

38 International Civil Aviation Organisation (ICAO) Engine Exhaust Emissions Databank, [Online], Available: http://www.caa.co.uk/default.aspx?catid=702.

39 Swedish Defence Research Agency (FOI) Aircraft Engine Emissions Database

9.77 For the 2014 Baseline Year, the aircraft were assigned into "groups" of similar characteristics (e.g. numbers of engines, engine types, engine mounting and wake category) with a "lead" aircraft selected to represent each group. These group assignments are shown in Table A4.6 (Appendix 9.4). The emissions, and input parameters for the ADMS-Airport model, were then based on the assumption that the total number of movements within each group was represented by the lead aircraft. As a sensitivity check, a comparison between the NOx emission rate for each group (assuming the individual aircraft types and movements) and the assumed, lead aircraft type and movements was carried out; a summary of these calculations is shown in Table A4.6 (Appendix 9.4). There is little difference between the NOx emission rates, and it was concluded that the grouping of the aircraft would have no significant effect on the assessment.

9.78 The approach used for the estimation of PM emissions arising from aircraft engines has undergone development in recent years. The original approach, based on the ICAO reported maximum Smoke Number, only estimated the non-volatile fraction of PM. To address this problem, the contribution of PM emissions from the volatile fraction was considered by a CAEP Working Group, and a First Order Approximation (FOA) method was derived; this approach estimates the non-volatile portion using the ICAO Smoke Number, but also estimates the volatile portion associated with the fuel sulphur content, fuel-based organics and lube oil. Version 3 of the FOA is now available (FOA *v3.0*) and is the approach recommended in the ICAO *Airport Air Quality Manual*. The FOA *v*3.0 approach has been used to estimate aircraft engine PM emissions.

9.79 Recent research comparing the FOA *v3.0* approach with measurements has identified a discrepancy in both the organic carbon and black carbon emissions indices [(40)]. Combined, these discrepancies result in a 3.4 factor underestimate of total $PM_{2.5}$ emissions. Accordingly, to account for this potential uncertainty, the FOA *v3.0* emissions indices for PM (both PM_{10} and $PM_{2.5}$) have been factored up by 3.4.

9.80 Emissions of PM from the turboprop and smaller (business) jet aircraft, where no Smoke Number indices are available, have been disregarded, but these are considered to be negligible.

9.81 The forthcoming Bombardier C100 aircraft will be equipped with two Pratt & Whitney PW1524G engines. The emissions from these engines have not yet been certified by ICAO, and there is no information in the emissions databases referenced above. Pratt & Whitney have stated to the Airport that the engine will meet a 45% margin below the CAEP6 standard for NOx, and a 50% margin below the CAEP6 standard for both hydrocarbons and Smoke Number. Information on emission rates of NOx and HC was provided by Bombardier for each mode of the LTO cycle, together with the Maximum Smoke Number, and are shown in Table A4.8 (Appendix 9.4). The emission rates were used directly, while PM emissions were estimated using the maximum Smoke Number in combination with the suggested Smoke Number scaling factors in the ICAO Airport Air Quality Manual and the FAO *v.*3.0 approach.

9.82 The forthcoming Embraer E190-E2 aircraft will be equipped with two Pratt & Whitney PW1900G series engines, which have also not yet received certification. These engines are very closely related to the PW1524G engines fitted to the Bombardier C100 aircraft; both have a maximum thrust rating of around 103 kN, both have a 12:1 bypass ratio, and both have a 73-inch fan diameter. The fuel flow and emissions

40 Stettler, M.E.J, Eastham, S and Barrett, S.R.H. (2011). Air Quality and public health impacts of UK airports. Part 1: Emissions. *Atmos Environ* 45, 5415-54124.

indices provided by Bombardier for the PW1524G engine have therefore been used for the PW1900G engine in the airport emissions inventories.

9.83 The International Civil Aviation Organisation (ICAO) has defined a specific LTO cycle with four modal phases, extending to a ceiling height of 3,000 feet (915 metres). Emission factors are provided for 'take-off' (100% thrust), 'climb-out' (85% thrust), 'approach' (30% thrust) and 'idle' (7% thrust). In reality, aircraft rarely take-off at 100% thrust - the actual take-off thrust used being dependent on a combination of factors including take-off weight and weather conditions. Following discussion with the Airport, and in consideration of the short runway, a take-off thrust of 100% was used for all aircraft departures, but is likely to represent a worst-case assumption.

9.84 Take-off roll along runway, and initial climb to 1500ft (457.5m) was assumed to be at 100% thrust setting. Climb-out after throttle back from 1500-3000ft (457.5-915m) was assumed to be at 85% thrust.

9.85 The majority of commercial jet aircraft operating at the Airport have reverse thrust capability, which may be deployed during landing to increase the rate of deceleration. However, the Airport discourages the use of reverse thrust to reduce noise, and the airlines also try to avoid the use of reverse thrust to minimise fuel consumption. As a result, only a very small number of aircraft movements at the Airport utilise reverse thrust above idle during landing. The assumption used in the modelling has therefore been that aircraft engine thrust is reduced to idle (7%) for landing roll-out (i.e. from the point of touchdown on the runway to the start of taxi); emissions from the small number of aircraft using reverse thrust above idle has been discounted as they will make an insignificant contribution to total runway emissions.

9.86 Emission factors within the ICAO and FOI databases are usually stated for new engines. Based on PSDH recommendations to account for engine deterioration, NOx emissions have been increased by 4.5% while, for all other pollutants, the fuel flow and subsequent calculation of emissions has been increased by 4.3%.

9.87 Times-in-mode for take-off, approach and climb-out have been derived from information provided by the Airport. For ground operations in 2014, information has been derived from the Electronic Flight Progress System (EFPS) that monitors the time that aircraft operate engines on the ground from engine start-up to start-of-roll at departure, and following aircraft touch down until engine shut-down on stand, on arrival. A summary of these data is provided in Table A4.9 (Appendix 9.4). For the future "Without CADP" scenarios, these times-in-mode were assumed to remain unchanged. For the future "With CADP" scenarios, the times-in-mode for taxi-in and taxi-out were adjusted in discussion with the Airport, in order to account for the new stand layouts and new parallel taxiway.

9.88 Emissions during climb-out and approach have been calculated to a ceiling height of 915 metres.

Brake & Tyre Wear

9.89 An allowance has also been made for PM emissions arising from brake and tyre wear based on a methodology developed during the PSDH work [41]. For brake wear, an emission factor of 2.51 x 10^{-7} kg PM_{10} per kg MTOW[42] was assumed. For tyre wear, the following relationship was used:

PM_{10} (kg) per landing = 2.23 x 10^{-6} x (MTOW kg) – 0.0874 kg Equation [2]

9.90 Emissions were calculated for all large aircraft. The relationship is not applicable to smaller aircraft, below 55,000 kg, and it was assumed the PM emissions from tyre wear follow a linear relationship between MTOW = 55,000 kg to MTOW = 0 kg.

Auxiliary Power Units

9.91 Auxiliary Power Units (APUs) are used to provide power to larger aircraft when the main engines are not running. APUs are used to condition the aircraft cabin when temperatures are uncomfortable, and are also required to start the main engines on some of the newer aircraft. Other requirements for APU use occur if there is an incompatibility between the aircraft system and the Fixed Electrical Ground Power (FEGP) or Mobile Ground Power Unit (MGPU) supplies, or if there is a technical fault.

9.92 Operational and Safety Information Notice (OSIN 04/12), issued by the Airport, requires the use of FEGP or MGPU whenever available and serviceable. APUs are required to be shut down as soon as practicable following arrival and not restarted until 10 minutes prior to departure, except when the ambient air temperature is below +5ºC or above +20ºC. Operators wishing to use APU when these temperature thresholds are exceeded, or where there are technical faults, are required to contact Air Traffic Control (ATC) who maintain a log of such events. An analysis of data for May-Oct 2012 indicates that such events are very uncommon, representing only about 0.35% of all aircraft movements (see Table A4.10, Appendix 9.4).

9.93 APU running times on arrival are dependent upon the availability of FEGP or MGPU; running times range from 1 to 5 minutes depending on how busy the Airport is. For the purpose of this assessment, a total APU running time of 13 minutes per LTO cycle has been assumed, which is likely to represent a worst case. Emissions for APUs have been calculated using the advanced approach as defined in the ICAO *Airport Air Quality Manual*. This assigns different emission indices to different APU operating loads, i.e. start-up (no load), normal running (maximum Environmental Control System (ECS)), and high load (Main Engine Start (MES)). The assumed Times-in-Mode, and assigned NOx, HC and PM emission rates are shown in Tables A4.11 to A4.13 (Appendix 9.4).

Engine Testing

9.94 Ground running of aircraft engines is occasionally required for testing and maintenance purposes. Emissions for the 2014 Baseline Year were derived from the records of ground running provided to the Council in the

41 Curran (2006) Method for estimating particulate emissions from aircraft brakes and tyres. Qinetic Q/05/01827
42 Maximum Take Off Weight

2014 Annual Progress Report [43]. These records include the number, duration and power settings of ground runs, the aircraft involved, and the stands used.

9.95 Ground running emissions were calculated from the duration of the run, and the associated fuel use and emission indices for the power setting used (100% or 7%). The total annual ground running emissions were then apportioned as an average emission rate and included in volume sources across the apron areas.

9.96 For all future scenarios, pollutant emissions from ground running were estimated by scaling up the 2014 Baseline Year emissions based on the projected increase in aircraft movements, taking account of the new aircraft types.

Airside Vehicles and Mobile Ground Power Units

9.97 Emissions from airside vehicles are associated with the transport of passengers and cargo to aircraft, and servicing and refuelling of aircraft, etc. Mobile Ground Power Units (MGPUs) provide auxiliary power for those aircraft without access to FEGP, when necessary.

9.98 An estimate of emissions from these sources has been based upon fuel (untaxed "red" diesel) consumption statistics for 2014 provided by the Airport, with the data disaggregated by user group (e.g. Ramp Services, Operations etc.). A list of vehicles with permanent airside passes for each user group was also provided, including the vehicle registration number and vehicle type[44]. Estimates of the Euro Standard distribution of these vehicles was based on the year of registration. An estimate of the average NOx and PM_{10} emissions from airside vehicles was made using fuel consumption data and Defra's emission factor toolkit [45], assuming an average vehicle speed of 5 km/h.

9.99 An inventory of MGPUs was also provided by the Airport, including the model number and age. All MGPUs operating at the Airport in 2014 were either electric, or were diesel-powered and met a Stage II or Stage IIIA emission standard according to EU Directive 2004/26/EC. All but two MGPUs at the Airport are Stage IIIA compliant; therefore, the assumption has been made that all MGPUs conform to Stage IIIA emissions standards, as the two older, Stage II MGPUs have limited use at the Airport and will be replaced in the future.

9.100 Emission factors for Stage IIIA diesel-powered plant (in g/kg fuel) have been obtained from the EMEP/Corinair *Emissions Inventory Guidebook* (Section 8 – Other mobile sources and machinery, Tables 8-3 to 8-5b) [46]. The total annual volume of red diesel used by the MGPUs (in 2014), was used to calculate the total annual NOx and PM emissions from MGPUs, using the emission factors obtained from the Corinair Guidebook.

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43 LCY Annual Performance Report (2014). [Online], Available: http://www.londoncityairport.com/AboutUs/OurEnvironment.aspx

44 For the purpose of this assessment, the winter equipment vehicles (e.g. tractors used for snow ploughs and de-icing equipment etc.) were ignored, as it is difficult to gauge their operational use in any given year. All fuel use was apportioned to those vehicles in constant operational use

45 Emissions Factor Toolkit v6.0.2 [Online], Available at (http://laqm.defra.gov.uk/review-and-assessment/tools/emissions-factors-toolkit.html)

46 EMEP/Corinair Emission Inventory Guidebook (2013). [Online], Available at: http://www.eea.europa.eu/publications/EMEPCORINAIR5

9.101 For the future year cases for airside vehicles, the total amount of fuel used in 2014 was scaled upwards by the ratio of the total number of passengers in each future-year case to the total number of passengers in 2014. The Airport has committed within its Air Quality Action Plan to ensuring that all airside vehicles (unless an exclusion is agreed with LBN) will comply with the London Low Emissions Zone as soon as possible [(47)], and that all replacement vehicles must comply with the latest Euro Standards. All non-LEZ compliant vehicles in 2014 were assumed to have been replaced by Euro 6/VI standard vehicles in all future cases. In addition, an adjustment was made to account for the age-related replacement of vehicles that are currently LEZ-compliant, such that the distribution of age in each future-year case remained unchanged (i.e. the number of years since manufacture). This approach takes account of Euro standards that have already been agreed within EU Directives, but not any future standards that may be implemented.

9.102 The Airport has recently completed the refurbishment of all FGEP on Stands 1-10, and has committed to installing FEGP on Stands 21-24, and on any new stands constructed as part of any apron improvements. The Airport has further decommissioned all MGPUs that do not conform to Stage II emissions limits as a minimum, and has invested in 10 new Powervamp Mobile Electrical Ground Power Units (MEGPU) which are "zero-emission". As FEGP will be available on most stands, the use of MGPU should be reduced in the future to principally that of backup supply. For all future year cases, it was assumed that MGPU fuel use would be reduced to 50% of that in 2014, which is likely to represent a worst case.

Fire Training

9.103 Emissions associated with fire training exercises make a very small contribution compared to other Airport-related sources, but have been included in this assessment for completeness. The Fire Service at the Airport provided details on current operations:

a) Fire training for fuel spills is carried out approximately three times per month. Either aviation kerosene or red diesel is used, with approximately 20-30 litres of fuel consumed over a 2 minute period.

b) The majority of fire training exercises use LPG. The volume of LPG consumed in 2014 (9,126 litres) was provided by the Airport.

9.104 Emissions data for the uncontrolled combustion of aviation kerosene and LPG were derived from the FAA *Air Quality Handbook* [(48)]. The location of the fire test rig, to the north of the Jet Centre, and the frequency of fire training operations, were assumed to remain unchanged in future years.

Road Traffic

9.105 Emissions arising from traffic on the local road network have been calculated using the ADMS-Roads (v3.4) dispersion model. Predictions are based on vehicle flow, composition and speed using the same emission factors published within the Emission Factor Toolkit (EFT, version 6.0.2) ([49]). The emission rates account for emissions of PM_{10} and $PM_{2.5}$ arising from brake and tyre wear and from road abrasion. Whilst PM emissions

47 This excludes certain types of specialist vehicles such as items of winter equipment and fire tenders, but this use only a very small proportion of total fuel in each year.

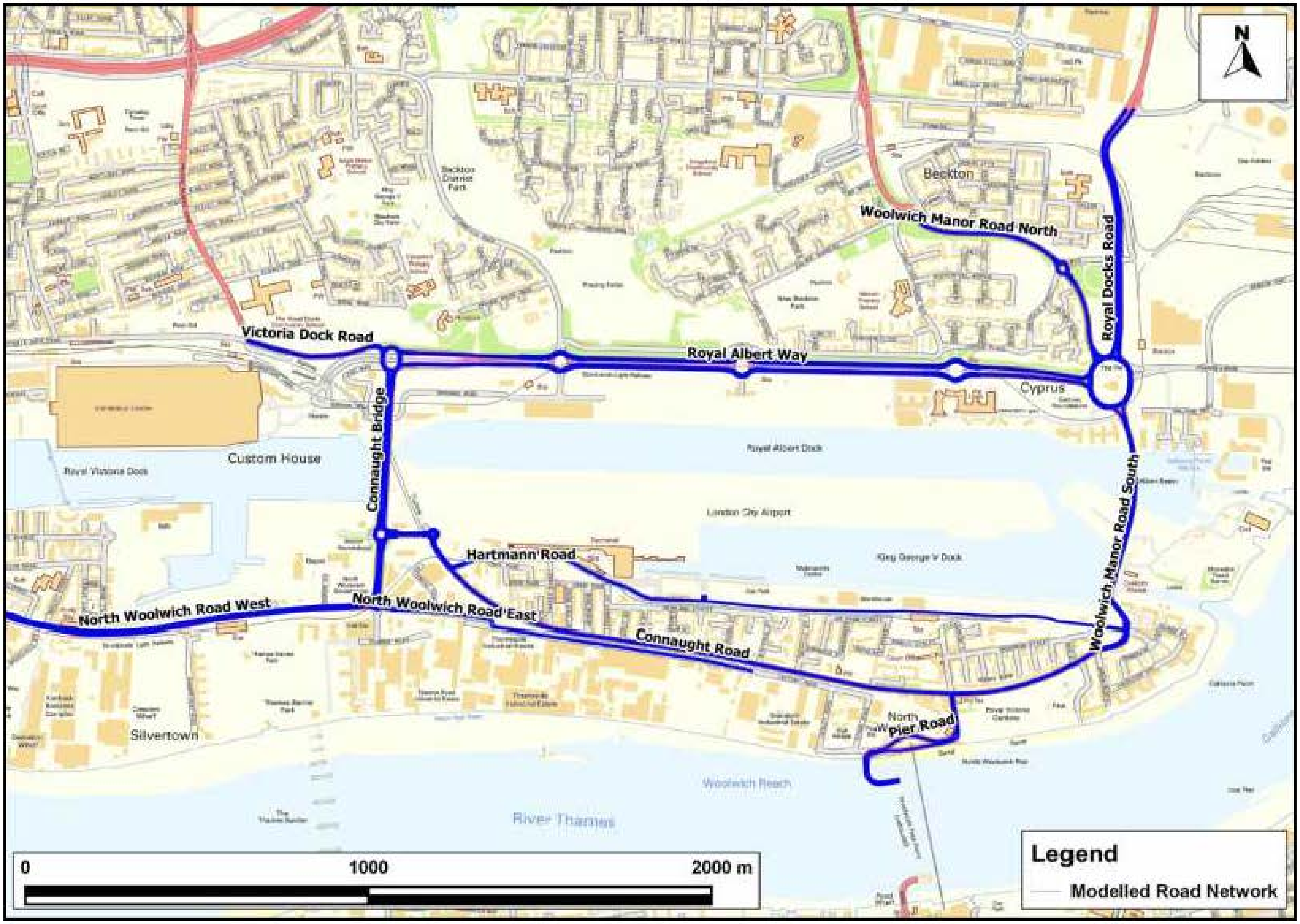
48 FAA (2005) . Air Quality Handbook. [Online], Available at: http://www.faa.gov/regulations_policies/policy_guidance/envir_policy/airquality_handbook/

49 Available at: http://laqm.defra.gov.uk/review-and-assessment/tools/emissions.html#eft

from entrainment (or “re-suspension”) of other materials on the road are also widely considered to be important, there are currently no data upon which robust emission rates can be calculated; any re-suspension component has therefore been necessarily ignored.

9.106 Annual average daily traffic (24 hr-AADT) flows, the proportions of Heavy Duty Vehicles (HDV) and average speeds for each road link were provided by Vectos for the 2014 Baseline Year and all future year scenarios, and are summarised in Tables A4.14 to A4.17 (Appendix 9.4). Additional information on the proportion of black cabs using the Airport access road (Hartmann Road) was also provided. The CADP proposals include the provision of a new access road to the Airport, along Hartmann Road east from Woolwich Manor Way; this new link has been included for the 2020, 2023 and 2025 future With CADP scenarios. The road links included in the assessment are shown in Figure 9.3 (NB – for the With CADP scenarios, public access to Hartmann Road via Woolwich Manor Way would be provided, as shown in this Figure).

Figure 9.3 – Road Links Included in the Assessment



Appendix AQ.1.8

9.107 Taxis (black cabs) currently picking up passengers from the Airport do so via a small rank on the terminal forecourt. This rank can only accommodate about 10 taxis, and so, during busy periods, a line of queuing taxis extends eastwards down Hartmann Road. A short survey related to taxi idling was carried out in April 2010 to inform the development of the Airport's Air Quality Action Plan. It is difficult to determine when a taxi is "unnecessarily idling", or is just in a slowly-moving queue, and so taxis were only considered to be "idling" if stationary, with engines running, for more than two minutes. Idling was not found to be a common occurrence along Hartmann Road; within the rank it was more frequently observed.

9.108 Emissions associated with queuing taxis in 2014 were derived from the total number of taxi movements per year, the assumed time queuing per movement (240 seconds), and a queuing emission rate. This emission rate was derived using the AIRE instantaneous emissions model[50] to calculate an idling emission rate for specific Euro standard taxis, and then calculating a weighted average of these emission rates using the London taxi fleet composition within the Emission Factor Toolkit (EFT).

9.109 For the future Without CADP scenarios, a similar approach to calculating taxi emissions was made, taking into account the revised forecast of taxi movements provided by Vectos. For the With CADP scenarios, a new marshalled taxi feeder park is to be established at the eastern end of the Airport. Stationary idling within the feeder park and along Hartmann Road will be prohibited.

Car Parks

9.110 Information on car park flows for the Baseline Year (2014) and all future year scenarios was provided by Vectos, and are shown in Tables A4.18 and A4.21 (Appendix 9.4). For the Without CADP scenarios, the existing car park layouts were assumed to remain unchanged. For the With CADP scenarios, the new decked and surface car park layouts were taken into consideration.

9.111 The car park emissions for NOx and PM_{10} have been calculated using speed-related emissions factors contained within the EFT, to take account of travelling vehicles.

9.112 The travelling distance for a vehicle entering or leaving the car park has been assumed to be the length of the perimeter of the parking area, assuming an average vehicle speed of 5 km/h.

9.113 Specific consideration has also been given to "cold start" emissions for vehicles leaving the car park. Vehicles with cold engines emit more pollution than those with warm engines. To account for this, the additional emissions from cold starts have been calculated using the EXcess EMissions Planning Tool (EXEMPT) developed by AEA Technology [(51)].

9.114 Emissions of $PM_{2.5}$ have been assumed to be the same as for PM_{10}, as a worst-case assumption.

[50] http://www.sias.com/ng/AIRE/AIRE.htm

51 Smith. A.. P. (2001) UG219 TRAMAQ. Excess emissions planning tool (EXEMPT) user guide. AEA/ENV/R/0639. AEA Technology

Stationary Sources

9.115 Emissions arising from stationary sources at the Airport (e.g. gas-fired heating plant) were calculated from gas consumption data for 2014 provided by the Airport. Data are only available in an aggregated form for the terminal building, which includes use by the terminal main substation and three other gas supplies serving CAH, the Ledger Building and various cooking appliances used by the caterers. Emission rates for combustion of gaseous fuels have been obtained from the EMEP/EEA *Emission Inventory Guidebook* (52), which gives emission rates in grammes of pollutant per gigajoule of energy (as fuel consumption). This has been used to calculate average annual emission rates based on the annual gas consumption, and assuming continuous operation throughout the year.

9.116 For future Without CADP scenarios, the Airport confirmed that there is currently no intention to increase boiler plant capacity, but to provide a conservative approach it was assumed that gas consumption increased in proportion to the total number of passengers in each case as compared with the 2014 Baseline Year (see Table A4.22, Appendix 9.4).

9.117 For the future With CADP scenarios, new gas boiler plant and a small (35 kWth) CCHP unit will be incorporated into the Western Energy Centre, in about 2016. The Eastern Energy Centre, comprising of four CCHP units (providing approximately 230kWth for the Eastern Terminal Extension and 330 kWth for the Hotel) and additional gas boilers, will then be phased in from about 2020 onwards. All gas boilers will conform to the "ultra-low" NOx emission standard of 40 mg/kWh. At some stage, the CCHP unit in the Western Energy Centre may be decommissioned, but the timing is unknown at this stage, and the precise requirements for the Eastern Energy Centre are still to be confirmed. To account for these uncertainties, all With CADP scenarios have assumed that gas consumption from the terminal area increases in proportion to the total number of passengers in each case as compared with the 2014 Baseline Year (see Table A4.22, Appendix 9.4) and that the Eastern Energy Centre CCHP is operational, 24 hours per day, at full (100%) load, from 2020 onwards (see Table A4.23, Appendix 9.4). This will have overstated the NOx emissions in future years, and represents a conservative approach.

9.118 The Tate & Lyle factory, which lies to the south of the Airport, operates gas and gas-oil boilers. Due to the location of this installation relative to the Airport, and the height of the stacks, the emissions arising from these boilers have also been included within the model for completeness as part of the baseline. Emission rates and stack parameters were provided by the Environment Agency and are summarised in Table A4.24 (Appendix 9.4). Emissions from the Tate & Lyle plant were assumed to remain unchanged for all future scenarios.

52 EMEP/EEA Emission Inventory Guidebook (2013). [Online], Available at: http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2013

Consideration of Peak Hour Activities

9.119 The modelling methodology described above has focused on predicting annual mean pollutant concentrations. The air quality objectives and limit values for nitrogen dioxide, PM_{10} and $PM_{2.5}$ are expressed as annual mean values, but there are also shorter-term criteria that need to be taken into account (specifically a 1-hour mean objective and limit value for nitrogen dioxide, and a 24-hour mean objective and limit value for PM_{10}).

Modelling of these shorter-term metrics introduces additional uncertainties into the assessment, and as noted by Defra in LAQM.TG(09): "*dispersion models are inevitably poorer at predicting short-term peaks than they are at predicting annual mean concentrations, and the process of model verification is extremely challenging*". For this reason, assessments of airport operations typically focus on predicting annual mean concentrations. The approach adopted for this study is that, as appropriate, these shorter-term metrics have been calculated from the annual mean using the empirical relationships recommended by Defra.

9.120 However, within its Scoping Opinion, LBN specifically requested that the assessment gives consideration to the impacts arising from any increase to the maximum number of aircraft departures and arrivals. Given the concerns with modelling of short-term concentrations (and specifically the 1-hour mean concentrations for nitrogen dioxide) this has been dealt with by a screening approach as described below.

9.121 Information on the timetabling of aircraft movements for all future years has been derived from the Update to the Need Statement (September 2015) prepared by York Aviation. These data have been analysed to provide an hour-by-hour analysis of aircraft movements for each assessment year, for both the Without and With CADP scenarios. This analysis is shown in Table A4.25 (Appendix 9.4).

9.122 For each scenario, the peak hours are 0800-0900h and 1800-1900h. Peak-hour movements are forecast to increase from 33 (2014 Baseline Year) to 35 (2025, Without CADP) and to 45 (2025, With CADP Core Case). These movements exclude Jet Centre operations, as the smaller aircraft make only a very small contribution to NOx emissions[53]. It should also be borne in mind that these movements represent both arrivals and departures (approximately a 50% split in each peak hour), and that NOx emissions are substantially higher on departure due to the requirement for 100% engine thrust on take-off; emissions on arrival are relatively small compared with departure. The incremental change to the number of peak-hour departures between the 2014 Baseline Year and the 2025 With CADP scenario is thus about 5.

9.123 There have been no recorded exceedences of the 1-hour mean objective/limit value at either of the automatic monitoring sites operated by the Airport, and in the majority of years, the maximum recorded level has been well below the 200 $\mu g/m^3$ threshold (see Table 9.7 and Figure 9.5).

9.124 A comparison may also be drawn with Heathrow Airport, which in 2014 operated at approximately 74.4 mppa with a total of 470,695 movements (using substantially larger aircraft than operate at LCY). This compares with 107,700 movements and approximately 6.5 mppa at the Airport for the With CADP (Faster Move to Jets) scenario in 2025.

53 It should be noted that the Jet Centre peak-hour movements decrease for the With Scheme scenarios.

9.125 At Heathrow Airport, a monitoring site (LHR2) is located 180 metres to the north of the centre of the northern main runway (and in the prevailing downwind direction), and 18 metres from the centre of the Northern Perimeter Road. There have been no recorded exceedences of the 1-hour mean objective/limit value at this site since 1997, and in the majority of years, the maximum recorded level has been well below the 200 µg/m^3 threshold.

9.126 Therefore, based on empirical monitoring evidence, it is considered extremely unlikely that the small increase in peak-hour aircraft movements at the Airport resulting from the CADP would cause any exceedences on the 1-hour mean objective/limit value for nitrogen dioxide. Accordingly, the requirement for any detailed modelling has been scoped out.

Background Contributions

9.127 The ADMS-Airport model predicts pollutant concentrations from those sources of emissions that have been explicitly included in the model (as defined above). It is also necessary to take account of the contribution from other pollutant sources that are not explicitly included – normally referred to as the "background contribution".

9.128 Background pollutant concentrations were obtained from national background pollutant maps published by Defra. These include modelling background concentrations for the whole country, published in a 1 x 1 km grid. These are published as total background pollutant concentrations, but are broken down by source contribution including road, rail, airport, domestic, industrial and rural sources.

9.129 In order to improve the spatial representation of the background pollutant concentrations, receptor-specific background concentrations have been calculated by interpolation of the mapped background concentrations using "kriging" (54). This has been carried out using the Surfer 8 geostatistical software.

9.130 In order to avoid 'double counting' of airport-related pollution sources, the 'airport' contributions to the background mapped concentrations have been removed. This has been carried out using the Background Sector Removal Tool, which is published by Defra for use with the background maps (55). The 'in-square' contributions of motorways, trunk roads and principal roads have also been removed from the background map calculations, as these sources are all explicitly included in the ADMS-Roads traffic model.

Odours

9.131 There is no straightforward way to quantify the potential odour effects associated with airport operations. There is no published evidence to suggest that there are any physiological health effects associated with exposure to VOCs at the concentrations at which airport odours are detectable, and the principal concern is related to nuisance or loss of amenity. A number of studies have attempted to draw comparison between an expansion in airport operations and the number of complaints that are received. One of the largest reported surveys was undertaken by Stansted Airport Ltd between August and November 2005 (56), during which

54 "Kriging is a geostatistical gridding method that is used to prepare contour maps.
55 Available at: http://laqm.defra.gov.uk/maps/maps2010.html
56 BAA (2008). Generation 2 Environmental Statement Volume 4: Air Quality.

period the airport invited some 14,000 local residents to report any incidents of odour annoyance. During the survey period, only a very small number (99 in total) of responses were received, the majority of these from residents living a relatively large distance from the airport. The study concluded that:

> *"One of the critical aspects of the work has been the low levels of data and information gathered following requests to the local community. There are no persistent reports of odour as there are with noise for example.*
>
> *Without further accurate data and information it is not possible to draw many conclusions about correlations between odour and other factors such as meteorological data because any such correlations would not stand up to statistical challenge and would be supposition. So, although general trends have been found that when prompted, a small number of people living locally will indicate that they have experienced an odour occurrence, it has not been possible to deduce any of the causes or factors related to odour occurrences from this study"*

9.132 The Stansted study also included an assessment of the relationship between odour complaints and the number of air traffic movements at four major airports (Heathrow, Gatwick, Manchester and Birmingham). The study concluded that there was no clear relationship between odour complaints and the number of aircraft movements, and that the number of complaints recorded each year, even at large airports such as Gatwick and Birmingham, are extremely low and in single figures.

9.133 As part of the legal agreement associated with the 2009 planning approval, the Airport commissioned a pilot study to investigate Volatile Organic Compounds (VOC) concentrations and the prevalence of airport-related odours [(57)]. The study comprised of walk-around surveys to record the presence of odours, and included VOC monitoring using a low sensitivity (ppb) Photo-Ionisation Detector (PID). Several important conclusions were drawn from this study:

a) Airport-related odours were perceived in the vicinity of the Airport at times when measured VOC concentrations remained at background concentrations. Given the relatively high odour threshold of aviation kerosene (1,000 to 10,000 ppb), it was concluded airport-related odours are probably associated with organic hydrocarbons produced by the pyrolysis of kerosene in the jet engine, i.e. associated with what are sometimes called 'burnt' hydrocarbons; and

b) The greatest potential for odour emissions is believed to occur during aircraft taxi movements after landing, when thrust settings are low and the engine components are very hot.

9.134 A commonly-applied approach in some airport assessments is to base the odour assessment on the change in aircraft-related VOC emissions. However, there is no evidence to correlate total aircraft-related VOC concentrations with the human perception of odours. Moreover, given that airport-odours are unlikely to be related to total VOCs, any such correlation is expected to be very weak.

57 AQC (2010). *Measurement of Volatile Organic Compounds (VOC) Concentrations and Odours*. Report No. 1004/5/F1.

9.135 A variation on this general modelling approach was undertaken at Copenhagen Airport in 2002 [(58).] This study quantified odour emissions from aircraft engines using actual fuel flow and emissions measurements, odour panel results, engine specific data and aircraft operational data, and used this information to predict odour concentrations. Important outcomes from the study were a calculated odour emission rate from the aircraft engines of 57 Odour Units (OU_E)[59] per milligramme of hydrocarbon, and the identification that the majority of the odorous emissions (97%) occurred whilst aircraft engines were running at idle. The calculations were carried out for only a limited number of engine types (predominantly the JT8D-219, which is not in use at The Airport) and the study recognised that "*the uncertainties become large when the experimental data is used to estimate the odour emissions for all aircraft engines*".

9.136 Notwithstanding the above caveats, the outcome of the Copenhagen study has recently been used in a study to assess potential odour effects at Farnborough Airport [(60)]. The study included measurements of VOCs and an olfactometry study, but the results were inconclusive and no use was made of the data in forming any conclusions. The study also used the odour emission rate derived from the Copenhagen study, only taking account of aircraft emissions during idle mode (on stand and taxiing), which produced results that seemed credible in comparison to the records of odour complaints.

9.137 A similar approach has been adopted for this assessment. Hydrocarbon emissions have been quantified from aircraft operations in idle mode using the approach outlined above. An odour emission rate of 57 OU_E/mg-HC has then been applied.

Meteorological Data

9.138 Hourly sequential meteorological data for the most recent three years (2012-2014) were obtained from the Meteorological Office station at the Airport. Wind roses for each year are shown in Appendix 9.5A. The 2014 Baseline Year assessment was undertaken using the 2014 meteorological data (together with the 2014 emissions inventory); a sensitivity check was then carried out to determine the "worst-case" meteorological dataset for future year scenarios, as described in Appendix 9.5.

9.139 Runway use at the Airport is determined by weather conditions. Runway 27 (westerly) is the preferred runway, with 62% of operations in 2014; however, when the wind direction is from the east, runway 09 (easterly) is used. The Airport provided details of runway allocation for each departure and arrival during 2014. These data showed a strong correlation demonstrating that during easterly wind conditions (between 0 degrees and 180 degrees), aircraft operated from Runway 09, whereas during westerly wind conditions (between 180 degrees and 360 degrees), aircraft operated from Runway 27. Therefore, in the ADMS-Airport model, runway allocation has been determined by wind direction. During hours where winds occur in the sectors 0 - 180º, Runway 09 is assumed to be in use, and sources using Runway 27 are "switched off".

58 Winther M, Kousgaard U and Oxbol A (2006) Calculation of odour emissions from aircraft engines at Copenhagen Airport, Sci Tot Env, 366, 218-232.

59 In simple terms, olfactometry is the technique used to measure the concentration of an odour by taking samples of odorous air and then evaluating the number of dilutions at which the sample is only detected by 50% of the odour panel. The number of dilutions required to achieve this odour threshold is expressed as odour units per cubic metre.

60 ARUP (2009). Farnborough Airport – Odour Assessment

During hours with winds occurring in the sectors 180 – 360º, Runway 27 is assumed to be in use and sources using Runway 09 are “switched off”.

NOx to NO_2 Relationship

9.140 Nitrogen dioxide (NO_2) concentrations have been calculated from the predicted NOx concentrations using the NO_2 from NOx calculator available on the Defra air quality website (33). This calculator requires an estimate of the proportion of primary NO_2 ($f\text{-}NO_2$). This was calculated individually for each receptor (including each gridded receptor for contour plotting) based on the relative contribution of different sources to total locally-generated NOx concentrations. For road vehicles, representative values of $f\text{-}NO_2$ are contained within the ‘NO_2 from NOx calculator’. For aircraft, $f\text{-}NO_2$ values obtained from the National Atmospheric Emissions Inventory were used (61). For all other sources, including APUs, MGPUs, training fires and terminal boiler plant, an $f\text{-}NO_2$ values of either 5% or 15% were assumed.

Assessment of Particulate Matter Concentrations

9.141 The guidance issued by EPUK/IAQM recommends that $PM_{2.5}$ is used to assess the impacts of combustion sources (including road traffic and aircraft emissions) rather than PM_{10}, as the air quality objective is much lower, and therefore represents a conservative approach.

9.142 Where PM_{10} is assessed, a derived annual mean criterion of 32 $\mu g/m^3$ has been used, based on the threshold at which the daily mean objective (no more than 35 days > 50 $\mu g/m^3$) is exceeded, following EPUK/IAQM guidance.

Spatial and Temporal Representation of Emissions

9.143 Emissions occur at different locations and over different time periods. The spatial representation of sources has been undertaken using a combination of line, point, area and volume sources. Aircraft taxiing and holding emissions were represented as line sources based on schematic taxi routes from the stands, to and from the runway. Emissions during take-off roll were distributed between the start-of-roll point on the runway and the estimated point of ‘wheels-off’.

9.144 Aircraft movements, including taxiing, take-off, initial climb, climb-out, approach and landing roll-out are all contained within an “airfile” in ADMS-Airport. This file contains information on the geometry of individual aircraft, the engine exhaust parameters (exit velocity, temperature and diameter), the geometry of the LTO cycle (e.g. taxiway start and end points, take-off start and end points, approach start and end points etc.), the times in mode, and the aircraft emissions.

9.145 Each aircraft movement between spatial nodes is included as a separate line in the airfile. ADMS-Airport then treats each source as a series of fixed jet sources between each node point. Each line of the airfile is assigned an “NT number”, which is the number of fixed jet sources along its length. For each part of the LTO

61 NAEI Report: Available online at: http://naei.defra.gov.uk/datawarehouse/3_9_324_136262_primary_no2_emission_factors_for_aviation_and_other_transport_sources_2010naei_v1.pdf

cycle, there is a maximum jet source spacing, which is used to calculate NT. i.e. NT = (distance between aircraft start and end points) / (max jet-source spacing).

9.146 The emission rates contained within the airfile are annual average emission rates based on the number of movements of a particular aircraft or group of aircraft, assuming 100% usage of both Runway 09 and Runway 27. A time-varying emission file was then used to apportion the movements to the runways on an hour-by-hour basis, depending on wind direction.

9.147 The Airport is permitted to operate flights between 0630-2230 hrs (weekdays), 0630-1300 hrs (Saturdays) and 1230-2230 hrs (Sundays), however, Airport activity data shows that Airport activities on the ground (aprons) occur between 0500-2300 hrs (weekdays), 0500-1300 hrs (Saturdays) and 1200-2300 hrs (Sundays). All emissions arising from Airport-related sources have therefore been assumed to take place between these hours.

9.148 Climb-out and approach trajectories have been calculated from information provided by the Airport. This includes the minimum angle of approach (5.5 degrees) as well as indicative times between lift-off and throttle-back, approach and landing, and estimated aircraft speeds during these movements.

9.149 Emissions from airside ground activities, including the use of APUs and MGPUs, airside vehicle movements, aircraft ground runs, and aircraft main engine idling on stand (the time between engine start-up and start of taxi-out on departure) have been modelled as a series of volume sources, covering the main apron areas (Stands 1-10, Stands 12-14, Stands 21-24, and the Jet Centre including Stand 15). Airside vehicle emissions and MGPU emissions are low-level and have therefore been modelled as volume sources with a depth of 2m and a source centre height of 1m. APU, aircraft ground running, and aircraft main engine idling emissions have an initial release height, as the jet engines/APU units are elevated on the aircraft fuselage, and the emissions are hot, giving them a degree of buoyancy. To account for this, APU and aircraft ground running emissions have been modelled as volume sources with a depth of 4m and a source centre height of 3m. The volume sources have been included in the time-varying emission file such that the emissions are switched off outside of Airport hours of apron activity (as described in paragraph 9.144).

9.150 For the With CADP scenarios, the volume sources representing Stands 21-24 have been extended to represent the new eastern apron. Emissions from the terminal building, car parks and taxi feeder park were represented as area sources, at terminal roof or ground level height as appropriate. Emissions from the fire training area were represented as a volume source with a depth of 1m and source centre height of 2.5m to account for the initial buoyancy of hot LPG combustion emissions. Emissions from the Tate & Lyle gas and gas-oil boilers were represented as point sources.

9.151 Emissions from the landside road network were calculated and assigned on a link-by-link basis. Road speeds were based on local speed limits, and were reduced close to junctions to take account of decelerating and accelerating vehicles, queuing and congestion.

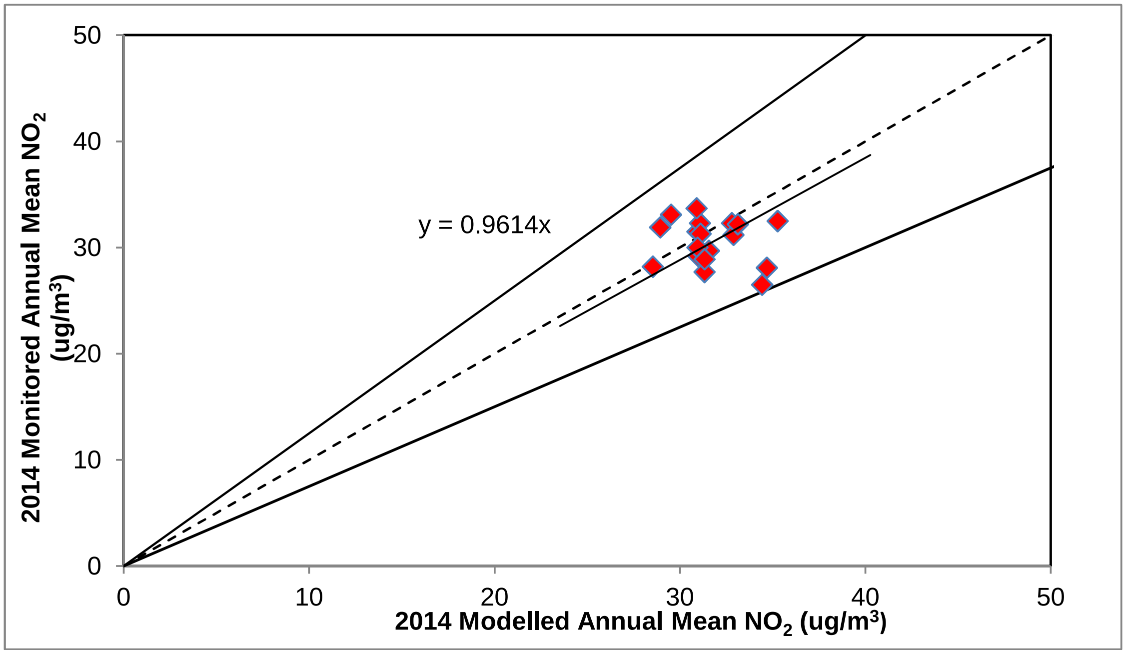
9.152 Emissions from the taxi ranks servicing the Airport were modelled as a line source.

Model Verification

9.153 The process of model verification refers to a comparison between the predicted and locally-measured pollutant concentrations. Model verification may or may not result in an adjustment of predicted results depending on the outcomes and/or the source types being considered.

9.154 Comparison of the annual mean modelled nitrogen dioxide concentrations in 2014 with monitored concentrations at sites within the Airport's Air Quality Measurement Programme (16 diffusion tube sites and two continuous sites) in 2014, shows the model over-predicts concentrations by around 4%, on average, as shown in Figure 9.4.

Figure 9.4 – Nitrogen Dioxide – Monitored vs Modelled NO_2 (µg/m^3)



9.155 LAQM.TG(09) provides guidance on the evaluation of model performance. Based on the data shown in Figure 9.4, the calculated correlation coefficient is -0.15, the Root Mean Square Error (RMSE) is 3.04 µg/m^3, and the Fractional Bias is -0.04. LAQM.TG(09) notes that where RMSE values are above 25% of the objective (i.e. 10 µg/m^3) that model inputs and verification should be checked. It further notes that *"ideally an RMSE value within 10% of the objective (4 µg/m^3) should be achieved".* The model performance in this assessment complies with this guidance, and is considered to be good.

9.156 The ideal value for the Fractional Bias is 0.0; the calculated value of -0.04 is not large and represents the model over-predicting concentrations. The model has not been adjusted for this small bias, and therefore represents a worst-case assumption.

9.157 The Airport undertakes PM_{10} monitoring at City Aviation House (CAH). The annual mean PM_{10} concentration measured at this site was 22 $\mu g/m^3$ in 2014; this compares with a predicted concentration of 21.7 $\mu g/m^3$. The model performance for PM_{10} is considered to be good and there has been no adjustment of the results.

9.158 There is no local monitoring of $PM_{2.5}$ against which a comparison of modelling results can be made. The modelled $PM_{2.5}$ concentrations have therefore not been adjusted, in line with the modelled concentrations of nitrogen dioxide and PM_{10}.

Uncertainty in Modelling Predictions

9.159 There are many components that contribute to the uncertainty of modelling predictions. The model used in this assessment is dependent upon the data that have been input, which will have inherent uncertainties associated with them. There are then additional uncertainties, as the model is required to simplify real-world conditions into a series of algorithms. An important stage in the process is model verification, which involves comparing the model output with measured concentrations (see above). The level of confidence in the verification process is necessarily enhanced when data from an automatic analyser have been used, as has been the case for this assessment. Because the model has been verified and shown to be performing well, there can be reasonable confidence in the prediction of Baseline Year (2014) concentrations.

9.160 Predicting pollutant concentrations in a future year will always be subject to greater uncertainty. For obvious reasons, the model cannot be verified in the future, and it is necessary to rely on a series of projections as to what will happen to aircraft and road vehicle emissions, aircraft and road traffic volumes, and background pollutant concentrations. A disparity between the road transport emission projections and measured annual mean concentrations of nitrogen oxides and nitrogen dioxide was however, identified by Defra in 2011, based on monitoring over the period 2004 to 2009 (18). This applied across the UK, although the effect appeared to be greatest in inner London; there was also considerable inter-site variation. Emission projections over the 6 to 8 years up to 2011 have suggested that both annual mean nitrogen oxides and nitrogen dioxide concentrations should have fallen by around 15-25%, while at many monitoring sites levels remained relatively stable, or had even shown a slight increase. This pattern is mirrored in some of the monitoring data assembled for this study, as set out below, although there is a statistically significant downward trend at the two automatic sites in the Airport's Air Quality Measurement Programme and at some sites in the adjacent boroughs (Greenwich Burrage Grove, Greenwich Eltham, Newham Cam Road, Newham Wren Close and Tower Hamlets Blackwall) in the more recent period 2010-2014.

9.161 The reason for the disparity is thought to relate to the on-road performance of modern diesel vehicles. New vehicles registered in the UK have to meet progressively tighter European type approval emissions categories, referred to as "Euro" standards. While the nitrogen oxides emissions from newer vehicles should be lower than those from equivalent older vehicles, the on-road performance of some modern diesel vehicles has proven to be no better than that of earlier models. There is a widespread consensus that the Euro VI emissions standard for Heavy Duty Vehicles is delivering as expected. The emissions standard for Euro 6 Light Duty Vehicles is being delivered in two stages (often referred to as "Euro 6a/b" and "Euro 6c"). Euro 6a/b vehicles are currently on the road, and Euro 6c is expected to be introduced from about 2018 onwards. The Euro 6 emissions standard is unchanged between Euro 6a/b and Euro 6c, but the test procedure is different – the latter is based on Portable Emissions Measurement Systems (PEMS) to ensure that emissions during real-world driving conditions are fully considered.

9.162 The emission factors for Euro 6a/b are incorporated into Defra's Emission Factor Toolkit (EFT v6.0.2) which has been used for this assessment (and which are based on COPERT4v10). COPERT4v10 assumes Euro 6 diesel cars and Light Goods Vehicles to have NOx emissions 65% lower than Euro 5, and with a Conformity Factor of 2.8 [(62)]. The COPERT4v11 report was published in September 2014 and contains updated emissions factors for both Euro 5/V and Euro 6/VI vehicles, and confirms that the current assumption in EFTv6.0.2 for Euro 6a/b is correct. It also confirms that NOx emissions from Euro 6c vehicles are expected to be lower with a Conformity Factor of about 1.5.

9.163 The implications for this assessment are that the absolute nitrogen dioxide concentrations predicted in 2020 may be higher than shown, when based on the revised emissions reduction forecasts. Despite the belief that the emissions factors are now more realistic, there remains some uncertainty in the short term. To account for this uncertainty in the projections, sensitivity checks have been conducted assuming that the future (2020) road traffic emissions per vehicle are unchanged from 2014 values. The predictions within this sensitivity check are likely to be over-pessimistic, as new vehicles meeting more stringent standards (Euro 6a/b) came into service from 2013/14. The Defra forecast figures indicate by 2020 there will be a roughly 70% penetration of Euro VI HDVs (the most polluting vehicles), and a roughly 58% penetration of Euro 6 LDVs. These new vehicles are expected to deliver real on-road reductions in nitrogen oxides emissions.

9.164 By 2025, Defra forecast that there will be a 95% penetration of Euro VI HDVs, and an 85% penetration of Euro 6 LDVs in London. In addition, by 2025 there will be an increasing proportion of Euro 6c vehicles in the fleet (approximately 40%), and the reduced NOx emissions associated with these vehicles have not been taken into account (as the COPERT4v11 emissions are not in EFTv6.0.2). It is therefore not considered appropriate to include sensitivity checks for the 2023 and 2025 assessment years.

9.165 It must also be borne in mind that the predictions in all future years are based on worst-case assumptions regarding the increase in traffic flows, such that all planned/committed developments that may have an impact on the study area are assumed to be fully operational, and an additional "growth factor" has been applied to take account of other potential developments in the area. This is likely to have overestimated the effects, which will, in part, offset any potential underestimation as described above.

Air Quality Neutral

9.166 The guidance relating to air quality neutral follows a tiered approach, such that all developments are required to comply with minimum standards for gas boilers, Combined Heat and Power (CHP) plant and biomass plant. Compliance with 'air quality neutral' is then founded on a comparison with emissions benchmarks that have been established for both building (energy) use and road transport, in different areas of London. Developments that exceed the benchmarks are required to implement on-site or off-site mitigation to offset the excess emissions.

62 APRIL (2015) Air Pollution Research in London: Joint Meeting of the Emissions Measurement and Modelling and Transport Group, 24 February 2015. Report available at www.april-network.org

Baseline Conditions (2014)

9.167 LBN has investigated air quality within its area as part of its responsibilities under the LAQM regime and has identified road traffic as the primary source of poor air quality in the borough. In 2002, the Council concluded that it would not meet the statutory objectives for two pollutants, nitrogen dioxide (annual mean) and PM_{10} (24 hour mean) and designated an Air Quality Management Area (AQMA) extending alongside the major roads in the Borough including North Woolwich Road, Connaught Crossing, Silvertown Way, Royal Albert Way and Royal Docks Road. However, the Airport and the roads to the south of it, including Hartmann Road and Albert Road, lie outside the AQMA boundary.

Monitoring At and Around the Airport

9.168 Information on existing pollutant concentrations in the vicinity of the Airport has been derived from a number of sources. These include:

a) Monitoring carried out by the Airport as part of its legal agreement associated with the 2009 planning permission to expand to 120,000 "noise-factored" movements;

b) Monitoring carried out in the LBN and adjacent local authorities; and

c) Estimated background concentrations for the study area derived from national maps available on the Air Quality Archive [63].

Monitoring Carried out by the Airport

9.169 A programme of ambient air quality monitoring was established by the Airport in 2006. This monitoring programme has now been incorporated into the legal agreement associated with the 2009 planning permission, and forms part of the Air Quality Measurement Programme (AQMP). The AQMP includes an automatic monitoring station situated on the roof of City Aviation House ('LCA-CAH') which measures concentrations of nitrogen dioxide and PM_{10}, and a network of nitrogen dioxide diffusion tubes located around the Airport and close to local housing. It is important to note that not all of the diffusion tube sites represent relevant public exposure, and they have been included in the AQMP to provide a better understanding of the spatial distribution of nitrogen dioxide concentrations in the vicinity of the Airport. In particular, there is no relevant exposure in terms of the annual mean objective at the waterfront to the north of Royal Albert Dock (sites LCA04, LCA11, LCA14, LCA16 and LCA17), at the Jet Centre apron (LCA10), or within Silvertown Quay (LCA03), as denoted on Figures 9.5 and 9.6 (see below).

9.170 In addition to the formal requirements of the AQMP, the Airport has commissioned a second automatic monitoring station adjacent to the Newham Dockside building, which is to the north of the Royal Albert Dock. This station (LCA-ND) measures nitrogen dioxide.

9.171 The location of the automatic monitors and the diffusion tube sites is shown in Figures 9.5 and 9.6. A summary of the automatic monitoring data collected over the five-year period January 2010 to December 2014 is provided in Tables 9.7 and 9.8; the diffusion tube data are summarised in Table 9.9.

63 Defra 2015. UK Air Quality Archive, available on the internet at www.airquality.co.uk

Appendix AQ.1.8

Table 9.7 - Summary of Nitrogen Dioxide (NO_2) Monitoring in LCY AQMP (2010-2014)

Site	2010	2011	2012	2013	2014
	Annual Mean				
LCA-CAH	35	33	35	32	30
LCA-ND	39	30[1]	30	27	29
	No. Hours > 200 µg/m^3				
LCA-CAH	0	0	0	0	0
LCA-ND	0	0	3	0	0

1. Data capture in 2011 was low (63%) due to an instrument fault. The measured value has been annualised according to procedures recommended by Defra in LAQM.TG(09)

Appendix AQ.1.8

Table 9.8 - Summary of PM_{10} Monitoring in LCY AQMP (2010-2014)[1]

Site	2010	2011	2012	2013	2014
	Annual Mean				
LCA-CAH	22	24	21	23	22
	No. Days > 50 µg/m³				
LCA-CAH	2	16	9	5	7

Notes

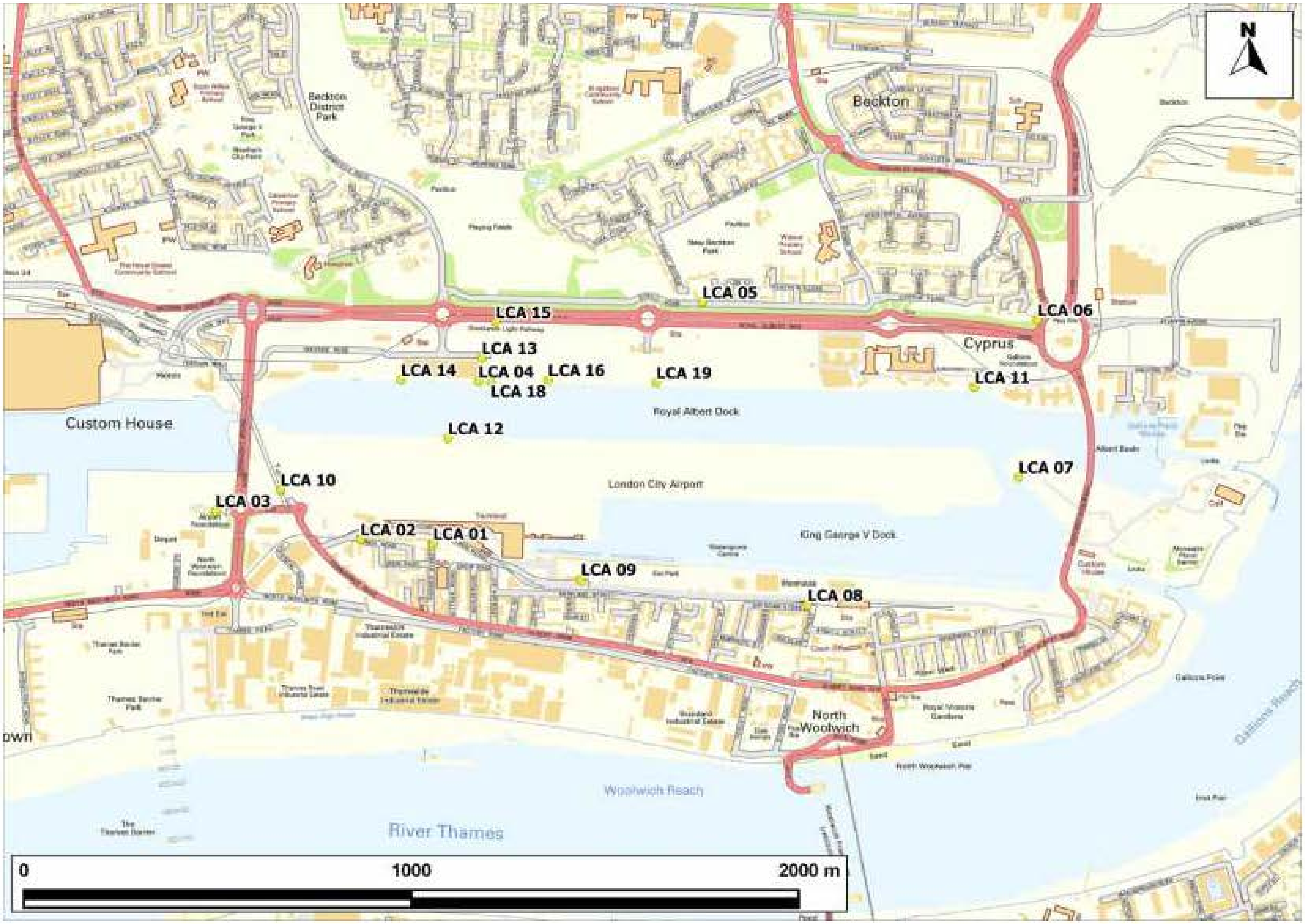
1. Concentrations reported as Volatile Correction Method (VCM) adjusted TEOM values

9.172 There have been no recorded exceedences of the nitrogen dioxide or PM_{10} objectives at the automatic sites since monitoring commenced. There were a number of recorded exceedences of the annual mean nitrogen dioxide objective at some of the diffusion tubes sites in 2011 and 2012 but none of these were at locations relevant to public exposure.

Figure 9.5 – Automatic Monitoring Sites in LCY AQMP.

Appendix AQ.1.8

Figure 9.6 - Diffusion Tube Monitoring Locations in LCY AQMP.



Appendix AQ.1.8

Table 9.9: Summary of LCY AQMP Nitrogen Dioxide Diffusion Tube Data 2010-2014

Site ID	Site Description	Annual Mean Nitrogen Dioxide Concentration (µg/m^3)				
		2010	2011	2012	2013	2014
LCA01	Top of Parker Street, adjacent to housing	34.2	31.5	32.2	32.9	28.1
LCA02	Camel Road, adjacent to nearest property on Hartmann Street	37.2	33.3	32.7	32.8	26.5
LCA03	Access road in Silvertown Quay. Approx. 36 metres from kerbside of main road	34.4	32.6	33.0	30.0	29.7
LCA04	Waterfront to east end of Newham Dockside	39.9	**41.1**	**43.2**	33.4	32.3
LCA05	Straight Road, at kerbside	31.7	28.9	29.9	27.5	29.2
LCA06	Pedestrian walkway adjacent to nearest housing at Gallions Way	33.0	33.5	32.7	31.2	32.3
LCA07	Landing Lights	33.3	32.8	33.1	30.4	31.9
LCA08	Brixham Street	29.3	28.7	28.4	25.9	28.2
LCA09	City Aviation House	34.1	31.1	30.8	29.9	31.5
LCA10	Jet Centre – airside	38.4	39.4	36.7	34.7	32.5
LCA11	Waterfront, eastern end of the University of East London	37.7	36.4	34.7	31.9	33.1
LCA12	ILS, to north of runway and south of Royal Albert Dock	32.4	32.3	29.5	28.5	31.2
LCA13	North west corner of Newham Dockside	35.2	33.7	29.6	30.0	32.3
LCA14	Waterfront at western end of Newham Dockside	37.4	36.1	33.3	31.6	33.7
LCA15	Kerbside (approx 1 m) of Royal Albert Way	36.7	31.3	33.2	31.6	32.2
LCA16	Waterfront, approx 180 m east of Newham Dockside	35.7	33.6	**43.5**	31.5	29.0
LCA17	North west of site 16, approx 85 m back from Waterfront	36.9	36.6	-	-	-
LCA18	Newham Dockside analyser	-	34.0	34.2	29.0	27.7
LCA19	Waterfront, approximately 460m east of Newham Dockside	-	37.7	34.8	30.9	31.3

Notes

1. Exceedences of the objective (40 µg/m^3) are shown in bold.
2. All data bias-adjusted using local factors derived from co-located triplicate tubes at LCA-CAH and a single tube at LCA-ND.
3. Land between the Royal Dock and the A1020 was used as an Olympic Coach Park during July and August 2012, and there was intermittent use of this site from January 2012 onwards. In addition, there were also berthed ships in the Dock and generators in the Coach Park. Emissions from these local sources may have affected measured concentrations at some sites in 2012, notably LCA04 and LCA16.

Monitoring Carried Out by Local Authorities

9.173 Air quality monitoring is also carried out by LBN and other, nearby local authorities (London Boroughs of Tower Hamlets and Greenwich). Data from a number of automatic monitoring sites within the proximity of the Airport have been derived from the London Air Quality Network [(64)]. These include Greenwich Millennium Village (classified as an "Industrial" site), Newham Wren Close and Tower Hamlets Poplar (Urban Background), Newham Cam Road, Greenwich Burrage Grove, Greenwich Woolwich Flyover and Tower Hamlets Blackwall (Roadside). The data are summarised in Tables 9.10, 9.11 and 9.12 for nitrogen dioxide, PM_{10} and $PM_{2.5}$ respectively.

64 London Air Quality Network (2011). [Online], Available at www.londonair.org.uk.

9.174 Monitoring of nitrogen dioxide concentrations is also carried out by LBN using diffusion tube samplers. There are two sites in close proximity to the Airport, one located on the western side of the main access road into the Airport car parks, and one close to the Gallions Way roundabout. The annual mean concentrations for 2009 to 2014 are shown in Table 9.13. It should be noted that the site at the Airport car park is not representative of public exposure.

Table 9.10 - Summary of Nitrogen Dioxide (NO_2) Monitoring at Local Authority Sites (2009-2014)

Site	2009	2010	2011	2012	2013	2014
	Annual Mean ($\mu g/m^3$)					
Greenwich Millennium Village	36.4	35.7	33.0	37	-	-
Newham Wren Close	38.4	38.4	39.0	38	32	34
Tower Hamlets Poplar	36.2	39.8	N/A	33	-	-
Newham Cam Road	**52.8**	**52.5**	**47**	**43**	40	39
Greenwich Burrage Grove	**49.1**	**52.7**	**43**	**45**	**45**	38
Greenwich Woolwich Flyover	**82.5**	**73.5**	**67**	**71**	**65**	**75**
Tower Hamlets Blackwall	**63.9**	**72.8**	**63**	**61**	**58**	**59**
	No. Hours > 200 $\mu g/m^3$					
Greenwich Millennium Village	0	0	0	2	-	-
Newham Wren Close	1	2	0	0	0	0
Tower Hamlets Poplar	0	**22**	N/A	**0**	-	-
Newham Cam Road	4	13	0	0	1	1
Greenwich Burrage Grove	3	1	1	1	0	0
Greenwich Woolwich Flyover	**53**	**38**	6	**27**	8	**26**
Tower Hamlets Blackwall	2	7	0	0	0	1

Table 9.11 - Summary of PM_{10} Monitoring at Local Authority Sites (2009-2014)[1]

Site	2009	2010	2011	2012	2013	2014
	Annual Mean ($\mu g/m^3$)					
Greenwich Millennium Village	19.6	22.1[2]	25	23	-	-
Newham Wren Close	23.6	21.7[2]	27	-		-
Tower Hamlets Poplar	22.0	21.7	23	21	-	-
Newham Cam Road	27.2	26.7[2]	28	-	31	29
Greenwich Burrage Grove	25.1	27.8	28	27	-	-
Greenwich Woolwich Flyover1	37.0	32.5[2]	35	32	32	-
Tower Hamlets Blackwall	34.1	29.2[2]	28	26	28	
	No. Days > 50 $\mu g/m^3$					
Greenwich Millennium Village	12	9[2]	25	21	-	-
Newham Wren Close	7(37)	3[2]	14(42.7)	-		
Tower Hamlets Poplar	7	6	18	9	-	-
Newham Cam Road	10	12(39.2)[2]	16(45)	-	23	26
Greenwich Burrage Grove	0	17	32	28	-	-
Greenwich Woolwich Flyover	**44**	33[2]	**42**	33	26	-
Tower Hamlets Blackwall	**43**	18[2]	32	25	24	

Notes

1. Concentrations reported as Volatile Correction Method (VCM) adjusted TEOM values unless otherwise stated. Exceedences of the objective are shown in bold.
2. Concentrations measured using FDMS in 2010 - 2014.

3. For years where the data capture is less than 90%, the 90th percentile of 24-hour means is given in parentheses.

Table 9.12 - Summary of $PM_{2.5}$ Monitoring at Local Authority Sites (2009-2014)[1]

Site	2009	2010	2011	2012	2013	2014
	Annual Mean (µg/m³)					
Greenwich Millennium Village	15.5	16.5	19.1	15.2	15.5	15.4
Greenwich Burrage Grove	19.6	19.9	24.7	18.1	17.8	17.2
Tower Hamlets Blackwall	19.1	18.1	N/A	15.2	16.4	16.1

Notes

1. Concentrations measured using FDMS in 2010 - 2014.

Table 9.13 - LBN Annual Mean Nitrogen Dioxide (µg/m³) Diffusion Tube Monitoring (2010-2014). Data have been bias-adjusted by LBN.

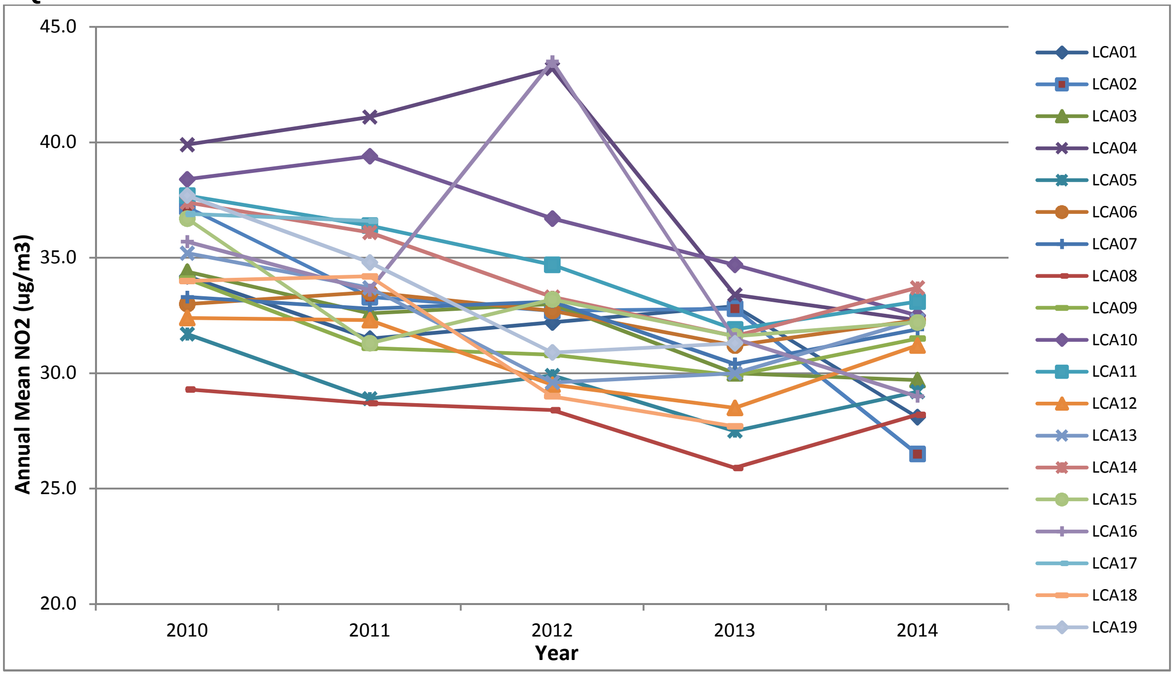
Site	2010	2011	2012	2013	2014
Airport Car Park	37.1	33.5	39.0	36.0	35.7
Galleons Way Roundabout	36.9	34.0	34.0	32.0	34.8

Trends in Measured Concentrations

9.175 A detailed analysis of trends in measured annual mean nitrogen dioxide concentrations has been carried out for monitoring sites in east London, in the 2014 Annual Report for the AQMP [(65)]. This has shown a statistically significant downward trend at both sites in the AQMP (LCA-CAH and LCA-ND) and at five monitoring sites in Newham and the neighbouring boroughs (Greenwich Burrage Grove, Greenwich Eltham, Newham Cam Road, Newham Wren Close and Tower Hamlets Blackwall). There is also evidence of a downward trend in concentrations measured at some of the diffusion tube sites in the AQMP (see Figure 9.7). There also appears to be evidence of a slight downward trend in annual mean PM_{10} concentrations at all sites. The implications of this are discussed in the section on Uncertainty.

65 Air Quality Consultants (2015) London City Airport Air Quality Measurement Programme: 2014 Annual Report

Figure 9.7 – Trends in Annual Mean Nitrogen Dioxide Concentrations (2010-2014) at AQMP Diffusion Tube Sites



Mapped Background Concentrations

9.176 The background concentrations across the study area have been defined using the national pollution maps ("background maps") published by Defra [66]. These cover the whole country on a 1x1 km grid and are published for each year from 2011 until 2030. The maps include the influence of emissions from a range of different sources, one of which is road traffic. As noted above, there are some concerns that Defra may have over-predicted the rate at which road traffic emissions of nitrogen oxides will fall in the near future. The maps currently in use were verified against measurements made during 2011 at a large number of automatic monitoring stations and so there can be reasonable confidence that the maps are representative of conditions during 2011. Similarly, there is reasonable confidence that the reductions which Defra predicts from other sectors (e.g. rail and industry etc.) will be achieved.

9.177 Measured 2014 background concentrations from across east London have been compared with concentrations derived from the background maps. These comparisons are shown in Appendix 9.6. The mapped 2014 concentrations of nitrogen dioxide correlate well with the measured concentrations and therefore the raw, mapped 2014 background concentrations have been used in the assessment. Mapped PM_{10} concentrations are slightly higher (+3.5%) than the measured data, but no adjustment has been made, representing a conservative assumption.

9.178 Two separate sets of 2020 background nitrogen dioxide and nitrogen oxides concentrations have been used for the future-year assessment. The 2020 background 'without emissions reduction' has been calculated using road traffic components of background nitrogen oxides held constant at 2014 values, whilst 2020 data are taken for the other components. Nitrogen dioxide has then been calculated using

66 Defra (2015) *Defra Air Quality Website*, [Online], Available: http://www.defra.gov.uk/environment/quality/air/airquality/

Defra's background nitrogen dioxide calculator [67]. The 2020 background 'with emissions reduction' assumes that Defra's revised background reductions occur as predicted.

9.179 As explained in the section on model uncertainty, it would be unrealistic to assume no change in vehicle emissions post-2020, as there will be a substantial penetration of Euro VI/6 vehicles by this time. Defra's predicted reductions in background nitrogen oxides and nitrogen dioxide concentrations have thus been assumed to apply in both 2023 and 2025.

9.180 For PM_{10} and $PM_{2.5}$, there is no strong evidence that Defra's predictions are unrealistic and so the year-specific mapped concentrations have been used in this assessment.

National Compliance

9.181 There are a number of AURN monitoring sites in the Greater London agglomeration that measured exceedences of the annual mean limit value for nitrogen dioxide in 2014, but none of these sites are in close proximity to the Airport. The national map [68] of roadside annual mean nitrogen dioxide concentrations, used by Defra to report compliance with the limit value to the European Commission, identifies exceedences of the limit value along many roads in London, including sections of Royal Albert Way, Connaught Bridge Road and North Woolwich Road (51 $\mu g/m^3$), the A13 Newham Way (63 $\mu g/m^3$), Royal Docks Road (73 $\mu g/m^3$), and the A12 and A102 north and south of the Blackwall Tunnel (104 $\mu g/m^3$). The national maps of roadside PM_{10} and $PM_{2.5}$ concentrations show no exceedences of the limit value anywhere in London. These maps are for 2012 concentrations; detailed maps of predicted concentrations in later years are not available.

Complaints

9.182 The Airport operates an environmental complaint handling procedure by which anyone can contact the Airport to register a complaint or request information about Airport operations. Complaints or requests for information can be registered by telephone, post, email or via the Airport website. Each complaint or request for information is registered by the Airport, and then investigated and resolved where practical. All environmental complaints and enquiries are reported to the London Borough of Newham. A summary of the complaints related to air quality issues since April 2000 is shown in Table 9.14 below. Very few complaints are recorded in each year, and there is no evidence that there has been any increase over the past 10 years.

Table 9.14 - Summary of Recorded Complaints at LCY

Period	No. Complaints	Nature of Complaint
Apr 2001 – Mar 2002	1	Airport odours
Apr 2002 – Mar 2003	1	Airport odours
Apr 2003 – Mar 2004	0	
Apr 2004 – Mar 2005	2	Smoke
Apr 2005 – Mar 2006	2	Airport odours
Apr 2006 – Mar 2007	1	Airport odours
Apr 2007 – Mar 2008	1	Airport odours
Apr 2008 – Mar 2009	0	
Apr 2009 – Mar 2010	1	Airport odours
Apr 2010 – Mar 2011	0	

67 Defra (2012) *Defra Air Quality Website*, [Online], Available: http://www.defra.gov.uk/environment/quality/air/airquality/
68 http://uk-air.defra.gov.uk/data/gis-mapping

Apr 2011 – Mar 2012	0	
Apr 2012 – Mar 2013	0	
Apr 2013 – Mar 2014	0	

Modelled Baseline (2014) Concentrations

9.183 The ADMS-Airport model has been used to predict 2014 Baseline pollutant concentrations at each of the existing sensitive receptor locations identified in Table 9.6. The results are shown in Tables 9.15 to 9.18[69]. The annual mean nitrogen dioxide (µg/m^3) concentrations are also shown as an isopleth in Figure A7.1 (Appendix 9.7).

9.184 All predicted annual mean nitrogen dioxide, PM_{10} and $PM_{2.5}$ concentrations are below the objective[70]. All of the predicted annual mean nitrogen dioxide concentrations are well below the 60 µg/m^3 threshold identified by Defra, and thus exceedences of the 1-hour mean objective are unlikely. These results are consistent with the measured concentrations in the Airport's AQMP.

9.185 The highest predicted 98th percentile of 1-hour mean odour concentrations is 2.0 OU_E/m^3, at Hartmann Road, to the south of the terminal. This is below the threshold for complaints related to moderately offensive odours, and is consistent with the very small number of complaints related to "airport odours".

[69] Within the tables, "Airport NOx, PM_{10} or $PM_{2.5}$" concentrations include all Airport source contributions and "Road NOx, PM_{10} or $PM_{2.5}$" concentrations include all landside traffic contributions.

[70] While the annual mean PM_{10} objective is 40 µg/m^3, 32 µg/m^3 is the annual mean concentration above which an exceedence of the 24-hour mean PM_{10} concentration is possible, as outlined in LAQM.TG(09) (Defra, 2009). A value of 32 µg/m^3 is thus used as a proxy to determine the likelihood of exceedence of the 24-hour mean PM_{10} objective, as recommended in EPUK/IAQM Guidance

Table 9.15 – Modelled Annual Mean Concentrations of NOx and NO_2 for 2014 Baseline (µg/m^3)

Receptor ID	Description	OS Grid Ref	Airport NOx	Road NOx	Background NO_2	Total NO_2
R1	Camel Road/Hartmann Road	541982, 180307	7.7	5.5	29.4	35.4
R2	Camel Road/Parker Street	542133, 180303	9.7	4.2	29.7	35.9
R3	Parker Street (Portway Primary School)	542177, 180229	4.2	2.0	29.7	32.6
R4	Newland Street (opposite entrance to LCY car park)	542549, 180153	2.0	2.8	29.6	31.8
R5	Newland Street/Kennard Street	542687, 180145	1.5	1.2	29.3	30.5
R6	Brixham Street/Dockland Street	543127, 180121	0.9	0.6	27.8	28.5
R7	Platterns Court/Billingway Dock Head	543676, 180077	0.7	1.4	26.5	27.5
R8	Albert Road/Woolwich Manor Way	543709, 180015	0.6	6.7	26.3	29.8
R9	Robert Street adj Albert Road (north side)	543523, 179954	0.6	4.6	26.3	28.8
R10	Collier Close adj Gallions Way Roundabout (eastern side)	543715, 180875	1.6	11.0	27.1	32.9
R11	Yeoman Close adj Royal Albert Way	543612, 180883	1.7	4.1	27.2	30.0
R12	Straight Road/Campton Close	542826, 180920	1.4	2.9	28.9	31.0
R13	Mill Rd adj North Woolwich Road (west)	540854, 180110	0.4	7.9	28.8	32.7
R14	Connaught Road/Leonard Street	542321, 180086	1.7	6.3	29.6	33.3
R15	Gallions Primary School adj Royal Docks Road	543749, 181324	0.8	2.8	26.5	28.2
R16	Drew Road/Leonard Street	542306, 180219	3.9	3.6	29.8	33.3
R17	Woolwich Manor Way (UEL)	543800, 180701	1.7	4.4	27.1	30.0
R18	Woolwich Manor Way, (UEL)	543650, 180655	3.1	1.3	27.2	29.3
R18 (20m)	Woolwich Manor Way, (UEL)	543650, 180655	2.7	0.8	27.2	28.9
R19	West Silvertown 1	540846, 180439	0.5	0.6	28.3	28.9
R19 (20m)	West Silvertown 1	540846, 180439	0.5	0.5	28.3	28.8
R20	West Silvertown 2	540681, 180448	0.4	0.6	28.3	28.8
R20 (20m)	West Silvertown 2	540681, 180448	0.4	0.5	28.3	28.8
R21 (20m)	Flats on Drew Road	542050, 180261	3.0	1.0	29.5	31.4
R22 (20m)	Flats on Docklands Street	543133, 180047	0.7	0.5	27.6	28.2
R22 (40m)	Flats on Docklands Street	543133, 180047	0.7	0.3	27.6	28.0
R23	Gallions Quarter	543868, 180637	1.4	2.2	27.0	28.8
R23 (20m)	Gallions Quarter	543868, 180637	1.4	0.7	27.0	28.0
R24	Gallions Quarter	543919, 180684	1.3	1.6	27.0	28.4
R24 (20m)	Gallions Quarter	543919, 180684	1.2	0.8	27.0	27.9
R25	University of East London Student Accommodation	543478, 180695	3.2	1.1	27.5	29.5
R25 (10.5m)	University of East London Student Accommodation	543478, 180695	3.0	1.0	27.5	29.4
R26	Felixstowe Court	543810, 180174	0.8	5.2	26.6	29.5
R26 (10.5m)	Felixstowe Court	543810, 180174	0.8	1.0	26.6	27.5

Appendix AQ.1.8

Table 9.16 – Modelled Annual Mean Concentrations of PM_{10} ($\mu g/m^3$) for 2014 Baseline

Receptor ID	Description	OS Grid Ref	Airport PM_{10}	Road PM_{10}	Background PM_{10}	Total PM_{10}
R1	Camel Road/Hartmann Road	541982, 180307	0.80	0.36	21.7	22.8
R2	Camel Road/Parker Street	542133, 180303	1.03	0.28	21.6	22.9
R3	Parker Street (Portway Primary School)	542177, 180229	0.45	0.13	21.6	22.1
R4	Newland Street (opposite entrance to LCY car park)	542549, 180153	0.21	0.18	21.4	21.8
R5	Newland Street/Kennard Street	542687, 180145	0.14	0.08	21.4	21.6
R6	Brixham Street/Dockland Street	543127, 180121	0.09	0.04	21.2	21.3
R7	Platterns Court/Billingway Dock Head	543676, 180077	0.07	0.10	20.8	21.0
R8	Albert Road/Woolwich Manor Way	543709, 180015	0.06	0.52	20.8	21.4
R9	Robert Street adj Albert Road (north side)	543523, 179954	0.05	0.36	20.9	21.3
R10	Collier Close adj Gallions Way Roundabout (eastern side)	543715, 180875	0.15	0.63	20.8	21.6
R11	Yeoman Close adj Royal Albert Way	543612, 180883	0.16	0.31	20.9	21.4
R12	Straight Road/Campton Close	542826, 180920	0.14	0.23	21.2	21.5
R13	Mill Rd adj North Woolwich Road (west)	540854, 180110	0.04	0.63	21.1	21.8
R14	Connaught Road/Leonard Street	542321, 180086	0.18	0.39	21.5	22.1
R15	Gallions Primary School adj Royal Docks Road	543749, 181324	0.07	0.22	20.8	21.1
R16	Drew Road/Leonard Street	542306, 180219	0.42	0.23	21.5	22.2
R17	Woolwich Manor Way (UEL)	543800, 180701	0.15	0.27	20.8	21.2
R18	Woolwich Manor Way, (UEL)	543650, 180655	0.27	0.08	21.0	21.3
R18 (20m)	Woolwich Manor Way, (UEL)	543650, 180655	0.24	0.05	21.0	21.3
R19	West Silvertown 1	540846, 180439	0.05	0.05	21.3	21.4
R19 (20m)	West Silvertown 1	540846, 180439	0.05	0.04	21.3	21.4
R20	West Silvertown 2	540681, 180448	0.04	0.05	21.2	21.3
R20 (20m)	West Silvertown 2	540681, 180448	0.04	0.04	21.2	21.2
R21	Flats on Drew Road	542050, 180261	0.31	0.07	21.6	22.0
R22 (20m)	Flats on Docklands Street	543133, 180047	0.07	0.03	21.2	21.3
R22 (40m)	Flats on Docklands Street	543133, 180047	0.06	0.02	21.2	21.3
R23	Gallions Quarter	543868, 180637	0.13	0.16	20.7	21.0
R23 (20m)	Gallions Quarter	543868, 180637	0.12	0.05	20.7	20.9
R24	Gallions Quarter	543919, 180684	0.11	0.11	20.6	20.8
R24 (20m)	Gallions Quarter	543919, 180684	0.11	0.05	20.6	20.8
R25	University of East London Student Accommodation	543478, 180695	0.30	0.08	21.1	21.5
R25 (10.5m)	University of East London Student Accommodation	543478, 180695	0.29	0.07	21.1	21.5
R26	Felixstowe Court	543810, 180174	0.07	0.33	20.8	21.2
R26 (10.5m)	Felixstowe Court	543810, 180174	0.07	0.07	20.8	20.9

Appendix AQ.1.8

Table 9.17 – Modelled Annual Mean Concentrations of $PM_{2.5}$ for 2014 Baseline ($\mu g/m^3$)

Receptor ID	Description	OS Grid Ref	Airport $PM_{2.5}$	Road $PM_{2.5}$	Background $PM_{2.5}$	Total $PM_{2.5}$
R1	Camel Road/Hartmann Road	541982, 180307	0.80	0.22	15.2	16.2
R2	Camel Road/Parker Street	542133, 180303	1.03	0.17	15.1	16.3
R3	Parker Street (Portway Primary School)	542177, 180229	0.45	0.08	15.1	15.6
R4	Newland Street (opposite entrance to LCY car park)	542549, 180153	0.21	0.11	15.1	15.4
R5	Newland Street/Kennard Street	542687, 180145	0.14	0.05	15.0	15.2
R6	Brixham Street/Dockland Street	543127, 180121	0.09	0.03	14.9	15.0
R7	Platterns Court/Billingway Dock Head	543676, 180077	0.07	0.06	14.6	14.7
R8	Albert Road/Woolwich Manor Way	543709, 180015	0.06	0.32	14.5	14.9
R9	Robert Street adj Albert Road (north side)	543523, 179954	0.05	0.22	14.6	14.9
R10	Collier Close adj Gallions Way Roundabout (eastern side)	543715, 180875	0.15	0.40	14.6	15.1
R11	Yeoman Close adj Royal Albert Way	543612, 180883	0.16	0.19	14.7	15.0
R12	Straight Road/Campton Close	542826, 180920	0.14	0.14	14.9	15.1
R13	Mill Rd adj North Woolwich Road (west)	540854, 180110	0.04	0.39	14.6	15.1
R14	Connaught Road/Leonard Street	542321, 180086	0.18	0.24	15.1	15.5
R15	Gallions Primary School adj Royal Docks Road	543749, 181324	0.07	0.13	14.5	14.7
R16	Drew Road/Leonard Street	542306, 180219	0.42	0.14	15.1	15.7
R17	Woolwich Manor Way (UEL)	543800, 180701	0.15	0.17	14.6	14.9
R18	Woolwich Manor Way, (UEL)	543650, 180655	0.27	0.05	14.7	15.0
R18 (20m)	Woolwich Manor Way, (UEL)	543650, 180655	0.24	0.03	14.7	15.0
R19	West Silvertown 1	540846, 180439	0.05	0.03	14.7	14.8
R19 (20m)	West Silvertown 1	540846, 180439	0.05	0.02	14.7	14.8
R20	West Silvertown 2	540681, 180448	0.04	0.03	14.6	14.6
R20 (20m)	West Silvertown 2	540681, 180448	0.04	0.02	14.6	14.6
R21	Flats on Drew Road	542050, 180261	0.31	0.04	15.1	15.5
R22 (20m)	Flats on Docklands Street	543133, 180047	0.07	0.02	14.8	14.9
R22 (40m)	Flats on Docklands Street	543133, 180047	0.06	0.01	14.8	14.9
R23	Gallions Quarter	543868, 180637	0.13	0.10	14.5	14.7
R23 (20m)	Gallions Quarter	543868, 180637	0.12	0.03	14.5	14.7
R24	Gallions Quarter	543919, 180684	0.11	0.07	14.5	14.6
R24 (20m)	Gallions Quarter	543919, 180684	0.11	0.03	14.5	14.6
R25	University of East London Student Accommodation	543478, 180695	0.30	0.05	14.8	15.2
R25 (10.5m)	University of East London Student Accommodation	543478, 180695	0.29	0.04	14.8	15.1
R26	Felixstowe Court	543810, 180174	0.07	0.21	14.5	14.8
R26 (10.5m)	Felixstowe Court	543810, 180174	0.07	0.05	14.5	14.6

Appendix AQ.1.8

Table 9.18 – Modelled 98th Percentile of 1-hr Mean Odour Concentrations in 2014 (OU_E/m^3)

Receptor ID	Description	OS Grid Ref	98th Percentile (OU_E/m^3)
R1	Camel Road/Hartmann Road	541982, 180307	2.0
R2	Camel Road/Parker Street	542133, 180303	1.9
R3	Parker Street (Portway Primary School)	542177, 180229	0.9
R4	Newland Street (opposite entrance to LCY car park)	542549, 180153	0.4
R5	Newland Street/Kennard Street	542687, 180145	0.3
R6	Brixham Street/Dockland Street	543127, 180121	0.1
R7	Platterns Court/Billingway Dock Head	543676, 180077	0.1
R8	Albert Road/Woolwich Manor Way	543709, 180015	0.1
R9	Robert Street adj Albert Road (north side)	543523, 179954	0.1
R10	Collier Close adj Gallions Way Roundabout (eastern side)	543715, 180875	0.2
R11	Yeoman Close adj Royal Albert Way	543612, 180883	0.2
R12	Straight Road/Campton Close	542826, 180920	0.2
R13	Mill Rd adj North Woolwich Road (west)	540854, 180110	0.1
R14	Connaught Road/Leonard Street	542321, 180086	0.3
R15	Gallions Primary School adj Royal Docks Road	543749, 181324	0.1
R16	Drew Road/Leonard Street	542306, 180219	0.8
R17	Woolwich Manor Way (UEL)	543800, 180701	0.2
R18	Woolwich Manor Way, (UEL)	543650, 180655	0.3
R18 (20m)	Woolwich Manor Way, (UEL)	543650, 180655	0.3
R19	West Silvertown 1	540846, 180439	0.1
R19 (20m)	West Silvertown 1	540846, 180439	0.1
R20	West Silvertown 2	540681, 180448	0.1
R20 (20m)	West Silvertown 2	540681, 180448	0.1
R21	Flats on Drew Road	542050, 180261	0.8
R22 (20m)	Flats on Docklands Street	543133, 180047	0.1
R22 (40m)	Flats on Docklands Street	543133, 180047	0.1
R23	Gallions Quarter	543868, 180637	0.2
R23 (20m)	Gallions Quarter	543868, 180637	0.2
R24	Gallions Quarter	543919, 180684	0.2
R24 (20m)	Gallions Quarter	543919, 180684	0.1
R25	University of East London Student Accommodation	543478, 180695	0.3
R25 (10.5m)	University of East London Student Accommodation	543478, 180695	0.3
R26	Felixstowe Court	543810, 180174	0.1
R26 (10.5m)	Felixstowe Court	543810, 180174	0.1

Appendix AQ.1.8

9.186 A summary of the 2014 Baseline Year emissions (tonnes/yr) is shown in Table 9.19. This shows the emissions from different source categories. As described in the methodology section above, Airport-related PM emissions are assumed to represent both the PM_{10} and $PM_{2.5}$ fractions, which represents a worst case. Emissions from aircraft dominate, but a direct comparison between Airport and Landside Road Traffic sources should be treated with caution, as the latter is defined by the scale of the road network included in the assessment.

Table 9.19 – Summary Emissions for 2014 Baseline (te/yr)

Source Category	NOx (te/yr)	PM_{10} (te/yr)	$PM_{2.5}$ (te/yr)
Airport Sources			
Aircraft (LTO cycle plus APU and engine testing)	183.7	15.0	15.0
Airside vehicles, MGPU and fire training	5.3	0.4	0.4
Gas Boilers	0.3	<0.1	<0.1
Taxi Ranks/Car Parks	0.2	<0.1	<0.1
Total Airport Related	189.5	15.4	15.4
Landside Road Traffic			
Road traffic on local road network in defined study area	34.5	2.5	1.5
Total emissions in assessment area	**224.0**	**15.2**	**14.2**

Assessment of Construction Impacts

Construction Traffic

9.187 Construction materials and equipment are to be delivered by both road and barge. The peak number of monthly HGV movements during the construction programme is 773 two-way trips. Assuming a 30-day working month, this equates to an average of 52 HGV movements per day, during the peak period[71]. As described in Chapter 6: Development Programme and Construction, these HGV movements would be divided between the two principal access routes:

a) Route 2 – Airside access, via the A1020 Connaught Bridge Road and the A112 Connaught Road

b) Route 3 – Compound and landside access, via the A117 Woolwich Manor Way or Albert Road

9.188 A third access route, Route 4, provides secondary compound and landside access, via the A1020 Connaught Bridge Road, the A112 Connaught Road, Camel Road and Hartmann Road, but is intended to be used only under exceptional or emergency circumstances, and HGV construction traffic movements along Camel Road/Hartmann Road will be minimal.

9.189 Guidance issued by EPUK/IAQM (17) indicates that a detailed air quality assessment is only likely to be required where developments increase HGV movements by more than 25 movements per day as an

71 The precise quantum of barge movements that will occur in the future cannot be stated with certainty at this stage. The estimated number of HGV movements is based on 14 barge movements/month. If no materials were transported by barge, this would generate an additional 280 HGV movements/month, equivalent to an additional 10 HGV movements/day. This would have no significant effect on the conclusions drawn.

annual average daily traffic (AADT) increment. Based on a 50:50 split in HGV movements between route 2 and route 3, the peak daily HGV trips during the CADP construction programme only barely exceeds this criterion (26 movements per day on route 2 and route 3). As this increment is based on an estimated peak month, the peak AADT increment is likely to be below the criterion. As such, the air quality impacts associated with emissions from construction traffic have been scoped out of a detailed assessment.[72]

9.190 It should be noted that the construction traffic movements in both 2020 and 2023 have been included within the operational traffic movements for those years, and have thus been explicitly considered within the operational assessment.

Sensitive Receptors

9.191 Dust sensitive receptors have been identified within the various distance bands described in Appendix 9.1, and are shown summarised in Table 9.20 below. It should be noted that these distances relate to the red line boundary of the Application Site, and in practice there will be far fewer sensitive receptors within the actual distances to demolition or construction works.

Table 9.20 – Number of Dust Sensitive Receptors

Buffer distance (m)	Number of Receptors
<20	Less than 100
20-50	100 - 500
50-100	100 - 500
100-350	More than 500

9.192 In line with the IAQM guidance, the construction activities have been categorised using the criteria presented in Appendix 9.1 to assess the likely impacts from demolition, earthworks, construction and 'track-out' activities, and the likely effects on sensitive receptors close to the CADP site.

Demolition

9.193 There will be a variety of demolition works throughout the period, including the demolition of the existing forecourt, access road and City Aviation House, which is scheduled for an 18 week period at the end of Year 5 in accordance with the *Updated Construction Programme*. The demolition works will be phased and will exceed the 50,000 m^3 threshold for a *large* dust emission class (based on the criteria set out in Table A1.1 in Appendix 9.1), as further described in UES Chapter 15: Waste.

9.194 There are some sensitive receptors within 20m of some of the works. The dust emission class for the demolition works is judged to be ***large.***

Earthworks

9.195 The characteristics of the soil at the development site have been defined using the British Geological Survey's UK Soil Observatory website (British Geological Survey, 2015), as set out in Table 9.21. Overall, it is considered that, when dry, this soil has the potential to be considerably dusty due to its small particle size.

[72] This approach to scoping out the air quality impacts from construction traffic adopts the revised screening criterion in the EPUK/IAQM Guidance.

Table 9.21 – Summary of Soil Characteristics

Category	Record
Soil layer thickness	Deep
Soil Parent Material Grain Size	Mixed (Argillic[a] - Arenaceous[b])
European Soil Bureau Description	Fluvial Clays, Silts Sands and Gravel
Soil Group	Heavy
Soil Texture	Peaty Clay

[a] grain size < 0.06 mm.

[b] grain size 0.06 – 2.0 mm.

9.196 Various excavations will be required for the new runway link, foundations for the new buildings and associated infrastructures, the new car parking and taxi feeder park, and various landside infrastructure services, as described in Chapters 6 and 15 of this UES.

9.197 The total area of earthworks will exceed the 10,000 m^2 threshold for a *large* dust emission class (based on the criteria set out in Table A1.1). There are a number of sensitive receptors within 20m of the earthworks, although much of the earthworks, with the exception of those required for the new hotel and car parking facilities, will take place much further than 20m from sensitive receptors. The dust emission class for the earthworks is judged to be ***large.***

<u>Construction</u>

9.198 The main element of the works will involve the construction of the new piled deck platforms, together with the new infrastructure including the 7 new stands, taxi-lane, East Pier, and the Western and Eastern Extensions to the Terminal. Additional construction works will be required for the outbound baggage (OBB) extension, hotel, Western and Eastern Energy Centres, forecourt reconfiguration, and the surface and deck car parking.

9.199 The total building volume will exceed the 100,000 m^3 threshold for a ***large*** dust emission class for construction activities (based on the criteria set out in Table A1.1). There will be substantial piling works, although the majority of piles are to be sunk directly into the KGV dock and there will be minimal potential for dust emissions.

9.200 The construction works will be phased, and at times there will be sensitive receptors within 20m of the works, but the majority of the works, with the exception of the construction of the new hotel and car parking facilities, will take place much further than 20m from sensitive receptors. The dust emission class for the construction works is judged to be ***large.***

Trackout

9.201 As described above, there will be less than an average of 40 HGV trips in any one day during the peak periods of activity. There are a small number of health and dust sensitive receptors within 20m of the highway, and within 200m of the site. The dust emission class for the trackout is judged to be ***medium.***

9.202 Table 9.22 summaries the dust emission magnitude for the proposed development.

Table 9.22 - Summary of Dust Emission Magnitude

Activity	Dust
Demolition	Large
Earthworks	Large
Construction	Large
Trackout	Medium

Sensitivity of the Area

9.203 This assessment step combines the sensitivity of individual receptors to dust effects with the number of receptors in the area and their proximity to the site. It also considers additional site-specific factors such as topography and screening, and in the case of sensitivity to human health effects, baseline PM_{10} concentrations.

Sensitivity of the Area to Effects from Dust Soiling

9.204 The IAQM guidance, upon which the GLA's guidance is based, explains that residential properties are 'high' sensitivity receptors to dust soiling, while places of work are 'medium' sensitivity receptors (Table A1.2). There are over 100 residential properties within 50 m of the site. Using the matrix set out in Table A1.3, the area surrounding the onsite works is of 'high' sensitivity to dust soiling. Table 9.22 shows that dust emission magnitude for trackout is 'medium' and Table A1.3 thus explains that there is a risk of material being tracked 200 m from the site exit. There are over 100 residential properties within 50 m of the roads along which material could be tracked and Table A1.3 thus indicates that the area is of 'high' sensitivity to dust soiling due to trackout.

Sensitivity of the Area to any Human Health Effects

9.205 Residential properties are also classified as being of 'high' sensitivity to human health effects. The matrix in Table A9.1.4 requires information on the baseline annual mean PM_{10} concentration in the area. Receptors 1 to 6 in Figure 9.2 are all within close proximity of the site boundary. The maximum predicted baseline PM_{10} concentration at these receptors is 22.8µg/m^3 (Table 9.16), and this value has been used. Using the matrix in Table A1.4, both the area surrounding the onsite works and surrounding roads along which material may be tracked from the site is of 'low' sensitivity to human health effects (Table 9.23).

Sensitivity of the Area to any Ecological Effects

9.206 The guidance only considers designated ecological sites within 50 m to have the potential to be impacted by the construction works. There are no designated ecological sites within 50 m of the site boundary or those roads along which material may be tracked, thus ecological impacts will not be considered further.

Table 9.23 - Summary of the Area Sensitivity

Effects Associated With:	Sensitivity of the Surrounding Area	
	On-site Works	Trackout
Dust Soiling	High Sensitivity	High Sensitivity
Human Health	Low Sensitivity	Low Sensitivity

Risk and Significance

9.207 The dust emission magnitudes in Table 9.22 have been combined with the sensitivities of the area in Table 9.23 using the matrix in Appendix 9.1, in order to assign a risk category to each activity. The resulting risk categories for the four construction activities, without mitigation, are set out in Table 9.24. These risk categories have been used to determine the appropriate level of mitigation as set out later in this Chapter.

Table 9.24 – Summary Significance Table Without Mitigation

Source	Dust Soiling	Human Health
Demolition	High Risk	Medium Risk
Earthworks	High Risk	Low Risk
Construction	High Risk	Low Risk
Trackout	Medium Risk	Low Risk

9.208 The IAQM does not provide a method for assessing the significance of effects before mitigation, and advises that pre-mitigation significance should not be determined. The pre-mitigation *risk* of dust impacts is, however, established, and is used to determine the appropriate best practice construction dust mitigation measures which should be employed to minimise the risk of impacts. With the determined best practice mitigation measures in place, the IAQM guidance is clear that the residual effects will normally be 'not significant'.

Assessment of Operational Impacts

Overview

9.209 Concentrations of nitrogen dioxide, PM_{10} and $PM_{2.5}$ have been predicted for 2020, 2023 and 2025, assuming that the proposed CADP does and does not proceed. Future predictions of the 98th percentile of 1-hour mean odour concentrations (OUE/m^3) have also been made.

9.210 The approach follows the general methodology for the 2014 Baseline Year assessment. In each case a comparison is drawn with the current (2014) situation and between the Without CADP and With CADP scenarios in each future year.

2020 (Transitional Year) Assessment

9.211 The predicted concentrations of nitrogen dioxide, PM_{10} and $PM_{2.5}$ at each relevant receptor location for the 2020 Without CADP and 2020 With CADP scenarios are set out in Tables 9.25 to 9.27 respectively. A more detailed description of the results is provided in Appendix 9.8 (Tables A8.1 to A8.6). The predicted 98th percentiles of 1-hour mean odour concentrations are set out in Table 9.28. The annual mean nitrogen dioxide (µg/m^3) concentrations are also shown as isopleths in Appendix 9.7.

Without CADP

9.212 The predicted annual mean concentrations of nitrogen dioxide in 2020 Without CADP are lower than in 2014 at all receptor locations, even with the assumption that there is no reduction in road traffic emission factors. This is principally due to existing and agreed measures at both the national and international levels to reduce emissions of nitrogen oxides from a wide range of sectors. The highest predicted concentration (33.3 $\mu g/m^3$) occurs at R2 (Camel Road) for the Without Emissions Reduction scenario, which is below the objective.

9.213 Predicted concentrations of PM_{10} and $PM_{2.5}$ are also lower in 2020 than in 2014. There are no predicted exceedences of the objectives.

9.214 The predicted 98th percentiles of 1-hour mean odour concentrations are higher in 2020 than in 2014, reflecting the greater number of aircraft movements. Predicted values are all below the threshold for 'moderately offensive' odours (3 OU_E/m^3) apart from at R1 and R2 (Camel Road/Hartmann Road) where concentrations of up to 3.3 OU_E/m^3 occur. This is still below the threshold for 'less offensive' odours (6 OU_E/m^3), as defined previously.

With CADP

9.215 The predicted annual mean concentrations of nitrogen dioxide in 2020 With CADP are generally lower than in 2014 at all receptor locations, even with the assumption that there is no reduction in road traffic emission factors. The highest predicted concentration (32.9 $\mu g/m^3$) occurs at R2 (Camel Road) for the Without Emissions Reduction scenario, and is below the objective. Predicted concentrations are lower at properties along the western extremity of Hartmann Road for the With CADP scenario compared to the Without CADP scenario, as Airport access is granted to the east from the junction with Woolwich Manor Road (thus diverting traffic flows).

9.216 The magnitudes of change in annual mean nitrogen dioxide concentrations range from zero to 4% and the impacts are *negligible* at all receptors**.**

9.217 Predicted concentrations of PM_{10} and $PM_{2.5}$ are lower in 2020 than in 2014. There are no predicted exceedences of the objectives, and all predicted impacts are *negligible*.

9.218 The predicted 98th percentiles of 1-hour mean odour concentrations are higher in 2020 than in 2014, reflecting the greater number of aircraft movements. Predicted values are all below the threshold for moderately offensive odours (3 OU_E/m^3) apart from at R1 and R2 (Camel Road/Hartmann Road) where concentrations of up to 3.6 OU_E/m^3 occur. This is below the threshold for 'less offensive' odours.

Table 9.25 – Predicted Impacts on Annual Mean Nitrogen Dioxide Concentrations (µg/m^3) – 2020 Core Case

Receptor ID	With Emissions Reduction				Without Emissions Reduction			
	Without CADP	With CADP	% Change	Impact Descriptor	Without CADP	With CADP	% Change	Impact Descriptor
Existing Receptors								
R1	28.7	28.6	0	Negligible	33.1	32.7	-1	Negligible
R2	29.2	29.0	0	Negligible	33.3	32.9	-1	Negligible
R3	26.0	26.2	1	Negligible	29.7	29.8	0	Negligible
R4	25.1	26.0	2	Negligible	29.0	29.8	2	Negligible
R5	24.0	25.5	4	Negligible	27.5	29.1	4	Negligible
R6	22.3	23.2	2	Negligible	25.5	26.6	3	Negligible
R7	21.5	22.0	1	Negligible	25.2	26.0	2	Negligible
R8	23.0	24.0	3	Negligible	28.0	29.7	4	Negligible
R9	22.3	23.0	2	Negligible	26.8	28.0	3	Negligible
R10	26.6	26.8	0	Negligible	33.1	33.2	0	Negligible
R11	23.9	24.0	0	Negligible	28.5	28.5	0	Negligible
R12	24.5	24.6	0	Negligible	28.6	28.6	0	Negligible
R13	25.8	25.9	0	Negligible	31.5	31.7	0	Negligible
R14	26.2	26.3	0	Negligible	31.2	31.0	0	Negligible
R15	22.2	22.4	0	Negligible	26.6	26.8	0	Negligible
R16	26.4	26.8	1	Negligible	30.5	30.6	0	Negligible
R17	23.7	24.2	1	Negligible	28.1	28.8	2	Negligible
R18	23.6	24.0	1	Negligible	27.2	27.6	1	Negligible
R18 (20m)	23.2	23.5	1	Negligible	26.6	26.9	1	Negligible
R19	22.7	22.8	0	Negligible	26.4	26.5	0	Negligible
R19 (20m)	22.7	22.8	0	Negligible	26.3	26.4	0	Negligible
R20	22.8	22.9	0	Negligible	26.5	26.6	0	Negligible
R20 (20m)	22.8	22.8	0	Negligible	26.4	26.5	0	Negligible
R21	25.0	25.3	1	Negligible	28.5	28.7	1	Negligible
R22 (20m)	22.0	22.4	1	Negligible	25.2	25.5	1	Negligible
R22 (40m)	21.9	22.1	0	Negligible	25.0	25.2	0	Negligible
R23	22.7	23.0	1	Negligible	26.5	27.0	1	Negligible
R23 (20m)	22.1	22.3	0	Negligible	25.6	25.8	1	Negligible
R24	22.3	22.6	1	Negligible	26.1	26.4	1	Negligible
R24 (20m)	22.0	22.2	0	Negligible	25.5	25.7	1	Negligible
R25	23.7	24.0	1	Negligible	27.1	27.5	1	Negligible
R25 (10.5m)	23.5	23.9	1	Negligible	26.9	27.3	1	Negligible
R26	22.9	23.9	2	Negligible	27.5	29.0	4	Negligible
R26 (10.5m)	21.5	21.8	1	Negligible	25.1	25.5	1	Negligible
New Receptors								
R27	24.6	24.9	1	Negligible	28.6	28.9	1	Negligible
R27 (20m)	23.4	23.6	1	Negligible	26.9	27.1	0	Negligible
R28	22.9	23.1	0	Negligible	26.5	26.6	0	Negligible
R28 (20m)	22.7	22.9	0	Negligible	26.1	26.3	0	Negligible
R29	24.8	25.0	1	Negligible	29.1	29.3	0	Negligible
R29 (20m)	23.4	23.6	0	Negligible	26.9	27.1	0	Negligible
R30	21.8	21.9	0	Negligible	25.2	25.4	0	Negligible
R30 (20m)	21.7	21.8	0	Negligible	25.1	25.3	0	Negligible
R31	21.8	21.9	0	Negligible	25.3	25.5	0	Negligible
R31 (20m)	21.7	21.8	0	Negligible	25.1	25.3	0	Negligible
R32	24.9	25.1	1	Negligible	28.3	28.5	1	Negligible
R32 (20m)	24.6	24.8	1	Negligible	28.0	28.2	0	Negligible
R33	24.5	25.1	2	Negligible	27.8	28.4	2	Negligible
R33 (20m)	24.2	24.7	1	Negligible	27.4	27.9	1	Negligible
R34	25.3	25.4	0	Negligible	29.8	29.8	0	Negligible
R35	24.2	24.4	0	Negligible	27.8	28.0	0	Negligible
R35 (20m)	23.9	24.0	0	Negligible	27.4	27.5	0	Negligible
R36	26.0	26.2	1	Negligible	31.4	31.6	1	Negligible
R36 (20m)	23.3	23.5	0	Negligible	26.9	27.1	0	Negligible

Receptor ID	With Emissions Reduction				Without Emissions Reduction			
	Without CADP	With CADP	% Change	Impact Descriptor	Without CADP	With CADP	% Change	Impact Descriptor
R37	24.9	25.0	0	Negligible	29.1	29.2	0	Negligible
R38	24.7	24.8	0	Negligible	29.7	29.9	0	Negligible
R39	24.8	24.8	0	Negligible	29.6	29.4	0	Negligible
R39 (10.5m)	23.7	23.7	0	Negligible	27.6	27.6	0	Negligible
R40	26.8	26.5	-1	Negligible	33.0	32.5	-1	Negligible
R40 (20m)	22.8	22.9	0	Negligible	26.4	26.5	0	Negligible
R41	24.4	24.4	0	Negligible	29.2	29.0	0	Negligible
R41 (13.5m)	23.0	23.0	0	Negligible	26.8	26.8	0	Negligible

Table 9.26 – Predicted Impacts on Annual Mean PM_{10} Concentrations ($\mu g/m^3$) in 2020

Receptor ID	Without CADP	With CADP	% Change	Impact Descriptor
Existing Receptors				
R1	21.1	21.0	0	Negligible
R2	21.0	21.0	0	Negligible
R3	20.5	20.5	0	Negligible
R4	20.3	20.5	1	Negligible
R5	20.1	20.4	1	Negligible
R6	19.9	20.1	0	Negligible
R7	19.7	19.8	0	Negligible
R8	20.0	20.3	1	Negligible
R9	20.0	20.2	1	Negligible
R10	20.4	20.4	0	Negligible
R11	20.1	20.1	0	Negligible
R12	20.1	20.1	0	Negligible
R13	20.6	20.6	0	Negligible
R14	20.6	20.6	0	Negligible
R15	19.9	19.9	0	Negligible
R16	20.5	20.6	0	Negligible
R17	19.8	19.9	0	Negligible
R18	19.9	20.0	0	Negligible
R18 (20m)	19.9	19.9	0	Negligible
R19	20.2	20.2	0	Negligible
R19 (20m)	20.2	20.2	0	Negligible
R20	20.1	20.1	0	Negligible
R20 (20m)	20.0	20.1	0	Negligible
R21	20.4	20.5	0	Negligible
R22 (20m)	19.9	19.9	0	Negligible
R22 (40m)	19.9	19.9	0	Negligible
R23	19.6	19.7	0	Negligible
R23 (20m)	19.5	19.5	0	Negligible
R24	19.5	19.5	0	Negligible
R24 (20m)	19.4	19.5	0	Negligible
R25	20.0	20.1	0	Negligible
R25 (10.5m)	20.0	20.1	0	Negligible
R26	19.8	20.0	1	Negligible
R26 (10.5m)	19.5	19.6	0	Negligible
New Receptors				
R27	20.9	20.9	0	Negligible
R27 (20m)	20.7	20.7	0	Negligible
R28	20.7	20.7	0	Negligible
R28 (20m)	20.7	20.7	0	Negligible
R29	20.8	20.8	0	Negligible
R29 (20m)	20.6	20.6	0	Negligible
R30	19.3	19.3	0	Negligible

Receptor ID	Without CADP	With CADP	% Change	Impact Descriptor
R30 (20m)	19.3	19.3	0	Negligible
R31	19.2	19.2	0	Negligible
R31 (20m)	19.2	19.2	0	Negligible
R32	20.2	20.2	0	Negligible
R32 (20m)	20.1	20.2	0	Negligible
R33	20.2	20.3	0	Negligible
R33 (20m)	20.1	20.2	0	Negligible
R34	20.4	20.4	0	Negligible
R35	20.7	20.7	0	Negligible
R35 (20m)	20.6	20.6	0	Negligible
R36	20.8	20.9	0	Negligible
R36 (20m)	20.3	20.3	0	Negligible
R37	20.5	20.5	0	Negligible
R38	20.3	20.4	0	Negligible
R39	21.0	21.0	0	Negligible
R39 (10.5m)	20.7	20.7	0	Negligible
R40	21.4	21.4	0	Negligible
R40 (20m)	20.7	20.8	0	Negligible
R41	21.1	21.1	0	Negligible
R41 (13.5m)	20.9	20.9	0	Negligible

Table 9.27 – Predicted Impacts on Annual Mean $PM_{2.5}$ Concentrations (µg/m^3) in 2020

Receptor ID	Without CADP	With CADP	% Change	Impact Descriptor
Existing Receptors				
R1	14.6	14.5	0	Negligible
R2	14.6	14.5	0	Negligible
R3	14.1	14.2	0	Negligible
R4	14.0	14.1	1	Negligible
R5	13.8	14.1	1	Negligible
R6	13.6	13.8	0	Negligible
R7	13.5	13.5	0	Negligible
R8	13.7	13.8	1	Negligible
R9	13.6	13.7	0	Negligible
R10	13.9	14.0	0	Negligible
R11	13.8	13.8	0	Negligible
R12	13.8	13.8	0	Negligible
R13	13.9	13.9	0	Negligible
R14	14.1	14.1	0	Negligible
R15	13.6	13.6	0	Negligible
R16	14.1	14.2	0	Negligible
R17	13.6	13.7	0	Negligible
R18	13.8	13.8	0	Negligible
R18 (20m)	13.7	13.7	0	Negligible
R19	13.6	13.6	0	Negligible
R19 (20m)	13.6	13.6	0	Negligible
R20	13.5	13.5	0	Negligible
R20 (20m)	13.5	13.5	0	Negligible
R21 (20m)	14.1	14.1	0	Negligible
R22 (20m)	13.6	13.7	0	Negligible
R22 (40m)	13.6	13.6	0	Negligible
R23	13.5	13.5	0	Negligible
R23 (20m)	13.4	13.4	0	Negligible
R24	13.4	13.4	0	Negligible
R24 (20m)	13.4	13.4	0	Negligible
R25	13.8	13.9	0	Negligible
R25 (10.5m)	13.8	13.9	0	Negligible
R26	13.5	13.7	0	Negligible
R26 (10.5m)	13.4	13.5	0	Negligible

Appendix AQ.1.8

Receptor ID	Without CADP	With CADP	% Change	Impact Descriptor
New Receptors				
R27	14.3	14.3	0	Negligible
R27 (20m)	14.1	14.1	0	Negligible
R28	14.1	14.1	0	Negligible
R28 (20m)	14.1	14.1	0	Negligible
R29	14.2	14.2	0	Negligible
R29 (20m)	14.0	14.1	0	Negligible
R30	13.3	13.3	0	Negligible
R30 (20m)	13.2	13.3	0	Negligible
R31	13.2	13.2	0	Negligible
R31 (20m)	13.2	13.2	0	Negligible
R32	13.9	14.0	0	Negligible
R32 (20m)	13.9	13.9	0	Negligible
R33	14.0	14.1	0	Negligible
R33 (20m)	13.9	14.0	0	Negligible
R34	14.0	14.0	0	Negligible
R35	14.1	14.1	0	Negligible
R35 (20m)	14.1	14.1	0	Negligible
R36	14.1	14.2	0	Negligible
R36 (20m)	13.8	13.9	0	Negligible
R37	14.0	14.0	0	Negligible
R38	13.7	13.8	0	Negligible
R39	14.3	14.2	0	Negligible
R39 (10.5m)	14.1	14.1	0	Negligible
R40	14.5	14.4	0	Negligible
R40 (20m)	14.1	14.1	0	Negligible
R41	14.3	14.3	0	Negligible
R41 (13.5m)	14.1	14.1	0	Negligible

Table 9.28 – Predicted 98th Percentile of 1-hour Mean Odour Concentrations (OU_E/m^3) in 2020

Receptor ID	OS Grid Ref	98th Percentile (OU_E/m^3)	
		Without CADP	With CADP
Existing Receptors			
R1	541982, 180307	3.3	3.6
R2	542133, 180303	3.1	3.3
R3	542177, 180229	1.5	1.7
R4	542549, 180153	0.7	1.6
R5	542687, 180145	0.5	1.5
R6	543127, 180121	0.2	0.7
R7	543676, 180077	0.2	0.3
R8	543709, 180015	0.2	0.3
R9	543523, 179954	0.2	0.3
R10	543715, 180875	0.3	0.4
R11	543612, 180883	0.3	0.4
R12	542826, 180920	0.4	0.6
R13	540854, 180110	0.2	0.2
R14	542321, 180086	0.6	0.9
R15	543749, 181324	0.2	0.2
R16	542306, 180219	1.3	1.8
R17	543800, 180701	0.3	0.4
R18	543650, 180655	0.5	0.6
R18 (20m)	543650, 180655	0.4	0.5
R19	540846, 180439	0.2	0.3
R19 (20m)	540846, 180439	0.2	0.3
R20	540681, 180448	0.2	0.2
R20 (20m)	540681, 180448	0.2	0.2
R21 (20m)	542050, 180261	1.2	1.4

Receptor ID	OS Grid Ref	98th Percentile (OU_E/m^3)	
R22 (20m)	543133, 180047	0.2	0.5
R22 (40m)	543133, 180047	0.2	0.3
R23	543868, 180637	0.3	0.4
R23 (20m)	543868, 180637	0.3	0.3
R24	543919, 180684	0.2	0.3
R24 (20m)	543919, 180684	0.2	0.3
R25	543478, 180695	0.5	0.7
R25 (10.5m)	543478, 180695	0.5	0.6
R26	543810, 180174	0.2	0.3
R26 (10.5m)	543810, 180174	0.2	0.3
New Receptors			
R27	541614, 180468	1.2	1.7
R27 (20m)	541614, 180468	0.8	1.1
R28	541460, 180476	0.6	0.8
R28 (20m)	541460, 180476	0.5	0.7
R29	541587, 180372	0.9	1.2
R29 (20m)	541587, 180372	0.7	0.9
R30	544067, 180548	0.2	0.2
R30 (20m)	544067, 180548	0.2	0.2
R31	544088, 180710	0.2	0.2
R31 (20m)	544088, 180710	0.2	0.2
R32	542418, 180704	0.6	0.9
R32 (20m)	542418, 180704	0.5	0.7
R33	542979, 180691	0.6	1.0
R33 (20m)	542979, 180691	0.5	0.8
R34	542884, 180843	0.4	0.7
R35	541917, 180713	0.7	1.0
R35 (20m)	541917, 180713	0.6	0.8
R36	541583, 180150	0.5	0.6
R36 (20m)	541583, 180150	0.4	0.6
R37	541862, 180129	0.7	0.9
R38	540890, 180071	0.2	0.2
R39	541882, 180859	0.4	0.6
R39 (10.5m)	541882, 180859	0.4	0.5
R40	541716, 180852	0.3	0.5
R40 (20m)	541716, 180852	0.3	0.4
R41	541627, 180863	0.3	0.4
R41 (13.5m)	541627, 180863	0.3	0.4

2023 (Design Year) Assessment

9.219 The predicted concentrations of nitrogen dioxide, PM_{10} and $PM_{2.5}$ at each relevant receptor location for the 2023 Without CADP and the 2023 With CADP Higher Passenger and With CADP Faster Move to Jets scenarios are set out below in Tables 9.29 to 9.31 respectively. The predicted concentrations for the 2023 With CADP Core Case are provided in Appendix 9.9[73]. A more detailed description of the results is provided in Appendix 9.8 (Tables A8.7 to A8.12). The predicted 98th percentiles of 1-hour mean odour unit concentrations are set out in Table 9.32. The annual mean nitrogen dioxide (µg/m^3) concentrations are also shown as isopleths in Appendix 9.7.

2023 Without CADP

9.220 The predicted annual mean concentrations of nitrogen dioxide in 2023 Without CADP are lower than in 2014 at all receptor locations. This is principally due to existing and agreed measures at both the national and international levels to reduce emissions of nitrogen oxides from a wide range of sectors. The highest predicted concentration (27.0 µg/m^3) occurs at R2 (Camel Road), and is below the objective.

9.221 Predicted concentrations of PM_{10} and $PM_{2.5}$ are also lower in 2023 than in 2014. There are no predicted exceedences of the objectives.

9.222 The predicted 98th percentiles of 1-hour mean odour concentrations are higher in 2023 than in 2014, reflecting the greater number of aircraft movements. Predicted values are all below the threshold for 'moderately offensive' odours (3 OU_E/m^3) apart from at R1 and R2 (Camel Road/Hartmann Road) where concentrations of up to 3.3 OU_E/m^3 occur. This is still below the threshold for 'less offensive' odours.

2023 With CADP Core Case

9.223 The 2023 CADP Core Case involves identical aircraft movements and airfield activity, but lower landside road traffic movements than the With CADP Higher Passenger Case sensitivity test. The latter therefore represents a worst-case 2023 development scenario with respect to air quality as overall road traffic emissions generated by the development are higher. As such, the results of the air quality assessment for the With CADP Higher Passenger Case, presented below, demonstrates the greatest potential air quality impacts in 2023; the predicted impacts associated with the 2023 With CADP Core Case are marginally lower, but the outcome is unchanged (see Appendix 9.9).

2023 With CADP Higher Passenger Case

9.224 The predicted annual mean concentrations of nitrogen dioxide in 2023 With CADP are lower than in 2014 at all receptor locations. The highest predicted concentration (27.0 µg/m^3) occurs at R2 (Camel Road), and is well below the objective.

[73] As described in an earlier section, the 2023 With CADP Higher Passenger Case assumes the same aircraft fleet mix and movements as the With CADP Core Case, but with a higher passenger load factor and associated increased surface access movements. By definition, impacts associated with the Higher Passenger Case will be greater than for the Core Case. The results for the Core Case are included in Appendix 9.9 for completeness.

9.225 The magnitudes of change in annual mean nitrogen dioxide concentrations range from zero to 6%. The impacts are described as *negligible* at all receptors other than at R5 (Newland Street) where the impact is *slight adverse*. The concentration at R5 remains well below the objective.

9.226 Predicted concentrations of PM_{10} and $PM_{2.5}$ are also lower in 2023 than in 2014. There are no predicted exceedences of the objectives, and all predicted impacts are *negligible*.

9.227 The predicted 98th percentiles of 1-hour mean odour concentrations are higher in 2023 than in 2014, reflecting the greater number of aircraft movements. Predicted values are all below the threshold for moderately offensive odours (3 OU_E/m^3) apart from at R1 and R2 (Camel Road/Hartmann Road), where concentrations of up to 3.8 OU_E/m^3 occur. This is still below the threshold for 'less offensive' odours.

2023 With CADP Faster Move to Jets Case

9.228 The predicted impacts associated with the With CADP Faster Move to Jets Case are generally marginally higher than the With CADP Higher Passenger Case, but the outcome is unchanged.

Table 9.29 – Predicted Impacts on Annual Mean Nitrogen Dioxide Concentrations (μg/m³) in 2023

Receptor ID	Without CADP	Higher Passenger Case			Faster Move to Jets Case		
		With CADP	% Change	Impact Descriptor	With CADP	% Change	Impact Descriptor
Existing Receptors							
R1	26.4	26.5	0	Negligible	26.6	0	Negligible
R2	27.0	27.0	0	Negligible	27.1	0	Negligible
R3	23.9	24.5	1	Negligible	24.5	2	Negligible
R4	23.0	24.8	5	Negligible	24.9	5	Negligible
R5	22.1	24.4	6	Slight Adverse	24.4	6	Slight Adverse
R6	20.4	21.6	3	Negligible	21.6	3	Negligible
R7	19.7	20.3	1	Negligible	20.3	2	Negligible
R8	20.8	21.8	2	Negligible	21.8	2	Negligible
R9	20.3	21.0	2	Negligible	21.0	2	Negligible
R10	23.7	24.1	1	Negligible	24.1	1	Negligible
R11	21.7	22.1	1	Negligible	22.1	1	Negligible
R12	22.3	22.7	1	Negligible	22.7	1	Negligible
R13	23.3	23.6	1	Negligible	23.6	1	Negligible
R14	23.8	24.3	1	Negligible	24.3	1	Negligible
R15	20.3	20.6	1	Negligible	20.6	1	Negligible
R16	24.3	25.2	2	Negligible	25.3	3	Negligible
R17	21.5	22.2	2	Negligible	22.3	2	Negligible
R18	21.7	22.4	2	Negligible	22.6	2	Negligible
R18 (20m)	21.2	21.9	2	Negligible	22.0	2	Negligible
R19	21.0	21.1	0	Negligible	21.1	0	Negligible
R19 (20m)	20.9	21.1	0	Negligible	21.1	0	Negligible
R20	21.1	21.2	0	Negligible	21.2	0	Negligible
R20 (20m)	21.1	21.2	0	Negligible	21.2	0	Negligible
R21 (20m)	23.0	23.5	1	Negligible	23.6	1	Negligible
R22 (20m)	20.2	20.8	1	Negligible	20.8	1	Negligible
R22 (40m)	20.1	20.4	1	Negligible	20.5	1	Negligible
R23	20.7	21.3	1	Negligible	21.3	1	Negligible
R23 (20m)	20.3	20.7	1	Negligible	20.7	1	Negligible
R24	20.5	20.9	1	Negligible	20.9	1	Negligible
R24 (20m)	20.2	20.5	1	Negligible	20.6	1	Negligible
R25	21.7	22.5	2	Negligible	22.6	2	Negligible
R25 (10.5m)	21.6	22.3	2	Negligible	22.4	2	Negligible
R26	20.8	21.7	2	Negligible	21.7	2	Negligible
R26 (10.5m)	19.7	20.1	1	Negligible	20.2	1	Negligible
New Receptors							
R27	22.4	22.6	1	Negligible	22.7	1	Negligible
R27 (20m)	21.3	21.6	1	Negligible	21.7	1	Negligible
R28	20.9	21.1	1	Negligible	21.1	1	Negligible
R28 (20m)	20.7	20.9	1	Negligible	20.9	1	Negligible
R29	22.4	22.7	1	Negligible	22.7	1	Negligible
R29 (20m)	21.3	21.6	1	Negligible	21.7	1	Negligible
R30	20.0	20.3	1	Negligible	20.3	1	Negligible
R30 (20m)	20.0	20.2	1	Negligible	20.2	1	Negligible
R31	20.0	20.3	1	Negligible	20.3	1	Negligible
R31 (20m)	19.9	20.2	1	Negligible	20.2	1	Negligible
R32	22.8	23.2	1	Negligible	23.3	1	Negligible
R32 (20m)	22.6	23.0	1	Negligible	23.0	1	Negligible
R33	22.5	23.8	3	Negligible	23.9	4	Negligible
R33 (20m)	22.2	23.3	3	Negligible	23.4	3	Negligible
R34	22.9	23.5	1	Negligible	23.5	2	Negligible
R35	22.1	22.4	1	Negligible	22.5	1	Negligible
R35 (20m)	21.8	22.1	1	Negligible	22.1	1	Negligible
R36	23.4	23.7	1	Negligible	23.8	1	Negligible

Receptor ID	Without CADP	Higher Passenger Case			Faster Move to Jets Case		
		With CADP	% Change	Impact Descriptor	With CADP	% Change	Impact Descriptor
R36 (20m)	21.3	21.6	1	Negligible	21.6	1	Negligible
R37	22.7	23.0	1	Negligible	23.0	1	Negligible
R38	22.5	22.7	0	Negligible	22.7	0	Negligible
R39	22.4	22.5	0	Negligible	22.5	0	Negligible
R39 (10.5m)	21.5	21.7	0	Negligible	21.7	0	Negligible
R40	23.9	23.7	0	Negligible	23.8	0	Negligible
R40 (20m)	20.8	21.0	0	Negligible	21.0	0	Negligible
R41	22.0	22.1	0	Negligible	22.1	0	Negligible
R41 (13.5m)	20.9	21.0	0	Negligible	21.0	0	Negligible

Table 9.30 – Predicted Impacts on Annual Mean PM_{10} Concentrations ($\mu g/m^3$) in 2023

Receptor ID	Without CADP	Higher Passenger Case			Faster Move to Jets Case		
		With CADP	% Change	Impact Descriptor	With CADP	% Change	Impact Descriptor
Existing Receptors							
R1	20.7	20.7	0	Negligible	20.7	0	Negligible
R2	20.6	20.6	0	Negligible	20.6	0	Negligible
R3	20.1	20.2	0	Negligible	20.2	0	Negligible
R4	19.9	20.1	1	Negligible	20.1	1	Negligible
R5	19.7	20.0	1	Negligible	20.0	1	Negligible
R6	19.5	19.7	0	Negligible	19.7	0	Negligible
R7	19.3	19.4	0	Negligible	19.4	0	Negligible
R8	19.7	19.9	1	Negligible	19.9	1	Negligible
R9	19.6	19.8	1	Negligible	19.8	1	Negligible
R10	20.0	20.0	0	Negligible	20.0	0	Negligible
R11	19.7	19.7	0	Negligible	19.7	0	Negligible
R12	19.7	19.8	0	Negligible	19.8	0	Negligible
R13	20.3	20.3	0	Negligible	20.3	0	Negligible
R14	20.2	20.2	0	Negligible	20.2	0	Negligible
R15	19.5	19.6	0	Negligible	19.6	0	Negligible
R16	20.2	20.3	0	Negligible	20.3	0	Negligible
R17	19.5	19.5	0	Negligible	19.5	0	Negligible
R18	19.5	19.6	0	Negligible	19.6	0	Negligible
R18 (20m)	19.5	19.5	0	Negligible	19.5	0	Negligible
R19	19.9	19.9	0	Negligible	19.9	0	Negligible
R19 (20m)	19.9	19.9	0	Negligible	19.9	0	Negligible
R20	19.8	19.8	0	Negligible	19.8	0	Negligible
R20 (20m)	19.8	19.8	0	Negligible	19.8	0	Negligible
R21 (20m)	20.1	20.1	0	Negligible	20.1	0	Negligible
R22 (20m)	19.5	19.6	0	Negligible	19.6	0	Negligible
R22 (40m)	19.5	19.5	0	Negligible	19.5	0	Negligible
R23	19.3	19.3	0	Negligible	19.3	0	Negligible
R23 (20m)	19.1	19.2	0	Negligible	19.2	0	Negligible
R24	19.1	19.2	0	Negligible	19.2	0	Negligible
R24 (20m)	19.1	19.1	0	Negligible	19.1	0	Negligible
R25	19.6	19.7	0	Negligible	19.7	0	Negligible
R25 (10.5m)	19.6	19.7	0	Negligible	19.7	0	Negligible
R26	19.4	19.6	1	Negligible	19.6	1	Negligible
R26 (10.5m)	19.2	19.3	0	Negligible	19.3	0	Negligible
New Receptors							
R27	20.5	20.5	0	Negligible	20.5	0	Negligible
R27 (20m)	20.3	20.3	0	Negligible	20.3	0	Negligible
R28	20.3	20.3	0	Negligible	20.3	0	Negligible
R28 (20m)	20.3	20.3	0	Negligible	20.3	0	Negligible
R29	20.4	20.4	0	Negligible	20.4	0	Negligible
R29 (20m)	20.2	20.2	0	Negligible	20.2	0	Negligible

Receptor ID	Without CADP	Higher Passenger Case			Faster Move to Jets Case		
		With CADP	% Change	Impact Descriptor	With CADP	% Change	Impact Descriptor
R30	18.9	19.0	0	Negligible	19.0	0	Negligible
R30 (20m)	18.9	18.9	0	Negligible	18.9	0	Negligible
R31	18.9	18.9	0	Negligible	18.9	0	Negligible
R31 (20m)	18.9	18.9	0	Negligible	18.9	0	Negligible
R32	19.8	19.8	0	Negligible	19.8	0	Negligible
R32 (20m)	19.7	19.8	0	Negligible	19.8	0	Negligible
R33	19.8	19.9	0	Negligible	19.9	0	Negligible
R33 (20m)	19.7	19.8	0	Negligible	19.8	0	Negligible
R34	20.0	20.0	0	Negligible	20.0	0	Negligible
R35	20.3	20.3	0	Negligible	20.3	0	Negligible
R35 (20m)	20.2	20.2	0	Negligible	20.2	0	Negligible
R36	20.4	20.5	0	Negligible	20.5	0	Negligible
R36 (20m)	19.9	19.9	0	Negligible	19.9	0	Negligible
R37	20.1	20.1	0	Negligible	20.1	0	Negligible
R38	20.0	20.1	0	Negligible	20.1	0	Negligible
R39	20.6	20.6	0	Negligible	20.6	0	Negligible
R39 (10.5m)	20.3	20.3	0	Negligible	20.3	0	Negligible
R40	21.0	21.0	0	Negligible	21.0	0	Negligible
R40 (20m)	20.4	20.4	0	Negligible	20.4	0	Negligible
R41	20.7	20.7	0	Negligible	20.7	0	Negligible
R41 (13.5m)	20.5	20.5	0	Negligible	20.5	0	Negligible

Table 9.31 – Predicted Impacts on Annual Mean $PM_{2.5}$ Concentrations ($\mu g/m^3$) in 2023

Receptor ID	Without CADP	Higher Passenger Case			Faster Move to Jets Case		
		With CADP	% Change	Impact Descriptor	With CADP	% Change	Impact Descriptor
Existing Receptors							
R1	14.2	14.2	0	Negligible	14.2	0	Negligible
R2	14.2	14.2	0	Negligible	14.2	0	Negligible
R3	13.8	13.8	0	Negligible	13.8	0	Negligible
R4	13.6	13.8	1	Negligible	13.8	1	Negligible
R5	13.5	13.7	1	Negligible	13.7	1	Negligible
R6	13.3	13.4	0	Negligible	13.4	0	Negligible
R7	13.1	13.2	0	Negligible	13.2	0	Negligible
R8	13.3	13.5	1	Negligible	13.5	1	Negligible
R9	13.3	13.4	0	Negligible	13.4	0	Negligible
R10	13.5	13.6	0	Negligible	13.6	0	Negligible
R11	13.4	13.4	0	Negligible	13.4	0	Negligible
R12	13.4	13.5	0	Negligible	13.5	0	Negligible
R13	13.6	13.6	0	Negligible	13.6	0	Negligible
R14	13.7	13.8	0	Negligible	13.8	0	Negligible
R15	13.2	13.3	0	Negligible	13.3	0	Negligible
R16	13.8	13.9	0	Negligible	13.9	0	Negligible
R17	13.3	13.3	0	Negligible	13.3	0	Negligible
R18	13.4	13.4	0	Negligible	13.4	0	Negligible
R18 (20m)	13.3	13.4	0	Negligible	13.4	0	Negligible
R19	13.3	13.3	0	Negligible	13.3	0	Negligible
R19 (20m)	13.3	13.3	0	Negligible	13.3	0	Negligible
R20	13.2	13.2	0	Negligible	13.2	0	Negligible
R20 (20m)	13.2	13.2	0	Negligible	13.2	0	Negligible
R21 (20m)	13.7	13.7	0	Negligible	13.7	0	Negligible
R22 (20m)	13.3	13.3	0	Negligible	13.3	0	Negligible
R22 (40m)	13.2	13.3	0	Negligible	13.3	0	Negligible
R23	13.1	13.2	0	Negligible	13.2	0	Negligible
R23 (20m)	13.1	13.1	0	Negligible	13.1	0	Negligible
R24	13.1	13.1	0	Negligible	13.1	0	Negligible
R24 (20m)	13.0	13.0	0	Negligible	13.0	0	Negligible
R25	13.4	13.5	0	Negligible	13.5	0	Negligible

Receptor ID	Without CADP	Higher Passenger Case			Faster Move to Jets Case		
		With CADP	% Change	Impact Descriptor	With CADP	% Change	Impact Descriptor
R25 (10.5m)	13.4	13.5	0	Negligible	13.5	0	Negligible
R26	13.2	13.3	0	Negligible	13.3	0	Negligible
R26 (10.5m)	13.1	13.1	0	Negligible	13.1	0	Negligible
New Receptors							
R27	13.9	13.9	0	Negligible	13.9	0	Negligible
R27 (20m)	13.7	13.7	0	Negligible	13.7	0	Negligible
R28	13.7	13.7	0	Negligible	13.7	0	Negligible
R28 (20m)	13.7	13.7	0	Negligible	13.7	0	Negligible
R29	13.8	13.8	0	Negligible	13.8	0	Negligible
R29 (20m)	13.7	13.7	0	Negligible	13.7	0	Negligible
R30	12.9	12.9	0	Negligible	12.9	0	Negligible
R30 (20m)	12.9	12.9	0	Negligible	12.9	0	Negligible
R31	12.9	12.9	0	Negligible	12.9	0	Negligible
R31 (20m)	12.9	12.9	0	Negligible	12.9	0	Negligible
R32	13.5	13.6	0	Negligible	13.6	0	Negligible
R32 (20m)	13.5	13.5	0	Negligible	13.5	0	Negligible
R33	13.6	13.7	0	Negligible	13.7	1	Negligible
R33 (20m)	13.5	13.6	0	Negligible	13.6	0	Negligible
R34	13.6	13.6	0	Negligible	13.6	0	Negligible
R35	13.7	13.7	0	Negligible	13.8	0	Negligible
R35 (20m)	13.7	13.7	0	Negligible	13.7	0	Negligible
R36	13.8	13.8	0	Negligible	13.8	0	Negligible
R36 (20m)	13.5	13.5	0	Negligible	13.5	0	Negligible
R37	13.6	13.7	0	Negligible	13.7	0	Negligible
R38	13.4	13.4	0	Negligible	13.4	0	Negligible
R39	13.9	13.9	0	Negligible	13.9	0	Negligible
R39 (10.5m)	13.7	13.7	0	Negligible	13.7	0	Negligible
R40	14.1	14.0	0	Negligible	14.0	0	Negligible
R40 (20m)	13.7	13.7	0	Negligible	13.7	0	Negligible
R41	13.9	13.9	0	Negligible	13.9	0	Negligible
R41 (13.5m)	13.7	13.8	0	Negligible	13.8	0	Negligible

Table 9.32 – Predicted 98th Percentile of 1-hour Mean Odour Concentrations (OU_E/m^3) in 2023

Receptor ID	OS Grid Ref	98th Percentile (OU_E/m^3)		
		Without CADP	Higher Passenger Case	Faster Move to Jets Case
Existing Receptors				
R1	541982, 180307	3.3	3.8	3.7
R2	542133, 180303	3.1	3.6	3.5
R3	542177, 180229	1.5	2.1	2.0
R4	542549, 180153	0.7	2.6	2.5
R5	542687, 180145	0.5	2.4	2.4
R6	543127, 180121	0.2	1.1	1.1
R7	543676, 180077	0.2	0.4	0.4
R8	543709, 180015	0.2	0.4	0.4
R9	543523, 179954	0.2	0.4	0.4
R10	543715, 180875	0.3	0.5	0.5
R11	543612, 180883	0.3	0.6	0.6
R12	542826, 180920	0.4	0.9	0.8
R13	540854, 180110	0.2	0.3	0.3
R14	542321, 180086	0.6	1.3	1.3
R15	543749, 181324	0.2	0.4	0.3
R16	542306, 180219	1.3	2.3	2.3
R17	543800, 180701	0.3	0.6	0.6
R18	543650, 180655	0.5	0.9	0.8
R18 (20m)	543650, 180655	0.4	0.7	0.7
R19	540846, 180439	0.2	0.3	0.3
R19 (20m)	540846, 180439	0.2	0.3	0.3
R20	540681, 180448	0.2	0.3	0.3
R20 (20m)	540681, 180448	0.2	0.3	0.3
R21 (20m)	542050, 180261	1.2	1.7	1.6
R22 (20m)	543133, 180047	0.2	0.7	0.7
R22 (40m)	543133, 180047	0.2	0.5	0.5
R23	543868, 180637	0.3	0.5	0.5
R23 (20m)	543868, 180637	0.3	0.5	0.5
R24	543919, 180684	0.2	0.5	0.5
R24 (20m)	543919, 180684	0.2	0.4	0.4
R25	543478, 180695	0.5	0.9	0.9
R25 (10.5m)	543478, 180695	0.5	0.9	0.8
R26	543810, 180174	0.2	0.4	0.4
R26 (10.5m)	543810, 180174	0.2	0.4	0.4
New Receptors				
R27	541614, 180468	1.2	1.6	1.5
R27 (20m)	541614, 180468	0.8	1.2	1.1
R28	541460, 180476	0.6	0.9	0.9
R28 (20m)	541460, 180476	0.5	0.8	0.8
R29	541587, 180372	0.9	1.2	1.2
R29 (20m)	541587, 180372	0.7	1.0	1.0
R30	544067, 180548	0.2	0.3	0.3
R30 (20m)	544067, 180548	0.2	0.3	0.3
R31	544088, 180710	0.2	0.4	0.3
R31 (20m)	544088, 180710	0.2	0.3	0.3
R32	542418, 180704	0.6	1.0	1.0
R32 (20m)	542418, 180704	0.5	0.8	0.8
R33	542979, 180691	0.6	1.6	1.5
R33 (20m)	542979, 180691	0.5	1.2	1.2
R34	542884, 180843	0.4	1.1	1.0
R35	541917, 180713	0.7	1.1	1.1
R35 (20m)	541917, 180713	0.6	0.9	0.9

R36	541583, 180150	0.5	0.8	0.7
R36 (20m)	541583, 180150	0.4	0.7	0.7
R37	541862, 180129	0.7	1.1	1.1
R38	540890, 180071	0.2	0.3	0.3
R39	541882, 180859	0.4	0.7	0.7
R39 (10.5m)	541882, 180859	0.4	0.7	0.6
R40	541716, 180852	0.3	0.5	0.5
R40 (20m)	541716, 180852	0.3	0.5	0.5
R41	541627, 180863	0.3	0.5	0.4
R41 (13.5m)	541627, 180863	0.3	0.4	0.4

Appendix AQ.1.8

2025 (Principal Year) Assessment

9.229 The predicted concentrations of nitrogen dioxide, PM_{10} and $PM_{2.5}$ at each relevant receptor location for the 2025 Without CADP, the 2025 With CADP Higher Passenger and With CADP Faster Move to Jets scenarios are set out below in Tables 9.33 to 9.35 respectively. The predicted concentrations for the With CADP Core Case are provided in Appendix 9.9[74]. A more detailed description of the results is provided in Appendix 9.8 (Tables A8.13 to A8.18). The predicted 98th percentiles of 1-hour mean odour unit concentrations are set out in Table 9.36. The annual mean nitrogen dioxide (µg/m^3) concentrations are also shown as isopleths in Appendix 9.7.

2025 Without CADP

9.230 The predicted annual mean concentrations of nitrogen dioxide in 2025 Without Development are lower than in 2014 at all receptor locations. This is principally due to existing and agreed measures at both the national and international levels to reduce emissions of nitrogen oxides from a wide range of sectors. The highest predicted concentration (25.5 µg/m^3) occurs at R2 (Camel Road), and is well below the objective.

9.231 Predicted concentrations of PM_{10} and $PM_{2.5}$ are also lower in 2025 than in 2014. There are no predicted exceedences of the objectives.

9.232 The predicted 98th percentile of 1-hour mean odour concentrations is higher in 2025 than in 2014, reflecting the greater number of aircraft movements. Predicted values are all below the threshold for moderately offensive odours (3 OU_E/m^3) apart from at R1 and R2 (Camel Road/Hartmann Road) where concentrations of up to 3.3 OU_E/m^3 occur. This is still below the threshold for 'less offensive' odours.

2025 With CADP Core Case

9.233 The With CADP Core Case involves identical aircraft movements and airfield activity, but lower landside road traffic movements than the CADP with Higher Passenger Case sensitivity test. The latter therefore represents a worst-case 2025 development scenario with respect to air quality as overall road traffic emissions generated by the development are higher. As such, the results of the air quality assessment for the Higher Passenger Case, presented below, demonstrates the greatest potential air quality impacts in 2025; the predicted impacts associated with the 2025 With CADP Core Case are marginally lower, but the outcome is unchanged.

2025 With CADP Higher Passenger Case

9.234 The predicted annual mean concentrations of nitrogen dioxide in 2025 With CADP are lower than in 2014 at all receptor locations. The highest predicted concentration (25.6 µg/m^3) occurs at R2 (Camel Road), and is well below the objective.

9.235 The magnitudes of change in annual mean nitrogen dioxide concentrations range from zero to 6%. The impacts are described as *negligible* at all receptors other than at R5 (Hartmann Road) where the impact is *slight adverse*. The concentration at R5 remains well below the objective.

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74 As described in an earlier section, the 2025 With CADP Higher Passenger Case assumes the same aircraft fleet mix and movements as the With CADP Core Case, but with a higher passenger load and associated increased surface access movements. By definition, the impacts associated with the Higher Passenger case will be greater than for the Core Case. The results for the Core Case are included in Appendix 9.9 for completeness.

9.236 Predicted concentrations of PM_{10} and $PM_{2.5}$ are also lower in 2025 than in 2014. There are no predicted exceedences of the objectives, and all predicted impacts are *negligible*.

9.237 The predicted 98th percentile of 1-hour mean odour concentrations is higher in 2025 than in 2014, reflecting the greater number of aircraft movements. Predicted values are all below the threshold for moderately offensive odours (3 OU_E/m^3) apart from at R1 and R2 (Camel Road/Hartmann Road) where concentrations of up to 3.6 OU_E/m^3 occur. This is below the threshold for 'less offensive' odours.

2025 With CADP Faster Move to Jets Case

9.238 The predicted impacts associated with the 2025 With CADP Faster Move to Jets Case are marginally higher than for the With CADP Higher Passenger Case, but the outcome is unchanged.

2025 Without CADP Higher Jet Centre Case

9.239 A semi-quantitative assessment of the 2025 CADP Higher Jet Centre Case has been based on a comparison of NOx emissions. The Higher Jet Centre Case assumes a small change to the scheduled movements (550 C100 aircraft are replaced by a similar number of E190 aircraft) and there are an additional 8,000 Jet Centre movements. This would increase NOx emissions from 300 te/yr (Without CADP) to 313 te/yr (Without CADP Higher Jet Centre). This would marginally increase NOx concentrations, but not to an extent at which the air quality objective for nitrogen dioxide would be exceeded.

Table 9.33 – Predicted Impacts on Annual Mean Nitrogen Dioxide Concentrations (µg/m^3) - 2025

Receptor ID	Without CADP	Higher Passenger Case			Faster Move to Jets Case		
		With CADP	% Change	Impact Descriptor	With CADP	% Change	Impact Descriptor
Existing Receptors							
R1	24.9	25.1	1	Negligible	25.1	1	Negligible
R2	25.5	25.6	0	Negligible	25.7	0	Negligible
R3	22.5	23.2	2	Negligible	23.2	2	Negligible
R4	21.6	23.8	5	Negligible	23.8	5	Negligible
R5	20.8	23.3	6	Slight Adverse	23.3	6	Slight Adverse
R6	19.2	20.4	3	Negligible	20.4	3	Negligible
R7	18.5	19.1	1	Negligible	19.1	1	Negligible
R8	19.4	20.4	2	Negligible	20.3	2	Negligible
R9	19.0	19.7	2	Negligible	19.7	2	Negligible
R10	21.9	22.4	1	Negligible	22.4	1	Negligible
R11	20.2	20.7	1	Negligible	20.8	1	Negligible
R12	20.8	21.3	1	Negligible	21.4	1	Negligible
R13	21.8	22.1	1	Negligible	22.0	1	Negligible
R14	22.2	22.9	2	Negligible	22.9	2	Negligible
R15	19.1	19.4	1	Negligible	19.4	1	Negligible
R16	22.8	24.1	3	Negligible	24.1	3	Negligible
R17	20.1	20.8	2	Negligible	20.9	2	Negligible
R18	20.3	21.2	2	Negligible	21.4	3	Negligible
R18 (20m)	19.9	20.7	2	Negligible	20.9	2	Negligible
R19	19.8	19.9	0	Negligible	19.9	0	Negligible
R19 (20m)	19.8	19.9	0	Negligible	19.9	0	Negligible
R20	20.0	20.1	0	Negligible	20.1	0	Negligible
R20 (20m)	19.9	20.0	0	Negligible	20.1	0	Negligible
R21 (20m)	21.7	22.3	2	Negligible	22.3	2	Negligible
R22 (20m)	19.0	19.6	2	Negligible	19.6	2	Negligible
R22 (40m)	18.9	19.3	1	Negligible	19.3	1	Negligible
R23	19.4	20.0	2	Negligible	20.1	2	Negligible
R23 (20m)	19.0	19.5	1	Negligible	19.6	1	Negligible
R24	19.2	19.7	1	Negligible	19.7	1	Negligible
R24 (20m)	18.9	19.4	1	Negligible	19.4	1	Negligible
R25	20.3	21.3	2	Negligible	21.4	3	Negligible
R25 (10.5m)	20.2	21.1	2	Negligible	21.2	3	Negligible
R26	19.4	20.3	2	Negligible	20.3	2	Negligible
R26 (10.5m)	18.5	19.0	1	Negligible	19.0	1	Negligible
New Receptors							
R27	20.9	21.0	0	Negligible	21.0	0	Negligible
R27 (20m)	19.9	20.3	1	Negligible	20.3	1	Negligible
R28	19.4	19.7	1	Negligible	19.7	1	Negligible
R28 (20m)	19.3	19.5	1	Negligible	19.6	1	Negligible
R29	20.9	21.1	1	Negligible	21.2	1	Negligible
R29 (20m)	19.9	20.2	1	Negligible	20.3	1	Negligible
R30	18.8	19.1	1	Negligible	19.2	1	Negligible
R30 (20m)	18.8	19.1	1	Negligible	19.1	1	Negligible
R31	18.8	19.1	1	Negligible	19.2	1	Negligible
R31 (20m)	18.8	19.1	1	Negligible	19.1	1	Negligible
R32	21.4	21.9	1	Negligible	22.0	1	Negligible
R32 (20m)	21.2	21.6	1	Negligible	21.7	1	Negligible
R33	21.1	22.7	4	Negligible	22.8	4	Negligible
R33 (20m)	20.9	22.2	3	Negligible	22.3	3	Negligible
R34	21.4	22.1	2	Negligible	22.2	2	Negligible
R35	20.7	21.0	1	Negligible	21.1	1	Negligible
R35 (20m)	20.4	20.7	1	Negligible	20.8	1	Negligible
R36	21.7	22.1	1	Negligible	22.1	1	Negligible

Receptor ID	Without CADP	Higher Passenger Case			Faster Move to Jets Case		
		With CADP	% Change	Impact Descriptor	With CADP	% Change	Impact Descriptor
R36 (20m)	20.0	20.3	1	Negligible	20.3	1	Negligible
R37	21.2	21.6	1	Negligible	21.6	1	Negligible
R38	21.1	21.3	1	Negligible	21.3	0	Negligible
R39	20.9	21.0	0	Negligible	21.0	0	Negligible
R39 (10.5m)	20.1	20.3	0	Negligible	20.3	1	Negligible
R40	22.0	22.0	0	Negligible	22.0	0	Negligible
R40 (20m)	19.5	19.6	0	Negligible	19.7	0	Negligible
R41	20.4	20.5	0	Negligible	20.5	0	Negligible
R41 (13.5m)	19.5	19.6	0	Negligible	19.7	0	Negligible

Table 9.34 – Predicted Impacts on Annual Mean PM_{10} Concentrations ($\mu g/m^3$) in 2025

Receptor ID	Without CADP	Higher Passenger Case			Faster Move to Jets Case		
		With CADP	% Change	Impact Descriptor	With CADP	% Change	Impact Descriptor
Existing Receptors							
R1	20.5	20.4	0	Negligible	20.4	0	Negligible
R2	20.4	20.3	0	Negligible	20.3	0	Negligible
R3	19.9	19.9	0	Negligible	19.9	0	Negligible
R4	19.7	19.9	1	Negligible	19.9	1	Negligible
R5	19.5	19.8	1	Negligible	19.8	1	Negligible
R6	19.3	19.4	0	Negligible	19.4	0	Negligible
R7	19.1	19.2	0	Negligible	19.2	0	Negligible
R8	19.4	19.7	1	Negligible	19.7	1	Negligible
R9	19.4	19.6	1	Negligible	19.6	1	Negligible
R10	19.7	19.7	0	Negligible	19.7	0	Negligible
R11	19.5	19.5	0	Negligible	19.5	0	Negligible
R12	19.5	19.5	0	Negligible	19.5	0	Negligible
R13	20.1	20.2	0	Negligible	20.1	0	Negligible
R14	19.9	20.0	0	Negligible	20.0	0	Negligible
R15	19.3	19.4	0	Negligible	19.4	0	Negligible
R16	19.9	20.0	0	Negligible	20.0	0	Negligible
R17	19.2	19.3	0	Negligible	19.3	0	Negligible
R18	19.3	19.3	0	Negligible	19.3	0	Negligible
R18 (20m)	19.2	19.3	0	Negligible	19.3	0	Negligible
R19	19.7	19.7	0	Negligible	19.7	0	Negligible
R19 (20m)	19.7	19.7	0	Negligible	19.7	0	Negligible
R20	19.6	19.6	0	Negligible	19.6	0	Negligible
R20 (20m)	19.6	19.6	0	Negligible	19.6	0	Negligible
R21 (20m)	19.8	19.8	0	Negligible	19.9	0	Negligible
R22 (20m)	19.3	19.3	0	Negligible	19.3	0	Negligible
R22 (40m)	19.2	19.3	0	Negligible	19.3	0	Negligible
R23	19.0	19.1	0	Negligible	19.1	0	Negligible
R23 (20m)	18.9	18.9	0	Negligible	18.9	0	Negligible
R24	18.9	18.9	0	Negligible	19.0	0	Negligible
R24 (20m)	18.8	18.9	0	Negligible	18.9	0	Negligible
R25	19.4	19.4	0	Negligible	19.5	0	Negligible
R25 (10.5m)	19.4	19.4	0	Negligible	19.4	0	Negligible
R26	19.2	19.4	1	Negligible	19.4	1	Negligible
R26 (10.5m)	19.0	19.0	0	Negligible	19.0	0	Negligible
New Receptors							
R27	20.3	20.2	0	Negligible	20.2	0	Negligible
R27 (20m)	20.0	20.1	0	Negligible	20.1	0	Negligible
R28	20.1	20.1	0	Negligible	20.1	0	Negligible
R28 (20m)	20.0	20.0	0	Negligible	20.0	0	Negligible
R29	20.2	20.2	0	Negligible	20.2	0	Negligible
R29 (20m)	20.0	20.0	0	Negligible	20.0	0	Negligible

Receptor ID	Without CADP	Higher Passenger Case			Faster Move to Jets Case		
		With CADP	% Change	Impact Descriptor	With CADP	% Change	Impact Descriptor
R30	18.7	18.7	0	Negligible	18.7	0	Negligible
R30 (20m)	18.7	18.7	0	Negligible	18.7	0	Negligible
R31	18.7	18.7	0	Negligible	18.7	0	Negligible
R31 (20m)	18.6	18.7	0	Negligible	18.7	0	Negligible
R32	19.5	19.6	0	Negligible	19.6	0	Negligible
R32 (20m)	19.5	19.5	0	Negligible	19.5	0	Negligible
R33	19.5	19.7	0	Negligible	19.7	0	Negligible
R33 (20m)	19.4	19.6	0	Negligible	19.6	0	Negligible
R34	19.7	19.7	0	Negligible	19.7	0	Negligible
R35	20.0	20.0	0	Negligible	20.0	0	Negligible
R35 (20m)	19.9	20.0	0	Negligible	20.0	0	Negligible
R36	20.2	20.2	0	Negligible	20.2	0	Negligible
R36 (20m)	19.7	19.7	0	Negligible	19.7	0	Negligible
R37	19.8	19.9	0	Negligible	19.9	0	Negligible
R38	19.8	19.9	0	Negligible	19.9	0	Negligible
R39	20.4	20.3	0	Negligible	20.3	0	Negligible
R39 (10.5m)	20.1	20.1	0	Negligible	20.1	0	Negligible
R40	20.8	20.7	0	Negligible	20.7	0	Negligible
R40 (20m)	20.1	20.1	0	Negligible	20.1	0	Negligible
R41	20.5	20.5	0	Negligible	20.5	0	Negligible
R41 (13.5m)	20.2	20.2	0	Negligible	20.2	0	Negligible

Table 9.35 – Predicted Impacts on Annual Mean $PM_{2.5}$ Concentrations ($\mu g/m^3$) in 2025

Receptor ID	Without CADP	Higher Passenger Case			Faster Move to Jets Case		
		With CADP	% Change	Impact Descriptor	With CADP	% Change	Impact Descriptor
Existing Receptors							
R1	13.9	13.9	0	Negligible	13.9	0	Negligible
R2	14.0	13.9	0	Negligible	13.9	0	Negligible
R3	13.5	13.6	0	Negligible	13.6	0	Negligible
R4	13.3	13.6	1	Negligible	13.6	1	Negligible
R5	13.2	13.5	1	Negligible	13.5	1	Negligible
R6	13.0	13.2	0	Negligible	13.2	0	Negligible
R7	12.9	13.0	0	Negligible	13.0	0	Negligible
R8	13.1	13.2	1	Negligible	13.2	1	Negligible
R9	13.1	13.2	0	Negligible	13.2	0	Negligible
R10	13.3	13.3	0	Negligible	13.3	0	Negligible
R11	13.2	13.2	0	Negligible	13.2	0	Negligible
R12	13.2	13.2	0	Negligible	13.2	0	Negligible
R13	13.3	13.4	0	Negligible	13.4	0	Negligible
R14	13.5	13.5	0	Negligible	13.5	0	Negligible
R15	13.0	13.0	0	Negligible	13.0	0	Negligible
R16	13.5	13.7	0	Negligible	13.7	0	Negligible
R17	13.0	13.1	0	Negligible	13.1	0	Negligible
R18	13.1	13.2	0	Negligible	13.2	0	Negligible
R18 (20m)	13.1	13.1	0	Negligible	13.1	0	Negligible
R19	13.1	13.1	0	Negligible	13.1	0	Negligible
R19 (20m)	13.1	13.1	0	Negligible	13.1	0	Negligible
R20	13.0	13.0	0	Negligible	13.0	0	Negligible
R20 (20m)	13.0	13.0	0	Negligible	13.0	0	Negligible
R21 (20m)	13.4	13.5	0	Negligible	13.5	0	Negligible
R22 (20m)	13.0	13.1	0	Negligible	13.1	0	Negligible
R22 (40m)	13.0	13.0	0	Negligible	13.0	0	Negligible
R23	12.9	13.0	0	Negligible	13.0	0	Negligible
R23 (20m)	12.8	12.9	0	Negligible	12.9	0	Negligible
R24	12.8	12.9	0	Negligible	12.9	0	Negligible
R24 (20m)	12.8	12.8	0	Negligible	12.8	0	Negligible
R25	13.2	13.3	0	Negligible	13.3	0	Negligible

Receptor ID	Without CADP	Higher Passenger Case			Faster Move to Jets Case		
		With CADP	% Change	Impact Descriptor	With CADP	% Change	Impact Descriptor
R25 (10.5m)	13.2	13.2	0	Negligible	13.2	0	Negligible
R26	13.0	13.1	0	Negligible	13.1	0	Negligible
R26 (10.5m)	12.8	12.9	0	Negligible	12.9	0	Negligible
New Receptors							
R27	13.6	13.6	0	Negligible	13.6	0	Negligible
R27 (20m)	13.5	13.5	0	Negligible	13.5	0	Negligible
R28	13.4	13.5	0	Negligible	13.5	0	Negligible
R28 (20m)	13.4	13.4	0	Negligible	13.4	0	Negligible
R29	13.5	13.6	0	Negligible	13.6	0	Negligible
R29 (20m)	13.4	13.4	0	Negligible	13.4	0	Negligible
R30	12.7	12.7	0	Negligible	12.7	0	Negligible
R30 (20m)	12.7	12.7	0	Negligible	12.7	0	Negligible
R31	12.7	12.7	0	Negligible	12.7	0	Negligible
R31 (20m)	12.7	12.7	0	Negligible	12.7	0	Negligible
R32	13.3	13.3	0	Negligible	13.3	0	Negligible
R32 (20m)	13.2	13.3	0	Negligible	13.3	0	Negligible
R33	13.3	13.5	1	Negligible	13.5	1	Negligible
R33 (20m)	13.3	13.4	0	Negligible	13.4	0	Negligible
R34	13.3	13.4	0	Negligible	13.4	0	Negligible
R35	13.5	13.5	0	Negligible	13.5	0	Negligible
R35 (20m)	13.4	13.5	0	Negligible	13.5	0	Negligible
R36	13.5	13.6	0	Negligible	13.6	0	Negligible
R36 (20m)	13.2	13.3	0	Negligible	13.3	0	Negligible
R37	13.4	13.4	0	Negligible	13.4	0	Negligible
R38	13.2	13.2	0	Negligible	13.2	0	Negligible
R39	13.6	13.6	0	Negligible	13.6	0	Negligible
R39 (10.5m)	13.5	13.5	0	Negligible	13.5	0	Negligible
R40	13.8	13.8	0	Negligible	13.8	0	Negligible
R40 (20m)	13.4	13.5	0	Negligible	13.5	0	Negligible
R41	13.6	13.6	0	Negligible	13.6	0	Negligible
R41 (13.5m)	13.5	13.5	0	Negligible	13.5	0	Negligible

Table 9.36 – Predicted 98th Percentile of 1-hour Mean Odour Concentrations (OU_E/m^3) in 2025

Receptor ID	OS Grid Ref	98th Percentile (OU_E/m^3)		
		Without CADP	Higher Passenger Case	Faster Move to Jets Case
Existing Receptors				
R1	541982, 180307	3.3	3.6	3.5
R2	542133, 180303	3.2	3.5	3.4
R3	542177, 180229	1.5	2.1	2.1
R4	542549, 180153	0.7	2.8	2.7
R5	542687, 180145	0.5	2.6	2.6
R6	543127, 180121	0.2	1.1	1.1
R7	543676, 180077	0.2	0.4	0.4
R8	543709, 180015	0.2	0.4	0.4
R9	543523, 179954	0.2	0.4	0.4
R10	543715, 180875	0.3	0.6	0.5
R11	543612, 180883	0.3	0.6	0.6
R12	542826, 180920	0.4	0.9	0.9
R13	540854, 180110	0.2	0.3	0.3
R14	542321, 180086	0.6	1.4	1.4
R15	543749, 181324	0.2	0.4	0.4
R16	542306, 180219	1.3	2.5	2.4
R17	543800, 180701	0.3	0.6	0.6
R18	543650, 180655	0.5	0.9	0.8

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R18 (20m)	543650, 180655	0.4	0.7	0.7
R19	540846, 180439	0.2	0.3	0.3
R19 (20m)	540846, 180439	0.2	0.3	0.3
R20	540681, 180448	0.2	0.3	0.3
R20 (20m)	540681, 180448	0.2	0.3	0.3
R21 (20m)	542050, 180261	1.2	1.7	1.6
R22 (20m)	543133, 180047	0.2	0.7	0.7
R22 (40m)	543133, 180047	0.2	0.5	0.5
R23	543868, 180637	0.3	0.5	0.5
R23 (20m)	543868, 180637	0.3	0.5	0.5
R24	543919, 180684	0.2	0.5	0.5
R24 (20m)	543919, 180684	0.2	0.5	0.4
R25	543478, 180695	0.5	0.9	0.9
R25 (10.5m)	543478, 180695	0.5	0.9	0.8
R26	543810, 180174	0.2	0.4	0.4
R26 (10.5m)	543810, 180174	0.2	0.4	0.4
New Receptors				
R27	541614, 180468	1.2	1.4	1.3
R27 (20m)	541614, 180468	0.8	1.1	1.0
R28	541460, 180476	0.6	0.8	0.8
R28 (20m)	541460, 180476	0.5	0.8	0.7
R29	541587, 180372	0.9	1.1	1.1
R29 (20m)	541587, 180372	0.7	1.0	1.0
R30	544067, 180548	0.2	0.3	0.3
R30 (20m)	544067, 180548	0.2	0.3	0.3
R31	544088, 180710	0.2	0.4	0.3
R31 (20m)	544088, 180710	0.2	0.3	0.3
R32	542418, 180704	0.6	1.1	1.0
R32 (20m)	542418, 180704	0.5	0.8	0.8
R33	542979, 180691	0.6	1.7	1.6
R33 (20m)	542979, 180691	0.5	1.3	1.3
R34	542884, 180843	0.4	1.1	1.1
R35	541917, 180713	0.7	1.1	1.0
R35 (20m)	541917, 180713	0.6	0.9	0.9
R36	541583, 180150	0.5	0.7	0.7
R36 (20m)	541583, 180150	0.4	0.7	0.7
R37	541862, 180129	0.7	1.1	1.0
R38	540890, 180071	0.2	0.3	0.3
R39	541882, 180859	0.4	0.7	0.7
R39 (10.5m)	541882, 180859	0.4	0.7	0.6
R40	541716, 180852	0.3	0.5	0.5
R40 (20m)	541716, 180852	0.3	0.5	0.4
R41	541627, 180863	0.3	0.4	0.4
R41 (13.5m)	541627, 180863	0.3	0.4	0.4

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Significance of Operational Impacts

2020 (Transitional Year)

9.240 The operational air quality impacts in 2020 are judged to be 'not significant' (Table 9.37). This professional judgement is made in accordance with the methodology set out above and taking into account the factors recommended by the EPUK/IAQM Guidance, and also acknowledging the uncertainty over future projections of traffic-related nitrogen dioxide concentrations, which may not decline as rapidly as expected. The latter has been addressed by giving consideration to both sets of modelled results for nitrogen dioxide; those with and without reductions in traffic emissions. It is to be expected that concentrations will fall in the range between the two sets of results, although by 2020 the impacts are likely to be closer to the 'With Reduction' results than the 'Without Reduction' results.

9.241 More specifically, the judgement that the air quality impacts will be not be significant takes account of the assessment that concentrations will be below, and mostly well below, the air quality objectives and all of the impacts are predicted to be *negligible.*

9.242 The significance of air quality impacts has also been considered using the flow chart provided in the London Councils guidance. This flow chart is intended to assist local authority officers in their decision as to whether a proposed development will have a significant impact on air quality. Table 9.38 (below) provides the outcome of this assessment based on the professional judgement of the authors of this UES chapter - AQC. The conclusion is that air quality is not a significant consideration.

9.243 A number of properties in close proximity to the extended apron are at risk of being affected by odours due to the increased number of aircraft movements. Predicted odour concentrations at properties close to the CADP proposals (e.g. R4 and R5) are well below the thresholds at which complaints are likely, and the spatial change to emissions sources is not likely to be significant. Predicted odour concentrations are higher in 2020 than in 2014, but remain below the threshold for less offensive odours. It is, however, considered that these predictions are likely to be overstated as no account has been taken of the shielding effect of the terminal buildings and pier, and elevated DLR infrastructure, which will substantially increase the dispersion of any odorous emissions. Taking this uncertainty into account, the impact of odour emissions is judged to be *negligible* to *slight adverse*, and the overall impact is *insignificant*. This conclusion is consistent with the absence of odour complaints in recent years.

2023 (Design Year)

9.244 The operational air quality impacts in 2023 are judged to be not significant (Table 9.37). This professional judgement is made in accordance with the methodology set out above and taking into account the factors recommended by EPUK/IAQM, also acknowledging the uncertainty over predictions by building a number of worst-case assumptions into the assessment.

9.245 More specifically, the judgement that the air quality impacts will be not significant takes account of the assessment that concentrations will be below the air quality objectives and all of the impacts are predicted to be *negligible* to *slight adverse*.

9.246 The significance of air quality impacts has also been considered using the flow chart provided in the London Councils guidance. Table 9.37 provides the outcome of this assessment based on the professional judgement of AQC. The conclusion is that air quality is not a significant consideration.

9.247 A number of properties in close proximity to the extended apron are at risk of being affected by odours due to the increased number of aircraft movements. Predicted odour concentrations at properties close to the CADP proposals are well below the thresholds at which complaints are likely, and the spatial change to emissions sources is not likely to be significant. Predicted odour unit concentrations are higher in 2023 than in 2014, but do not exceed the threshold for less offensive odours. For reasons stated above, it is considered that these predictions are likely to be overstated. Taking this uncertainty into account, the impact of odour emissions is judged to be *negligible* to *slight adverse*, and the overall impact is insignificant. This conclusion is consistent with the absence of odour complaints in recent years.

2025 (Principal Assessment Year)

9.248 The operational air quality impacts in 2025 are judged to be not significant (Table 9.37). This professional judgement is made in accordance with the methodology set out above taking into account the factors recommended by EPUK/IAQM, and also acknowledging the uncertainty over predictions by building a number of worst-case assumptions into the assessment.

9.249 More specifically, the judgement that the air quality impacts will be not significant takes account of the assessment that concentrations will be below the air quality objectives and all of the impacts are predicted to be *negligible* to *slight adverse*.

9.250 The significance of air quality impacts has also been considered using the flow chart provided in the London Councils guidance. Table 9.37 provides the outcome of this assessment based on the professional judgement of AQC. The conclusion is that air quality is not a significant consideration.

9.251 A number of properties in close proximity to the extended apron are at risk of being affected by odours due to the increased number of aircraft movements. Predicted odour unit concentrations at properties close to the CADP boundary are well below the thresholds at which complaints are likely, and the spatial change to emissions sources is not likely to be significant. Predicted odour unit concentrations are higher in 2025 than in 2014, but do not exceed the threshold for less offensive odours. For reasons set out above, it considered that these predictions are likely to be overstated. Taking this uncertainty into account, the impact of odour emissions is judged to be *negligible* to *slight adverse*, and the overall impact is *insignificant*. This conclusion is consistent with the absence of odour complaints in recent years.

Table 9.37 - Factors Taken into Account in Determining Air Quality Significance

Factors	Outcome of Assessment	
	2020	2023 and 2025
Number of people affected by increases and/or decreases in concentrations and a judgement on the overall balance.	A large number of people would be affected by an imperceptible increase in concentrations With Development, but levels would be lower than in 2014.	A large number of people would be affected by an imperceptible increase in concentrations With Development, but levels would be lower than in 2014.
The magnitude of the changes and the descriptions of the impacts at the receptors	The magnitude of change at most receptor locations is less than1%. All impacts are negligible to slight adverse.	The magnitude of change at most receptor locations is less than 1%. All impacts are negligible.
Whether or not an exceedence of an objective is predicted to arise in the study area where none existed before or an exceedence area is substantially increased.	No exceedences of the objectives are predicted.	No exceedences of the objectives are predicted.
Whether or not the study area exceeds an objective and this exceedence is removed or the exceedence area is reduced.	The Airport itself does not lie within the AQMA boundary, but the general study area does. The CADP would not affect the AQMA boundary.	The Airport itself does not lie within the AQMA boundary, but the general study area does. The CADP would not affect the AQMA boundary.
Uncertainty, including the extent to which worst-case assumptions have been made	A number of worst-case assumptions have been built into the assessment, and the uncertainty related to forecast road traffic emissions in 2020 has been considered.	A number of worst-case assumptions have been built into the assessment.
The extent to which an objective is exceeded.	No exceedences of the objectives are predicted.	No exceedences of the objectives are predicted.

Table 9.38 – Assessment of the Significance of Air Quality Impacts Based On London Councils Guidance

Effect of Proposed Development	Assessment		
	2020	2023	2025
Is the development located in an AQMA?	The Airport and application site is not located within an AQMA, but the wider study area is. For the purpose of this assessment it is assumed the answer is YES.		
Will it interfere with or prevent implementation of measures in the Air Quality Action Plan?	The CADP proposals will not affect the Council's AQAP. The answer is NO.		
Is it likely to cause a worsening of air quality or introduce new exposure into the AQMA?	Predicted concentrations are generally lower in 2020 than in 2014, even assuming "without emissions reduction" for road vehicles. Concentrations are generally higher With CADP in 2020 compared to Without CADP scenario, but the incremental change is less than 1% at the majority of receptors. A small number of properties on Hartmann Road would experience a reduction in concentrations. The CADP proposals would introduce no new exposure. The answer is NO.	Predicted concentrations are lower in 2023 than in 2014. Concentrations are generally higher With CADP in 2023 compared to Without CADP scenario, but the incremental change is less than 1% at the majority of receptors. The CADP proposals would introduce no new exposure. The answer is NO.	Predicted concentrations are lower in 2025 than in 2014. Concentrations are generally higher With CADP in 2025 compared to Without CADP scenario, but the incremental change is less than 1% at the majority of receptors. The CADP proposals would introduce no new exposure. The answer is NO.
	Air quality is not a significant consideration		

National Compliance

9.252 In assessing national compliance, it is important to recognise that the air quality objectives and the EU limit values are fundamentally different. In the UK, the Secretary of State for Environment, Food and Rural Affairs (Defra) is nominated as the "competent authority", and it is only the competent authority that can determine compliance with the EU limit values. Compliance is determined through national monitoring and modelling (the Pollution Climate Mapping (PCM) model). There are a number of important differences between the way in which national compliance is determined, and the way in which local authorities use monitoring and modelling to determine compliance with the objectives. Because of these differences, there are widespread disparities between compliance with the limit values and objectives across the UK.

9.253 As stated in the Baseline Conditions section of this Chapter, Defra has only published the national interactive maps of roadside annual mean nitrogen dioxide concentrations for 2012; it is not possible to replicate the output of Defra's Pollution Climate Mapping (PCM) model for any future year. However, Defra has recently published information on the 50 highest PCM modelled road links in London, under the Environmental Information Regulations (EIR)[75]; these data are provided for 2025.

9.254 Data released by Defra under the EIR provide PCM predicted values for a number of road links in East London; the highest predicted value (51 $\mu g/m^3$) occurs at the A13 in Canning Town. The highest predicted concentration in 2025 in the Greater London agglomeration (which occurs at Marylebone Road) is 56 $\mu g/m^3$.

9.255 The incremental change associated with CADP in 2025[76] has been predicted at receptor locations 4 metres from the kerbside of the A13 (to coincide with Defra's PCM modelling approach). The results have been predicted for the "With CADP Faster Move to Jets Case", as this represents the greatest impact, and demonstrate an incremental change of 0.09 $\mu g/m^3$.

9.256 The following conclusions can be drawn with respect to the guidance in National Networks NPS:

- The CADP Scheme will not cause a compliant zone or agglomeration to become non-compliant. The Defra PCM model forecasts indicate that the Greater London agglomeration will already be non-compliant in 2025, and beyond;

- The CADP Scheme will not affect the ability of a non-compliant area to become compliant. The highest PCM predicted value in 2025 (at Marylebone Road) is 5 $\mu g/m^3$ (annual mean, nitrogen dioxide) higher than at the A13. The incremental change brought about by the CADP Scheme at the A13 is 0.09 $\mu g/m^3$, and is negligible.

9.257 It is concluded that the CADP Scheme does not affect national compliance with the EU limit value.

Health Impacts

9.258 Paragraphs 9.46 and 9.47 describe the health effects associated with air pollution. Details are provided on risk coefficients that have been determined for mortality associated with changes in exposure to

75 https://www.gov.uk/government/publications/50-highest-modelled-nitrogen-dioxide-no2-concentrations
76 This has been calculated as the "With CADP" minus the "Without CADP"

nitrogen dioxide and $PM_{2.5}$. These risk coefficients can be applied to understand the health significance of the changes that are predicted to arise from the CADP. A worst-case analysis has been applied in the first instance, as described below. As this demonstrates insignificant impacts, it is not necessary to proceed to a more detailed analysis.

9.259 The analysis relies on the results presented in this Chapter for the impacts for the With CADP Core Case in 2025. The analysis is based on consideration of the highest increases in concentrations, which occur at receptor R5. The annual mean nitrogen dioxide concentration is predicted to increase by 2.5 $\mu g/m^3$ (based on the un-rounded numbers summarised in Table 9.33) and that for $PM_{2.5}$ by 0.3 $\mu g/m^3$ (based on the un-rounded numbers summarised in see Table 9.35). The risk coefficients are 3.9% per 10 $\mu g/m^3$ change in annual mean nitrogen dioxide and 6% per 10 $\mu g/m^3$ change in annual mean $PM_{2.5}$. These risk coefficients are applied to the mortality rate for the population over 30 years of age in Newham, which is 1,238 per 100,000. Using these numbers, and applying the calculation procedure as set out in the recent report by King's College London [(77)], shows that around 9,000 people over 30 years of age would need to be exposed to the increase in annual mean nitrogen dioxide at R5 to give rise to one additional death in 2025. This is similar to the entire population (all ages) of the Royal Docks (10,679 people [(78)]). In the case of $PM_{2.5}$, around 50,000 people over 30 years of age would need to be exposed to the increase in annual mean nitrogen dioxide at R5 to give rise to one additional death in 2025. This is around five times the entire population (all ages) of the Royal Docks. In practice, the increase in exposure averaged across the population around the Airport will be well below the concentrations of nitrogen dioxide and $PM_{2.5}$ at R5, and thus the numbers that would need to be exposed to give rise to one additional death brought forward per year will be much higher in practice. These numbers would be much higher than the population actually exposed and thus the risks of detectable effects will be ***negligible*** and hence not significant. They do not justify a more detailed calculation.

9.260 The incremental changes associated with the 2025 With CADP Higher Passenger case are marginally higher for nitrogen dioxide (an increase of 2.6 $\mu g/m^3$ (as opposed to 2.5 $\mu g/m^3$ for the Core Case) but this does not affect the conclusions above.

Total Emissions

9.261 A summary of the 2020, 2023 and 2025 emissions (tonnes/yr) is shown in Table 9.39. This shows the emissions from different source categories. As described in the methodology section above, Airport-related PM emissions are assumed to represent both the PM_{10} and $PM_{2.5}$ fractions, and which represents a worst case. Emissions from aircraft dominate in all years, but a direct comparison between Airport and Landside Road Traffic sources should be treated with caution as the latter is defined by the scale of the road network included in the assessment. It should also be born in mind that emissions from aircraft have been calculated within a ceiling altitude of 915m; emissions at altitude cannot be directly compared with those derived from solely ground-based sources.

9.262 Airport source NOx emissions increase by between 11% (2020) and 29% (2025) in the With CADP as compared to Without CADP cases, in broad proportion to the increasing numbers of passengers and scheduled aircraft movements. The increase in Airport source emissions from 2020 to 2025 is in part

[77] King's College London (2015) Understanding the Health Impacts of Air Pollution in London.
[78] Office for National Statistics. (2011). 2011 Census. Usual resident population, March 2011 Available www.ons.gov.uk Last Accessed 24/04/13

offset by a reduction in road traffic emissions, but as stated above, this comparison is biased by the scale of the road network included in the assessment.

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Table 9.39 – Summary Emissions for 2020, 2023 and 2025 (te/yr)

Source Category	NOx (te/yr)		PM_{10} (te/yr)		$PM_{2.5}$ (te/yr)	
	Without CADP	With CADP	Without CADP	With CADP	Without CADP	With CADP
	2020					
Airport Sources						
Aircraft (LTO cycle plus APU and engine testing)	292.1	321.9	17.1	18.3	17.1	18.3
Airside vehicles, MGPU and training fires	3.0	3.1	0.3	0.3	0.3	0.3
Gas Boilers/Energy Centre	0.4	2.7	<0.1	<0.1	<0.1	<0.1
Taxi Ranks/Car Parks	0.2	0.6	<0.1	0.1	<0.1	0.1
Total Airport Related	295.7	328	17.4	18.7	17.4	18.7
Landside Road Traffic						
Road traffic on local road network – Without Emissions Reduction	49.8	49.4	N/A	N/A	N/A	N/A
Road traffic on local road network – With Emissions Reduction	28.0	28.3	2.8	2.9	1.5	1.6
	2023 Core Case					
Airport Sources						
Aircraft (LTO cycle plus APU and engine testing)	295.6	356.5	17.2	18.1	17.2	18.1
Airside vehicles and MGPU	2.8	2.9	0.3	0.3	0.3	0.3
Gas Boilers/Energy Centre	0.4	2.8	<0.1	<0.1	<0.1	<0.1
Taxi Ranks/Car Parks	0.2	0.6	<0.1	0.1	<0.1	0.1
Total Airport Related	299.0	363	17.5	18.5	17.5	18.5
Landside Road Traffic						
Road traffic on local road network (Core Case)	21.2	21.8	2.8	2.9	1.5	1.6
Road traffic on local road network (Higher Passenger Case)	21.2	22.1	2.8	2.9	1.5	1.6
	2023 Faster Move to Jets					
Airport Sources						
Aircraft (LTO cycle plus APU and engine testing)	295.6	372.3	17.2	18.7	17.2	18.7
Airside vehicles and MGPU	2.8	2.9	0.3	0.3	0.3	0.3
Gas Boilers/Energy Centre	0.4	2.8	<0.1	<0.1	<0.1	<0.1
Taxi Ranks/Car Parks	0.2	0.6	<0.1	0.1	<0.1	0.1
Total Airport Related	299.0	379	17.5	19.0	17.5	19.0
Landside Road Traffic						
Road traffic on local road network	21.2	21.8	2.8	2.9	1.5	1.6

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Source Category	NOx (te/yr)		PM_{10} (te/yr)		$PM_{2.5}$ (te/yr)	
	Without CADP	With CADP	Without CADP	With CADP	Without CADP	With CADP
	2025 Core Case					
Airport Sources						
Aircraft (LTO cycle plus APU and engine testing)	296.4	367.2	17.2	18.3	17.2	18.3
Airside vehicles, MGPU and training fires	2.9	3.0	0.3	0.3	0.3	0.3
Gas Boilers/Energy Centre	0.4	2.8	<0.1	<0.1	<0.1	<0.1
Taxi Ranks/Car Parks	0.2	0.6	<0.1	0.1	<0.1	0.1
Total Airport Related	299.9	374	17.5	18.7	17.5	18.7
Landside Road Traffic						
Road traffic on local road network (Core Case)	17.7	18.2	2.8	2.9	1.5	1.6
Road traffic on local road network (Higher Passenger Case)	17.7	18.5	2.8	2.9	1.5	1.6
	2025 Faster Move to Jets Case					
Airport Sources						
Aircraft (LTO cycle plus APU and engine testing)	296.4	383.3	17.2	18.8	17.2	18.8
Airside vehicles, MGPU and training fires	2.9	3.0	0.3	0.3	0.3	0.3
Gas Boilers/Energy Centre	0.4	2.8	<0.1	<0.1	<0.1	<0.1
Taxi Ranks/Car Parks	0.2	0.5	<0.1	<0.1	<0.1	<0.1
Total Airport Related	299.9	390	17.5	19.2	17.5	19.2
Landside Road Traffic						
Road traffic on local road network	17.7	18.2	2.8	2.9	1.5	1.6

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Air Quality Neutral

9.263 In terms of the minimum standards, the CADP proposals comply with the Mayor's adopted SPG. Ultra-low NOx boilers (<40 mgNOx/kWh) would be installed, and abatement (95% catalytic reduction) would be applied to the CHP engines (to achieve an emission rate of <40 mg NOx/Nm3, as compared with the GLA standard of 95 mg NOx/Nm3).

9.264 The application of the air quality neutral guidance to airports is not straightforward. The Building Emission Benchmarks (BEBs) and Road Transport Emission benchmarks (TEBs) have only been derived for a limited number of land-use classes. Whilst some of these land-use classes form part of the CADP proposals (e.g. Retail (A1), Restaurants and Cafes (A3), Hotels (C1) etc.), much of the Gross Internal Floor Area (GFA) is *Sui Generis*. In addition, road transport movements generated by, for example, retail development within the Airport, are unlikely to be well-characterised by other retail development across London.

9.265 Emissions arising from aircraft are not included in the air quality neutral assessment as the supporting report to the SPG explains that "*the responsibility for mitigation/offsetting could not reasonably lie with the airport operator as they have very limited control over what aircraft are used by the airlines*".

Building Emission Benchmarks

9.266 The CADP proposals would provide an additional 33,810 m^2 (Gross Floor Area) of Terminal and Pier floorspace. At this stage, the precise allocation of space to different uses has not been determined, but based on preliminary information provided by Pascall + Watson, and with reference to the current use of floorspace, the following assumption has been made for the CADP1 proposals:

- A1 Shops – 1,376 m^2;
- A3 Restaurants and Cafes – 2,610 m^2;
- B1 Business – 10,481 m^2;
- B8 Storage – 2,570 m^2; and
- Sui Generis – 16,773 m^2.

9.267 In addition, the Hotel proposed by CADP2 would provide an additional 14,000 m^2 of C1 floorspace.

9.268 The building NOx emissions associated with the CADP proposals are based on a number of worst-case assumptions as follows:

- Annual gas usage for the boilers would increase in line with passenger movements;
- NOx emissions from the new boilers would be consistent with standard EMEP/EAA emission factors; and
- The CHP plant (560 kWt) would operate at full load on a continuous basis.

9.269 Whilst this is an appropriate, conservative approach for the prediction of pollutant concentrations, it will significantly overestimate NOx emissions. For the purpose of this assessment, the following, revised assumptions have been made:

- Annual gas usage for the new terminal and piers would be 1,241,455 kWh (based on information provided by Atkins Global);
- NOx emissions from the new boilers would comply with the "ultra-low NOx standard" or <40mg/kWh; and
- The CHP engines have been revised to provide 480 kWt, operating for 5,000 hours per annum (as set out in the Update to the Energy and Low Carbon Strategy (September 2015).

9.270 As there are no benchmark emissions for *Sui Generis* use, it has been assumed that this floorspace is given over to Class A1 use (which has the strictest (lowest) benchmark value). The calculation of the Total Benchmarked Building Emission is shown in Table 9.40.

Table 9.40: Calculation of Total Benchmarked NOx Emissions

Land Use	GFA (m^2)	BEB ($gNOx/m^2/annum$)	Benchmarked Emissions (kg/annum)
A1	1,376	22.6	31.1
A3	2,610	75.2	196.3
B1	10,481	30.8	322.8
B8 [a]	2,570	23.6	60.7
C1	14,000	70.9	992.6
Sui Generis (A1)	16,773	22.6	379.1
Total Benchmarked Building Emission			**1,982.6**

[a] The B8 use is for the provision of storage for the A1 (retail) use, and not general warehousing. The B8 use could be assumed to be part of A1, but this would have little effect of the calculated Total Benchmarked Building Emission, and would not affect the outcome.

9.271 The Total Building NOx Emission can be calculated from the information set out above, and from that provided in Appendix 9.4, Table A4.23 of the UES:

- Boilers - 1,241,455 kWh/annum and <40 mgNOx/kWh = 49.7 kgNOx/annum
- CHP - 0.06 gNOx/second[79] and 5,000 operational hours at 100% load = 1080 kgNOx/annum
- Total = 49.7 + 1080 = **1,129.7** kg/annum

9.272 As the Total Building NOx Emission (1,130 kg/annum) is less than the Total Benchmarked Building Emission (1,982 kg/annum), it can be concluded that the CADP proposals comply with the "air quality neutral" principle, and no further mitigation is required.

Appendix AQ.1.8

Road Transport Emission Benchmarks (TEB)

9.273 The TEBs, as specified in the SPG, are based on the number of trips generated by different land-use classes, together with the associated trip lengths and vehicle emission rates. Such trip generation data are normally obtainable from the Updated Transport Assessment, as this is the basis for the calculation of AADT data. However, for the CADP proposals, a bespoke, first principle approach was used, with the trip data derived from passenger profiles (provided by York Aviation) and staff numbers. It is thus not possible to derive trip rates by land use class from the Updated Transport Assessment.

9.274 Where TEBs have not been derived for specific land-use classes, it is possible to compare scheme-related trip rates with benchmarked trip rates. The derivation of the benchmarked trip rates is shown in Table 9.41. For Sui Generis use, a weighted trip rate has been derived from land use classes A1, A3, B1, B8 and C180. The average benchmarked trips/annum has been divided by the Gross Floor Area (GFA) of the development (i.e. 33,810 m^2).

Table 9.41: Derivation of Benchmarked Trip Rates

Land Use	Trips/m^2/annum	GFA (m^2)	Total Benchmarked Trips/Annum
A1	131	1,376	180,256
A3	170	2,610	443,700
B1	18	10,481	188,658
B8 [a]	6.5	2,570	16,705
C1	6.9	14,000	96,600
Sui Generis	27	16,773	452,281
Average Benchmark Trip Rate/GFA m^2/annum			**40.8**

[a] The B8 use is for the provision of storage for the A1 (retail) use, and not general warehousing. The B8 use could be assumed to be part of A1, but this would increase the Average Benchmark Trip Rate/GFA m^2/annum and would have no effect on the outcome of the assessment.

9.275 The traffic data set out in Appendix 9.4 Table A4.17 of the UES shows that the CADP Proposals would generate an additional 3,540 (LDV) movements per operational day, based on changes to AADT flows on Hartmann Road. Taking into account the GFA of the CADP proposals, this is equivalent to 32.7 trips/m^2/annum.

9.276 As the Transport Trip Rate is lower than the Benchmark Trip Rate, it can be concluded that the CADP proposals comply with the “air quality neutral” principle, and no further mitigation is required.

9.277 The calculations above are related to building and landside emissions only, as the SPG provides no guidance on how to account for emissions arising airside. Table 9.19 in Chapter 9 sets out the summary emissions for the 2014 Baseline. Ground Support Equipment (GSE) (including airside vehicles and MGPUs) accounts for about 7.0 tonnes of NOx; the MGPUs contribute about 6.4 tonnes of this total. The CADP proposals will introduce Fixed Electrical Ground Power (FEGP) to all stands (other than at the Jet Centre) which will practically eliminate the use of MGPU use to occasions where there is FEGP failure. NOx emissions from GSE will be substantially lower in future years with the CADP proposals (as demonstrated in Table 9.39).

[80] Due to the wide variation in trip rates, it would not be appropriate to select the lowest value. The trip rates for each land use class have been weighted according to GFA and used to calculate an average value for Sui Generis.

Mitigation

Construction Mitigation

9.278 Measures to mitigate dust emissions will be required during the construction phase of the development in order to reduce impacts upon nearby sensitive receptors.

9.279 The site has been identified as a *High* Risk site during demolition, earthworks and construction, and *Medium* Risk for trackout, as set out in Table 9.24. The GLA's SPG on *The Control of Dust and Emissions During Construction and Demolition* [(81)] describes measures that should be employed, as appropriate, to reduce the impacts, along with guidance on what monitoring that should be undertaken during the construction phase. This reflects best practice experience and has been used, together with the professional experience of the consultant and the findings of the dust impact assessment, to draw up the following set of measures that should be incorporated into the specification for the works[82]:

Site Management

a) Develop and implement a stakeholder communications plan that includes community engagement before work commences on site;

b) Develop a Dust Management Plan (DMP);

c) Display the name and contact details of person(s) accountable for air quality pollutant emissions and dust issues on the site boundary;

d) Display the head or regional office contact information;

e) Record and respond to all dust and air quality pollutant emissions complaints;

f) Make a complaints log available to the local authority when asked;

g) Carry out regular site inspections to monitor compliance with air quality and dust control procedures, record inspection results, and make an inspection log available to the Local Authority when asked;

h) Increase the frequency of site inspections by those accountable for dust and air quality pollutant emissions issues when activities with a high potential to produce dust and emissions are being carried out and during prolonged dry or windy conditions;

i) Record any exceptional incidents that cause dust and air quality pollutant emissions, either on or off the site, and ensure that the action taken to resolve the situation is recorded in the log book; and

j) Hold regular liaison meetings with other high risk construction sites within 500 m of the site boundary, to ensure plans are co-ordinated and dust and particulate matter emissions are minimised. It is important to understand the interactions of the off-site transport/deliveries which might be using the same strategic road network routes.

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81 GLA (2014) The Control of Dust and Emissions from Construction and Demolition SPG

82 The mitigation measures set out in this section are largely unchanged from those defined in the CES, but the precise wording and ordering of text has changed to reflect that within the GLA SPG

Preparing and Maintaining the Site

a) Plan the site layout so that machinery and dust-causing activities are located away from receptors, as far as is possible;

b) Erect solid screens or barriers around dusty activities or the site boundary that are at least as high as any stockpiles on site;

c) Fully enclose site or specific operations where there is a high potential for dust production and the site is active for an extensive period;

d) Install green walls, screens or other green infrastructure to minimise the impact of dust and pollution;

e) Avoid site runoff of water or mud;

f) Keep site fencing, barriers and scaffolding clean using wet methods;

g) Remove materials that have a potential to produce dust from site as soon as possible, unless being re-used on site. If they are being re-used on-site cover as described below;

h) Cover, seed, or fence stockpiles to prevent wind whipping;

i) Carry out regular dust soiling checks of buildings within 100 m of site boundary and cleaning to be provided if necessary;

j) Provide showers and ensure a change of shoes and clothes are required before going off-site to reduce transport of dust;

k) Put in place real-time dust and air quality pollutant monitors and ensure they are checked regularly;

l) Agree monitoring locations with the Local Authority; and

m) Where possible, commence baseline monitoring at least three months before phase begins.

Operating Vehicle/Machinery and Sustainable Travel

a) Ensure all on-road vehicles comply with the requirements of the London Low Emission Zone;

b) Ensure all Non-road Mobile Machinery (NRMM) complies with the standards set within the GLA's Control of Dust and Emissions During Construction and Demolition SPG. This outlines that, from 1st September 2015, all NRMM of net power 37 kW to 560 kW used on the site of a major development in Greater London must meet Stage IIIA of EU Directive 97/68/EC (Directive 97/68/EC of the European Parliament and of the Council, 1997) and its subsequent amendments as a minimum. NRMM used on any site within the Central Activity Zone or Canary Wharf will be required to meet Stage IIIB of the Directive as a minimum. From 1st September 2020 NRMM used on any site within Greater London will be required to meet Stage IIIB of the Directive as a minimum, while NRMM used on any site within the Central Activity Zone or Canary Wharf will be required to meet Stage IV of the Directive as a minimum;

c) Ensure all vehicles switch off engines when stationary – no idling vehicles;

d) Avoid the use of diesel- or petrol-powered generators and use mains electricity or battery-powered equipment where practicable;

e) Impose and signpost a maximum-speed-limit of 10 mph on surfaced haul routes and work areas (if long haul routes are required these speeds may be increased with suitable additional control measures provided, subject to the approval of the nominated undertaker and with the agreement of the Local Authority, where appropriate);

f) Produce a Construction Logistics Plan to manage the sustainable delivery of goods and materials; and

g) Implement a Travel Plan that supports and encourages sustainable staff travel (public transport, cycling, walking, and car-sharing).

Operations

a) Only use cutting, grinding or sawing equipment fitted or in conjunction with suitable dust suppression techniques such as water sprays or local extraction, e.g. suitable local exhaust ventilation systems;

b) Ensure an adequate water supply on the site for effective dust/particulate matter suppression/mitigation, using recycled water where possible and appropriate;

c) Use enclosed chutes, conveyors and covered skips;

d) Minimise drop heights from conveyors, loading shovels, hoppers and other loading or handling equipment and use fine water sprays on such equipment wherever appropriate; and

e) Ensure equipment is readily available on site to clean any dry spillages, and clean up spillages as soon as reasonably practicable after the event using wet cleaning methods.

Waste Management

a) Reuse and recycle waste to reduce dust from waste materials; and

b) Avoid bonfires and burning of waste materials.

Measures Specific to Demolition

a) Soft strip inside buildings before demolition (retaining walls and windows in the rest of the building where possible, to provide a screen against dust);

b) Ensure water suppression is used during demolition operations;

c) Avoid explosive blasting, using appropriate manual or mechanical alternatives; and

d) Bag and remove any biological debris or damp down such material before demolition.

Measures Specific to Earthworks

a) Re-vegetate earthworks and exposed areas/soil stockpiles to stabilise surfaces as soon as practicable;

b) Use Hessian, mulches or trackifiers where it is not possible to re-vegetate or cover with topsoil, as soon as practicable; and

c) Only remove the cover from small areas during work, not all at once.

Measures specific to construction

a) Avoid scabbling (roughening of concrete surfaces), if possible;

b) Ensure sand and other aggregates are stored in bunded areas and are not allowed to dry out, unless this is required for a particular process, in which case ensure that appropriate additional control measures are in place; and

c) Ensure bulk cement and other fine powder materials are delivered in enclosed tankers and stored in silos with suitable emission control systems to prevent escape of material and overfilling during delivery.

Measures specific to trackout

a) Regularly use a water-assisted dust sweeper on the access and local roads, as necessary, to remove any material tracked out of the site;

b) Avoid dry sweeping of large areas;

c) Ensure vehicles entering and leaving sites are covered to prevent escape of materials during transport;

d) Inspect on-site haul routes for integrity and instigate necessary repairs to the surface as soon as reasonably practicable;

e) Record all inspections of haul routes and any subsequent action in a site log book;

f) Install hard surfaced haul routes, which are regularly damped down with fixed or mobile sprinkler systems or mobile water bowsers, and regularly cleaned;

g) Implement a wheel washing system (with rumble grids to dislodge accumulated dust and mud prior to leaving the site where reasonably practicable);

h) Ensure there is an adequate area of hard surfaced road between the wheel wash facility and the site exit, wherever site size and layout permits;

i) Access gates should be located at least 10 m from receptors, where possible; and

j) Apply dust suppressants to locations where a large volume of vehicles enter and exit the construction site.

Operational Mitigation

9.280 The assessment has predicted no significant air quality or odour impacts during operation of the CADP during the Transitional Year (2020), the Design Year (2023) and the Principal

Assessment Year (2025). Therefore, additional mitigation measures above those already in place, and those embedded in the CADP proposals are not considered necessary.

9.281 The Airport published its Air Quality Action Plan in July 2012, which set out a range of measures to improve local air quality over the period up until 2015. A revised Action Plan, covering the period 2015-2018 is currently being developed and will be submitted to LBN for approval by the end of 2015. It is intended that a number of measures will be consolidated, but all relevant measures will be retained. These measures will bring about compliance of all airside vehicles (unless exemption is granted) with the London LEZ as soon as possible, will continue with random emissions testing of all airside vehicles, and will decommission the older MGPUs.

9.282 Embedded within the CADP proposals are a number of measures that will reduce pollutant emissions:

a) The installation of FEGP to all refurbished and new stands will substantially reduce reliance on MGPUs;

b) The appointment of a third party transport management company to manage and regulate the taxi rank will marshal all taxis in the forecourt area and taxi feeder park. Idling will not be permitted by stationary vehicles;

c) The provision of the eastern access onto Hartmann Road will significantly reduce traffic flows at the western end (close to Camel Road) and will be beneficial in reducing pollutant concentrations at this location;

d) The provision of the 560 kWt CCHP plant at the new Eastern Energy Centre will allow emissions of nitrogen oxides to be controlled (the proposed Development includes for 95% catalytic reduction of emissions); ultra-low NOx boilers (<40mgNOx/kWh) will be used at both the Western and Eastern Energy Centres; and

e) The Airport Travel Plan will increase the public transport (DLR) mode share and reduce the impact of road traffic.

Residual Effects

Construction

9.283 The IAQM guidance is clear that, with appropriate mitigation in place, the residual effect will normally be 'not significant'. With the mitigation measures set out above in place and effectively implemented, the residual effects are judged to be ***insignificant*.**

9.284 The IAQM guidance does, however, recognise that even with a rigorous dust management plan in place, it is not possible to guarantee that the dust mitigation measures will be effective all of the time, for instance under adverse weather conditions. During these events, short-term dust annoyance may occur, however, the scale of this would not normally be considered sufficient to change the conclusion that overall the effects will be ***insignificant*.**

Operation

9.285 The mitigation measures as described above are largely embedded in the existing Action Plan or are within the CADP proposals, and have been taken into account in the air quality assessment. The residual effects are therefore unchanged from those stated previously.

Cumulative Effects

9.286 The only likely cumulative air quality effects of the CADP proposals are those related to traffic generated by other consented or proposed schemes (as listed in Table 18.2, Chapter 18: Cumulative Effects). The traffic generated by these schemes has been included in the future baselines and Without CADP scenarios) and, as such, has been explicitly considered. In addition, sensitive receptors at these consented or proposed schemes have been included in the assessment.

Conclusions

9.287 The air quality impacts associated with the construction and operation of the proposed CADP development have been assessed.

9.288 The construction works have the potential to create dust. During demolition and construction it will therefore be necessary to apply a package of measures to minimise dust emissions, as part of the CADP Construction Environmental Management Plan (CEMP). Even with these measures in place, there remains a risk that a number of properties might be affected by occasional dust-soiling impacts. Any effects will be temporary and relatively short-lived, and will only arise during periods of dry weather when the wind is blowing towards a receptor, at a time when dust is being generated and mitigation measures are not fully effective. The overall impacts of the construction works are judged to be ***not significant*****.**

9.289 During operation, the predicted concentrations of nitrogen dioxide, PM_{10} and $PM_{2.5}$ are all below the objectives, whether the proposed CADP proceeds or not. A large number of properties would experience imperceptible increases to pollutant concentrations.

9.290 The overall air quality impact of the proposed CADP is judged to be ***not significant.*** This takes into account that all predicted concentrations are below the objectives, and that the impacts are negligible at the majority of receptor locations, with slight adverse impacts at one receptor. With regard to the London Councils guidance, it is judged that air quality is *not a significant consideration****.***

9.291 The CADP proposals would not affect national compliance with the EU limit values.

9.292 A small number of properties in close proximity to the apron area will be at increased risk of being affected by odours due to the increased numbers of aircraft operations associated with the proposed CADP development. However, there is some uncertainty with the predictions which are likely to be overstated as no account has been taken of the considerable shielding effect afforded by the terminal buildings, piers and DLR infrastructure. Taking this uncertainty into account, the effects are judged to be ***not significant.***

9.293 The Airport has already instigated a programme of measures within its Air Quality Action Plan which will further minimise any impacts in future years. In addition, a number of measures to reduce pollutant emissions have been embedded in the CADP proposals. These include the provision of FEGP to all new stands; the introduction of measures to prohibit idling by stationary taxis; the reduction of traffic flows along the western part of Hartmann Road by provision of the eastern access point; the provision of new Energy Centres with a high level of NOx abatement; and the development of an updated Airport Travel Plan.

9.294 The CADP Proposals meet both the building and road transport related benchmarks defined in the Mayor's SPG, and the Proposals are ***air quality neutral.***

9.295 The proposed CADP is consistent with the NPPF, the Airport Policy Framework, the London Plan and the Mayor's Air Quality Strategy, and relevant policies within the Council's Core Strategy. It does not conflict with any elements of the Council's Air Quality Action Plan, and it is concluded that there are ***no air quality constraints to the development.***

London Airspace Management Project (LAMP)

9.296 Phase 1a of the London Airspace Management Project (LAMP) represents the first stage of the Future Airspace Strategy to modernize airspace over South East England. In preparation for Phase 1a of LAMP, the Airport is seeking to ensure that its 10 standard instrument departure routes (SIDs) and 2 standard arrival routes (STARs) below 4,000 ft are RNAV (Area NAVigation) compliant. The key feature of an RNAV compliant route is that it enables an aircraft to use modern GPS based navigational aids, rather than ground beacons, to follow a defined route.

9.297 The proposed changes under LAMP will not affect the numbers of arrivals or departures, or the use of Runways 09 and 27, assumed in this assessment. The changes are designed to affect aircraft routing at altitude (i.e. between 1,000 and 4,000 ft).

9.298 By convention, pollutant emissions from aircraft are calculated within the Landing and Take-off Cycle, and which includes all operations during arrival and departure up to a ceiling height of 3,000 ft. In reality, however, emissions from aircraft at altitudes above more than a few hundred feet will have an imperceptible impact on ground-level pollutant concentrations. The proposed RNAV replications will therefore not affect ground-level pollutant concentrations, and there are no implications for the CADP proposals or the conclusions within this Chapter.

9.299 The proposed RNAV replications will potentially allow aircraft to plan smoother descent patterns on arrival, which will result in a small reduction in fuel burn and corresponding pollutant and CO_2 emissions. Thus, the total pollutant concentrations within the LTO cycle for future years may be lower than reported in this Chapter, but any benefit is expected to be small, and does not affect the outcome of the assessment.

3. Project for the Sustainable Development of Heathrow: Report of the Air Quality Technical Panels

Project for the Sustainable Development of Heathrow - Report of the Air Quality Technical Panels

Executive Summary

1. This Report sets out the work and findings of the technical Panels set up by the Department for Transport in 2004 to advise the Government on ways to strengthen and update the assessment of air quality around Heathrow Airport, following publication of the Air Transport White Paper "The Future of Air Transport" in December 2003. It records the Panels' review of available evidence and measurement data. It gives their analysis of existing methodology and modelling. Above all, it sets out their conclusions and recommendations on how best to assess air quality at the airport in future years, including the modelling tools and assumptions to be used.

2. There is an accompanying report of an independent peer review panel whose task was to review the process established to deliver the air quality advice and whether the resulting technical report took appropriate account of the current state of scientific knowledge, whether its conclusions were clearly and fairly presented, were justified in light of the current state of knowledge, and were appropriately comprehensive and fit for purpose.

3. Together, the reports provide the basis for the next phase of the work by the Department, on the generation of emissions inventories and revised modelling of future air quality at Heathrow. This in turn will inform further assessment of the likely impacts of any further development at Heathrow, and whether measures are available to ensure that any further development meets the conditions laid down in the White Paper. The results will form part of a further public consultation in due course before Government announces any conclusions.

Background and rationale

4. The White Paper "The Future of Air Transport", identified the need for a national strategic framework for the future development of airport capacity in the United Kingdom, looking forward 30 years. One reason given in the White Paper for this strategic framework was the requirement to address the environmental impacts that air travel generates.

5. The White Paper noted the Government's support for a third runway at Heathrow once it could be confident that the key condition relating to compliance with air quality limits can be met. It was judged that there was a substantially better prospect of achieving this if development of a third runway and terminal capacity was deferred until the 2015-2020 period, as long as action is taken meanwhile to tackle the NO_2 problem. The Government's support is also conditional on measures to prevent deterioration of the noise climate and improve public transport access.

6. The White Paper said that the Government would institute, with the airport operator and relevant bodies and agencies, a programme of action to consider how these conditions can be met in such a way as to make the most of Heathrow's two existing runways and to enable the addition of a third runway as soon as practicable after a new runway at Stansted. This commitment is being taken forward through the Project for the Sustainable Development of Heathrow (PSDH). PSDH will help determine whether further development is likely to be consistent with the environmental conditions laid down in the White Paper. In other words it addresses the commitments made in the White Paper, but does not authorise or preclude development itself.

7. A number of organisations are involved in taking forward PSDH, including the airport operator BAA, the National Air Traffic Services (NATS), the Civil Aviation Authority (CAA), airlines, DfT Rail (formerly the Strategic Rail Authority) and the Highways Agency. The key areas of work for PSDH are air quality, surface access, mixed mode operations and aircraft noise.

Panel Remit for Air Quality

8. In 2004 as part of PSDH, the Department for Transport's Aviation Environmental Division set up three Panels of air quality-related experts. The Panels were to advise the Government on ways to strengthen and update the air quality assessment of Heathrow Airport, as undertaken for the White Paper. The focus of the work of the Panels has been on providing guidance to DfT on the tools to assess air quality at Heathrow Airport. It is the Government who will then use this guidance to re-assess current and future scenarios for Heathrow development, up to the year 2030. The guidance is not necessarily transferable to other UK airports but is acknowledged to have relevance given the 'state of the art' developments emerging in some areas of the technical panel work.

9. The Panels, have met frequently since summer 2004, and covered:

- dispersion modelling (Panel 1);
- monitoring of air pollution (Panel 2); and
- emission source data (Panel 3).

10. Each panel consists of scientific and technical experts specifically invited for their contribution to local air quality understanding at airports. Panels have a balanced membership, including recognised air quality assessors and measurement experts, model users and developers and experts from academic and private research communities. Many of the experts are representatives from recognised best practice working groups, such as Air Quality Expert Group (AQEG), the UK Air Dispersion Model Users Group, and there has been *ad hoc* representation from the international expert community. Policy makers (Government), London Borough technical representatives, airport and airline operators and road network managers have also been part of the technical panel process.

11. The overall process adopted by the Panels was to:

- review the technical and scientific robustness of previous local air quality assessment work undertaken by the DfT for Heathrow;
- review the evidence available to refine future assessments, including accounting for new and emerging best practice and changes to assessment requirements;
- identify and specify research and other work needed to improve understanding of air quality assessments;
- examine the adequacy of measurements of airborne pollutants from different sources around Heathrow for verification of models and also for compliance with standards;
- perform innovative analysis of existing data to gain further understanding of key issues and ways forward;
- commission / undertake additional data collection or analysis to assist in current understanding of issues or to improve available methods;
- review the suitability and adequacy of previous and currently available emission source data;
- commission / undertake expansion or enhancement of emission source data to assist in current understanding of issues or to improve available methods for future use;
- consider the suitability and adequacy of previous and currently available dispersion models used to represent local air quality around airports;
- identify, specify, commission and analyse an inter-comparison of potential modelling approaches for use at Heathrow - focused on the effect of different approaches to key dispersion issues; and
- agree the appropriate tools and data to be used in further air quality modelling to be undertaken by the Government, in light of commitments made in the White Paper.

12. Whilst the Panels have reviewed other pollutants, the focus of the work has followed the commitment in the White Paper, and has focused on human health related air quality standards. The primary focus has therefore been on annual average concentrations of nitrogen dioxide (NO_2) and secondly by particulate matter (PM_{10}).

13. No specific timetable was given in the White Paper for the outcome of this work. However, when the Panels were convened, they agreed to aim to complete the guidance within two years.

14. The work of the three technical Panels has been the subject of an external independent and rigorous peer review process, following the Office of the Commissioner for Public Appointments (OCPA) procedures. A Peer Review Panel (PRP) was established by the Department for Transport in September 2005 to review and scrutinise the work of the Panels and publish conclusions on whether the Panels' work has been clear and fair in establishing a technical basis for future assessments of air quality impacts at Heathrow. All members of the panel were independent from Government and from the institutions providing representatives to the Technical Panels.

Key Conclusions

15. The work of the Panels is outlined in the Project for the Sustainable Development of Heathrow - Report of the Airport Air Quality Technical Panels, 2006. This includes:

- Chapter 1 - a synthesis of the panel process, remit and key findings across all panels set against key questions;
- Chapter 2 - findings from air quality measurements;
- Chapter 3 - recommendations on how to represent sources of emissions; and
- Chapter 4 - findings from modelling the dispersion of air pollution.

16. The output of the three Panels addresses improvements over the relative results of the previous work, by specifying detailed inputs (Panel 2 and 3), model verifications (Panel 1 and 2) and output requirements (Panel 1), as well as improvements in source representation and characterisation (Panels 3 and 1).

17. Overall, the panels found that the key pollutants were nitrogen dioxide (NO_2), nitrogen oxides (NO_x), and particulate matter (PM_{10}). Ozone (O_3) was also included as it is important in the formation of NO_2. Panels found that the statutory annual mean NO_2 objective was currently being exceeded at some locations around Heathrow. Looking at changes over time, there had been a significant reduction in NO_x concentrations over a 12 year period, but the reduction in NO_2 over this period had been very small. The Panels found no breaches of any statutory PM_{10} objectives.

18. It was not the role of the Panels to undertake future year modelling of Heathrow, or to generate the emissions inventory needed to do so. Instead panels have provided detailed recommendations on how best to set a 'bottom-up inventory'. - Given the pollutants and standards shown to be of interest, the inventory setup is focused on calculating annual average concentrations only, and so uses 'representative' diurnal and seasonal profiles for sources. The inventory method has been specifically designed to generate data for base and future years over a long period (from 2002 to 2030).

19. Where possible Panels have included expert judgements of uncertainty against individual issues. However, the quantification of uncertainty across the inventory, and its expected effect on final dispersed concentrations, is well outside the remit of the PSDH Panels. Indeed, it will only be possible once the modelling has been undertaken.

20. The Panels concluded that in general, sources of nitrogen oxides (NO_x) emissions are better characterised, and hence inventory methods for NO_x are less uncertain, than inventories for particulate matter. Further, emission estimates of aircraft source groups are generally more certain than those for road transport and other airport airside sources (in that order) on account of detailed 'certification' data and performance assessment for the aircraft source.

21. Panel 1 has used 5 different dispersion models in a controlled comparison of a nominal base case to understand the suitability of different approaches. The models include descriptions of pollutant transport by dispersion and advection. Four of the five models used were based on Gaussian dispersion, while the fifth used a Lagrangian particle approach. All models used the same emissions inventory and

meteorological data to ensure that the inter-comparison focused on the dispersion elements of the models. Model outputs were compared at a pre-agreed number of receptor points including monitoring sites. Source apportionment was a specific requirement.

22. Model accuracy was assessed through validation against monitoring data. The model inter-comparison indicates accuracies in the range 10 - 20% for the annual mean NO_2, well within the EU guidelines for modelled annual mean NO_2 of 30%. In addition to comparisons with monitoring data, several 'fitness for purpose' criteria and diagnostic tests were carried out to help assess model performance.

23. Across all models, the Panels found that the modelling of plumes from aircraft during take-off and landing is not well established. Specific problems include plume rise and the effect of wake vortices. Panel 1 recommended areas of improvement to the recommended dispersion model to address these and other issues.

24. Following the model inter-comparison Panels 2 and 3 were in full agreement with Panel 1 in recommending the CERC model ADMS-Airport (a Gaussian dispersion model) for future modelling work at Heathrow. It fulfils all of the fitness for purpose criteria, and was the best performing model for each of the comparison criteria. Like the other models, ADMS-Airport is demonstrably better than the pre-White Paper approach. It was agreed that some limited use of the LASPORT Lagrangian particle model could be useful to test the effects of a different atmospheric transport framework as a sensitivity test, given its use for a number of European airports. It was also agreed that limited model runs using the netcen model might also be appropriate to provide comparisons with earlier analyses, for audit trail purposes for the Department for Transport.

Peer Review

25. The review was carried out by an independent peer review panel (PRP), chaired by Professor Bernard Silverman FRS. Peer review included detailed examination and questioning of the Panel Report findings and statements, and included observation of the panel processes leading to its completion. The key conclusions of the PRP were that:

- the Report takes appropriate account of the current state of scientific knowledge and its application to the subject of the review (whilst acknowledging that certain elements of the most recent work referred to in the Report has so far only appeared in pre-publication format, pending its submission to the standard review processes of scientific publication);
- the conclusions of the Report are clearly and fairly presented;
- the conclusions set out in the Report are justified in light of the current state of knowledge;
- the Report is appropriately comprehensive and fit for purpose;
- the Panels have fairly identified areas where there is uncertainty and/or the potential for specific future research; and
- the discussions at Technical Panel meetings were robust and open; debate was not dictated, or constrained, by either the respective Chairs of those meetings,

by the presence of representatives of DfT or of other Government Departments, or by the presence of the PRP members. Decisions were made after proper debate and consideration and were not pre-determined or imposed on the Technical Panel members.

Next Steps

26. Following the reports of the Technical Panels, the Department for Transport will carry out further assessments of air quality at Heathrow, including:

- Collation and processing of recommended emission inventory data, both improved and changed activity data and updated/enhanced emission rate data.
- Production of procedures to translate and enhance data in the activity-emissions-dispersion stages of modelling.
- Creation of the specified emissions inventories for the base year and several future forecast years.
- Enhancement and sensitivity testing of selected model approaches to account for developments within the Panels (such as the improved parameterisation of initial dispersion using results from LIDAR measurement work initiated by the Panels).
- Extensive verification tests of the base year air quality model(s). These include source attribution tests, uncertainty analysis and model performance statistics as well as comparison to monitoring and previous modelling work.
- Future year air quality modelling for a number of different years and development scenarios.

27. The results will inform advice to Ministers and a public consultation exercise in due course before firm decisions are reached on how to make best use of Heathrow's existing two runways, and whether a third runway could be added after a new runway at Stansted, whilst complying with strict conditions on air quality.

Acknowledgements

28. The Department for Transport would like to acknowledge and thank all panel members for their considerable work leading to and including the preparation of this report. Particular thanks go to the Panel chairmen:

- **Professor Mike Pilling, University of Leeds (Panel 1);**
- **Professor Duncan Laxen, Air Quality Consultants Ltd (Panel 2); and**
- **Professor David Raper, Manchester Metropolitan University (Panel 3).**

29. The Department for Transport also recognises with thanks the work of the Peer Review Panel, and the benefits of this process to the final product, and subsequent work arising from it.

PRP: Statement of the Peer Review Panel

1. This report summarises the review process applied to the report ("the Report") of three technical panels set up by the Department for Transport ("DfT") to investigate issues relating to the future operation and development of Heathrow Airport. The review was carried out by an independent peer review panel ("PRP"), chaired by Professor Bernard Silverman FRS. Based on examination of the Report and observation of the processes leading to its completion, the overall unanimous views of the PRP are as follows:

- The PRP believes that the Report takes appropriate account of the current state of scientific knowledge and its application to the subject of the review, whilst acknowledging that certain elements of the most recent work referred to in the Report have so far only appeared in pre-publication format, pending submission to the standard review processes of scientific publication.
- The PRP considers the conclusions of the Report to be clearly and fairly presented.
- The PRP believes that the conclusions set out in the Report are justified in light of the current state of knowledge.
- The PRP considers the Report to be appropriately comprehensive and fit for purpose.
- The PRP believes that the Panels have fairly identified areas where there is uncertainty and/or the potential for specific future research. The PRP is grateful that the Technical Panel members have been able to address a number of issues raised by the PRP.
- The PRP considers that the summaries in the Report are appropriate and adequate, and that the first chapter of the Report contains a clear and fair summary of the key issues and findings of the Report as a whole.
- The PRP commends the overview section to readers who wish to gain an overall appreciation of the Report without necessarily covering the material in detail.
- The PRP considers the Report to contain clear and correct bibliographic references. Although many of the references are company reports or consultants' reports and are, therefore, not necessarily readily available in the public domain, the PRP has been assured that the DfT holds copies of all the cited reports and documents.
- The discussions at Technical Panel meetings were robust and open; debate was not dictated, or constrained, by either the respective Chairs of those meetings, by the presence of representatives of DfT or other Government Departments, or by the presence of the PRP members. Decisions were made after proper debate and consideration and were not pre-determined or imposed on the Technical Panel members.

Background

2. The White Paper "The Future of Air Transport", published by the Secretary of State for Transport in December 2003, identified the need for a national

strategic framework for the future development of airport capacity in the United Kingdom, looking forward 30 years. One reason given in the White Paper for this strategic framework was the requirement to address the environmental impacts that air travel generates. When considering the possibility that a third runway might be constructed at Heathrow Airport, the White Paper made reference to the air quality standards that will become mandatory from 2010 and stated that one of the key conditions for such a development would be the need to ensure compliance with these air quality limits.

3. A programme of action was therefore instituted, to consider how these conditions could be met. To deal with the issue of air quality, three Technical Panels were established to revisit the air quality assessments made in the run up to the White Paper. The Technical Panels were to focus, respectively, on: modelling approaches (Panel 1); data measurement (Panel 2); and sources of emissions (Panel 3) and to produce the Report. The membership of the Technical Panels comprised independent experts from a variety of scientific, technical and operational backgrounds, supported by officials from relevant Government Departments. The need for further research and data collection was identified and it was envisaged that this work would be completed by the end of 2005; in the event the Report was finalised in March 2006.

Constitution of the Peer Review Panel

4. The PRP was established by the DfT in September 2005, as a result of the Government's intention that the work of the Technical Panels would be subject to rigorous peer review. The PRP was to play a role in assessing and analysing the suitability and reasonableness of the processes and technical actions of the Technical Panels in response to their respective remits and to report its conclusions on their work.

PRP Remit

5. The stated brief of the Peer Review Panel was as follows: "The Peer Review Panel's main objective will be to review the work of the Technical Panels and publish its conclusions on whether their work has been unbiased and fair in terms of establishing a technical basis for future assessments of air quality impacts. This is to be used in Ministers' consideration of the future development of Heathrow."

6. It was expected that the work of the PRP would reach and publish conclusions on the work of the Technical Panels by

- learning about the basis for and conduct of the ongoing work of the Technical Panels;
- scrutinising their work for reasonableness in terms of both their evidence base and conclusions;

- questions to and further information from the Technical Panel Chairs and, if necessary, the Technical Panel members in response to presentation of interim information on the work of the Technical Panels;
- consideration and assessment of the full technical report of the Technical Panels.

Membership of the PRP

7. The Peer Review Panel was constituted through a formal process in line with guidance from the Office of the Commissioner for Public Appointments (OCPA). Applications were sought through advertising in the national press and through the use of an executive search agency. Following a sift and interview process, monitored by an OCPA assessor, a chair and three additional panel members were appointed. The selection panel comprised the DfT Chief Scientist, the manager of the air quality work associated with the DfT Project for the Sustainable Development of Heathrow (PSDH) and an independent OCPA assessor. The resulting membership of the PRP comprised:

8. Professor Bernard Silverman (Chair), Master of St Peter's College, Oxford and Professor of Statistics at Oxford University. He is a Fellow of the Royal Society and a Fellow, Council Member and Past President of the Institute of Mathematical Statistics. His research interests range from general statistical theory and methodology to the application of statistics in a wide range of subject areas across the physical and biological sciences, engineering and medicine.

9. Stephen Boughton, retired Solicitor, formerly a partner in Linklaters, specialising in business and company law, corporate finance and mergers and acquisitions. He currently undertakes a range of charitable, voluntary and public service roles.

10. Dr Roy Colvile, Senior Lecturer in Air Quality Management at Imperial College London. He originally trained as an experimental physicist and now has wide experience in the field of atmospheric dispersion modelling. He is a member of the UK Air Quality Expert Group.

11. Professor Ian Poll OBE, Professor of Aerospace Engineering at Cranfield University and Technical Director of Cranfield Aerospace Ltd. He is a Fellow, Council member and a Past President of the Royal Aeronautical Society, a Fellow and Council member of the Royal Academy of Engineering and a Fellow of the American Institute of Aeronautics and Astronautics. His principal areas of expertise are aerodynamics and aircraft performance.

12. The expertise of the PRP therefore covered a range of disciplines, from mathematics and statistics, through aerodynamics/aeronautics and atmospheric dispersion, to legal. All members of the PRP were independent from Government and from the institutions providing representatives to the Technical Panels. Potential conflicts of interest were disclosed at an early stage, discussed and judged not to be of concern to the work of the PRP.

PRP Process and Procedures

13. In order for the peer review process to be effective, it was necessary for the PRP to work independently of the Technical Panels and at arms' length from them, and also to be independent of the DfT. The PRP did, however, allow representatives of the DfT to attend their meetings, and also to provide technical and secretarial support for their work.

14. Roger Gardner of the Air Quality and Environmental Technology Branch, Aviation Environmental Division attended throughout (except where it was felt that a confidential discussion was needed). Once the Report was at an advanced stage, he was joined by Paul Taylor of Atkins (formerly with Halcrows), who was retained by DfT as technical support throughout the Air Quality technical panel process, and was a member of all three Technical Panels.

15. The presence of Roger Gardner and Paul Taylor enabled rapid feedback to be given from the PRP to the members of the Technical Panels and assisted in clarifying certain issues raised by the members of the PRP. The PRP is satisfied that the presence at meetings of representatives of the DfT and of Paul Taylor did not compromise the independence of the review process, not least because of the mutual understanding and acceptance of the need for independence.

16. The PRP decided at an early stage to limit its work to the terms of the remit described above and to focus their work as narrowly and precisely as was reasonable. Particularly bearing in mind that the PRP's work should not itself require further external independent review, the PRP sought to review, not to repeat, the work of the Technical Panels, and also to concentrate on the Report itself. The PRP have not reviewed or commented on the various Annexes.

17. The process adopted emulated a publication peer review, providing interim feedback on advanced drafts of the Report in the hope that any issues raised could be accounted for in the final version. Since only near final drafts were considered, the PRP was able to maintain an appropriate distance and independence from the work of the Technical Panels and to avoid becoming enmeshed in their processes and deliberations.

18. At the same time, however, this interim review process allowed the PRP to gain a deeper appreciation of the likely content of the final Report and to raise points which the Technical Panels were able to address.

19. In addition to reviewing the written Report itself, the PRP monitored the later part of the process by which the Report had been constructed, to provide further quality control of the Report and additional confirmation that it was based on sufficiently sound and rigorous work by the Technical Panels. Accordingly, the PRP attended certain meetings of the Technical Panels, in order to observe their operations, as follows:

- Meeting of Panel 1 held on 28 September 2005;
- Plenary Session of all three Panels held on 12 and 13 October 2005; and
- Final meeting of Panel 1 held on 31 October 2005.

20. All PRP members attended at least one of these meetings, but none attended all. The objective of planning for this variation in attendance was to ensure, firstly, that all PRP members would be able to comment on "process issues" and, secondly, that no PRP member would become too closely identified with the work of any particular Technical Panel, such that the independence of that PRP member would be compromised.

21. The role played by PRP members at the Technical Panel meetings they attended was primarily to act as observers of the discussion and decision-making processes, asking questions of Technical Panel members only where the PRP members felt that clarification of issues was necessary or where amplification was required. The PRP did not seek to influence the conduct of proceedings at those meetings or the conclusions and recommendations reached. An "arm's length" relationship with the Technical Panels was maintained by the PRP.

22. The PRP wishes to add an additional comment on the process followed at the final meeting of Panel 1 held on 31 October 2005, at which agreement was reached as to which models were to be recommended. As the Panel 1 report states, these decisions were taken after the making of full presentations on each of the five models considered, and after a full inter-comparison and assessment of model performance. The decisions were taken in open forum, with the whole of Panel 1, including representatives of the five modelling groups, present. The PRP considered this process to be demonstrably open, fair and reasonable.

23. Following on from attendance at the Technical Panel meetings and review by the individual PRP members of draft sections of the Report, the PRP discussed and agreed its responses to, and comments on, the drafts. Further discussion took place by e-mail, before comments and questions were passed (by e-mail) to the Chairs and members of the Technical Panels. The Technical Panels were invited to respond in writing to PRP comments, where necessary, but no direct communications about the Report took place between PRP members and Panel members. The PRP suggested that members of each Technical Panel should review the draft reports produced by the other Technical Panels, to ensure consistency of approach and so that conclusions and recommendations contained in one Panel report which might affect the contents of another Panel report were properly dealt with.

24. At every stage, the PRP's decisions were made by consensus, and the process described led to the PRP's unanimous conclusions about the final Report.

Department for Transport

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e Key Issues and Findings

Table of contents

Introduction

1. In 2004, as part of the overall Project for the Sustainable Development of Heathrow (PSDH), the Department for Transport Aviation Environmental Division set up three Panels of air quality-related experts. The Panels were to advise the Government on ways to strengthen and update the air quality assessment of Heathrow Airport, as undertaken for the White Paper on *The Future of Air Transport* (DfT 2003b). The Panels have met frequently since summer 2004, and covered:

- dispersion modelling (Panel 1);
- monitoring (Panel 2); and
- emission source data (Panel 3).

2. Chapter 1 is a synthesis of the work of all the Panels. It asks a series of questions, covering:

- What is PSDH about?
- How does the package of air quality work relate to other work?
- What was the remit of the Panels?
- What are the cross-cutting issues for all Panels?
- What did previous air quality assessments of Heathrow find, and why?
- What were the key issues investigated?
- What are the key findings?
- What are the recommendations (for best practice)?
- How was the work peer reviewed?
- What future work will be undertaken at Heathrow?

3. The focus of all the work summarised in this report is on providing guidance to DfT on the tools to assess air quality at Heathrow Airport. Chapter 1 pulls together key points from all panels as an aide - for full understanding of the recommendations made, the reader should refer to the original detail and justification of each recommendation. These are found in:

- the subsequent chapters detailing the work of each of the Panels in turn;
- the technical annexes to this report (mainly reports of Panel-commissioned work) and
- key working papers produced by Panel members during the process. [1]

What is the Project for Sustainable Development at Heathrow about?

4. PSDH takes forward the commitment made in the Government's White Paper *The Future of Air Transport* [2] to examine how to make best use of Heathrow's existing two runways, and whether a third runway could be added at Heathrow (after an additional runway at Stansted) whilst complying with the conditions on air quality, noise and improved public transport access. PSDH will determine whether further development is likely to be consistent with the environmental conditions laid down in the White Paper. In other words, it addresses the commitments in the White Paper, and does not authorise or preclude development itself.

5. A number of organisations are involved in taking forward PSDH, including the airport operator BAA, the National Air Traffic Services (NATS), the Civil Aviation Authority (CAA), airlines, DfT Rail (formerly the Strategic Rail Authority) and the Highways Agency. The key areas of work for PSDH are air quality, surface access, mixed mode operations and aircraft noise. Each influences the others, and so the links between them are explained below, with specific reference to issues affecting or being affected by, the role of the Air Quality Panels. The Government has taken the lead on the air quality assessment work.

How does air quality relate to other areas of work in PSDH?

Summary

- **Surface Access: Source of traffic data for air quality modelling, and roads related mitigation testing based on air quality problem areas.**
- **Airport Operations: source of aircraft movement data needed for scenarios.**
- **Airport Noise: source of future airframe/engine combinations for air quality modelling, the balancing effects of mitigation between noise and air quality issues.**

Links to Surface Access work-stream

6. The expansion of Heathrow would place pressure on the road and rail networks surrounding the airport. As the Government has no plans for further widening of the strategic roads surrounding the airport beyond those announced in Summer 2003, solutions would need to be based on improved public transport (particularly rail) and potentially some form of demand management, such as road user charging. Work on surface access for both road and rail, involving a number of organisations including DfT Rail and the Highways Agency, is jointly led by the Department for Transport and BAA.

7. The surface access work includes the development of traffic modelling tools which would be the source of much of the traffic activity data used in Panel 3 emission inventories. Equally the disaggregation possible in the air quality modelling suggested by Panel 1 would also be somewhat dictated by the format of the traffic modelling. Whilst outside the remit and control of the Air Quality Panels, regular discussions have taken place between members of the Panels, and of the PSDH surface access working group, to ensure that outputs from the latter are adequate for the former. This has involved considerable changes to traffic modelling work to reflect the emergent detailed requirements of the Air Quality Panels.

8. Equally, the policies being adopted in relation to demand management need to be reflected in the air quality modelling. The complexity of some of these measures can again influence the set-up required of the air quality modelling. Discussions between members of the air quality and surface access teams have addressed this where feasible.

Links to Airport Operations work-stream

9. 'Mixed mode' (the use of runways for both departing and arriving aircraft) is a possible way of making better use of Heathrow's existing runways, which currently operate in 'segregated mode' (one runway is used for departures and one for arrivals). Development of mixed mode options is being led initially by BAA, working closely with NATS, the CAA and Government, with a view to public consultation in due course.

10. The development of mixed mode scenarios includes reviews of measures originally intended to mitigate noise such as westerly preference and the Cranford Agreement (see Glossary). Changes in these could have an impact on air quality receptors. Furthermore, for air quality, NATS feasibility work on how mixed mode might be operated safely and efficiently at Heathrow would affect aircraft landing and take-off (LTO) operational assumptions, thereby influencing the Air Quality Panels' work.

Links to Airport Noise work-stream

11. The White Paper made further development of Heathrow conditional on there being no net increase in the total area of the 57dBA noise contour compared with summer 2002 (an area of 127 square kilometres). For PSDH, the Environmental Research and Consultancy Department of the CAA are modelling the noise impacts of airport development options to check whether they meet this condition. The work also reviews some of the noise mitigation measures at Heathrow, in line with the commitment given at the time of the Terminal 5 decision. The airport noise team has had close involvement with the Aircraft Engine Technical subgroup of Panel 3, providing data and advice on expected future airframe/engine combinations and future technology introductions, for use in its inventory recommendations.

How was the Air Quality Panels' work peer reviewed?

Summary

- **Independent extenal peer review panel, September 2005 to May 2006.**
- **Rogorous scrutiny of technical panels covering: process adopted, evidence base, unbiased findings and recommendations, reporting.**
- **Peer review confirms robustness of technical panel's work.**

12. The work of the three technical Panels has been the subject of an external independent and rigorous peer review process, reporting to Ministers. A Peer Review Panel (PRP) was established by the Department for Transport in September 2005 to review and scrutinise the work of the Panels and publish conclusions on whether the Panels work has been unbiased and fair in establishing a technical basis for future assessments of air quality impacts at Heathrow. The peer review concentrated on the main reports of the technical Panels (and did not review annexes or accompanying commissioned reports). The peer review report is provided alongside the Panel reports.

13. The Peer Review panel was set up using the Office of the Commissioner for Public Appointments (OCPA) procedures. The Peer Review panel consisted of:

- (Chair) Professor Bernard Silverman, Master of St Peter's College, Oxford and Professor of Statistics at Oxford University. He is a Fellow of the Royal Society and a Fellow and Past President of the Institute of Mathematical Statistics.
- Stephen Boughton, Solicitor in business & company law (retired). He was formerly a partner in Linklaters, and is currently a local magistrate.
- Dr Roy Colvile, Senior Lecturer in Air Quality Management at Imperial College London and a member of the UK Air Quality Expert Group
- Professor Ian Poll OBE, Professor of Aerospace Engineering at Cranfield University and Technical Director of Cranfield Aerospace Ltd. He is a Fellow and a Past President of the Royal Aeronautical Society, a Fellow of the Royal Academy of Engineering, and a Fellow of the American Institute of Aeronautics and Astronautics.

14. The expertise of the Peer Review Panel therefore covered a range of disciplines, from mathematics and statistics, through aerodynamics/aeronautics and atmospheric dispersion, to legal. All members of the panel were independent from Government and from the institutions providing representatives to the Technical Panels.

What was the remit of the Air Quality Panels?

Summary

- **Balanced expert membership of Panels across disciplines, relevant organisations, and users.**
- **Guidance on technical/scientific basis for local air quality assessments at Heathrow, including ambient monitoring, emission inventories and dispersion modelling.**
- **Modelling of any future development at Heathrow will be conducted after the Panels.**
- **Recommend longer term research (outside the duration of the Panels).**

15. Annex 1 to this report sets out the terms of reference, membership, objectives and key issues to be addressed by each Panel. The White Paper promised further work to:
16.
    a. review the data, knowledge and tools behind the assessments to date;
    b. see how best use could be made of the existing runways at Heathrow; and
    c. see whether a third runway could be added in due course, whilst meeting key environmental conditions.

16. The work of the Panels is effectively point a - a review of what methodologies should be applied and how. Points b and c are then further work to be undertaken by Government, applying the Air Quality Panels' recommendations to current and future scenarios for Heathrow development, up to the year 2030.

17. The role of the Panels has been:

- to determine where and how the assessment tools might be improved;
- to propose actions necessary to improve the information base for the assessment;
- to review work set in hand to fill gaps in knowledge or update tools or data;
- to recommend additional work outside the timescale of the Panels if necessary; and
- to recommend appropriate modelling methodology(s) for the assessment.

The goal has been a broadly accepted technical and scientific basis for conducting further local air quality assessments, both of current impacts and future predicted impacts.

18. The core issues specific to air quality are separated into three Panels:

- Panel 1 - dispersion modelling;
- Panel 2 - ambient measurement; and
- Panel 3 - emissions source data.

Further explanation of the orientation of each Panel's work is provided in their own reports:

- Chapter 2 - monitoring and measurements for model development;
- Chapter 3 - emission sources; and
- Chapter 4 - dispersion modelling.

Careful thought was given to the arrangement of the chapters, and the Panels together agreed that this arrangement provided a better explanation of the issues than simply arranging the reports according to the numbering of the Panels.

19. Each Panel consists of members specifically invited for their contribution to local air quality understanding at airports. Panels have a balanced membership, including:

- policy makers (Government);
- London Borough technical representatives;
- airport and airline operators;
- road network managers;
- recognised air quality assessors - practitioners from consultants, applied academics and others;
- model users and developers;
- academic and private research communities; and
- representatives from recognised best practice working groups, such as the Air Quality Expert Group (AQEG), the UK Air Dispersion Model Users Group, and *ad hoc* representation from the international expert community.

20. The overall process the Panels went through includes:
21.
    a. review the technical and scientific robustness of local air quality assessment work undertaken by the DfT for Heathrow (see Annex 2);
    b. review the evidence available to refine future assessments, including accounting for new and emerging best practice and changes to assessment requirements;
    c. identify and specify research and other work needed to improve understanding of air quality assessments;
    d. examine the adequacy of measurements of airborne pollutants from different sources around Heathrow for compliance with standards and for verification of models;
    e. analyse existing data using data mining techniques to gain further understanding of key issues and ways forward;
    f. commission / undertake additional data collection or analysis to assist in current understanding of issues or to improve available methods;
    g. review the suitability and adequacy of previous and currently available emission source data;
    h. commission / undertake expansion or enhancement of emission source data to assist in current understanding of issues or to improve available methods for future use;
    i. consider the suitability and adequacy of previous and currently available dispersion models used to represent local air quality around airports;

j. identify, specify, commission and analyse a complex inter-comparison of potential modelling approaches for use at Heathrow - focused on the effect of different approaches to key dispersion issues;
k. agree the appropriate tools and data to be used in further air quality modelling undertaken by the Government in light of commitments made in the White Paper.

What are the pollutants of concern for all Panels?

Summary

- **Key pollutants for assessment: NOx, NO_2 and PM.**
- **Ozone: for role in atmospheric chemistry in dispersion models.**
- **Not required: benzene, 1,3-butadiene, carbon monoxide, lead, PAHs and sulphur dioxide.**

21. One of the first tasks undertaken by the Panels was to determine which pollutants should be the main focus of the study. The possible pollutants were discussed independently by all the technical Panels, within the remit of addressing local air quality impacts. Hence, no consideration was given to pollutants with impacts at the global level, e.g. carbon dioxide, nitrous oxide, etc. However, the Panels recognised that when consideration is given to measures limiting local impacts, it will be important to take account of the implications of these measures for other impacts.

22. A detailed review of the potential pollutants of concern was undertaken (see Chapter 2 and the Key Pollutants Report in Annex 5), led jointly by the chairs of Panel 2 (monitoring) and Panel 3 (emissions). The review of pollutants focused on the nine health-related pollutants described in the national Air Quality Strategy and its Addendum (DETR 2000, Defra 2003). The Panels did not identify any other local pollutants that needed to be addressed in the review.

23. Based on available monitoring and modelling data, the review concluded that benzene, 1,3-butadiene, carbon monoxide, lead, polycyclic aromatic hydrocarbons (PAHs) and sulphur dioxide were **not** priority pollutants, and did not require detailed consideration in this study:

- **Benzene and 1,3-butadiene** In the absence of local industrial sources, these are strongly correlated with road traffic emissions. Previous studies have measured relatively low levels of volatile organic compounds (VOCs) (including benzene and 1,3-butadiene) in the vicinity of Heathrow, which are all well below the relevant health based standards;
- **PAHs** Estimates of PAH emissions from aircraft translate to extremely low concentrations around airports, orders of magnitude below the UK objective for the marker compound benz-a-pyrene. Road traffic is a relatively minor source of PAHs in the UK and concentrations near to roads are below the UK objective;

- **Carbon monoxide** Both monitoring and previous modelling indicate that levels in the vicinity of Heathrow Airport are likely to be well below the relevant health based standards;
- **Lead** Lead is not added to aviation fuel, and is no longer added to petrol. Measured roadside concentrations are now very low;
- **Sulphur dioxide** Both monitoring and previous modelling demonstrate that concentrations at Heathrow easily conform to all relevant health based standards. Fuel sulphur contents are unlikely to increase and for some fuels, such as airside diesel, may decrease.

24. Given the importance of ozone in the formation of nitrogen dioxide, the Panels decided that it would be appropriate to collate monitoring data for ozone within the study area. While ozone information is important for atmospheric chemistry effects in dispersion modelling, the technical Panels did not consider a priority area to be modelling the impact of Heathrow emissions on ozone concentrations.

25. In summary, the pollutants for which subsequent assessments would be undertaken for DfT are therefore recommended to be nitrogen oxides (NO_X), nitrogen dioxide (NO_2), and particulate matter (PM).

What are the constraints on the future operation of Heathrow Airport ?

Summary

- **ATM capped per annum.**
- **Noise capped to total area of 57dBA Leq contour.**
- **Air quality capped to EU annual mean limit value for NO_2 of 40μg/m3.**
- **Total number of car parking spaces capped.**
- **No further widening of strategic roads around Heathrow.**

26. The principal constraints over the future development of Heathrow are:

- **Air transport movements** Heathrow is subject to an overall cap on air transport movements - 480,000 air transport movements (ATMs), that is landings or take-offs, a year - imposed as part of the Terminal 5 planning consent in 2001. Strictly speaking, the cap applies from the date the terminal opens, but BAA have indicated, through the Heathrow Area Consultative Committee forum, that they will manage air traffic in the interim to ensure that the limit is respected. Current traffic is around 470,000 ATMs a year.
- **Noise** The Terminal 5 decision also requires Heathrow to live within a noise contour cap at 57dBA Leq of 145 square kilometres, as from 2016. The 2003 White Paper goes further and states that any further development at Heathrow should not increase the total area of the 57dBA Leq contour beyond its size in the summer of 2002, which was 127 square kilometres.
- **Air quality** The critical pollutant at Heathrow is NO_2 for which the annual mean must not exceed 40 $\mu g/m^3$. The UK annual mean objective for NO_2 is already in place. The EU annual mean limit value for NO_2 becomes mandatory

from 2010, although proposals recently published by the Commission suggest there may be limited room for securing compliance up to 2015 in certain circumstances where abatement programmes are in place to demonstrate that conformity will be achieved before the new deadline.

- **Car parking** The Terminal 5 decision limits total car parking spaces on the airport to 42,000, of which only 17,500 are available for employees.
- **Road network** Government has no plans for further widening of the strategic roads surrounding the airport beyond those announced in Summer 2003. Solutions would need to be based on improved public transport, particularly rail, and potentially some form of demand management.
-
- [1] Relevant working papers addressing very specific technical matters are referred to in the individual Panel chapters. These will be placed on the Aviation section of Department for Transport's website at http://www.dft.gov.uk

  [2] Hereafter referred to as the White Paper.

Previous assessments - What did they do, and what were the shortcomings?

Summary

- **Review of all previous Heathrow-focused work.**
- **Most previous work was relative, based on comparing large numbers of options (for different airports) to each other.**
- **Many shortcomings were a product of the way the model was set up - tied to purpose.**
- **Many of the shortcomings relate to Emission Inventory uncertainty.**
- **Key dispersion shortcomings relate to representation of aircraft LTO stages and background sources, and characterisation of initial dispersion of aircraft plumes and near-road effects.**

27. At the time of the White Paper, uncertainty over whether air quality standards would be met at Heathrow in the future - for nitrogen dioxide (NO_2) in particular - was a key factor persuading the Government not to support an additional runway at Heathrow straight away. Annex 2 provides a detailed review of previous air quality assessments at Heathrow, including the approaches used, the key areas of uncertainty, and gave an early indication of potential tasks that the Panels might undertake to redress identified shortcomings.

28. Previous Heathrow work includes:

Heathrow-focused

- South East and East of England Regional Air Services Study (SERAS) 2000-2002;
- White Paper *The Future of Air Transport* 2003;

- British Airways 2003;
- BAA 2004; and

Other models around Heathrow

- CERC West London Model 2002.

29. The Panels were specifically asked to review the 'Heathrow-focused' work shown above and to examine other modelling tools used at airports in the UK and elsewhere. A specific remit was to consider fundamental alternative approaches to modelling, such as Lagrangian vs. Gaussian dispersion methodologies. However, whilst the work was not restricted to UK applications, the transferability of other models to the UK context was necessarily a real factor in evaluation.

30. Most previous 'Heathrow-focused' work was performed by netcen (an operating division of AEA Technology) using a 'kernel' approach based on the proprietary model ADMS3. It compared a very large number of airport scheme options, using a single simple air quality key indicator (a form of Appraisal Summary Table), rather than providing a validated and detailed estimate of air pollution concentrations by contributing source types.

31. The British Airways and BAA 'Heathrow-focused' work were for a different purpose, and the methodologies were not an evolution of the White Paper methodology. The BAA 2004 work was solely an attempt to improve representation of air quality at Heathrow, including a much improved emissions inventory for 2002 and 2010, more disaggregated modelling, and additional model verification against extra monitoring data. It did not test different Heathrow development scenarios.

32. Overall, many of the earlier shortcomings relate to Emission Inventory uncertainty, defining the remit of Panel 3. In relation to dispersion, the key areas of improvement to previous work for Panel 1 are:

33\.

    a. suitability of methods used to represent source types in dispersion models, and especially all elements of the landing and take-off cycle for aircraft;
    b. accuracy of representation of background emissions levels;
    c. characterisation of the initial dispersion of the aircraft plume (including jet turbulence and plume rise);
    d. characterisation of near road dispersion effects; and
    e. NO_X/NO_2 conversion under current and future conditions, including ozone trends.

33. The output of the three Panels addresses improvements over the relative results of the SERAS and White Paper work, by specifying detailed inputs (Panel 2 and 3), model verifications (Panel 1 and 2) and output requirements (Panel 1), as well as improvements in source representation and characterisation (Panels 3 and 1). Further details are contained in Annex 2.

What are the key Panel findings and conclusions?

34. The main Panel results are presented in subsequent chapters. In summary findings are provided on the basis of:

- Additional data collection - monitoring, emission sources;
- Innovative data analysis - monitoring, emission sources, activity data and meteorology;
- Enhanced and expanded methodologies and tools - especially for key emission sources;
- Extensive dispersion model inter-comparison exercise - including sensitivity tests of changes in current and future importance of specific sources, and the importance of bottom-up approaches; and
- Recommendations for additional research and development of key issues lying outside the scope or timetable of the Panel reporting.

35. The following sections on findings and conclusions focus on answers to cross-cutting questions. Answers to these questions are pulled together from the findings of the three Panels. Throughout the Panels' work there has been considerable crossover between them, which was fostered by having some members sitting on more than one Panel.

36. Within the main Panel reports, clear recommendations are made. It is difficult to summarise these in the synthesis without losing key context. Instead, a simple 'shorthand' summary of the main conclusions and recommendations is given in bullet form at the beginning of each section (the answer(s) to the question in the title). These should only be used as an aide - the reader should refer to the original recommendation detail in all cases.

Was extra monitoring undertaken to better understand air quality around Heathrow ?

Summary

- **All existing monitoring reviewed.**
- **4 new sites and several expansions to existing sites.**

37. Early on, Panel 2, in collaboration with Panel 1, reviewed the available monitoring stations around Heathrow, including their location, their type, what was measured and how, and the quality of available data. Gaps in monitoring coverage were identified, and monitoring studies developed to fill them.

38. Monitoring sites included in the assessment were selected with the primary objectives in mind:

    39.
    - to adequately describe the existing pollution climate; and
    - to provide a robust dataset for validation of the base year model.

39. It was also recognised that particular attention would need to be paid to the area to the northeast of the airport, due to the prevailing south-westerly winds.

40. Panel 2 recommended that four new monitoring sites be set up, with a number of existing sites expanded to measure extra pollutants. These enhancements started between Spring and October 2005. Sites were supported directly by DfT, by the London Borough of Hillingdon, by the London Borough of Hounslow, and by BAA. The locations of monitoring sites are shown in chapter 2 and collected data are in Annex 8 - including a description of the sites, the site type, and the pollutants measured at each.

Are air quality standards currently being breached, and are any trends detectable?

Summary

- **Standards for annual mean NO_2 breached at: airfield perimeter near Northern Perimeter Road and north side of M4.**
- **Significant and proven reduction in total NOx concentrations over time (at perimeter), but only very small downward trend in NO_2.**
- **No significant reduction in on-airport NOx over time.**
- **No breaches of hourly mean NO_2.**
- **No breaches of any PM10 standard.**
- **No breaches of proposed PM2.5 cap (indicative results only).**

Breaches

41. The annual mean UK objective of 40 µg/m^3 for NO_2 applies from 2005, with the EU limit value, also 40 µg/m^3, applying from 2010. The monitoring data for 2004, the most recent full year of ratified data available, showed levels above 40 µg/m^3 at two sites: LHR2 at the airfield perimeter and close to the Northern Perimeter Road, at 55 µg/m^3, and LHR16, alongside residential properties close to (within 30 metres) and north of the M4, at 47 µg/m^3. The locations of the various monitoring sites are shown in chapter 2. The other sites around the airport were between 31 and 39 µg/m^3. Levels had been higher in 2003, when higher pollution levels than normal were experienced across much of the UK.

42. There have been no measured exceedences of the UK 1-hour objective or the equivalent EU limit hourly value at any site since measurements began in 1993.

43. The annual mean UK objective for PM_{10} of 40 µg/m^3 applies from 2004 and the EU limit value from 2005. During both 2003 and 2004 the data at many of the sites are likely to have been significantly influenced by the Terminal 5 construction activities. The monitoring data for 2004, the most recent full year available, did not show exceedences at any of the sites. The highest value was 27.3 µg/m^3 at LHR11, a site likely to have been affected by Terminal 5 construction. Levels were higher in 2003, but still not above the standard. The

only example of monitored concentrations above the standard within the study area, was at LHR10, on the edge of the hard shoulder of the M25, in 1996.

44. The 24-hour UK objective and EU limit value for PM_{10} (50 µg/m3 not to be exceeded more than 35 times per year) is more likely to be exceeded than the annual mean. Again, there were no exceedences at any site in 2004, the first year in which the objective applies. The highest value was 22 days above 50 $\mu g/m^3$ at LHR11 which is a site likely to have been affected by Terminal 5 construction works. Levels were higher in 2003, with more than 35 days above 50 $\mu g/m^3$ at LHR2 (39 days), LHR11 (67 days) and LHR12 (40 days). The latter two sites were again likely to have been affected by Terminal 5 construction works.

45. $PM_{2.5}$ was not a priority pollutant for Panel 2, but using some adjustments (see chapter 2), concentrations close to major roads (LHR10) and the airport (LHR2) are estimated to be around 17-21 $\mu g/m^3$. These would all be below the concentration cap of 25 $\mu g/m^3$ currently proposed by the Clean Air for Europe *Thematic strategy on air pollution* (European Commission 2005b).

Trends

46. Over the period 1993 to 2004, there has been a highly significant downward trend in annual mean NO_X concentrations (over 6 $\mu g/m^3$ a year) at the airfield perimeter site (LHR2), but only a minimal (but proven) downward trend in nitrogen dioxide concentrations (0.5 $\mu g/m^3$ per year). The trends for airport specific sources have been examined by looking at those hours with winds blowing from the airport to LHR2 on the airfield boundary, and subtracting an upwind background value for those same hours. No significant trends have been identified for NO_X or NO_2 over the period 1997 to 2004 - implying that airport NO_X and NO_2, unlike general NO_X and NO_2, have not reduced over time.

47. In the last five years, 2000 to 2004, annual mean PM_{10} concentrations have shown no clear significant trends, i.e. concentrations have remained broadly constant over this period. This is consistent with results from other areas of the UK in recent years.

48. When considering monitoring results, a working uncertainty of ±10% can be assumed for measurements of NO_X and NO_2 concentrations when at the level of the EU Limit Value. There are currently no uncertainty values for the PM measurements, but the method used is the same as that applied across the Government's national network.

Can relative contributions from different sources be estimated from measurements?

Summary

- **Airport provides > 25% of total NOx at the northern airport boundary, reducing to <15% 1km further north.**
- **Airport sources can be detected at around 3km from the airport.**
- **Aircraft taking-off add a significant contribution to concentrations at the airport boundary, especially to the northeast.**
- **Aircraft emissions exhibit the characteristics of a buoyant source.**
- **Airport contributions to PM_{10} are very low.**

49. The relative source contribution from different contributors to local concentrations can be estimated at monitoring sites by re-analysing the data according to wind speed and wind direction. Also, by breaking these data down and comparing to activity such as alternating which runway is used for take-offs. Further understanding also comes from splitting these analyses by time of day and day of week. For example, daytime hours coincide with aircraft activity, whereas at night-time aircraft activity is minimal. See chapter 2 for details of the methods used.

50. The general picture is of a regional background NO_X concentration of 35-45 µg/m^3, which is enhanced by the airport to give a local background of 70-80 µg/m ^{3}, and further enhanced close to the motorways to levels of 110-210 µg/m^3, and again to 120-130 µg/m^3 on the airfield perimeter.

51. Analysis suggests that the direct emissions from the airport contributes about 30 µg/m^3 (just over 25% of the total) to the annual mean NO_X concentration at the airfield boundary (north east side). This falls to about 6-10 µg/m^3 (or 8-14% of total) by a kilometre further downwind. Further away, the airport sources can be detected at least 2.8 kilometres from the airport.

52. Extracting monitoring data related to the daily switching in the use of the northern runway and southern runway for take-offs to the west, shows that aircraft emissions during take-off make a significant contribution to concentrations at the airfield boundary. This also shows that during periods of stronger winds (>6 m/s), the aircraft contribution reduces by a factor of 10 between a close monitor (~200 metres from the centre of the runway) and a distant monitor (over 1200 metres) in a transect to the north of the northern runway.

53. Confirmation of the influence of aircraft emissions can also be determined by considering the variation in NO_X concentrations with day of the week. Whilst road traffic emissions are generally much lower at weekends, aircraft emissions remain relatively constant throughout the week. Sites which are strongly influenced by road traffic emissions demonstrate much lower NO_X concentrations at weekends.

54. Bivariate pollution roses strongly suggest that the aircraft emissions of nitrogen oxides behave as a buoyant source. This is consistent with the pattern of concentrations due to on-airport sources showing an unusual dependence on wind speed. Concentrations do not show a strong decline as wind speed

increases, as would be expected for a ground level non-buoyant source. Strong winds are therefore still associated with significant contributions from the airport. This has an important implication for receptors to the northeast of the airport, as not only do the predominant south-westerly winds blow emissions in this direction, but there is also a greater probability of high wind speeds from this direction. The areas to the northeast of airport will therefore register the largest contribution from aircraft.

55. For NO_X and NO_2, additional fast-response monitoring was also undertaken next to LHR2, the site close to the airport perimeter and the northern runway take-off area. Short-lived high concentrations of NOx were observed, rising to over 1000 $\mu g/m^3$ as a 10 second average. In contrast, when the southern runway was being used for take-offs, short-lived peaks at LHR2 were only a few tens of $\mu g/m^3$. This illustrates that the plumes from aircraft using the northern runway are still very coherent at the airfield boundary.

56. The general picture for PM_{10} concentrations in the area around the airport is of annual means of 24-25 $\mu g/m^3$. This compares to regional background concentrations in similar parts of London away from the airport of about 21-23 $\mu g/m^3$. The local background enhancement from the airport related sources is therefore much lower than for NO_X, at about 1-2 $\mu g/m^3$. Concentrations measured close to major roads (LHR10) and the airport (LHR2) are about 28-30 $\mu g/m^3$.

57. At the north-eastern airfield boundary, the direct airport contribution is around 1 $\mu g/m^3$ (about 3% of the total). Thus, whilst PM_{10} is subject to additional uncertainty compared with NO_X, due to the difficulties in measuring PM_{10} concentrations, it is confidently concluded that airport contributions to PM_{10} are very low.

How do air quality models determine the contribution from different sources of emissions?

Summary

- **Emission inventories provide dispersion models with data by source, location and time.**
- **Panel 3 has not generated the inventory, but provides detailed recommendations on how best to set a 'bottom-up inventory', and associated uncertainties.**
- **Reviews of previous inventory work used to define relative importance of each source and level of detail needed in inventory.**
- **With focus on annual average concentrations, the inventory can use 'representative' diurnal and seasonal profiles for sources.**
- **Panel 3 inventory specifically designed to generate data for base and future years over a long period (from 2002 and 2030).**

58. Air quality models are able to determine the proportion of pollutant concentrations which are attributable to each source type, rather than just

relying on a simple proportionate split based on emissions. The ability of any particular model to apportion concentrations in this way is a function of the setup, the number and type of separate processes within the overall model and, of course, the initial input data to the dispersion stage: as calculated emissions and as activity data. In other words, the emission inventory.

59. Emission inventories are the means of quantifying emissions of key pollutants from different sources in different locations over different times. Heathrow is the focus of this inventory and the aim of Panel 3 has been to make recommendations on the quality, accuracy of, and best methodologies to quantify emissions at and around the airport, so as to reflect their contribution to local air pollutant concentrations. The remit of Panel 3 clearly could not include the identification of a sharp spatial boundary to the inventory (particularly as the dispersion model to be used was not known until Panel 3 had itself completed its work).

60. By its very nature, a complex inventory such as that required for PSDH is not readily summarised here. The individual recommendations from Panel 3 are simply listed in Table 1.1. However, the reader is strongly encouraged to refer to Panel 3's report in chapter 3, which explains the detail behind the recommendation including, for each source group, detailed methods and data sources to quantify the mass of pollutants emitted by that source over a given time period. This approach is usually described as a "bottom-up" inventory and uses activity data or measured emissions data related directly to each source category to calculate the relevant emissions. By its nature a "bottom-up" inventory provides the key data needed for source attribution, namely separate emission estimates for each source category.

61. Panel 3 concluded that the following sources needed to be included in any Heathrow emissions inventory:

- Aircraft during ground operations and in flight during landing and take-off, including APU operations, brakes/tyres and ground engine test emissions;
- Airside vehicles and aircraft ground support equipment;
- Road vehicles on airside and landside roads (including non-airport related traffic);
- On-airport car parks, bus stations and taxi queues;
- Airport and off-airport heating and boiler plant;
- Airport fire training exercises; and
- 'Rest of London' and other background sources as input to the study area.

62. Some of the sources in this list clearly have an insignificant impact on air quality, and are generally only included for completeness. This includes engine testing and fire training, and even heating plant (in terms of ground level concentrations).

63. Within each overall source category there are individual sources (such as a single heating plant) or there may be various degrees of aggregation (such as a car park) depending on the complexity of that source and its relative significance to source contribution. The level of detail applied to each source

category determines the level to which the emissions can be attributed to individual sources or source groups. In Panel 3, information on previous inventory work has been used to recommend the relative importance of the source contribution needed for the Heathrow area modelling post-Panels.

64. To enable the emissions inventory to be used in a dispersion model, the emissions data need to be described spatially, both in terms of the geographical location of the sources and their dimensions. In some cases, the methodology used for calculating emissions starts from spatially disaggregated activity data and so the spatial distribution of emissions emerges naturally. However, in some cases the methodology leads only to a total emission and a way of spatially disaggregating the emissions has to be devised, making use of a surrogate variable.

65. The temporal variation in emission source strength is clearly also necessary to determine relative source contributions in a dispersion model. Each source or source group may vary according to a different temporal pattern. In principle, it is necessary to provide hourly variations to emissions to correlate with the hourly meteorological basis of the dispersion model - but in practice 'representative' diurnal and seasonal profiles for each source category may be sufficient. This is especially true when the modelling is focused on long term criteria such as annual mean concentrations.

66. Finally, both spatial and diurnal variations in emission source attribution would be expected to change year on year. The emission inventory approach developed in Panel 3 is specifically designed to allow data to be generated for both a base case and several future years (in the case of Heathrow Airport from 2010 to 2030). Obviously the source attribution would change over these time periods through relative changes in activity and emission factors between source types.

What are the principal uncertainties in Emissions Inventories?

Summary

Overall

- **3 key areas; aircraft; airside support vehicles, and surface access traffic.**
- **Overall estimate of uncertainty from inventory - outside Panel remit.**

Characterisation

- **Sources of NOx emissions better characterised than PM.**
- **Inventory methods for NOx less uncertain than for PM.**
- **NOx estimates from aircraft more certain than for road transport or airside sources**

Activity Data

- **More robust for aircraft than for airside, than for surface access.**
- **Alternative methods for airside estimates remain unclear in effect.**
- **Manage surface access uncertainties by ranking the relative importance of traffic parameters to air quality modelling at Heathrow.**

Emission Factors

- **More robust for aircraft than for surface access, than for airside.**
- **Increased uncertainty in future, in same source type order.**
- **Use of improved roads emission factor dataset, to account for large effect of technology charges over time.**
- **Off-road airside vehicle emission factors have considerable uncertainty.**

Time and Space

- **More robust for aircraft than for surface access, than for airside.**
- **Aircraft sources most sensitive to airport operating scenario.**
- **Surface access sources sensitive to generally limited time period traffic modelling.**
- **Airside vehicle location data is necessarily coarse.**

67. It is important to understand the nature and extent of uncertainties in the emission estimates, both in individual sources and in the overall inventory, if the results are to be understood in terms of their total and relative impact on ambient concentrations.

68. Where, possible Panel 3's report (chapter 3) includes expert judgements of uncertainty both in the emission estimation methods and the base data (i.e., activity data and the emission factors) for each source or source group, both for NO_X to NO_2 and for particulate matter. These are intended as best estimates of the overall uncertainty in each source group and were made by expert members responsible for developing the emission estimation methodology for that source. However, the quantification of uncertainty across the inventory, and its expected effect on final dispersed concentrations, is well outside the remit of the PSDH Panels. Indeed, it would only be possible once the inventory had been built.

Pollutant characterisations

69. In general, sources of NO_X emissions are better characterised, and hence inventory methods for NO_X are less uncertain, than inventories for particulate matter. This is particularly true for aircraft sources where there are currently few data on particulate emissions either in terms of mass or size distribution. However, emission estimates of aircraft source groups are generally more certain (particularly for NO_X but less so for particulate matter and speciated hydrocarbons) than those for road transport and other airport airside sources. This is due to the detailed records available to characterise activity data, and the certification data available for the vast majority of aircraft engines.

70. In general uncertainties in emissions inventories can be grouped into three key areas, irrespective of source types:

- Activity data
- Emission Factors
- Spatial and temporal representation

71. The levels of uncertainty increase with future projections in all cases.

Activity data

72. Panel 3 is reasonably confident on the robustness of aircraft movement data for the base case year. These data are available from the airport operator, BAA, who can account for all aircraft movements including the type. Other databases are available to assign engine type to those aircraft movements. In addition, aircraft engine power settings during the operational cycle (landing, take-off, climb and taxiing and reverse thrust) are generally well characterised and are based on engine thrust settings defined by actual flight management data from operators.

73. Relatively, surface access movement data are significantly less robust and rely on a combination of traffic modelling and count data - both of which are subject to different uncertainties. There is a higher degree of uncertainty in the fleet composition from traffic models (e.g., the split between vehicle types such as passenger cars, light goods vehicles and heavy goods vehicles) and higher uncertainties in other traffic variables important to air quality but not necessarily to traffic modelling (such as the characterisation of speed, queues/delay, and especially details of transient operations important for NO_X production in modern vehicles). Panel 3 suggests that road transport activity data account for probably the highest degree of uncertainty (accounting for scale of emissions from this source type) within the airport and local area inventory. To assist in addressing this situation, coverage and understanding of traffic uncertainties has been improved by Panel 3 being able to establish the order of relative importance of traffic parameters (variables) to air quality modelling at Heathrow, so focusing effort where most needed.

74. Airside vehicles, movements and duty cycles, are likewise difficult to quantify. Panel 3 has used its best endeavours to interrogate data collected by BAA to try and identify a more robust procedure for estimating airside emissions. However, the available relationships between activity and emissions for this source type are sparse, and within the timescales of PSDH it is unclear whether the proposed methodology would be available. In any event, Panel 3 has endeavoured to improve the resolution of the standard fuel-based approach to airside, to reduce the inherent uncertainty.

75. For other relatively minor sources such as power plant and fire training exercises, Panel 3, given the time available, has endorsed previous methodological approaches to estimating activity data.

Emission factors

76. Emission indices for aircraft engines are defined by the International Civil Aviation Organisation (ICAO), for NO_X and less precisely for particulates. The judgement of Panel 3 (see evidence in chapter 3) is that these factors are a good reflection of emissions at predefined engine settings in standard ambient conditions for the certified pollutants. Interpolation between the predefined settings to obtain emissions is also reasonably well understood. The Panel expert view is that uncertainties in aviation emission factors for the current case are reasonably low.

77. For future years, emissions factors for aircraft operating up to 2030 will be less well defined. However, commercial aircraft have a long service life and many of the aircraft types flying now may still be operating in 2010, 2020 and potentially even 2030. Compared to other transport modes, technical progress in aircraft emissions is relatively predictable, a result of the constraints imposed by flight safety and the large investment costs involved. Using evidence from current research programmes together with aircraft fleet calculations allows emissions estimates to be made for the future.

78. Road transport emission factors are based upon measurements from samples of vehicles, tested over a variety of standardised test cycles, covering a range of average speed operational conditions. These emission measurements are subsequently grouped by vehicle classes (age, engine size or weight, legislation class etc), and average speed-related emission functions derived. These emission functions mask significant variability, which can typically be between +/- 20% to 50% of the mean value. Unfortunately, of all pollutants, the masked variability is highest for NO_X emissions.

79. The existing UK road transport emission factor database was last updated in 2001, and by 2006 excludes a lot of emission data collected since then in relation to newer vehicles. Panel 3 recommends that the latest data on vehicle emission factors must be incorporated into the inventory, otherwise future year estimates would have excessive uncertainty. In addition, assumed emission factors for technologies yet to reach the market undoubtedly introduce additional uncertainty.

80. Emission factors for road-going airside vehicles are equivalent to those for road transport, and are determined to have largely the same uncertainties. For off-road airside vehicles/ plant, emission factor uncertainties are considerable, including additional uncertainties if converting emissions to a factor related to the amount of fuel used, on scaling factors to correct for changes in fuel sulphur content, and generally poor data on off-road airside fleet replacement rates. The view of Panel 3 is that uncertainties in emission factors for airside vehicles are the largest of all source types at Heathrow.

Spatial and temporal representation in emission inventories

81. The remit of Panel 3 clearly precludes the identification of a sharp spatial boundary, which would have allowed a tighter focus on requirements than has been possible.

82. The position of individual aircraft on the apron, taxiway or runway or when on approach and during take-off and initial climb can in principle be known with a high degree of certainty from ground radar data. Consequently, Panel 3 is reasonably confident that the spatial and temporal representation of aircraft emissions for the **current** airport layouts can be well characterised.

83. The temporal distribution of surface access emissions is more problematic. The key is that traffic models rarely cover the 24-hour 7-day a week situation that air quality must address, and so the diurnal profile and weekday/weekend situations are often poorly covered (for example when compared to aircraft movements). The key to better surface access data for air quality is early involvement with parallel traffic modelling studies - as air quality requirements are often beyond the needs of the traffic planners/engineers. Traffic data for air quality purposes is often a combination of traffic model outputs and additional processing of these outside of the traffic model. Panel 3 experts have met with the surface access workstream regularly.

84. Airside vehicle movements are also problematic to define within a spatial and temporal context. Although there is a clearly defined airside road network within the airport it is impracticable to assign vehicles and support equipment to them with a high degree of spatial resolution (for example, the rate of use of such vehicles at Heathrow is better known than previously, but the precise locations visited within the airport is still poor).

Table 1.1 Summary of detailed recommendations for the Emission Inventory

Source and type	Recommendation
Aircraft emissions	
ICAO engine emission factors	Pending further advice from CAEP, the fuel flow curve fitting method should be used. If fuel flow data is not available, suitable power (HC and CO) and polynominal (NO_X) fits are recommended and should be used.
Use of Characteristic vs Average Values	Average Values from the emissions databank should be used for the NO_X and particulate emissions inventory.
Effect of ambient conditions	The NO_X factors are based on a reasonable interpretation of the best publicly available information and should be used in generating new inventories. No ambient condition corrections are recommended for particulate emissions.
Effect of forward speed	The same method adopted for ambient conditions is also applied to take-off, assumed to take place at 150 kts. Factors

	can be supplied for each engine in the ICAO Emissions Databank. These can be applied to each individual flight according to engine fit. Spatial allocation of the increased emissions should be applied as a function of the take-off roll in accordance with Figure 3.3.
Climb-out and Approach	Generic factors have been derived for emission fluctuations resulting from engine deterioration: a 4.3% increase in fuel flow during the LTO cycle compared to ICAO databank values; a 4.5% increase in NO_X emissions compared to ICAO databank values. These percentages should be applied to the ICAO databank values to account for engine deterioration.
Engine start and transient emissions	NO_X and particulate emissions from engine start-up, shut down and transient operation are negligible and should be ignored for PSDH inventory purposes.
Primary NO_2 emissions	Based on the available data, the mean value by category in Table 3.3 should be used for assessing primary NO_2 emissions from aircraft engines. If sensitivity studies are required on primary NO_2 proportions, then the extreme values should be used.
Future aircraft	To provide technology forecasts for engine emissions capability through to 2030, an independent review should be carried out using Panel 3 guidance and informed by input from industry, specifically manufacturers and major Heathrow airline operators.
Times in mode	Using runway occupancy survey data obtained specifically for Heathrow Airport operations for take-off and landing rolls; survey data collected by NATS for taxi-out and hold, and taxi-in times; and data from the Heathrow NTK system for take-off to 1,000 feet and the airborne acceleration and climb phase from 1,000 feet to 3,000 feet.
Reduced thrust take-off to power cut-back	The average take-off thrust setting should be considered as the same percentage reduction, as the average take-off weight as a percentage reduction of the Performance Limited Take-Off Weight. Values for representative types from BAA. For aircraft operators and types not identified by the above source, the following process should be used:- 1 if data is not present for a specific operator, but is for operators of exactly the same aircraft/engine combination, then the mid point of the range of values for this aircraft/engine of the other operators should be used; 2 if data is not present for a specific operator, but is for operators of the same aircraft type, then the mid point of the range of values for this aircraft type with different engines of

	the other operators should be used; 3 if data is not present for a specific operator, and is not available for operators of the same aircraft, then use a representative value at the centre of the range of values for aircraft with the same number of engines, except for the BAe146 and developments with 4 engines, where the maximum reduction of 25% should be assumed. The above procedure is considered appropriate for re-calculation of the 2002 emission inventory. For future cases 5% should be added to the take-off thrust where there are uncertainties due to missing data. At the beginning of the take-off run, there is a delay of between 3 - 10 seconds before the engine reaches the maximum take-off thrust, used for the departure. This is due to engine inertia, control system effects and the thrust setting procedures used by the pilot in command. Fuel flow data obtained for a variety of aircraft and engine types during the take-off run have been averaged to provide revised thrust, fuel flow and emissions time histories for the start of the take-off roll.
Reduced thrust acceleration, clean-up and climb	Based on the take-off thrust level, the climb thrust should be approximated as: • CLB (85%) for take-off power levels between 100% (full) and 90%; • CLB1 (78%) for take-off power levels between, 90% and 80%; • CLB2 (70%) for take-off power levels between 80% and 75% (minimum take-off thrust). For the few types that are certificated to use take-off power levels less than 75%, the climb thrust should be assumed to be the same as for the take-off. Climb profiles can be taken from radar data for each type, though these may be simplified for groups of particular aircraft types, especially as ATC normally impose a speed restriction of 250 kts below 10,000 feet. Aircraft tracks will follow the individual NPRs at the airport, and movements of each type can be apportioned to each SID using track-keeping statistics.
Final approach and landing roll	For modelling purposes, the aircraft trajectory is well defined as the 3° glideslope, and power levels of 15% of the full

	rated sea level static thrust (F_{00}), for the 160 kts phase down to 2,000 feet, with an increase to 30% F_{00} at this altitude to the touchdown point. The speed at touchdown can be assumed as 150 kts for Category 'D' aircraft, 130 kts for Category 'C' aircraft, and 110 kts for Category 'B' aircraft.
Reverse thrust operation	For modelling purposes, it would seem reasonable to assume that reverse thrust can be treated as being at the 'idle' power setting for 60%, i.e., for the majority of operations at Heathrow. This can be further split into the frequency of reverse thrust used by individual aircraft types. Analysis of the worldwide operations of one airline in relation to Heathrow, suggests that the maximum thrust levels recorded during reverse thrust operations when reverse power has been used, is at <50% of the full rated thrust (F_{00}). Further analysis using FDR information, suggests that the average level used at Heathrow was about 30% of the full rated thrust (F_{00}). As a result for modelling purposes, it would be appropriate to use a level of 30% F_{00} for a duration of 19 seconds for the remaining operations.
Taxi thrust settings/techniques	For modelling, the lower power settings relative to ICAO, used during the taxi phase, result in lower fuel flows of about 15% to 20%, for most types, except for Rolls Royce powered aircraft where they are generally between 30% and 35% lower than the ICAO 7% 'idle' setting would suggest. As the NO_X Emissions Index varies little at these lower powers, it is recommended that NO_X production levels should be reduced by the same amount relative to the ICAO databank figures.
APU emissions	A revised APU Inventory approach based on TIM and load conditions should be considered in future Heathrow emission inventory studies, where sufficient manufacturer data are available.
Brakes and tyres	Provided the inventory confirms that brake and tyre PM_{10} emissions do not form a major contribution to the overall Heathrow particulate concentration, then the method based on landing weight is regarded as acceptable. If that is not the case, further data on wear rates and suspension rates for larger aircraft would be required to reduce the overall PM_{10} concentration uncertainty.
Engine testing emissions	Future NO_X estimates should be made by a simple scaling of emissions based on the 2000 analyses by the ratio of the total LTO aircraft (exhaust) emissions in 2000 relative to those for the year in question. For PM_{10} estimates will be based on the netcen method, scaling it in line with the new NO_X estimates. Engine testing makes such a small contribution to total NO_X and PM_{10} emissions, that it does not warrant a greater level of detail.

Airport airside emissions	
Airside vehicle types	For PSDH, subject to further ratification of available data, mileage information in the Airside Vehicle Permit Database should be used for estimating emissions of vehicles not involved in aircraft turnaround. Using vehicle age as a surrogate for engine emissions technology does not take into account instances where environmentally-enhanced vehicles have been purchased or vehicles retrofitted. However, any over-estimate arising from this is likely to be small. It is difficult to estimate the number of cold starts associated with light-duty vehicles airside. It is recommended that cold-start emissions from light duty vehicles are omitted. This is a minor omission compared to the hot-running.
Aircraft support vehicles and plant	Subject to robust emissions factor data being available, emissions estimates for aircraft support vehicles/ plant should ideally be derived using vehicle engagement standards, duty cycle emissions estimates and aircraft movement data. Manual observations of turnaround operations should be made, to ensure that idling and keyed-off time is correctly accounted for. For airside road vehicles, it is recommended that mileage data be used to estimate fugitive PM_{10}. For off-road vehicles associated with aircraft movements, fugitive PM_{10} may be derived by estimating total distances travelled during an aircraft turnaround.
Surface access activity	
Choice of traffic modelling approach	Overall, of the 4 traffic model types, 'mobility models' and 'econometric models' of traffic are inappropriate for use in PSDH air quality modelling. This leaves a choice of 'network flow models' and 'micro-simulation models'.
Modelled base year	Base year traffic data used in air quality models should be from the same traffic model as will be used in future year scenarios. The optimal base year for Heathrow air quality modelling is 2002, and so backcasting of HTM base year results is required, using matrix estimation.
Discounting construction effects	Construction effects on road traffic should be discounted in base and future year scenarios by applying derived adjustments (and before backcasting).
Road network extent	Network extent, link density, zoning size, and model boundary effects should be improved over previous work, using a 'network flow model' or an additional nested 'micro-simulation model' if justified from traffic model performance

	criteria.
Minor Roads	Minor roads should be included in the air quality modelling using the 'residue vehicle-kilometres per grid-square' approach as a minimum.
Scenarios and forecast years	Full traffic data required for each agreed scenarios and forecast year, to allow proper comparison of proposed operations at Heathrow.
Diurnal profiles	Many aspects of Heathrow operations and associated traffic are untypical, and this needs to be reflected in traffic modelling data for air quality. Where feasible, traffic modelling should seek to maximise the proportion of the day modelled, given air quality requirements. Subject to testing, the 'binning' method (or an equivalent) for deriving weekday diurnal traffic profiles should be used to ensure that air quality data can reflect the 'every hour of every day' required in dispersion modelling. This should be undertaken separately by road type, where feasible.
Weekend	Separate account of weekend traffic conditions are required for air quality purposes, especially given activity levels at the airport. Derived weekend profiles should where feasible use the 'binning' method (or an equivalent), and should be made relative to weekday modelled periods.
Fleet and composition - by purpose	If feasible, traffic inputs into the air quality model should differentiate vehicle fleet by purpose-based sub-fleets: such as airport-related traffic and non-airport related traffic.
Fleet and composition - by vehicle type	Traffic model vehicle type composition needs to be as broken down as much as possible, to minimise the uncertainty in subsequent fine detail breakdowns by exhaust emission legislation groups in the vehicle fleet emission modelling.
Defining heavy duty vehicle proportions	The pedigree of the HDV count data should be checked before use. If it is thought to be lacking, classified counts should be carried out on key roads near Highways Agency automatic counters to ascertain a more accurate figure for calibration of the base case model. The HA ATC data can then be used to generate a factor to convert 12 hour proportions to those over 24 hours.
Vehicle Speed	Vehicle speed is an important determinant of emissions, and there is a body of speed data sources outside of traffic models that could be used to generate speed-related diurnal profiles by road. Vehicle speeds must be scenario and forecast year responsive.
Validating modelled speeds	Data held in the journey time database should be used to assist in validating the base year speed data provided by the traffic model for relevant roads for the periods modelled.

Road traffic queues	Queuing data should be included in the air quality modelling, where available and where data are expected to make a demonstrable difference in resultant surface access-related concentrations. The false link, add-on additional emissions approach to be used, where practicable.
Road vehicle emission rates	
Deriving vehicle emission factors	Whilst there are distinct advantages for the use of instantaneous emission factors for spatial and temporal resolution of emissions and subsequently predicted air quality concentrations, the limited availability of suitable input data restricts their immediate use. It is recommended that the average speed emission modelling approach is adopted. However, since the release of the last UK road transport emission factors in 2001, new emission data has become available from UK and international test programmes. These results, combined with the latest forecasts of fleet composition, should be employed within the PSDH programme.
Road traffic emission technology developments	Consider both the high and low scenarios for Euro V and Euro VI. Future standards may be modelled by scaling Euro IV and V (heavy duty vehicles only) emissions factors. In addition certain technologies will imply other changes in modelling assumptions - emissions standards leading to the adoption of catalytic de-NO_X after treatment systems (e.g. Lean NO_X Traps or Selective Catalytic Reduction) on light duty diesel vehicles will require changes to the assumptions for diesel cold start emissions; - systems using consumable reagents (e.g. Selective Catalytic Reduction) may need to assume that a proportion of systems are not refilled with reagent and hence exhibit elevated emissions levels.
Primary NO_2 emissions on roads	It is necessary for models to have the ability to account for primary NO_2 by source type. Primary NO_2 emissions will have their greatest impact close to the source i.e. roads. However, to model future scenarios explicitly it would be first necessary for primary NO_2 emissions inventories to be developed.
Emissions associated with trip-ends	Air quality modelling to reflect trip end-related additional emissions,using airport car park data, mode split model data relating to passenger trip end types, and airport employee-related trip ends. Levels of disaggregation would depend on output options in the wider surface access modelling suite.
Primary PM10 emissions from non-engine sources	Brake and tyre wear emissions of PM_{10} from road traffic should be included, using emission factors broken down by basic vehicle types (such as those in recent COST346 work). Further research on brake and tyre wear emissions data disaggregated by relevant road types is recommended

	outside of PSDH, as fugitive emissions are expected to vary noticeably by road type.
Other sources of emissions	
Heating Plant	Emissions from a given heating plant (g/year) should be calculated as the product of the total amount of fuel used (of each type, if more than one type), expressed as the energy equivalent of the fuel in MJ/year, and an emission factor (g/MJ).
Fuel consumption	Fixed by category of plant, using historic data.
Fire-training ground emissions	Negligible.

What dispersion models have been compared?

Summary

- **Comparison between netcen ADMS-bespoke v EDMS-Aermod v ADMS-airport v ERG London Toolkit Airport Model v Lasport.**
- **Common inventory and meteorological data to aid comparison.**
- **Standardised criteria used.**

85. Output from five models was analysed and examined exhaustively in a structured and controlled model inter-comparison exercise. Pollutant concentrations were modelled based on aircraft-related emissions, including those from airside support vehicles, as well as on emissions from road vehicles around the airport and from background sources. The models include descriptions of pollutant transport by dispersion and advection. Four of the five models used were based on Gaussian dispersion, while the fifth (Lasport) used a Lagrangian particle approach. Short descriptions of the models are given below (for more information see chapter 4):

- netcen used their own netcen airport air quality dispersion model platform that was used, in an earlier version, in SERAS. The model is based on ADMS3, a Gaussian dispersion model widely used for urban modelling. Near field effects in the dispersion of aircraft emissions were included through an initial spread of the plume. NO_X dispersion was directly modelled and the NO_X to NO_2 conversion was determined via an empirical correlation developed by netcen (AQEG 2004).
- Cambridge University used EDMS, which is the required FAA model for air quality assessments of airports. The dispersion model it uses is the US Environmental Protection Agency's AERMOD, an advanced Gaussian Plume model, which accommodates terrain features and parameterizes the trajectory and mixing of the aircraft jets, including the effects of momentum and buoyancy, using recent LIDAR measurements in the USA. The model was modified to accommodate the emissions and meteorological data for the inter-comparison, but some aspects, e.g., engine fuel flow rates, were 'hard-wired' in

the model and could not be readily changed. The conversion from NO_X to NO_2 was based on a UK empirical approach (Jenkin 2004).

- Cambridge Environmental Research Consultants (CERC) used ADMS-Airport, which is an extension of ADMS-Urban using a jet model to represent aircraft sources. This incorporates the speed of the aircraft, so that the effective momentum and buoyancy of the plume decrease with increasing speed. The effects of vortices were partially represented by displacing the jet sources downwards for the initial climb, as for LASPORT, in the sensitivity analysis. Chemistry was explicitly modelled.
- The Environmental Research Group (ERG) at King's College London used the Airport Model they have developed as an addition to their London Toolkit, based on ADMS-3 and extended to include aircraft jet sources modified empirically based on measurements. Engine speed was incorporated to determine LTO emissions while buoyancy was parameterised based on a wind speed analysis of monitoring data at LHR2. The determination of NO_2 from the calculated NO_X concentrations was empirical, using relationships developed by ERG across London and including primary NO_2. The effects of regional contributions to NO oxidation by ozone were accommodated empirically using methods giving similar results to that developed by Jenkin (2004).
- Manchester Metropolitan University (MMU) used LASPORT, a commercial Lagrangian particle model developed in collaboration with the German Airports Association. The model was run with three nested grids; the resolution of the central grid, describing the area of interest around Heathrow, was 50 metres. The aircraft plume model accommodated mixing and thermal characteristics and incorporated the downward projection associated with wake vortices following rotation. NO_X concentrations were converted to NO_2 using the Jenkin (2004) method.

86. All models incorporated a rural background component based on one or more rural monitoring sites outside London. All models used the same emissions inventory and meteorological data to ensure that the inter-comparison focused on the dispersion elements of the models.

How good are the tested dispersion models around Heathrow ?

Summary

- **Modelling of plumes from aircraft during take-off and landing is not well established, including plume rise and effect of wake vortices.**
- **The fraction of NOx emitted as primary NO_2 is important - both for aircraft and surface access.**
- **It is not feasible to determine model uncertainty using** *a priori* **analysis of source contributions.**
- **Validation against monitoring data show typical accuracy of 10 - 20% for annual mean NO_2, with minimal bias, which is well within EU guidelines of 30%.**

87. A key issue is the representation of aircraft plumes, including the effects of the velocity of the jet, and its buoyancy related to its temperature. The majority of the pollutant emission associated with ground level receptors occurs during the aircraft take-off roll, prior to rotation. The presence of the ground limits the effects of buoyancy and the aircraft plume tends to stay closer to the ground, although LIDAR measurements show that plume rise through buoyancy is an important consideration, particularly under low wind conditions. A further issue is the effects on the plume of wake vortices produced by aircraft lift. These effects were investigated through LIDAR measurements, at Heathrow, of the aircraft plumes, based on aerosol scattering, undertaken as part of this investigation. Four of the five models used an empirical representation of these effects. The fifth (ADMS-Airport) modelled the jet more explicitly.

88. A further issue is the representation of the effects of airport buildings. These were accommodated through a surface roughness parameter for the airport as a whole, but for subsequent work can be reflected using variable surface roughness grids.

89. The transport of emissions to receptor points depends on the local meteorology, and projections of future concentrations require information about historical meteorological conditions to be used together with predictions of future emissions. Since the main pollutant of concern is NO_2, which is mainly a secondary pollutant formed from NO in the atmosphere, the models must also include a method for determining the amount of NO_2 formed from NO, either by directly simulating the chemistry (ADMS-Airport) or via an empirical correlation (the other four models). An important issue is the fraction of total NO_X (NO + NO_2) emitted as NO_2. This was typically 5% for road traffic, but is increasing largely as a result of the growth in diesel vehicles. In 2002, the primary NO_2 in London had risen to ~10% and is expected to continue to increase, at least in the near term, as the diesel component of the vehicle fleet increases. Primary NO_2 is also emitted by aircraft, with the fraction depending on the engine operating conditions. These changes in primary NO_2 affect the final concentration in a complex way, depending on the distance from the emission source. Future changes in the fraction may lead to uncertainties and bias in projections of NO_2, especially with some empirical approaches.

90. It was not feasible for Panel 1 to determine the model uncertainty from an *a priori* analysis of the contributions from the model components (such as emissions), because the required data were not available. Instead, it followed common practice and assessed the model accuracy through validation against monitoring data. This has been carried out in London, using data from a large number and range of urban monitoring sites, for ADMS-Urban and for the ERG London Toolkit model. These show accuracies in the range 10 - 20% for the annual mean NO_2, with minimal bias. The model inter-comparison indicates a comparable performance, well within the EU guidelines for modelled annual mean NO_2 of 30%.

91. The central component of the comparison and evaluation of the dispersion models was an inter-comparison based on 2002 data. The main air quality

objective at risk of exceedence is the annual mean NO_2 concentration, which was the primary target of the simulations performed in this analysis. Comprehensive tests of model performance can be more easily achieved with higher frequency outputs, so hourly mean outputs were also used where possible. The model outputs were compared at a pre-agreed number of receptor points and were also compared with analysed monitoring data from Panel 2. Source apportionment, as a means of examining concentrations deriving from airport emissions, and hence of testing near field dispersion of aircraft plumes, was a specific aim.

92. Receptor points were mainly chosen to represent measurement sites and a north-south transect from the northern runway to north of the M4. The transect usefully reveals important differences between the models such as the fall-off in concentration due to aircraft sources and near-road concentration profiles. In addition, contour plots for NO_2 and NO_X concentrations were calculated.

93. Source apportionment was carried out for the following source categories:

- Aircraft sources. These were assumed to include all emissions associated with aircraft operations.
- On-airport non-aircraft sources. These were assumed to include all other sources on Heathrow Airport within (but not including) the boundary road.
- Road transport sources.
- Other sources. This included an assumption for rural background concentrations and other modelled London sources such as domestic gas combustion.

94. In addition, the modelling groups were requested to run a simple scenario which involved removing all aircraft sources in order to test the model response to a change in NO_2 concentration.

95. All models were rigorously examined as part of the inter-comparison. The following Table 1.2 summarises the common tests used. In addition to comparisons with monitoring data, several fitness for purpose criteria and diagnostic tests were carried out to help assess model performance. A summary of the results for each model may be found in Table 4.6 in chapter 4.

Table 1.2 Summary of the comparisons made between models

Criterion	Description	Purpose
Scatter plots	Comparison of annual mean predictions against measurements of NO_X and NO_2	To compare how well the models do against measurements. Some indication of the uncertainty of the model predictions can also be gained.
Wind speed dependence	An estimate of the wind speed dependence of NO_X measurements at LHR2 with background concentrations removed to	Data analysis work showed that the wind speed dependence of aircraft sources is markedly different to typical ground-level sources e.g. road transport. This diagnostic test provides an indicator of

	provide an indication of the airport contribution.	how well the models treat the dispersion from aircraft sources.
Polar plots	Bivariate pollution roses derived from NO_X, wind direction and wind speed. Plotted as a surface with background removed. Derived for LHR2.	A diagnostic test that aims to highlight the wind speed and wind direction dependence of predicted concentrations with measurements. This is a qualitative diagnostic test and is effective at representing the variability of NO_X concentrations with wind speed and direction.
Contour plots	Surface predictions of annual mean NO_X and NO_2.	Used to highlight spatial patterns in predicted concentration.
Transect plots	Predicted NO_X and NO_2 concentrations for receptor points forming a line north of the northern runway.	Used to compare the fall-off in concentration for different source contributions e.g. road vehicles, aircraft, non-aircraft and airport sources.
Runway alternation	Measurements or predictions of NO_X at LHR2 extracted to reveal aircraft taking-off on the northern or southern runway.	This diagnostic test potentially reveals some important aspects of airport emissions. First, it provides and indication of the dilution over two different distances i.e. from LHR2 to the northern (180 metres) or southern runway (1600 metres). Second, the assessment is made by hour of the day, which incorporates a wide range of atmospheric conditions e.g. more stable conditions at night.
Future NO_2 and ozone	Models need to account for primary NO_2 changes (by source type) and potential changes to background ozone.	There is increasing evidence that primary NO_2 emissions are increasing and it is important that models can account for this. Similarly, background concentrations of ozone could be increasing and this would affect NO_2 concentrations

Is there a recommended model or models?

Summary

- **ADMS-Airport should be used for the main modelling work at Heathrow.**
- **Possible use of Lasport as sensitivity test of using a different atmospheric transport framework.**
- **Possible use of netcen model for audit trail purposes back to White Paper, if required.**

96. Panel 1 was in full agreement in the recommendation of the CERC model ADMS-Airport for future modelling work at Heathrow It fulfils all of the fitness for purpose criteria, and was the best performing model for each of the comparison criteria listed in Table 1.2.

97. Like the other models, ADMS-Airport is demonstrably better than the pre-White Paper approach, as shown through the comparison against measurements in the model inter-comparison.

98. The following performance was found for ADMS-Airport against the specific criteria:

- Scatter Plots - gave the best overall agreement with the measurements.
- Wind speed dependence - concentrations too high at low wind speeds (< 2 m/s) but gave better agreement with data than the other models.
- Polar plots - showed the best spatial pattern, although it over-predicted at low wind speeds.
- Contour plots - appropriate and acceptable resolution, e.g. around roads.
- Transect plots of the aircraft contribution - predicted results are closest of all the models to the estimates derived from the measurement analysis.
- Runway alternation - comparison with the measured diurnal profile at LHR2 is very good for take-off on the northern runway, but less good for landing. Its performance was better than that of the other two models that could be tested against this criterion.
- Future NO_2 and O_3 - models chemistry explicitly, so issues arising from changes in primary NO_2 and background ozone can be accommodated.
- Panel 1 discussed the possible use by the DfT of additional models. It was agreed that some limited use of LASPORT could be useful to test the effects of a different atmospheric transport framework (Lagrangian vs. Gaussian) as a sensitivity test, given its extensive use for European airports. Limited model runs using the netcen model may also be appropriate to provide comparisons with earlier analyses, for audit trail purposes.

How can the recommended dispersion model be improved?

Summary

- **Characterisation of aircraft plumes.**
- **Repeat diagnostic tests and expanded uncertainty analysis using emission inventory generated following Panel 3.**
- **Testing the sensitivity of the model to : likely range of emissions uncertainty, future meteorology, behaviour of jet plumes, and future changes in primary NO_2 and background O_3.**

99. Further work is needed on the characterisation of aircraft plumes:

- The LIDAR data should be analysed as they become available to assist in determining the structure and development of the plumes arising from aircraft sources.
- Modelling studies, along with LIDAR and laboratory observations, are needed to determine the range of conditions under which engine exhausts during ground-roll are likely to lift-off.
- Simple representations of vortex and plume motions during the initial stage of climb-out and the final stage of landing should be developed to examine their likely importance from an air quality standpoint.
- The appropriate level (the balance of complexity, accuracy, robustness and practicality, e.g., run times) of modelling for these processes should be reconsidered in the light of these results and any further research that is needed should be identified.
- Models should be used to determine the impact of the location of emission along the runway, and the associated uncertainty in their position, on the resulting exposure at critical receptor locations.

100. There is a strong need for appropriate experts from the PSDH technical panels to examine these issues, as data become available, to facilitate an improved representation of the aircraft plume in ADMS-Airport, if necessary.

101. A key element in assessing the accuracy of the model output is comparison with monitoring data. The diagnostic tests developed for the model inter-comparison should be useful in this regard. The larger number of monitoring locations, sited specifically to provide stringent tests of model output, should be particularly valuable. The established performance of ADMS-Urban provides confidence in the representation of concentrations of NO_2 from sources outside the airport by ADMS-Airport. Particular emphasis should be given to the modelling of airside sources in this validation exercise. The emissions inventories, developed from the proposals of Panel 3, will provide the basis for a fuller uncertainty analysis than has been possible in the work of Panel 1. Analysis of the sensitivity of the model output to likely ranges of uncertainty in model input, especially that related to emissions, to the future meteorology, to the behaviour of the jet plumes and to future changes in primary NO_2 and background O_3, will be essential.

102. As the model developer CERC is able to make modifications to the algorithms within the PSDH timescales, provided the changes specified are compatible with the basic formulation of ADMS-Airport and the jet model in particular. Effects that can be accounted for within the model framework include the influence of the ground on the jet through increased surface drag and asymmetrical entrainment, the possible convergence of the plumes, and the influence of an inhomogeneous velocity field resulting from wake vortices.

What future work will be undertaken to assess the impacts of future operations at London Heathrow Airport?

Summary

- **Implement the new approaches to emission inventories from Panel 3.**
- **Improve and test selected models to account for developments from Panel 1.**
- **Verification of final model against monitoring and activity data.**
- **Modelling of future year cases including: max use, mixed mode, third runway.**

103. The White Paper promised further work to:

104.

   a. review the data, knowledge and tools behind the assessments to date,
   b. see how best use could be made of the existing runways at Heathrow,
   c. see whether a third runway could be added in due course, whilst meeting key environmental conditions.

104. The work of the Panels covered item a, while items b and c will be done in further work following that of the Panels. Essentially the output of the Panel process is a review of what should be done and how. The work to follow will be carried out by DfT and will include:

- Collation and processing of recommended emission inventory data, both improved and changed activity data and updated/enhanced emission rate data
- Production of procedures to translate and enhance data in the activity-emissions-dispersion stages of modelling;
- Creation of specified Emissions Inventory. The inventory is to be generated for the base year and several future forecast years.
- Enhancement and sensitivity testing of selected model approaches to account for developments within the Panels (such as the improved parameterisation of initial dispersion using LIDAR results)
- Verification tests of the base year air quality model(s). This includes source attribution tests, uncertainty analysis and model performance statistics as well as comparison to monitoring and previous modelling work.
- Future year air quality modelling, potentially at 5-year periods from around 2010 to 2030 (dependent on other workstreams)
- Model assessment of the key future year cases:
  -
  - maximum use in segregated mode, within the existing constraints (as equivalent do- minimum)
  - mixed mode operation with existing runways (partial and full variants)
  - new short third runway to north of the existing runways
- Report back to Ministers after public consultation on how to make best use of Heathrow's existing two runways, and whether a third runway could be added after a new runway at Stansted, whilst complying with strict conditions on air quality.

Department for Transport

Measurements for Model Development

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Introduction and Panel 2 Objectives

1. The work of Panel 2 has been designed to meet the objective set out in the terms of reference to "examine the adequacy of measurements of airborne pollutants from different sources around Heathrow for the purposes of compliance with standards and verification of models." The specific objectives of Panel 2 have been:

- to define the existing air quality climate in the vicinity of the airport;
- to analyse the available data to help understand sources in the area and their dispersion; and
- to ensure that adequate monitoring data are available for the validation of the air quality modelling studies being carried out by Panel 1.

2. The following specific tasks were identified:

- to identify the pollutants of concern;
- to identify existing air quality monitoring around Heathrow Airport, including geographic coverage, methods, and data availability;
- to consider the adequacy of existing monitoring to describe both the current air quality climate and to provide information for a robust base year validation of the air quality models;
- to recommend any additional monitoring that might be required to fulfil the above objectives; and
- to undertake a detailed analysis of existing monitoring data in order to identify exceedences of the relevant air quality standards, specific source contributions, and trends in pollutant concentrations.

3. A number of specific reports were prepared to support the Panels' work, and this chapter takes account of the information in them. They have been included at the end of this report as:

- Annex 5 Key pollutants report;
- Annex 6 Investigation into the sources of air pollution;
- Annex 7 LIDAR study at Heathrow; and
- Annex 8 Air quality monitoring around Heathrow.

Pollutants of concern

4. One of the first tasks undertaken by the Panel was to determine which pollutants should be the main focus of the study. The possible pollutants were discussed by all the Panels. It was determined that a detailed review of the potential pollutants of concern should be carried out (see Annex 5), and that this review should focus on the nine health-related pollutants described in the national Air Quality Strategy (DETR 2000) and its Addendum (Defra 2003). The Panels did not identify any other local pollutants that needed to be addressed in the review. The task of the Panels was to address local impacts. Hence no consideration was given to pollutants with impacts at the global level, for example carbon dioxide and nitrous oxide. However it is recognised that when consideration is given to measures to limit local impacts it will be important to take account of the implications of these measures for other impacts, such as a trade-off between reducing nitrogen oxides emissions and potentially increasing carbon dioxide emissions.

5. Based on available monitoring and modelling data, the review concluded that benzene, 1,3-butadiene, carbon monoxide, lead, polycyclic aromatic hydrocarbons (PAHs) and sulphur dioxide were not priority pollutants, and did not require detailed consideration in this study:

- In the absence of local industrial sources, benzene and 1,3-butadiene are strongly correlated with road traffic emissions. Previous studies have measured relatively low levels of volatile organic compounds (VOCs) (including benzene and 1,3-butadiene) in the vicinity of Heathrow Airport, which are all well below the relevant health based standards;
- Estimates of PAH emissions from aircraft translate to extremely low concentrations around airports, orders of magnitude below the UK objective for the marker compound benz-a-pyrene. Road traffic is a relatively minor source of PAHs in the UK and concentrations near to roads are below the UK objective;
- Both monitoring and modelling for carbon monoxide indicate that levels in the vicinity of Heathrow Airport are likely to be well below the relevant health based standards;
- Lead is not added to aviation fuel, nor to petrol. Measured roadside concentrations are now very low; and
- Both monitoring and modelling demonstrate that concentrations of sulphur dioxide at Heathrow easily achieve all relevant health based standards. Fuel sulphur contents are unlikely to increase and for some fuels, such as airside diesel, may decrease.

6. The Panel 2 study has therefore focused on nitrogen oxides (NOX), nitrogen dioxide (NO2), particulate matter (PM) and ozone (O3).

7. Nitrogen oxides (NOX): This is the term used to cover the sum of two pollutants, nitric oxide (NO) and nitrogen dioxide (NO2) 1 . Nitrogen oxides are measured at an extensive network of sites monitoring in the vicinity of Heathrow Airport.

8. Nitrogen dioxide (NO2): This pollutant is emitted directly from combustion sources, although usually only representing some 5-20% of the total NOX. Importantly, it is also formed in the atmosphere from reaction of NO with ozone. There is an extensive network of sites monitoring NO2 in the vicinity of Heathrow Airport. These data indicate likely exceedences of the annual mean air quality objective at a number of locations. In addition, detailed modelling work carried out for the Terminal 5 and SERAS studies indicated that exceedences of the EU limit value in 2010 are also likely (DfT 2003b). This represents a key compliance hurdle that must be overcome if proposals for a third runway are to be taken forward.

9. However there are considerable uncertainties in these modelling studies, and one of the key priorities of the PSDH work has been to provide more robust predictions of NO2 concentrations in future years. The Panel 2 study has therefore focused its attention on NO2.

10. Particulate matter: Measurements of PM10 are carried out at a number of sites in the vicinity of the airport. Whilst these data indicate few current exceedences of the 24-hour air quality objective and EU limit value, predictions of PM10 levels in future years are subject to greater uncertainty than for NO2, due to the complexity of source contributions. In addition, it is likely that new limit values for PM, and PM metrics (such as PM2.5), will be introduced in future years. A limited assessment of both PM10 and PM2.5 has therefore been included in the Panel 2 study.

11. Ozone: Ozone is only measured at a limited number of sites in the Heathrow area. Whilst there are measured exceedences of the air quality objectives at these sites (see www.heathrowairwatch.org.uk), the principal interest is in relation to the role that ozone plays in converting emissions of NO, which is the predominant part of NOX emissions, to NO2. Account also has to be taken of the photochemical reactions controlling the balance between NO2 and ozone. An understanding of this chemistry is fundamental to the prediction of NO2 concentrations in future years. Ozone has therefore also been included in the data analysis.

Base year

12. Early discussions were held by the Panels as to which year would be appropriate for the model inter-comparison study. It was agreed that 2002 would be the most appropriate year for a number of reasons, as set out in Chapter 3. In this Chapter data for all available years are presented to help put 2002 into context and to allow an analysis of trends.

[1]The term nitrogen oxides, when used in local air quality assessments, does not include nitrous oxide (N2O), which is a pollutant of concern due to its global warming contribution.

Air quality criteria

13. As set out above, the principal pollutants of concern in the vicinity of Heathrow Airport are NO2 and particulate matter (PM). Air quality criteria for the protection of human health have been established for both pollutants.

14. At the European level, the Air Quality Framework Directive (96/62/EC) provides a strategic framework for tackling air quality by the setting of air quality limit values for a number of air pollutants. The limit values related to NO2 and particulate matter (PM10) are set out in the first air quality daughter directive (1999/30/EC). This directive sets limit values for hourly and annual mean NO2 concentrations that must be achieved by 2010, and for 24-hour and annual mean PM10 concentrations that must be achieved by 2005. The directive includes recommendations for monitoring of PM2.5 concentrations, but no limit values have been set.

15. The directive also contains indicative Stage II limit values for 24-hour and annual mean PM10 concentrations to be achieved by 2010. These indicative limit values have no legal standing and are currently under review as part of the European Commission's Clean Air for Europe (CAFÉ) Thematic Strategy, which was published in September 2005 (European Commission 2005b) (see below).

16. At the UK level, air quality objectives for both NO2 and PM10 have been established. These were first defined within the former National Air Quality Strategy (DoE 1997). The objectives for NO2 are set at the same concentration as the EU limit value, but are to be achieved at the earlier date of 2005. The CAFÉ Thematic Strategy does not propose any change to the limit values for NO2.

The national Air Quality Strategy objectives for PM10 have been revised twice: in the Air Quality Strategy in 2000 (DETR 2000) and more recently in the Addendum to the Strategy published in 2003 (Defra 2003). The latter sets out provisional air quality objectives (not incorporated into legislation) for London and the rest of England.

17. The limit values and air quality objectives for both NO2 and PM10 are set out in Table 2.1 and Table 2.2 respectively.

Table 2.1 EU Limit Values and Air Quality Strategy Objectives for nitrogen dioxide (NO2)

Legislation	Concentration	Measured as	Achieved by
EU first daughter directive - limit value	40 µg/m3	Annual mean	1 January 2010
200 µg/m3 with up to 18 exceedences per year	1 hour mean	1 January 2010	
Air Quality Strategy (2000) - objective	40 µg/m3	Annual mean	31 December 2005
200 µg/m3 with up to 18 exceedences per year	1 hour mean	31 December 2005	

Table 2.2 EU Limits and Air Quality Strategy Objectives for PM10

Legislation	Concentration	Measured as	Achieved by
EU first daughter directive - Stage I limit value	40 µg/m3	Annual mean	I January 2005
50 µg/m3 with up to 35 exceedences per year	24 hour mean	1 January 2005	
EU first daughter directive - Stage II indicative limit value	20 µg/m3	Annual mean	I January 2010
50 µg/m3 with up to 7 exceedences per year	24 hour mean	1 January 2010	
Air Quality Strategy (2000) - objective	40 µg/m3	Annual mean	31 December 2004
50 µg/m3 with up to 35 exceedences per year	24 hour mean	31 December 2004	
Air Quality Strategy Addendum (2003) provisional objectives - London only	23 µg/m3	Annual mean	31 December 2010
50 µg/m3 with up to 10 exceedences per year	24 hour mean	31 December 2010	
Air Quality Strategy Addendum (2003) provisional objectives - UK except London	20 µg/m3	Annual mean	31 December 2010
50 µg/m3 with up to 7 exceedences per year	24 hour mean	31 December 2010	

Note: PM10 concentrations are expressed in gravimetric units

18. The CAFÉ Thematic Strategy referred to above, has proposed a number of revisions to the existing directives. The Strategy recommends that the 2005 limit values for PM10 remain in place, but that the indicative 2010 limit values are replaced by a PM2.5 concentration cap of 25 µg/m3, to be achieved by 2010. An exposure reduction target for PM2.5 is also proposed, set at a 20% reduction between 2010 and 2020. This reduction target would be applied to the average concentration measured at urban background locations across a Member State.

Instrumentation and quality protocols

19. There are a variety of methods available for the measurement of ambient air quality. For the purpose of this review, the Panel has relied extensively on monitoring carried out using automatic analysers, operating in networks with a high level of

quality assurance/quality control (QA/QC). This was considered important to ensure the integrity of the data in describing the existing air quality climate and for validation of the base-case model.

20. The Panel also reviewed additional monitoring data, collected by non-automatic samplers. In particular, this included measurements of NO2 using passive diffusion tube samplers, carried out by both British Airways and the local authorities. Whilst these diffusion tube data are subject to additional uncertainty, they do provide a greater spatial analysis of NO2 concentrations around the airport.

21. The diffusion tube results are not presented in this report. In the review of these data it was concluded that the results largely supported those provided by the automatic analysers, giving greater confidence to the assumptions made for background concentrations, but that these data would not be useful for validation of the base-year model.

Nitrogen dioxide

22. The chemiluminescent analyser is widely used for continuous monitoring of NO2 concentrations in the UK. It is the reference method specified in the EU Directive (CEN 2005a). The instrument provides hourly concentrations of both NOX and NO2.

23. All routine automatic monitoring data referred to in this report have been measured using single chamber chemiluminescent analysers. In order to capture short-lived changes in concentrations due to aircraft plumes, a dual chamber fast response chemiluminescent analyser was installed at LHR2. This was calibrated in the same manner as the single chamber analyser, but in the event it produced un-reliable NO2 concentrations. It is not known why this was the case and the instrument performance will be investigated further. However, the average concentrations determined for total NOX matched the averages from the single chamber instrument, thus the fast response NOX results are considered sufficiently reliable to be analysed.

Particulate matter

24. The measurement of particulate matter (PM) in ambient air is not straightforward. There are a wide number of different techniques used but due to the very complex nature of PM the method that is selected for use can significantly influence the result.

25. The European reference method for PM10 is a filter-based gravimetric sampler (CEN 1999). A principal disadvantage of the method, aside from operational issues, is that the time resolution of the measurement is limited to 24 hours. The method is therefore not well suited to public reporting of data in real time, nor for detailed investigations of source apportionment and pollution episodes.

26. Monitoring of PM10 concentrations within the UK is therefore largely founded on the TEOM analyser. The instrument operates continuously and provides hourly concentrations of PM10. A principal disadvantage of the method is that it operates with a heated manifold (at 50°C) which causes loss of semivolatile components of PM, notably ammonium nitrate. The TEOM therefore tends to read lower concentrations in comparison to the European reference sampler. Pending the

outcome of equivalence studies that are currently being carried out by Defra, a default correction factor of 1.3 is applied to the data, as recommended by the EC Working Group on Particulate Matter (2001).

27. The PM monitoring data reported in this study are all based on the TEOM analyser. The PM10 data have been adjusted by the default correction factor of 1.3. No correction factor has been applied to the PM2.5 TEOM data, as there is no default adjustment factor available 2 . The PM2.5 concentrations will therefore be low, by an unknown amount, in relation to their gravimetric equivalent values. It will therefore not be possible to compare the PM2.5 data with the proposed EC targets.

28. The TEOM analyser uses a size selective inlet to remove the larger, unwanted particles before the concentration of PM is determined. Instruments may be equipped with either PM10 or PM2.5 inlets in order to make the required determination.

Ozone

29. Continuous monitoring of ozone concentrations in the UK is based predominantly on the use of UV photometry. It is the reference method specified in the EU directive (CEN 2005b). The instrument provides hourly concentrations of ozone. All monitoring data referred to in this report have been measured using UV photometers.

Quality assurance and quality control (QA/QC)

30. In order to draw robust conclusions from the measurements it is essential that a high standard of QA/QC is applied. The Panel has drawn on monitoring data collected from various networks, including those operated at a national level, and at a local level on behalf of the local authorities and BAA. Whilst there are inevitable differences in the detailed QA/QC activities applied in each network, the general principles used in the national networks have been applied in all cases. This includes quality assurance for the design, siting and calibration of the equipment and subsequent quality control for the validation and final ratification of the data.

31. The air quality Directives specify an upper limit for overall uncertainty for automatic measurements of NOX, NO2, PM10 and Ozone (expressed as 95% confidence limits), as follows:

- NOX and NO2 15% uncertainty
- PM10 25% uncertainty
- Ozone 15% uncertainty

32. These monitoring uncertainty values apply at concentrations around the limit value. They are **not** calculated uncertainty values but the limit that automatic monitors must be capable of meeting.

33. A common approach to determining the overall uncertainty of measurement data for these pollutants has been prepared by the European Centre for Standardisation (CEN 2002). Standards setting out how the national networks in each Member State should operate the equipment in order to achieve the required uncertainty have also been prepared recently (CEN 2005a). These documents describe detailed performance

characteristics, against which each analyser must be tested. They imply that measurement uncertainty can only be assessed on an individual site and instrument level, since the uncertainty will dependent on the results of type approval testing and on-going operational tests. The UK national air quality monitoring networks will need to be compliant with these standards by 1 January 2008.

34. At this stage there are no analysers in common use in the UK or Europe that have been put through a complete set of performance tests relating to this standard. However experience that has been gained from the Environment Agency's MCERTS scheme, which draws upon performance data published in the United States and other countries, suggests that modern gas analysers should be capable of conforming with the new CEN standards.

35. AQEG (2004) considered that it is likely that the great majority of measurements of NOX and NO2 in the UK network will meet the uncertainty requirements of the air quality Directives. Panel 2 expects that all data referenced within this report will achieve a similar degree of overall uncertainty.

36. Estimates of measurement uncertainty have been determined previously by various organisations, based on manufacturer's instrument performance specifications and on-going quality assurance tests of selected networks, such as the London Air Quality Network (Fuller and Cue 2003). The possible range of uncertainties are summarised here for illustration:

- In 2002 the NPL calculated ratified measurement uncertainty for 16 affiliated AURN sites in London. Based on actual or representative measurements in 2002 the uncertainty (2s) was estimated at 8% to 15% at the EU limit value concentration, with the majority of datasets being between 9% and 12%.
- In 2003 NPL used audit results for the wider ERG operated London Air Quality Network to demonstrate that uncertainties (2s) of better than ±10% were found for the vast majority of sites and that this supported the uncertainty estimates derived by calculation.
- The AURN Site Operator's manual reports calculated estimates of uncertainty based on reviewing the calibration chain and looking at measured instrument characteristics, both in service and in laboratory conditions. Accuracy estimates for the AURN (2s) were estimated to be 11% for NO2 and O3.
- ERG has estimated the 'best possible' uncertainty for typical analysers used to measure gaseous pollutants in the London Air Quality Network. The measurement uncertainty was estimated at 5% to 7% (2s) for NOX at high concentrations. Several operational factors were not included and these figures are likely to be under estimates.
- As a result of such uncertainty assessments, the London Air Quality Network has adopted a working uncertainty of ±10% for the measurements of NOX, NO2 and O3 concentrations at the EU limit value concentrations.

37. The uncertainty values described above should only be applied to measured concentrations. Where concentrations are derived by subtracting values from two monitoring sites the uncertainty will be greater, but by an unknown amount.

38. The case regarding PM10 measurements is slightly different, as the uncertainty of the data needs to comply with measurements carried out using the reference method, which may give significantly different results from the TEOM analyser. Calculating the overall uncertainty is therefore not straightforward. This issue is currently being addressed through various European and UK initiatives, including detailed PM10 equivalence trials that are being undertaken by Defra.

LIDAR studies

39. LIDAR (Light Detection and Ranging) equipment is based on a pulsed ultraviolet beam which is swept rapidly in the horizontal or vertical planes. The backscattering from atmospheric aerosol is then detected to give a 2D image of particle concentrations out to more than 1 kilometres from the source. Where the beam is directed through the plume from an aircraft taking off, then the outcome is a cross-section of the plume. The methodology is described in more detail in Annex 7.

2 It is expected that the correction factors for PM2.5 would be larger than that for PM10.

Monitoring locations

40. An initial task undertaken by the Panel was to identify the location of all monitoring stations in the Heathrow area. Existing and new monitoring sites are shown in figure 2.1. Monitoring sites included in the assessment were selected with the primary objectives in mind, i.e. to adequately describe the existing pollution climate and to provide a robust dataset for the validation of the base year model. It was recognised that the existing pollution climate needed to be considered in four basic contexts:

- concentrations near to roads;
- concentrations near to the airport;
- local background concentrations not immediately influenced by local sources; and
- regional background concentrations, that would occur without the airport.

41. It was also recognised that particular attention would need to be paid to the area to the northeast of the airport, due to the prevailing southwesterly winds. Fortunately, a long-term monitoring site, LHR2, has been located in this area since 1993. This site is just within the airfield [3] perimeter fence. It lies 180 metres to the north of the centre of the northern runway and 18 metres from the centre of the Northern Perimeter Road. The airport boundary is around 165 metres further to the north, along the A4 road.

42. Following this evaluation of existing monitoring sites and detailed discussions with members of Panel 1, it was concluded that there was a requirement to establish a

number of additional monitoring sites. This additional monitoring would serve three main purposes:

- The ability to provide a better understanding of the dispersion of pollutants on moving away from the airport to help with the source apportionment and model verification studies. It was determined that this would be best achieved by installing monitors for nitrogen oxides at two locations on a transect between LHR2 and LHR18, the chosen locations being LHR19 and LHR20.
- The ability to define worst-case concentrations due to the combined impact of roads and airport emissions at a location with relevant exposure, to help assess compliance with the air quality objectives and limit values. It was determined that this would be best achieved by installing monitors for nitrogen oxides and PM10 to the northeast of the airport (downwind of the prevailing wind) alongside the A4, the chosen location being LHR4.
- The ability to define air quality to the south-east of the airport, where concentrations are influenced by traffic on the A30 road and aircraft taking off and landing on the southern runway, 27L, in order to fill a gap in the pollution climate of this particular area and to monitor compliance. This would be achieved by monitoring in an area representing relevant exposure, the chosen location being LHR7.

43. Sites LHR19 and LHR20 were supported directly by DfT and were set up on 23 February and 3 March 2005 respectively. Site LHR4 was established by the London Borough of Hillingdon on 9 March 2005, as this site would be suitable for compliance monitoring to fulfil the authorities Local Air Quality Management responsibilities. Difficulties were experienced with establishing the LHR7 site, which was being established by the London Borough of Hounslow for the purposes of compliance monitoring, and this site was only commissioned in October 2005. Therefore, no data have been available for this report.

44. The Panel discussions identified six or more potential new monitoring stations that could be justified in an ideal world, in order to cover every eventuality that may occur for both model verification and compliance testing. However, with the establishment of these four new sites, the Panels were confident that the appropriate balance had been achieved, bearing in mind practicality, costs and the available timescale, and that no further additional monitoring would be required.

45. The potential requirement for PM2.5 monitoring was also considered by the Panels. Bearing in mind the forthcoming legislation on PM2.5, it was concluded that the establishment of a permanent monitoring site at LHR2 would be prudent, but that this would not be required for the model inter-comparison exercise, nor for future model verification.

46. The locations of the monitoring sites are shown in Figure 2.1, with Table A8.1 in Annex 8 providing a description of the sites, the site type, and the pollutants measured at each location. The sources of the data are provided in Table A8.2.

47. The LIDAR study was carried out during May 2005 at two locations at Heathrow Airport, with three different beam paths, as shown in Figure 2.2 and described in Annex 7.

3 In this context, the term 'airfield' is used to identify the restricted airside part of the airport, so as to distinguish if from the 'airport', the boundary of which extends beyond the airfield area.

Nitrogen dioxide and nitrogen oxides

Measured concentrations of NOx and NO2

48. Annual mean NOX and NO2 concentrations measured at each site are described in Tables A8.3 and A8.4 respectively in Annex 8. To assist interpretation the data are also shown mapped in Figure 2.4 and Figure 2.5, with annual mean concentrations in 2002, 2003 and 2004 provided at each location.

Figure 2.1 Location of the monitoring sites

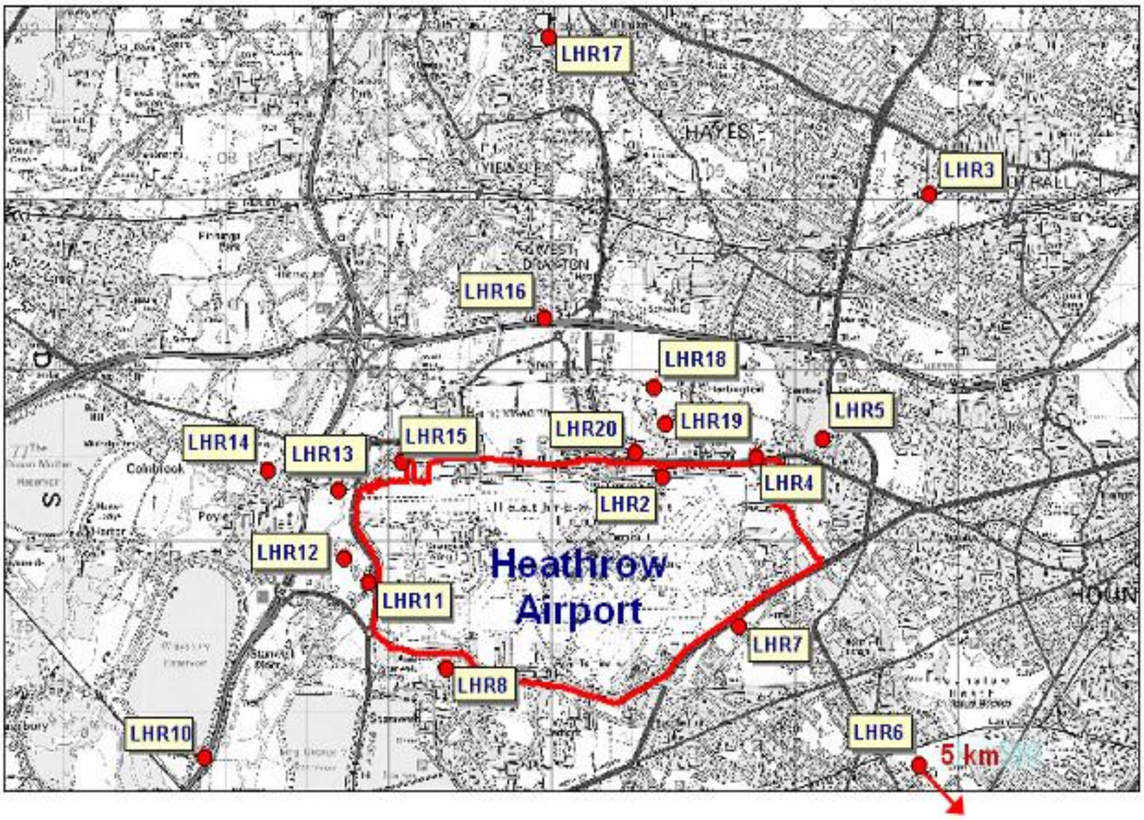
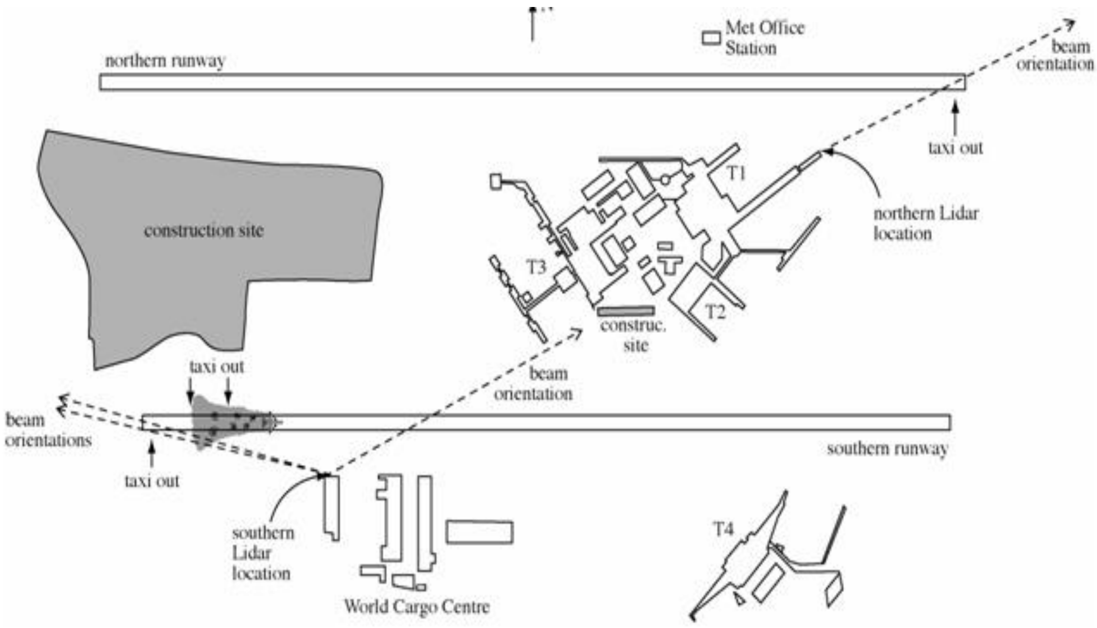
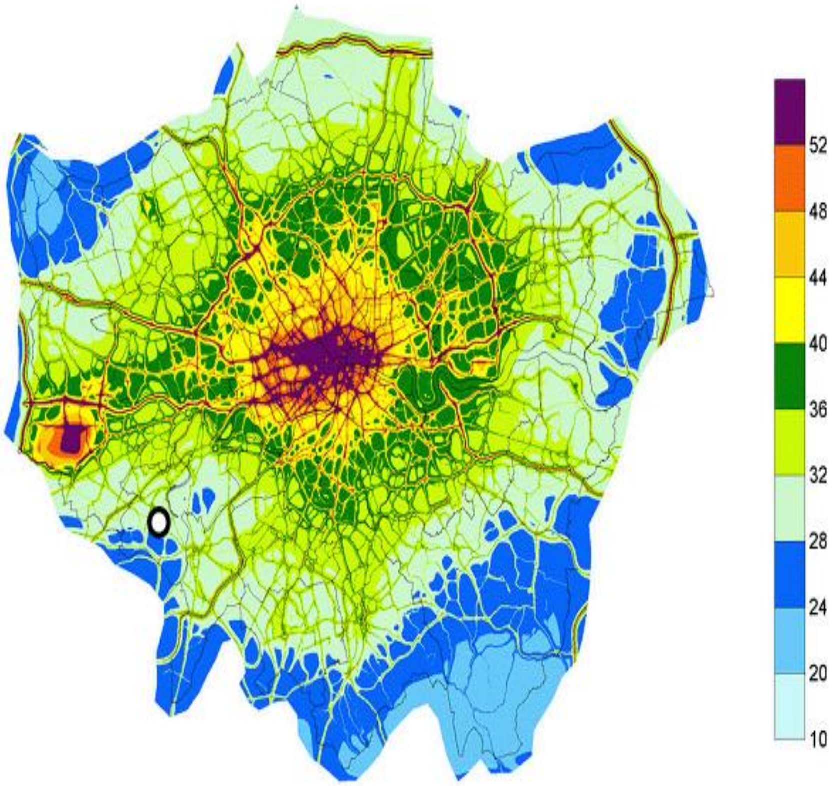


Figure 2.2 Location of LIDAR and orientation of beams



Principal points of taxi-out entry onto the runway during the studies are as marked. An aircraft and associated plume is depicted in its ground run having powered up its engines and simultaneously accelerated away for some 10 seconds having initially joined the runway from the easternmost of the entry points shown.

Figure 2.3 Annual mean nitrogen dioxide (ug/m3) in London in 2001

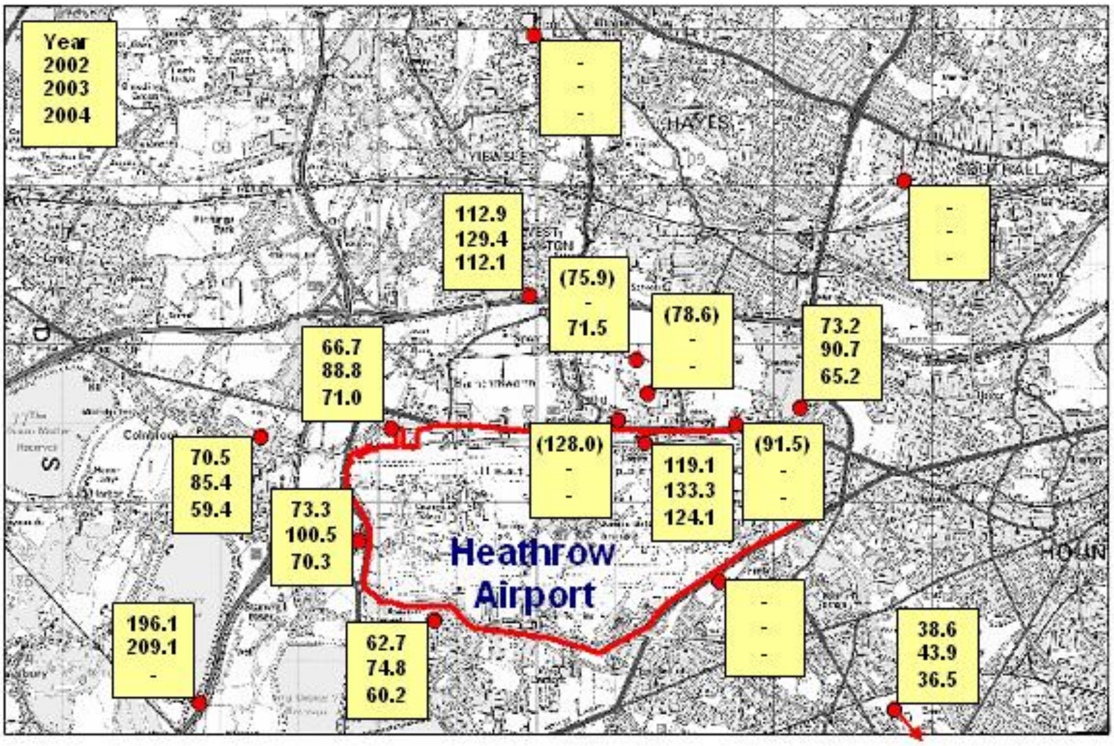


49. Annual mean NOX concentrations at local background sites in the area around Heathrow generally fall in the range 70-80 µg/m3. These may be compared with the background that might be expected without Heathrow. Examination of the map of modelled NO2 concentrations across London (Figure 2.3) indicates that the LHR6, Teddington site will be reasonably representative of the concentrations that would be expected in this part of London without the airport. On this basis, the Teddington site (LHR6) results in Figure 2.3, which are broadly in the range 35-45 µg/m3 can be used to give a good indication of the regional background NOX concentration that would apply in the study area without the airport. The airport is thus enhancing the regional background by some 25-45 µg/m3.

50. Concentrations of NOX at monitoring sites close to local sources are even higher. For example, annual mean concentrations at both LHR2 (at the airfield perimeter and close to the Northern Perimeter Road) and LHR16 (within about 30 metres of the M4 motorway) are about 50 µg/m3 above the local background. The relationship between NOX concentrations at regional background, local background, motorway (LHR10, about 1 metres from the hard shoulder of the M25, and LHR16, about 30 metres from the hard shoulder of the M4) and airfield perimeter (LHR2) locations is illustrated in Figure 2.6. The data described are for 2002 to 2004. There are clearly year-to-year variations, but the enhancement at local background, and at sites close to local airport and road traffic sources can be seen.

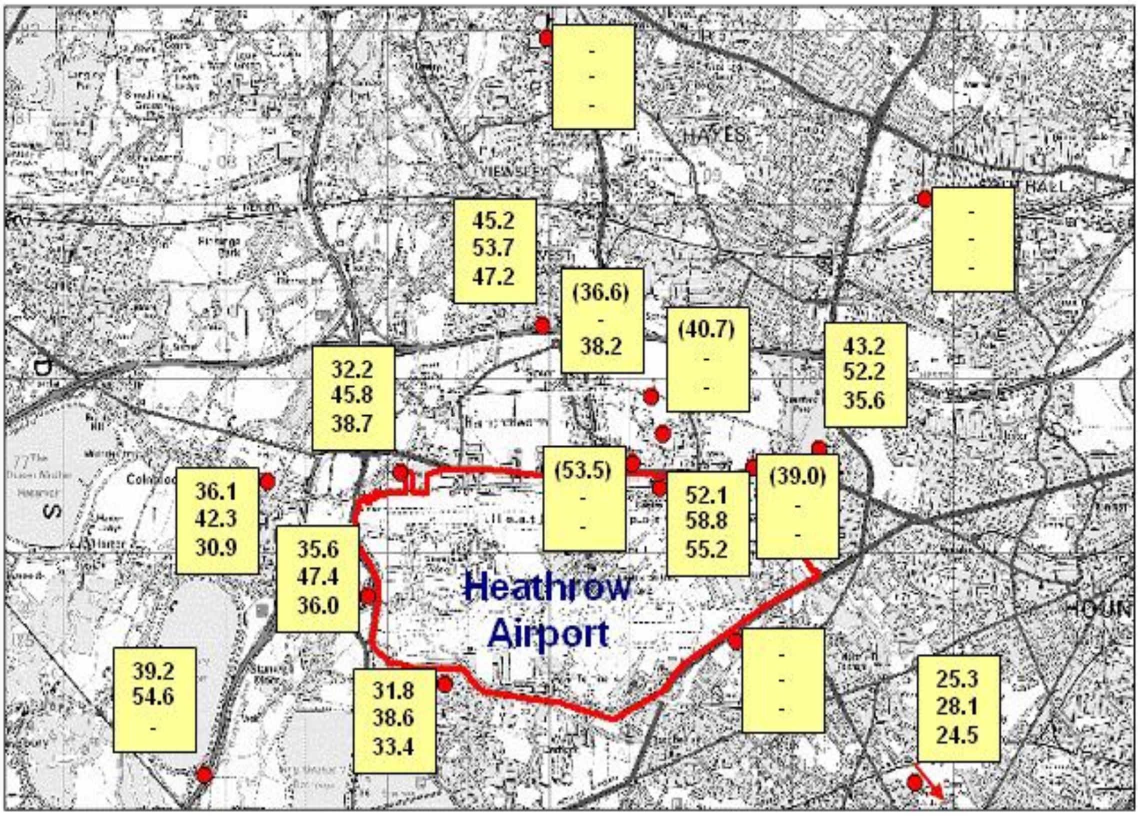
51. Annual mean NO2 concentrations above 40 µg/m3 were measured at a number of sites in the period 2002 to 2004. In 2002 and 2004 these included LHR2 and LHR16 (described above), and LHR5 (a background site in Cranford). There were exceedences at an additional four sites in 2003, including LHR10 4 (the M25 motorway kerbside site) and LHR11, LHR14 and LHR15 (all background sites). Measured NO2 concentrations across the UK were generally higher in 2003 due to the unusual meteorology during that year but the conditions were not considered to be exceptional or outside of the normal year-to-year variation observed over a long period (Laxen and Marner 2004).

Figure 2.4 Annual mean nitrogen oxides concentrations (ug/m3) 2002-2004



Concentration in brackets are short-term 2005 data adjusted to 2002 annual mean equivalent (apart from LHR18 which is adjusted to the 2002 annual mean equivalent from the 2004 annual mean). A dash means no data or data capture <75%.

Figure 2.5 Annual mean nitrogen dioxides concentrations (ug/m3) 2002-2004



Concentration in brackets are short-term 2005 data adjusted to 2002 annual mean equivalent (apart from LHR18 which is adjusted to the 2002 annual mean equivalent from the 2004 annual mean). A dash means no data or data capture <75%.

Figure 2.6 Range in annual mean NOx concentrations (2002-2004) at different categories of monitoring sites

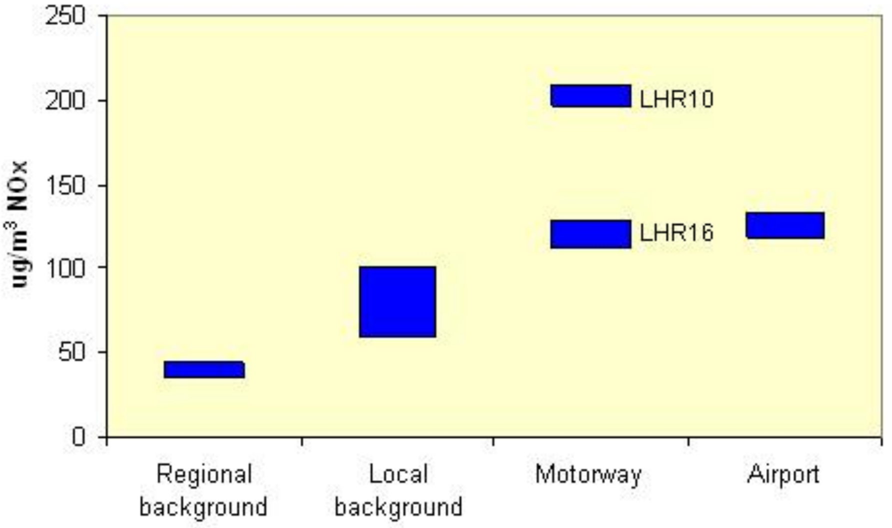
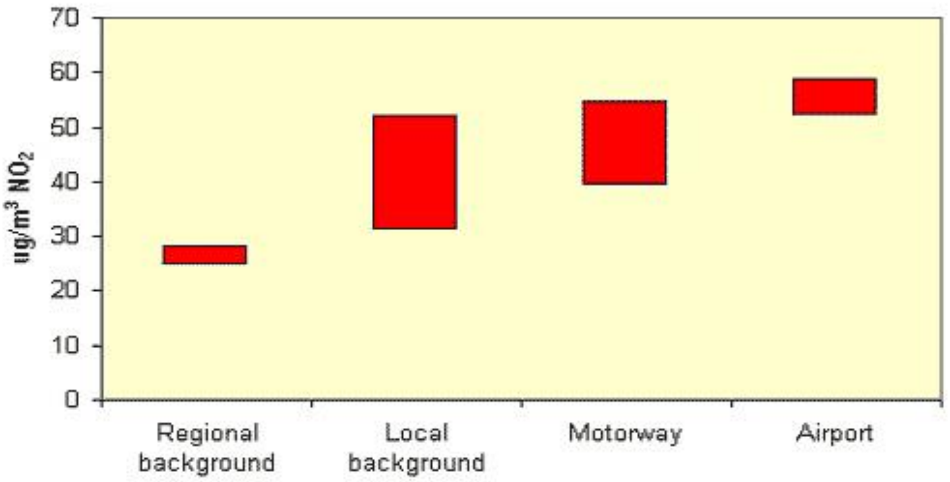


Figure 2.7 Range in annual mean NO2 concentrations (2001-2004) at different categories of monitoring sites



52. There have been no measured exceedences of the 1-hour objective and EU limit value at any site since measurements began in 1993 (see Table A8.5 in Annex 8).

53. The relationship between NO2 concentrations at regional background, local background, motorway and airfield perimeter (LHR2) locations is shown in Figure 2.7. The data described are for 2002 to 2004. As with measured NOX concentrations, there are clearly year-to-year variations, but the enhancement at local background, and at sites close to local sources can be seen.

54. A notable feature is that whilst NOX concentrations at the motorway site (LHR10) are higher than at the airport site (LHR2), higher NO2 concentrations are recorded at LHR2. This can be explained by considering the NO2/NOX ratios at each site, as set out in Table A8.6 in Annex 8. Ratios are highest at the background sites (about 50-60%) due to the time available for fresh NO emissions to mix with ozone and be converted to NO2. When NO concentrations are high, close to sources, then ozone is depleted and the conversion becomes ozone limited. This accounts for the much lower ratios at LHR 10, which is about a metre from the hard shoulder of the M25 (15-25%), and close to fresh emissions of NOX. The ratios are intermediate at LHR2 and LHR16, as these sites are further from the emission source, but still influenced by relatively fresh emissions. These observations are significant in emphasising the importance of NOX to NO2 conversion rates within the dispersion model.

55. The ratios of NO2/NOX set out in Table A8.6 in Annex 8 suggest that ratios are increasing over time. In part this will be due to lower NOX concentrations and hence the greater availability of ozone, especially at the sites more influenced by fresh emissions, but it also likely to be due to an increase in emissions of primary NO2, and to a lesser extent rising background ozone concentrations over this period. These trends will be important to take into account when modelling future years.

4 There was no reported annual mean concentration at this site for 2004 due to the M25 widening works.

Results from new monitoring sites

56. The Panel recommended that four new monitoring sites were set up. It was recognised that the information would be of limited value for this phase of the work on PSDH, but would be of value for subsequent model verification work and for compliance monitoring. Monitoring commenced at three of the sites in Spring 2005. The fourth site was delayed due to logistical problems, and not commissioned until October 2005. At the time of writing, no data are available from this site.

57. Results are available for roughly an eight month period. They have been ratified for most of this period at LHR19 and LHR20, but are yet to be ratified at LHR4. The available results are summarised in Table 2.3.

Table 2.3 Concentrations measured at new monitoring sites LHR4, LHR19 and LHR20 March to October 2005

Location	NOx (ug/m3)	NO2 (ug/m3)	PM10 (ug/m3)
LHR2 - Heathrow Airport	96.1	46.8	30.9
LHR4 - Hillingdon 3	65.1	33.9	23.5
LHR18 - Harlington	56.4	35.6	25.6
LHR19 - West End Lane	60.2	36.5	

LHR20 - Heathrow Point West	97.6	47.6	

58. After investigation the results for LHR20 are currently considered unreliable, as the levels are well above what would be expected for this location. The site was something of a compromise (finding sites is always challenging). It is located just back from the kerb of a small roundabout on a relatively quiet road, which leads to offices. However, from subsequent investigations it is understood that buses and taxis may frequently wait adjacent to the monitor with their engines running.

59. To be of some relevance to the model inter-comparison studies, which are based on the year 2002, the 2005 results for the three new sites have been used to estimate 2002 annual mean concentrations. This has been done by using the ratio of the period mean to the 2002 annual mean for nearby long-term sites. The sites used for this adjustment were LHR2, LHR14 and London Brent AURN. The factors used are given in footnotes to Table A8.3 in Annex 8.

Trends in NOx and NO2 concentrations

60. A detailed analysis of trends in pollutant concentrations has been carried out for Panel 2. Trend analysis has been generally based on the use of the non-parametric Mann-Kendall test and the non-parametric Sen's method. The Mann-Kendall test is used to detect whether there is any trend in a monotonic (regularly increasing or decreasing) time series with no seasonal cycle. The Sen's method is used only where there is a proven trend, to estimate the linear magnitude of the trend (slope and intercept) - in this case the change in concentrations year on year. The probability of a trend being significant is expressed in percentage terms, where a value greater than or equal to 99.9% means the trend is highly significant, and a value less than 90% means that the trend is not significant at all.

61. These tests are regularly used in air quality reviews and are the basis for trend analyses for NOX, NO2 and PM10 in the AEQG reports for these pollutants (AQEG 2004; AQEG 2005a). The methods are enacted in a bespoke tool MAKESENS (Salmi et al. 2002), prepared through EMEP.

62. There are some important caveats. All data used are annual averages only. For PSDH, of the available monitoring sites, only LHR2 has a sufficient sample size for use of the Sen's method. Equally, given the small number of years of data for most sites except LHR2, by virtue of the Mann-Kendall test approach, the probability of a proven trend across a range of sites will generally not be better than 95%.

63. The LHR2 site has operated since 1993, and provides the longest period of data. Trends in annual mean NOX and NO2 at this location are described in Figure 2.8 and Figure 2.9 respectively. LHR2 shows a highly significant downward trend in annual mean NOX concentrations over this period, with a change of over 6 µg/m3 a year

(significant at the 99.9% level). However, for NO2 the equivalent change over time is not evident. There is a minimal downward trend (0.5 µg/m3 a year) in NO2 over this period, statistically significant at the 90% level.

64. This difference between trends in NOX and NO2 is related to the non-linear relationship between NOX and NO2 Comparison with similar analyses for national and London-specific monitoring networks (Carslaw 2005a) shows that:

- National data for 13 long running sites of all types (1993-2002) shows a -5.1 ±1.6% decline in annual average NOX, compared to a -3.4 ±1.7% decline for NO2, both significant at the 90% level;
- National data for **urban** sites shows a -5.0% decline in annual average NOx, compared to a -3.1 ±1.7% decline in annual average NO2, both significant at the 90% level.
- London data (1997-2003) for 36 roadside sites shows a significant decline in annual average NOX at 21 sites of 11.7 µg/m3 a year, compared to a much smaller 0.5 µg/m3 reduction a year in NO2 at just eight sites for the same period, both significant at the 90% level.

Figure 2.8 Trend in annual mean NOx concentrations at LHR2 1993-2004

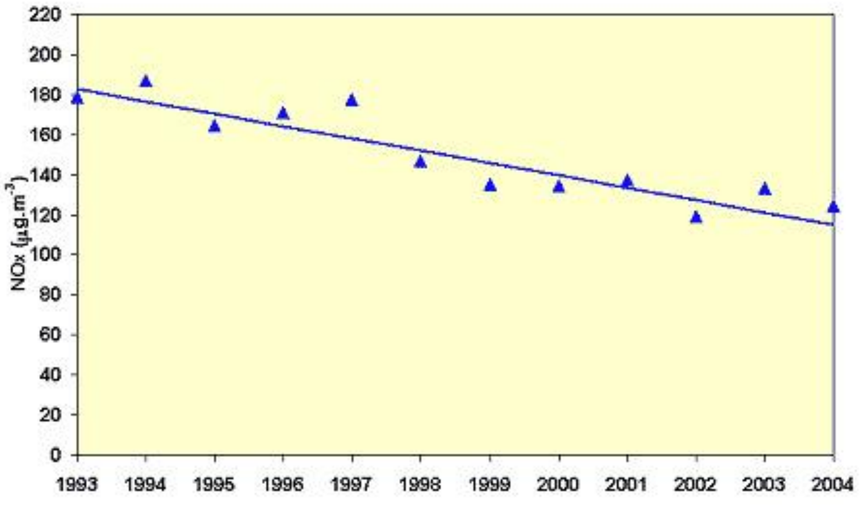
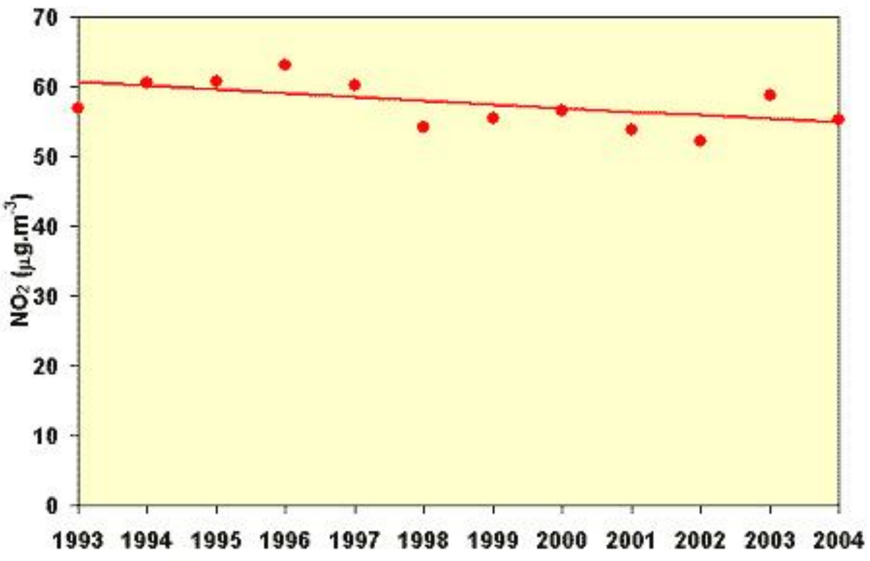
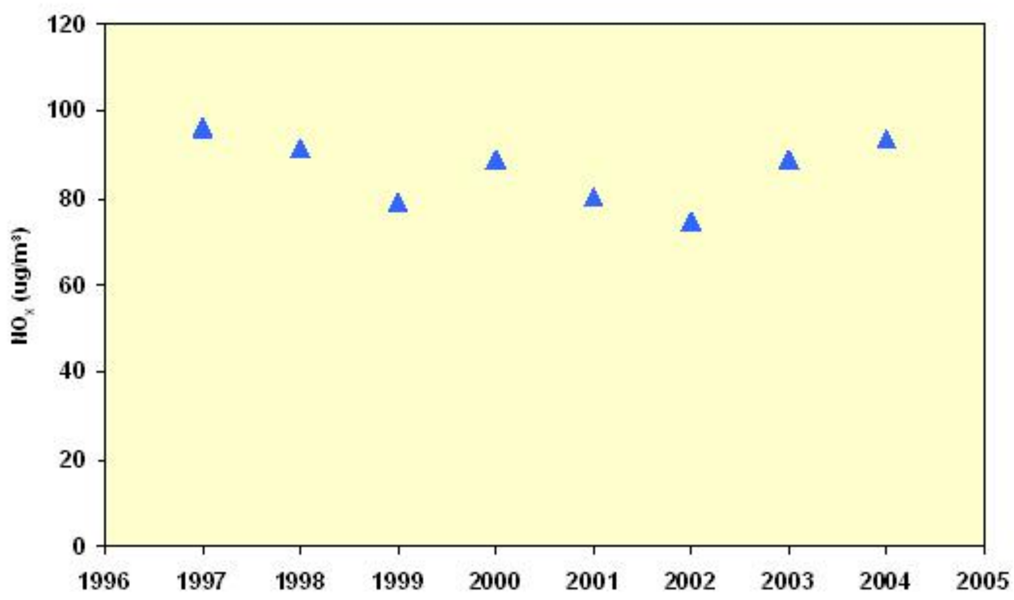


Figure 2.9 Trend in annual mean NO2 concentrations at LHR2 1993-2004



65. It is also useful to examine trends in concentrations at LHR2 when a component representing the background contribution is removed. This will then broadly represent the trend in the contribution of 'airport' NOX sources to LHR2 concentrations. For this analysis NOX concentrations measured at the LHR6 site have been removed from the LHR2 data for all hours with a wind direction between 180°-260°. The results for the period 1997 to 2004 show no statistically significant trend in annual average NOX from on-airport sources (see Figure 2.10). This contrasts with the significant downward trend in total NOX at LHR2 over the period 1993-2004, which remains statistically significant when analysed for the same 1997-2004 period (at the 90% level). This implies that the airport sources have not reduced over time compared to the general reduction in NOX concentrations.

Figure 2.10 Trend in annual mean NOx concentrations for on-airport sources 1997-2004



Source contribution of aircraft emissions to measured pollutant concentrations

66. A method has been developed to identify the contribution from aircraft emissions to measured pollutant concentrations at sites in the vicinity of Heathrow Airport. The method is based upon standard pollution roses, which combine wind direction and pollutant concentration, but also includes wind speeds. The resulting *bivariate pollution roses* can be used to identify emissions contributions from different types of source. Essentially bivariate pollution roses show concentrations as contours as a function of the direction from which the wind is blowing and wind speed, which increases from 0 m/s at the centre to 8 m/s on the periphery of the polar diagram. The method is a variant of an approach developed by Yu et al. (2004) and applied to large urban airports. It is described in detail in Annex 6 (*A data mining investigation into the sources of air pollution in the vicinity of Heathrow Airport* by David Carslaw).

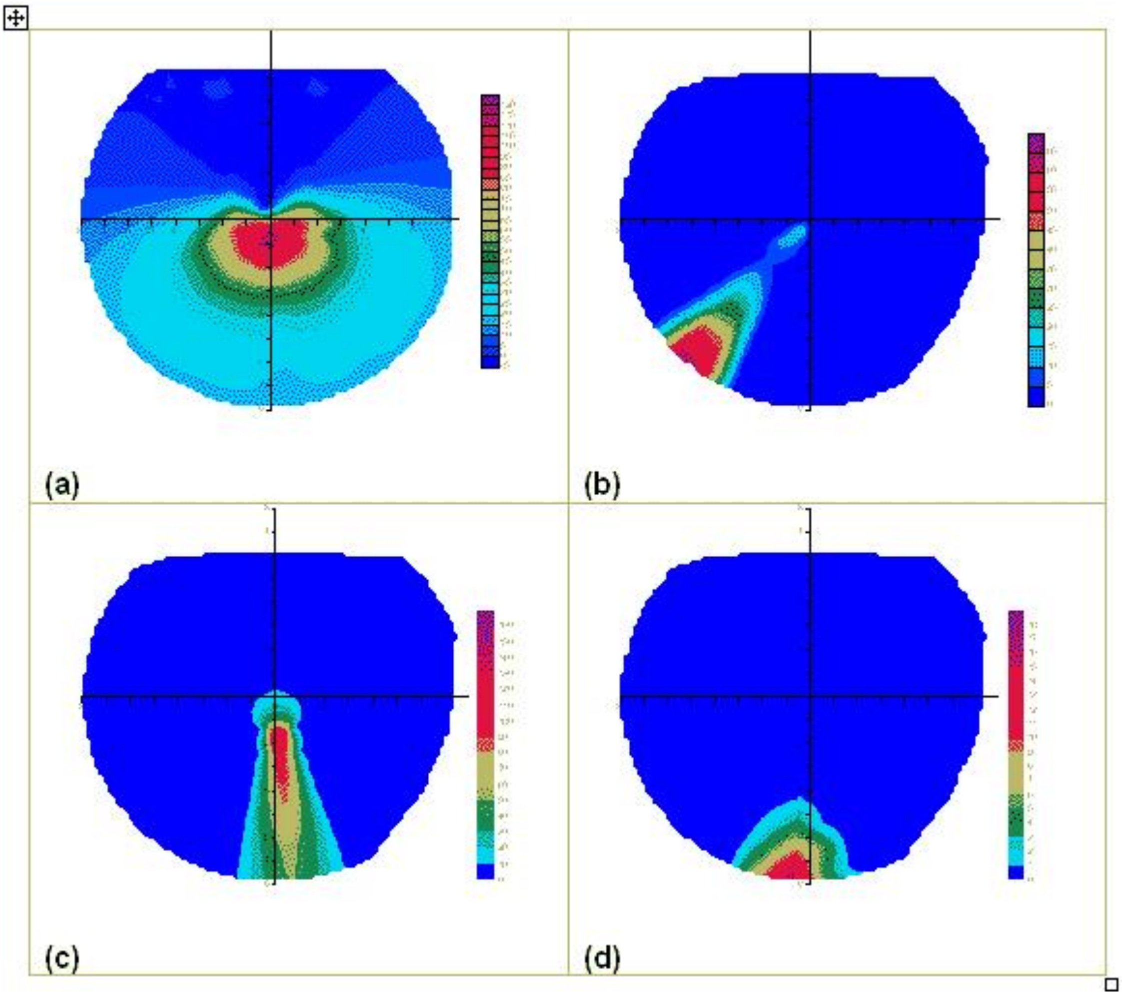
67. To illustrate the approach and the behaviour of different source types, bivariate pollution roses have been derived for road, point (chimney stack), volume and jet sources using the ADMS3.1 model. The sources were defined in relation to the receptor as follows:

- road source - infinite length, east to west orientation, 100 metres to south;
- point source - 200 metres stack, 3000 metres to south west;
- volume source - from ground level to 80 metres, 500 metres to south;

- buoyant jet source - horizontal emission 2 metres above the ground, at 375 m/s and 280ºC, 500 metres to south.

68. The resultant bivariate pollution roses for the different source types are shown in Figure 2.11. These results clearly demonstrate that very different concentration patterns are derived for different source types. The road source (Figure 2.11a) shows that concentrations are highest for low wind speed conditions and decrease with increasing wind speed. In contrast, the pattern from the chimney stack shows that concentrations increase with increasing wind speed when the wind is from the direction of the stack, as shown in Figure 2.11b. The volume source (Figure 2.11c) appears to display similar characteristics to the road source i.e. concentrations decrease with increasing wind speed. The buoyant jet source (Figure 2.11d) concentration pattern is very similar to the chimney stack i.e. concentrations increase with increasing wind speed.

Figure 2.11 Bivariate pollution roses



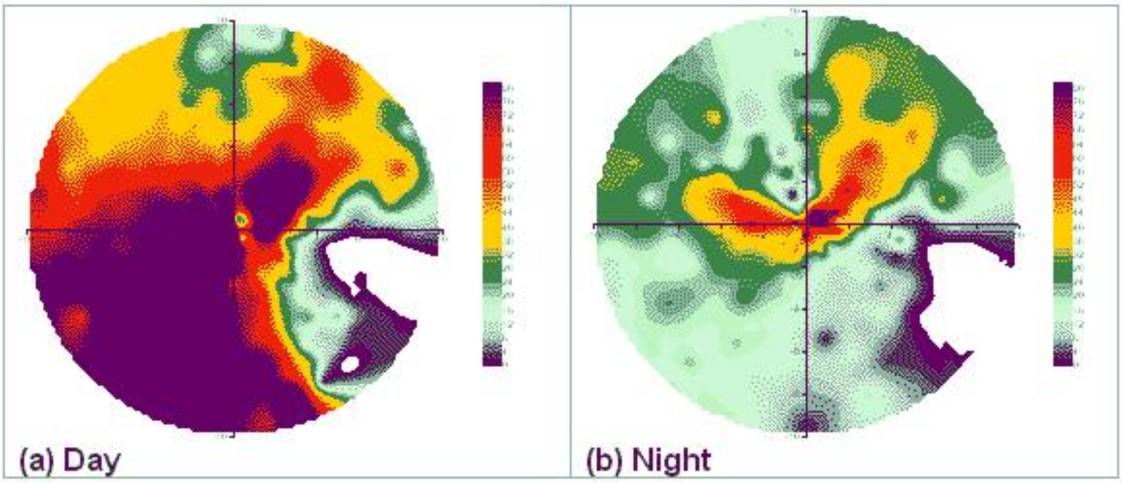
(a) (b) (c) (d)

69. Bivariate pollution roses for NOX concentrations have been calculated for a number of monitoring sites close to Heathrow Airport. These have been calculated for daytime (assumed to be from 0600 and 2200 hrs) and night time (2300 to 0500 hrs). The daytime hours coincide with aircraft activity, whereas at night time aircraft

activity is minimal. By contrasting these two periods, some indication of the relative importance of aircraft sources can be made. All of these plots have a background concentration removed, in order to highlight the contribution from local sources. An example of the plot for the LHR2 site is shown in Figure 2.12.

70. The daytime plot (Figure 2.12a) shows the highest concentrations occur predominantly in the south-west quadrant over all wind speeds (0 to 10 m/s). This is clear evidence of a source of NOX to the south-west, consistent with the close proximity of aircraft sources in that direction. The pattern is consistent with an important contribution being made by elevated sources. It is also apparent that there is a less significant source of NOX to the north and in particular the north-east. This is related to lower wind speeds, in the range 0-4 m/s, and is probably due to the Northern Perimeter Road. At night the road source and other sources to the north remain important but the source to the south and south-west virtually disappears. This is consistent with the interpretation of an aircraft/airport source to the south and south-west.

Figure 2.12 Bivariate NOx pollution roses for LHR2 day and night



71. Figure 2.13 shows all of the daytime bivariate NOX pollution roses overlaid onto a map of the Heathrow area. Whilst these plots do not provide conclusive proof of aircraft or airport source contributions, they do provide a consistent indication that sources in the direction of Heathrow Airport can be detected at sites up to at least 2.8 kilometres from the runway. They also fit the pattern for emissions from the airport behaving like a buoyant jet source.

72. The minimal airport contributions at LHR2 with winds from the south-east sector can, in part, be explained by aircraft not usually departing to the west when winds are easterly. The exception is the 'Westerly preference' to take-offs, which operates during the daytime, at times when the easterly (tailwind) component is less than 5 knots (about 2.6 m/s). When the easterly wind component is greater than this value, aircraft are instructed by ATC to switch runways and depart towards the east. South-easterly winds will then no longer take aircraft emissions to LHR2 from the northern runway.

73. Similar bivariate pollution roses have been produced for NO2 concentrations, for daytime periods only (see Figure 2.14). These plots show a clearer pattern of concentrations compared with the NOX plots, but are also consistent in terms of the directions that are most important. One explanation for the increased clarity could be that the Heathrow sources of NOX are generally a reasonable distance away from the measurement sites (a few hundred metres to several kilometres). Over these distances there would generally be sufficient time for NO to be converted to NO2. The effect of plotting NO2 rather than NOX therefore diminishes the importance of very local sources such as roads but enhances the signature of more distant sources.

Figure 2.13 Bivariate pollution roses for NOx (ug/m3)

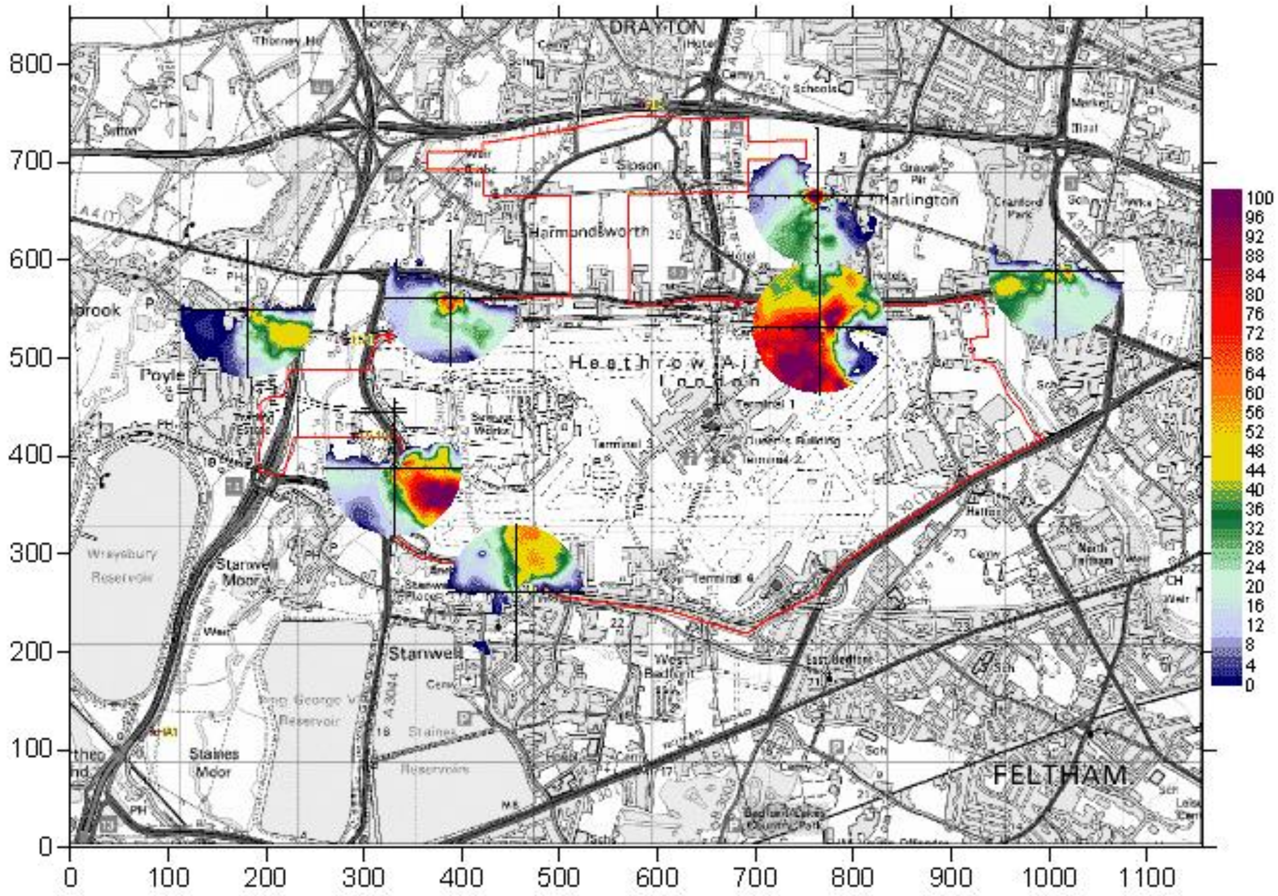
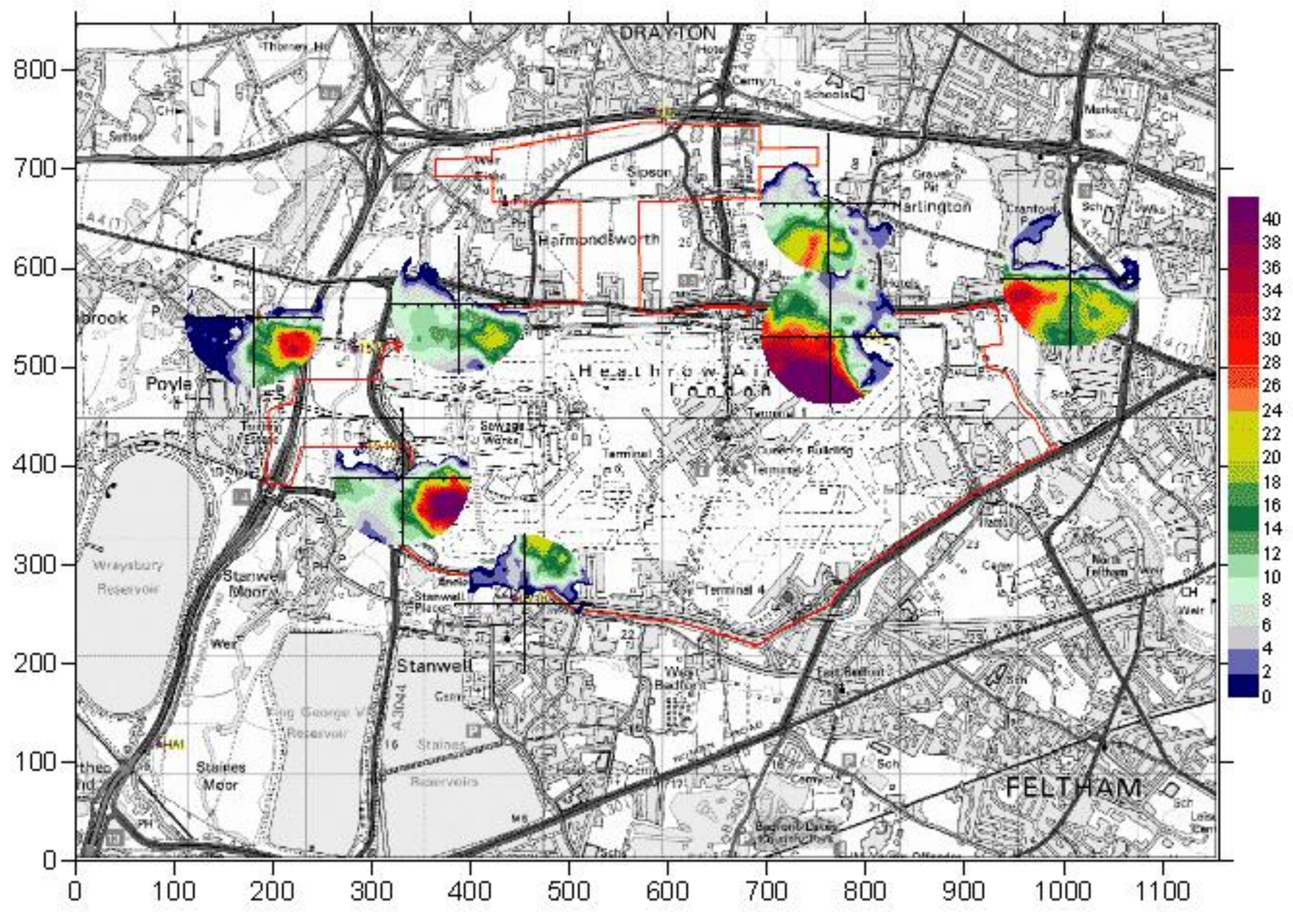


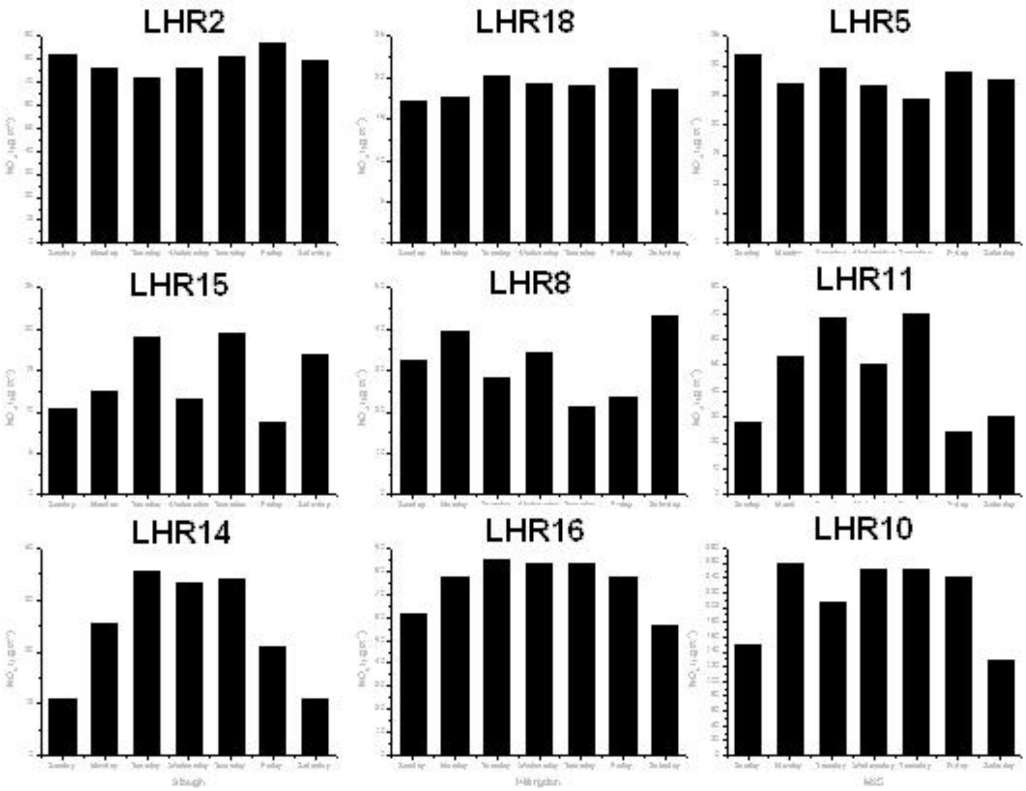
Figure 2.14 Bivariate pollution roses for NO2 (ug/m3)



75. The LHR15 (Green Gates) plot does not show a very clear aircraft signal, despite its proximity to the runway. This is probably because an aircraft signal is only detected during easterly operation, when aircraft land only on the northern runway (09L). The more significant signal seen at LHR14 (Slough Colnbrook) might be because other (road traffic) sources have been detected.

75. Confirmation of the influence of aircraft emissions can also be determined by considering the variation in NOX concentrations with the day of the week. Whilst road traffic emissions are generally much lower at weekends, aircraft emissions remain relatively constant throughout the week. Figure 2.15 shows the day of the week variation at nine monitoring sites for winds from the airport over 4 m/s and with the background removed. Sites which are strongly influenced by road traffic emissions (LHR10 and LHR16, in red) demonstrate much lower NOX concentrations at weekends. LHR14 also shows lower concentrations at weekends, this being a site that is probably significantly influenced by road traffic emissions on the M4 and M25 motorways. In contrast, relatively constant NOX concentrations are measured at the LHR2, LHR8, LHR15 and LHR18 sites, indicating an appreciable airport signal. The same applies to LHR5, which is downwind of the airport in the direction of the prevailing wind. The behaviour at LHR11 is more consistent with a site influenced by road traffic.

Figure 2.15 Day of the week variation in filtered NOx concentrations at monitoring sites close to Heathrow Airport



Airport contribution to NOx concentrations

76. The bivariate pollution roses described above can be used to estimate an upper limit of airport contributions to measured NOX concentration at different monitoring sites. The contribution made by airport sources is determined by subtracting the background to determine the airport contribution to concentrations and then averaging these concentrations weighted by the wind direction and wind speed frequency throughout the monitoring period.

Figure 2.16 Wind speed/direction probability plot based on Heathrow data from July 2001-December 2004

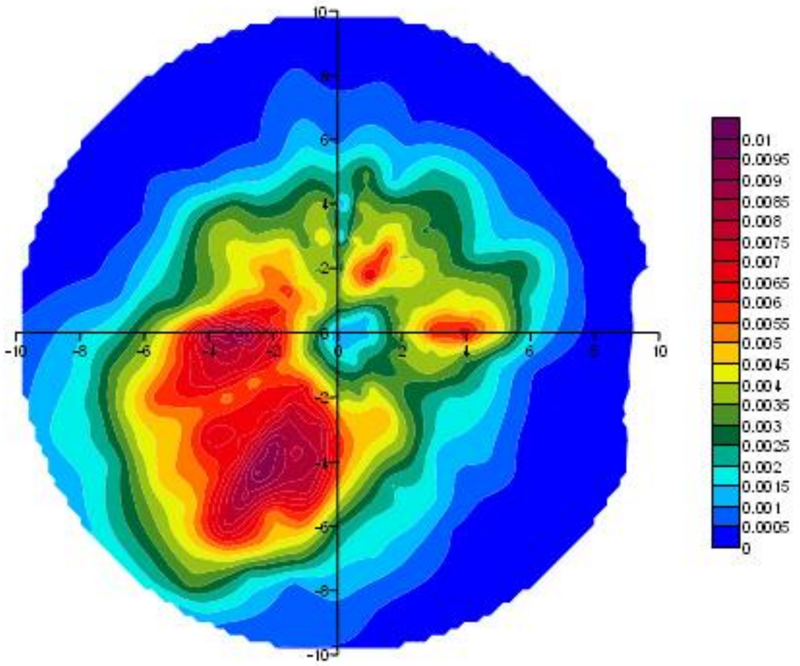


Table 2.4 estimated airport contribution to measured NOx concentrations

Location	Measured NOx (ug/m3)	Upper limit for airport contribution (ug/m3)	Upper limit for airport contribution (%)	Range (ug/m3) **	Direction range (degrees)
LHR2	117	31.5	27.0	21.5-31.5	150-260
LHR18 - Harlington	71	9.9	14.0	5.7-9.9	160-260
LHR5 - Hounslow 2	79	9.5	12.0	5.7-9.5	200-260
LHR15 - Green Gates	75	3.0	4.0	1.1-3.0	100-170
LHR14 - Slough Colnbrook	69	1.8	2.6	1.7-1.8	100-170
LHR8 - Oaks Road	66	5.9	8.9	2.2-5.9	350-80

77. Figure 2.16 shows a wind speed/direction joint probability plot, which has been derived by considering the number of hours over a period of time where the wind speed and wind direction are between different intervals, divided by the total number

of hours. The figure not only shows the predominance of south-westerly winds measured at Heathrow but that there is also a greater probability of high wind speeds from this direction. This has important implications and suggests that for the dispersion of aircraft plumes the areas to the northeast of airport will register the largest contribution from aircraft; not only because of the prevailing wind direction, but also the higher fraction of higher wind speed conditions. The airport sources contribute most at LHR2 with the higher wind speeds as shown in the background adjusted bivariate pollution roses in Figure 2.13 and Figure 2.14.

78. If the data in Figure 2.16 are multiplied with the bivariate pollution roses described in Figure 2.13, an estimate of the contribution to overall measured NOX concentrations can be made. With the exception of LHR2, the estimate will be an upper limit due to the influence of other sources (such as roads) between the airport and the monitoring station. In an attempt to minimise this effect, the wind speed data for sites other than LHR2 have been restricted to hours >3 m/s. During these higher wind speeds, the influence of local roads will be diminished.

79. The results of these calculations are shown in Table 2.4. For LHR2 it is estimated that the airport contributes around 31.5 µg/m3 of the total measured NOX (27.0 %). The sites to the east and south of the airport generally have a small contribution from the airport. The contributions made by the airport at LHR5 (Hounslow 2) and LHR18 (Harlington) are similar (5.7-9.9 µg/m3). These results provide a potentially important tool for validation of the base year model results. It must though be borne in mind that there is greater uncertainty associated with these values than for total measured concentrations, as they are calculated by difference, and also include added uncertainty due to multiplication by wind frequency.

Analysis of runway operations

80. The daily pattern of runway use at Heathrow Airport can also be used to identify the contribution of aircraft sources. The northern and southern runways are separated by about 1.4 kilometres. It may therefore be expected that the contribution from aircraft operating on the northern runway will be much greater at monitoring sites close to the northern boundary of the airport. LHR2 is 134 metres to the north of the edge of the northern runway, and 180 metres from the centre.

81. Aircraft take off and land on the northern and southern runways during westerly operations but, due to operational restrictions, only take off from the southern runway during easterly operations. During normal operations, take-off is from the one runway in the morning (0600-1500 hrs) and then switched to the other runway for the remainder of the day. As the airport operates in segregated mode, the runway not being used for departures will be used for arriving aircraft.

82. Hourly data of aircraft operations on each runway were provided by the National Air Traffic Services (NATS) for the period July 2001 to December 2004. Hourly

concentrations of NOX at the LHR2 site were filtered for wind speeds >6 m/s and for wind directions encompassing the airport, and then segregated according to runway use. The results are described in Figure 2.17, which shows a considerable difference in the diurnal profile depending on which runway is used for take-off. A key conclusion is that the northern runway profile is very similar to the calculated NOX emissions profile for aircraft operations.

83. A diurnal profile has also been produced for the LHR18 site, which is 1 kilometre further from the northern runway than LHR2 (see Figure 2.18). A similar profile is observed, but with lower NOX concentrations. The difference during the daytime between northern and southern runway use at LHR2 is around 100 µg/m3, which declines to around 10 µg/m3 at LHR18. Thus the NOX contribution from the use of the northern runway decreases by a factor of about 10 between these two locations during periods with stronger winds (>6 m/s).

Figure 2.17 NOx concentrations measured at LHR2

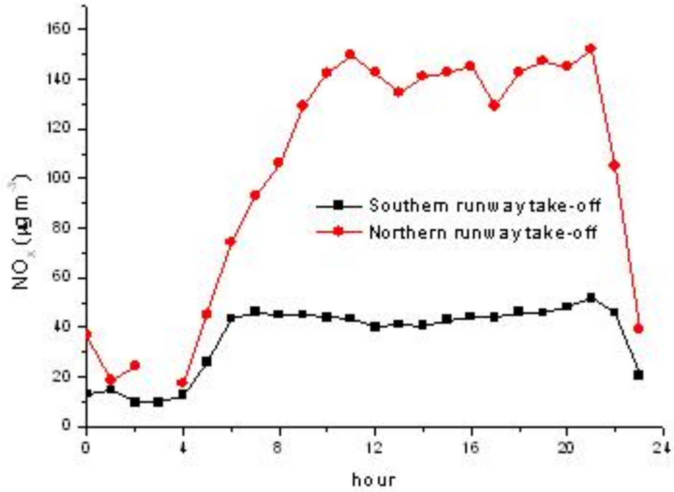
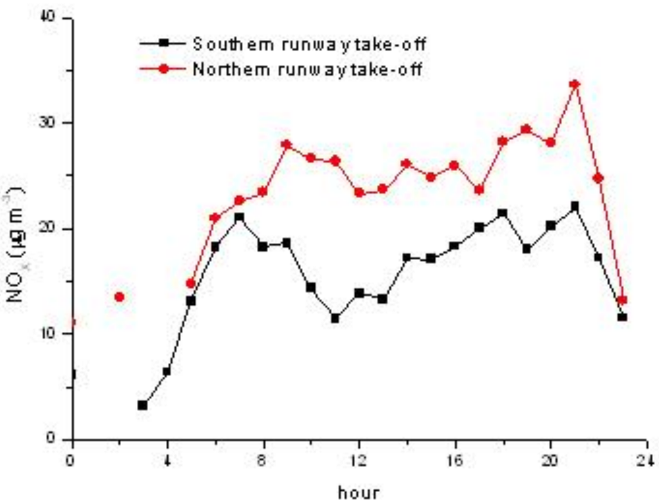


Figure 2.18 NOx concentrations measured at LHR18



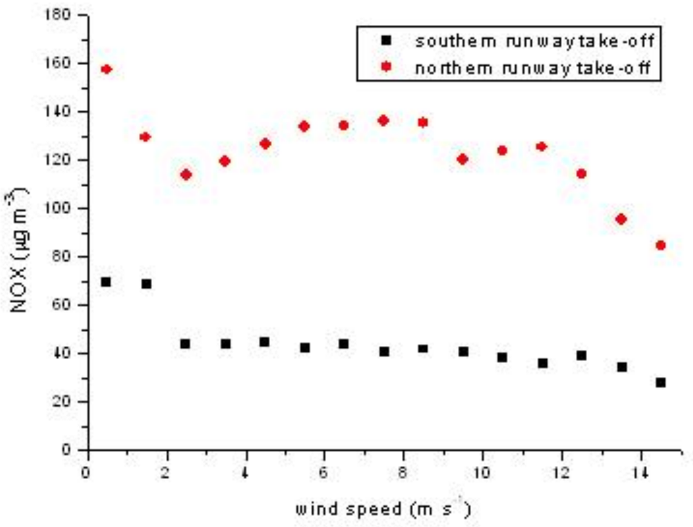
NOx and NO2 Chemistry

84. The pattern of runway operations also permits a more detailed analysis of the NOX photochemistry, which may prove useful in validation of the modelled NO2/NOX ratios. At LHR2 the difference between northern and southern runway take-off is calculated to result in a difference in NOX of 60 µg/m3. The corresponding change in NO2 was calculated to be 15 µg/m3, i.e., a NO2/NOX ratio of 25%. At LHR18, the same calculations suggest a NOX and NO2 difference of 4.7 and 2.3 µg/m3, respectively i.e. a ratio of 49%. NOX concentrations due to emissions from aircraft taking off on the northern runway 27R decreases by 92% between LHR2 and LHR18, whereas NO2 concentrations decrease by a smaller amount, 85%. A more efficient conversion to NO2 would be expected at LHR18 for two reasons. First, there is more time available for the NO-O3 reaction to take place and second, there will be fewer hours at LHR18 that will be ozone-limited. At LHR2 there is likely to be a much greater proportion of hours that are ozone-limited because of the higher NO concentrations at that site due to the proximity of aircraft sources.

NOx concentrations related to wind speed

85. A further analysis based on the NATS data has been used to investigate the relationship between measured NOX concentrations and wind speed. Measured background NOX concentrations at the LHR8 site have been subtracted from LHR2 and the data then segregated according to take-offs from the southern or northern runway. The results plotted against wind speed are shown in Figure 2.19.

Figure 2.19 NOx concentrations measured at LHR2 against wind speeds



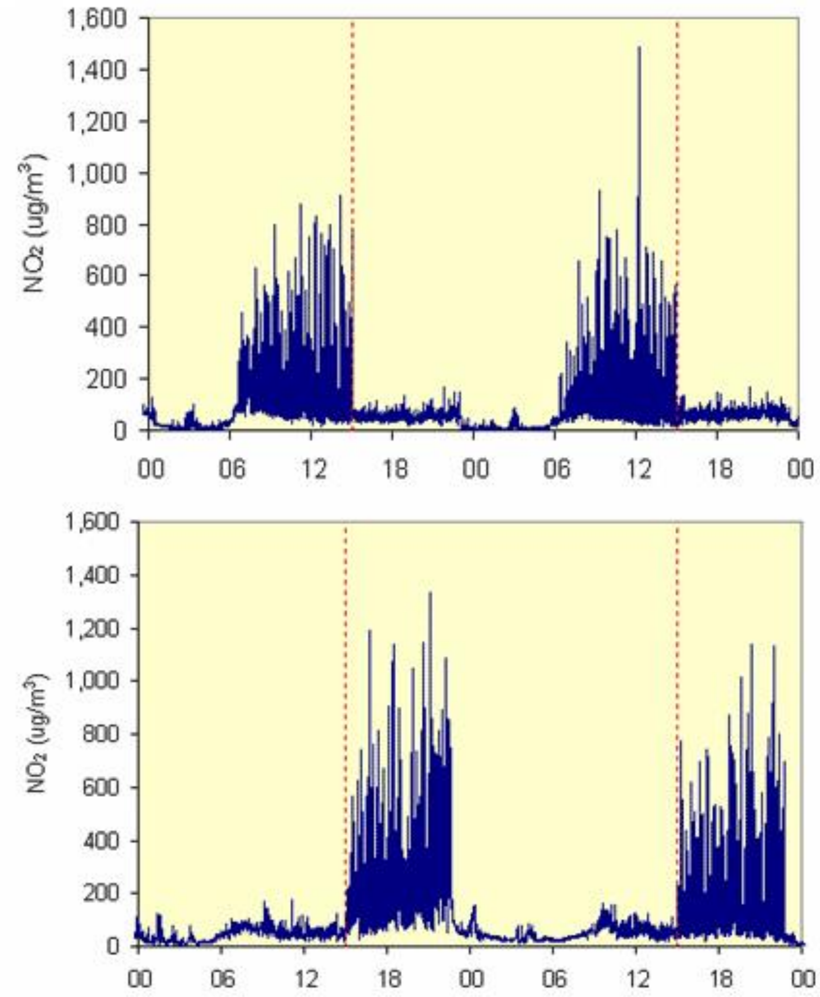
86. A number of important conclusions can be drawn from these data. During take-off on the northern runway NOX concentrations decrease with wind speeds up to about 2 m/s, and then increase to about 8 m/s before declining again. During take-off on the southern runway, concentrations remain fairly constant with increasing wind speeds, only declining above 15 m/s. The different dispersion characteristics of aircraft plumes over distance can be seen. In addition, NOX concentrations during southern runway take-off are about one-third of those during northern runway take-offs, again providing evidence of how rapidly the aircraft plumes are dispersed

Fast-response monitoring of nitrogen oxides

87. Results for the fast-response monitor only became available late in the study and no detailed analysis has been carried out. The instrument was run to produce 10 second average concentrations. Results for two sets of two days in October are shown in Figure 2.20.

88. The fast response monitor shows the dramatic impact of the changed use of the runway 027R (the northern runway) for take-offs. This is carried out to mitigate noise impacts and is scheduled for 15.00 hours, when the use of 027R for take-offs is swapped with 027L (the southern runway). This change switches on or off large spikes in NOX concentration, up to around 1,400 µg/m3. This is evidence that the LHR2 monitoring site, 134 metres from the edge of the northern runway, is affected by very distinct aircraft plumes during aircraft take-off. When the southern runway is being used for take-off (and the northern for landings) there is no strong evidence of aircraft plumes.

Figure 2.20 10-second average NOx concentrations measured at LHR2

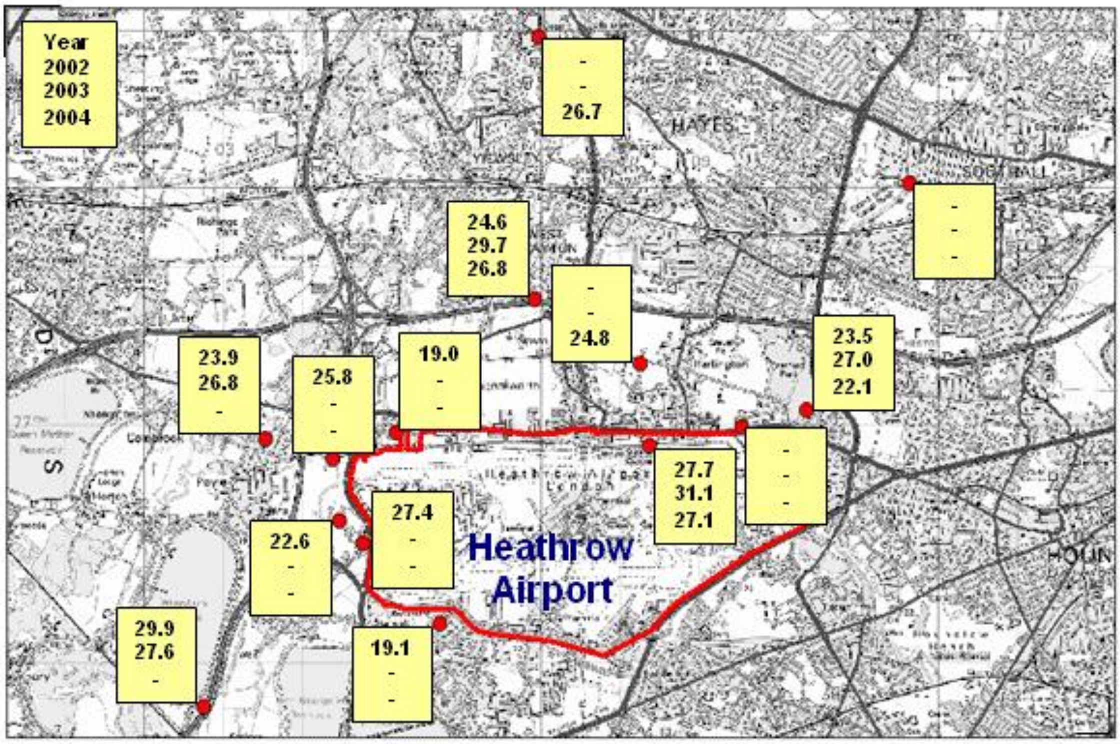


Particulate matter (PM10 and PM2.5)

Measured concentrations of PM10 and PM2.5

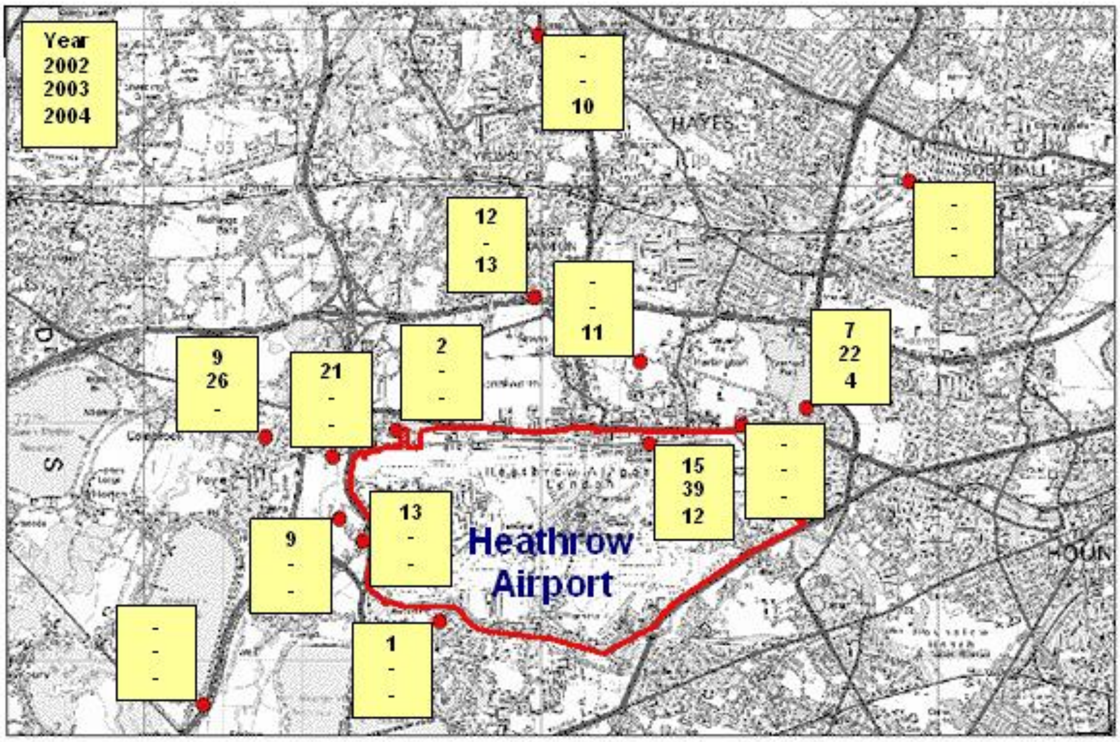
89. Monitoring of both PM10 and PM2.5 concentrations has been expanded in recent years. However, during both 2003 and 2004 the data at many of the sites are likely to have been significantly influenced by the Terminal 5 construction activities. It is not within the scope of this report to consider the impact of construction sites upon PM10 and PM2.5 concentrations and these data must therefore be treated with some caution.

Figure 2.21 Annual mean PM10 concentrations (ug/m3) 2002-2004



90. A summary of annual mean PM10 concentrations and the number of days greater than 50 µg/m3 is provided in Tables A8.7 and A8.8 respectively in Annex 8. To assist interpretation the data are also shown mapped in Figure 2.21 and Figure 2.22, with concentrations in 2002, 2003 and 2004 described at each location 5 . With the exception of site LHR11 in 2003 (which was likely to have been significantly affected by the Terminal 5 construction works) there have been no measured exceedences of 40 µg/m3 at any location. There have been a number of exceedences of the 24-hour mean objective and limit value (no more than 35 days > 50 µg/m3 in each year), but once again the majority of these sites are likely to have been influenced by the local construction works. The exception was LHR2 in 2003, where 39 days above 50 µg/m3 were recorded.

Figure 2.22 Number of days exceeding 50 ug/m3 as a 24-hour mean PM10 concentration



91. Annual mean background PM10 concentrations in the area are about 24-25 µg/m3. This compares to background concentrations in similar parts of London away from the airport of about 21-23 µg/m3 (Laxen and Marner 2004). The local background enhancement is therefore about 1-2 µg/m3. Concentrations measured close to major roads (LHR10) and the airport (LHR2) are about 28-30 µg/m3. The impact of PM10 emissions from the airport is relatively minor in comparison to NOX.

92. Annual mean PM2.5 concentrations are summarised in Table A8.9 in Annex 8. There are far fewer monitoring sites, and the majority of data available are likely to have been affected by the Terminal 5 construction activities (albeit that this is likely to be to a lesser extent than the PM10 concentrations, as more of the construction PM emissions will be in the PM2.5-10 range than as PM2-5). It may be concluded that the local background annual mean PM2.5 concentration is about 12-13 µg/m3 measured by TEOM. There is no direct information on what gravimetric PM2.5 concentrations are. Where comparisons have been made it has been found that the typical ratio for PM2.5 to PM10 (gravimetric) is 0.6-0.7 (CAFÉ Working Group on Particulate Matter 2004).

93. On this basis, the PM10 data around Heathrow translate into annual mean background PM2.5 concentrations in the area of about 14-18 µg/m3. This compares to background concentrations in similar parts of London away from the airport of about 13-16 µg/m3 (AQEG 2005a). The local background enhancement would therefore be around 1-2 µg /m3. Concentrations measured close to major roads (LHR10) and the airport (LHR2) would be around 17-21 µg/m3. These concentrations are all below the

concentration cap of 25 mg/m3 being proposed by the European Commission (2005b) as part of its Clean Air for Europe Thematic Strategy.

5 The values for sites set up to monitor Terminal 5 construction in 2004 and 2004 are not shown Figure 2.21 and Figure 2.22.

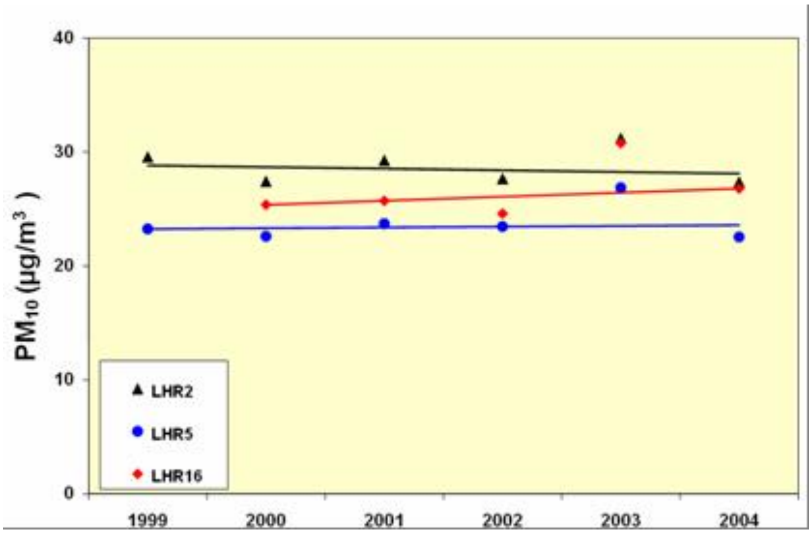
Trends in measured PM concentrations

94. Trends in annual mean PM10 concentrations at three monitoring locations have been considered for the period 1999-2004 using the same methodology as used for nitrogen oxides (see Figure 2.23). These include the airfield perimeter site (LHR2), an urban background location (LHR5) and a site predominantly influenced by road traffic emissions (LHR16). The results show no statistically significant trend over this period at any site. For comparison, data collected from the 48 national network sites (AQEG 2005a), show a downward trend in concentration (around 0.5 µg/m3 a year) observed between 1992 and 2000 which then appears to have flattened off, or even reversed in the period 2000 to 2003. The precise reason for this is not known, but may be linked to meteorology and possibly the increased penetration of diesel vehicles (AQEG 2005a). There are insufficient data available to describe trends in measured PM2.5 concentrations in a robust manner.

Airport contribution to PM10 concentrations

95. The same methodology as described in paragraphs 74 to 79 for nitrogen oxides can be used to estimate the airport contribution to measured PM10 concentrations. For LHR2 a contribution of about 0.9 µg/m3 is estimated, representing approximately 3.1% of the total. This is an unadjusted TEOM concentration. There will be significant uncertainty associated with this estimate but even if it was a factor of 2 higher it would still be a small number.

Figure 2.23 Trend in annual mean PM10 concentration

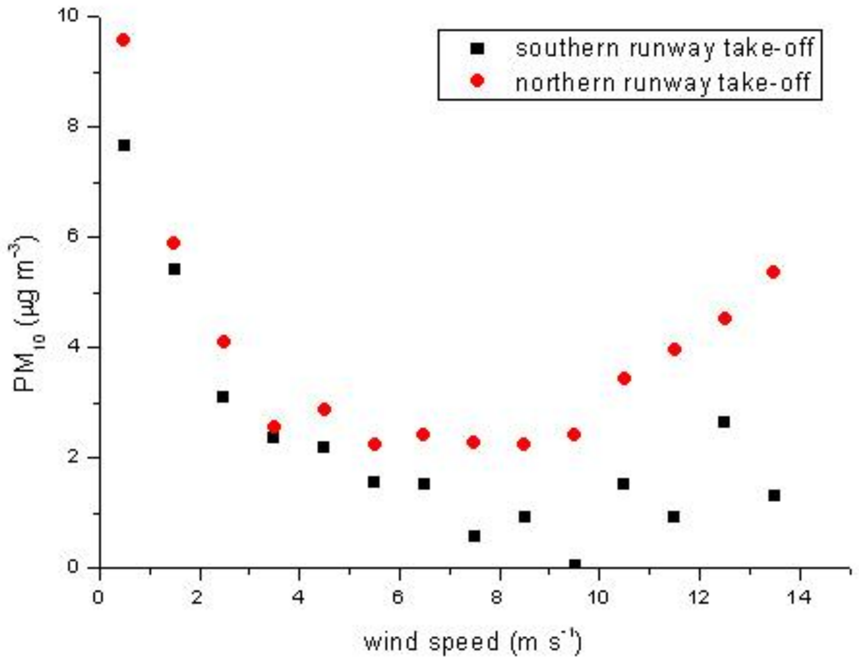


Concentrations expressed as rolling monthly means at LHR2, LHR5 and LHR16 (1999-2004). Best fit linear trend of -0.15ug/m3/year; +0.07ug/m3/year; +0.36ug/m3/year respectively. No significant trend detected.

PM10 concentrations related to wind speed

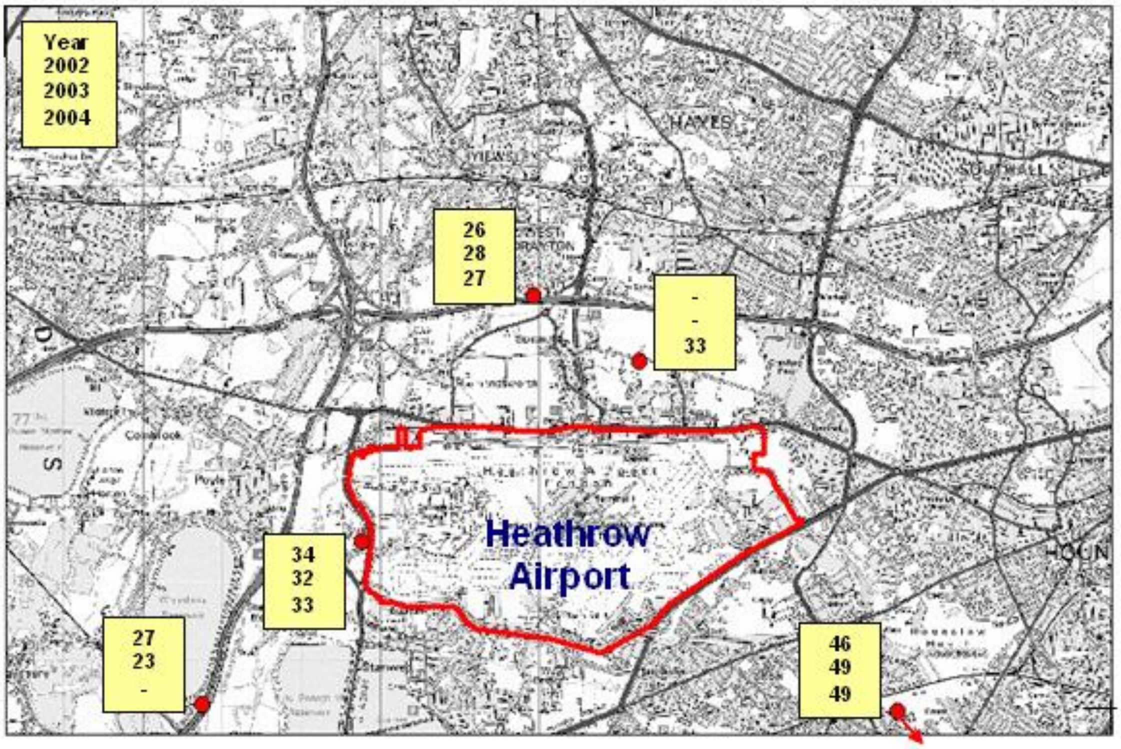
96. A similar approach to that described in paragraph 2.84 has been used to analyse PM10 concentrations by wind speed at the LHR2 site, and the results are described in figure 2.24. The profile is markedly different from that for NOx concentrations. At low wind speeds there is little difference in measured PM10 concentrations between the southern and northern runway use for take-off, but as wind speeds increase, PM10 concentrations also increase, to a greater extent for northern runway operations. This indicates a contribution of aircraft emissions to measured PM10 concentrations, but importantly, a potentially significant contribution from re-suspended particulate matter. At this stage it is not possible to quantify this contribution, but it could be an important consideration for modelling of PM10 concentrations.

Figure 2.24 PM10 concentrations measure at LHR2



Ozone

Figure 2.25 Annual mean ozone concentrations (mg/m3) 2002-2004



Measured concentrations of ozone

97. A summary of annual mean ozone concentrations is provided in Table A8.10 in Annex 8. The data are also shown mapped in Figure 2.25 with concentrations in 2002, 2003 and 2004 described at each location. Regional background concentrations of ozone are on average about 45 to 50 µg/m3 (LHR6). Levels are lower at background sites in the vicinity of the airport due to NOX depletion at around 30-35 µg/m3. As expected the lowest concentrations are measured at roadside sites, e.g. 20-25 µg/m3 at LHR10.

LIDAR

98. The LIDAR study at Heathrow Airport has provided information on the near-field dispersion of aircraft plumes (see report in Annex 7). The dispersion further from the source has been studied using the LIDAR instrument at Manchester Airport, although at the time of writing only preliminary results have been reported to the Panels.

99. Results from the studies have suggested that in the near-field the plume from an aircraft at the start of take-off behaves as a wall jet (the ground being the 'wall'), being

spread out laterally by interaction with the ground. This near-field jet dispersion lasts for several tens of seconds, and extends a few hundred metres from the aircraft.

100. At the point where aircraft power-up to start their take-off roll, the jet plume forms a single plume that expands outward and upward. The width is roughly equal to the downstream distance with the height around 18% of the downstream distance, i.e., the plume is 100 metres wide and 18 metres high at a distance 100 metres downstream of the aircraft.

101. Once the aircraft are moving down the runway the behaviour changes and two jet plumes form, with spacing just wider than the wingspan. This observation applies to wing-mounted jet engines. It is not yet known whether the same behaviour applies to tail mounted jet engines.

102. After the jet phase, the plume disperses through wind shear and buoyancy. Buoyancy is more significant under light winds, and can lead to the plume leaving the ground. There are some indications of this in the Heathrow data, but it has been demonstrated more clearly in the preliminary results of a separate study carried out at Manchester Airport. The data from the Manchester Airport study are still being analysed in detail. They show, however, evidence of buoyant plumes leaving the ground and of plumes behind aircraft after lift-off slowly descending.

Panel 2 conclusion and recommendations

Key points

The Panel's principal general conclusions were:

- A review of the possible pollutants related to the local impact of airports identified the need to focus on NO2 and particulate matter. NO2 is one component of NOX emissions, and concentrations are also determined by reaction with ozone, thus NOX and ozone have been included. For particulate matter, consideration has been given to PM10 and PM2.5.
- Data have been taken from several networks with monitoring stations in the Heathrow area, which use automatic analysers operated to a high standard of quality assurance and quality control (QA/QC). There are more sites with NOX analysers than PM10 or ozone analysers. There are only a few sites with PM2.5 analysers. The data referenced within this report are expected to have a level of uncertainty similar to or better than required by the EU Directive, namely ±15% for NOX and NO2, and ±25% for PM10.
- An evaluation of the available monitoring identified a justification for four additional sites, to help understand the dispersion of pollutants away from the airport; to define worst-case exposure to airport and traffic sources; and to define exposure to the south-east of the airport. These sites have been

established by DfT and the London Boroughs of Hillingdon and Hounslow. No further monitoring is considered necessary.

- The NO2 results show that the annual mean UK air quality objective, which applies from 2005, is likely to be exceeded on the edge of the airfield (LHR2) and close to the motorways (LHR10 and LHR16). The 1-hour objective is not expected to be exceeded.

Nitrogen oxides and nitrogen dioxide

The Panel's principal conclusions in relation to NOX and NO2 were:

- The general picture is of a regional background NOX concentration of 35-45 µg/m3, which is enhanced by the airport to give a local background of 70-80 µg/m3, and further enhanced close to the motorways to levels of 110-210 µg/m3, and to 120-130 µg/m3 on the airfield perimeter.
- Over the period 1993-2004 there has been a highly significant downward trend in annual mean NOX at the airfield perimeter (LHR2), but a minimal downward trend in NO2.
- Over the shorter period 1997-2004 at the airfield perimeter (LHR2), whilst there has been a significant downward trend in total NOX there has been no significant trend in the contribution of on-airport sources to NOX. These sources were identified by subtraction of local background and examining winds from the airport.
- The ratio of NO2 to NOx shows evidence of increasing in recent years at all sites. This may be due to increasing primary emissions of NO2 and to a rising ozone background.
- Bivariate pollution roses, which incorporate wind speed as well as wind direction, have been used to infer the airport and aircraft contributions to local concentrations. They strongly suggest that the aircraft emissions of NOX behave as a buoyant source rather than a ground-level source.
- The bivariate pollution roses indicate that the airport sources of NOX and NO2 can be detected at least 2.8 kilometres from the airport. Analysis of the results suggests that the airport contributes around 30 µg/m3 to annual mean NOx concentrations at the north-eastern airfield perimeter, declining to around 6-10 µg/m3 around 1 kilometre further away to the north-east. To the west and southwest the contribution just outside the airport boundary is lower at around 2-6 µg/m3. The prevailing south-westerly winds account for the higher contribution to the northeast.
- The daily switching in the use of the northern runway and southern runway for take-offs to the west has been used to show that aircraft emissions during take-off make a significant contribution to concentrations at the airport boundary. This analysis has also shown that during periods of stronger winds >6 m/s, the aircraft contribution reduces by a factor of 10 between a monitor 180 metres from the centre of the runway and a monitor 1,230 metres from the centre of the runway in a transect to the north of the northern runway.
- Short lived high concentrations of NOX are observed at the monitoring site LHR2, 180 meters north of the centre of the northern runway during take-off, rising to over 1,000 ug/m3 as a 10 second average. When the southern runway is being used for take-offs short-lived peaks at LHR2 are only a few tens of

ug/m3. This suggests that the plumes from aircraft using the northern runway are still very coherent as they pass the nearby monitoring site LHR2.

Particulate matter

The Panel's principal conclusions in relation to particulate matter were:

- The general picture is of a regional background PM10 concentration of 21-23 µg/m3, which is enhanced by the airport to give a local background of around 25 µg/m3, further enhanced close to the motorways to levels of 25-30 µg/m3 and to 27-31 µg/m3 on the airfield perimeter. The airport and local road thus make only a marginal contribution to local concentrations compared with their contributions to NOX.
- Analysis of the data suggests that sources on the airport are only contributing around 1 µg/m3 to annual mean PM10 at the airfield perimeter.

Dispersion of aircraft take-off plumes

The Panel's principal conclusions in relation to the dispersion of aircraft take-off plumes were:

- A study of the dispersion of aircraft plumes during take-off has been carried out using a LIDAR instrument. In the near-field the plumes from the aircraft engines at start of take-off merge to form a single plume that behaves as a wall jet, being spread out laterally by interaction with the ground. This near-field jet dispersion lasts for several tens of seconds and extends a few hundred metres from the aircraft. After this phase the plume disperses through wind shear and buoyancy. Buoyancy is more significant under light winds, and can lead to the plume leaving the ground. During or shortly before aircraft roll, two separate plumes may form on either side of the aircraft owing to flows associated with the development of lift.
- Further analysis of LIDAR data should improve the capability to model aircraft emissions more accurately. This work is being pursued as a follow-on task from the work of the Panel.

Panel 2 recommendations

The following are the recommendations arising from the work of Panel 2:

- The evidence of increasing NO2/NOX ratios over recent years has implications for modelling of concentrations in future years.
- Monitoring should continue at the new sites LHR4, LHR7 and LHR19 for compliance purposes and to inform future modelling studies. Site LHR20 should be discontinued or relocated.
- The contributions of the on-airport sources to concentrations around the airport have been estimated. This should provide a useful basis for model validation.
- The pattern of concentrations due to on-airport sources shows an unusual dependence on wind speed. It would be appropriate to test the model performance to see if this pattern can be replicated.

- Further analysis of fast-response NOX data would help understand plume dispersal. This could be analysed quantitatively, potentially by aircraft type, and in relation to wind speed and wind direction.
- The use of LIDAR has the potential to greatly improve understanding of plume behaviour from aircraft at different stages from ground manoeuvring to take-off. Further work should be carried out to evaluate available data to help improve input parameters for the modelling of aircraft emissions.

Department for Transport

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Introduction and Panel 3 objectives

1. The work of Panel 3 has focused upon characterising key pollutant sources within Heathrow Airport and its environs and providing a more robust estimate of their temporal and spatial magnitude. A first task of the Panel was to determine which pollutants were to be considered as part of the review process. This was a cross cutting exercise involving both Panel 1 and Panel 2. A joint Key Pollutants report was produced which, after considering trends in pollutant concentrations at and around Heathrow Airport and evidence from scientific literature, supported an initial decision that NO_2 and PM_{10} were the species that should be evaluated (Raper and Laxen 2005). After determining which pollutants to consider the Panel took as a starting point the 2002 Heathrow Airport Emissions Inventory (Underwood et al. 2004). Through an iterative process the Panel identified the major sources where emission estimates could improve on previous studies. The result was to identification of emission sources into three groups with sufficient uncertainty in emission strengths and magnitude to be addressed further. These were: Aircraft, Airside Sources and Landside Road Vehicles.

2. The main objectives of Panel 3 were:

- To identify key emission sources;
- To reduce uncertainty in emission characteristics; and
- To provide recommendations for future emission calculation.

3. This report is based on a series of detailed technical reports and working papers produced as part of the detailed review process. Each of the substantive sections dealing with Aircraft Emissions, Airside Sources and Road Vehicle Emissions contains a summary of the key findings of these reports. Also where appropriate within each of these sections there are a series of **recommendations** related to future emission inventory construction.

Technical Reports

1. Eyers CJ. 2005a. The Use of Characteristic and Average Emissions Factors in the PSDH Inventory for London Heathrow Airport. QinetiQ/05/01725.

2. Eyers CJ. 2005b. Correction to Engine Emission Data Resulting from Engine Deterioration. QinetiQ/05/01726.

3. Horton GC. 2005. The calculation of the effects of ambient conditions and forward speed on aircraft gas turbine emissions. QINETIQ/05/01805.

4. Curran RJ. 2005. Deterioration of Engine Emissions Performance for Application to London Heathrow Inventories. QinetiQ/05/01726.

5. Garcia-Naranjo A and Wilson CW. 2005. Primary NO2 from Aircraft Engines operating over the LTO cycle. RC110187//05/01.

6. Morris K and Easey N. 2005. Results from two surveys of the use of Reverse Thrust of aircraft landing at Heathrow airport. ENV/KMM/1128/14.18. (PDF, 112KB)

7. Buttress J and Morris K. 2005. An estimation of the total NOX emissions resulting from aircraft Engine Ground Running at Heathrow airport. ENV/KMM/1127/14.18. (PDF, 130KB)

8. Curran RJ. 2006. Method for estimating particulate emissions from aircraft brakes and tyres. QINETIQ/05/01827. (PDF, 180KB)

9. Hurley CD, Eyers CJ and Calvert WJ. 2006. Estimation of Total Particulate Emissions from Civil Aero Engines at London Heathrow. QinetiQ/06/00472. (PDF, 164KB)

Working Papers

1. Taylor P. 2004a. *An introduction to Road Traffic Models.* Working Paper P3.1-WP06.

2. Taylor P. 2004b. *Primary PM10 Emissions from Non-Engine Sources.* Working Paper P3.2-WP19.

3. Hackman M. 2005a. *Vehicle Traffic Speeds.* Working Paper P3.4-WP25.

4. Taylor P. 2005. *Relative Importance of Traffic Parameters*. Working Paper P3.4-WP31.

5. Hackman M. 2005a. *Diurnal Traffic Profiles for Heathrow.* Working Paper P3.4-WP33.

Cross Cutting Report

6. Raper D and Laxen D. 2005. *Key Pollutants.* Annex 5 to this report.

4. The techical reports and working papers listed above are all available via the Aviation section of the Department for Transport's website at: http://www.dft.gov.uk. It should be noted that the individual reports and working papers behind chapter 3 have not been peer reviewed.

Emission sources affecting air quality at London Heathrow Airport

5. The spatial and temporal concentration of pollutants observed at Heathrow airport and within its environs is influenced by a wide number of airport, local and background sources. This clearly was a problem for Panel 3 in determining those sources that are likely to have a significant impact on air quality at Heathrow Airport. Usually, an emissions inventory relates to a specific spatial domain, for example a city, region or country. The remit of Panel 3 was to examine those sources which have the potential to significantly impact airport air quality and this clearly precludes the identification of a precise spatial boundary. As a consequence for the purpose of Panel 3 assessment it was decided that the following sources have a significant impact upon air quality at London Heathrow Airport:

- Aircraft in the landing take-off flight (LTO) phases, and ground operations including APU emissions and engine test emissions;
- Airside vehicles, plant and aircraft support equipment;
- Road vehicles on airport landside roads and on the road network around the airport;

6. Other sources are conventionally included in the inventory for completeness, although they make a minor contribution to total airborne concentrations for the pollutants of interest. These include:

- Airport car parks and taxi queues;
- Airport heating and boiler plant; and
- Airport fire training exercises.

Previous inventory source identification and strengths

7. An emission inventory for London Heathrow airport has been compiled many times in the last few decades, an early example being that of Parker (1973). A major inventory activity related to the Heathrow Terminal 5 planning application, starting at Warren Spring Laboratory (Leech 1994) and later continuing at netcen (an operating division of AEA Technology plc) (Underwood et al. 1994), was commissioned by BAA plc. This work included inventories for a current year - originally 1991 but later updated to 1993/4 (Underwood et al. 1995) - and forecasts for (then) future years (2002, 2016); the pollutants NO_X, CO, NMVOC and SO_2 were included in the inventories, with PM_{10} added to the later versions (Underwood et al. 1996). These inventories underwent a number of revisions during the period of the Terminal 5 Public Inquiry, with the final versions appearing in evidence (Pratt 1998), by which time benzene had been added to the pollutant list. For the Terminal 5 evidence, additional sensitivity cases for 2016 were requested by the Inspector up to a maximum airport throughput of 100 million passengers per annum (mppa), in addition to the base case of 80 mppa.

8. Netcen continued thereafter to compile regular updates of the Heathrow emissions inventory for a current year, including 1998 (Underwood and Walker 1999) (NO_X, CO, NMVOC, PM_{10} and - later - SO_2), 2000 (Underwood and Walker 2003) (excluding landside road network) (NO_X, PM_{10}, NMVOC) and 2002. The last of these was compiled in two parts, Part 1 (Underwood et al. 2004a) including NO_X and PM_{10} only and Part 2 (Underwood et al. 2004b) included CO, CO_2, SO_2, benzene and 1,3-butadiene. A significant part of the difference in estimates of annual emissions of a given pollutant from one inventory to the next arises from improvements in sources of activity data, operational data and emission factor data. For aircraft emissions, the 1998 inventory was the first to have (partial) recognition of reduced-thrust take-off. In addition to the series of updates of a current-year emission inventory, netcen also prepared, for BAA, a forecast emission inventory for 2010 (Part 1: NO_X and PM_{10} (Underwood et al. 2004c); Part 2: CO, CO_2, SO_2, benzene and 1,3-butadiene (Underwood et al. 2004d)).

9. In addition to the inventories prepared for BAA, netcen also prepared, for the DfT, inventory forecasts (NO_X and PM_{10}) for Heathrow as part of the SERAS (South East and East of England Regional Air Services) study (DfT 2003a), for the years 2015 and 2030. These forecasts were prepared in the context of an optioneering exercise, using less detailed information and methodologies than for the BAA inventories. Subsequently, the methodology was refined for the air quality assessments underpinning the air transport White Paper (DfT 2003b), for which NO_X inventories were prepared for the years 2010, 2025 and 2030, for various assumptions about the evolution of aircraft engine emissions performance and various runway configurations.

Aircraft emissions

Introduction

10. The dominant source of airport-related emissions from aircraft are the main-engine exhausts during the take-off phase. The methodology recommended for the estimation of these emissions is the principal focus of the discussion in this Chapter. Separate consideration is also given to estimation of emissions from Auxiliary Power Units (APUs), brakes and tyres and engine testing.

11. For aircraft operating during the LTO phases, the contribution to aircraft exhaust emissions (in kg) arising from a given 'mode' of aircraft operation (taxiing, for example) is given by the product of the duration (seconds) of the operation, the number of engines per aircraft [1] , the engine fuel flow rate at the appropriate thrust setting (kg fuel per second) and the emission factor for the emission of interest (kg emission per kg fuel). The annual emissions total for the mode (kg per year) is obtained by summing contributions over all engines for all aircraft movements in the year of interest.

12. For the vast majority of aircraft engines operated at major airports, values for times-in-mode (although not engine specific), fuel flow and emissions factors are set out in the ICAO engine emissions databank (ICAO 2005). These values are standard 'certification' values. Although technically well founded from a certification point of view, actual aircraft operation results in variation from these 'certification' values. The methodology recommended for the assessment of these variations for Heathrow operation is described here, together with the method for obtaining predictions of emissions from future aircraft.

13. In line with the key pollutants of interest in this Heathrow analysis (Raper and Laxen 2005), this chapter focuses upon oxides of nitrogen (NO_X) and particulate emissions.

[1] Except for less-than-all-engine taxi operations

Main engine emissions

Movement data

14. For the purposes of estimating main engine emissions, movement data are needed broken down by aircraft and engine type together with information on stand and runway used. For past years, actual flight-by-flight data for Heathrow are available from BAA, but less detailed information is likely to be available for future cases. A methodology for assessing emissions based on these types of movement data is described in the next section.

15. For future cases, aircraft emissions are more likely to be calculated from:

- Predicted number of movements for existing aircraft type;
- Updated engine mix for existing aircraft types;
- Emissions assumptions for new engine types on existing aircraft types;
- Number of movements for new aircraft types;
- Engine emissions assumptions for new aircraft types;
- Assignment of each of these movements to terminal, runway and departure route; and
- Assumptions of the climb performance characteristics of new types.

16. This dataset is unique to any given future year, airport and set of scenario assumptions.

17. There NO_X is a key emission, best estimates will be obtained by focussing on large aircraft movements. NO_X emissions from small aircraft and helicopters are generally one or two orders of magnitude less per movement than current large commercial aircraft. Because of the lack of available data, the relative particulate emissions are less clear. For Heathrow, the dominance of large aircraft suggests that they will dominate the particulate emissions from aircraft sources.

Aircraft and engine types

18. For a 'current year' inventory (for example, 2002), aircraft movement data provides airline and aircraft type information. Acceptable engine fits can be estimated based on airline fleet data for those airlines operating at the airport. There are a number of sources for engine data either from the airlines themselves or from commercial sources. [2]

19. Given the coverage of the available engine fit information on all major commercial aircraft at Heathrow, the uncertainty resulting from missing information on small aircraft and helicopters is likely to be extremely small.

20. For future years, aircraft types not yet in production - sometimes not even yet designed - will need to be included in the inventory. To characterise emissions from such aircraft, a technology review will be carried out to assess the rate of progress of emissions technology. When combined with fleet growth assumptions for a particular future scenario, the review data will provide forecast emissions from future aircraft types.

ICAO engine emission factors

21. Having established the aircraft and engine types and their individual movements, it is necessary to calculate the emissions from these aircraft.

22. ICAO engine emission factors (ICAO 2005) give certification test results for most [3] engines in service, at four thrust settings (7%, 30%, 85% and 100%). These data are taken under certification test conditions and much effort is made to maintain the accuracy of the data. Measurement system uncertainty is believed to be of the order of one percent for NO_X. Engine-to-engine variability and other technical and operational factors which may result in actual emissions deviating from these certification values are discussed in the following sections. Data for some engines not listed in the ICAO databank (usually turboprops) can be obtained from the FAA Aircraft Engine Emission Database. [4] Although the data in this latter reference are of variable quality, the influence on emissions results at Heathrow of the relevant (usually smaller) aircraft types is insignificant for NO_X and highly unlikely to be significant for particulate emissions.

23. ICAO recommends that emission indices (for NO_X, UHC and CO) for thrust settings, other than those used in the certification process, should be calculated by use of the Boeing Fuel Flow Curve Fitting Method. However, this methodology requires knowledge of fuel flow and such data are not normally available. Where fuel flow data are not available, CAEP recommends that a power-law fit of emission index versus thrust is the best option for UHC and CO and a multi-order polynomial fit is the best option for NOx emissions, though the order of the fit varies from engine type to engine type.

Recommendation: Pending further advice from CAEP, for PSDH it is recommended that the fuel flow curve fitting method is used. If fuel flow data is not available, suitable power (UHC and CO) and polynomial (NO_X) fits are recommended for PSDH.

24. For particulate emissions, the ICAO databank does not contain emission factors for PM_{10} directly, but does include 'smoke number' (SN), an indirect measure of carbon-based particulate emissions calculated from the reflectance of a filter paper measured before and after the passage of a known quantity of smoke-bearing exhaust gas. A methodology has been proposed to CAEP, known as the "First Order Approximation" (FAO). The method provides a correlation between particulate mass and the published smoke number. It also provides a first estimate of sulphur-based and fuel-based volatile particulate emissions. Whilst this method is still in development within CAEP, a preliminary version has been recommended for approval by CAEP and is therefore of sufficient maturity to allow it to be adapted for use for PSDH analysis. The FOA method comprises a correlation between SN and particulate mass using data from experimental work, now supported by engine measurements and a typical engine air fuel ratio for each of the four LTO engine conditions. Where SN data in the databank is incomplete, a method for approximating the SN value at each setting is proposed, thus avoiding the previous need to use maximum SN at all engine settings. Sulphur-based volatile particulate emissions are estimated on the basis of typical fuel sulphur content and a 3% initial mass conversion rate to S(VI) (expressed as mass of sulphate). It is recognised that further conversion will occur after the emission leaves the engine; this 3% value should be regarded only as a source emission estimate. Finally, an estimate of fuel-based volatile emissions are made based on a single NASA engine test and using engine UHC emissions indices to apply this result to other engine types. A fuller description and references are contained in Hurley et al. (2006). There remain significant uncertainties in deriving PM_{10} emission factors from SN and the limited sources of other data, and updates to this method should be expected as more data emerges from current trials. Nevertheless, these improvements to the non-volatile estimates and the inclusion, for the first time, of volatile particle mass estimates are believed to represent a significant step forward. That said, emission factors for PM_{10} remain considerably more uncertain than those for NO_X.

Use of Characteristic vs Average Values

25. For each engine quoted in the ICAO Emissions Databank, there are two emissions D_P/F_{00} [5] values given for NOX, UHC, CO and smoke, namely 'Average' and 'Characteristic'. The Average Value is simply the average DP/F00 for the test results from the engine(s) submitted for certification testing for each engine type, corrected to the reference standard engine and reference atmospheric conditions. The Characteristic Value is the average DP/F00 (or smoke number) value divided by a dimensionless coefficient corresponding to the number of engines tested. This is in recognition that at the certification stage there are usually not many engines to production standard available for testing, so the manufacturer is allowed to select any number of engines, including a single engine if so desired, for testing. Statistically derived coefficients, corresponding to the number of engines tested, are then also applied to ensure a 90% confidence that the mean of the anticipated total engine production will not exceed the regulatory level. The combined value of these coefficients for NOX are:

Table 3.1 Coefficient used to calculate Characteristic Values from Average Values according to the number of engines tested

Number of engines tested	1	2	3	4	5	6	7	8	9	10
Coefficient	0.8627	0.9094	0.9441	0.9516	0.9567	0.9605	0.9634	0.9658	0.9677	0.9694

Source: ICAO 1993, Appendix 6

26. If more than 10 engines are tested, the coefficient is:

1 - (0.09678 / v(Number of engines tested))

27. The factors by which the Average Value is increased to calculate Characteristic Value for engine certification emissions have been examined in the context of the PSDH investigation (Eyers 2005). While valid for certification, it is concluded that the Characteristic Value contains a significant margin to account for uncertainties in the certification process when applied to the single engine type undergoing certification. These factors have been found to be inappropriate for an inventory application where a 'best estimate' of emissions is being sought, as is the case for PSDH. In the wider context, if a 'not-worse-than' estimate were to have been required, then it is likely that some minor factors used for calculation of the Characteristic Value could be applied. The application of such factors would depend on the individual airport and the degree of certainty required.

28. Although focussed on NOX, the rationale described can be extended to particulate matter.

Recommendation: Average Values from the emissions databank are used for the NO_X and particulate emissions inventory.

Variation from ICAO factors - Technical effects

29. Whilst recognising that ICAO emissions factors give a good grounding for engine emissions when available, a number of technical issues were identified relating to aircraft operation and performance that may affect actual airport emissions. Some of these purely operational issues are dealt with later in this chapter This section describes the recommended approach to account for purely technical effects on emissions relative to the published ICAO databank emissions.

30. The technical issues covered in this section are:

- Ambient conditions effects on emissions;
- Forward speed effect on emissions;
- Engine deterioration effect on emissions;
- Engine start and transient emissions;
- Primary NO_2 emissions; and
- Emissions from future engines

31. ICAO is also developing recommendations for the effects of ambient temperature and forward speed on emissions. Whilst preliminary recommendations were made to CAEP/6, this work is being reconsidered in the light of the work presented in this section.

Effect of ambient conditions (temperature, pressure, humidity)

32. During engine certification, emission data are measured at four specific operating points (7%, 30%, 85% and 100% of the full rated output thrust), which were intended to represent the four phases (taxi, approach, climb-out and take-off, respectively) of the LTO cycle, when the certification scheme was first constructed. These data are all taken at, or corrected to, ISA [6] , sea level, static conditions. However, actual operations occur at various ambient conditions, possibly leading to errors in the predictions of aircraft emissions, for example, at certain times of the day or for certain engine types. As part of the PSDH work, studies were carried out to understand the potential scale of any effects of ambient conditions. The study revealed that modern engines were potentially sensitive to ambient conditions and that the effect on the Heathrow inventory was not negligible. As a result, an inventory-type methodology has been developed for assessing changes to NO_X emissions at Heathrow due to ambient conditions. The study result and methodology are briefly summarised here and described in more detail in Horton (2005).

33. The data which are available for civil aircraft gas turbine emissions, taken from the certification tests, consists of four values of the parameter ElNOx at the four prescribed operating points of 7%, 30%, 85% and 100% of full rated output thrust (F_{00}). The ICAO specification for taking these measurements (ICAO 1993) requires that they should be corrected to ISA, sea level conditions and defines the approach to be adopted for performing the corrections. There is no similar correction for smoke (particulates) in the ICAO specification.

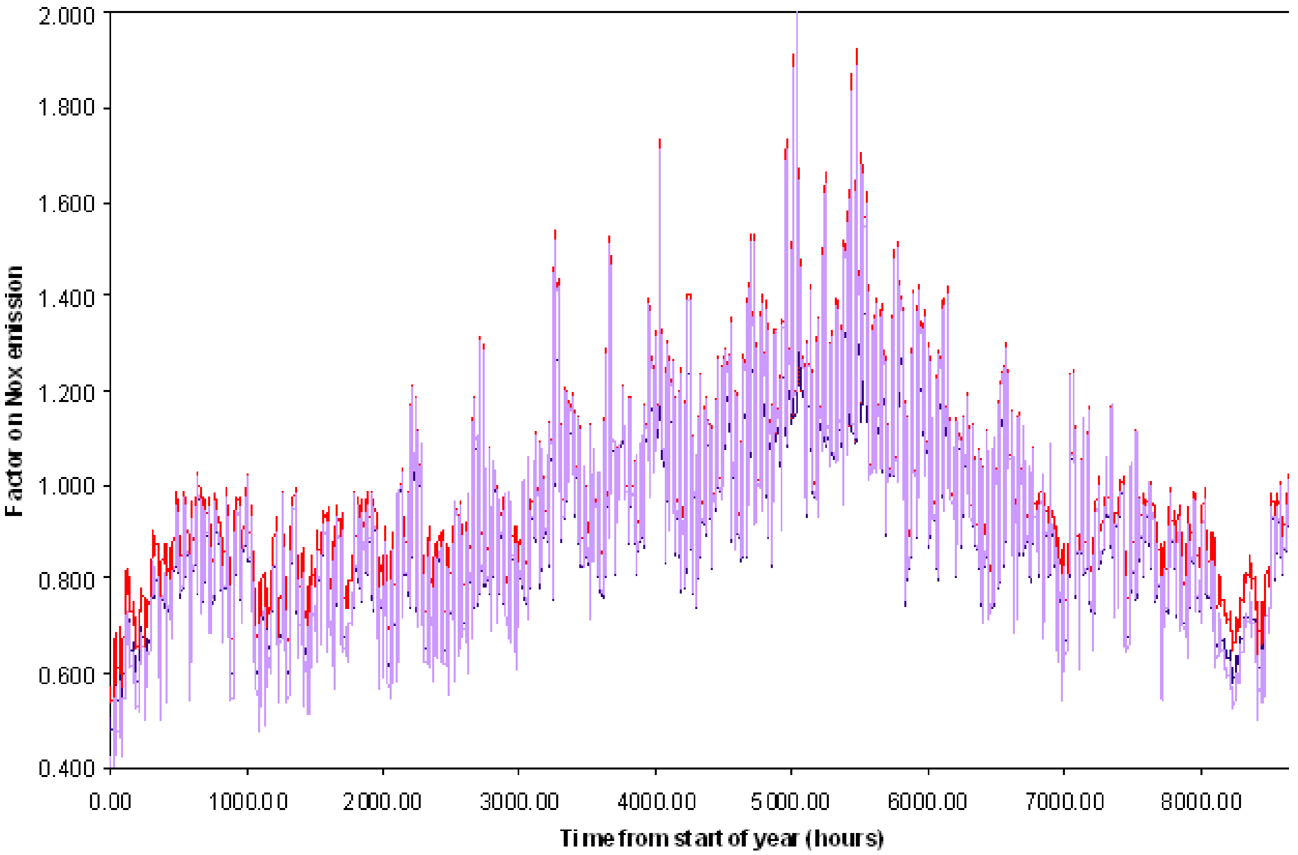
34. Taking this approach in reverse, it is theoretically possible to account for actual ambient conditions by applying the ICAO correction factors from ISA, sea level, to the actual ambient conditions encountered. However, the ICAO methods depend on data being available for an emission index (El) as a function of combustor inlet pressure and temperature, taken at the four prescribed operating points. These data are normally available to the organisation taking the measurements (generally the engine manufacturer), but are not normally made publicly available. However, the absence of these temperature and pressure data can be approximated using assumptions based on the generic behaviour of gas turbine engines. This method assumes, for example that changes in compressor exit pressure and temperature are proportional to the ambient pressure and temperature changes and that the relationship between combustor inlet temperature (Tb) and EINOx can be characterised in terms of the engine overall pressure ratio (OPR). Tb and EINOx values have been extracted from four engines across the range of OPRs. From these various engines backed by a theoretical consideration of increasing NOx emission sensitivity to increased pressure, three 'generic' sets of Tb values have been derived, one for engines of less than 25 OPR, one for engines with OPR values between 25 and 35 and one for engines of greater than 35 OPR. These generic sets of Tb values have been used to analyse the effect of ambient conditions.

35. Although the lack of real Tb data to match the ElNOx values is a potential source of error, it is believed that the magnitude of such errors in relation to the total emissions is likely to be small, particularly as the overall approach is to derive factors to be applied to the measured emissions rather than to predict the absolute levels. A sensitivity study has been carried out which demonstrated the relatively high sensitivity of the derived factors to curve fitting methods and calculated values used for Tb. For curve fitting, the 'best estimate' values used in the methodology were shown to represent close to the maximum sensitivity to ambient conditions. The sensitivity study therefore suggests that the predicted sensitivity to ambient conditions (and forward speed - see the next section) may be higher than found in actual operation but is less likely to be lower. Nevertheless, with the information available, the methodology represents the best estimate of sensitivity to ambient conditions. Details of this methodology are given in Horton (2005).

36. By using the approach described above, the effect of changes in ambient conditions on NO_X emission have been performed for each hour of a complete year using meteorological data for Heathrow for 2002. An extreme example is shown in Figure 3.1 in which a high (40:1) pressure ratio engine [7] shows NO_X variations above ±50% during variations in the relatively temperate Heathrow climate. Other engines at Heathrow have lower pressure ratios and will exhibit less sensitivity.

37. Whilst over the year, when averaged for engines operating at Heathrow, these factors represent a reduction of only 2 or 3% compared to standard ICAO NO_X values for the Heathrow climate [8] , the seasonal and diurnal effects are significant. This has the potential to significantly affect the spatial and temporal distribution of NO_X emitted from aircraft. A methodology to account for these seasonal and diurnal variations has therefore been developed for application in PSDH.

Figure 3.1 Hourly NOX emissions factors for a high pressure ratio engine at Heathrow Airport in 2002.



38. The methodology comprises the following steps:

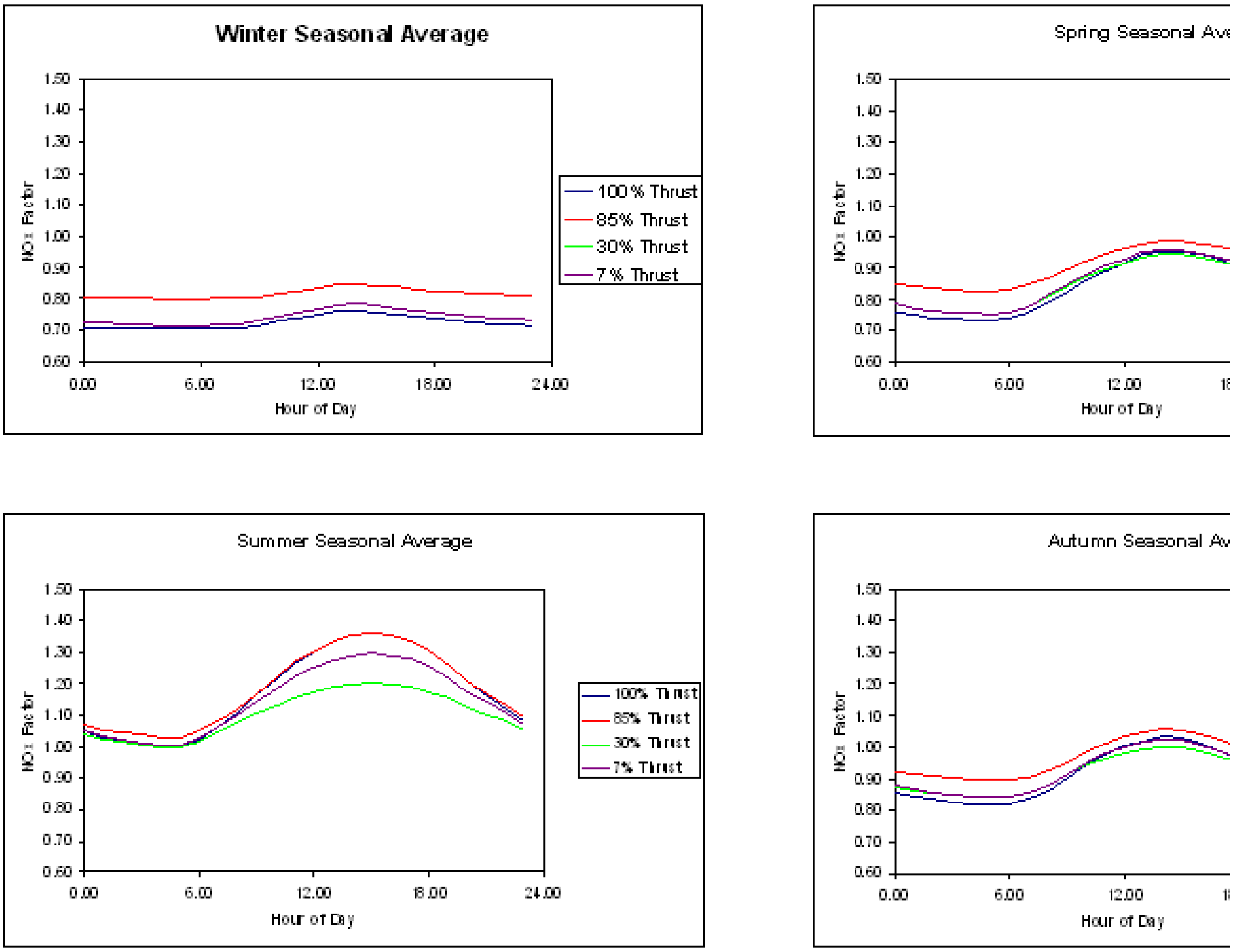
- Identify the engine type, time of day and season for an individual flight;
- Identify whether take-off is at full thrust or not (If not, use data for 85%); and
- Use look-up tables [9] to obtain the EINOx factor for that particular LTO phase, to be applied independently of other factors (e.g., forward speed) to the NO_X calculated for that LTO phase.

39. The look-up tables referred to in the methodology are simply the application of the engine modelling approach described in Horton (2005). For 2002, these are combined with actual meteorological data to produce NO_X factors for each movement. For forecast cases, these are combined with meteorological data for Heathrow and ICAO databank values to produce, for each engineor group of engines in the ICAO databank, a set of seasonal/diurnal EINOx factors at each of the four ICAO thrust settings. The factor for the most appropriate of the four thrust settings should be used for each phase of the LTO cycle, although, if required, NO_X values for operation between the four ICAO thrust settings can be obtained using a curve fitting method similar to the Boeing Fuel Flow Method, on the four ambient-corrected values.

40. An example of seasonal/diurnal EINOx factors for the same 40:1 pressure ratio engine in Figure 3 are shown in graphical form in Figure 3.2 below, demonstrating the inventory impact on emissions for this ambient-condition-sensitive engine.

41. Manufacturer comments in PSDH and sensitivity studies (Horton 2005) on the Tb versus EINOx values have suggested that the NO_X variations selected may be high. It is intended to review this methodology through the ICAO/CAEP process. If more detailed data can be obtained, for example from engine manufacturers which give an EINOx/Tb correlation based on their proprietary information, then an improved correlation may become available to use to adjust those factors currently proposed.

Figure 3.2 Seasonally averaged factor for NOX emissions factor variation with time of day for a high pressure ratio engine



Recommendation: Currently, the factors proposed are based on a reasonable interpretation of the best publicly available information and should be used in generating new inventories.

42. The above methodology is concerned primarily with NO_X emissions corrections for ambient conditions. Particulate emissions are less well understood and there is no equivalent correction in the ICAO methodology.

Recommendation: In the light of this lack of data, and the relatively poor characterisation of aircraft generated particulates, it is suggested that no ambient condition corrections are made for particulate emissions.

Effect of forward speed

43. When an aircraft is moving, there is an effect on the engine as air is pushed into the intake as a result of the forward speed. This effect changes the engine operating parameters compared to static conditions and as a result may also change the emissions production.

44. The starting point for the assessment of forward speed effects was advice due to be issued by ICAO following work carried out by CAEP Working Group 3's Alternate Emissions Methodology Task Group (AEMTG). In ICAO, at CAEP's sixth meeting, it was recommended by Working Group 3 that "the effect of forward speed was small due to the manner of operation of the engine control system and did not need to be included". Whilst it is accepted that forward speed is unlikely to have a major effect on emissions, the work carried out on ambient effects suggested there were non-negligible effects from ambient conditions. Thermodynamically, forward speed is an ambient effect change for the engine. Hence further investigations were made to assess the magnitude of this small effect, particularly for the aircraft using Heathrow.

45. To estimate the effect of forward speed on the emissions, the approach has been essentially the same as that for changes in ambient conditions, with the key influence being the effect of Mach number on the engine inlet relative temperature and pressure. Flight Data Recorder (FDR) information from a limited range of aircraft operating at Heathrow was examined to allow the model to reflect control system reactions during take-off. [10] Further details are given in Horton (2005).

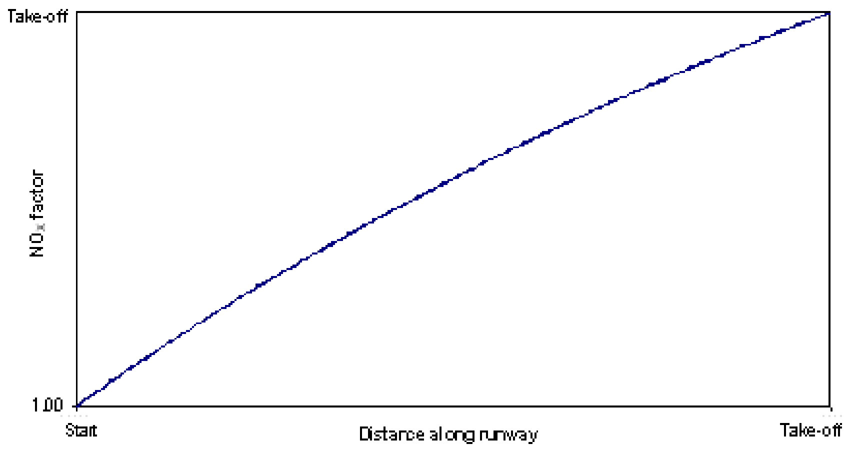
46. To complete the calculation of forward speed effects on emissions, definitions of the forward speed at the different conditions are required. Based on an average for a range of aircraft operating at Heathrow, those which have been adopted are given in Table 3.2.

Table 3.2 Aircraft flight phases and speeds

Flight phase	Average speed
Take-off	150 kts at point of take-off
Climb out	175 kts
Approach	140 kts

47. For take-off, the variation of NO_X emissions during the take-off run at 100% and 85% thrust has been calculated showing maximum increases between 5 and 9% (according to aircraft type) at the take-off point relative to static conditions. These increases average between 2 and 7% for the whole take-off run.

Figure 3.3 Change of NOX emissions factor [11] with distance along runway



Showing at any point along the runway the NOX mass emission rate as a factor of the NOX at static conditions

48. Although subject to the same caveat over improved data as in the previous section, these factors are significant, particularly for the engines with the higher pressure ratios. The change in the factor between static (Factor = 1) and take-off speed (Final factor) is a function of the forward speed and the curve shape can be calculated which is suitable for use for all turbofan engines. This curve is shown in Figure 3.3.

49. **Recommendation: As these variables are not known for each movement, it is suggested that the same method adopted for ambient conditions is also applied to take-off, assumed to take place at 150 kts. Factors can be supplied** [12] for each engine in the ICAO Emissions Databank. These can be applied to each individual flight according to engine fit. Spatial allocation of the increased emissions should be applied as a function of the take-off roll in accordance with Figure 3.3.

Climb-out and Approach

50. Forward speed effects on NOX for climb-out and approach are similar to the take-off case except that speeds are substantially constant whilst small changes in pressure and temperature occur due to the atmospheric lapse rate. As the major effect is the forward speed and the ground-level impact of emissions at higher levels are normally much less than ground level emissions, a simplifying assumption has been made to calculate forward speed NOX factors at ground level, to be applied to climb-out and approach up to 3,000 feet. Forward speeds are those quoted in the table above. Factors can be supplied for each engine in the ICAO emissions databank as for the take-off case. [13] Typical values are a 7% increase in NOX for climb out and 4 to 9% increase for approach. Again sensitivity studies and the manufacturer viewpoint suggest that the forward speed effect may be lower than shown here but is unlikely to be significantly higher.

51. As was the case for the effect of ambient conditions on particulate emissions, there is no reliable information available on the effect of forward speed. As these are similar in character to ambient condition changes, the same conclusion - that of no change in particulate emissions due to forward speed effects - has been be reached. A

small increase due to increases in fuel flow could be included, but this gives a false impression of the significant uncertainty involved in estimation of particulate emissions.

52. It was noted at the beginning of this section that ICAO may be publishing a recommendation that forward speed effects can be ignored for inventory purposes. Based on the insights from this work, that conclusion would appear to be less appropriate for higher precision inventory work such as PSDH involving a significant proportion more recent higher OPR engines. The conclusions from this work have been presented to ICAO (CAEP) for their consideration.

Effect of engine deterioration

53. One major uncertainty relating to characterisation of aircraft engine emissions data is the change in emissions due to the effects of aging on engine operation. Certification data in the ICAO databank is based on tests normally conducted using new (or close to new) production engines and certification data is corrected to production standard. No account of the effects of engine aging or maintenance practice is provided. A review of available evidence has been carried out to derive a value of engine deterioration and the consequential effects on the specific fuel consumption (SFC) and emissions which can be applied to PSDH studies (Curran 2005). From this overview, generic factors have been derived for emission fluctuations resulting from engine deterioration as follows:

- a 4.3% increase in fuel flow during the LTO cycle compared to ICAO databank values;
- a 4.5**%** increase in NOX emissions compared to ICAO databank values.

Recommendation: It is suggested that a 4.3% increase in fuel flow (during the LTO cycle) and a 4.5% increase in NOX emissions be applied to the ICAO databank values to account for engine deterioration.

54. For particulate emissions, there is inadequate information available to derive a separate factor resulting from engine deterioration. Particulate emissions can be factored by the increase in fuel flow, but with the proviso that the uncertainty of particulate emission measurements far exceeds the value of this factor.

Engine start and transient emissions

55. ICAO engine emission data currently does not take account of emissions during engine start-up, shut down or transient operation. If significant, these emissions need to be taken into account in the PSDH emissions inventory.

56. For start up and shut down emissions, an International Coordinating Council of Aerospace Industry Associations (ICCAIA) working paper to CAEP Working Group 2 (ICCAIA 2005) was recently accepted by the Emissions Methodology Task Group. This paper discusses the issues of engine starting and shut down emissions, and makes a simplified estimate of how much unburned hydrocarbon (UHC) emissions can be

expected during the engine start sequence to idle. The working paper draws the following preliminary conclusions:

- shut down emissions are negligible; and
- starting UHC emissions can be of a similar magnitude to the ICAO LTO cycle UHC emissions for in-production engines.

57. NOX is not specifically mentioned in the above paper. However, ICCAIA has confirmed (Madden 2005) that this is because NOX emissions during start-up and shut-down are considered as being negligible. ICCAIA have also confirmed that NOX emissions during engine transient operations can be considered negligible compared to the overall emissions levels.

58. The position for particulate emissions during start-up and transient operation is less clear. Under such conditions, there is an opportunity for conditions in the combustion chamber of the engine to be less than optimum, potentially producing non-negligible particulate emissions. Visual evidence - in terms of the lack of visible smoke - suggests that for conditions encountered at Heathrow, current engines are well controlled during these start-up and transient phases from the point of view of non-volatile particulate emissions. It is suggested that compared to particulate emissions during the rest of the LTO cycle, non-volatile particulate emissions during start-up, transient and shut-down operations are negligible. There is potential for the UHC emissions during start-up to contain a proportion of volatile particles. As for the UHC species emitted during normal operation, there is no available information on this speciation and a methodology to quantify the relatively small quantities involved is not available.

Recommendation: It is concluded that NOX and particulate emissions from engine start-up, shut down and transient operation are negligible and can be ignored for PSDH inventory purposes.

Primary NO2 emissions

59. The preceding sections of this chapter have considered NOX emissions. However air quality is legislated in terms of NO2 only. In this section, a methodology is described to estimate the proportion of NO2 (compared to total NOX) emitted by aircraft engines during airport operations. This data provides input to air quality studies using dispersion and atmospheric chemistry modelling.

60. Aircraft engines emit oxides of nitrogen in different forms. At elevated temperatures, similar to those found in the engine combustor, nitric oxide (NO) is the thermodynamically stable form of NOX. At ambient temperatures found in the environment NO2 is the stable state of the NOX emissions. The conversion of NO to NO2 from the high temperature regimes in the combustor to the temperature regimes found at the engine exit, in the exhaust plume and in the ambient air is a very complex process which depends on other chemical compounds being mixed in with the engine exhaust. There are few data available that identify what the NOX speciation at aircraft engine exit actually is.

61. Measurements of NOX in the literature fall into two distinct categories; those measured with sampling probes and those measured by non-intrusive means. The measurements undertaken by sampling probes were initially designed for the measurement of combustion efficiency through the measurement of CO and UHC. Because of this, they freeze the chemical reactions by reducing the temperature to around 150°C. At this lower temperature the conversion of NO to NO2 is enhanced and hence the speciation measured in this manner exaggerates the true primary NO2 fraction from the engine.

62. Non-intrusive measurements are becoming more prevalent, especially around airports. However, there are difficulties in making these measurements associated with knowing the true diameter of the exhaust plume close up to the engine; while at distances away from the engine the exhaust has cooled significantly and the natural process of converting the NO to NO2 has begun. Again, these measurements do not help us understand the primary NO2 in the exhaust.

63. Due to the difficulties associated with identifying what the true primary NO2 emissions are from information in the literature a modelling study was initiated to identify what these emissions were. Previous modelling studies have indicated that only small changes to the NO2/NOx speciation occur in the hot end of any gas turbine engine, most of the speciation is determined by the combustion process and dilution of the hot gases before they enter the high pressure turbine and in the cooling engine exhaust plume.

64. To support PSDH, three gas turbine combustors were modelled over a range of engine operating conditions to try to identify the effects of engine OPR and LTO operating condition. Models of the combustor were produced by linking a series of reactor models together to form a reactor network. A detailed kinetic scheme for kerosene, which included a detailed NOX chemistry mechanism, was used to predict the combustor emissions. These combustor emissions were compared with data from similar engines in the ICAO database to validate the models and give the NOX speciation predicted credibility. Full details of the methodology used are available in Garcia-Naranjo and Wilson (2005). The results of this modelling are shown in Table 3.3, as recommended primary NO2 emissions values for use in airport air quality models. Note that the values in the table are higher than the modelling results, to reflect uncertainties in the modelling approach used.

Table 3.3 Primary NO2 emissions under different operating conditions

ICAO LTO operating condition	Take-off (100% F_{00})	Climb out (85% F_{00})	Approach (30% F_{00})	Idle (7% F_{00})
Predicted primary NO_2	1 - 8% mean 4.5%	2 - 8.5% mean 5.3%	10 - 20% mean 15.0%	25 - 50% mean 37.5%

65. As the engine operating condition reduces with respect to the take-off condition, the percentage of the exhaust NO_X seen as NO_2 increases. This is to be expected since

at the lower operating condition the combustor is operating less efficiently and will have higher amounts of CO and UHC present. Both CO and UHC have been shown to increase to conversion rates of NO to NO_2 (Hori 1992).

66. As the OPR of the engine increases the percentage of primary NO_2 in the exhaust reduces. Again this was to be expected as increasing the OPR of the engine results in a higher pressure ratio at
idle, more efficient combustion and reduce emissions of CO and UHCs.

67. It should be recognised that these percentages are based on a limited sample of data and that further work and measurements may become available to better define the relationship to operating condition and range of appropriate values.

Recommendation: Based on the available data, it is recommended that the mean of the values in Table 3.3 are used for assessing primary NO_2 emissions from aircraft engines. [14] If sensitivity studies are required on primary NO_2 proportions, then the extreme values shown should be used.

Future aircraft

68. Technology will also have an effect on future aircraft emissions in terms of the fleet mix and emissions capability of aircraft using Heathrow in future years. The current Heathrow fleet results from a combination of technology capability, purchasing policies and aircraft size mix dictated by decisions made over the past 30 years. Emissions of the Heathrow fleet in any future year will be a combination of the current aircraft still flying, a revised aircraft size mix according to routes, runway lengths, etc., and the technology capability of aircraft and engines purchased (or brought out of retirement) between now and the future year in question.

69. The technical capability, in emissions terms, of future engine technology is subject to many variables but is primarily driven by technology breakthroughs combined with political and commercial pressures. For any given aircraft type, engines tend to be in production for around eight years, following which a newer technology engine becomes available offering emissions charicteristics aligned to the available technology and operating pressures prevalent in the intervening years. Occasionally, this technology is available for retrofit to existing engines and aircraft types. In addition, new aircraft types become available, normally with new engine types sized for the specific application. Engine technology, in terms of aircraft gas turbines, has reached a maturity in which there are few areas in which simple gains can be made. All engine designs are therefore a trade-off between fuel consumption, emissions and noise. There are further trade-offs between types of emissions and between emissions at airports and during the cruise phase of flight.

70. For future NO_X emissions, there is a significant issue with fuel efficient, low noise, high overall pressure ratio (OPR) engines. With current ICAO standards, these engines are permitted to emit higher levels of NO_X per unit thrust - partly because of the technical difficulty of controlling NO_X emissions at high pressures and temperatures. The absolute amount of NO_X generated for an engine of fixed thrust is a product of the specific fuel consumption (fuel consumption per unit thrust) and the amount of NO_X per unit fuel consumed (called the Emissions Index or EI). In general,

specific fuel consumption decreases with increasing OPR. However, for a given combustor technology, the amount of NO_X generated per unit fuel consumed increases with increasing OPR. The resultant NO_X per unit thrust may therefore increase or decrease. As the limit of controllability of NO_X production is approached in engines above about 40 OPR, the NO_X increase tends to dominate unless controlled by advances in combustion technology. This effect is increased by the higher allowance in NO_X per unit thrust in the ICAO standards for these higher OPR engines. As a consequence of these significant technical variabilities, there is significant uncertainty in predicting future NO_X emissions. To these uncertainties must be added the political and commercial pressures which dictate the technology capability of engines offered to airlines, the objectives signed up to by the industry itself (such as ACARE), the commercial state of the airline industry, and political pressures which dictate the purchasing decisions of airlines themselves.

71. For future particulate emissions, the lack of understanding of the technology factors affecting particle mass and size distribution makes accurate prediction impossible. Whilst a return to 'smoky' engines of the 1960s will not happen, correlating future particulate emissions with combustor design will be capable only of providing approximate figures to complement the uncertain particulate data on current engines.

72. To provide technology forecasts for engine emissions capability through to 2030, a review will be carried out to update the technology assessment carried out for the air transport White Paper (DfT 2003b). The assessment will be carried by an independent gas turbine technology organisation using the guidance above and informed by input from industry, specifically manufacturers and major Heathrow airline operators. In the case of strongly differing views not reconciled by discussion, the independent organisation will inform DfT of any unresolved differences when making its recommendations.

73. The output of the review will provide the technology basis for engine allocations to future aircraft. Actual emissions values will depend on the scenario and cases being modelled.

[2] For example, JP Fleets (http://www.buchair.com)

[3] All engines with thrust above 26.7 kN

[4] FAA Aircraft Engine Emissions Database. AEE-110. Developed by the FAA Office of Environment and Energy http://www.faa.gov/

[5] D_p/F_{oo} is the mass in grams (D_p), of any pollutant emitted during the reference landing and take-off (LTO) cycle, divided by the rated output (F_{oo}) of the engine in kilonewtons.

[6] International Standard Atmosphere, corresponding to a temperature of 15°C (288°K) and a pressure of 101,325 Pa.

[7] In this methodology, high pressure ratio engines are the most sensitive to ambient conditions.

[8] When weighted by the number of aircraft movements over the diurnal cycle.

[9] Based on the modelling described in Horton (2005), tables for a given set of specified engines and ambient conditions are available via DfT

[10] The data also indicated a wide variance in the changes in fuel flow during take-off between different engines and between the same engine type on the same aircraft on different flights. The figure of 1.5 to 2.0% was, chosen as a representative generic value.

[11] The NO_X emissions factor is the NO_X mass emission rate at any point along the runway divided by the NO_X at static conditions. For the figure, the actual NO_X factor scale varies by aircraft/engine type, as does the take-off distance. These are described in Horton (2005)

[12] Tables for a given set of specified engines and ambient conditions are available via the DfT.

[13] As footnote 12 above.

[14] NO_X mass emissions in the ICAO databank are quoted in terms of NO_2 mass equivalent (i.e., as if all the NO_X is converted to NO_2). Hence the primary NO_2 percentages are used to reduce the mass of NO_X emitted from the databank values, assuming the remaining NO_X is nitric oxide (NO).

Variation from ICAO factors - Operational effects

74. The ICAO engine emissions certification process uses a set of four reference power settings and associated 'times-in-mode' for the demonstration of engine environmental performance in this area. These were loosely based on average conditions for aircraft operations when standards were first developed, around forty years ago, and are conducted on isolated engines in test cells.

75. In the past, these data have been used to develop emissions inventories for aircraft operations at airports in the absence of better information, and are not applicable to modern aircraft, or their normal mode of operation. Another factor is that they do not take account of the differences in performance characteristics between different aircraft types and in particular between those of twin and four-engined aircraft.

76. This difference between the performance of twin and four-engined aircraft arises as a consequence of the certification process, whereby an aircraft is required to meet runway use and flight path criteria with a single engine failed at a critical point along the take-off run (i.e., at the decision speed, V_1). In normal operations, all engines are operating and so a twin engined aircraft will have twice the thrust required to just meet the performance requirements, whilst a four-engined one will have an excess of power of only 33%. The effect of this is that twin-engined aircraft would normally take-off earlier, and climb more rapidly than an equivalent aircraft with four engines.

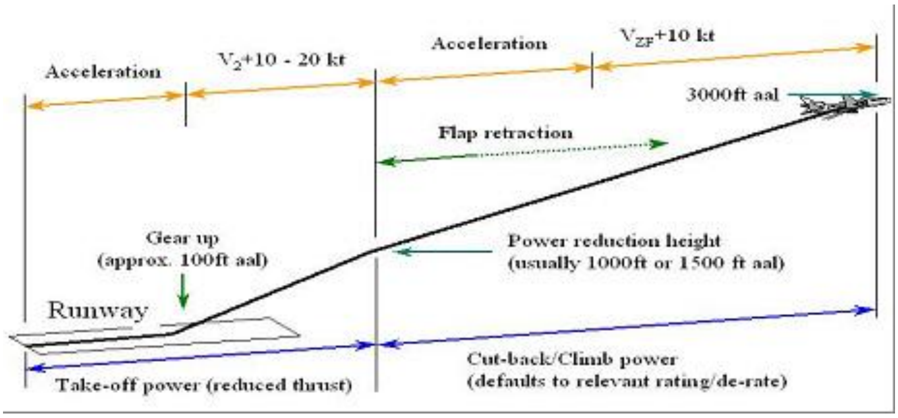
77. As a result, more recent airport emission inventories recognise that transport category aircraft do not take off at 100% thrust, with the actual thrust selected depending on, *inter alia*, actual aircraft take-off mass and other aspects such as ambient temperature, wind speed and runway characteristics. Similarly the power settings for idle, approach and climb out phases and the times spent in each mode vary according a number of operational and design factors. This section details those factors affecting operations specifically at Heathrow, in the context of PSDH.

Times in mode

78. The approach taken for identifying the times-in-mode for the different phases of aircraft operations at Heathrow, has been to use information based upon survey data from BAA Heathrow, NATS, and the NTK (Noise and Track Keeping) system for inventories produced for BAA in the past (Underwood and Walker 2003; Underwood et al. 2004a). This methodology remains valid, and no change to the basic philosophy is felt necessary, although a much more detailed analysis is being undertaken to define the times-in-mode more accurately and precisely.

79. For the PSDH analysis, the basis of the information will be taken from a number of sources, as for the inventories. Specifically: runway occupancy survey data obtained specifically for Heathrow operations for take-off and landing rolls; survey data collected by NATS for taxi-out and hold, and taxi-in times; and additional information now available from ground radar data. Data from the Heathrow NTK system are used for take-off to 1,000 feet and the airborne acceleration and climb phase from 1,000 feet to 3,000 feet.

Figure 3.4 Normal take-off procedure



Note: Not all airlines use take-off procedures that involve acceleration at the point of power reduction, some instead initiating acceleration at 3,000 feet.

Reduced thrust take-off to power cut-back

80. The take-off phase is a complex process as illustrated in Figure 3.4. However, the thrust management element is relatively simple and follows a standard process from the point that the take-off is initiated.

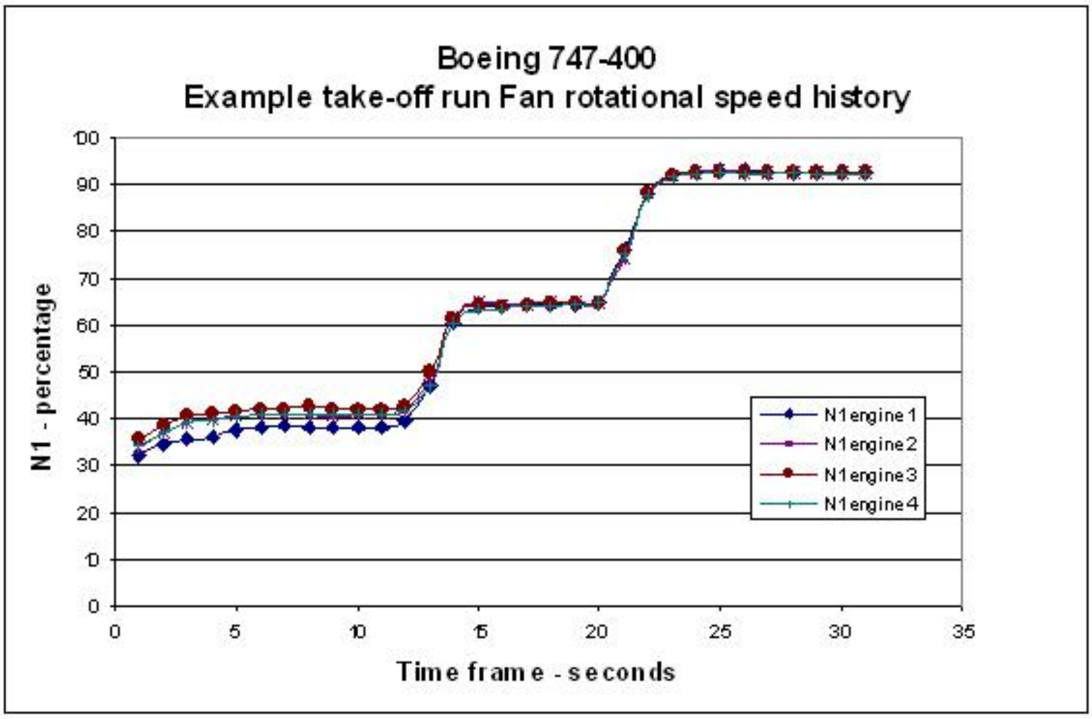
81. The pre-determined take-off power is set at the beginning of the take-off roll. For small engines the throttles are normally advanced in one go. However, for the larger engined aircraft, it is normally set in two phases, the first is to an intermediate power setting (for between 4 to 8 seconds) and the second to the final take-off power setting, after the aircraft has moved approximately one to two fuselage lengths down the runway. The power is then left at this setting until the aircraft has reached the power cut-back altitude, a minimum of 800 feet (ICAO 2003), where the throttles are retarded.

82. Aircraft take-off power settings can have a significant effect on the actual amount of emissions produced during the take-off phase. This is especially so for NO_X emissions, where, not only the fuel flow increases for an increase in power, but the Emissions Index also increases compounding the effect of the actual take-off power used.

83. A number of surveys (Gerencher 2005; Dawes 2005) have shown that operators rarely use full power for take-off, and then mainly for reasons of safety. There are a number of reasons for this, but the main one is to preserve engine performance margins (and fuel efficiency), and to save engine maintenance costs, but also has the effect of lowering emissions of NO_X. An exception to this is at Heathrow where at least two operators also specify full power to be used after 22:50 (local time) for their Boeing 747-400 fleets in order to meet the night-time departure noise limits with these aircraft.

84. There are basically two methods of applying the take-off power required: de-rated and reduced power (Morris 2002) De-rated thrust is a term used to describe a fixed, approximately constant power reduction to the maximum full rating, and is set by the manufacturer. It is sometimes referred to as 'push-button' derate, describing the normal mode of selection.

Figure 3.5 Example of fan rotational speed history on take-off



85. The most common method of reducing the amount of thrust set for take-off, however, is the 'assumed temperature' method reduced thrust. This uses the aircraft certificated performance to define the ambient temperature at which the actual aircraft mass would be limiting for the runway being used, and setting the thrust for this temperature. Due to the different air densities, this technique results in thrust levels slightly higher than those actually required (Boeing 1989), and hence the calculated limiting take-off masses are of a conservative nature.

86. There are regulated limits to the level of thrust reduction available, the minimum usually being 75% of the full rated thrust, however, it is possible to use the reduced thrust technique with a derate, to a level of 75% of the de-rated thrust, i.e. lower than 75% of the full rating.

87. Previous studies (Morris 2002; King and Waitz 2005), have suggested a linear relationship between the relative levels of the Performance-Limited Take-off Weight (PLTOW) and actual take-off mass, and the amount of thrust reduction available - the greater the difference between PLTOW and actual take-off mass, the greater the thrust reduction available. In this case, the average take-off thrust levels used can be estimated from knowledge of the average take-off weights and the average PLTOW. Note that when limited to relatively low masses, the two techniques will probably give different limiting mass even when the thrust levels are identical.

88. Three surveys have been carried out to understand the actual thrust levels used at Heathrow, two in depth for single carriers (Morris 2003; King and Waitz 2005), and one for a range of carriers conducted by BAA with the Heathrow Air Operations Committee (AOC) (Dawes 2005). From these three surveys, the average actual take-

off weights and PLTOW's were analysed using the process above to determine the most probable average thrust settings used for departure by aircraft operating from Heathrow.

89. The three surveys noted, cover the majority of all operations at Heathrow airport, and can be considered representative of other operators of the same, and similar types. In this way an assessment of the effect of reduced power on all operations at Heathrow airport, can be made.

90. Take-off profiles can be derived from radar data for each type below 1,000 feet, and it is probable that these can be simplified for groups of particular aircraft. Track-keeping is good at Heathrow and assuming that aircraft movements of each type follow individual NPR's from the airport to within ±1.5 kilometres of the centreline, can be confirmed by track-keeping statistics for each Standard Instrument Departure (SID).

Recommendation: The average take-off thrust setting can be considered as the same percentage reduction, as the average take-off weight as a percentage reduction of the Performance Limited Take-Off Weight. These values for representative types are available from Dawes (2005).

For aircraft operators and types not identified by the above source, the following process should be used:

1. if data is not present for a specific operator, but is for operators of exactly the same aircraft/engine combination, then the mid point of the range of values for this aircraft/engine of the other operators should be used;

2. if data is not present for a specific operator, but is for operators of the same aircraft type, then the mid point of the range of values for this aircraft type with different engines of the other operators should be used;

3. if data is not present for a specific operator, and is not available for operators of the same aircraft, then use a representative value at the centre of the range of values for aircraft with the same number of engines, except for the BAe146 and developments with 4 engines, where the maximum reduction of 25% should be assumed.

The above procedure to account for missing data is considered appropriate for re-calculation of the 2002 emission inventory for use in model verification. However, it is recommended that for future cases 5% be added to the take-off thrust where there are uncertainties due to missing data.

At the beginning of the take-off run, there is a delay of between 3 to 10 seconds before the engine reaches the maximum take-off thrust, used for the departure. This is due to engine inertia, control system effects and the thrust setting procedures used by the pilot in command. Fuel flow data obtained for a variety of aircraft and engine types during the take-off run have been averaged to provide revised thrust, fuel flow and emissions time histories for the start of the take-off roll. Further details are in Horton (2005).

Reduced thrust acceleration, clean-up and climb

91. After the take-off has been completed, normal procedure is to accelerate the aircraft to the initial climb speed of V_2 + 10 to 20 kts, and climb to the power reduction altitude. The minimum height for this is 800 feet above the airfield level (ICAO 2003), but for historical reasons is normally either 1,000 feet or 1,500 feet aal (above aerodrome level). At this point, the power is reduced to a level that is lower than that used for take-off. For normal operations this will be determined by the aircraft's FMC that will automatically adjust the power setting to the maximum CLB rating or, CLB1 or CLB2 de-rates (nominal 10% and 20% reduction of power, respectively, relative to the full climb (CLB) setting) depending on the initial thrust set for take-off.

92. It should be noted that some operators may chose to set something different, and are permitted to do so, as long as it complies with the requirements to be no less than "the lesser of the maximum climb power and that level necessary to maintain the specified engine inoperative minimum net climb gradient (1.2, 1.5 or 1.7 percent for 2, 3 or 4 engines) for the flap/slat configuration of the aeroplane, in the event of loss of an engine, without a throttle increase by the pilot-in-command" (ICAO 2003). One example of this is for operations of the Boeing 747-400 by British Airways, where for noise purposes, the power reduction is completed in two phases, the first at 1,000 feet to CLB after which the flaps are retracted to 10° and the aircraft allowed to climb to 4,000 feet where the power is further reduced to the CLB1 de-rate setting, the flaps/slats are fully retracted, and the aircraft accelerated to the en-route climb speed (Flindell et al. 1998).

93. Above the take-off power reduction altitude, the aircraft is climbed to 3,000 feet and, dependant on the operator's procedure, will either continued to climb at V_2 + 10 to 20 kts, with the flaps and slats in the take-off position; or accelerated to a speed normally either V_{ZF}, or V_{ZF} + 10 to 20 kts with flap/slat retraction occurring either before, during or after the power reduction.

94. At 3,000 feet, the flaps and slats are retracted (if not already done so) and the aircraft is accelerated smoothly to the en-route climb speed. Again, operators may chose to do something different, and are permitted to do so, as long as it complies with the minimum requirements for safety.

95. The potential complexity of having to account for a myriad of different procedures can be offset against the impact that these differences, that only occur above 1,000 feet, would be expected to have on ground level concentrations. As result, a relatively simple standard procedure for the third segment clean-up and climb can be assumed without generating large errors, though where variations can be specifically identified, these can be taken account of as well.

96. One restriction to the level of climb power set is that it must not be greater than that used for take-off. The actual climb rating depends upon the aircraft type and engine fit. However, for most types, the full climb rating (CLB) does appear to be at, or close to 85% of the full rated power (i.e. the same as is assumed by the ICAO certification process), and the climb de-rates at about 78% and 70% respectively for CLB1 and CLB2.

Recommendation: Based on the take-off thrust level, the climb thrust can therefore be approximated as:

- **CLB (85%) for take-off power levels between 100% (full) and 90%;**
- **CLB1 (78%) for take-off power levels between 90% and 80%;**
- **CLB2 (70%) for take-off power levels between 80% and 75% (minimum take-off thrust).**
- **For the few types that are certificated to use take-off power levels less than 75% (Dawes 2005), the climb thrust should be assumed to be the same as for the take-off.**

Climb profiles can be taken from radar data for each type, though these may be simplified for groups of particular aircraft types, especially as ATC normally impose a speed restriction of 250 kts below 10,000 feet. Aircraft tracks will follow the individual NPRs at the airport, and movements of each type can be apportioned to each SID using track-keeping statistics.

Final approach and landing roll

97. At 3,000 feet, aircraft arriving at Heathrow will already be established on the 3° glideslope, so the flightpath is relatively predictable. The power settings used during the approach will vary for a number of reasons but mainly as a result of the requirement to reduce speed from 180 kts to 160 kts during the initial phase of the final approach, and then again from 160 kts to the required threshold speed, with landing gear extended and flaps at the normal setting for landing (i.e., speed is not uniformly reduced). Other factors can also be significant, and throttle movements cannot necessarily be predicted during windy conditions, especially when the wind is gusting significantly.

98. A number of examples of recorded power settings during the approach phase, have been analysed by the ANMAC Technical Working Group when investigating arrivals noise issues (ANMAC 1999)' and show a range of power setting profiles for different aircraft types in different meteorological conditions. A specific approach for a Boeing 777-200, has also been analysed for the ICAO CAEP/6 WG4 (Morris 2005). From these, a general trend can be identified, and a simplified standard approach profile can be constructed.

99. At 3,000 feet (˜ 10 nautical miles (nm) from the threshold) the aircraft are under speed control and with only moderate flap settings (approximately 10° for both aircraft such as the 737-400, and 747-400) and decelerating from 180 kts normally at or just above idle power to 160 kts.

100. Undercarriage extension is initiated at about 2,000 feet (˜ 6.5 nm from the threshold) along with another increment of flap, and the engines spooled up to approximately 30% F00, coincident with the final flap selection at about 1,500 feet (˜ 5 nm from the threshold). After this the aircraft decelerates due to the extra drag to the predetermined threshold speed which varies with type and landing weight, but for modern Transport Category aircraft, is normally in the range 130 to 160 kts.

101. The throttles are normally retarded to the idle setting during the landing flare, and the engines remain spooling down to the point where the aircraft touches down on the runway. After touchdown, the aircraft is slowed down by the use of wheel brakes and operation of the thrust reversers, as described in the next section.

Recommendation: For modelling purposes, the aircraft trajectory is well defined as the 3° glideslope, and power levels of 15% $_{Foo}$, for the 160 kts phase down to 2,000 feet, with an increase to 30% F00 at this altitude to the touchdown point. The speed at touchdown can be assumed as 150 kts for Category 'D' aircraft (B777, B747, etc.), 130 kts for Category 'C' aircraft (A320, B737, etc), and 110 kts for Category 'B' aircraft (BAe ATP, Fokker 50, etc.).

Reverse thrust operation

102. After touchdown, the aircraft must be brought to a speed low enough to be able to safely exit the runway. This is attained by the use of wheel brakes and thrust reversers on the main engines. For normal operations, there are a number of factors that affect the amount of actual thrust that is selected during the reverse phase, and these include: runway state with reduced braking action, runway occupancy requirements (AIP AD 2-EGLL-1-15 notes: Pilots are reminded that rapid exit from the landing runway enables ATC to apply minimum spacing on final approach that will achieve maximum runway utilisation and will minimise the occurrence of 'go-arounds'), the location of rapid exit taxiways (RETs), the aircraft characteristics and braking systems.

103. The use of reverse thrust (that is a power above idle, whilst the engine thrust reversers are deployed), is limited during the night quota period by the UK AIP with the request to "avoid the use of reverse thrust after landing, consistent with the safe operation of the aircraft". The results of three surveys (Dawes 2005; Morris 2005; Morris and Easey 2005), suggest that a significant number of operators have incorporated this request into their standard operating procedures for all their operations (day-time and night-time). It should be noted that these surveys are not Heathrow specific, but worldwide operations for specific carriers.

104. From observations at the airport, it is also clear that some operators do use power settings greater than idle in an attempt to minimise their runway occupancy. In these conditions, the time of operation at the higher power has been observed at between 2 seconds, and 33 seconds with an average operating time of 19 seconds.

105. For a typical operation, the thrust reverser is deployed immediately on touchdown, and the aircraft is additionally slowed using the wheel brakes. This is especially true when carbon brakes have been fitted as they work just as well at high temperatures and provide more effective braking than reverse thrust. If reverse power above idle is employed, the throttles are advanced to a pre-determined position after the reversers have fully deployed, and following a period of reverse thrust, stowed normally at a ground speed of between 50 and 60 kts when they become relatively ineffective and Flight Manual requirements dictate they are not to be used below 60 kts for most aircraft types.

Recommendation: For modelling purposes, it would seem reasonable to assume that reverse thrust can be treated as being at the 'idle' power setting for 60%, i.e., for the majority of operations at Heathrow. This can be further split into the frequency of reverse thrust used by individual aircraft types using information from (Morris and Easey 2005). Analysis of the worldwide operations of one airline (Morris 2005) in relation to Heathrow, suggests that the maximum thrust levels recorded during reverse thrust operations when reverse power has been used, is at <50% of the full rated thrust (F00). Further analysis carried out by ERCD using FDR information, suggests that the average level used at Heathrow was about 30% of the full rated thrust (F00). As a result for modelling purposes, it would be appropriate to use a level of 30% F00 for a duration of 19 seconds for the remaining operations.

Taxi thrust settings/techniques

106. For aircraft operations at Heathrow airport, the universally applied normal procedure is to start up all engines prior to, or during pushback from the terminal stand, and taxi with all engines running to the holding point at the take-off runway (Dawes 2005; Gerencher 2005).

107. Power settings for this operation are generally at or slightly above the engine ground idle power setting, with occasional increases to levels of about 10% to 15% F_{00}, for about 5 to 10 seconds to overcome the inertia at the beginning of the taxi, to negotiate sharp significant turns on the taxiway route, or to increase speed when crossing an active runway if it is necessary to get to the take-off runway in use.

108. To ensure a constant flow of aircraft onto the runway, it is normally necessary to wait at one of the holding points, before entering the runway for departure. As there is no reason to run the main engines at an elevated power setting, they are normally kept at idle, with brief bursts of power before moving to a new position, or entering the runway.

109. Taxi-in to the terminal is similar to taxi-out, in as much as it is conducted at low power settings - typically idle or close to idle, however, most airlines have a procedure that allows for an engine to be shut down where the opportunity arises. There are a number of reasons why engines can not be shut down however, such as the requirement for a cooling-down period (especially after having used reverse thrust above idle), and the difficulty of having to turn an aircraft on the taxiway against the live engine. This coupled with advice from one manufacturer that NO_X emissions may not benefit from this technique, has dissuaded some operators from pursuing its use more thoroughly.

110. The actual use of this technique is not recorded, and as a result, it is difficult to estimate the number of occasions that engines are shutdown on taxi-in, but it is probably of the order of 25% or less. There is a renewed interest in this technique for reducing other emission species (principally hydrocarbons and potentially particulates), as well as fuel burn benefits, and taxiing with engines shut down may well be more frequent in the future.

111. As with taxi-out, power settings are generally at or slightly above the engine ground idle power setting, with occasional increases to levels of about 10% to 15% F_0 **0** (Morris 2005). Analysis of idle (taxi) settings (Morris and Easey 2005), however, has shown that these are generally less than the 7% assumed by the ICAO certification process, being typically about 5%, though some engine types appear closer to 3%. This is fairly consistent with other surveys (Brooke et al. 1995), which have also suggested levels of this value.

Recommendation: For modelling, the lower power settings relative to ICAO, used during the taxi phase, result in lower fuel flows of about 15% to 20%, for most types, except for Rolls Royce powered aircraft where they are generally between 30% and 35% lower than the ICAO 7% 'idle' setting would suggest. As the NO_X Emissions Index varies little at these lower powers, it is recommended that NO_X production levels are reduced by the same amount relative to the ICAO databank figures.

112. Taxi routes are well-defined to and from each terminal to each runway end, as are the holding areas. Taxi speeds do vary, though they are generally between about 15 to 30 kts, depending upon both proximity to the terminal areas and holding areas, taxiway turns, and aircraft type.

APU emissions

113. Auxiliary Power Units (APUs) are normally installed in the rear fuselage of an aircraft. Their main duties are to provide electrical power and conditioned air to aircraft when the main engines are not operating, or when not available from another source. They are also used to start the first main engine.

114. For PSDH, an APU emissions inventory approach has been outlined, based on similar principles to an aircraft main engine LTO cycle emissions inventory. In essence, times-in-mode would be used with four different load conditions to calculate the total NO_X and PM_{10} emissions from the 'APU fleet' at Heathrow. This can be neatly described by the equation below:

$$APUemissions = \sum_{mode=1}^{mode=4} Time_{mode} \times FuelFlow_{mode} \times EmissionsIndex_{mode}$$

115. The four load conditions are selected based upon information from one of the two major manufacturers. While some load conditions (such as main engine start or MES) have distinctive emissions indices, others (such as 'full ECS' (environmental control system) and 'full ECS + electric') have relatively similar NO_X emissions indices to each other. The load conditions are:

1. No load,

2. Electric,

3. Full ECS + electric,

4. MES + electric.

116. Times-in-mode for the four different load conditions are based on total running times reported by BAA as typical for Heathrow operations, combined with typical no-load and MES times.

117. Data on APU NO_X and PM_{10} emissions indices have been obtained from manufacturer test data and grouped into aircraft families to preserve confidentiality of commercial data. Combining these with the times in mode provides the emissions mass.

118. It should be noted that APUs generally have higher particulate emissions indices than modern main engines. As the previous Heathrow inventory work used average main engine emissions data to assess APU particulates, it is likely that this new method will provide higher values of PM_{10} emissions from APUs. Further description, including EIs and times-in-mode are contained in Christou (2005).

Recommendation: A revised APU Inventory approach based on TIM and load conditions should be considered in future Heathrow emission inventory studies, where sufficient manufacturer data are available for test scenarios.

Brakes and tyres

119. One of the main sources of primary PM_{10} emissions from aircraft is considered to be the wheel brake pads and tyres. PM_{10} emissions from tyres and brakes are dependent on many factors including aircraft weight, number of wheels, brake material (carbon or steel) weather conditions, engine type, pilot actions and airline procedures. However, combinations of these dependencies are largely unknown and a more straightforward approach needs to be adopted in order to predict these emissions from the Heathrow aircraft fleet.

120. Based on work carried out by netcen, originally for Stansted Airport, data has been gathered for a limited number of aircraft brake and tyre wear rates, and assumptions were made on the percentage of the eroded material which becomes suspended as PM_{10}. For brakes, this data gives wear rates in terms of kg wear per landing for F100/BAe146 and B737 aircraft. For tyres, BA have provided data for A319, A320, A321, B747, B757, B767 and B777 aircraft. Assuming greater wear is proportional to landing weight, [15] a relationship has been developed of the form:

Wear (kg/landing) = k x landing weight

where the k is based on the available data. These data are contained in Curran (2006).

121. No information specific to aircraft tyres or brakes was found concerning the percentage of the mass lost that ends up as suspended PM_{10}. A study undertaken by UNECE (2003) on emissions from road vehicle brakes quoted that 70% of the eroded material ends up as suspended matter. As we are dealing with aircraft, where brake

operation is generally more extreme, the netcen conservative assumption that 100% of eroded material ends up as suspended matter in the PM_{10} size range has been retained.

122. For tyres, UNECE estimated that between 1-10% of the eroded tyre material ends up as suspended PM_{10}. netcen took the upper estimate of 10% and applied it to the average of the tyre wear rates from the Stansted work. Combining these wear and suspension rates gives an expression of the form:

PM_{10}total = {(100% x kbrakes) + (10% x ktyres)} x landing weight per landing.

123. Based on limited wear data form a few aircraft types, numerical values have been developed for these equations using the Maximum Take-off Weight or Maximum Ramp Weight as surrogates for the landing weight (data for which is not normally available). Further details on the methodology are contained in Curran (2006).

124. A table of common aircraft data is shown in the table below. Data for other aircraft can be derived from typical landing weights for those aircraft types using the numerical values in Curran (2006).

Table 3.4 Emission rates from some common types of aircraft

Aircraft	Emission rate (kg/landing)
B747-400	0.78
B777-200	0.51
B767-300	0.31
B737-300	0.04
A319	0.06
A321	0.11

125. This methodology has used the data available but does still contain significant uncertainty. In particular the percentage of worn material that remains suspended as PM_{10} is unknown and conservative assumptions have been made here. In addition the extrapolation of wear rates for smaller commercial aircraft using landing weight to cover the full size range is a significant extension beyond known data. Provided the inventory confirms that brake and tyre PM_{10} emissions do not form a major contribution to the overall Heathrow particulate concentration, then this method is regarded as acceptable. If that is not the case, then further data on wear rates and suspension rates for larger aircraft would be required to reduce the overall PM_{10} concentration uncertainty.

Recommendation: Provided the inventory confirms that brake and tyre PM10 emissions do not form a major contribution to the overall Heathrow particulate concentration, then the method based on landing weight is regarded as acceptable. If that is not the case, further data on wear rates and suspension rates for larger aircraft would be required to reduce the overall PM10 concentration uncertainty.

[15] Kinetic energy may be a more complete measure, but as aircraft have similar landing speeds, the key variable is landing weight.

Engine testing emissions

126. Engine ground running is an essential part of the operation of any airline. There are a number of reasons for running the main engines on the ground but they are generally only recorded as falling into one of the following three categories:

- Check starts - a check to ensure that the engine will start after minor maintenance action;
- Runs at no more than ground idle - function checks to ensure that the engine operates correctly after maintenance action. These include thrust reverser function checks, etc.; and
- Runs at powers greater than ground idle - function checks where greater than idle power is required to check, for instance, the correct operation of certain valves, leak checks, etc.

127. Regulations on the location and type of engine ground run that may take place are set and policed by the airport operator, BAA Heathrow, who must give permission for all ground running and keep logs of the runs that have taken place. These rules are published as Operational Standing Instruction OSI/02/03.

128. A number of estimates have been made of the total NO_X emissions from aircraft during Engine Ground Running at Heathrow, including those by netcen for 2000 (Underwood and Walker 2003) and 2002 (Underwood et al. 2004a), and by British Airways (Buttress and Morris 2005).

129. For the netcen 2000 and 2002 inventories, an estimate of the emissions from engine testing on the airport (both within and outside maintenance areas) was based on a detailed log of tests carried out in one month of the year of interest, together with the recorded total number of tests in the year. Similarly, the British Airways analysis used detailed information from the BAA ground running logs for December 1999, and July 2000, and was then scaled up to the full year. As both aircraft type and operator were recorded in the ground run logs, it was possible to identify the engine type being run by matching the aircraft types and most probable engine fit, using information from databases of aircraft production lists. The British Airways analysis excluded PM_{10}.

Recommendation: Future estimates of NOx emissions from engine ground testing, will be made by a simple scaling of emissions based on the 2000 analyses by the ratio of the total LTO aircraft (exhaust) emissions in 2000 relative to those for the year in question. For PM10, estimates will be based on the netcen method, scaling it in line with the new NOx estimates. Engine testing makes such a small contribution to total NO_X and PM10 emissions that the source does not warrant a greater level of detail in estimating the future emissions than this.

Airport airside emissions

Introduction

130. Airside vehicles and plant are essential to airport operations. They include cars, vans, buses, heavy goods vehicles (HGVs) and specialist equipment, and are involved in operations such as aircraft turnaround, servicing, maintenance and safety. Although not a dominant source of airport-related emissions, they still produced an estimated 200+ tonnes of NO_X in 2002 (Underwood et al. 2004a).

131. Previous estimates of airside vehicle/ plant emissions at Heathrow have followed a top-down approach based on fuel use (Underwood at al. 2004a). This section discusses improved information that may allow an improved, bottom-up approach to estimating emissions.

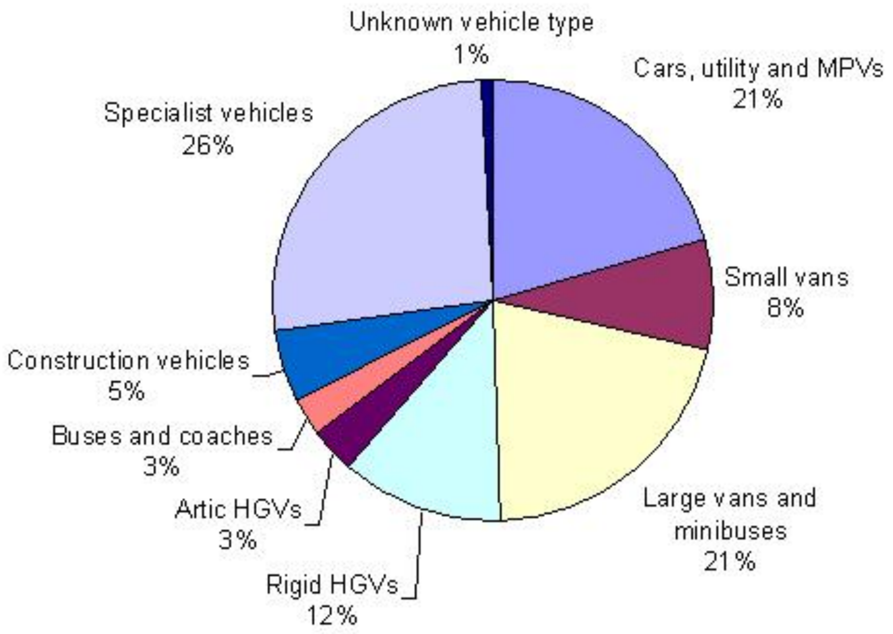
Airside vehicle types

132. Airside vehicle fleets vary by airport, but are typically a diverse range of specialist and non-specialist vehicle types, technologies, fuel types and use characteristics. It is important to understand fleet make-up, including fuels used, and its usa as fully as possible, since they determine airside vehicle emissions.

133. The Heathrow Airport Airside Vehicle Permit Database contains information on vehicles used airside. There are around 7,500 vehicles with permanent permits and 400 with limited duration passes, which are typically issued for a few months (Heathrow ID Centre 2005).

134. Figure shows a breakdown of the Heathrow airside fleet (Smith et al. 2003). Around a quarter of the fleet consists of specialist vehicles. The fleet is, however, dominated by cars and light vans, which account for 29% of all permits. Large vans and minibuses account for 21% of the fleet, heavy goods vehicles (HGVs) 15%, construction vehicles 5% and buses and coaches 3%.

Figure 3.6 Analysis of vehicle types in the Heathrow Airside Vehicle Permit Database

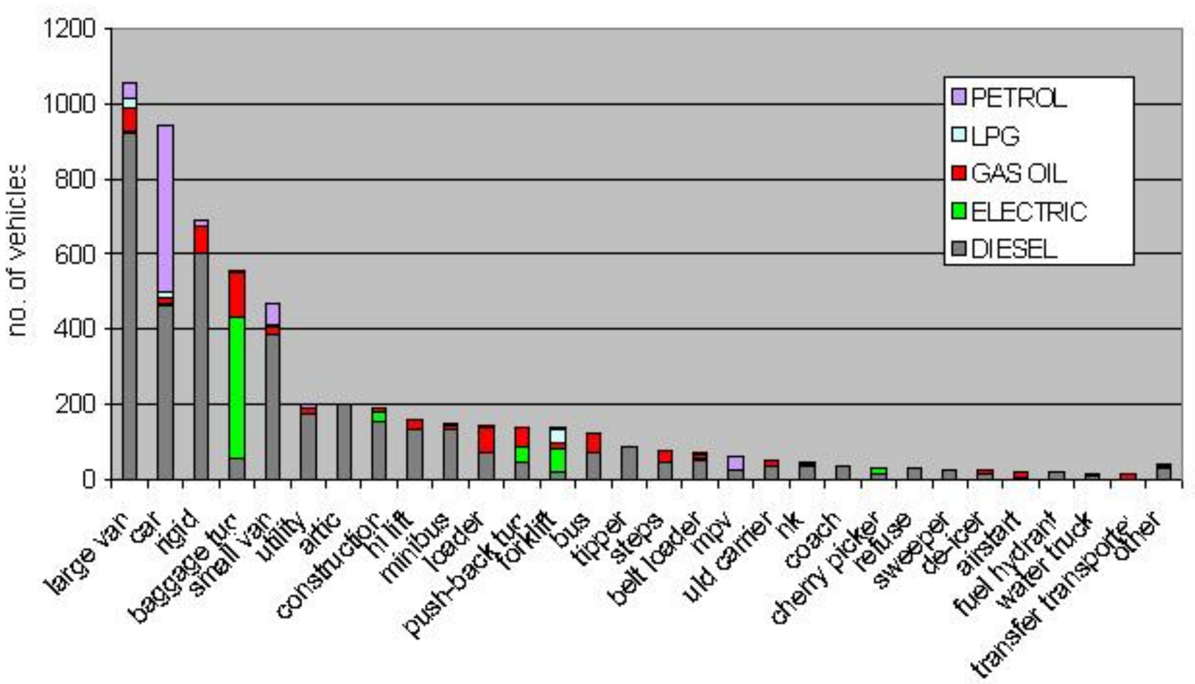


135. Figure 3.7 shows a breakdown of the airside fleet by fuel type (Smith et al. 2003). The majority of the fleet uses either diesel or gas oil (79%), with 11% of vehicles running on petrol (mainly cars), 9% on electricity (mainly baggage tugs and forklifts) and 1% on LPG (forklifts, vans and cars).

136. Standard vehicle types have much higher mileages than the specialist vehicles, although still less than the national average for these vehicle types. Articulated HGVs have the highest annual mileage, at around 40,000 miles per year. Tippers follow, at around 20,000 miles per year, followed by buses and coaches at 18,000 miles and rigid HGVs at 13,000 miles. Large vans average 10,000 miles per year and cars and small vans 8,000 miles per year.

137. A significant proportion of the mileage covered is outside Heathrow Airport. Many of the standard vehicle types travel on the national road network. For some vehicles, only a small percentage of the mileage is at Heathrow.

Figure 3.7 Airside vehicle fleet by fuel type and vehicle type



138. Previous work for BAA Heathrow identified mileage data as of insufficient quality to use in emissions calculations, since some mileage estimates at that time appeared inaccurate and the mileage data do not reflect the additional idling time airside (Underwood et al. 2004a). However, recorded information in the Airside Vehicle Permit Database has since been improved and may now provide a better basis for emissions estimates than fuel use data. The majority of idling activity occurs during aircraft turnaround, for which additional information could be used to derive emissions.

Recommendation: For PSDH, subject to further ratification of available data, mileage information in the Airside Vehicle Permit Database should be used for estimating emissions of vehicles *not* involved in aircraft turnaround.

Using vehicle age as a surrogate for engine emissions technology does not take into account instances where environmentally-enhanced vehicles have been purchased or vehicles retrofitted. However, any over-estimate arising from this is likely to be small.

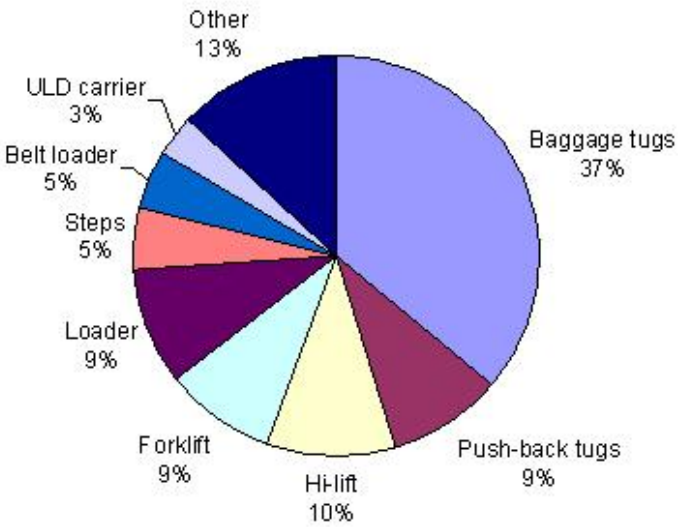
It is difficult to estimate the number of cold starts associated with light-duty vehicles airside. Therefore, it is recommended that cold-start emissions from light duty vehicles are omitted. This is a minor omission compared to the hot-running exhaust emissions.

Aircraft support vehicles and plant

139. The breakdown of specialist vehicles/ plant is shown in Figure 3.8 (Smith et al. 2003). The largest category is baggage tugs, followed by hi-lifts, loaders and

pushback tugs. Many of the specialist vehicles consist of specialised equipment fitted to a standard truck chassis - for example hi-lifts, tippers, sweepers, unit load device carriers, fuel hydrants and water trucks.

Figure 3.8 Breakdown of specialist vehicles in the Heathrow Airside Vehicle Permit Database



140. Most of the specialist airside equipment (tugs, loaders, steps, forklifts, airstarts) average only one or two thousand miles per year. Exceptions are unit load device carriers, fuel hydrants and hi-lifts that travel around 4,000 miles per year, and sweepers and water trucks which travel 7,000 miles per year. Some specialist airside vehicles, such as loaders and push-back tugs, spend a large proportion of operating time idling. This means that additional emissions arise which cannot be estimated directly from the mileage of the vehicles.

141. Engagement standards, which specify the numbers of different generic vehicle types required in turnarounds for specific aircraft types, provide another data source for understanding vehicle activity data. Engagement standards also specify times for which these vehicles are required. They have been agreed with and validated by the Heathrow Airline Operators' Committee (AOC) and correspond well with observations that BAA Heathrow has made (Dawes 2005). They provide an independently validated estimate of the numbers of vehicles required during a turnaround and the time for which they are in use.

142. Generic equipment types involved in aircraft turnaround include pushback tugs or tractors, baggage tractors, refuelling trucks, unit load device trucks, baggage conveyors, steps, high loaders, main deck loaders and catering loaders.

Operating patterns (or duty cycle)

143. Operating patterns of many of the vehicles airside include low speeds (with 20 mph the airside speed limit), short journeys, long periods of idling, frequent cold

starts, and low exhaust temperatures. However, tests performed on a selection of airside vehicles showed temperatures of above 200°C were achieved for 95% of the time, due to the heavy loads being carried, pushed or pulled (Smith et al. 2003).

144. BAA Heathrow commissioned a drive cycle and power take-off (PTO) test cycle for vehicles operating airside at Heathrow (Rowlands 2005). These cycles reflect actual operations at the airport and can aid understanding of likely emissions from airside vehicles. In the development of the drive cycle, eight different vehicles were monitored in normal daily operation, and four different vehicle types in simulations of PTO operation. The vehicles monitored (at a data capture rate of 1 Hz) were:

- Drive cycle development:
  - pushback tug;
  - inter-terminal baggage operation;
  - aircraft steps;
  - baggage tug;
  - coach; and
  - cargo lorry.
- PTO assessment:
  - lower deck loader; and
  - baggage belt loader.
- Both drive cycle development and PTO assessment
  - catering vehicle; and
  - refueller.

Figure 3.9 BAA Airside Vehicle Duty Cycle

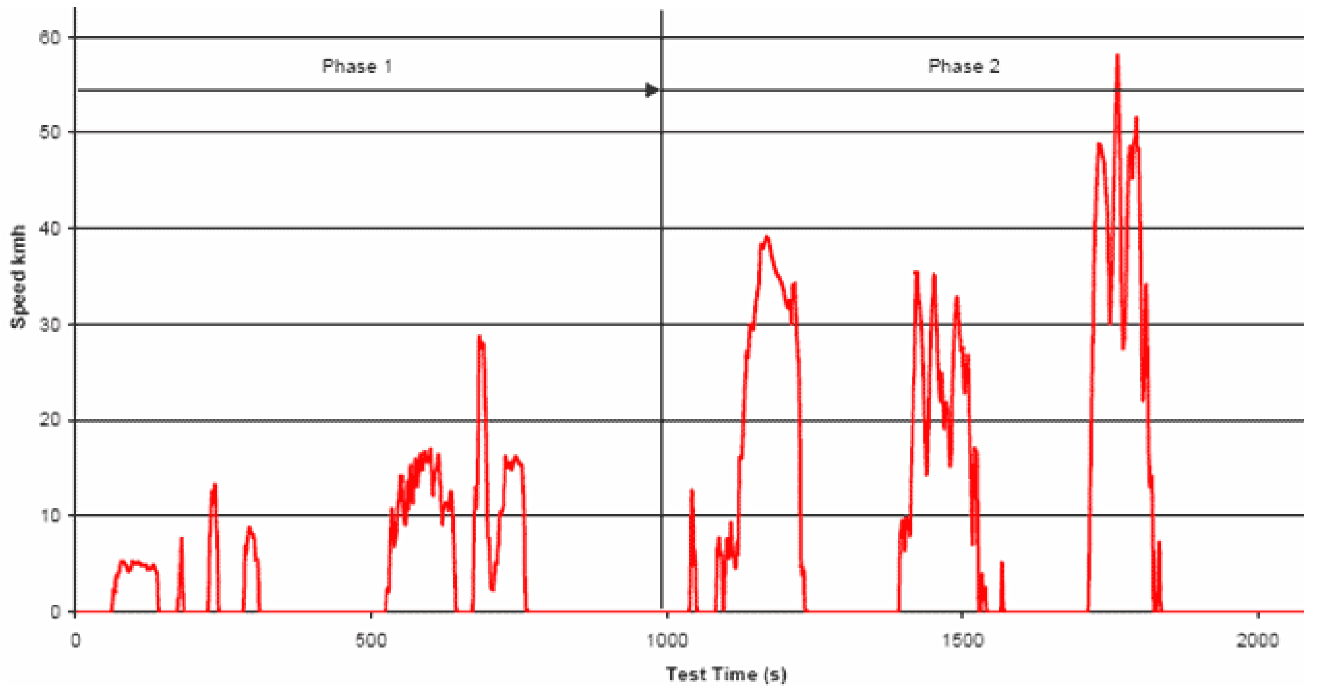
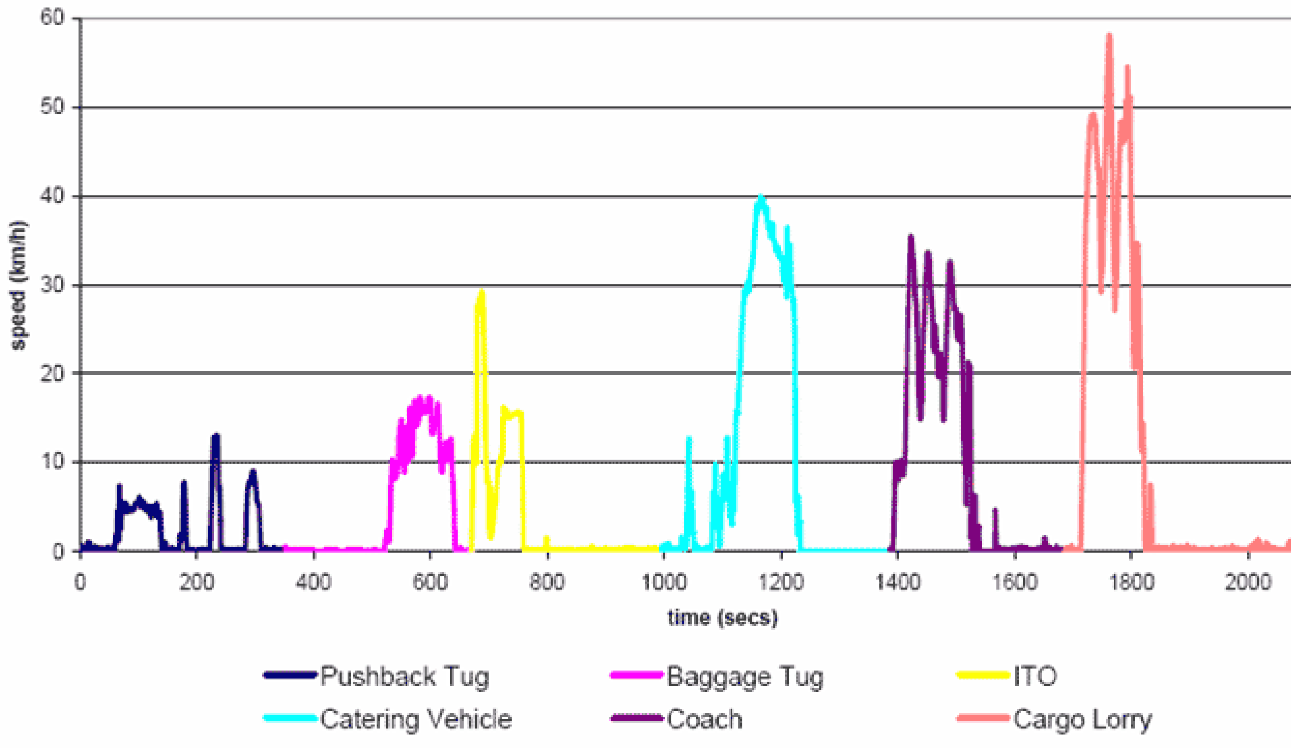


Figure 3.10 Components in the Airside Duty Cycle



145. Resultant data files were analysed to establish operational to non-operational (key off) ratios for each vehicle. Data were further examined to extract driving events of approximately five minutes' duration that most accurately captured the complete driving operation. To ensure that these sub-cycle events were representative of overall operations, they were verified against complete vehicle data sets using analysis of average speed, acceleration and speed frequencies. Selected sub-cycle events for six vehicle types were then incorporated into the drive cycle.

146. The completed duty cycle is shown in Figure 3.9. It is representative of typical movements airside, both at high-speed and low-speed conditions. 60% of the cycle is at idle, reflecting observed data from vehicles monitored. Phase 1 of the cycle represents low-speed movements associated with vehicles such as tugs, whereas phase 2 represents higher-speed movements. Figure 3.10 shows the components from different vehicle types that comprise the duty cycle. The components represent typical movements that these vehicles make. The coach component, for instance, represents a movement around one of the terminals.

147. Comparison of the BAA Airside Duty Cycle with other drive cycles (Figure 3.11 to Figure 3.15) show that airside vehicle activity differs significantly from road traffic in other locations. In particular, speeds are significantly lower and there is substantially more idling time. These suggest that airside vehicle and road traffic emissions will differ substantially, due to operating conditions.

148. Figure 3.13 shows European test cycles for light- and heavy-duty vehicles and a taxi cycle representative of taxis driving from central London to Heathrow. All have higher speeds and substantially less idling than the BAA Airside Duty Cycle.

149. Figure 3.14 and Figure 3.15 compare the BAA Airside Duty Cycle with congested cycles. Although speeds are comparable, the congested cycles have far less idling time.

Figure 3.11 Comparison of BAA Airside and new European (light-duty) drive cycles

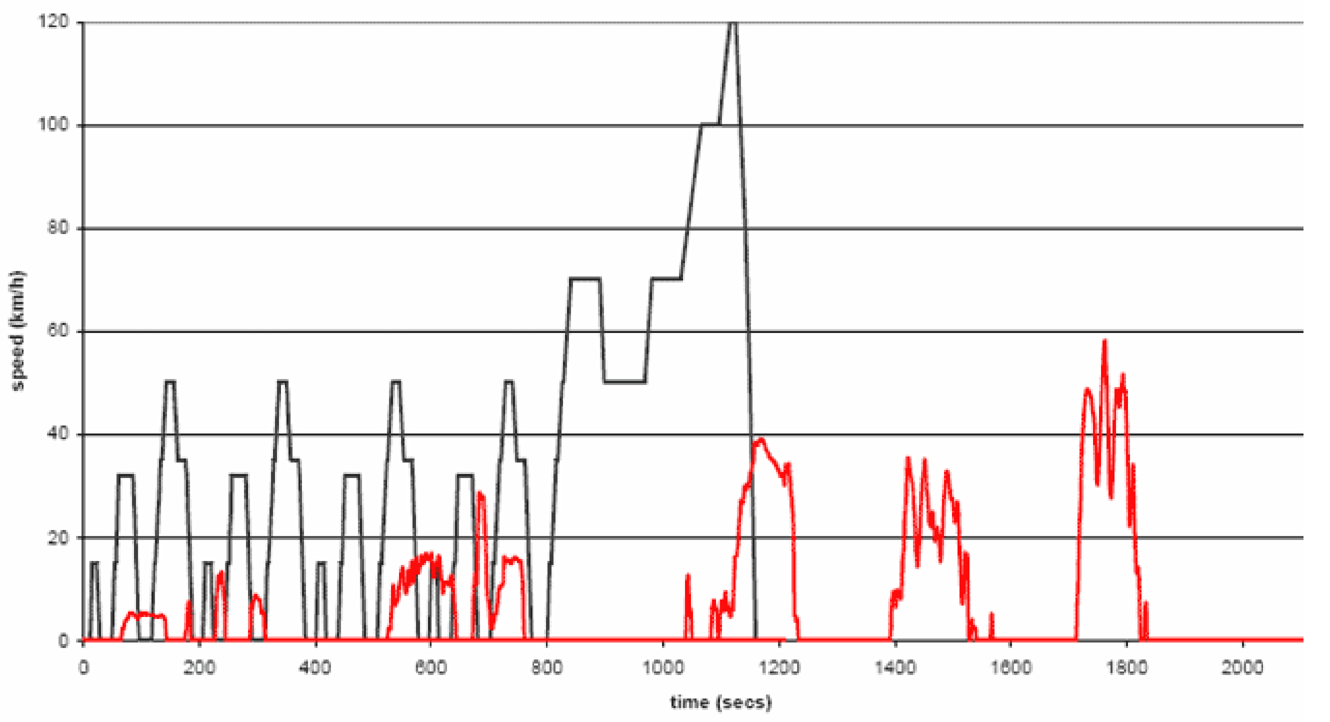


Figure 3.12 Comparison of BAA Airside and FIGE (heavy-duty) drive cycles

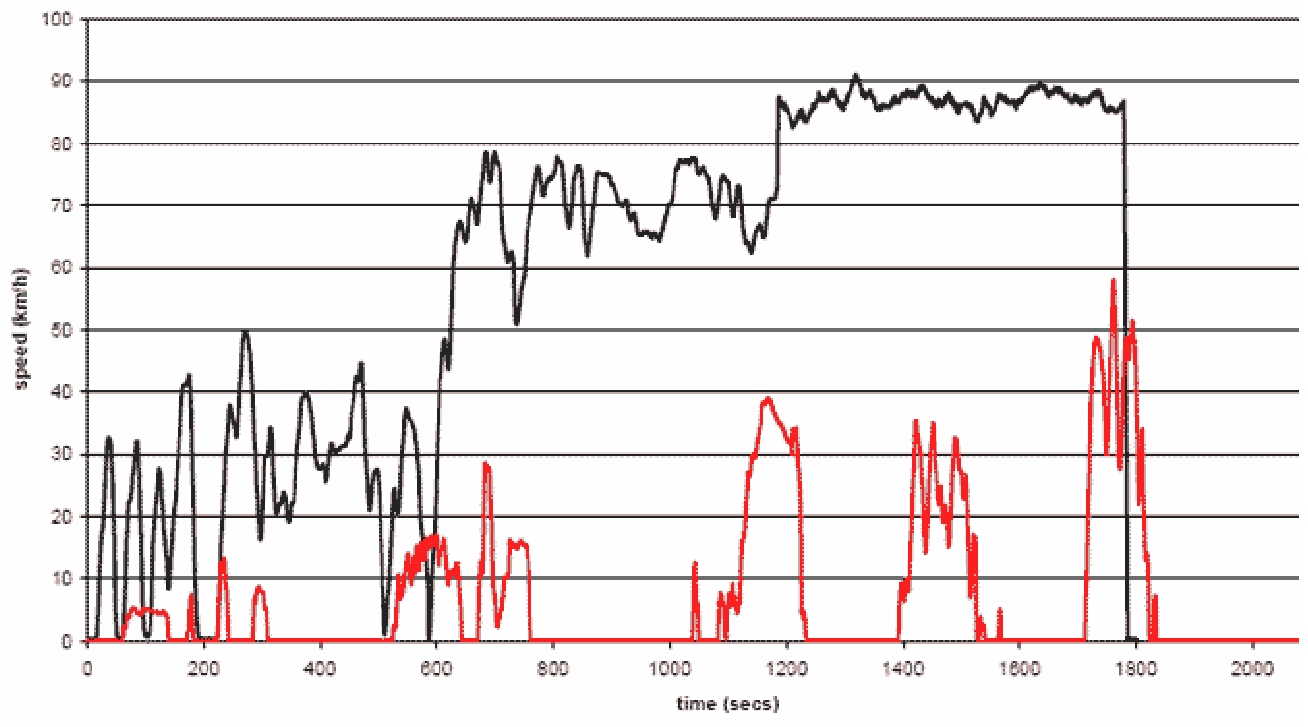


Figure 3.13 Comparison of BAA Airside and Millbrook Heathrow Taxi Drive Cycles

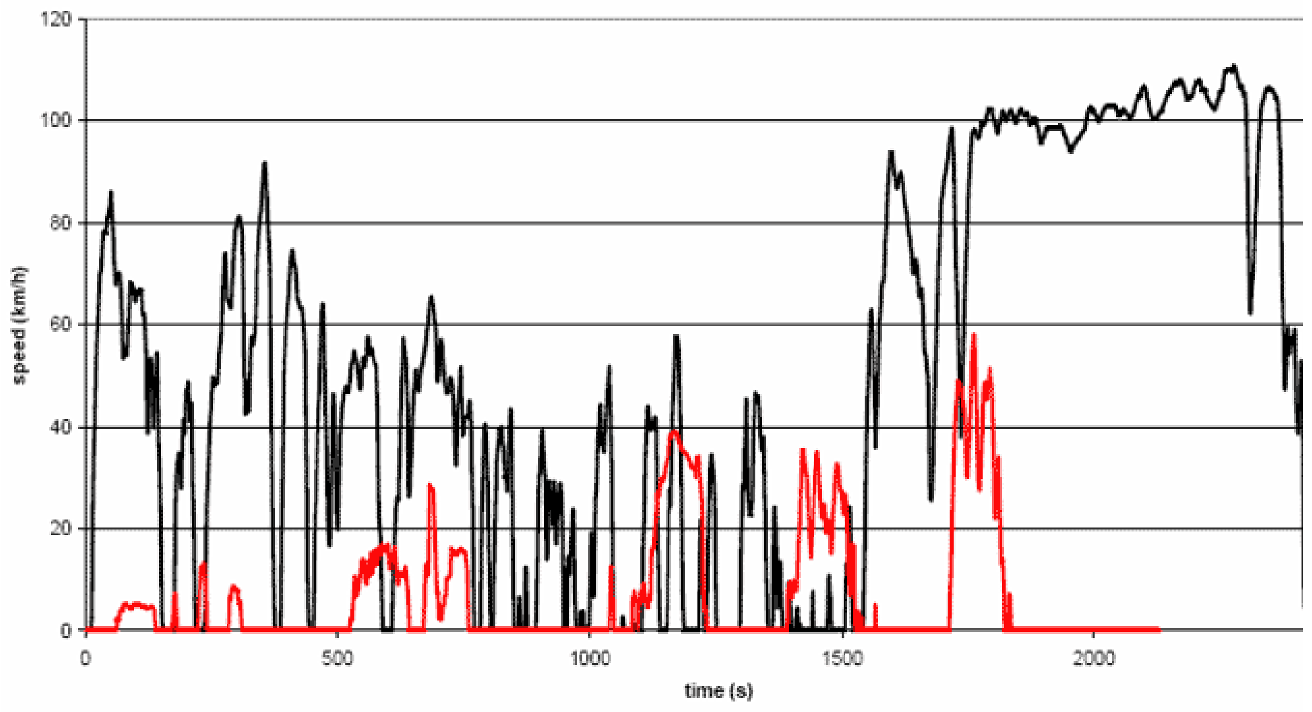


Figure 3.14 Comparison of BAA Airside and London Transport Bus Cycles

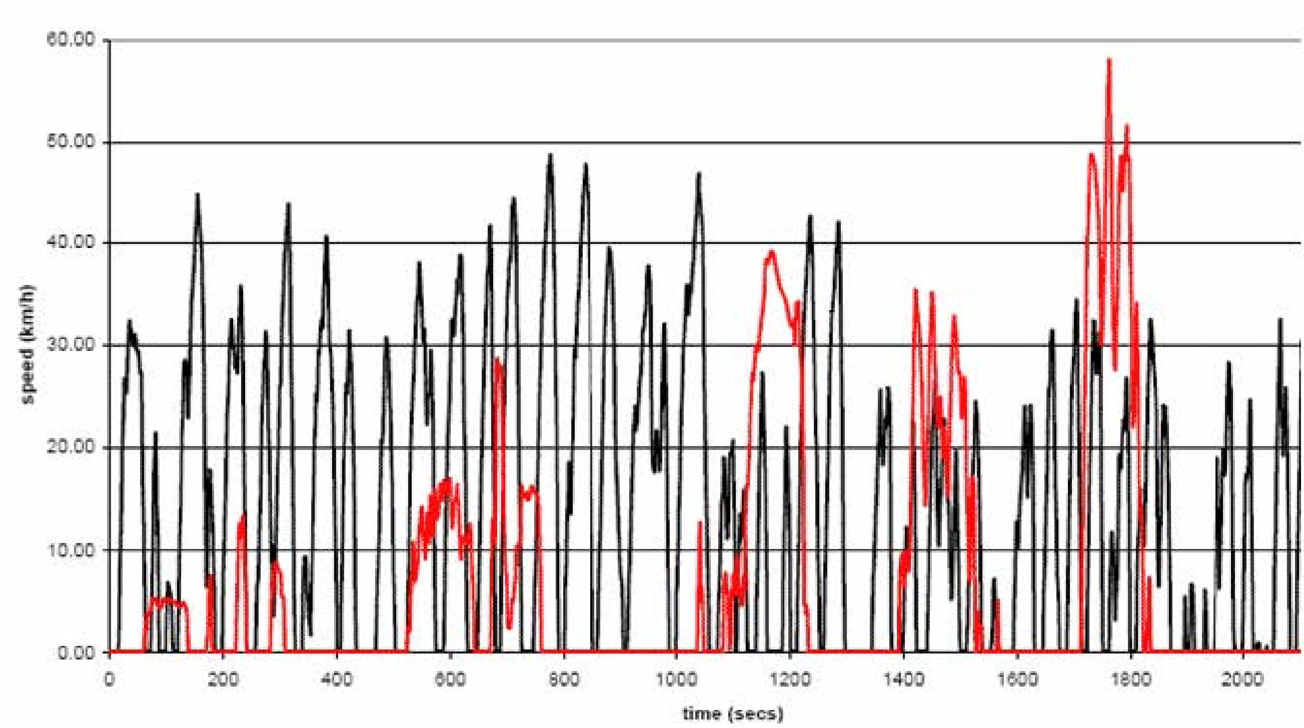
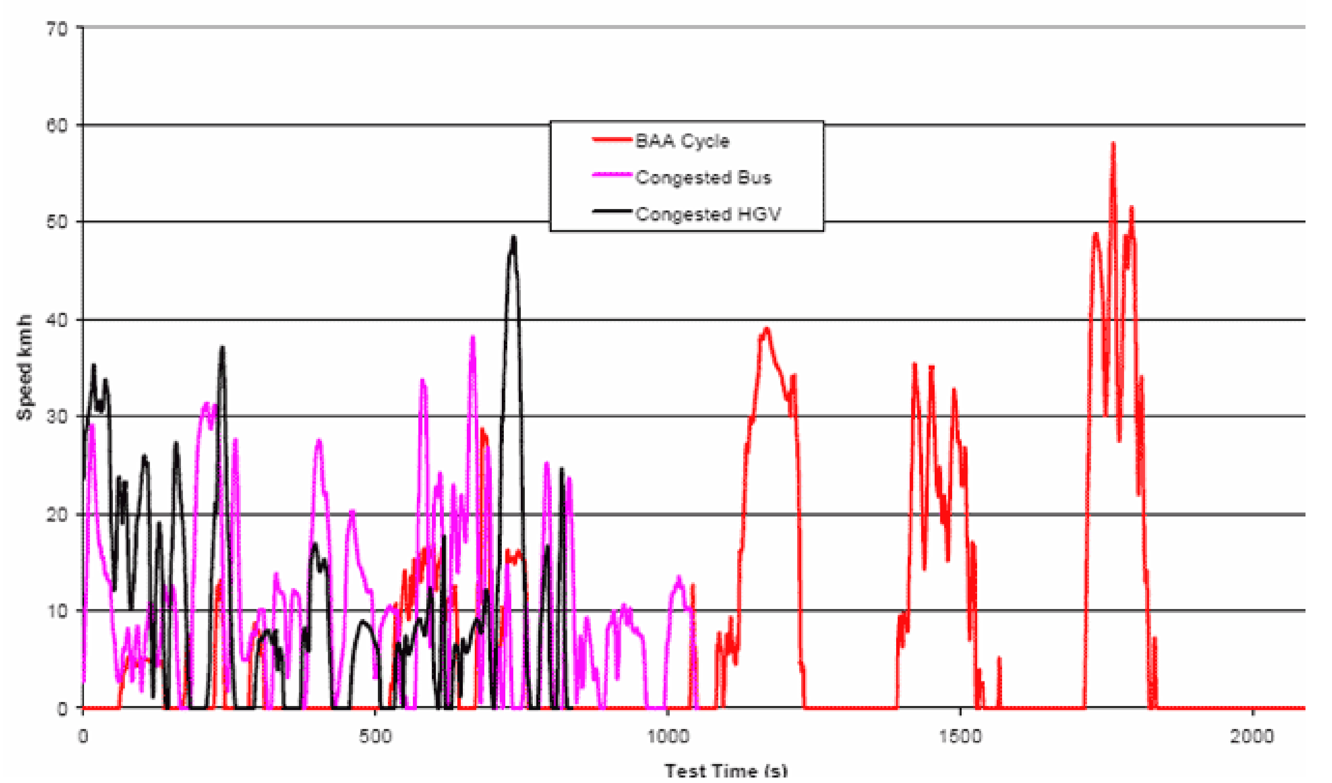


Figure 3.15 Comparison of BAA Airside and UG214 Congested Drive Cycles



150. The BAA Airside Duty Cycle and PTO cycle may be used to estimate emissions for aircraft turnaround. At the time of writing, BAA is investigating estimating emissions estimates by using the cycles in conjunction with PHEM (Passenger car and Heavy Duty Emissions Model). PHEM contains information on a wide range of engine types and models emissions for a duty cycle without recourse to rolling-road emissions testing.

151. Emissions for each vehicle type can be derived for an aircraft turnaround, based on duty cycle emissions and the engagement standards above. Where the idling time (during aircraft turnaround) for a particular piece of equipment differs substantially from that in the duty cycle, emissions may be corrected, based on manual observations of turnaround operations. Total emissions may then be derived based on air transport movements and the numbers and types of airside vehicles involved in aircraft turnaround.

Recommendation: For PSDH, subject to robust emissions factor data being available, emissions estimates for aircraft support vehicles and plant should be derived using vehicle engagement standards, duty cycle emissions estimates and aircraft movement data. Manual observations of turnaround operations should be made, to ensure that idling and keyed-off time is correctly accounted for.

Recommendation: For airside road vehicles, it is recommended that mileage data be used to estimate fugitive PM10. For off-road vehicles associated with aircraft movements, fugitive PM10 may be derived by estimating total distances travelled during an aircraft turnaround.

Future airside vehicle fleet

152. The future airside vehicle fleet at Heathrow will be influenced by Euro emissions standards (for standard vehicles), non-road mobile machinery emissions limits (for specialist vehicles) and by management and control policies.

Table 3.5 Euro emissions standards vehicles and implementation dates

Stage	*Engine power (kW)*	*Maximum emissions limit (g/kWh)*				*Implementation date*
		CO	**UHC**	**NOX**	**PM**	
I	37-75	6.5	1.3	9.2	0.85	31/03/99
	75-130	5.0	1.3	9.2	0.70	31/12/98
	130-560	5.0	1.3	9.2	0.54	31/12/98
II	18-37	5.5	1.5	8.0	0.8	31/12/00
	37-75	5.0	1.3	7.0	0.4	31/12/03
	75-130	5.0	1.0	6.0	0.3	31/12/02
	130-560	3.5	1.0	6.0	0.2	31/12/01
IIIA	18-37	5.5	7.5 (UHC + NO_X)		0.6	31/12/06
	37-75	5.0	4.7 (UHC + NO_X)		0.4	31/12/07
	75-130	5.0	4.0 (UHC + NO_X)		0.3	31/12/06
	130-560	3.5	4.0 (UHC + NO_X)		0.2	31/12/05
IIIB	37-56	5.0	4.7 (UHC + NO_X		0.025	31/12/12
	56-75	5.0	5.0	0.19	0.025	31/12/11
	75-130	5.0	5.0	0.19	0.025	31/12/11
	130-560	3.5	3.5	0.19	0.025	31/12/10
IV	56-130	5.0	5.0	0.19	0.025	30/09/14
	130-560	3.5	0.19	0.4	0.025	31/12/13

Non-Road Mobile Machinery Emissions Limits

153. Table 3.5 above shows the mandatory emissions limits apply to all new diesel Non-Road Mobile Machinery engines in the 19-560 kW power range, including those used in aircraft ground support equipment [16] . It also shows the implementation dates. Engines are required to comply with the above emissions limits on a type approval test cycle. National Atmospheric Emissions Inventory modelling (McGinley 2004) assumes an average load factor (as a proportion of maximum engine power) for generic aircraft ground support equipment of 0.8 and a factor of 0.5 for 'terminal tractors'.

Management and Control Policies

154. Current management policies will affect the make-up of the future airside vehicle fleet. For new applications for an airside permit, on-highway vehicles are required to be at least Euro III standard, and for Non-Road Mobile Machinery, 97/68/EC Stage II, or Stage I where no Stage II standard exists. The maximum permitted age for diesel and petrol fuelled on-highway vehicles or equipment is 10 years from the date of manufacture, but this is extended to 15 years where fitted with exhaust abatement technology approved on the PowerShift register. For Non-Road Mobile Machinery, these age limits are 15 and 20 years respectively. Exemptions to the age limits are made in exceptional circumstances, such as for rarely used specialist high cost equipment, which requires longer lead times for replacement. Alternatively-fuelled vehicles are granted exemption from the age limits. Additional age-related controls are set for inter-airport transfer of existing vehicles.

[16] EC Directive 97/68/EC as amended by 2001/63/EC (European Commission 2001a), 2002/88/EC (European Parliament 2003) and 2004/26/EC (European Parliament 2004).

Surface access sources

155. This section determines the most appropriate way to improve the "adequacy and reliability of source emission data" for surface access sources, concentrating on road traffic.

156. For road traffic sources, the requirement was to "Draw upon data and knowledge available to ensure that a suite of road traffic emissions performance data is adequate to represent emissions from local and national roads in the vicinity of Heathrow for the full timeframe of any future scenarios." Hence the Panel has considered and recommended improvements to the roads activity data, primarily traffic modelling, and to the derived emissions factors associated with such activity.

157. Provision of these data has several dependencies, not least of which is the link to surface access assessments for proposed operations at Heathrow. Whilst these are outside the remit/control of the Air Quality Panels, regular discussions have taken place between representatives of Panels 1 and 3, and of the PSDH surface access working group, to ensure that outputs from the latter are adequate for the former.

158. Annex 9 includes an illustration of generic data requirements from road traffic modelling for use in air quality assessments at Heathrow. It should be read in conjunction with this section on surface access. The precise requirements are dependent on the modelling approach that would be used for any subsequent work.

Traffic modelling

159. There are two potential sources of road traffic data that could be used in estimating emissions: traffic surveys and road traffic models. Information from traffic surveys is attractive because it relates to real traffic on real roads, whereas traffic models are a computerised reflection of the actual conditions. However, traffic

surveys have the disadvantage that they only provide information relating to the specific survey points (rather than area wide information), and it is harder to estimate future year conditions by just using survey data. Traffic models can be built to cover the area of concern, are explicitly designed to provide future forecasting capability, and allow for expansion of the traffic system within the study area. Hence modelling is the preferred source of traffic data for air quality assessments.

160. The purpose of any improvements to traffic modelling data for use in air quality assessments is summarised as:

- Sufficient traffic data to minimise infilling uncertainties in air quality modelling;
- Improve representation of traffic sources over White Paper work;
- Allow improved air quality model verification in the base year; and
- Take adequately account of the road traffic effects of proposed air quality mitigation measures.

161. On the first point, it is important to understand how far the road traffic models will provide generated results data, as opposed to externally derived data, because that in turn will influence the degree of certainty attached to the inputs to air quality modelling, and the extent to which effective modelling of air quality mitigation measures is possible.

162. On the last point, there are a range of policy measures available for mitigation of road traffic's contribution to air pollution, both for general traffic and airport-related traffic. Many of these were tested within the previous White Paper air quality modelling. Definition of mitigation measures is outside the scope of Panel 3 work, but as an illustration of their scope, direct traffic management measures might include public transport improvements; airport access charging; park and ride; area-wide road user charging; speed controls; junction restrictions and closures; or Low Emission Zones. The intention is that a series of tests will be undertaken of ranges of policy measures aimed at reducing emissions from (a) airport-related traffic and (b) all traffic. Once the potential contributions of the individual policy measures have been established, the most promising ones will be assembled into synergistic packages for further testing and appraisal. This process will lead to a preferred package of measures for use in the main air quality modelling of proposed future operations at Heathrow.

Choice of traffic modelling approach

163. PSDH Working Paper 6 [17] (Taylor 2004a) provides an introduction to road traffic models, from an air quality modeller's perspective. It explains the steps involved in modelling road traffic, the methods usually used in the UK to represent this, and some of the resulting issues for modelling vehicle emissions. It includs the effect of uncertainties attached to road traffic model data when used in emission modelling. For comparison with previous work, PSDH Working Paper 6 provides an outline of the surface access modelling approach used for SERAS, including commentary on key limitations and uncertainties in using such data as input to an air quality model.

164. It is important to remember that one of the main purposes of road traffic models is to test hypotheses. The design of a particular model is thus tailored to its purpose and hence extraneous detail is excluded. This is very important where the traffic model output is subsequently re-used as input to an air quality model. Most traffic models have not been designed with emissions estimation in mind. Before emissions can be calculated, it will therefore be necessary to embellish the basic model data in several ways.

Recommendation: Overall, of the four traffic model types referred to in PSDH Working Paper 6, 'mobility models' and 'econometric models' of traffic are inappropriate for use in PSDH air quality modelling. This leaves a choice of 'network flow models' and 'micro-simulation models'.

165. The bases of the two approaches are outlined in PSDH Working Paper 6, but fundamentally these tools aim to simulate traffic flows over a network which represents the real road system at different times of day. Different characteristics are attributed to represented road links, [18] including their length, traffic capacity, traffic flow, travel time or vehicle speed, and traffic composition (vehicle types).

166. In subsequent sections, the pro's and con's of the two approaches to the Heathrow Traffic Model (HTM) are highlighted. Fundamentally, either could provide data for air quality modelling use, and either would require some (and different) further processing of the model output in order to generate the actual data required for air quality modelling. Hence, whatever HTM approach is used, there will be a volume of traffic data that is of necessity generated outside that model, with uncertainties attached.

Overall uncertainty estimates in traffic data

167. As a general indication, previous work by Environmental Research Group (ERG) at Kings College for the GLA suggested general uncertainties for a 'whole of London' air quality model as shown below. Note that these estimates do **not** apply to the current LAEI and ERG models.

- Input flows (for each vehicle type) uncertainty of 32% at 2σ;
- Input speed data uncertainty of 26% at 2σ;
- LGV fleet emission rates uncertainty of 35% at 2σ;
- HGV fleet emission rates uncertainty of 45% at 2σ.

168. Note also the uncertainties in the ability to validate traffic models, akin to similar issues with air quality models. Traffic model validation involves comparing the results produced by the model to observations. Traffic observations are based on roadside interview survey data and traffic count data (typically Automated Traffic Counts collecting total movements, and Manual Classified Counts collecting vehicle type data). All manual classified count data are subject to variation. Typical 'error' levels, in the statistical sense, are given in the DfT's Traffic Appraisal Manual [19] (Highways Agency 1997) and are:

- All vehicles and cars and taxis ±10%;
- Light goods vehicles ±24%;
- Other goods vehicles ±28%; and
- All (light plus other) goods vehicles ±18%

Relative importance of traffic parameters

169. PSDH Working Paper 31 [20] (Taylor 2005) reviews the variables generated via traffic modelling and recommends their relative importance for ultimate use in air quality assessments. Under each rank heading, issues are shown in order of importance.

170. Note that air quality models can, and frequently do, use traffic models which contain few of the parameters needed, and so are required to estimate other parameters by other means. However, for PSDH, the purpose of the panels is to define appropriate best practice for air quality assessment at Heathrow, and as such reducing the number of parameters that come from assumptions alone is as important as reducing the error in the basic traffic data.

171. Equally, just because a traffic model can provide a variety of parameters does not mean there are equal confidence in them. For example, detailed traffic models (such as HTM) are only formally validated for some of the traffic parameters that are then used in air quality assessments.

172. The relative importance of traffic parameters for air quality modelling should be the cornerstone of defining traffic data requirements, concentrating effort and recommendations where they are really fundamental to the end (air quality) use. The basic ranking is used in the following sections, and in summary is:

Pre-requisite - modelled base year;

Rank 1 - road network extent;

Rank 2 - traffic flow (periods modelled - profiles);

Rank 3 - fleet and composition;

Rank 4 - road traffic speeds;

Rank 5 - road traffic queues;

Rank 6 - trip ends; and

Rank 7 - other traffic parameters.

[17] P3.1-WP06 – *An introduction to Road Traffic Models*.

[18] By traffic lane for 'micro-simulation models'.

[19] *Design manual for roads and bridges Vol. 12 Traffic appraisal of roads schemes Section 1 Traffic appraisal manual Part 1 The application of traffic appraisal to trunk roads schemes*

[20] P3.4-WP31 – *Relative Importance of Traffic Parameters*.

Modelled base year

173. Previous work (SERAS and the air transport White Paper) did not include a base year air quality model, which at the time would have been for 2000. This was justified on the basis that the assessment at the time was strictly relative and not absolute. The base case would normally be used to calibrate and validate the model (where feasible).

174. Following the work of the Panels, the air quality model will be verified for its base year results against CMS (continuous air quality monitoring sites) and by comparison with activity data (Data Mining). The model will then be used to estimate future year scenarios. Hence, base year traffic data used in the air quality model should come from a base year traffic model rather than from base year count data. This would allow air quality model verification factors to also account for the inherent uncertainties in the modelling approach used for traffic.

Optimal year for Base Case

175. However, the optimal base year for the Heathrow air quality model and for the HTM are not the same. For air quality, the Panels have agreed that 2002 is the optimal base year:

- The body of emission inventory data available strongly suggests an air quality model base year of 2002 to minimise uncertainty.
- A detailed airside emissions inventory has been produced by BAA for Heathrow. This level of detail has never been available before. It is for 2002, issued in August 2004.
- Netcen have developed a detailed emissions inventory for the BAA AQ model for Heathrow. It is for 2002, issued in September 2004.
- The GLA's London Atmospheric Emission Inventory (LAEI) is periodically updated. The latest release is for 2002, and was released in April 2005.
- 2002 is the first full year for data from the key Heathrow continuous monitoring sites, including extra sites put in for Terminal 5. This is crucial for model verification.
- 2002 is the only year free of influence on continuous monitoring results from ongoing major construction projects in the immediate area of Heathrow (Terminal 5 construction, and the M25 widening scheme).

176. The year 2003 should be avoided in air quality terms for verification. Whilst it is real and clearly worst case, it is widely recognised as an unusual conjugation of meteorological circumstances, and this would not help detailed model verification.

177. For road traffic, the HTM is under development, and hence is using the latest available data, including additional surveys this year both updating traffic time series and addressing known weaknesses in previous traffic modelling at Heathrow. Thus the HTM will have a base year of 2004/05. On this basis, the traffic modelling will need further processing tools to allow:

- backcasting to 2002 for air quality base modelling; and
- discounting of construction scheme effects in modelling air quality for future years.

Backcasting methods

178. It is possible to develop a HTM based on 2004/05 and backcast to 2002, using the technique of 'Matrix Estimation'. Whilst this may introduce some additional uncertainties in HTM data provided for the air quality base year model, it is a standard application of a widely recognised technique.

179. In essence, the technique is a systematic factoring of a prior matrix so that, when assigned to an earlier year's network, the factored flows match a set of constraining traffic counts for that earlier year. The process is undertaken separately for each modelled hour and also separately by vehicle class, to the extent that traffic counts by vehicle class are available. The accuracy of matrix estimation increases the more cross-related counts are available for use as constraints, although counts used as constraints cannot be used as source data for the adjustments themselves. Following the matrix estimation, traffic variables for use in air quality modelling can generally then be derived using the same methods as in the traffic model base year, and for any future years.

180. Hence in this case, the matrix from the validated 2004/05 HTM base model (after adjustment for construction traffic) will be factored (mainly down), assigned to the 2002 equivalent network (that is, without either the road works currently in hand or the resulting new capacity), and compared to a set of set-aside traffic counts obtained in 2002 and used as constraints in the factoring process. The average traffic flow and average speed data are then derived from the 2002 data for the modelled hours in the same way as in 2004/05, except that the factors and relationships employed will relate to 2002 rather than 2004/05.

Discounting construction effects

181. Care will be needed to account properly for the Terminal 5 construction affects (ongoing), and the M25 widening scheme (construction in 2004-2005 with opening in 2006), in the base year and in all future year forecasts.

182. Information on travel to and from the M25 and Terminal 5 works, by both workers and construction vehicles, is being collated by the PSDH surface access working group. At this stage, the precise method for discounting construction traffic is **not finalised**, although the principles are clear. The available methods would differ if the HTM was based on the 'network flow model' or the 'micro-simulation model' approach.

183. The 'network flow model' for Heathrow would use trip matrices derived by adjusting existing NAOMI v5.5 trip matrices, which do **not** include construction traffic, to accord with 2005 traffic counts, which **do** include construction traffic. Thus, while the resulting traffic volumes would reflect the construction traffic, the trip patterns would predate construction. On this basis, only the volumes need adjustment, which can be achieved by reducing those traffic counts used as constraints (in matrix estimation) by any differences with the construction travel surveys. For the 'micro-simulation model', construction effects would be inherent in the base year model, and so could only be removed by further processing of the model output.

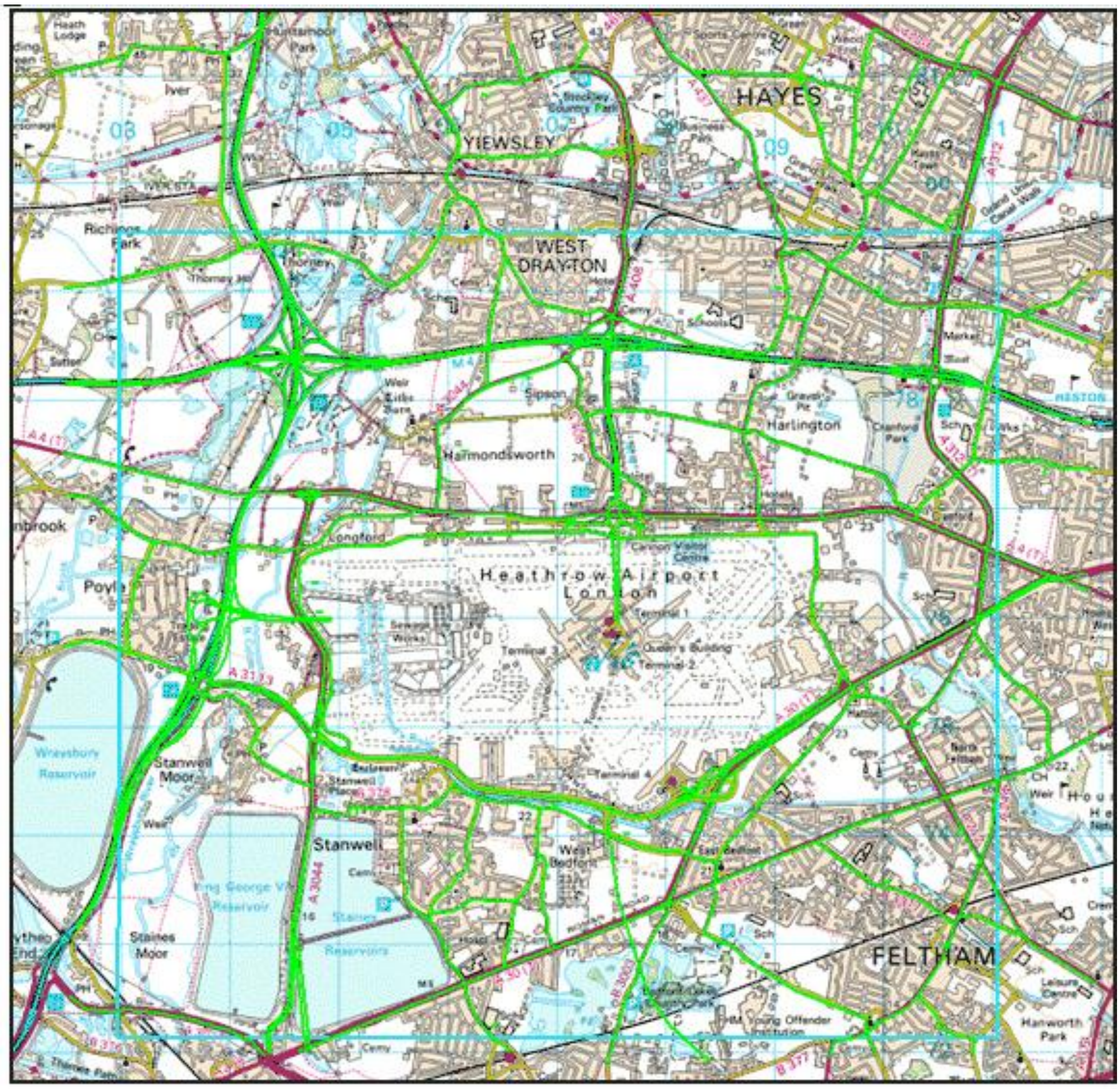
184. Note that, at this stage, there is potential uncertainty in the approach. The road network around Heathrow generally has a demand well above available capacity. As a result, the effect of construction on reducing traffic levels could be over-estimated using this method.

Recommendations: Base year traffic data used in air quality models should be from the same traffic model as will be used in future year scenarios. The optimal base year for Heathrow air quality modelling is 2002, and so backcasting of HTM base year results is required, using matrix estimation. Any construction effects on road traffic should be discounted in the base and future year scenarios by applying derived adjustments, and before backcasting.

Road network extent

185. For detailed air quality modelling of complicated study areas, where concentrations are close to air quality standards, then air quality models would ideally include all roads in the study area. This is because the air quality model must deliver results in absolute terms - compared to air quality standards - and not just consider road links with changes resulting from the proposed scheme (as is the case with WebTag type assessments).

Figure 3.16 Extent of the SERAS Major Road Network



Green links indicate the Major Road Network and the blue box indicates the SERAS study area

Network density

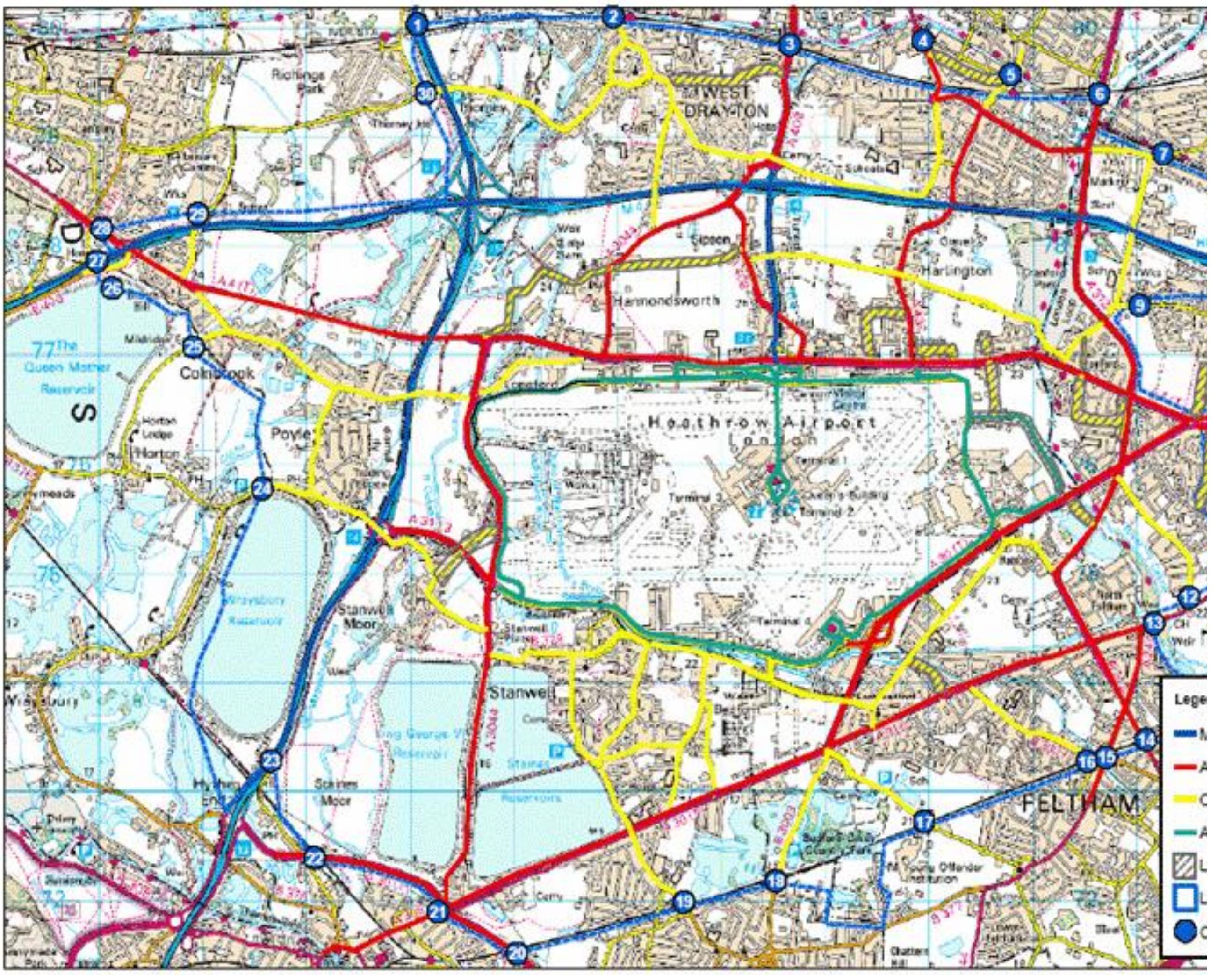
186. The most practical methodology for network extent would be an adaptive traffic model that can apply different models according to the detail required for air quality assessments. For example, a traffic model based on a hierarchy that offers at the first level all A-roads and motorways, at the next level selected B-roads, the the next level again minor roads, and so on. Such an adaptive modelling approach would allow for inventory development at the coarse scale through to the testing of traffic management and control scenarios at the finest scale. The extent that this is feasible is dependant on factors other than just air quality requirements.

187. In SERAS, only the Major Road Network (MRN) was explicitly modelled within the air quality model. The maximum extent of this was limited to a predefined

SERAS 'area for detailed air quality assessment', common in size to all assessed airport and runway combinations. This area was not defined on the basis of traffic criteria. The MRN incorporates two types of road, with only 'Part1' roads including full traffic data with junction delay and queue length - based on a 'network flow model' (SATURN). Very few links surrounding Heathrow (essentially those leading directly into the airport) had this level of detail in SERAS. Figure 3.16 shows the extent of the SERAS MRN, for comparison.

188. In contrast, the 'network flow model' under development by the PSDH surface access working group, would provide 'Part1' equivalent data for a very large area around Heathrow, giving a significant improvement in representation. The model has a network covering the whole of Great Britain, with the level of detail decreasing the further one moves away from Heathrow. Figure 3.17 shows the link coverage of the 'network flow model' for an illustrative area around Heathrow. It also shows the likely extent of any 'micro-simulation model', for comparison. The link density in the area immediately around the airport would be very similar in the 'network flow model' and the 'micro-simulation model'. For the 'micro-simulation model', such a network would not include the extent of known Air Quality Management Areas or hotspots, and would not necessarily reflect the impacts of traffic displaced to outside the 'micro-simulation model' area.

Figure 3.17 Illustration of the road network coverage immediately around Heathrow



Shows the link coverage of the 'network flow model' in relation to the likely extent of any 'micro-simulation model'

189. For PSDH, 'boundary effects' need to be accounted for by extending the model beyond the area encompassing the sensitive receptors for air quality. The air quality model should where possible avoid use of any of the traffic model buffer area within the detailed air quality model study area. Where possible the centre of a modelled road network should be adjusted to reflect the location of the air quality model boundaries. In SERAS, the maximum extent of the detailed study area was constrained (given the large variation in options tested). For PSDH, any 'micro-simulation model' approach would be based on the small existing model for Heathrow. As such it is already centred on the air quality study area. The 'network flow model' would be developed from the M25 Rapid Widening Model for the HA. Although Heathrow is within the area of influence identified for the M25 Rapid Widening, the boundary passes close to the airport and, as a result, some compression of the zoning and network to the south, south west and east of the airport has taken

place which has had an effect on the ability of the model to replicate traffic flows in this area. To ensure appropriate traffic model performance in the vicinity of the airport, the network and zoning in these areas is to be re-expanded.

Explicitly modelled elements

190. The network provided to the air quality model needs to be to a ground-truth representation of road geometry (i.e., 'real' in Ordnance Survey grid reference terms). Depending on the type of traffic model, this could require additional manipulation of the traffic network representation in order to reflect the geometry. Traffic data needs to be provided separately by direction of travel. Data should ideally be by carriageway, if possible, at junction approaches (to account for queuing and accelerating speed effects), and for dominant movements (for example, filter/turning lanes). For 'micro-simulation models', all data would need to be by traffic lane, even though data collection does not necessarily allow for disaggregation in this way.

191. In proportion to the hierarchy of the network, junctions should ideally be modelled explicitly (for example, all motorway junctions made explicit, together with most A-road junctions and key B-road junctions).

192. Validation of the air quality model should also be taken into account when defining traffic model extent. Where possible, the level of network coverage around air quality continuous monitoring system validation sites (say to 200 metres) should be as detailed as possible, to reduce the size of verification factors.

Minor roads

193. Although traffic models may give relatively complete coverage of the more important roads, a significant proportion of vehicle-kilometres may be driven on the remaining 'minor' roads. These roads vary widely in character, from commercial access roads to locally significant routes in the suburbs and, on the periphery of the area, roads that are essentially rural in character. However, most of these roads share the characteristic that they are only generally used to access the nearest 'major' road. It is often very difficult to establish a precise figure for this traffic. Minor roads tend to be overlooked by conventional traffic survey programmes, which usually concentrate on the busier parts of the network.

194. Nevertheless, any roads not explicitly modelled in the traffic model, still need to be reflected in the air quality model. This is typically achieved by aggregated contribution to background emissions. This requires very basic data such as total vehicle-kilometres per grid-square. In London, this can come from the Rotating Traffic Census undertaken by the DfT (as included in the LAEI). This provides an estimate of total vehicle kilometres travelled on both major and minor roads within the London area. It is possible to subtract the total kilometres accounted for in the traffic model from this total to give a 'residue', which can be considered to be the traffic on the minor road network. These additional vehicle-kilometres are then apportioned across London on the basis of the relative density of the minor road network in different parts of the city. As it is not generally possible to apportion flows accurately to individual minor roads, the emissions estimates for these roads are generally treated as an 'area' rather than 'line' source. Similarly, as it is not normally

possible to establish an average traffic speed for each link, a typical urban driving speed is often assumed.

195. Whilst a very similar approach to this was used in SERAS, the physical extent of minor roads sources was fixed at an emissions source area of at least 2.5 kilometres larger in any direction than the maximum detailed air quality study area for each scenario. How large this modelled area should be is debatable, and in the recommended approach it would, given the extent of the 'network flow model' network),be significantly more extensive than in previous work.

Recommendations: The network extent, link density, zoning size, and model boundary effects can be improved over previous work, using a 'network flow model' or an additional nested 'micro-simulation model' if justified by the traffic model performance criteria. Even without the 'micro-simulation model' option, the 'network flow model', as under development, would be an improvement over SERAS for this the highest ranked traffic requirement for air quality. Minor roads should be included in the air quality modelling using the 'residual vehicle-kilometres per grid-square' approach as a minimum.

Traffic flow - periods modelled and estimates for non-modelled hours

Scenarios and forecast years

196. It is expected that there will be a requirement for separate traffic data for use in air quality assessment for a range of scenarios and forecast years, from the base case through to 2030, perhaps at 5-yearly intervals. For air quality, the key definition of 'opening year' is effectively when the infrastructure being assessed is fully operational (not the first year of phased opening). Scenarios could include a number of operational alternatives, such as: Base case; Mixed mode; Third short runway; and Maximum use, as equivalent to a Do-Minimum reference case.

Recommendations: Full traffic data will be required for each of the agreed scenarios and forecast years (shown above), to allow proper comparison of proposed operations at Heathrow.

Diurnal profiles

197. PSDH working paper 33 [21] on diurnal traffic profiles outlines the data sources available to assist in deriving these profiles. Many aspects of Heathrow operations and associated traffic are untypical, and this needs to be reflected in traffic modelling data for air quality, where technically feasible. For example, in the Heathrow area there may be a surge of traffic from 05:30 onwards in response to the first departures. There is a separate pattern based on airport passenger travel preferences and airport worker shift patterns, both of which often have different patterns to the non-airport traffic. There is also likely to be a superimposed profile associated with the weekend exit from London on Friday and return to London on Sunday evening and Monday morning. Finally, the concept of clearly distinct peak/interpeak/offpeak periods may be reduced around Heathrow, particularly where airport related flows are significant.

Hence the traffic profiles in and around Heathrow may be different to UK average conditions for the types of road.

198. The basic unit for air quality is the annual average daily traffic (AADT). Time periods used in traffic models are typically peak hours; peak periods; interpeak periods; or 12-hour weekday. Peak hour models are the mainstay of traffic assessments. Conversely, air quality ideally needs profile data for 24 hours, 7 days a week, 52 weeks a year (preferably separately including working days, weekends, bank holidays, special events and seasonal effects). This disparity in modelled period is one of the fundamental differences between traffic and air quality assessments.

199. In practice, traffic data for detailed air quality modelling often includes:

- Hourly flows for 12-hour 'day' taken from a combination of separately modelled morning and afternoon peak hours or periods, and an inter-peak;
- 12 hour 'night' period taken from representative traffic count sites; and
- Generated 24-hour profile then provided separately for working day 5-day average and for weekend, or as a 7-day average;

200. Diurnal profiles should not be fixed, as the profile may vary as demand increases or changes its sensitivity to the time of day. For example if the peak periods were at capacity and hence traffic growth constrained, but the inter-peak periods had available traffic capacity and grew at normal rates, then the diurnal profile would plateau out over time. It is important to account for the effect of congestion on the diurnal profile of roads around Heathrow.

201. In the air transport White Paper work, the only active traffic modelling was undertaken with a morning peak model. All other time period flow data were adjustments of this model, relating it to other times of day using a combination of count data and national or London-wide factors. Further, diurnal flow profiles were common to all modelled scenarios, irrespective of changes in traffic demand from the scenario tested. Equally, for non-airport related traffic, profile shapes were not changed to account for network growth assumptions. These were recognised as limitations (and a product of the relative assessments approach undertaken at the time).

202. For PSDH the starting point is the network demand model (feeding into the assignment models) providing information for the weekday morning and evening peak periods, as well as for the inter-peak and off-peak periods. Each period covered 3 hours. The 'network flow models' would provide information for the morning and evening peak hours and for an average inter-peak hour, all on an average weekday in a neutral month (October). If 'micro-simulation model' approaches were used, this would only provide information for the morning and evening peak hours (and hence even more additional processing would be required to generate diurnal profile data).

203. For PSDH, a potential alternative approach is being investigated for generating diurnal profiles. This effectively uses a '*binning*' method analogous to that used for the mining of air quality monitoring data. The idea is that the total hours in the year would be divided in groups of hours, within which flow levels are reasonably equal based on automatic traffic count (ACT) data. Within the time bins, data for the

modelled hours would be replaced with that taken direct from the traffic models, whilst the flow levels in the other bins would be made relative to the level in the modelled hours. The number of hours in each bin (i.e., frequency of flow X) would also be determined from ATC data, with the total number of hours summing to the total number of hours in a year, namely 8760. Hence, the profile is determined using an equation of the form:

AADT = MHF x (h1 + f2 x h2 + f3 x h3) / (8760/24)
where
MHF = modelled weekday hour flow (modelled periods 1 to n)
H = number of hours in bin (bin groups 1 to n)
F = relative flow factor (bin groups 1 to n)

Binning can be disaggregated, and so the approach could be applied by road type, giving diurnal profiles reflecting the different types of road around Heathrow.

204. The accuracy of the approach improves in proportion to the number of flow groups and to the number of hours for which information is derived directly from traffic models. One of the advantages of this approach is that it can respond to additional traffic model data, by changing the relative flow factors. Hence, if insufficient traffic model data are available to produce a diurnal profile of each of the 24 hours, then the same approach can be used to provide a 'stepped' diurnal profile, for time periods such as the morning peak period.

205. By using local ATC data (some of it specially collected), the approach could ensure that diurnal profiles are more Heathrow specific, and reflects to the extent possible some of the peculiarities associated with Heathrow.

Recommendations: Many aspects of Heathrow operations and associated traffic are untypical, and this needs to be reflected in traffic modelling data for air quality. Where feasible, traffic modelling should seek to maximise the proportion of the day modelled, given air quality requirements. Subject to testing, the 'binning' method (or an equivalent) for deriving weekday diurnal traffic profiles should be used to ensure that air quality data can reflect the 'every hour of every day' required in dispersion modelling. This should be undertaken separately by road type, where feasible.

Weekend

206. The above diurnal profiling provides results for weekday only. In the White Paper work, no account was taken of weekend traffic differences. In the PSDH work, no traffic models for the weekend are being developed. Models other than for an average weekday in a neutral month are rarely created.

207. To reflect weekend conditions at Heathrow, which are unlikely to be typical of average UK roads given the airport activity, weekend data could be derived by treating the weekend hours as one or more separate flows groups in the diurnal binning methodology outlined above. The information for the weekend flows would thus be derived in the same way as the information for any other un-modelled flows.

Recommendations: Separate account of weekend traffic conditions are required for air quality purposes, especially given the activity levels at the airport. Derived weekend profiles should where feasible use the 'binning' method (or an equivalent), and should be made relative to weekday modelled periods.

[21] P3.4-WP33 - Diurnal Traffic Profiles (data sources) at LHR (May 2005)

Fleet and composition

208. The demand for travel for different purposes, and by different vehicle types, may well grow at different rates in the future. Transport and traffic demand models which treat the various trip purposes and vehicle types separately will enable the variations in growth rates to be taken into account in forecasting total traffic levels in the future.

By purpose

209. It would assist the air quality model for Heathrow if traffic inputs could dseparate the vehicle fleet into purpose-based sub-fleets: such as airport related traffic (including passenger and employee and associated airport facilities traffic) and non-airport related traffic. The contributions to the air quality problems from airport-related and non-airport-related traffic might then be identified, and modelled explicitly in the air quality modelling. This would allow focused mitigation measures, such as airport employee specific actions, to be assessed.

210. In the White Paper work, total traffic flow was disaggregated by airport and non-airport related trips in the morning peak hour traffic model, with the split of traffic between airport and non-airport flows constant in other time periods.

211. For PSDH, using 'network flow model' approaches, then airport- and non-airport related trips might be provided in a number of ways, as the airport-related trip matrices could be taken from separate Heathrow surface access 'Mode Share Models' (which address air passenger trips and airport employee trips to and from work by road). In principle, it would be possible to treat air passengers and airport workers as separate user groups throughout the assignments, or post assignment to allocate these trips to the paths created during the 'network flow model' runs. However, the feasibility of this approach is dependent on matters outside the control of the Air Quality Panels.

212. For PSDH, 'micro-simulation model' approaches would not, in any event, reflect the split between airport and non-airport traffic directly in the model output. Further processing of model output would be required, through Origin-Destination pairing, to enable the origins and destinations of trips assigned to any chosen link to be identified. Airport-related trips by link could thus be distinguishable as those with at least one end in an airport zone in the traffic model zoning. However, this approach could not provide air passenger trips and airport worker trips separately.

213. For PSDH, the available traffic modelling approaches cannot separately identify, within the general airport-related traffic, business and goods vehicles servicing the airport.

Recommendation: If feasible, traffic inputs into the air quality model should differentiate vehicle fleet by purpose-based sub-fleets: such as airport-related traffic and non-airport related traffic.

By vehicle type

214. Generally traffic models do not actually estimate traffic flows as a function of vehicle type. Splits of vehicles into different types are typically applied to traffic flows using composition data derived for standard road types or from count data. Micro-simulation models can, in principle, include comprehensive vehicle classes, but are often limited by the intensive level of input data required. Traffic models can provide a range of fleet composition data, depending on purpose and set-up, from passenger car units (PCUs) only; to cars and other vehicles; light duty vehicles/heavy duty vehicles (LDV/HDV); through in some cases to the DfT's COBA (COst Benefit Analysis) classifications. Demand models often include a more detailed breakdown of vehicle types than are used in assigning the traffic to the network.

215. For air quality modelling, the vehicle fleet emissions model is required to calculate emissions at a very fine degree of dissaggregation (for example, pre-1991, 1600-2000 cc, unleaded, petrol-engine, saloon car, with 3-way catalytic converter). The majority of this disaggregating is undertaken by air quality modellers, separately from the dispersion model and the traffic model. To reduce uncertainties in this process, the traffic model needs to maximise the basic traffic composition data. The ideal is the COBA vehicle classification. Where-ever possible diurnal profiles should also be provided separately by vehicle type, especially for LDV and HDV.

216. In London, buses and taxis are significant contributors to air pollution but are often poorly characterised in traffic models. Taxis are particularly important at airports. In addition the fleet composition around an airport serving business scheduled flights or holiday charter flights, is likely to be very different.

217. For the White Paper, information on the basic traffic composition was not available from the traffic model, nor was there sufficient ATC data at the time. Instead, all the data was provided as total flow only, with simple percentages of AADT flows that are heavy goods vehicles (HGVs) estimated using national average values by the five COBA road types.

218. In theory, disaggregate traffic demand modelling could result in a finer split of vehicle type than is usually available. However, in assigning such demand to the network using 'network flow modes', these vehicle types are aggregated again. The vehicle types available as inputs to the air quality model are dependent on matters outside the control of the Air Quality Panels.

Recommendation: Traffic model vehicle type composition needs to be as broken down as possible, to minimise the uncertainty in subsequent fine detail breakdowns by exhaust emission legislation groups in the vehicle fleet emission modelling.

Specific issue - Defining heavy duty vehicle proportions

219. A comparison has been made between measured traffic flow data, provided by DfT and the Highways Agency (HA), in the area of Heathrow. Although the traffic flows from the two sets of measurements were broadly in agreement, the proportion of heavy duty vehicles (HDV - see Glossary) were not. As HDVs emit about 10 times more NO_X pollution than light duty vehicles, modelling the number of HDVs on roads accurately is particularly important.

220. The HA traffic data reports higher HDV proportions than the DfT data. There are two main reasons for the discrepancy.

- The definitions of a HDV are different in the two datasets. The NAEI defines a HDV as being over 3.5 tonnes gross laden weight. The DfT carries out manual classified counts based on vehicle appearance which tallies closely with the NAEI definition. The HA data identifies a HDV as being larger than 5.2 metres in length. Some large vans weighing less than 3.5 tonnes gross laden weight are longer than 5.2 metres and so would be counted as HDVs by the HA when they are LDVs according to the NAEI definition. Using HA data will overestimate emissions. The level of overestimate varies from road to road depending on the fleet composition.
- The DfT HDV counts are typically manual classified counts based on a12-hour survey carried out every few years. The HA HDV counts are based on continuous measurements, i.e., every minute in the year. 24-hour counts generally have higher HDV proportions than 12-hour counts. Therefore, the DfT data may not reflect current conditions or those over 24 hours.

Recommendation: The pedigree of the HDV count data should be checked before use. If it is thought to be inadequate, classified counts should be carried out on key roads near HA automatic counters to ascertain a more accurate figure for calibration of the base case model. The HA ATC data can then be used to generate a factor to convert 12-hour proportions to those over 24 hours.

Road traffic speeds

221. Typically traffic models derive speeds based on relationship curves using traffic flows and the road type. Such speeds thus only apply to the specific period being modelled, such as the morning peak, but they are often further applied over the rest of the day. It is common for traffic model data available for air quality modelling to be limited to average link speeds, and not speeds through hotspots, such as specific junctions. In reality such data is often simply based upon the permitted local speed limits. However, significantly more rigour is required for PSDH.

222. Vehicle speed is an important determinant of emissions. Emissions factors are generally related to speed either by road type (such as motorway or urban road) or by specific speeds. It is important to note that an urban emission factor would have been measured over a real world cycle that is likely to have included stops and starts, and junctions. All speed-related emission calculations are disaggregated to detailed vehicle types (see above). Depending on the traffic modelling methodology the

coarsest speed for emission modelling would be the average over a link. A better approach is to obtain average speeds close to junctions and average speeds for the 'free flow' zones between junctions.

223. Speed data needs to be provided separately by direction of travel. Data should be by carriageway if possible at junction approaches, depending on the type of traffic model used. Speed should be provided as a diurnal profile of speeds on each link. Where possible, speed should be provided separately for each vehicle category, but particularly for LDV versus HDV.

224. Whilst it is often difficult enough to get the type of speed data described above, this is still on the fairly crude assumption that the air quality model uses average speed as the indicator of vehicle emissions. For the newest vehicle technologies, average speed is less important as a descriptor of emissions than speed variability. New emission modelling approaches are being developed in the EU that take into account both the average speed and corrections for operational dynamics such as rates of acceleration, or the proportion of time above a certain engine load. However, the level of data required on individual vehicle operating characteristics are not generally available (such as from the traffic models, apart from micro-simulation models), and thus even the new generation of emission models will still include basic average speed routines.

225. Some emissions inventories are compiled using speed data obtained from 'floating car' survey data in preference to the traffic model output. It maybe more appropriate to calibrate traffic models using these data in the first instance. There is a body of floating car available for London and the Heathrow area. PSDH working paper 25 [22] (Hackman 2005) outlines the available data sources for vehicle speeds in the Heathrow area, and also provides worked examples illustrating the effect on emissions of using different definitions of speed for the same road link.

226. For the White Paper, speed data on the majority of links (non-Part 1) was simplistically defined, and did not reflect differences in speed, and hence emissions, between vehicle types for the same average link speed. For the most detailed modelled area (Part 1) speed data for each hour were derived from a speed-flow formula, but for many links there were not enough data even for this and speed profiles were fixed at single values for the morning period, the afternoon period and the off-peak period.

227. For PSDH, the minimum acceptable definition of vehicle speeds would be average link speeds for all vehicle types, with data provided by road type using appropriate speed-flow curves. It is essential that estimated vehicle speeds are responsive to scenario changes, and are not fixed between forecast years or different schemes.

228. The ideal would be diurnal profiles of vehicle speed, by road type, by vehicle group, by trip purpose, but this level of disaggregation would be very unlikely from UK traffic modelling. Whilst the 'micro-simulation model' approach in principle produces detailed outputs speeds, queues and delays by traffic lane, giving a clearer picture of speeds, in practice this would still not provide the degree of disaggregation described above.

229. For PSDH, a potential alternative approach is under investigation for generating diurnal speed profiles. This would use the '*binning*' method outlined above on flow, and is therefore not repeated here. The key uncertainty over the binning is the source of speed data for non-modelled hours. This is still under investigation (see also PSDH working paper 25 referred to above), and may use MIDAS data where available, or speed-flow curves. As for flow, the binning approach could provide different profiling by road type. Available data for weekend speeds is very limited, and for air quality modelling this would have to be simply based on speed-flow equations by road type.

Recommendation: Vehicle speed is an important determinant of emissions, and there is a body of speed data sources outside of traffic models that could be used to generate speed-related diurnal profiles by road type. Vehicle speed data must be responsive to different scenarios and forecast years.

Specific issue - Validating modelled speeds

230. Vehicle emission factors in the NAEI vary with vehicle type, Euro emission class and speed. Speed data for the emission estimates is obtained from the traffic models. Emissions vary with speed with higher emissions at low and high speeds. Could the uncertainty associated with the modelled speed data be reduced?

231. The modelled speeds need to be compared with measured speeds for the base case to determine their reliability. The HA has developed a journey time database (JTDB) for the motorways and All Purpose Trunk Roads (APTR) in the HA core network based on measurements. This journey time data can be used as a surrogate for speed data. The database contains average journey times and traffic flow information for each road link in the HA network for each 15-minute interval throughout the year. The total vehicle hours delay is split into that due to recurrent congestion (where normal traffic flows exceed capacity) and non-recurrent congestion (for example, events such as accidents or roadworks). The effect on congestion can be significant on busy roads - for example, the speed limit on the A30 between M25 Junction 13 and the A3044 is 70 mph whereas the daily average recurrent congested speed is 34 mph. Speeds in off-peak hours will approach the speed limit whereas those in peak hours will be low. As emissions of the key pollutants tend to increase at both low and high speeds, these wide variation in speeds throughout the day needs to be represented accurately. Many of the roads in the Heathrow area are congested so accurately representing speeds throughout the day is important.

232. Queue lengths are not measured, but the time spent queuing is reflected as delay time in the JTDB. Although vehicles in queues are likely to be an important source of emissions near junctions, the quality of available emissions data for slow moving vehicles in stop/start conditions with short, sharp and frequent periods of acceleration and deceleration remains poor.

Recommendation: Data held in the journey time database should be used to assist in validating the base year speed data provided by the traffic model for the relevant roads for the periods modelled.

Road traffic queues

233. The amount of queuing traffic can be important in accounting for the effect on emissions of different driving profiles. For the same average speed, queuing conditions entail considerably more acceleration, deceleration and idling, thereby increasing emissions over a simple equivalent low cruise speed.

234. Depending on the traffic/emissions/air quality model used, congested conditions can be represented at key junctions using data on queues such as the length, numbers of vehicles, or the elapsed time. For example, some emissions models can use SATURN traffic model parameters PSTOPS and SSTOPS to develop formula to represent the different queue formations (and hence ACDI profiles) at signal-controlled and priority junctions.

235. Typically, whatever the approach used, the traffic model has to be interrogated to identify the back of the queue, to then create a false link against which 'additional' queue emissions can be allocated.

Recommendation: Queuing data needs to be included in the air quality modelling, where validated data are available and where data are expected to make a demonstrable difference in resultant surface access-related air pollutant concentrations. The false link, add-on additional emissions approach is to be used, where practicable.

[22] P3.4-WP25 – *Vehicle Traffic Speeds.*

Road vehicle emissions

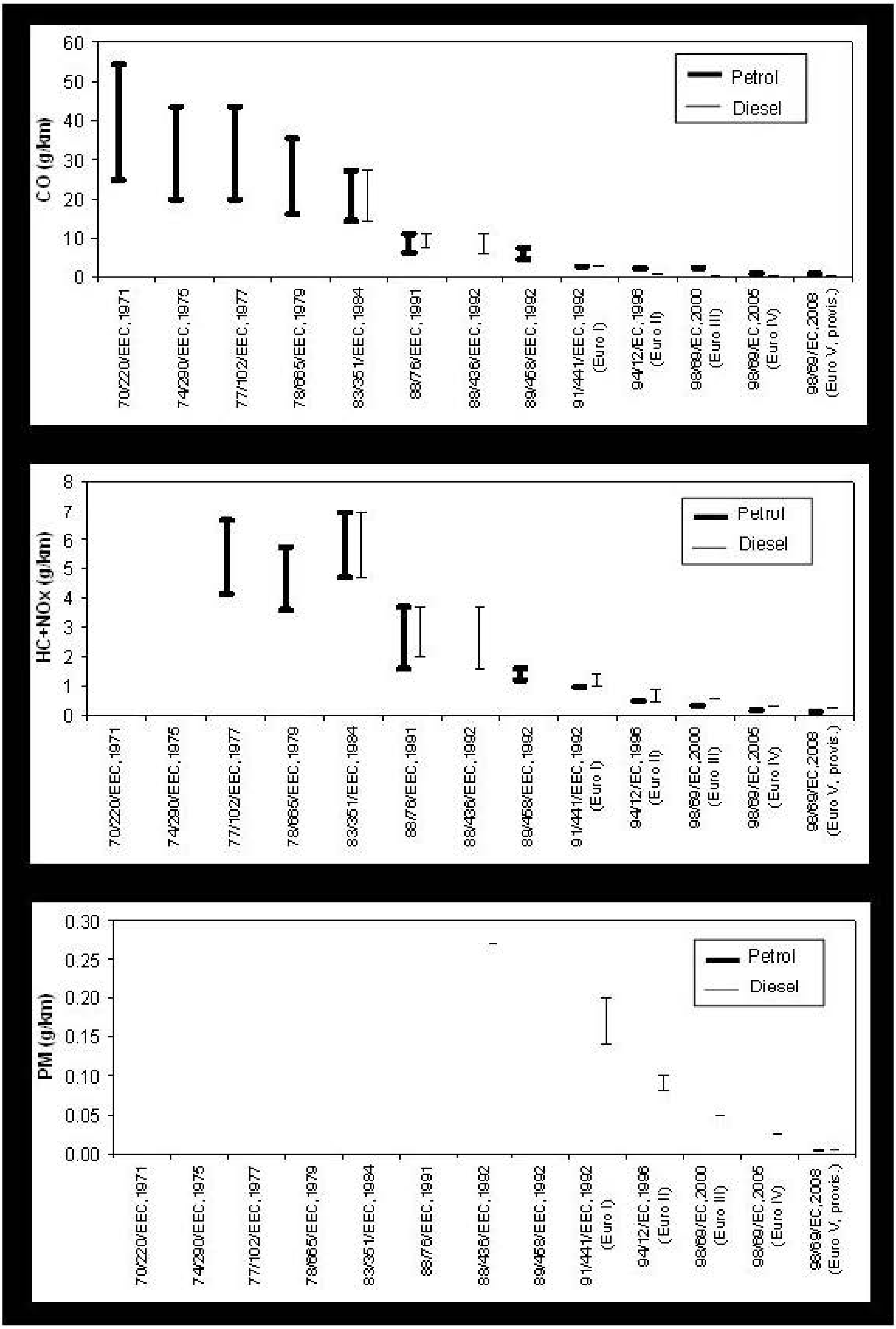
236. In line with the key pollutants of interest in this Heathrow analysis (Raper and Laxen 2005), this section focuses upon NO_X and particulate emissions.

237. The combustion of a hydrocarbon fuel in air produces mainly carbon dioxide (CO_2) and water vapour (H_2O). However, combustion engines are not perfectly efficient, and some of the fuel is not burnt or only partly burnt, which results in the presence in the exhaust of hydrocarbons and other volatile organic compounds (VOC), carbon monoxide (CO) and particles containing carbon and other contaminants. In addition, at the high temperatures and pressures found in the combustion chamber, some of the nitrogen in the air and fuel is oxidised, forming mainly nitric oxide (NO) with historically a 'small' amount of nitrogen dioxide (NO_2). The total emissions of oxides of nitrogen are conventionally abbreviated NO_X. The main sources of emissions from road vehicles, and the pollutants concerned, are:

- Hot exhaust emissions: CO, VOC, NO_X, PM, unregulated pollutants;
- Cold-start exhaust emissions: CO, VOC, NO_X, PM, unregulated pollutants;
- Evaporative emissions: VOCs;
- Tyre and brake wear: PM;
- Road surface wear: PM; and
- Resuspension of road surface dust: PM.

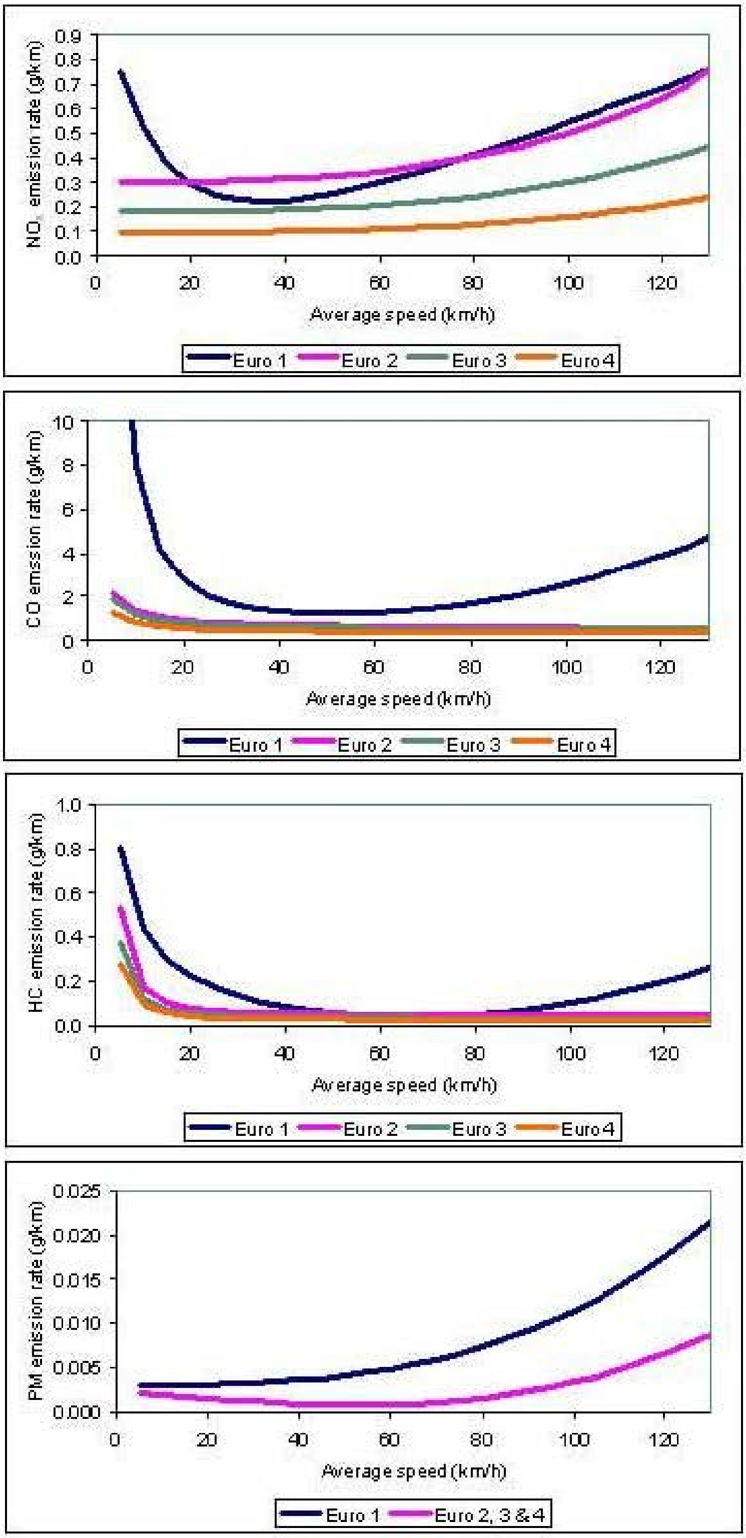
238. Road transport emissions are a significant source of many of the air pollutants regulated by UK and European standards. However, in most cases there is no direct correspondence between the compounds controlled by exhaust emission legislation and those targeted by air quality objectives and limits. Emission limits (see Figure 3.18) are set for carbon monoxide (CO), total hydrocarbons, total oxides of nitrogen (NO_X), and for diesel vehicles, total particulates. Within the UK, the corresponding air quality standards related to CO, nitrogen dioxide (NO_2), benzene, 1,3-butadiene, and particulate matter measured as PM_{10}.

Figure 3.18 Changes in exhaust emission standards for cars in the EU



Source: Boulter 2005.

Figure 3.19 Average speed emission functions for a typical light-duty catalyst equipped vehicle



Emission source strength

239. The magnitude of emission is a function of the number and type of vehicles, and the way in which they are operated. Measurements have shown that the highest rates of emission (in grammes per kilometre or g/km) occur in congested, slow moving traffic, and that there is also a tendency for emission rates to increase at high speeds, especially those of oxides of nitrogen. Graphs illustrating typical variations in emission rates as a function of average speed are given in Figure 3.19, for catalyst-equipped petrol engined cars. Other types of engine and vehicle respond differently to changes in average speed. However, emissions from a particular vehicle operated under specific circumstances may deviate considerably from the average pattern (Barlow et al. 2001; Hickman 1999).

240. Emission rates under stop-start driving conditions, often associated with congested traffic conditions, are much higher than those when vehicles are driven more smoothly. For example, studies have shown HC emissions from a car travelling at a steady speed to be only half of those measured at the same average speed, but with the car driven in a more typical way, over driving cycles containing accelerations, decelerations and periods of idling.

241. An engine that is cold is inefficient, and extra fuel has to be supplied for satisfactory operation. This significantly increases the rates of emission of CO and HC, as well as the fuel consumption. The effect is greatly compounded in the case of vehicles with catalytic emission control systems. Catalysts do not begin to work until their temperature reaches a 'light-off' value of around 300^oC, and also require an accurately controlled exhaust composition for full effectiveness. So, not only does a cold engine produce more emissions, but also they are not treated by the catalyst system. Typical results for non-catalyst petrol cars show emission increases of 40 - 50% for CO and HC, and 10% for CO_2 from tests in which the engines were started cold, at an ambient temperature of 20 - 25^oC. Similar tests on catalyst equipped cars show emission increases of an order of magnitude (though their absolute rates of emission when cold are no higher than for non-catalyst cars). These, and many other factors will influence the emissions from traffic in specific locations. However, the effects of cold start conditions on NO_X and PM emissions are relatively smaller than those for CO and HC.

242. European and UK legislation is in place, and under continual review, restricting emissions from all of the major UNECE categories of air pollutant sources. With respect to the control of emissions from road transport, the approach is two-fold whereby limits are set on the allowable emissions from the exhaust of individual vehicle types, supported by the introduction of regulations on the formulation and quality of road fuels. The adopted methodologies for compliance with this legislation has itself been twofold, with the development of improved engine technology, such as modifications to the engine map, and exhaust after-treatment systems including three-way catalysts; oxidation catalysts; exhaust gas recirculation; selective catalytic reduction; de-NO_X traps; diesel particulate filters; and regenerative traps. All of these technologies have varying levels of control on the emission of specific pollutants, and thus the introduction of these types of technologies into the vehicle fleet, have positive and negative effects on specific emissions. For example, the installation of

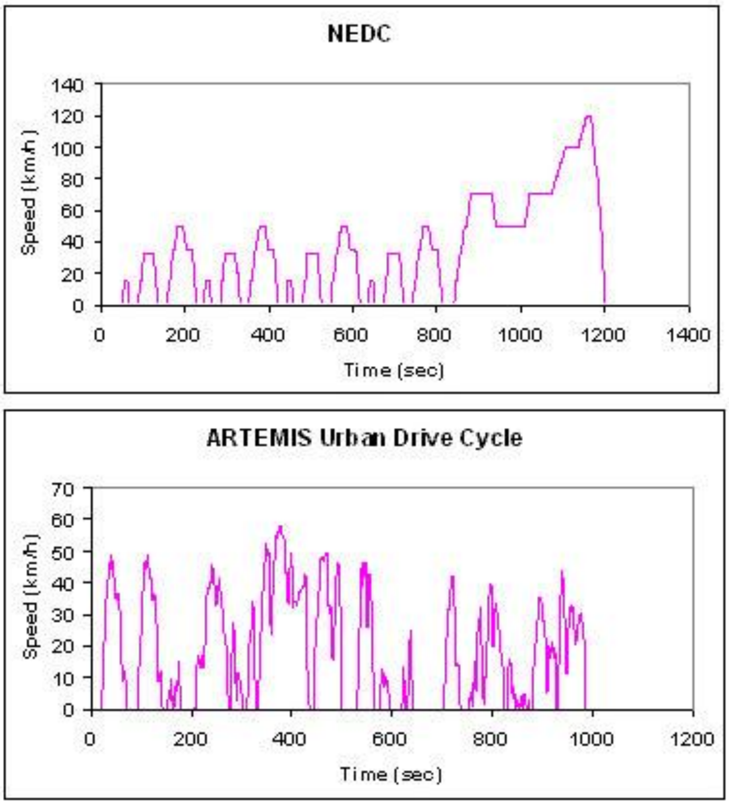
the early types of regenerative particulate traps, undoubtedly reduce PM emissions but can be associated with an increase in the proportion of primary NO_2 released.

Emission legislation and derivation of representative emission factors

243. Before any new vehicle model enters the European vehicle market, it is subject to and must comply with Type Approval tests. The measurement of exhaust emissions forms one component of the Type Approval test, whereby a test vehicle is driven over a test cycle specified in legislation, and its emissions are measured. Type Approval compliance essentially requires the vehicles emissions to be within defined limit values (see Figure 3.18). Because HGVs can be fitted with a variety of engines from different manufacturers, the conventional way to access HGV Type Approval has been to 'approve' the engine emissions, in isolation from the vehicle, through testing at a set of pre-defined engine speed and load combinations.

244. The standard light-duty Type Approval test cycles encompass relatively low rates of acceleration and deceleration. A comparison of the existing legislative test cycle (the New European Drive Cycle or NEDC) and a typical real-world test cycle (such as the CADC [23]), it becomes apparent that real-world operation contains significantly greater transient operation (Figure 3.20).

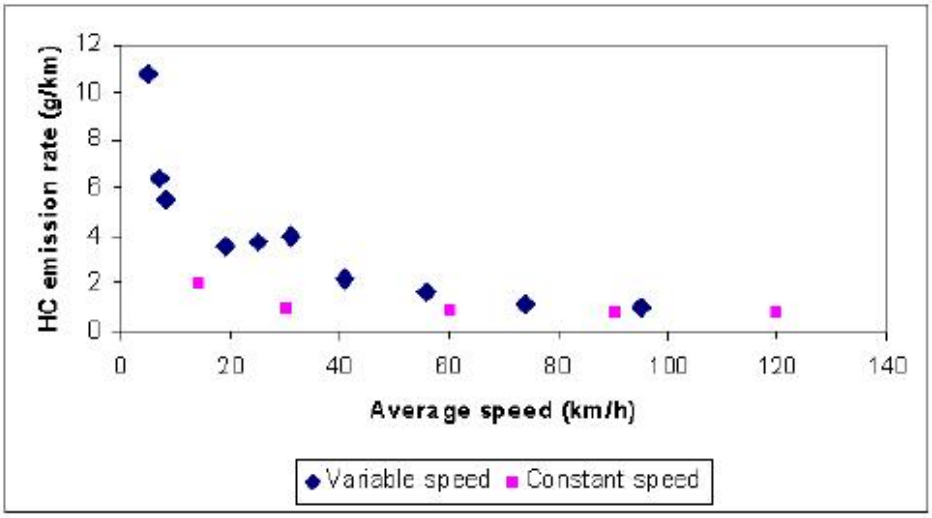
Figure 3.20 The EU NEDC type approval cycle and the new ARTEMIS urban test cycle.



245. There are therefore questions regarding the representative nature of the Type Approval procedure for the estimation of vehicle or fleet emissions. Given this concern, all road transport emission factors produced over the last 15 years or so, are derived from tests conducted on vehicles operated over a real-world driving cycles rather than the legislative cycles.

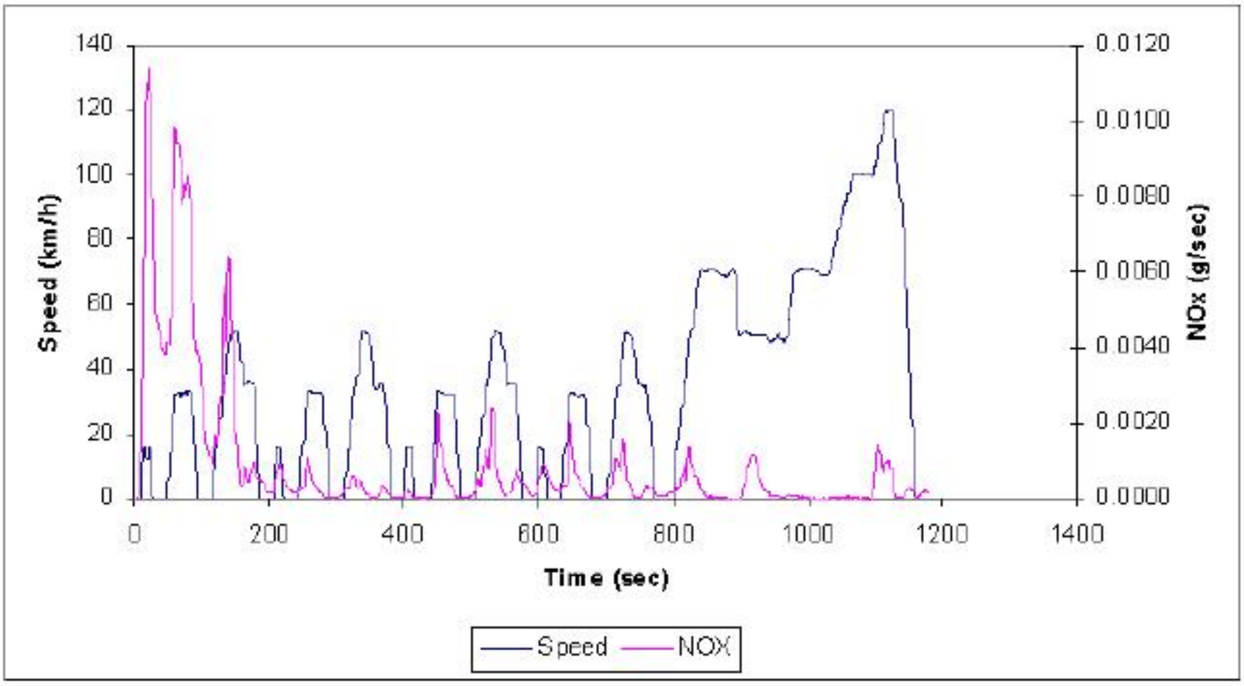
246. Figure 3.21 clearly shows the significant difference in emissions associated with vehicles driven at constant speeds, against those driven with a variable speed, but with the same average speed. This effect appears more significant at the lower urban speeds, and again emphasises the need to use emission data derived from real world measurements.

Figure 3.21 The impact of vehicle speed variation on emissions



247. Figure 3.22 provides an example of emission response with vehicle operation, over the NEDC driving cycle. What is evident from this plot is that emissions are essentially zero for much of the operation, but exhibit emission peaks, when loads are applied to the engine. The peaks over the first 140 seconds of the vehicle operation are related to a cold start.

Figure 3.22 Emission characteristics of a 1.6 litre petrol Euro 2 passenger car



248. In general, real-world emission factors are higher than those typically related to Type Approval measurements. The EU project ARTEMIS, which builds upon the earlier work of the EU MEET project, will deliver new road transport emission factors in 2006. Where appropriate and available in time, the results from these and other UK

and EU emission factor measurement programmes will be incorporated into the revision of the emission factor database.

249. Emission data are generally more robust for conventional vehicle types, passenger cars and conventional fuels (diesel and petrol). The robustness of those data associated with other fuel types (such as LPG, CNG, bio-diesel or diesel emulsions), fuel qualities (sulphur and aromatic contents) and alternative engines (for example, injection configurations, dual-fuel, hybrid, gas or electric) are generally poorer. In addition, while much emphasis is placed upon exhaust after-treatment devices such as diesel particulate traps, the durability of these remains uncertain, particularly once these vehicles are cascaded into the second hand market.

Deriving vehicle emission factors

250. Emissions factors are produced on the basis of typical driving cycles that subsume or 'average out' the variations associated with individual journeys, such as the vehicle condition (its age, engine tuning and operating efficiency); individual driver behaviour (for example, gentle as opposed to aggressive driving); and ambient temperature.

251. The accepted method for the derivation of emission factors has been the measurement of emissions from a test vehicle over a series of real-world driving cycles, with a range of average speeds incorporating cycles which characterise low speed urban through to high speed motorway driving conditions. These tests are routinely undertaken on a selection of vehicles which are representative of the vehicle fleet, in terms of engine size and performance, and would routinely be repeated on the same vehicle and similar vehicle models to provide some indication of uncertainty. Historically these fleet emission test programmes have, in the case of light-duty vehicles, involved tests of samples involving up to 200 vehicles. More recently, over the last decade or so, these test programmes have been restricted to significantly smaller sample sizes, but have generally involved more tests, and the measurement of more pollutant species. The issue of the small sample sizes for test programmes is, and will remain, a reality for the development of transport emission factors; particularly for heavy duty vehicles which remain based on very few test cases.

252. For each vehicle tested, the average rate of emission (in grammes per kilometre or g/km) during the test and the average speed (in kilometres per hour or km/h) of the test cycle are derived. Grouping the emission test results according to the appropriate vehicle classification (by size, emission standard), relationships between the average rates of emission and the average speed may be derived. For the existing UK emission factors, a standard polynomial function (chosen with a subjective element), of the following form was adopted:

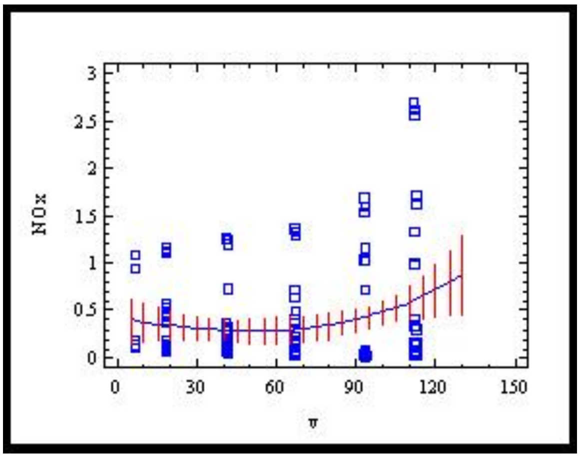
$$E = a + bv + cv^2 + dv^3 + \frac{e}{v} + \frac{f}{v^2} + \frac{g}{v^3}$$

where *E* is the rate of emission, *v* is the average speed and *a* to *g* are coefficients.

253. In many cases, one or more of the terms were excluded from the final function (*i.e.*, the coefficient was set as being equal to zero): only terms that appreciably

improved the correspondence between the function and the base data were included. Even so, because of the wide scatter, many of the data sets gave statistically poor correlation with the average speed. However, the variability of the data derived in this manner (as shown by the example data in Figure 2.23 for a sub-set of passenger cars) are typical of exhaust emission measurements and appears to show real vehicle to vehicle and test to test differences. Thus, provided that the vehicle samples and test conditions for each class of vehicle were representative of the type of vehicle and its operation, the functions generated in this way will give a good average emission rate for any particular average speed for that vehicle class.

Figure 3.23 The speed / emission function for NOX emissions from cars



Emissions from medium size Euro 2 petrol cars, with the base data and 95% confidence intervals.

Source: Barlow et al. 2001

[23] CADC – Common ARTEMIS Drive Cycle. A real-world test cycle comprising urban, rural and high speed driving.

Trends in vehicle emission model development

Introduction

254. Vehicle emission levels are dependent upon many parameters, including:

Vehicle type Technology level	Weight Gradient

Fuel type Operation (speed, acceleration, gear..)	Mileage Level of maintenance

Road traffic emission technology developments

283. EU Directives have set successively tighter mandatory emissions standards for new vehicles since the early 1970s. The pollutant emissions regulated are carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NO_X) and, in the case of diesel vehicles, particulate matter (PM). Recent standards are often colloquially referred to as 'Euro standards'. At present 'Euro IV' standards are in the process of being phased in and for heavy duty engines, used in HGVs and buses, a further round of standards ('Euro V') is already defined in legislation ready for introduction in 2008-9.

284. These emissions standards are performance requirements defined in terms of the maximum permissible emissions of each pollutant per kilometre traveled (cars and LGVs) or per unit of energy delivered by the engine (for HGV and bus engines) when tested on a specified test cycle. In order to meet new standards, vehicle manufacturers have to introduce new or improved technologies. Typical Euro IV & V technologies are summarized in Table 3.8 below.

Table 3.8 Typical Euro IV & V vehicle technologies

	Petrol car or LGV	Diesel car or LGV	HGV or bus
Euro IV	Closed loop electronic control systems, 3-way catalysts, close coupled catalysts for control of cold start emissions.	High pressure electronically controlled fuel injection, intercooled turbocharging, exhaust gas recirculation, and retarded ignition timing.	High pressure electronically controlled fuel injection, intercooled turbocharging, selective catalytic reduction systems or retarded ignition timing and exhaust gas recirculation.
Euro V			As Euro IV with improved selective catalytic reduction systems.

Non-engine source type	**PM10 emission factor as g/km**	
	Light duty vehicles	Heavy duty vehicles
Brake and tyre wear	0.0069	0.0497
Road surface wear	0.0031	0.029
Re-suspended material	0.0008	0.0144
Equivalent exhaust emissions	*0.0139*	*0.0793*

Plant	Fuel	Annual fuel energy input (MJ)	
523 Cargo CHP	Gas	1.12E+09	
	Gasoil	1.11E+07	

448	Gas	4.10E+08	
	Gasoil	1.80E+06	
TERMINAL 4	Gas	6.84E+07	
Smaller BAA boilers - oil fired			
225	Gasoil	2.84E+05	
316	Gasoil	3.23E+06	
390	Gasoil	3.23E+06	
391	Gasoil	3.23E+06	
450	Gasoil	1.17E+07	
679	Gasoil	1.20E+07	
867	Gasoil	1.08E+06	
895	Gasoil	1.88E+06	
923	Gasoil	1.23E+06	
941	Gasoil	1.97E+05	
1092	Gasoil	7.31E+06	
1157	Gasoil	1.82E+06	
BM Hanger	Gasoil	1.13E+07	
Smaller BAA boilers - gas fired [1]			
706	Gas	3.61E+06	
123	Gas	1.11E+07	
495	Gas	3.53E+06	
Customs House	Gas	1.82E+06	
Visitors & CP	Gas	6.22E+06	
216 Canteen	Gas	4.50E+05	
Taxi Feed Can	Gas	5.19E+06	
BA heating plant			
Terminal 4	Gas	2.35E+06	
Heathrow Cargo	Gas	3.07E+07	
Heathrow Maintenance Number 1	Gas	4.68E+08	
Heathrow Maintenance Number 1 [2]	Gas-Oil	2.72E+06	
Hatton Cross Site[3]	Gas	2.34E+06	
Compass Centre	Gas	1.60E+07	
Early Baggage Store Terminal 4 [3]	Gas	2.69E+05	
Hatton Cross Unit 3[3]	Gas	2.34E+06	
Northside House	Gas	2.32E+06	
Total		2.23E+09	

Pollutant	Emission factor (g/litre)

Appendix AQ.1.8

NO_X	1.8
PM_{10}	0.07

Panel 3 Conclusion

316. Panel 3 gave extensive consideration to identifying best practice in developing both current case and future case emissions inventories for Heathrow Airport. The starting point of this process was a detailed review of the Heathrow Emissions Inventory 2002 produced by netcen (Underwood et al. 2004a and b). It was agreed that this would form the benchmark against which Panel 3 would seek to reduce uncertainties in emission estimates through a process of commissioning new research and through the use of expert judgement. The Panel decided that there were three key areas: aircraft, aircraft support vehicles and plant, and surface access, where improvements to the methodology of the 2002 Emission Inventory could be made within the timescale of the PSDH process. Where possible Panel 3 has been able to provide an indication of the possible impact of the recommended changes to the inventory methodology will have on emissions. But it is beyond the scope of the Panel activities to quantify the change in magnitude of emissions across all activities. This is particularly true for surface access where the effect of more robust modelling on traffic flows and speeds remains relatively uncertain.

- The effect of ambient conditions (temperature, pressure and humidity) which could change NO_X emissions by up to ± 30% depending upon the season and time of day;
- The effect of forward speed which may increase NO_X by an average of 4-8% depending upon the characteristics of the engine design;
- The effect of aircraft engine deterioration which may increase NO_X emissions by 4.4%; and
- Emissions of primary NO_2 which are likely to range between 4.5% and 37.5% of the total NO_X emissions dependant on the power setting.

Airport support vehicles and plant

320. Panel 3 concluded that there were significant uncertainties in the magnitude and spatial distribution of airside emissions in the benchmark 2002 inventory. In particular there was uncertainty over fleet composition and duty cycles. The work of the Panel has in a limited way resolved some of these uncertainties but it is agreed that further work is required over some time. The Panel suggested that the overall airside methodology employed in the benchmark 2002 inventory is appropriate, but should take into account new fleet composition data and emerging information on duty cycles (from recent PSDH work). It is uncertain whether this change to the methodology will increase or decrease emission totals until additional work is undertaken.

Surface access

321. Panel 3 concluded that road traffic movements and the associated operational emissions could be characterised more robustly in future Heathrow emission inventories, but the key to this is the specification for the traffic modelling - as air

quality requirements are often beyond the needs of the traffic planners and engineers. In the case of PSDH, the traffic modelling being undertaken by others has been changed in many areas, where feasible, to reflect the needs of the emerging detailed air quality modelling specification from Panels 1 and 3.

Activity

322. Key improvements in the coverage and understanding of traffic uncertainties are:

- Established the order of relative importance of traffic parameters to air quality modelling at Heathrow, and focusing effort accordingly:

Pre-requisite	modelled base year
Rank1	road network extent
Rank2	traffic flow (with diurnal profiles)
Rank3	fleet and composition
Rank4	road traffic speeds
Rank5	road traffic queues
Rank6	Trip ends
Rank7	Other traffic parameters

- Use of the most appropriate traffic activity modelling approaches for air quality, and the pros and cons associated with it;
- Base year traffic modelling to be adjusted to optimal base year for air quality modelling, using agreed backcasting methodology (including taking account of the effect of construction work on traffic);
- Network extent, link density, zoning size, and model boundary effects to be improved over previous work, using a 'network flow model' or an additional nested 'micro-simulation model' approach;
- Minor roads to be included using the 'residual vehicle-kilometres per grid-square' approach;
- Improved representation of diurnal profile of flow, speed and composition, both within traffic models and using innovative tools outside the traffic model;
- Improved vehicle composition data from the traffic model in order to facilitate linkage to the vehicle fleet emissions model;
- Provide separate data for weekend and working weekday conditions;
- Include queuing effects through the 'false link' technique where feassible;
- Include the additional emissions associated with trip ends based on the type of trip.

Emissions

323. Key improvements in relation to emissions are:

- Recent developments in road transport vehicle emission modelling have highlighted some of the disbenefits of the 'traditional' average speed approach. Whilst these new approaches (including 'traffic situation' and 'instantaneous' models) provide temporal and spatial improvements, the lack of existing input data for these models negates their use in the PSDH process. Therefore the use of an average speed emission model, incorporating the latest emission data for recent vehicle technologies, fuels and Euro classes is recommended;

- Improved understanding of future road traffic emission technology developments, including high and low scenarios for Euro V and Euro VI;
- Specify the use of future emission scaling factors based on latest views on the likely take-up of emission reducing technologies, and use changes in the assumptions in standard emission models to reflect trade-offs between some of the new technologies;
- Importance of accounting for primary NO_2 from road traffic, and the need to reflect
  this in the emissions inventory (although noting that separate data for primary NO_2 is not yet available);
- Method to account for primary PM_{10} emissions from non-engine related sources, including brake and tyre wear, road surface wear, and re-suspended material.

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Table of contents

Introduction

1. The remit of Panel 1 within PSDH is set out in full in Annex 1 and summarised in Chapter 1. This chapter cross-references that remit with the identified shortcomings of previous work, and explains how Panel 1 tasks have been identified to redress these to the benefit of further post-Panels air quality assessment of future operations at Heathrow. The final section in Chapter 1 makes recommendations for future work.

2. The general remit for Panel 1 was to examine approaches to modelling local air quality in the vicinity of Heathrow and to make recommendations for specific modelling approaches to be used for air quality predictions, especially in relationship to the proposed third runway. Chapter 1 summarises and Annex 2 contains a detailed review of key previous assessments of air quality around Heathrow, focusing on their description and shortcomings. Previous Heathrow work includes:

Heathrow-focused

- South East and East of England Regional Air Services Study (SERAS) 2000-2002 (DfT 2003a)
- *The Future of Air Transport* White Paper (DfT 2003b)
- British Airways 2003
- BAA 2004, and

Other models around Heathrow

- CERC West London Model 2002 (Williams and Girnary 2002)

3. The Panel was specifically asked to review the 'Heathrow-focused' work shown above and to examine other modelling tools used at airports (in the UK and elsewhere). A particular requirement was to consider the EDMS/Aermod and LASPORT models, and to consider fundamental alternative approaches to modelling, such as Lagrangian versus Gaussian dispersion methodologies. However, whilst the work was not restricted to UK applications, the transferability of other models to the UK context was necessarily a real factor in evaluation.

4. Most prior 'Heathrow-focused' work was performed by netcen using a 'kernel' approach based on ADMS3. It compared a large number of airport scheme options using a single simple air quality key indicator (a form of Appraisal Summary Table (AST)), rather than providing a validated and detailed estimate of air pollution concentrations by contributing source types. The output of the three panels addresses improvements over the results of the SERAS and air transport White Paper work, by specifying detailed inputs (Panel 2 and 3), model verifications (Panel 1 and 2) and output requirements (concluding section of this chapter), as well as improvements in source representation (Panels 3 and 1).

5. Annex 2 outlines in detail the key areas of uncertainty in previous sources work. Many of these relate to emission inventory uncertainty (Panel 3). For Panel 1, the key areas for *"recommendations for improvement to previous work (SA1)"* can be summarised as:

6.
    a. suitability of emissions source representation in dispersion using point/strips/volume (including especially all elements of the LTO cycle);
    b. accuracy of representation of background emissions levels;
    c. characterisation of the initial dispersion of the aircraft plume (including jet turbulence and plume rise);
    d. characterisation of near road dispersion effects; and
    e. NO_X/NO_2 conversion now and later (including ozone trends).

6. Item a above is tied strongly to Panel 3 tasks, especially the section on the representation of aircraft source emissions from 'stand to land' including all elements of the landing and take-off (LTO) cycle. However, model process

improvements were also investigated by Panel 1 to improve representation (such as the use of an adjusted jet model to reflect aircraft jet sources).

7. The effect of variations in background contributions to air pollutant concentrations (item b) has been shown by assessment using five different model approaches in a model inter-comparison (MIC).

8. Item c has been the subject of much work in Panel 2 and Panel 1, including specifically commissioned LIDAR studies of aircraft at Heathrow, and subgroups addressing the use of jet models, and aircraft wake vortices. Ultimately, most of these effects could be included by using some form of model parameterisation in the recommended model, through further analysis of the LIDAR data, following the Panel reports.

9. Item d has been addressed through a review of available model approaches to near road dispersion, with specific monitoring surveys being undertaken to assist understanding and subsequent verification (including transects from airside to roadside and beyond). The Data Mining and its use in inter-comparison has also provided insightful lessons and recommendations on this issue.

10. Item e has been addressed by all Panels, providing both localised parameters for NO_2/NO_X over time (Panel 2), improved understanding primary NO_2 emissions (Panel 3 for aircraft and roads), and developments in parameterization of NO_X-related chemistry and its use in models.

Requirements for modelling

11. The analysis of monitoring data has demonstrated that the key pollutant, i.e. that most likely to exceed Government air quality objectives, is NO_2 and that the objective most at risk of exceedence is the annual mean of 40 $\mu g/m^3$ (see Chapter 2 conclusions and recommendations). Panel 1 was required to consider other pollutants as well, but this specific objective for nitrogen dioxide has proved the central focus of its work.

12. The model or models selected have to be able to describe quantitatively the concentrations and spatial distribution of NO_2 concentrations in the vicinity of Heathrow. The assessment performed by Panel 1 considered the following aspects of potential models:

- The representation of emissions from aircraft, from airside, from road traffic and from other sources, as well as contributions to pollutant concentrations from the regional background.
- Dispersion of pollutants from their sources and the impact of meteorology and other confounding factors on resulting concentrations.
- The conversion of nitric oxide, NO, the main primary pollutant, into nitrogen dioxide, NO_2, the main air quality pollutant of interest, and the dependence of concentrations on the amount of directly emitted (primary) NO_2 and on the concentration of ozone in the background air.

13. Validation of models is best achieved by comparison against a combination of monitoring and activity data, by judicious use of source apportionment techniques. For the purposes of Panel 1 recommendations, simple comparisons with total measured concentrations would gloss over some of the key dispersion issues identified. While the key objective of interest for NO_2 is the annual mean, there are advantages if more detailed data are also available from a model, such as hourly concentrations, to facilitate validation for a variety of conditions, such as wind speed and direction, and against airport specific operations such as runway alternation.

14. While the models were tested against available monitoring data using existing emissions inventories and meteorological data, the requirement is for a model that can predict future concentrations using best estimates of future emissions, meteorology and background pollutant concentrations. Uncertainties in those estimates place requirements on chosen model(s) to be able to disentangle the impact of source contributions on dispersed concentrations in order to understand the sensitivity of predictions to changes in both model processes and activity data. It is important to do so as the recommended models will be testing scenarios up to the year 2030, when the relative importance of sources may have changed, and hence the acceptable performance of models in reflecting that source adequately may be more onerous than required under current source apportionment.

15. A major element of Panel 1's activities was a formal model inter-comparison (MIC) of five different models. The details of this inter-comparison, which was based on the year 2002, are provided below. A range of tests of model performance was conducted, which provided an exacting analysis of the relative performance of the models. It is important to note however, that the focus of the MIC was on understanding the performance of dispersion in the selected models. In practice, the models used are invariably a toolkit of models (processing, emissions, dispersion, etc.), and for the MIC several elements have been 'standardised' to focus the comparison on differences in dispersed concentration results.

16. The next three sections of this chapter provide necessary background on atmospheric transport, on key issues relating to atmospheric dispersion for airport studies, and on relevant atmospheric chemistry issues over the relatively short timescales under consideration. These sections are effectively a scientific assessment of the modelling approaches available in practice for airport assessments. The majority of Panel 1 work has been focused on providing a practical and best practice way forward for the DfT to respond to Ministers, rather than a justification of any need for new theoretical developments. Clearly the make-up of the Panel has ensured that practical ways forward are based on a sound theoretical understanding of dispersion modelling for local air quality.

17. The main sections of the chapter contain a brief review of the methodologies employed by the five models followed by a comparative analysis of the results obtained in the MIC. The section on Model inter-comparison outlines a detailed analysis of model requirements from Panel 1 for the recommended

modelling approaches, including a review of key areas of uncertainty. The final section in this chapter provides a summary of the key recommendations from Panel 1 on the dispersion modelling approaches to be employed in the planned assessments of air quality around Heathrow.

Fitness for purpose criteria

18. In addition to the mostly quantitative comparisons made as part of the MIC, several other 'fitness for purpose' criteria were considered. The chosen assessment approach should aim to be:

- demonstrably better than the pre-White Paper approach;
- able to include more than one model if necessary (so as to include a range of outcomes if results suggest a need);
- able to account for the substantive questions and issues addressed by the technical panel process;
- show the best agreement possible with relevant monitored data;
- to identify 'the best approach reasonably possible' at a given point in time (and having the confidence of the modelling community), conscious that all aspects of the process will be constantly improving hereafter;
- able to adequately represent both a base case and a series of future cases over the PSDH horizon; and
- capable of sufficient flexibility to allow required sensitivity testing (inputs, assumptions) and mitigation testing (infrastructure and operational management plans to address air quality).
- It is important to stress that the development of operationally useful models often has more to do with finding the appropriate balance of complexity, accuracy, robustness, transparency and practicality (such as, set up and run times) than the explicit inclusion of complex physical or chemical processes that, though present, can be shown to have little influence on the relevant model outputs over the operational range of inputs.

Atmospheric transport and advection frameworks

19. Atmospheric modelling frameworks can take a number of forms, e.g. Gaussian, Lagrangian, Eulerian, receptor-type modelling, and empirical models. However, a broad division can be made between deterministic models that use mathematical formulations to describe physical and chemical processes, and the more empirical models that use statistical relationships between measurements and other data to parameterise the models. The complexity of chemical and physical processes, occurring in the vicinity of Heathrow, means that some degree of empiricism is necessary. All of the models used in this investigation incorporate relationships based on 'empirically derived coefficients' to some extent, but the degree of empiricism varies between the models.

20. A review of some of the models used for NO_2 has been provided by AQEG (2004) and more detailed treatments can be found in standard texts such as Jacobson (1999), Seinfeld and Pandis (1998) and Pasquill and Smith (1983).

In the context of PSDH, a brief description of Gaussian, Lagrangian, Eulerian and semi-empirical models is given below, with additional commentary in the section on Model inter-comparison.

Gaussian dispersion

21. The Gaussian formulation is one of the most commonly used frameworks for modelling local dispersion of a pollutant. It describes the transport and diffusion of a gas (or particle) from a source to a receptor according to stability class and other parameterized characteristics of the atmosphere. It can be applied to plumes from point, line and area sources. In its basic point source form, the concentration (c) in a plume emitted from a stack, is predicted with the following mathematical expression:

$$c(x,y,z) = \frac{q}{2\pi u \sigma_y \sigma_z} \exp\left(-\frac{y^2}{2\sigma_y^2}\right)\left\{\left[\exp\left(-\frac{(z-h)^2}{2\sigma_z^2}\right)\right]+\left[\exp\left(-\frac{(z+h)^2}{2\sigma_z^2}\right)\right]\right\}$$

where

where	x	= direction of advection of the plume
	y	= horizontal direction
	z	= vertical direction
	q	= source strength
	u	= mean horizontal wind speed in the x direction
	h	= stack height
	σ_y, σ_z	= horizontal and vertical standard deviations of the plume in the y and z directions

Note that the plume spread increases with distance from the stack so that σ_y, and σ_z depend on x.

22. Early applications of Gaussian models were rather simple, usually being used to describe the long-term behaviour of an elevated release from a stack. However, Gaussian models have become quite sophisticated (for example, ADMS) and have accommodated much more detailed descriptions of dispersion from elevated sources, line sources and volume sources. Also, as described elsewhere in this report, it is now possible to included chemistry and sub-models that are suitable for airport applications.

Lagrangian

23. The description of a Lagrangian model is often taken to refer to a moving coordinate system and can take the form of a trajectory box model or a particle model. Such models are sometimes referred to as Random Walk models. In the case of a Lagrangian particle model (such as the one used in the section on Model inter-comparison), atmospheric transport and diffusion are simulated by tracking the movement of large numbers of 'particles' that represent

quantities of an air pollutant according to average wind and turbulence parameters with random movement also considered. Both average wind conditions and specific prescribed flow-fields can be accommodated to control the movement of the particles. Lagrangian models can be quite computationally intensive, their accuracy depending on the number of particles released, and they can accommodate chemical sub-models. Care has to be taken with the averaging process for overlapping trajectories (Jacob 1999).

Eulerian

24. As opposed to the moving Lagrangian framework, Eulerian models operate on a fixed coordinate system, where the emission, transformation and transport are parameterized in terms of the fluxes to and from a two or three-dimensional fixed coordinate system (see for example Jacob 1999). Such a modelling system tends to be mathematically complex, is computationally intensive and not so well suited to the treatment of emissions on a plume-scale, which may need to be embedded as a 'sub-model'. No suitable, readily available Eulerian model operating at the relevant spatial scale, and incorporating the appropriate meteorological fields, was identified by Panel 1 to cover the Heathrow area and within the timescale required for the subsequent DfT assessments of future operations.

Empirical and semi-empirical models

25. Empirical models were originally developed as an aid to mapping air pollution concentrations in a more rigorous manner than could be accomplished with sparse measurements. The basis is to take the sparse measurements and correlate them with some reasonable proxy statistic for the emission source density (or the emissions themselves) to determine a relationship between this proxy and ambient concentrations. It is assumed that the proxy data are much better known or are available on a much finer scale such that the relationships can be used as the basis of mapping pollutant concentrations. As such, this technique works best with relatively short-lived pollutants, such as NO_X, or where the emission source density dominates the ambient concentrations. The advantage over interpolation of sparse measurements is great where robust relationships can be shown from independent data. Moreover, the computational requirements of this technique are reasonably low.

26. Such empirical models have been applied on national, regional and local scales for NO_X and have become relatively sophisticated in terms of refinements of predictors (AQEG 2004). Their major restriction is that future predictions can become inherently more uncertain than deterministic models, when some physical or chemical process may change in the future. This is simply because the models are built upon present-day relationships and if these change as a result, for example, of a changing source characteristic (such as fractional primary emission, release height, etc.) or process (such as background oxidising capacity), then it is difficult to provide quantitative evidence to demonstrate the validity of these future relationships.

27. Semi-empirical models, such as the ERG model partially overcome this problem by incorporation of deterministic elements, such as a Gaussian dispersion model, for specific components. Such an approach retains some of the elements of computational simplicity with the advantage of a deterministic approach to pollutant dispersion but sometimes has the disadvantage of uncertainties over the empirical components for future scenario or projections applications.

Available approaches for airport-scale modelling

28. There are currently four types of models actually used for airport studies:

- Semi-empirical site-specific bespoke models;
- Gaussian Plume type models (e.g., ADMS, AERMOD);
- Lagrangian Particle models (e.g., LASAT, AIRPOL/F_L); and
- Eulerian Chemical Grid models (e.g., AIRPOL/F_R).

29. The theoretical basis of these approaches was outlined above. This section draws out airport modelling specifics in using these approaches. The key dispersion issues Panel 1 needed to address using these approaches are then outlined in the following section.

30. Except for special considerations that apply adjacent to terminal buildings, or for calm wind conditions, Gaussian models are often appropriate for the relatively flat environment of an airport, especially in areas relatively close to the emission sources. The consequence of calm wind issues with Gaussian approaches can be seen in the MIC.

31. The impact of airport sources on larger urban-scale environments presents challenges that are often addressed using Eulerian grid models or Lagrangian particle models, although often at the expense of grid detail over the airport area itself. As stated in Yamartino et al. (2004), "In European EIA studies of an airport, one generally includes consideration of emissions of traffic, industry, residential heating, and agriculture over an area of approximately 20 x 20 km^2 around the airport."

32. Basically, the closer one wishes to model to individual airport sources (e.g., queuing aircraft, ground support), the more those sources are likely to dominate local concentrations and the more near-field physical phenomena associated with that source or its surroundings must be considered.

33. There are a number of areas that are characterised by striking differences in approach and result. These are:

- Significant discrepancies and gaps exist in the treatment of jet aircraft plume motion, entrainment and rise in the relevant operational modes (i.e., primarily idle, taxi and take-off);
- Some plume/aircraft interactions are modelled only roughly (e.g., wingtip vortex trapping and dispersion of pollutants), if at all;

- Differences in the approach to oxidation of NO to NO_2; and
- Differences in the treatment of building (such as terminal buildings) effects.

34. The first three items listed above are discussed further in the following section. The last item (treatment of buildings) has not been explicitly investigated by Panel 1, primarily as the key locations of interest for the air quality standards of concern are off airport. Use of CFD or wind tunnel modelling of the terminal area would be one means of improving the representation of building effects, but these are very time consuming methods that would only really be appropriate for a limited number of specific cases, not a full air quality assessment. Both approaches would require detailed data of building structures for Heathrow.

35.

Key dispersion issues

Initial dispersion

35. Material emitted into the atmosphere from a pollutant source forms a plume (a generic term used to describe both 'buoyant plumes' and 'momentum jets') that generally has a velocity, temperature and hence density different from the atmosphere and therefore has a characteristic momentum flux and buoyancy flux associated with it. Density differences and velocity shear between the plume and the ambient flow induces turbulent motions that mix ambient air into the source material (a process called entrainment) diluting the plume and reducing its velocity relative to that of the mean wind. On a larger timescale the buoyancy forces acting on the plume may induce the plume to move vertically upwards. As the plume is advected and its velocity relative to that of the mean wind decreases the ambient turbulence plays an increasing role in mixing ambient air into the plume until eventually the motions and temperature/density fluctuations within the plume are similar to those of the ambient atmosphere. At this stage the plume is well mixed and the initial dispersion is complete.

36. The time and advection distance required for this total mixing, and the distribution of the released pollutant when it is completed, depend on a number of factors. These include principally the initial momentum flux and buoyancy flux of the pollutant containing emission at its release point, together with the height and direction of the release, and also the ambient airflow. In general the greater the buoyancy flux or the momentum flux, or the weaker the environmental turbulence, the longer it takes for initial mixing to be completed.

37. Although road traffic emissions are of major significance for pollutant concentrations in the neighbourhood of Heathrow, the momentum flux and buoyancy flux of each vehicle source is relatively small. Thus a very detailed treatment of the initial dispersion of road traffic emissions is not necessary in understanding their impact. Typically, parameterisations are used which are based on an initial mixing depth for road traffic which at its most sophisticated

takes account of vehicle speed, type (HGV or LGV) and exhaust location (see for example, Carruthers and Rogers 2006).

38. Of the important sources of pollutants at Heathrow, only jet engines have very large momentum and buoyancy fluxes. The consideration of their impact on dispersion is essential in determining pollutant distributions caused by these sources. The large momentum flux from a main aircraft engine produces an exhaust jet that will advect material horizontally away from the engine, and mix and dilute pollutants with the ambient air. In doing this, the relative velocity of the jet to the ambient flow progressively decreases. The buoyancy flux generates acceleration vertically upwards. For any particular source momentum flux there will initially be a horizontal jet, with the vertical component of the flow developing further away from the engine due to the buoyancy flux. For larger buoyancy fluxes the development of the vertical component will occur closer to the engine.

39. Any vertical displacement of the pollutants in the plume will reduce ground level concentrations. This mechanism for the possible reduction of ground level concentrations has led to considerable recent interest amongst modellers of aircraft engine emissions.

40. To complicate matters the ambient wind will also have an influence. The larger the ambient wind speed the greater the mixing and dilution of the plume. However, large ambient winds also inhibit the vertical rise of the plume and keep it closer to the ground, producing larger ground level concentrations. There can be a 'worst' ambient wind speed at which the maximum ground level concentration will be experienced.

41. Plume rise from an elevated source of buoyant material emitted into the atmosphere with vertical momentum (such as a chimney stack) is well understood, and can be well quantified (see for example, Briggs 1984). This approach has been generalised to emissions in an arbitrary direction (Ooms and Mahieu 1981) and can therefore be adapted to a horizontally directed source such as a jet engine. The approach has been developed for incompressible flows but models are also available for compressible flows.

Small scale atmospheric transport and diffusion

42. When the initial mixing is complete the pollutant motions are those of passive constituents of the atmosphere. Any plume of pollution is advected by the mean wind and mixed and hence diluted by the atmospheric turbulence - such processes are well described and modelled in the literature (for example, Pasquill and Smith 1983). Of particular relevance to the dispersion here is that in stable flows, occurring in light wind night time conditions, turbulence mixing is relatively weak, which may result in high pollution concentrations for low level sources but conversely little impact from elevated sources or those subject to significant plume rise. In convective conditions, occurring when there is a strong solar flux, turbulent mixing is relatively strong, resulting in faster dilution of the plume from lower level sources but increased

impact of plumes from elevated sources, which are mixed down to the surface more quickly.

The effect of landing and take-off (LTO) aircraft operations on plume motion

43. There are a number of flow complexities, additional to those outlined in the preceding section on Initial dispersion, that arise when considering the plume from an aircraft jet engine near the ground. These include:

- The effects of compressibility (the exit Mach number is typically slightly less than one).
- The effect of the motion of the aircraft over the ground, as this increasingly spreads out the momentum and buoyancy of the plume as the aircraft accelerates along the runway, thereby reducing the plume's tendency to rise.
- The influence of the ground itself, through the constraints imposed on entrainment into the plume from beneath the plume, which may initially cause the plume to remain close to the ground.
- The specific behaviour of a "wall jet" as distinct from an unbounded jet.
- The orientation of the jet exhaust to the horizontal following rotation.
- The interaction of plumes from adjacent engines where entrainment may cause them to converge.
- The potential impact of the aircraft wake which is discussed separately in the next section.

44. Compressibility effects are dynamically negligible when the Mach number is less than 0.3 (Robertson and Crowe 1976). Such effects quickly diminish as the jet entrains ambient air and the local Mach number decreases to 0.3. Entrainment in the region where the Mach number is high (above about 0.3) may be modified, though the overall effect in the far field is unlikely to be significant. As shown in subsequent sections on model inter-omparison, available jet models in air quality use do not take compressibility effects into account. Such effects could, if desired and justified for dispersion effects at relevant receptors, be represented through a virtual source adjustment. At most, the Panel expects that this would cause a small change in the spatial distribution of pollutants.

45. The plume rise described in paragraph 41 is influenced by the motion of the plume source. This can be studied by a change of reference frame where the source is stationary and there is a flow past the source. Theory (Turner 1973) shows that the buoyant plume rise is substantially reduced by the flow past the source. Returning to the situation with the source in motion, theory requires that the buoyant plume rise be reduced due to the reduction in the buoyancy per unit length of the plume as a result of the source motion. This process may be relevant to the development and dilution of the plume from an aircraft in motion.

46. Results from the EnFlo wind tunnel (Hayden and Robins 1998) at the University of Surrey largely support the principals outlined above.

Experiments with non-buoyant momentum jets showed that a consequence of interaction with the surface was enhanced lateral spread, with little corresponding change in the vertical, typical of the 'wall jet' (Launder and Rodi 1983). When the plume had both momentum and buoyancy three classes of behaviour were noted. In the first, where buoyancy effects were weak, the plume behaved much as a passive wall jet. In the second, buoyancy generated an enhanced vertical spread, though the plume remained in contact with the surface; and in the third the plume lifted clear of the surface (this process was generally slow because of the strong stream-wise momentum in the emissions).

47. Finally, the possible interaction between the vorticity shed from the lifting wings and the buoyant jets from the engine was not studied in this preliminary modelling work but is discussed in the next section.

48. The LIDAR studies at Los Angeles Airport by Wayson et al. (2004) concluded that there was a plume rise and that this could be modelled as fixed at 12 metres. The spread of the concentration profile produced a vertical spread s_z of 4.1 metres and a lateral spread s_y of 10.5 metres. The authors state that the "Effects of aircraft type, temperature, wind speed, wind direction and atmospheric stability were not found to be statistically significant in the data analysis". All the data presented were taken at a position close the where the aircraft started their take-off roll, where trailing vortices would be weak.

49. Bennett and Bennett and Graham undertook LIDAR experiments at Heathrow and Manchester Airports. A report on the work at Heathrow is in Annex 7. Initial results of the work at Manchester were provided in private communication to Panel 1 but, at the time of writing, has not yet been published. They found significantly larger plume rises, particularly at small wind speeds. Where the plumes did not lift off the ground they found that there was greater spreading than would occur in the absence of plume buoyancy. These observations need to be reconciled and also compared with the physical processes described above as well as with theoretical analyses and modelling in future work.

Effect of the aircraft wake

50. The importance of any plume rise on the ground level concentrations in the vicinity of an airport has led to concerns over the potential significance of the organised wake vorticity on the motion and dispersion of the jet engine exhausts. There are three issues here. How strong is any organised vorticity in the wake, where is it and does the resulting velocity field influence the motion of the jet exhausts? The last point might be more usefully stated as "does the velocity field induced by the vorticity inhibit any plume rise? Lateral motions, in themselves, will have little influence on the ground level concentrations distant from the source position."

51. The lifting surfaces of the aircraft produce shed vorticity that can roll up into vortices that trail longitudinally behind the aircraft (Spalart, 1998). The

processes are a little more complex than this, particularly close to the aircraft when the wing has several separate lifting surfaces and when the wing is close to the ground. But the simple description of a pair of counter-rotating vortices trailing from the wingtips will be used here. The generation of such a trailing vortex system is an inherent consequence of lift production by a wing.

52. Whenever an aircraft produces lift, vortices are generated and these induce a flow field that propagates the vortices downwards. When the aircraft is near the ground at an airport the vortices can propagate towards the ground and produce velocities on and near the ground that may be of concern to other aircraft. See the FAA Advisory Circular 90-23F (FAA 2002). The vortices also influence the motion of the pollutant plume from an engine, causing it to descend. This effect is included in some airport dispersion models, for example LASPORT and ADMS-Airport, in which a vertical downward displacement of the plume is incorporated. Incorporation of these effects into dispersion models should be considered further.

53. Of concern in this note is the significance of vortices that are generated while the aircraft is on the ground during its take-off roll, in particular whether these vortices are strong enough to influence the motion of the exhaust plume, particularly to inhibit the plume rise due to buoyancy. Although there have been a number of studies that include observations of trailing vortices near the ground, it has not been possible to find a definitive publication on this matter when the aircraft is still on the ground and so information from several sources has been reviewed and brought together.

54. The behaviour of vortices close to the ground is complex and not that well understood in detail. A lateral motion is induced by their interaction with the surface that causes them, al least initially, to move away from the centreline. This motion also generates vorticity of opposite sign near the surface which interacts with the original system and slows, perhaps stops, the lateral movement (Spalart 1998). Furthermore, this whole process is quite unsteady and significantly influenced by cross-winds.

55. Of interest here is any interaction between the vortices and the exhaust jets. Relevant information may be available from the LIDAR studies once they have been comprehensively analysed.

56. The strength of the trailing vortex system is directly related to the lift force generated by the wing which, in turn, is proportional to the square of the aircraft velocity relative to the air, at fixed lift coefficient. When the aircraft is on the ground in its take-off roll leading to rotation, the lift force is initially zero and will remain relatively small during the initial stages of acceleration, reaching a maximum just prior to rotation. After rotation, the lift coefficient, the lift force and the strength of the trailing vortex system will increase substantially, ultimately allowing the aircraft to ascend.

57. The post rotation lift coefficient lies between 1.3 and 1.7. At rotation (about 10 degrees) the change in lift coefficient is about 1. Therefore, before rotation the lift coefficient is in the range 0.3 to 0.7, with an average of about 0.5. Hence,

the post to pre-rotation lift coefficient ratio is approximately 3. Clearly, any trailing vortices arising during the take-off roll will be substantially weaker than those established just after rotation and very much weaker in the early stages of the take-off roll.

58. Of equal concern for dispersion modelling might be the effect of trailing vortex systems after take-off that undergo self-induced advection towards the ground. Further consideration of this and its effects on jet plume behaviour would be worthwhile. The same will be true as the aircraft is landing, though here the engine power settings are low, as are emissions, and the issues are consequently of considerably less import than after take-off. However, simplified representations of both situations should be readily incorporable into operational dispersion models. The objective would not be to include a faithful representation of all that might take place in practice but to include sufficient to test the importance and likely impact of effects induced by the vortex systems.

59. Two sets of airport/aircraft LIDAR data, available at the time of writing, have been considered where vortices generated during the take-off roll could have an influence on the initial dispersion:

- Data from Wayson et al. (2004). These have already been discussed in the previous section. They concluded that the effects of ambient temperature, wind speed, wind direction and turbulence (atmospheric stability class) were not statistically significant. Differences between aircraft type did occur but they could not be proven to be statistically significant with the data available. The mean height was attributed to a buoyant plume rise. The one cross-section shown indicated a ground based, compact plume. All the data presented were taken at a position close to where the aircraft start their take-off roll, where trailing vortices would anyway be very weak.
- Data from Bennett (2005) for the take-off roll showed a generally ground based compact plume but one that had significant buoyant rise, particularly in light winds. This behaviour was supported with further data in Bennett and Christie (2005) particularly for wind speeds less than 3 m/s. The authors suggested that the plume from an aircraft near the start of its take-off roll would show buoyant rise for wind speeds below 5 m/s, while for an aircraft well into its take-off roll wind speeds below 3 m/s would be required for the plume to show buoyant rise. These results are generally consistent with the discussion in the previous section and they do not show any explicit effect of shed vorticity.
- In addition, there are two further observations in Graham et al. (2005) (included as Annex 7 of this report) that were taken behind Boeing 747-400s that were well into their take-off roll. They show ground based non-compact plumes with two clear centres some 1.1 wingspans apart. Whether this pattern is due to longitudinal trailing vortices, due to the divergent flow under the wing, or due to some other cause is unclear. These observations are the only evidence found that could imply some importance of the wing flow dynamics on the behaviour of the engine exhaust plume.

60. Based on the earlier arguments and these observations, it was concluded that any effects of the wing flow dynamics on the motion of the exhaust plumes is not important, if at all, until the aircraft is well into its take-off roll. It is difficult to be more precise without more information and detailed analysis. As noted, the time from just prior to rotation to lift-off is a small fraction of the total take-off time and uncertainty in the detailed modelling of dispersion in this final stage should have little impact on the overall calculations.

61. Whilst there have been useful LIDAR surveys at a number of airports during the Panel 1 work, these data are very recent, several of the surveys have not yet been published or the post-survey analysis completed, and little has been peer reviewed. Note also that the Heathrow LIDAR survey, as reported in Annex 7, was published after Panel 1 last met. A workshop on interpretation of recent LIDAR surveys at airports, in the UK and USA, took place in March 2006 and developments from this are ongoing.

62. During the initial stages of climb-out and the final stages of landing, when aircraft are close to the ground, the trailing vortex system is strong and may transport engine emissions to the ground. Analysis and improved representation of such effects, particularly during take-off when emission rates are greatest, may well be a wise use of modelling resources in addition to further study of the take-off roll. The effects outlined above may be more pertinent under the potential Mixed Mode operations to be considered in future years at Heathrow, when any relevant vortices may interact more than in segregated mode.

Surface characteristics

63. Mean airflow and turbulence in the lowest part of the atmospheric boundary layer are strongly affected by the nature of the underlying surface. For instance, over a relatively smooth surface the surface friction coefficient is small and the depth of the region over which the majority of the flow speed reduction to zero occurs is rather thin (in the order of 10 metres or so), and turbulence generation is also relatively weak. In contrast, over a complex surface, for example as occurs in urban areas, the flow patterns are very complex and strong turbulent motions are generated. Frequently, the impact of the surface on the mean flow is characterized through the surface roughness parameter. This can be used to take account of surface effects above any surface obstacles or buildings, but provides only a broad indication of flow close to the buildings. Where surface characteristics vary, as for instance around Heathrow, where flat grass lies adjacent to very large buildings, the surface can be represented by a variable roughness, but more usually by an enhanced roughness for the smoother areas to take some account of the impact of buildings. An additional consideration in modelling is that the surface roughness at the meteorological observation site may not be representative of the area as a whole. Where pollutant dispersion is being modelled, account needs to be taken of this in determining the input meteorological parameters for the dispersion models.

Recommendations for further model development and application

64. These recommendations are presented in order of priority:
65.
   a. Analyse the LIDAR studies as these become available to assist in determining the structure and development of the plumes arising from aircraft sources.
   b. Use modelling studies along with LIDAR and laboratory observations to determine the range of conditions under which engine exhausts during ground-roll are likely to lift-off.
   c. Include simple representations of vortex and plume motions during the ground roll (if shown to be relevant), initial stage of climb-out and the final stage of landing to examine their likely importance from an air quality standpoint.
   d. Reconsider, if necessary, the appropriate level (the balance of complexity, accuracy, robustness and practicality, e.g., run times) of modelling for these processes and specify any further research needed.
   e. Use modelling studies to determine the impact of the location of emission along the runway and the associated uncertainty in their positioning on the resulting exposure at critical receptor locations.

Atmospheric chemistry

NO to NO_2 conversion

65. Combustion processes, including those occurring in aircraft and automotive engines, lead to formation of nitrogen oxides ($NO_X = NO + NO_2$). The bulk of the directly emitted NO_X is in the form of NO. NO_2 is one of the pollutants targeted by the Air Quality Strategy, because of its impact on human health. NO_2 is formed from NO in the atmosphere by reaction with ozone, O_3:

NO + O3 à NO2 + O2 (1)

66. If ozone (O_3) is present in excess of NO and has a typical background concentration of 30 ppb [1] , this reaction is rapid, taking about 90 s, but the formation of NO_2 can take several minutes if the NO concentration is comparable to that of O_3, and is incomplete if the concentration of NO exceeds that of ozone, which is likely to be the case in the region around Heathrow. The process is further complicated by the photolysis of NO_2 during the day to regenerate NO and O_3:

NO 2 + sunlight à NO + O (2)

O + O2 à O3 (3)

This coupling between NO_2 and O_3 through reactions (1) to (3) has led to their collective definition as 'oxidant' and forms the basis of the methodology, discussed briefly below, to model the conversion of NO into NO_2.

67. There are two complications that make the prediction of future NO_2 concentrations more difficult. The first is the observation of an increase in the fraction of NO_X emitted in the form of NO_2, so-called primary NO_2. Formerly, it was argued that only about 5% of the NO_X released from combustion was in the form of NO_2. This fraction has been observed to increase significantly in recent years, to over 10%, with after-treatment systems on diesel exhausts implicated in the increase (AQEG 2004). Predictive models of NO_2 must account for this increase, but this process is made difficult by uncertainties in determining the future penetration of diesel vehicles into the UK fleet and in the changes in primary NO_2 emissions resulting from changes in technology. In addition, the parameterisation of NO_X chemistry in simple models depends on the fraction present as primary NO_2, as discussed below.

68. As discussed above, the rate of conversion of NO into NO_2 and the amount converted depend on the concentration of ozone present in air mixing with the vehicle or aircraft exhaust. Ozone is formed on a regional scale on timescales of hours or even days, from reactions involving volatile organic compounds, nitrogen oxides and sunlight. This chemistry is sufficiently slow that it has no direct effect on the chemistry considered here, except through its influence on the ozone concentration. The models used in the present analysis all determine the ozone concentration from the measured regional background. Prediction of future nitrogen dioxide concentrations will necessarily have to use estimates of the regional background ozone on the basis of projected precursor emissions. However there is evidence that the *hemispheric* background concentration of ozone is increasing at a significant rate, because of increases in distant emissions and intercontinental transport of ozone precursors (AQEG 2004). Predictive models must be capable of incorporating such increases and of assessing their effects through sensitivity analysis.

[1] Concentrations of atmospheric pollutants are frequently expressed in units of parts per billion (1,000,000,000) - ppb. This is the ratio of the number of molecules of the pollutant of interest to the total number of molecules in a given volume of air. The relationship between concentrations in ppb and in $\mu g/m^3$ depends on the pressure and temperature, and the molecular weight of the pollutant. At the standard temperature of 293°K (about 20°C), and the standard pressure of 101.3 kPa (about average atmospheric pressure at sea level), the conversion factors between the two sets of units are:

for nitrogen dioxide (NO_2) 1 ppb = 1.913 $\mu g/m^3$

for nitric oxide (NO) 1 ppb = 1.248 $\mu g/m^3$.

Parameterisation of NO_X chemistry in simple models

69. Dispersion models generally employ two principal approaches for the calculation of NO_2 concentrations in the atmosphere. The first attempts to explicitly model time-dependent chemistry (and mixing) and the second aims to derive relationships between different species, principally NO_X and NO_2, although sometimes ozone also. The latter approaches use *empirical relationships.* Empirical approaches tend to be applied retrospectively to the total calculated concentration of NO_X.

70. In the first case the concentration of NO_2 is considered on an hourly basis and depends on several factors such as ambient concentrations of ozone and meteorological variables that determine, for example, the photolysis rate of reaction (2) above. Additionally, these approaches can also account for numerous complex reactions involving hydrocarbons and loss processes. In these approaches it is necessary to explicitly define the fraction of NO_X that is emitted in the form of NO_2, i.e., the primary NO_2. In principle, these approaches should adequately describe how the concentration of NO_2 varies for any practical scenario that results from a change of emissions of NO_X or NO_2 from any source, as well as background ozone concentrations.

71. Empirical relationships most commonly seek a relationship between annual mean NO_X and NO_2 from ambient measurements. These approaches have been used by Defra in deriving annual mean concentrations of NO_2 across the UK (for example, AQEG 2004; Stedman et al. 2001). Most of these approaches differentiate between 'background' and 'roadside' environments. The latter environment, for example, is essentially defined by the proximity of a monitoring site to a road (< 5 metres). This differentiation is necessary because there is generally a higher ratio of NO_2 to NO_X at background locations because of the availability of ozone and the time available for the NO - O_3 reaction to occur. Whilst these simplified techniques are useful, they also have several disadvantages. The principal disadvantage is that they do not attempt to describe the underlying physical and chemical processes of NO_2 formation, which are complex and non-linear. Implicit in these techniques is the contribution from NO-O_3 chemistry, a NO_2 contribution via reactions with VOCs, and also a contribution from primary NO_2 emissions. It is generally not possible to use empirical techniques to test changes in many aspects affecting NO_2 concentrations, e.g., to estimate how NO_2 concentrations would change if tropospheric O_3 concentrations increased, or indeed what might happen if primary NO_2 emissions changed.

72. More recently, empirical approaches have been developed further. Jenkin (2004) presents an empirical approach that is more closely linked with knowledge of the key fundamental chemistry. The Jenkin approach is able to account separately for background concentrations of ozone and primary NO_2. However, it still categorises predictions of NO_2 into two environments: 'background' and 'road-influenced'. As such, there remains the issue of how it should be applied to the calculation of NO_2 concentrations over a surface, which represents a continuum of NO_X environments. The Jenkin approach only considers annual mean concentrations.

73.

Model inter-comparison

MIC study objectives

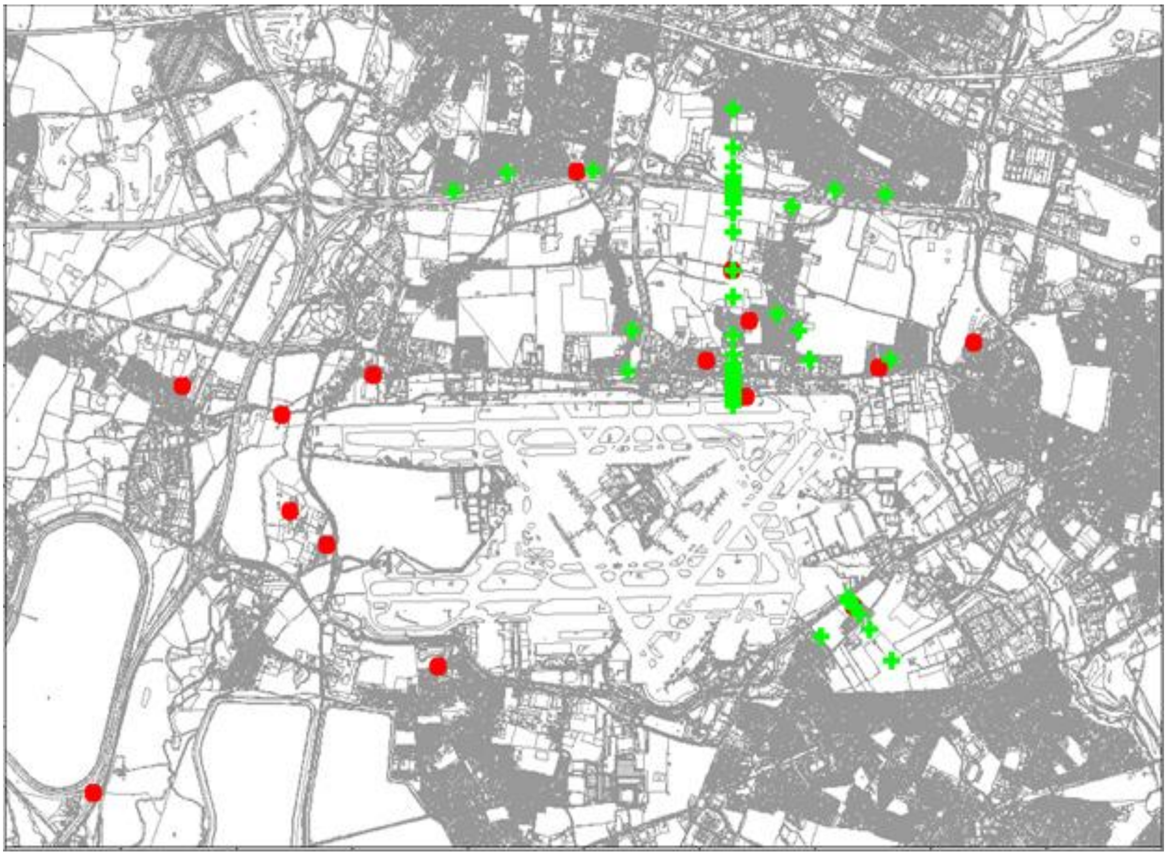
73. The broad objective of the study was to determine which model(s) is (are) suitable for conducting air quality modelling studies to determine future air pollution levels in and around Heathrow including the impact of a third runway and other developments (e.g., mixed mode) and mitigation measures. Given the analysis of the monitoring data reported in Chapter 2, which identifies the annual mean NO_2 concentration as the UK air quality objective most at risk, the ability of models to predict the annual mean NO_2, and its sensitivity to different scenarios and parameters, is of key importance.

74. Specific aims of the MIC study were as follows:

- Conduct scientific assessment of candidate models;
- Conduct inter-comparison and validation study of candidate models including:
    -
    - For full Heathrow inventory - long term averages, short term averages (1 hour), output at receptor points and as contour maps and including source apportionment;
    - Predictions of near field dispersion from aircraft based on forthcoming LIDAR study at Heathrow.

The different models are briefly described below and full descriptions are given on the Aviation section of the Department of Transport's website at http://www.dft.gov.uk.

Figure 4.1 Locations for model inter-comparison



Red = automatic monitoring sites; Green = receptors for modelling

Inputs

Emissions

75. The models used a consistent set of emissions input data. The 2002 BAA inventory for Heathrow was used for all on-airport sources. Beyond the airport boundary road, use was made of the London Atmospheric Emissions Inventory (LAEI) for 2002. MMU and netcen model domains extended slightly beyond the M25 to the east, which is an area not covered by the LAEI. In this case the NAEI (2002 version) was used for these sources. It is not expected, however, that the inclusion of these additional sources would have much of an effect on predicted concentrations in the vicinity of Heathrow. The addition was necessary more for model set-up purposes.

Background concentration

76. Each modelling team utilised background concentrations appropriate for routine usage of their model. Table 4.6 at the end of this section outlines how each model accounted for background conditions.

Meteorology

77. All models used a consistent hourly sequential data set for 2002 from the Met Office site at Heathrow. These data underwent additional processing as described in Annex 3.

Outputs

78. Output was required at both receptor points and as contour plots. Both NO_2 and NO_X were required as minimum. Where models also calculated PM_{10} and O_3 with little additional work these were also determined for some cases.

Receptor points

79. Receptor points were chosen to represent locations where continuous hourly concentrations of NO_X and NO_2 are measured (10 sites) and additional points to assist in the comparison of the models. The additional receptor points were primarily chosen to represent a north-south transect from the northern runway to north of the M4. The transect usefully reveals important differences between the models such as the fall-off in concentration due to aircraft sources and near-road concentration profiles. In total 91 receptor points were chosen, as shown in Figure 4.1.

Contour plots

80. The standard output domain was an area of 12 x 9 kilometres with Ordnance Survey map reference 502172 at the south-west corner. Output included annual average concentration contour maps of NO_2 and NO_X. Where models readily calculate 99.8^{th} percentile of hourly average NO_2 concentration and maps these were also considered.

Source apportionment

81. An important part of the study is the prediction of NO_X concentrations by different source categories. This is important because such information is essential when future mitigation measures are considered. The following important source categories were agreed:

- ***Aircraft sources:*** Assumed to include all emissions associated with aircraft operations.
- ***On-airport non-aircraft sources:*** Assumed to include all other sources on Heathrow Airport within (but not including) the boundary road.
- ***Road transport sources*** .
- ***Other:*** This included an assumption for rural background concentrations and other modelled London sources such as domestic gas combustion.

In addition, the model groups were requested to run a simple scenario of removing all aircraft sources (defined above) to test the model response to a change in NO_2 concentration.

82. The analysis of model runs comprised the following:

0 Qualitative assessment of model calculation

1 Quantitative assessment of model calculations:

a receptor point calculation

- for annual means inter-comparison and validation - scatter plots of annual averages vs. measured values means, fraction bias of annual means

- for annual mean inter-comparison - source apportioned annual mean continuation

- for additional hourly average calculation - comparison with insights gained from data mining (e.g. polar plots and runway alternation)

b contour outputs - model inter-comparison

- areas exceeding different concentration thresholds including area of exceedence of 40 $\mu g/m^3$ by annual average NO_2 concentration

2 Practical modelling issues

-run time

-model set-up and practicality for scenario testing

-other issues arising

Candidate airport dispersion models

83. The following sections provide a short summary of the models used in the MIC. Full reports written by each of the groups are available separately. Each of the model groups also undertook sensitivity analyses to explore the importance of how various parameterisations affected modelled concentrations. These tests are not considered in this report, but are summarised in each of the individual modelling reports. The full reports can be found on the Aviation section of the DfT's website at http://www.dft.gov.uk.

Netcen airport dispersion model

Introduction

84. The netcen airport air quality assessment methodology is aimed at predicting annual-mean concentrations of key pollutants. The total annual-mean concentration is considered to have two contributions:

- the contribution from explicitly-modelled sources, such as aircraft, airside vehicles and landside road vehicles; and
- the contribution from 'background', i.e., from all other sources.

85. Although the overall air quality assessment methodology includes both quantification of emissions and atmospheric dispersion modelling, this report focuses solely on the latter.

Methodology

86. Dispersion modelling is carried out using ADMS 3 (CERC 2005a), under license from Cambridge Environmental Research Consultants (CERC), using the latest version available at the time of any particular assessment. ADMS belongs to the modern generation of dispersion models that exploit advances over the last few decades in understanding the transport-diffusion of pollutants in the lower levels of the atmosphere. ADMS has been compared against experimental data in a wide variety of situations, sufficient to justify its applicability to sources on the airport, provided adequate consideration is given to near-source effects that are not automatically dealt with by the model. These are discussed further below. Information on ADMS validation can be found on the CERC website (CERC 2001).

87. ADMS has various model options that can be used singly or in combination to represent particular features of the dispersion situation. Modelling choices generally made for netcen airport air quality studies are:

- No chemistry. Although ADMS 3 has a module for calculating the conversion of NO to NO_2 in the atmosphere after release, this facility is not used. Instead, use is made of empirical or semi-empirical relationships between annual-mean NO_2 concentrations and annual-mean NO_X concentrations (see below).
- No building wakes. Given the primary focus is prediction of concentrations outside the airport perimeter, buildings on the airport are generally accounted for only via the choice of an effective roughness length for the airport as a whole, although specific building effects are sometimes taken into account in modelling boiler-house stack emissions.
- No deposition. The dry deposition velocities and scavenging coefficients appropriate for the key pollutants at airports are small enough that attenuation of the airborne plume due to dry and wet deposition can be ignored over the distance scales relevant local air quality studies.

In addition, the modules for coastal or topographical effects have not been invoked in the airport studies carried out by netcen to date.

88. Near-field effects are represented by assuming sources have a minimum initial vertical extent, which is input into ADMS as the depth of the volume sources used to represent releases. Clearly this will not provide the details of the concentration pattern in the immediate vicinity of sources, but the initial depth parameters are chosen to give a representative amount of dilution in the near field. For aircraft on the ground, the current methodology uses a depth of 15 metres, [2] which is viewed as representing the additional dispersion caused by

the relative velocity of exhaust plume and ambient air. In the current methodology there is no explicit treatment of the potential for aircraft exhaust plumes to lift off the ground in response to the emitted heat flux. The potential overestimation of the aircraft contribution to ground-level concentrations in the first kilometre or so from the airport is accepted until there is a better understanding of the lift-off and ultimate rise of near-ground buoyant jet releases from moving aircraft. For road vehicles, the initial vertical depth is taken to be 3 metres, representing the effect of traffic-induced turbulence. For both types of source, the initial source height is taken to be the half-height of the volume source.

89. Care is taken in the modelling to retain an adequate representation of the combined influence of the temporal variation of emissions and the hourly variation in meteorological conditions. Similarly, care is taken to represent realistically the correlation between mode of operation of the airport (for example, easterly operation or westerly operation) and the wind vector.

90. ADMS is applied to the large number of sources on the airport using a 'dispersion kernel' technique. This exploits the fact that the annual-mean concentration arising from a number of sources is the simple sum of the annual-mean concentrations from each source taken individually, provided the sources behave passively (i.e., one source does not change the turbulent environment in which another source is dispersing). Thus, for example, all ground-level sources with the same initial-dispersion parameters and the same diurnal/seasonal profiles are handled by performing a single ADMS run for one such source and applying the resulting concentration field to each source (with an appropriate shift of origin). The kernel approach leads to shorter computer run times, a significant advantage - given the large number of sources on an airport - when hourly-sequential meteorological data are used to generate annual-mean concentrations.

91. For aircraft emissions above the ground, a series of ADMS runs (each for a single source) is carried out spanning the range of heights of interest, and interpolation is used for sources at intermediate heights. An approximate 'doubling' rule is used to set the heights (7.5, 15, 30, 60, 125, 250, 500 and 1,000 metres), on the grounds that this provides an adequate basis for interpolation to any height of interest (when ground-level concentrations are the focus of concern).

92. For the background contribution, a version of the UK National Scale Empirical Model (AQEG 2004) is used, as developed by netcen for Defra (the Department for the Environment, Food and Rural Affairs) for use in policy assessment and local authority air quality review and assessment, taking care to remove the contribution from sources that are already included in the explicit dispersion modelling. This background model itself involves ADMS modelling and a kernel approach, albeit at a 1 kilometre scale, for the area sources within the 1 x 1 kilometre disaggregated NAEI (National Atmospheric Emissions Inventory). Explicit ADMS modelling is also carried out for large point sources. However, the modelling involves a number of idealisations and approximations, and concentrations calculated for a given year are adjusted on the basis of a fit to national monitoring data for that year. Forecast concentrations are linked to NAEI emissions forecasts but retain a memory of the year that was used in the fit to monitoring data.

93. The modelling process directly yields annual-mean NO_X concentrations, but the key air quality metric of interest from a human health viewpoint is annual-mean NO_2 concentration. netcen derives annual-mean NO_2 concentrations from annual-mean NO_X concentrations using non-linear empirical or semi-empirical relationships based on UK national monitoring data. Assessments to date have used a purely empirical relationship described in the AQEG (2004) report. Current work, however, is using an approach based on the work of Clapp and Jenkin (2001) and further developed in Jenkin (2004), which allows moderate changes in background ozone level and primary NO_2 fraction to be taken into account.

Cambridge University application of the EDMS model

Introduction

94. EDMS is the Federal Aviation Administration's (FAA) required model for air quality assessments at airports and airbases. It comprises a comprehensive emissions database coupled to an atmospheric dispersion model. This study used EDMS Version 4.3. There is an interface for 'constructing' the airport and, if required, off-airport roadways. An extensive database is used to incorporate aircraft movement and other airport activities and their associated pollutant emissions. The various aircraft, vehicles and other emission sources produce the spatial and temporal emission patterns.

Methodology

95. An AIRPORT menu allows for the 'construction' of the airport by the placing of:

- Runways and runway queues;
- Aircraft taxiways;
- Gates;
- Buildings.

96. The FILE menu provides for:

- Model setup;
- The inclusion of operational profiles on an hourly, daily and monthly basis.

97. These EMISSIONS menu determines emissions for:

- Aircraft activity;
- Ground support equipment (GSE) and auxiliary power units (APU);
- On-road vehicles;
- On-road vehicles in parking areas;
- Stationary sources;
- Training fires.

In addition to the database it is possible to develop user-created aircraft, user-created GSEs and user-created APUs. There are also default options available for many of the aircraft and airport activities.

98. EDMS 4.3 currently provides emissions for CO, THC, NMHC, VOC, NO_X, SO_X, PM_{10} and $PM_{2.5}$. The last two are available for all airport sources with the exception of APUs. It is of particular concern for this study that the model does not have the capability to model the chemistry involved in formation of nitrogen dioxide NO_2, the pollutant of great interest in the UK and throughout Europe.

99. The emissions database is interfaced to the US Environmental Protection Agency's Guideline dispersion model AERMOD. AERMOD is a widely-used comprehensive atmospheric dispersion model incorporating much recent knowledge on dispersion processes in the atmosphere. The dispersion model has been subject to several evaluation/validation studies (though not in a specifically airport context).

100. AERMOD is essentially an advanced Gaussian plume model but is able to treat terrain features, buildings, convective conditions and other complex scenarios. The AERMOD model within EDMS does include a specific airport-related physical process. The trajectory and mixing of the engine jets are parameterized in terms of a plume height and size and these are based on recent LIDAR studies (Wayson et al. 2004). The effects of jet momentum and buoyancy are treated with this parameterisation.

101. AERMOD uses several different source configurations to represent the emissions including point, area and volume (though not line) sources. The model can produce output concentrations that are 'source-apportioned'. The model typically works on hourly emissions and meteorological data over a year or more. Output concentrations are available for annual or shorter time averages.

102. EDMS has been developed in a US context and thus reflects US operations, regulatory status, data formatting and other US standards. For example, meteorological data is required in formats that are standard in the US. A different format is used in the UK and thus some data manipulation is required to change the formats. Similarly parts of the database reflect US vehicles. However, the model has flexibility through the 'user-created' options and allows the import and export of data directly to the dispersion model. This assists in the use of the model outside the US. A further related difficulty is that some parameters in the model are 'hard-wired' in the sense that they cannot be changed by the user.

Accuracy and uncertainty

103. There are two issues here. One is the uncertainty in this particular model inter-comparison study and the other is the uncertainty of the application of a model like EDMS to a particular airport. They will be treated together in what follows.

104. There are several distinct sources of uncertainty arising in modelling studies. The emissions inventory, both in magnitude and in the spatial and in the temporal descriptions, will have an uncertainty that, presumably, can be estimated. In the present study the emissions inventory was, to an extent, prescribed. For predictions into the future this will also be the case.

105. There will be an uncertainty in the meteorological input data. In this study meteorological data was available on-site for 2002. However due to some doubt about the correctness of the meteorological data some modifications were made to the data. The MIC study agreed to use the modified data set as the best estimate but there is still a possible source of error in this study arising from the meteorological input data. It is at low wind speeds that most uncertainty often arises and these are the wind speeds that conventionally lead to the higher concentrations. Interestingly in the MIC study it was apparent from the data mining that this was not the case and that the low wind speeds were not as critical to producing large concentrations as first thought. This observation suggested that the buoyancy of the emissions can be of importance.

106. There are also uncertainties associated with the AERMOD dispersion model itself. These may be due to the omission of relevant physics or chemistry or to the various assumptions and approximations that arise in developing mathematical models of complex problems. For example there is still discussion about the importance or not of plume buoyancy and of the role of vortices shed from the lifting wing and their possible influence on the engine exhausts.

107. There have been evaluation studies of the dispersion model AERMOD (Hanna et al, 2001). In that evaluation study, using five sets of field experimental data, 57% of the hourly averaged predictions were within a factor of two of the measurements. This was in the context of point source releases rather than an airport scenario. It was also for hourly averages rather than annual averages. The accuracy of the prediction is far better for the annual average as uncertainties are smoothed out by the use of a year of hourly data. For dispersion in an urban setting with emissions from many sources (such as roadvehicles) accuracies of the order of 20 (±10)%, as judged by comparison with monitoring data, are typical for annual average concentrations, as demonstrated below for the CERC and ERG models. Without further information this might be considered appropriate in an airport context for good quality models that have been used extensively at the site over many years.

ADMS-Airport dispersion model developed by CERC

Introduction

108. ADMS-Airport is an air quality model developed by Cambridge Environmental Research Consultants (CERC) and designed to calculate pollutant concentrations in the vicinity of an airport. The model represents an extension of the well known ADMS-Urban (Carruthers et al 2000), also

developed by CERC, which models the impact of the complex mix of sources typical of an urban area including road, industrial, commercial and domestic sources and other diffuse or small sources aggregated onto a grid. ADMS-Urban itself represents a development of the widely used Atmospheric Dispersion Modelling System (ADMS 3) (Carruthers et al 1994) developed by CERC in collaboration with the Met Office and UK power companies (and subsequently University of Surrey). Each of these models run on PCs with user friendly Windows based interfaces and links to GIS for input as well as output and the presentation of results. Both ADMS-Urban and ADMS-Airport also link directly to the emission database system EMIT (CERC 2005b).

Methodoloy

109. The basic approach used in ADMS is to calculate pollutant concentrations for each hour using as input hourly varying meteorological data, emissions data and background pollutant data. The meteorological input data are derived from standard meteorological measurements from one station - typically Julian day number and hour (which, with latitude, determine solar elevation), wind speed and direction, cloud cover and temperature for each hour are used to calculate the friction and convective velocity scales, Monin-Obukhov length and boundary layer height. These quantities are then used to derive vertical profiles of mean velocity, turbulence, temperature, etc., for use in the dispersion algorithm. The model is able to account for the effects of variations in surface elevation and surface roughness on the mean wind and turbulence and also the effects on airflow and dispersion of specific main buildings. However these effects have not been included in the current study because of the increase in model run time and increased complexity of required input data. The emissions data may be based on hourly activity data or be actual estimated/measured emissions for each hour or use typical diurnal profiles. Sources are generally represented explicitly within the output domain but aggregated onto a grid outside the output domain. The background data of pollutant concentrations (NO_X, NO_2, O_3, PM_{10}) are taken from rural monitors outside the emissions domain with the background value for each hour being that measurement most closely aligned with the upwind direction. The concentrations in the calculation domain consist of the background and those calculated by ADMS-Airport from the emissions, using the local ADMS model for explicitly defined sources nested within a trajectory model.

110. The additional features of ADMS-Airport as compared to ADMS-Urban relate to its treatment of aircraft sources and it is this aspect of the model which is discussed in greater detail here. The approach is to use a modified version of the ADMS 3 jet model (CERC 2005a) to represent emissions from the jet engines. Specifically a series of horizontal jet sources is used to represent aircraft engines modelled to take into account the speed of the engines over the ground - this ensures that the effective momentum and buoyancy of the emissions decreases with increasing engine speed so that any plume rise occurring is reduced. The jet model does not take compressibility effects into account; however, as already discussed, although the exit Mach number is close to one, it rapidly decreases, so that compressibility effects on the plume spread are unlikely to be significant. The impact of wake vortices

on aircraft **before** the aircraft is airborne is not reflected in current modelling. For airborne aircraft this effect is included simply as a downward displacement of the plume. However, with the ability of ADMS to take account of spatially varying velocity fields, velocity fields induced by aircraft wake vortices could be included in the flow and therefore their impact on the trajectory of the plumes more precisely modelled. Additionally, the inhibiting effect of the ground on entrainment from beneath the plume and hence on the jet plume growth, and also the impact of plume-plume interaction are ignored. These effects can also be assessed and included as required within the ADMS-Airport model framework.

111. Other aspects of ADMS-Airport of particular relevance to the current study include treatment of road sources and chemistry. Roads are treated as line sources with width equivalent to the road width and initial mixing depth representing the vertical mixing very close to the exhaust. Additionally allowance is made for traffic induced turbulence and the effect of both canyons and noise barriers can be accounted for if necessary. The chemical reaction uses explicit reactions for the NO, NO_2, O_3 interactions, and a limited set of surrogate reactions for the impact of VOCs.

Accuracy and uncertainty

112. There are many diverse sources of uncertainty in an air quality model such as ADMS-Airport. This makes a well formulated estimate of uncertainty (e.g. using a Monte-Carlo analysis) a very difficult and time consuming task which is well beyond the scope of the current study. A full analysis would involve assessing the impact of varying each of the sources of uncertainty within reasonable ranges; see for example Colvile at al. (2002), Fisher et al. (2002), and Carruthers et al. (2003). However, some indication of the sources of model uncertainly are given below and its likely accuracy. Sources of uncertainty can be broadly considered in two different categories. The first relates to the various model inputs, the second to the details of the model itself.

113. Model input includes the full range of data used for emissions, meteorological data and background ambient concentration data. It includes the level of detail these data are available for input to the model and also how the basic input data is used to derive input appropriate for the model. For instance, what emission factors are used for aircraft emissions, how are meteorological input parameters for the model (Monin-Obukhov length, mixed layer velocity scale, etc.) derived from standard meteorological observations, what surface roughness is used, and which monitoring sites are most appropriate for producing background concentrations?

114. The second source of uncertainty relates to the model itself and includes the uncertainty in the various model algorithms in their representation or omission of the physical and chemical processes. Examples are the representation of the aircraft jet emissions in the model and the representation of the impact of the surface inhomogenetics on the wind and turbulence fields.

115. For calculations of future projections, scenarios, and so on, it would be expected that the uncertainty associated the deterministic aspects of the model, that is the model algorithms for the physical and chemical processes, to be broadly similar. However, uncertainty associated with input parameters will increase as projections are made further into the future. Whilst the uncertainty in emissions may be associated with a generally downward trend, background ozone levels are likely to rise and to be significantly above current levels by 2030.

116. The accuracy of the results for the Heathrow area are typical of those obtained from a comparison study conducted with monitoring data from sites across London for 2001 and 2002, as the scatter plots (Figure 4.2) and Table 4.1 illustrate.

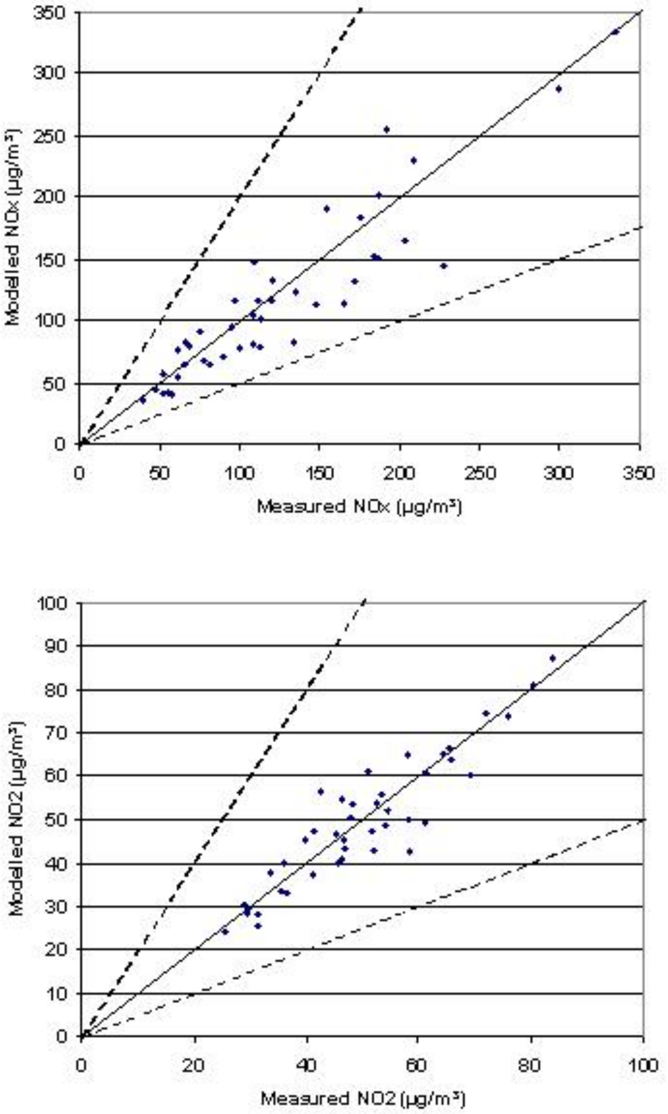
117. Of particular relevance to the jet model within ADMS-Airport and the effect of buoyancy on the plume trajectory is the validation of ADMS using LIDAR data (Carruthers et al. 1996). In this comprehensive study, high spatial and time resolution data of plume cross sections were obtained by LIDAR for four buoyant power station sources (Bennett 1995) and one low level neutrally buoyant source (Woods 1993). These data were used to derive plume rise and plume spread (both vertical and transverse) for a range of distances downstream from the sources, and compared with predictions of ADMS and also two other models (R91 and the US EPA model ISCST).

118. Comparisons of plume rise showed that the mean fractional bias ranged up to about 15% for ADMS and was typically much higher for R91. Errors in the plume spread were of similar magnitude. Such comparisons provide confidence that the underlying plume rise model, from which the ADMS-Airport jet model has been developed, is soundly based.

Table 4.1 Comparison of average measured and modelled NO_X and NO_2 concentrations for AURN sites in London, 2001 and 2002

	Average measured (µg/m³)	Average modelled (µg/m³)	Average Fractional Bias
NO_X	125.1	117.8	0.07
NO_2	50.0	49.3	0.02
Source: Williams et al. 2006			

Figure 4.2 Measured and modelled NO_X and NO_2 concentrations for AURN sites in London, 2001 and 2002



The solid line shows the 1:1 relationship and the dashed lines show the ± 30% limits Source: Williams et al. 2006

119. Further indication of the accuracy of the model for current predictions is provided by the comparisons of the model with measured concentrations and also by the sensitivity of the model to the different parameters as discussed in this section. Model output statistics and the box and whisker plots of comparisons of hourly average model calculation with measurements presented in the CERC report show hourly concentrations within a factor of two for over 70% of hours for NO_X, and for 80% of hours for NO_2. Calculated annual means being much easier to calculate are generally within ±10 or 20% of measured concentrations for each monitoring site with an overall fractional bias taking account of all sites of 0.045 or approximately 5%. The sensitivity

of the model to mean wind speed, surface roughness and 'chemical reaction time' showed sensitivity to these parameters but within the range of accuracy detailed above. The impact of representing all aircraft sources as jets significantly improved the model diagnostics (e.g., dependence on wind speed, diurnal variation of LHR2) which gives greater confidence for future projections and scenario studies. It had a more limited impact on the calculated annual mean concentrations of NO_2.

120. Development of ADMS commenced in 1988. Since then extensive validation and inter-model comparisons have been conducted both on specific components of the models (e.g. meteorological preprocessor, plume rise model, etc.) and also on calculated concentrations. See for example Carruthers et al. (1988), Hanna et al. (1999), Carruthers et al (1999), and Johnson, Stidworthy and Carruthers (2004), and also documents available at: http://www.cerc.co.uk under *Documentation*.

121. The ADMS models are now in widespread use. ADMS-Urban on which ADMS-Airport is based has been used by over 80 local authorities in conducting their Review and Assessment of air quality under the Local Air Quality Management programme in the UK. These local authorities included the large urban authorities of the Central London and West London Cluster Groups of London Boroughs as well as authorities with more rural areas, such as Cheshire and the East Riding of Yorkshire. In the UK and around the world ADMS-Urban has been used successfully in many locations including the following: Beijing (planning the large-scale development for the 2008 Olympics), Shanghai (city planning, traffic sources), Hong Kong (city planning, traffic and airport), five cities in Liaoning Province in China (industrial, heating and area sources), Budapest (decision making and air quality forecasting, large industrial sources and traffic), Strasbourg (air quality assessment, traffic sources), Rome (real time traffic management of 'now-casting', traffic sources), Bologna (assessment of new tram system, traffic sources), California (traffic sources) and Belfast (domestic coal burning).

122. Both ADMS-Urban and ADMS 3 have been used extensively to model airports. ADMS-Urban has been used by CERC and CATE (Centre for Aviation Transport and the Environment at Manchester Metropolitan University; formerly ARIC) to model airports including Heathrow, Manchester, Newcastle, Birmingham, East Midlands, Belfast and Dublin Airports. Most of the UK's airports have been modelled by Netcen using their model which incorporates ADMS 3.

London Toolkit Airport Model developed by ERG

Introduction

123. The Environmental Research Group (ERG) at King's College London has developed a unique air quality management system, the 'London Air Pollution Toolkit'. This has been used for a number of important developments for London, including detailed modelling as part of the Mayor of London's Air Quality Strategy, the impacts of a possible London Low Emission Zone (LEZ)

(Watkis et al. 2003) and the Congestion Charging Scheme (Beevers and Carslaw 2005). It is capable of modelling more than 1 million individual sources with different source characteristics, and has a grid resolution up to 5 x 5 metres. Within the model there is a detailed treatment of NO_2/NO_X chemistry (Carslaw et al. 2001; Carslaw and Beevers 2004; Carslaw and Beevers 2005). As part of the Heathrow PSDH project the 'Toolkit' has been extended to model 100,000 detailed jet sources, for aircraft in various operational modes. Heathrow sources were modelled without empirical correction derived from measurements. The modelling used Heathrow hourly meteorological data for 2002.

Methodology

124. To represent the London area other than Heathrow use was made of the London Atmospheric Emissions Inventory (LAEI). Heathrow Airport emissions were provided separately. All emissions information related to the base year 2002. At Heathrow the airport emissions were processed into the following source categories:

- Aircraft approach, landing and taxi out, taxi in, hold, take-off, initial climb and climb out, as well as Auxiliary Power Unit (APU) emissions and engine testing;
- Airside vehicles;
- Heating plants;
- Public and staff car parks, car rental and taxis queues; and
- Fire Training Ground.

125. Take-off is the aircraft mode that provides the largest contribution to ground-level NO_X concentrations. Each accelerating aircraft engine was therefore represented by horizontal stationary jet sources at 10 metres intervals along the runway, from the start of the ground-roll to where the aircraft leaves the ground. The effect of accelerating aircraft was included to reflect the maximum emission close to the start of the ground-roll, thereby reproducing the steep emission gradient along the runway.

126. The aircraft approach, landing, taxi out, taxi in, initial climb and climb out were all represented by stationary jet sources at 10 metres intervals. Within the jet model the variation of aircraft NO_X emissions throughout 2002 was reproduced using an hourly variation file for each jet model run. Jet velocities were varied for the different operational settings of take-off, approach and taxiing and were assumed to be 85%, 30% and 7% of full thrust, respectively. Finally, a relationship was derived to simulate the aircraft contribution to ground level concentrations at different heights.

127. The emissions from all car parks, car rental, taxis and the fire training ground were combined and represented as volume sources at 1 x 1 kilometre resolution and a height of 50 metres. Airside vehicles, in contrast were represented as volume sources with dimension 50 x 50 x 2 metres. Finally the main heating plants were modelled as specific point sources.

128. Jet plumes are subject to rapid change in temperature and velocity over short distances. Analysis of measured data at LHR2 showed that the plume from aircraft taking off along the northern runway had a wind speed relationship that suggested a buoyant jet plume. Preliminary tests, varying jet release temperatures were undertaken to reflect these measurements. As a result of these tests a jet temperature well below that of the estimated release temperature was chosen to represent aircraft at Heathrow. Subsequent sensitivity tests of this assumption for NO_X predictions around the airport site, were shown to be small, however.

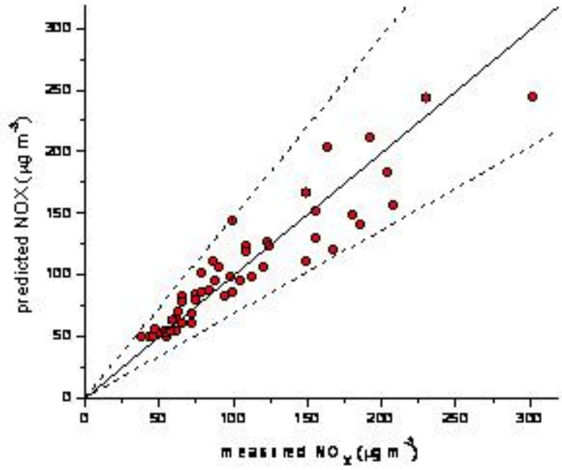
129. The conversion between NO_X and NO_2 was based on the NO_X increment above a background site. This approach provides a consistent method across the whole of London and is the basis for the Heathrow modelling. The relationship for background NO_X to NO_2 conversion is described in Carslaw et al (2001) and the estimation of direct NO_2 emissions in London in Carslaw and Beevers (2004) and Carslaw and Beevers (2005). Using this method an assumption can be made regarding the percentage of primary NO_2 from any source (10 % in 2002), and can be varied for future predictions.

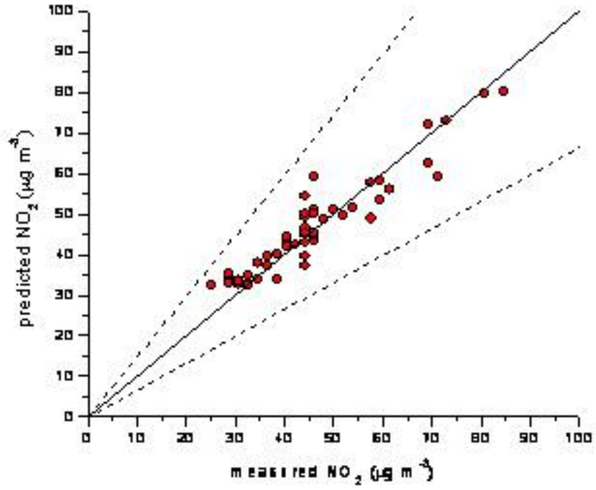
130. In addition to changes in primary NO_2 from road vehicles there is also a regional contribution to OX (NO_2 + O_3) via background O_3. This has been estimated to change through time and as such should also be incorporated into future predictions of NO_2. A detailed description of the partitioning between regional OX (O_3) and locally generated OX (primary NO_2) is given in a number of publications (Clapp and Jenkin 2001; Carslaw and Beevers 2004; Carslaw and Beevers 2005; Jenkin 2004). The latter paper provides a method by which changes in regional OX can be applied to empirically derived NO_X and NO_2 and relationships. This has been adapted for use in the ERG model and results have shown to have good agreement with the Jenkin method.

Accuracy and uncertainty

131. The model has been validated against monitoring data in London for a wide range of locations. The measured and modelled results for NO_X and NO_2 for 2002 are shown in Figure 4.3. In general the agreement is good. The plots of measured vs predicted concentrations give an R^2 value of 0.87 and 0.89 for NO_X and for NO_2, respectively. The RMS error for the predicted annual mean NO_X and NO_2 concentrations is ±16% and ±11%, respectively. The bias is very small, showing that the ERG model has very little bias in its predictions throughout London. These results are discussed in greater detail in the full report by ERG (see the Aviation section of the Department of Transport's website at http://www.dft.gov.uk).

Figure 4.3 Comparison between annual mean measured and modelled NO_X (left) and NO_2 (right) for London for the London Toolkit Airport Model (ERG).





The solid line shows the 1:1 relationship and the dashed lines show the ± 30% limits

132. ERG have previously used Monte Carlo modelling techniques to assess the uncertainties associated with roadside NO_2 predictions and to determine the most important input variables. Tests required the model to be run 1000 times and produced an uncertainty assessment varying flows and emissions from LGVs, HGVs, buses, vehicle speed as well as the dispersion model itself. The analysis revealed that roadside NO_X predictions are most sensitive to the assumptions regarding HGV emissions and flows and the dispersion model used to predict roadside concentrations. For the prediction of NO_2, the non-linear NO_X/NO_2 relationship was found to be the most important factor. Whilst the ERG model has changed considerably since this work was

undertaken, the results showed that in 1997, uncertainties in NO_X predictions were estimated to be 258 ±83 ppb and NO_2 47 ±10 ppb (2 s).

133. The problems associated with Monte Carlo analysis include, choice of individual parameter uncertainties, the distribution of these uncertainties, the interrelationships between model parameters, (Monte Carlo analysis assumes that each is independent) and ultimately whether the estimated uncertainty agrees with measurements. Furthermore, Monte Carlo assessments are typically run 10,000 times and are thus prohibitively time-consuming for most model applications.

LASPORT model applied by Manchester Metropolitan University

Introduction

134. LASPORT is a commercially-available Lagrangian model, designed specifically for airport applications and is built upon the LASAT Lagrangian model which is in accordance with the German Guideline VDI 3945 Part 3. LASPORT is designed for emission and dispersion calculations of airport-induced tracer emissions and runs on a standard PC-based platform under a Windows© operating system. It was developed by Janicke Consulting on behalf of, and in collaboration with, the German Airports Association (*ADV, Arbeitsgemeinschaft Deutscher Verkehrsflughäfen*).

Methodology

135. LASPORT is a Lagrangian model that uses a certain number of fictitious 'particles' to represent the mass of a pollutant released in order to simulate the dynamics and particle motion from both deterministic velocities and semi-random pseudo-velocities generated using Monte Carlo techniques. Hence, particles are transported by both the average wind and the turbulent terms due to wind fluctuations. In this application, NO_x emissions were the focus of the study.

136. Within the program package, emissions from aircraft traffic, auxiliary power units (APU) and ground power units (GPU), handling and GSE (ground support equipment) facilities, start-ups, vehicular traffic, and other sources can be accounted for. One of the advantages of the model is that it is oriented to airport applications and the aircraft source characteristics can be specified in detail (aircraft, engines, taxi-ways, take-off characteristics, etc.). This facility was only partially used in this particular exercise, since emissions were prescribed from an external inventory of emissions (the BAA 2002 inventory).

137. The results of a dispersion calculation are long-term means (e.g., annual means) and short-time means (e.g., percentiles or short-time values according to EC Directives). Several parameters (e.g., sources locations and source strengths) and input files (e.g., meteorological time series, terrain profiles) must be specified for a dispersion calculation. Because of the time-dependency of the emission sources, it is useful to carry out the dispersion calculation on the basis of a time series. Here, for every hour of the year the

meteorological parameters (wind velocity, wind direction, atmospheric stability) and the emission strengths are specified in form of hourly means. In this way, correlations between meteorology and emissions (e.g., high traffic volume during daytime, preferred departure direction being dependent on wind direction) are accounted for directly.

138. Since LASPORT is a Lagrangian model, output is specified to a fixed grid of variable resolution. It also allows for the definition of a number of nested grids as it is often desirable to resolve the concentration distribution in the near field with a high spatial resolution and also to cover a larger area with a lower resolution in the far field.

139. A series of three nested grids were used to describe the study area in this application. The central grid describes the area of most interest and for which concentrations at receptor points were required. The one used in this case has a resolution of 50 metres.

140. The computational time needed for a dispersion calculation depends upon the number of particles released and the extent of the calculation area. Every simulation particle carries a certain mass of a tracer, its amount being determined by the parameters *mass per particle* and *quality factor*. The greater the quality factor, the smaller is the mass carried by a particle, and the greater is the number of particles emitted for a given emission strength and the longer is the calculation time.

141. The emission source parameters were common to all models. Roads were represented as line sources; other background sources as 'volumes'; aircraft as volume sources with dimensions varying according to mode; stacks as point sources etc.

142. One of the unique features of LASPORT was its treatment of the aircraft plume. A plume depth can be specified that accounts for mixing and thermal characteristics during roll-out. Once the aircraft has rotated to sufficient altitude, the emissions are displaced downwards to account for downward projection of wake vortices by the airframe, according to external assessments of this effect. The default value for the plume was 25 metres and the downward projection was 100 metres.

143. Modelling was undertaken using hourly sequential meteorological data for Heathrow for 2002 and corrected for known errors. The hourly data include wind speed, wind direction and cloud cover by time of day and year. The hourly data have been run through the ADMS-Urban meteorological pre-processor which computes the reciprocal of the Monin-Obukhov length. A minimum Monin-Obukhov length of 30 metres was selected based on the minimum recommended value by CERC for modelling within the London area (range of 30 to 100 metres).

144. Rural background pollutant concentrations need to be added to the modelled values to allow for the pollutant emissions entering the model

domain. Monitored concentrations from four rural sites were used, depending on the wind direction for the relevant hour.

145. Emissions data for the aviation part of the modelling study are described in detail by Underwood (2004a) but the overall approach can be summarized as follows:

- BAA 2002 inventory for Heathrow;
- roads data from CERC originating from the LAEI 2002; and
- internal roads data from netcen and perimeter road data from David Carslaw.

146. By default, emissions of nitrogen oxides are specified as NO_X (the sum of NO_2 and NO in units of NO_2) in LASPORT. Concentrations of NO_2 can be calculated with an internal empirical correlation function or, as was the case in this study, NO_X data can subsequently be processed with a user-preferred empirical function. In this study, the Jenkin technique was used. Primary NO_2 can also be specified; the assumed proportions of primary NO_2 were 15% for aircraft and 10% for other emission sources.

Accuracy and uncertainty

147. A detailed assessment of uncertainties was not undertaken for the LASPORT model as this was beyond the timeframe for the PSDH modelling inter-comparison. Some sensitivity tests were undertaken, and the results are provided in the detailed report on the LASPORT work for PSDH (see the Aviation section of the DfT's website at http://www.dft.gov.uk). There are few peer reviewed published uncertainty assessments for the Lasport model.

[2] This 15 metre depth, however, is interpreted as a ±15 metre vertical spread about a source height initially close to the ground (at the actual height of the jet release) that has been reflected at the ground to generate a 15 metre vertical spread. Thus, when the aircraft has climbed above 15 metre height the initial vertical spread is ±15 metre about the aircraft height.

Validation of candidate models with measurements at monitoring sites in the vicinity of Heathrow

148. Several comparisons have been made with measurement concentrations. They fall into two broad categories: direct comparison with measured concentrations and diagnostic tests that aim to reveal important dispersion characteristics. Some of these tests simply provide a direct comparison of the model outputs, which is useful for exploring some of the differences between the models. Table 4.2 summarises the tests applied and explains their purpose. Some of the important comparisons are outlined in the following text. An overall summary with commentary is given in Table 4.6. Together with the fitness for purpose criteria, this analysis is used as the basis for selection of the recommended model.

Scatter plots

149. Figure 4.4 shows how the model predictions of annual mean NO_X agree with the measurements. Also shown on these plots are the ± 30% uncertainty limits. These limits correspond to the data quality objectives for modelling annual mean NO_2 from the European Commission (2005a). Table 4.3 shows the root mean square (RMS) error of the predictions including and excluding the M25. The reason for also presenting results that exclude the M25 is that the site is only about 1 metre from the edge of the hard shoulder of the motorway. It is thus very sensitive to the exact location being correctly represented. At a late stage in the analysis it was found that the distance from the centre of the motorway was not being represented accurately in some of the models, thus the results for this site need to be treated with caution. If the M25 is excluded all models show a similar performance on this basis except netcen, which has more scatter.

150. The comparison of the measured annual mean NO_2 concentrations with those predicted at the monitoring sites is shown in Figure 4.5. Also shown on these plots are the ± 30 % uncertainty limits. These limits correspond to the data quality objectives for modelling annual mean NO_2 from the European Commission (2005a). The following observations can be made concerning these plots. First, three of the models predict all NO_2 concentrations within ± 30 % uncertainty (ADMS-Airport, EDMS and LASPORT). In most models there is a strong indication that NO_2 at the M25 site is over predicted, in part because of an over prediction in NO_X and/or because the NO_2 is over predicted. It should be stressed, however, that the results for the M25 need to be treated with caution because of uncertainty about the exact geographic representation of this site. If the M25 site is ignored, all models predict annual mean NO_2 within ± 30 % uncertainty.

Table 4.2 Summary specific criteria used to compare the models for the MIC

Criterion	Description	Purpose
Scatter plots	Comparison of annual mean predictions against measurements of NO_X and NO_2	To compare how well the models do against measurements. Some indication of the uncertainty of the model predictions can also be gained.
Wind speed dependence	An estimate of the wind speed dependence of NO_X measurements at LHR2 with background removed to provide an indication of the airport contribution.	Data analysis work showed that the wind speed dependence of aircraft sources is markedly different to typical ground-level sources, e.g., road transport. This diagnostic provides an indicator of how well the models treat the dispersion from aircraft sources.

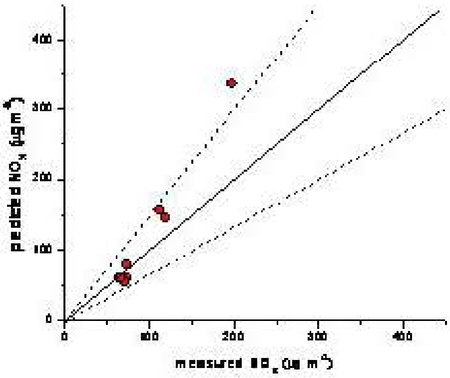
Polar plots	Bivariate pollution roses derived from NO_X, wind direction and wind speed. Plotted as a surface with background removed. Derived for LHR2.	A diagnostic that aims to highlight the wind speed and wind direction dependence of predicted concentrations with measurements. This is a qualitative diagnostic and is effective at representing the variability of NO_X concentrations with wind speed and direction.
Contour plots	Surface predictions of annual mean NO_X and NO_2.	Used to highlight spatial patterns in predicted concentration.
Transect plots	Predicted NO_X and NO_2 concentrations for receptor points forming a line north of the northern runway.	Used to compare the fall-off in concentration for different source contributions e.g. road vehicles, aircraft, non-aircraft airport sources.
Runway alternation	Measurements or predictions of NO_X at LHR2 extracted to reveal differences for aircraft taking off or landing on the northern runway.	This diagnostics potentially reveals some important aspects of airport emissions. First, it provides and indication of the dilution over two different distances, i.e., from LHR2 to the northern (180 metres) or southern runway (1600 metres). Second, the assessment is made by hour of the day, which incorporates a wide range of atmospheric conditions, e.g., more stable conditions at night.
Future NO_2 and ozone	Models need to account for primary NO_2 changes (by source type) and potential changes to background ozone.	There is increasing evidence that primary NO_2 emissions are increasing and it is important that models can account for this. Similarly, background concentrations of ozone could be increasing and this would affect NO_2 concentrations.

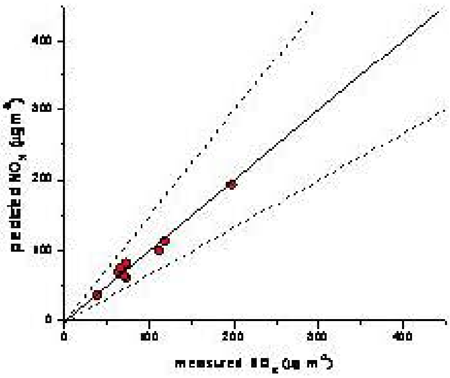
Table 4.3 RMS error for annual mean NO_X predictions

Model/Group	RMS error (μg/m^3)	RMS error without the M25 (μg/m^3)
Netcen	52.4	21.2
EDMS	8.7	8.9
ADMS-Airport	10.4	9.9

ERG	35.0	8.1
LASPORT	79.5	11.2

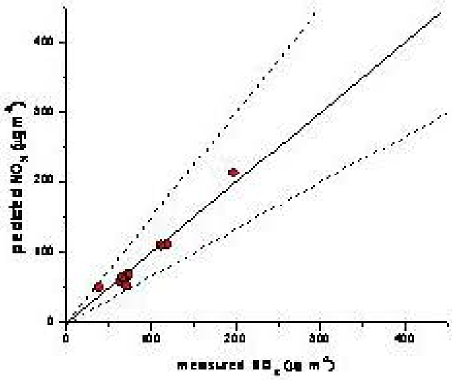
Figure 4.4 Measured annual mean NO_X vs. predicted NO_X

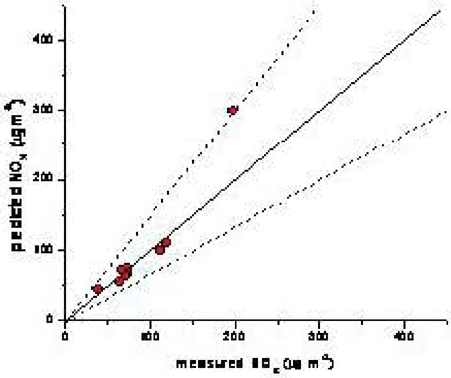




Netcen

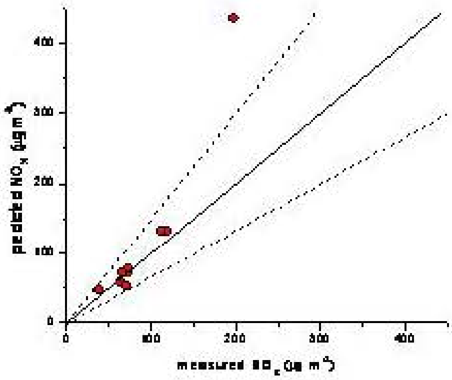
EDMS





ADMS-Airport

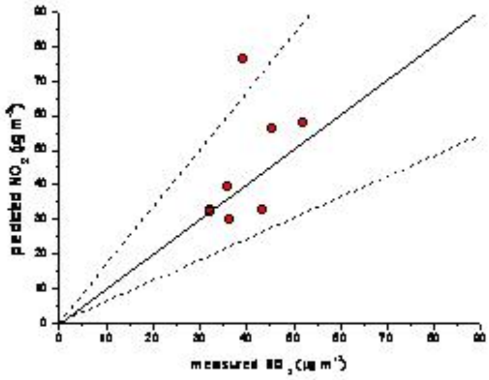
ERG



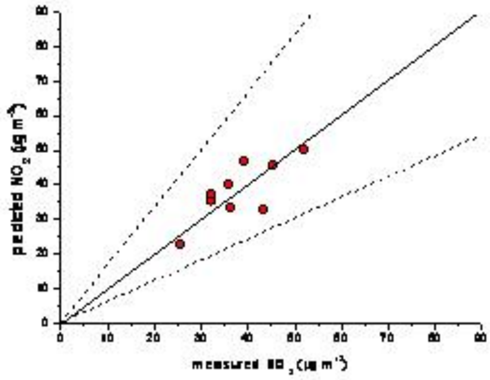
LASPORT

The solid line shows the 1:1 relationship. The dashed lines show the ± 30 % limits.

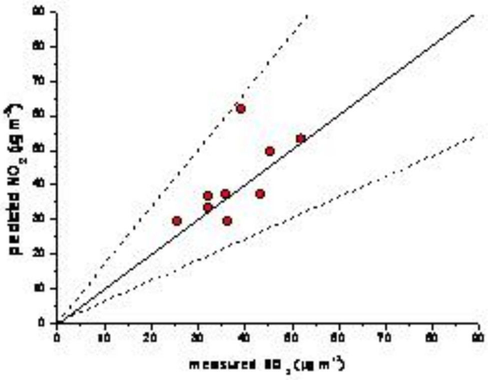
Figure 4.5 Measured vs. predicted annual mean NO_2 for each model



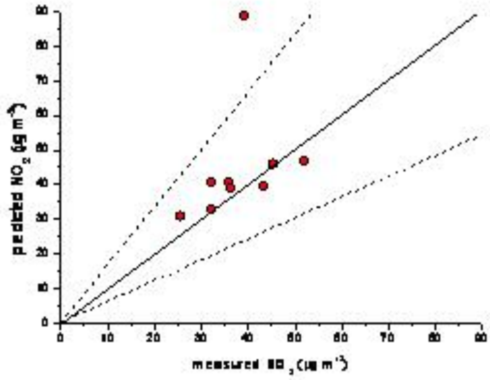
Netcen



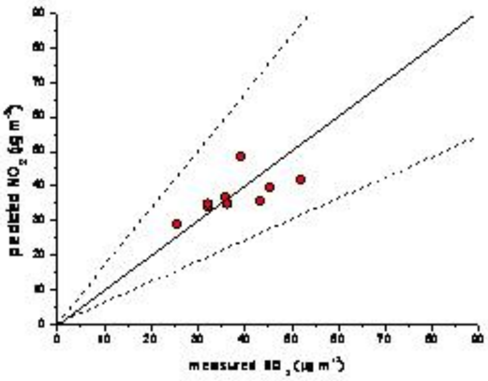
EDMS



ADMS-Airport



ERG



LASPORT

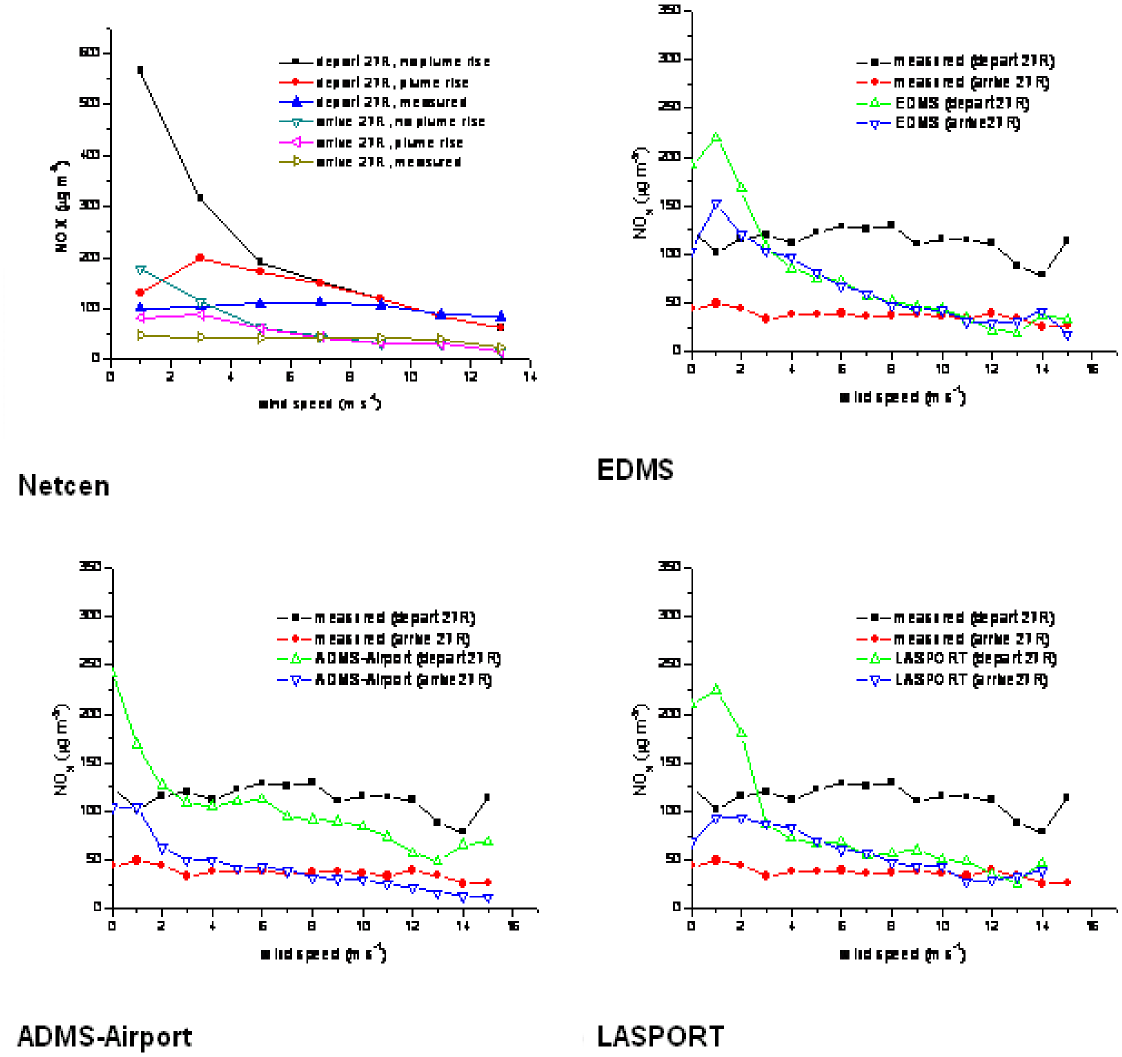
The solid line shows the 1:1 relationship. The dashed lines show the ± 30 % limits.

151. The root-mean square errors are shown in the table below. The best overall agreement is for ADMS-Airport, EDMS and LASPORT. However, if the M25 is excluded the mean error drops from 10.2 to 5.1 µg/m^3 and the models show a similar performance. It should be noted that several of the models do not directly calculate NO_2, and so performance against measurements is partly a product of the NO_X - NO_2 conversion method used outside the dispersion model itself.

Table 4.4 RMS error for annual mean NO_2 predictions

Model/Group	RMS error (µg/m^3	RMS error without the M25 (µg/m^3)
Netcen	14.5	6.7
EDMS	5.2	4.8
ADMS-Airport	8.5	4.1
ERG	16.9	4.6
LASPORT	5.9	5.3

Figure 4.6 Model wind speed dependence by runway operation mode and comparison with measurements



Wind speed dependence

152. Plots of the wind speed dependence of the airport contribution to NO_X are shown in Figure 4.6. Table 4.6, at the end of this section, summarises the performance of the models in the inter-comparison. G1-G3 relate to general criteria for a satisfactory model, while S1-S7 relate to the specific criteria identified in Table 4.2. These plots highlight the extent to which the models replicate the relationship derived from the analysis of measurements, which shows that concentrations of NO_X from the airport remain high at high wind speeds. This behaviour contrasts markedly with the relationship expected from a ground-level source such as a road. All of the models over estimate concentrations to some extent for low wind speed conditions (i.e., < 2 m/s). Overall, the best agreement with the relationships derived from the analysis of measurements is from the ADMS-Airport model. The results from netcen improve significantly if plume buoyancy is accounted for.

153. It should be noted that there are relatively few hours in each year where the wind speed is = 2 m/s and even fewer that coincide with aircraft taking off or landing on the northern or southern runway during westerly operation. In fact, an analysis of aircraft movement and meteorological data shows that there were only 311 hours when the northern runway was used for departure and 496 hours used for arrivals during 2002 when the wind speed was = 2 m/s. These data suggest that some caution should be applied to interpreting some of these results, and that further model testing over a longer period of time would improve the robustness of the comparisons made.

154. Model sensitivity tests undertaken by netcen and ADMS-Airport highlight that improved wind speed dependence at low wind speeds is shown if plume buoyancy effects are accounted for from aircraft emissions. Taking account of buoyancy effects from aircraft jet plumes appears to be an important process to account for in dispersion models.

Polar plots for NO_X

155. These results are highlighted in Figure 4.7. Three models were able to provide hourly mean NO_X estimates at LHR2, which are required to construct these polar plots (ADMS-Airport, EDMS and LASPORT). ERG was able to derive a plot for the aircraft contribution only. The following observations can be made. The ADMS-Airport results appear to represent the overall pattern of concentration well, but there is some evidence of concentrations being too high at low wind speeds. The EDMS results also show concentrations that are too high at low wind speeds **and** high concentrations from the south-east that are not apparent in the measurements. The LASPORT results also show that concentrations are too high at low wind speed, but the pattern of concentration is reasonable. On this basis, the results of ADMS-Airport compare best with the measurements. The aircraft-only pattern of ERG is also shown to compare well with the measurements. However, it is not known how this pattern would change by including other non-aircraft airport sources.

Contour plots

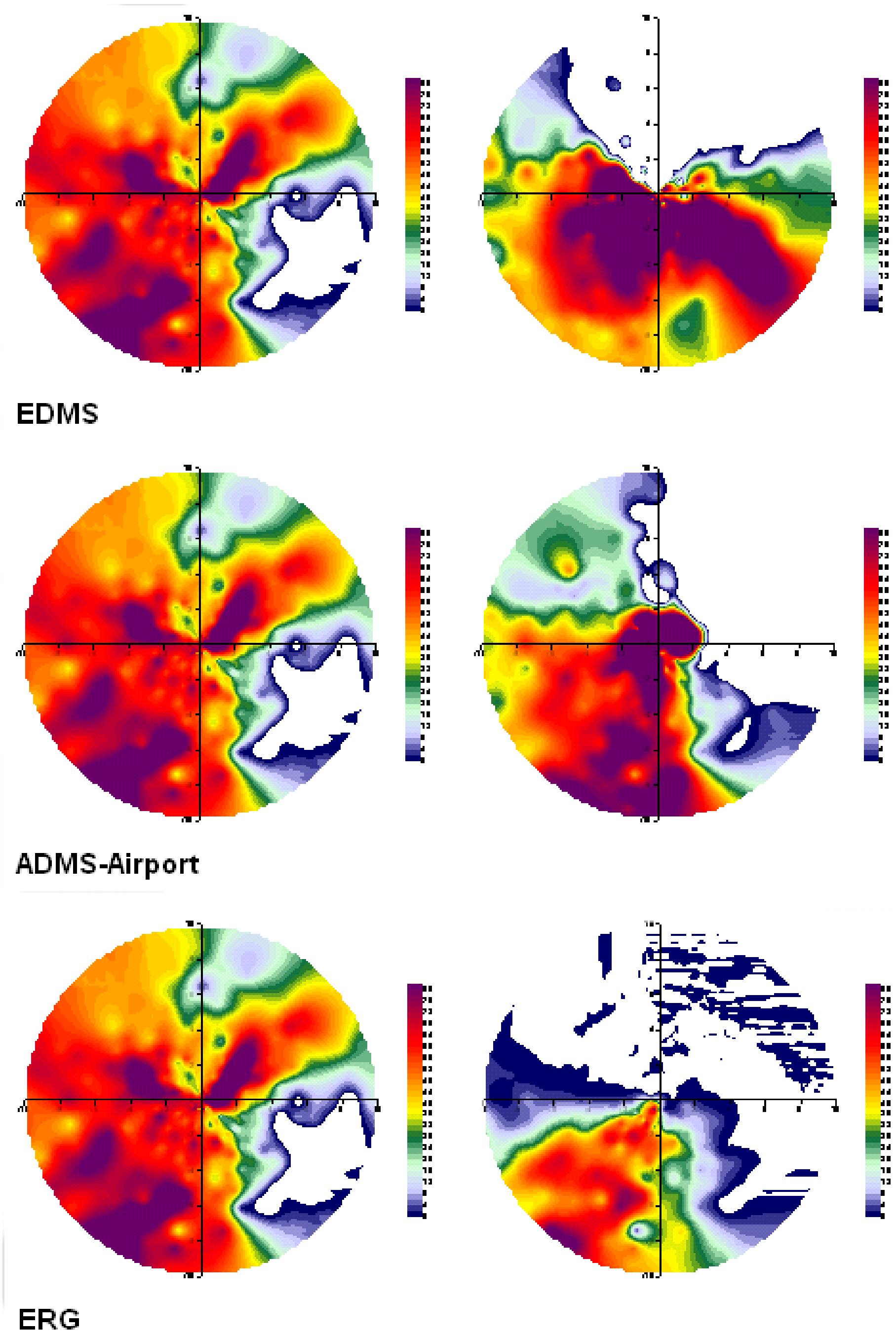
156. Surface contour plots of annual mean NO_X are shown in Figure 4.8. The plots highlight the importance of both road and airport sources to annual mean NO_X concentration within the study area. It should be noted that, within the time constraints of the PSDH study, the EDMS model used a coarse grid for showing concentrations, which affected the reliability of the surface contour plots (but not the values calculated for specific receptor points).

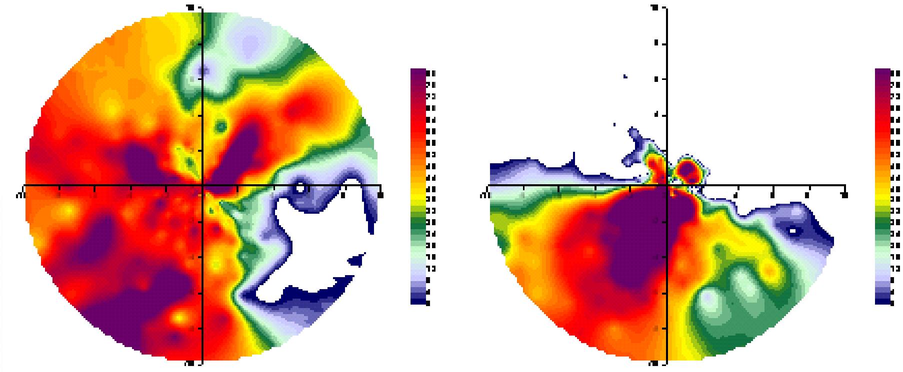
157. Surface contour plots of annual mean NO_2 are shown in Figure 4.9. These plots highlight the locations in which NO_2 is predicted to exceed the annual mean NO_2 limit value of 40 $\mu g/m^3$. Most models highlight that exceedences of the limit value are important close to roads across the study area. However, it is also clear that exceedences are predicted either on or close to the airport itself. It should be noted that EDMS does not currently have a capability for predicting NO_2 - these results are thus determined outside the model and should be treated with caution. It should also be noted that very

small differences in the absolute predicted annual mean NO_2 concentration result in large changes in the area above 40 µg/m^3. Table 4.5 shows the percentages of the modelled domain where the annual mean NO_2 exceeds 40 µg/m^3 .

Figure 4.7 Polar plots of NOX at LHR2 with background subtracted.

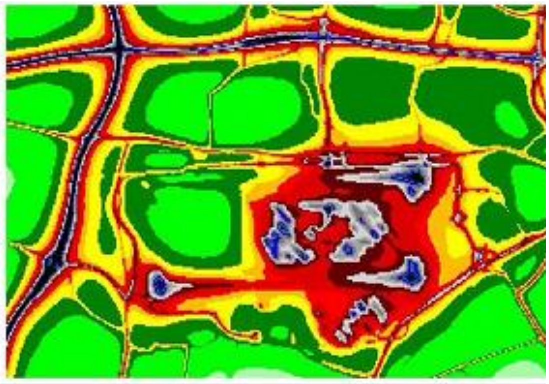
Measured Modelled



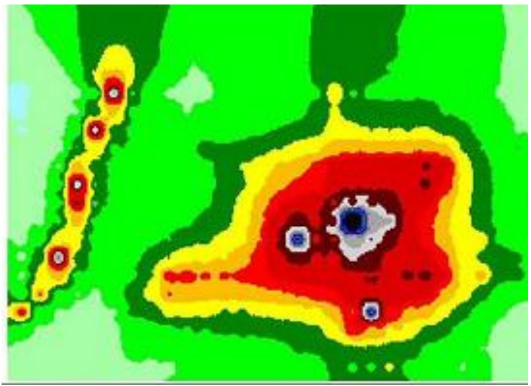


LASPORT

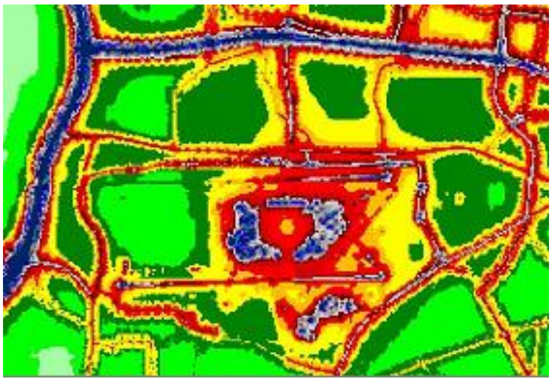
Figure 4.8 Annual mean NO_X surface plots ($\mu g/m^3$)



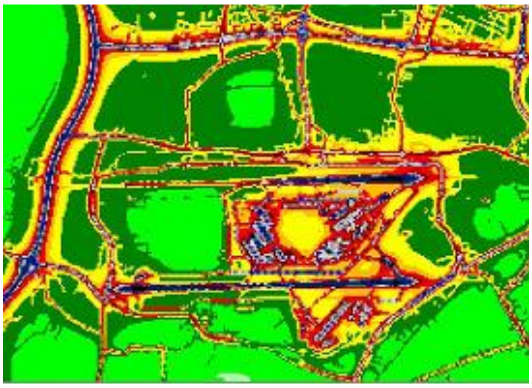
Netcen



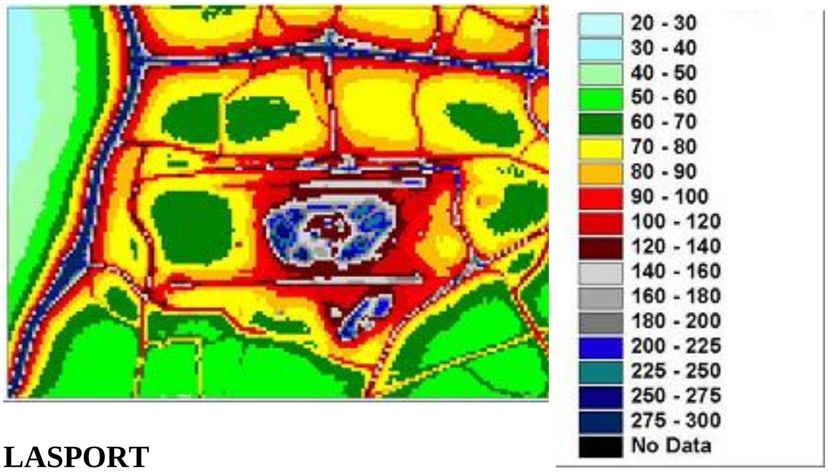
EDMS



ADMS-Airport

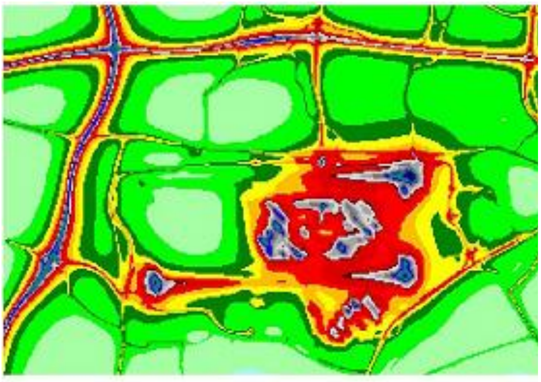


ERG

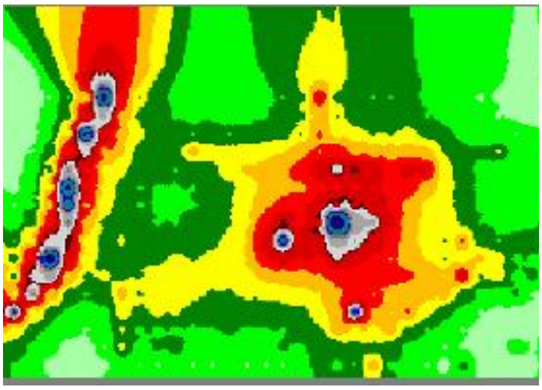


LASPORT

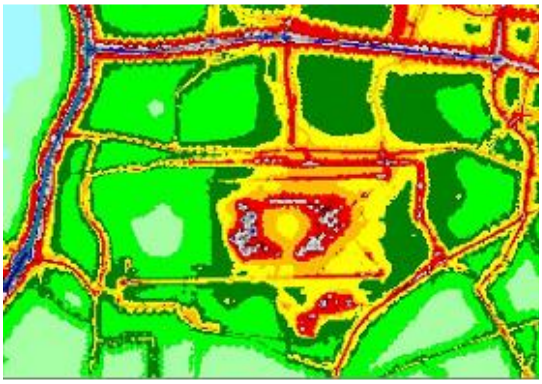
Figure 4.9 Annual mean NO_2 surface plots ($\mu g/m^3$)



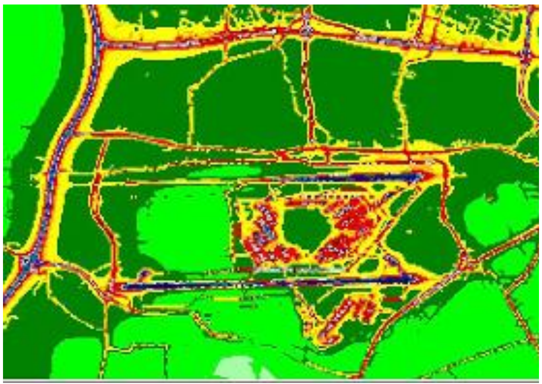
Netcen



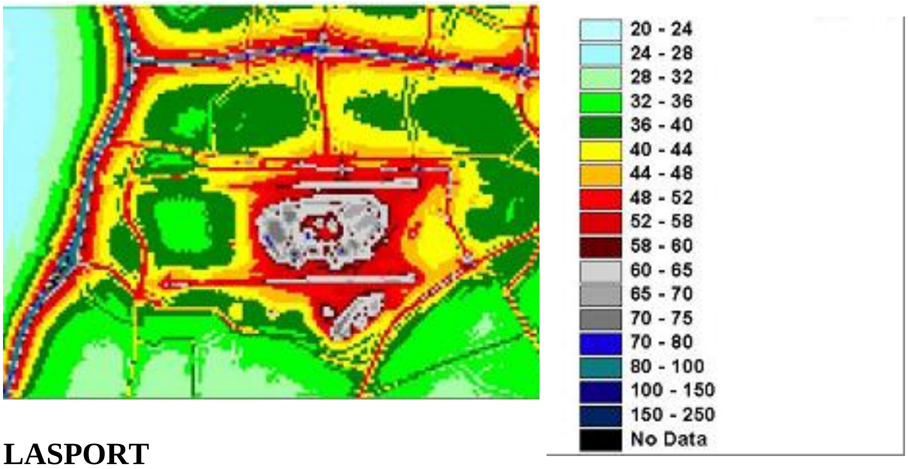
EDMS



ADMS-Airport



ERG



LASPORT

Table 4.5 Predicted percentage area > 40 µg/m3 annual mean NO2.

Model	% area > 40 µg/m^3 NO_2
Netcen	32
EDMS	39
ADMS-Airport	37
ERG	31
LASPORT	49

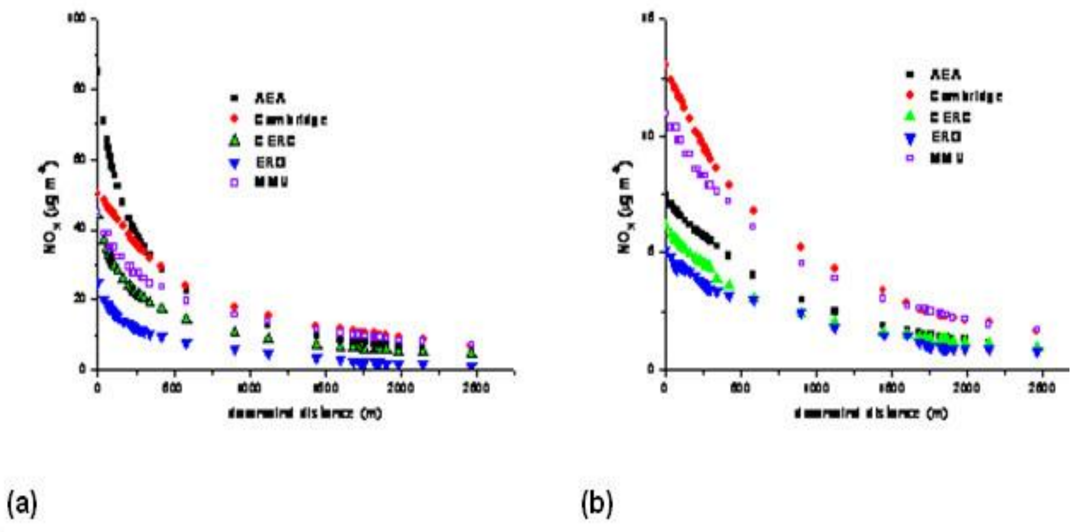
Transect plots

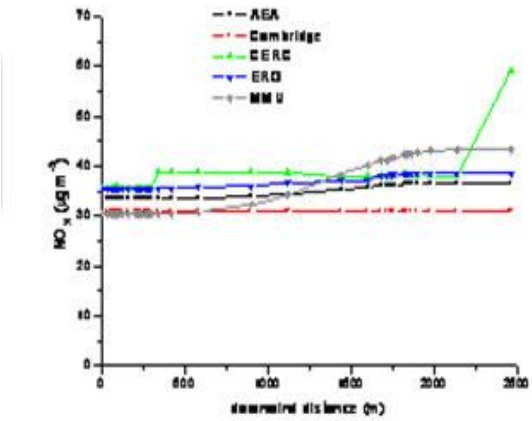
158. These plots highlight how the models differ in terms of the importance of different source types including aircraft, non-aircraft airport sources and road transport sources. Figure 4.10a shows the aircraft contribution from each of the models. There is over a factor of three difference between the lowest and highest estimates, which suggests that the treatment of aircraft plume dispersion is markedly different between the models. The lowest aircraft contributions are predicted by ERG and the highest predicted by netcen and LASPORT. The fall-off in concentration is similar in most cases except for nwhere the near-field concentrations tend to be higher than the other models. ERG also predicts the lowest concentrations for non-aircraft airport sources (Figure 4.10b). However, the highest contribution in this case is from EDMS and LASPORT. All the models predict that the background NO_X concentration tends to increase with increasing distance from the airport (Figure 4.10c). The contribution from road traffic sources is clearly seen in Figure 4.10d where, in particular, the transect across the M4 (shown by the large peak on the right of the plot) is clearly visible. Three of the models produce largely similar predictions for road transport sources: ADMS-Airport, ERG and netcen. There is a tendency for EDMS to produce lower concentrations close to roads and for LASPORT to produce high concentrations. In the case of LASPORT, the fall-off in concentration is less than for the other models. Taking all sources into account (Figure 4.10e), all

these influences can be seen, for example, in the proportionally greater contribution made by airport sources for netcen and EDMS and the higher road transport contribution from LASPORT. A comparison can be made with estimated contributions made by total airport emissions with that derived from the data analysis approaches described in Chapter 2, as shown in Figure 4.10f. Although the LHR18 site does not lie exactly on the transect, it is very close, as shown by Figure 4.1. The grey boxes shown on Figure 4.10f highlight the range of likely airport contributions derived at two sites (LHR2 and LHR 18) derived from the measurement analysis. On this basis, the results of ADMS-Airport and ERG agree most closely with that analysis.

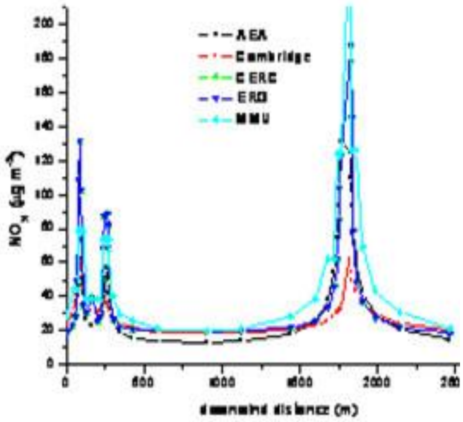
159. Figure 4.10 shows the transect of predicted NO_2 concentration. The NO_2 results not only reflect the varying contributions made by different NO_X sources described above, but also the treatment of chemistry. It shows that most models show an increasing concentration towards the northern runway, which is less apparent for the ERG model. The higher NO_X concentrations predicted by LASPORT close to roads shown in Figure 4.10e does not translate directly to higher concentrations of NO_2, which might be expected because of the NO_X to NO_2 calculation used based on the Jenkin (2004) 'road influenced' locations. That relationship would tend to predict lower NO_2 concentrations for a particular concentration of NO_X and might not be appropriate across the entire transect shown because many locations would be considered as background. Overall, the ADMS-Airport model tends to produce the highest NO_2 concentrations across the transect but not the highest concentrations of NO_X.

Figure 4.10 ***Transect plots***

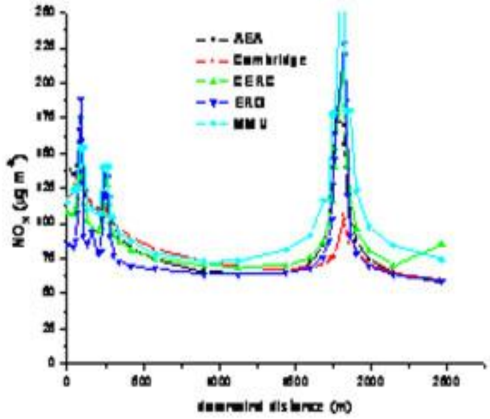




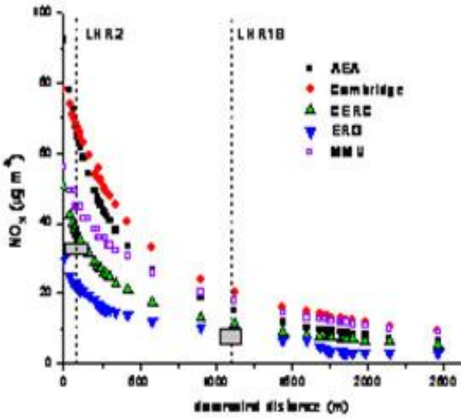
(c)



(d)



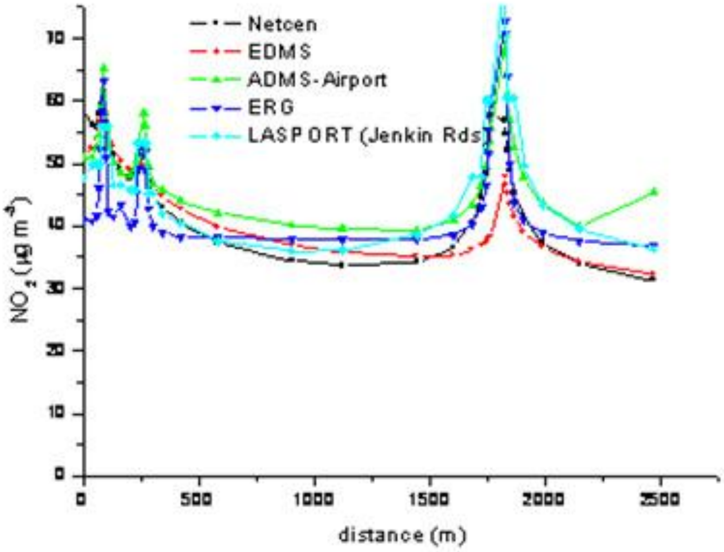
(e)



(f)

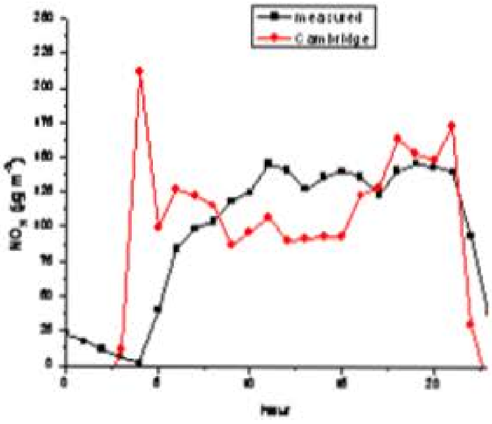
(a) Transect of the aircraft annual mean NOX contribution (µg/m3), (b) transect of the non-aircraft on airport annual mean NOX contribution (µg/m3), (c) transect of the background annual mean NOX contribution (µg/m3), (d) transect of the road transport annual mean NOX contribution (µg/m3), (e) transect of the total annual mean NOX contribution (µg/m3), (f) transect of the total airport annual mean NOX contribution (µg/m3). Note that the distance is that from the transect receptor closest to the northern runway as shown in Figure 4.1.

Figure 4.11 Transect of the total annual mean NO_2 contribution ($\mu g/m^3$).

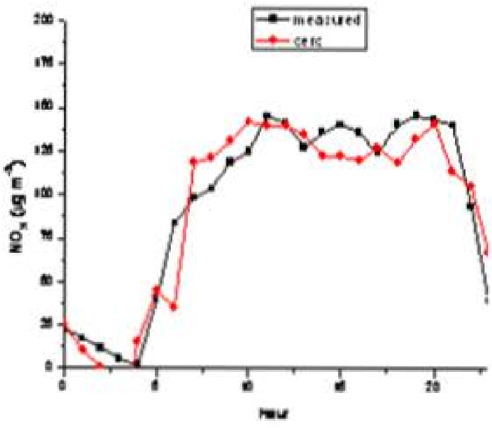


Note that the distance is that from the transect receptor closest to the northern runway as shown in Figure 4.1. Note also that the LASPORT curve extends beyond the vertical scale shown for the M4 point (cut for clarity).

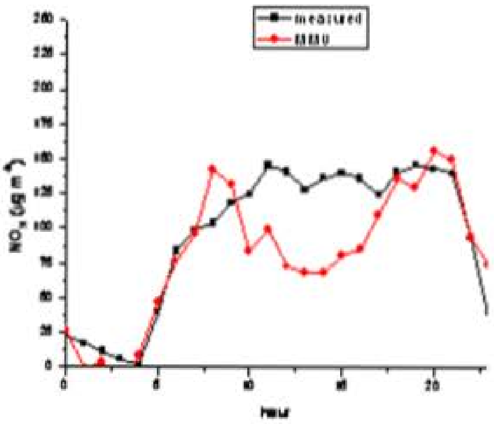
Figure 4.12 Model vs. measurements diurnal variation of NO_X for runway departure



EDMS

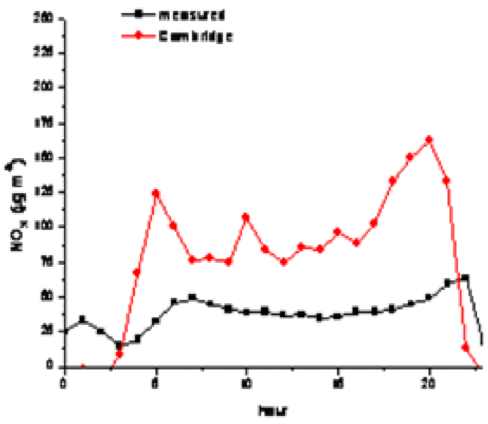


ADMS-Airport

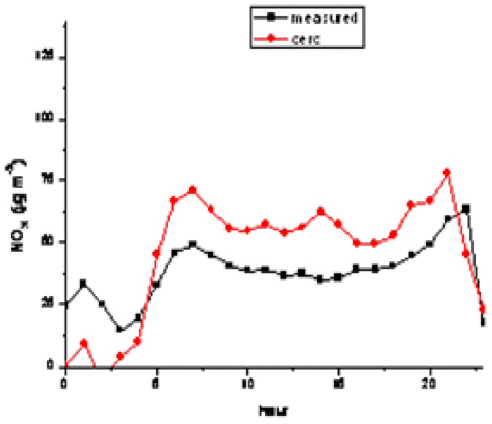


LASPORT

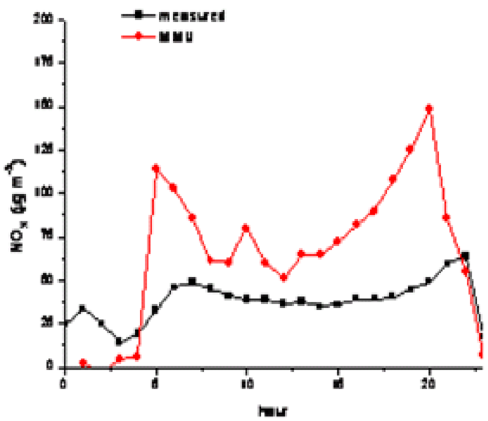
Figure 4.13 Model vs. measurements diurnal variation of NO_X for runway arrival on 27R



EDMS



ADMS-Airport



LASPORT

Runway alternation

160. The activity movements of aircraft at Heathrow Airport provide an opportunity to test various aspects of the models. A key comparison, for example, is the effect of departure versus arrival on the northern runway (27R) during westerly operation. Figure 4.12 and Figure 4.13 summarise model performances against this criterion, as diurnal profiles, for the three models that were able to provide this information. For departures the ADMS-Airport model agrees very well with the measurements. LASPORT and EDMS agree less well and show predicted concentrations that are either too high (particularly in the early morning or late evening) or too low (during the middle of the day). On this basis the ADMS-Airport results show best agreement with the measurements. The agreement is less good for arrivals,

although the performance of ADMS-Airport is still the best. Note that the concentrations are significantly lower for arrivals.

Model response of NO_2 to a change in NO_X concentration

161. One of the tests used in the MIC was to consider how concentrations of NO_2 would change if NO_X emissions changed. The scenario modelled was the removal of all aircraft NO_X emissions. This test is important because it highlights how the models might respond to different mitigation measures. It is recognised however that it is an unrealistic scenario, but its purpose is simply to highlight the characteristics of a change. Figure 4.14 highlights the change for the models that predict NO_2. There are several points that should be noted. First, the ADMS-Airport results give the largest change in NO_2 for a change in NO_X and ERG the least (there is approximately a factor of two difference between these models). However, it should also be remembered that the ADMS-Airport NO_2 predictions are higher than ERG's across the model domain. The response to a change in NO_X for ERG and netcen is almost linear across the range; particularly so for ERG. It would however be expected that a model that treats the chemistry explicitly should give a more reasonable response to NO_2 when NO_X changes, i.e., the ADMS-Airport model.

162. It was noted previously that all models that relate NO_2 to NO_X empirically could adopt ~~the approach to calculating annual mean NO_2 proposed by Jenkin (2004), which offers the potential to account for primary NO_2 and changes to ozone concentrations. However, the Jenkin approach describes two relationship types: "background" and "road-influenced". A remaining difficulty with adopting the approach and applying it to predict NO_2 over a surface is how to interpolate between two discrete relationships and how these relationships cope with a range of scenarios for NO_X reduction.~~

Figure 4.14 Change in annual mean NO_2 concentration resulting from a scenario that models the removal of all aircraft NO_X emissions

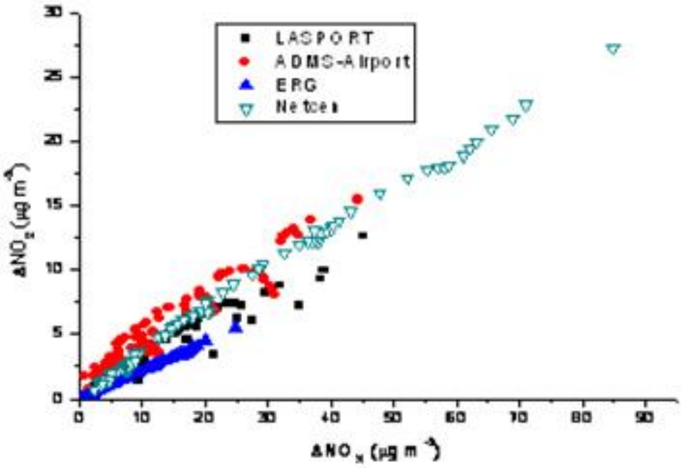
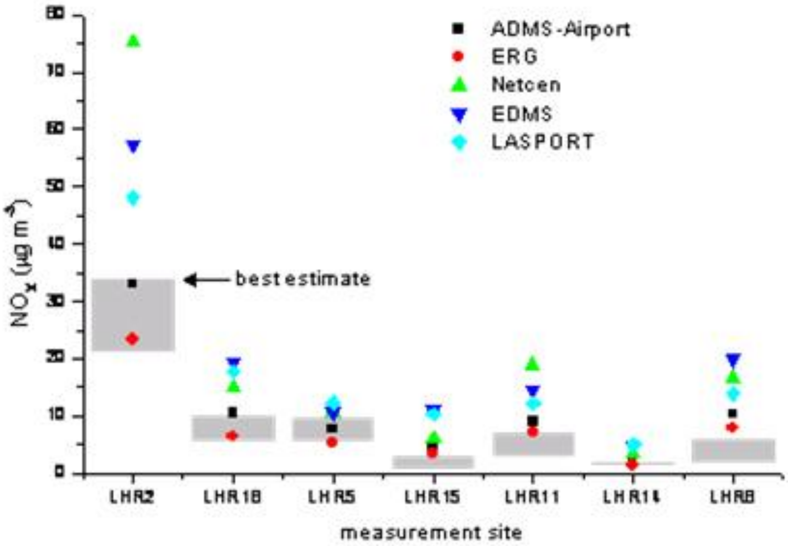


Figure 4.15 Estimates of the airport contribution



Derived from an analysis of measurements (grey boxes) and the model predictions. Note that at LHR2, the most likely value is close to the upper limit shown by the grey box.

Airport contribution

163. Estimates of the airport contribution have been made at 7 monitoring sites based on an analysis of the measurements (Carslaw 2005a). These estimates were defined as a range. At LHR2 it is thought that the actual airport contribution would be very close to the upper limit. At other sites it would be expected that the estimate would be below the upper limit; but the actual contribution is difficult to assess because of the influence of other non-airport sources at these sites. Figure 4.15 shows the comparison of the estimated airport contribution to annual mean NO_X derived from the analysis of measurements and that derived from the models. Overall, the predictions of CERC and ERG are closest to the measured estimates.

Table 4.6 MIC performance summary

Model uncertainty

Assessment of model performance

164. The main sources of uncertainty and bias for predictions of NO_2 in the models used in the MIC are:

- The emissions models;
- The meteorology;
- The dispersion model; and
- The method used to convert NO_X into NO_2.

165. The same emissions inventory for 2002 was used for all models, although with some differences in model domains. Thus inadequacies in the inventory are unlikely to account for the differences between the model predictions, except through the robustness of the comparison of model results with monitoring data. The meteorology for 2002 is discussed earlier and in Annex 3. The appropriateness of the dispersion models used was discussed extensively in the section on atmospheric transport and advection frameworks, in the sections on the individual models and the full reports from the modelling groups (see the Aviation section of the Department of Transport's website at http://www.dft.gov.uk) and in the model inter-comparison. The main problems in the chemistry are the conversion of NO to NO_2, via reaction with ozone (reaction (1), paragraph 66), the allowance for primary NO_2 and for future changes in its fractional emissions and the allowance for any future changes in background ozone. Currently, the more explicit simultaneous treatment of chemistry and transport of ADMS-Airport provides a more transparent approach to the incorporation of temporal or spatial changes in primary NO_2 or ozone than the empirical approaches.

166. A full *a priori* analysis of model uncertainty is not currently feasible, because objective uncertainty estimates are not currently available in the model components, such as the emissions inventories. This issue has been discussed by Colvile et al. (2002) in relation to the application of ADMS-Urban in central London, who concluded that what they described as a 'bottom-up' approach, based on estimates of the size of each source of uncertainty, is not feasible. Instead they employed a 'top-down approach' by comparing model output to a variety of representative measurements of atmospheric concentrations. A similar conclusion was reached by ERG .

Table 4.7 Data quality objectives for air quality assessments

	NO_2 and NO_X	**PM_{10} / $PM_{2.5}$**	**Ozone and related NO/NO_2**
Fixed measurements Uncertainty / Minimum data capture / Minimum time coverage	15% / 90%	25% / 90%	15% / 90% during summer75 % during winter
Modelling uncertainty: Annual averages	30%	50%	50%

Source: European Commission 2005a

167. In their 'top-down approach', Colvile et al. (2002) estimated a model precision of ±10%, with a bias (over-prediction) of 0 - 12%, for the annual mean NO_2 for 1996 and 1997. Similarly good results, reported by CERC and ERG, were discussed earlier. Thus, on the basis of validation against extensive historic datasets for London, the performance of the models for annual mean NO_2 is satisfactory and within the objectives specified by the EU and comparable with likely measurement uncertainties. The scatter plots from the model inter-comparison show, on the basis of more limited datasets, that a performance within the EU specification is obtained even in the more complex environment of Heathrow.

168. Panel 1 identified LHR10 (the monitoring site adjacent to the M25) as being a modelling outlier. None of the MIC dispersion models were able to accurately predict concentrations at this kerbside site. Only when this site was removed did the models predict NO_2 to within 30%. The M4 site, LHR16 is also close to the motorway and the predictions were in reasonable agreement with monitoring. The Panel has not been able to determine at how far from a motorway the models perform reasonably well, and so a caveat may be required relating to potentially overestimated concentrations near the M25 motorway (especially relevant when related to potential mitigation measures and their modelling).

169.

170.

Looking ahead - future uncertainties

169. All projections of future air quality are subject to uncertainties. These uncertainties are likely to be greater for a future year compared with the present day because of the need to rely on projected input data, which is itself uncertain. In addition to these uncertainties, there are other factors to consider in the context of modelling NO_2 at Heathrow. Some of these important considerations are considered briefly below.

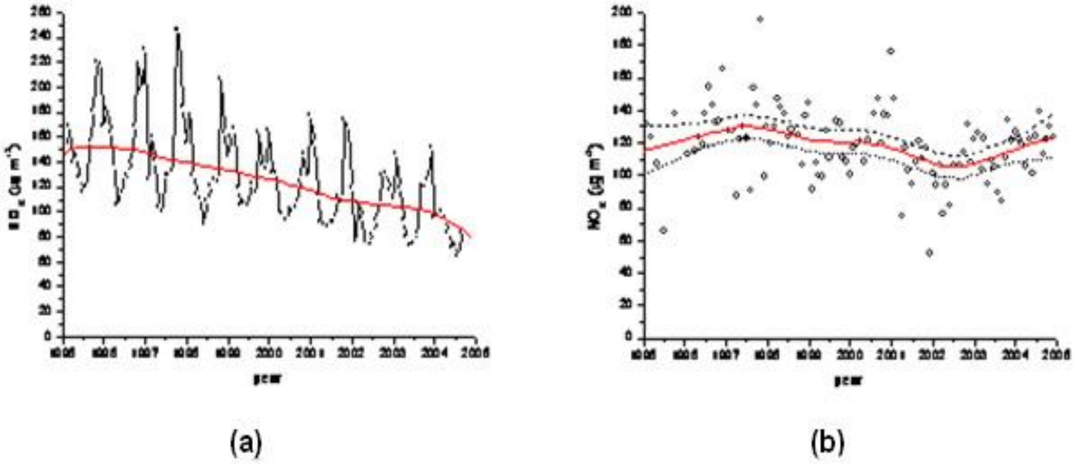
Source apportionment in 2020

170. Aircraft emissions of NO_X are likely to be proportionately more important in the future (e.g., 2010-2020) for NO_X concentrations in the vicinity of the airport. This is primarily because road traffic emissions are projected to continue to decline (AQEG 2004) due to continued improvements of vehicle engine and emissions control technologies. For example, compared with 2000, UK road transport NO_X emissions are projected to decrease from 844 to 418 kilotonnes by 2010; a decrease of 50% (AQEG 2004). By 2015 and 2020 the decrease compared to 2000 is 62% and 64%, respectively (AQEG 2004). By contrast, aircraft NO_X emissions, for the same thrust, are predicted to reduce by around 20% by 2015 and around 30% by 2020 (Eyers 2005c). Indeed, the 10 year time series of measured NO_X concentrations in London

and LHR2 highlights that sites dominated by road traffic show greater decreases than data at LHR2 that have been filtered to highlight aircraft emission trends, as shown in Figure 4.16. These estimates imply that models will increasingly be required to represent the dispersion of aircraft emissions accurately.

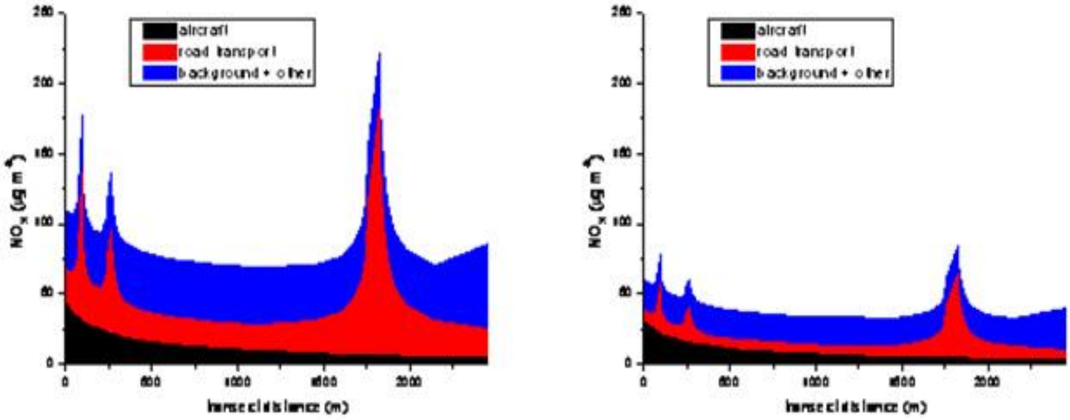
171. An indication of the impact that these projected changes in emissions have on concentrations of NO_X can be gained by considering the source apportionment results from the MIC study. In addition to the projected changes for aircraft and road transport source, it has been assumed that other NO_X sources will decline by 50% from 2000 to 2020. Figure 4.17 shows the effects of these assumptions when applied to the source apportionment results from the ADMS-Airport model for 2002 and 2020. The Figure shows that the proportion of the total predicted NO_X that is due to aircraft increases between 2002 and 2020. Note that these projections assume that the total movements of aircraft at Heathrow remain constant between 2002 and 2020. Any increase in aircraft movements would further increase the proportion of the total NO_X attributable to aircraft.

Figure 4.16 Trends in NO_X concentrations



(a) Trend in mean monthly NO_X concentration for 10 London air pollution sites dominated by road transport emissions (7 background, 3 roadside). (b) trend in NO_X at LHR2 filtered by wind direction (150-260^o i.e. direction of the aircraft) showing a locally weighted regression smoothing fit line with 95 % confidence intervals (Cleveland, 1979). Both data sets have been filtered by wind speeds > 6 m/s.

Figure 4.17 Source apportionment of NO_X



(a) (b)

(a) Source apportionment of NOX transect based on MIC results using the CERC model for 2002, and (b) indicative source apportionment for 2002

Primary NO_2

172. The proportion of NO_X emitted in the form of NO_2 from road transport is currently poorly quantified. There is currently no emissions inventory for primary NO_2 emissions for any source type in the UK. There is, however, empirical evidence that suggests that the mean NO_2/NO_X ratio of road transport emissions in London was around 10% (by volume) in 2002 (Carslaw and Beevers 2005). Currently, vehicle emissions work is being undertaken that aims to quantify the NO_2/NO_X ratio from a range of vehicle types and vehicle emissions control technologies. AQEG is also due to report on a review of Primary NO_2 by summer 2006. Looking ahead therefore, it is very likely that emissions inventories will be developed for primary NO_2. These will help reduce the uncertainties in modelling future NO_2 and should improve model estimates of NO_2 concentrations.

Future ozone concentrations

173. There is some evidence that baseline ozone concentrations have increased at remote locations such as Mace Head (for example, Simmonds et al. 2004). This increase is estimated to have been about 0.5 ppb per annum (1 $\mu g/m^3$) from 1987 to 2003. Although the hemispheric background ozone concentrations may continue to increase to 2030, it is not clear how this change will be manifest at the regional scale. In the context of Heathrow, increases in ozone will be most important for near-field NO_2 concentrations (i.e., a few tens of metres from sources). This is because most of the atmosphere will be limited by the availability of NO_X in the future and increased ozone concentrations will not affect local background concentrations of NO_2 by much. For example, using the approach of Jenkin (2004), for future background concentrations of NO_X of 20 $\mu g/m^3$, an increase in ozone by 6

μg/m^3 would increase NO_2 concentrations by 0.8 μg/m^3. At a roadside location with a NO_X concentration of 80 μg/m^3, a 6 μg/m^3 increase in ozone would increase NO_2 by 3.2 μg/m^3 (a factor of four more than at background). Note that these relationships are based on annual averages. The changes shown here could be subject to noticeable uncertainty from shorter time period effects, such as if hourly O_3 and NO_X relationships change in the future.

174. The data mining work also showed that the airport NO $_X$ is well-oxidised, as shown by relatively high NO_2/NO_X ratios, which are similar to background monitoring sites (Carslaw 2005a). It is probable that increases in ozone will be more important for road sources than aircraft sources for locations outside the perimeter of Heathrow.

Meteorological data

175. The most important issue related to meteorology is the assumption regarding base year used in the projections. This issue is also closely linked with assumptions regarding background concentrations of pollutants such as ozone. The MIC only considered 2002.

176. The MIC also used an adjusted 2002 data set because of various problems identified with the Met Office data at Heathrow. Future model validation using post-2002 data could reduce uncertainties because of the improved measurement of wind speed at the Met Office site.

177. In the longer term (for example in 2030) there is also the additional uncertainty due to the influence of climate change on meteorology. However, the influence of climate change on UK meteorology is highly uncertain. Nevertheless, it does appear that it could become windier during winter months (AQEG 2005b). This potentially would have the effect of increasing the importance of aircraft source compared with road transport. Increased summertime temperatures could also lead to increased ozone concentrations, as discussed above.

Future uncertainty in NO_2

178. Although it is likely that aircraft will make an increasingly important contribution to NO_X concentrations in the vicinity of Heathrow, it does not follow that this will be the case for NO_2. First, increases in the NO_2/NO_X emission ratio of road traffic emissions would increase the importance of road traffic on NO_2 concentrations (particularly close to roads), as shown by recent trends (Carslaw 2005b). Second, any increases in tropospheric background ozone would likely effect near-field road transport sources more than airport sources. These influences suggest that a balanced approach to minimising uncertainties is required that takes proper account of the key processes involved.

Overall assessments of future uncertainty

179. Future modelling, using the emissions inventories developed from the proposals of Panel 3, should include a full analysis of model uncertainty based on comparison against the expanded set of monitoring data that will be available. The techniques developed for the model inter-comparison should facilitate source apportionment and assessment of model performance with respect to the issues raised in this Model uncertainty section. Predictions of the uncertainty in modelling future scenarios can then be quite rigorously assessed. Any attempts to make such assessments at this stage are not feasible because the required breakdown of data are not available from the model inter-comparison (which was for a different purpose).

Panel 1 conclusions and model recommendations

180. Chapter 2 has demonstrated that the UK air quality objective most at risk from airport and associated traffic emissions is the annual mean concentration of NO_2. The 1-hour objective and the objectives for particulate matter are unlikely to be exceeded. The analysis of models was consequently concentrated on annual mean NO_2, although a number of analyses of hourly mean data were made in order to understand and compare model characteristics and performance in greater detail.

181. Key issues affecting model performance and the choice of the recommended model are:

- The ability to model contributions from road traffic emissions and from the background to NO_2 concentrations. Available data on comparisons between monitoring data and model results for a wide range of conditions in London have demonstrated that the annual mean NO_2 concentration can be modelled with an accuracy of ±10-20% with only a small bias.
- Modelling of airport emissions is less well established. A central element is the modelling of plumes from aircraft during take-off and landing. The LIDAR study reported in Chapter 2 should provide important data for the future development of the recommended model, although these data were not available at the time of the model inter-comparison.
- The NO_2 concentration is sensitive to primary emissions of NO_2, especially close to sources. There is clear evidence that the NO_2/NO_x ratio is increasing from road traffic, so that models must be able to accommodate such changes in predictions of future years. There is also evidence that the background concentration of ozone, which converts NO to NO_2, is increasing.

182. Output from five models was compared against monitoring data for nine sites in the vicinity of Heathrow. A range of criteria was developed for the comparison. The results were examined exhaustively by Panel 1 and formed a central component in the selection of the recommended model. In addition, a number of fitness for purpose criteria were used.

183. Panel 1 was in full agreement in the recommendation of the CERC model ADMS-Airport for future modelling work at Heathrow. It satisfied all of the fitness for purpose criteria laid out in paragraph 18.

- Like the other models, ADMS-Airport is demonstrably better that the pre-white paper approach, as shown through the comparison against measurements in the model inter-comparison. The main improvements that have been addressed were outlined in paragraphs 5 to 10.
- It is able to account for the substantive issues and questions raised by the Panel1. In relation to the three issues raised above, (i) its performance in London has been validated extensively against monitoring data, (ii) the Gaussian plume model, used as the basis for modelling the aircraft plumes, has been validated against LIDAR data for buoyant power station plumes. The aircraft plume model is likely to require some revision once the aircraft LIDAR data are fully analysed. (iii) ADMS-Airport models chemistry explicitly, so that issues arising from changes in primary NO_2 and background ozone can be accommodated.
- The panel judged that ADMS-Airport is the most appropriate dispersion model available, for this specific application. It is flexible, detailed and has comprehensive disaggregation. It is able to deal with emissions data at the appropriate level of complexity and provide output including source attribution at appropriate resolution on practical timescales.
- Its ability to incorporate future NO_X emissions is comparable to that of the other models, while its approach to primary NO_2 is the most transparent of the models examined.
- The model can be set up so that scenario and sensitivity analyses can be performed with acceptable computer efficiency.

184. The performance of the models in the inter-comparison is summarised in Table 4.6. The general criteria (G1 - G3) have been discussed above. The following performance was found for ADMS-Airport against the specific criteria:

- S1 (scatter plots of measured vs modelled for NO_X and NO_2 at the monitoring sites). The model gave the best overall agreement with the measurements.
- S2 (wind speed dependence). The concentrations are too high at low wind speeds (< 2 m/s) but gave better agreement with data than the other models.
- S3 (polar plots). It showed the best spatial pattern, although it over-predicted at low wind speeds.
- S4 (contour plots). The results show appropriate and acceptable resolution, e.g. around roads.
- S5 (transect plots of the aircraft contribution). The predicted results are closest of all the models to the estimates derived from the measurement analysis.
- S6 (runway alternation). The comparison with the measured diurnal profile at LHR2 is very good for take-off on the northern runway, but less good for landing. Its performance was better than that of the other two models that could be tested against this criterion.
- S7 (future NO_2 and O_3). This issue was discussed above.

185. Panel 1 discussed the possible use by the Department for Transport of additional models. It was agreed that some limited use of LASPORT could be useful to test the effects of a different atmospheric transport framework (Lagrangian vs. Gaussian) as a sensitivity test, given its extensive use for European airports. Limited model runs using the netcen model may also be appropriate to provide comparisons with earlier analyses, for audit trail purposes.

186. The behaviour of the aircraft plume and the best approach to modelling it using ADMS-Airport needs further examination. Important aspects are the buoyancy of the plume and its dependence on wind speed, and the possible effects of aircraft wakes. Additional effects include the influence of ground on the jet through increased surface drag and asymmetrical entrainment, and the possible convergence of the plumes. Further information will be available from the LIDAR measurements and further work is planned by Panel 1 to assess these data and to advise on modifications of the aircraft plume model component. The model developer, CERC, is able to make modifications to the algorithms within required timescales provided the changes specified are compatible with the basic formulation of ADMS-Airport and the jet model in particular. A further issue is the location of emissions along the take-off roll; analysis of the monitoring data suggests that the emissions are not uniform. These data are available from the analysis of Panel 3.

187. The accuracy of the models has been assessed by comparison with monitoring data, rather than from identification of specific sources of uncertainty. ADMS, like other similar models, has been validated by comparison against data in London and shows an accuracy of 10 - 20% for the annual mean NO_2. Its performance for Heathrow, as shown in the scatter plots, looks comparable, although there appear to be difficulties associated with the airport contribution at LHR2 at low wind speeds, and an issue with the kerbside M25 site (common to all models). The former is probably related to the buoyancy of the plume and should be corrected via modifications following analysis of the LIDAR measurements. The increased number of monitoring sites should provide improved constraints on the model. Panel 2 has recommended that high frequency NO and NO_2 monitoring, coupled with aircraft type and movement data, would be of value in refining models, especially in relation to the effects of wind speed and wind direction. This recommendation is endorsed by Panel 1.

188. There are clear indications from monitoring data that the fraction of NO_2 in NO_x emissions from road traffic is increasing. (Carslaw 2005b; Carslaw and Beevers 2005; Jenkin 2004)). The increase appears to be associated with diesel vehicles and is likely to change in the future with increases in diesel car sales and with increased fitting of some types of particulate traps (AQEG 2004). The development of primary NO_2 emissions inventories for road traffic has been recommended by Panel 3. Primary NO_2 emissions also occur from aircraft and the NO_X fraction as NO_2 increases at lower engine operating conditions. Panel 3 has identified emissions data for different aircraft operating conditions and has recommended that these data are sources and used in subsequent modelling work, together with appropriate

sensitivity analysis. The effects of primary NO_2 emissions on the ambient NO_2 concentration are greatest close to emission source, so that the road traffic emissions of primary NO_2 are likely to have the greatest impact on exposure around Heathrow, but all sources need to be adequately modelled if accurate predictions are to be made.

189. The fractional contribution of aircraft to NO_X concentrations at receptors close to Heathrow is likely to increase, as road traffic emissions diminish. This may not be the case for NO_2, the pollutant of concern, because of the increases in primary NO_2 from road traffic and the increase in background O_3. It is essential to develop and use accurate emissions inventories and dispersion models if the impact of future changes in airport operation are to be properly assessed.

Panel 1 recommendations

190. The following recommendations are made by Panel 1:

1 ADMS-Airport should be used for future air quality modelling studies at Heathrow, associated with PSDH.

2 Further work is needed on the characterisation of aircraft plumes:

- The LIDAR data from Heathrow and Manchester should be analysed to assist in determining the structure and development of the plumes arising from aircraft sources. [3]
- Modelling studies, along with LIDAR and laboratory observations, are needed to determine the range of conditions under which engine exhausts during the take-off roll are likely to lift-off.
- Simple representations of vortex and plume motions during the initial stage of climb-out and the final stage of landing should be developed to examine their likely importance from an air quality standpoint.
- The appropriate level (the balance of complexity, accuracy, robustness and practicality, e.g., run times) of modelling for these processes should be reconsidered in the light of these results and any further research that is needed should be identified.
- Models combined with monitoring data should be used to determine the impact of the location of emission along the runway and the associated uncertainty in their positioning on the resulting exposure at critical receptor locations.

There is an urgent need to examine these issues, as data become available, to facilitate any necessary improvements in the representation of the aircraft plume in ADMS-Airport.

3 A key element in assessing the accuracy of the model output is comparison with monitoring data; the diagnostic tests developed for the MIC should be valuable in this regard. The larger number of monitoring locations, sited specifically to provide stringent tests of model output, should be particularly valuable. The established

performance of ADMS-Urban provides confidence in the representation of concentrations of NO_2 from sources outside the airport by ADMS-Airport. Particular emphasis should be given to the modelling of airside sources in this validation exercise.

4 The final modelling should include substantial analysis to test the sensitivity of the model output to likely ranges of uncertainty in model input, especially that related to emissions, to the future meteorology, to the behaviour of the jet plumes and to future changes in primary NO_2 and background O_3. In the absence of a full statistical analysis, which is not, at this stage, feasible, such an analysis, coupled with model validation against monitoring data, should provide a robust test of the accuracy of the model and of the concentration fields generated from it.

191. CERC is the model developer and is able to make modifications to the algorithms within required timescales provided the changes specified are compatible with the basic formulation of ADMS-Airport and the jet model in particular. Effects that can be accounted for within the model framework include the influence of ground on the jet through increased surface drag and asymmetrical entrainment, the possible convergence of the plumes, and the influence of an inhomogeneous velocity field resulting from wake vortices.

[3] A workshop on interpretation of recent LIDAR surveys at airports, in the UK and USA, took place in March 2006 and developments from this are ongoing.

Air Quality Technical Report - Summary

What is the purpose of the report?

1. This report represents the completion of the *first stage* of our commitment in the Air Transport White Paper to conduct a thorough review into how air quality targets can be met if we were to expand Heathrow. Additional runway capacity could be achieved either by introducing 'mixed mode' (mixing arrivals and departures) on the existing two runways, or by adding a short third runway to the north of the existing airport.

2. The report sets out the recommended methodology and approach for assessing air quality at Heathrow in future against the strict air quality limits set out in the White Paper. It is not a policy report.

Whose report is it?

3. The report is the work of three panels of scientific and technical air quality experts, including representatives from universities, the Department for Environment, Food and Rural Affairs, local government and the scientific and technical research community. The panels have met regularly over the last two years to review the data, knowledge and tools used by the Government to date, and to agree on a technically robust way forward for assessing the air quality impacts of future development at Heathrow.

4. The work of the panels has been independently peer reviewed (a list of those who participated is on the DfT website) and cleared as unbiased and technically sound.

What were the main findings?

5. The panels have confirmed that the three main pollutants of concern at Heathrow are nitrogen dioxide (NO_2), nitrogen oxides (NO_X) and particulate matter (PM_{10}), but have emphasised that the *key* air quality hurdle is NO_2. This is the only pollutant for which EU limit values (applying from 2010) are currently being breached at a number of sites around the airport and are likely to continue to pose a problem in the future, if no action is taken.

6. The panels have looked at a range of existing modelling tools and recommended the most appropriate (in terms of flexibility and the level of complexity it can handle) for the Heathrow study. In the course of their work, they identified a need to strengthen air quality measurement around the airport, and in response some additional monitoring has been put in place.

7. The panels have made a large number of detailed recommendations on how best to represent and model pollutants in future, which have been accepted in full. We believe that applying them will lead to a greatly improved, more sophisticated modelling approach compared with the earlier White Paper work in this area, which was acknowledged to contain significant uncertainties.

What happens next?

8. This is a specialist report which helps to ensure that we are best-placed to carry out an effective assessment of the likely position as regards air quality around Heathrow in the years ahead, taking into account expected growth in air and road traffic. It does *not* reach any conclusions about the viability of a third runway or the introduction of mixed mode operations, which is a matter for the next stage of the work.

9. Building on the report, we will now proceed to model future scenarios at Heathrow and test them for air quality impacts. This work will be carried forward over the coming months. It will also look at action that might be taken to reduce emissions over time. The outcome will inform policy conclusions on the prospects for proceeding with 'mixed mode' or a third runway without breaching our national or European air quality obligations.

10. We expect to go out to public consultation with our findings next year. Policy decisions are expected around the end of 2007. The full technical report and executive summary can be found on our website along with notes of the panel meetings.

Air Quality Technical Report - Q and A

Q. What is the purpose of the report?

A. The report sets out the recommended methodology for assessing air quality at Heathrow. These assessments will enable us to determine whether 'mixed mode' and/or the addition of a third runway are possible within the strict air quality limits set out in the Air Transport White Paper. The report does not make any conclusions about the likelihood of meeting these air quality targets.

Q. What happens next?

A. Air quality at Heathrow will now be reassessed using this methodology. We expect to consult on options for mixed mode and a third runway in 2007.

Building on the recommendations in the report, the DfT is now running the selected air quality models, using the outputs from modelling of surface access scenarios.

Q. Why was this report necessary?

A. Previous work in this area was felt to be insufficient. Government therefore established a programme of work in spring 2004 to review the way in which air quality around Heathrow should be reassessed.

Q. What was wrong with the previous methodology?

A. Earlier technical work noted that there were problems related to representing background emissions, future aircraft operations, initial dispersion of aircraft plumes and future trends in the effects of nitrogen oxides and primary nitrogen dioxide. Previous technical work was relative, not absolute, and hence the emissions inventory uncertainty was large in some areas. These issues have been addressed in the technical panel report.

Q. How has it been verified?

A. The air quality report represents the outcome of a comprehensive technical review over the past two years, involving scientific and technical experts in the field including representatives from universities, the Department for Environment, Food and Rural Affairs, local authorities and the aviation industry. Panel activity has been peer reviewed (list of participants available on our website) and cleared as unbiased, fair and technically sound. The peer review panel, comprising independent reviewers, was established in line with practice recommended by the Office of the Commissioner for Public Appointments (OCPA).

Q. How will you ensure that you satisfy you own criteria of 'being confident that air quality limits will be met' before approving further development?

A. The technical process has been designed to give us the best possible means of estimating future emissions. We will have to take account of remaining uncertainties, for example by suitable sensitivity testing and [where necessary] adopt a cautionary approach.

Q. Are you not just trying to change the methodology to get the answer you require?

A. No. This review and report has been a necessary step to address uncertainties acknowledged at the time of the White Paper and to enable us to proceed to the next stage of inventory construction and scenario modelling. Furthermore, it has been independently peer reviewed and cleared as unbiased, fair and technically sound.

Q. What are the main pollutants at Heathrow?

A. Nitrogen Oxides (NO_x), nitrogen dioxide (NO_2), particulate matter (PM_{10}) and ozone (O_3).

Q. What impact does this report have on meeting the EU limit on nitrogen dioxide emissions by 2010?

A. It is well known that EU limit values are currently being breached in the immediate vicinity of Heathrow and adjacent to the M4, M4 spur and the A4 (and the report confirmed this). The potential for introducing mixed mode operations and/or a third runway are subject to our being able to show that levels of NO_2 emissions at Heathrow can be managed within the EU limit as soon as possible. EU negotiations are underway on a new Ambient Air Quality Directive, if agreed, it will contain the possibility for Member States to postpone compliance with the EU limit values for NO_2 for up to five years providing that a comprehensive action plan is produced and submitted for approval.

Even if agreed, the UK will need to bring these areas within compliance with the limit values by 2015 at the latest.

Q. How many monitoring stations were used in the study and where are they located?

A. The details are in the full report at paragraphs 2.40 - 2.47. Monitoring sites were selected in order to adequately describe the existing pollution climate, which was to be considered in four basic contexts: concentrations near to roads, concentrations near to the airport, local background concentrations and regional background concentrations. It was also recognised that particular attention would need to be paid to the area to the northeast of the airport, due to the prevailing south-westerly winds.

There were 18 monitoring sites in total. Of this number, 2 sites breached the $N0_2$ limit in 2004. The location of these sites was LHR2 (to the north of the airport within the perimeter fence) and LHR16 (alongside the M4, west of Junction 4 (West Drayton).

Q. What are the key findings of the report on emission levels?

A.

- Confirmation that the EU limit values for $N0_2$ were breached at a number of sites around Heathrow in 2002 and 2004
- The overall trend for NO_x is improving but the reduction in NO_2 is considerably less marked.
- The EU limit value for PM_{10} which applies from 2005 did not show any exceedences at any sites.
- There are no other pollutants at Heathrow that are of significant concern.

Q. I live near Heathrow - should I be worried?

A. The main air pollution issue around Heathrow relates to the long-term limit value for nitrogen dioxide. This is based on the fact that there is some evidence for a long-term effect of nitrogen dioxide on respiratory symptoms in children and for a small effect on lung function in adults and children. There is uncertainty over whether the effect is due to nitrogen dioxide itself or to some other pollutant (pollutants often occur together so it can be difficult to separate their effects). It is important to take a precautionary approach but nitrogen dioxide is considered to have a less severe effect on health than either particles or ozone.

Q. What are the key recommendations of the report?

A.

- Recommended use of a particular air quality model for future assessments
- Detailed recommendations relating to the way emissions should be assessed now and in future (up to 2030)

Q. How much did the report cost and who paid for it?

A. The technical panel work up to mid 2006 cost around £700,000. The panels and the peer review process have been funded from within the Department for Transport's programme budget. Funding is in place to carry out the air quality modelling, reflecting the recommendations of this report.

Q. How much worse would air pollution be with a third runway?

A. A third runway could lead to an increase in annual air transport movements (ATMs) from 480,000 to around 655,000 or more. Whilst this would be highly advantageous for the UK economy, it would bring with it environmental implications, regarding noise and air quality. That is why the Air Transport White Paper makes it quite clear that we will only proceed with a third runway if we can be confident that the key condition relating to compliance with air quality limits can be met. We will not know this until we have carried out the necessary modelling work, building on this report.

Q. What does this all mean for the prospects for a third runway (and/or mixed mode) at Heathrow?

A. It is too early to say. Application of the Panel's recommendations should enable us to conduct a more robust assessment of Heathrow's future air quality, but it is not until the methodology has been put in place and the air quality modelling carried out, that we will know whether a third runway and/or mixed mode is more or less likely.

Q. When will the modelling be completed?

A. Further modelling will be carried out in the coming months. We expect to go out to public consultation in 2007, with policy decisions expected around the end of that year.

Q. Where can I get a copy of the report?

A. The full technical report (300 pages) is available on our website as is the executive summary. Notes of the panel meetings have been published on the DfT website throughout the process.

Annex 1
Air quality panels – terms of reference and membership

Introduction

A1.1 The Department for Transport set up technical panels to review how air quality at Heathrow is assessed. This meets the commitment made in the White Paper *The Future of Air Transport* published in December 2003. Uncertainty over compliance with air quality standards at Heathrow – for Nitrogen Dioxide (NO_2) – was a key factor persuading the Government not to support an additional runway at Heathrow straight away. The White Paper promised further work to see how best use could be made of existing runways at Heathrow, and whether a third runway could be added in due course, while still meeting key environmental conditions.

Aim

A1.2 To review the data, knowledge and tools which underpinned the Government's assessments to date, and to agree on a technically robust approach to assessing the air quality impacts of future options for development at Heathrow. The work should be completed by early 2006.

Scope

A1.3 The work will consider how best to represent current air quality impacts at Heathrow through measurement and modelling work, and to define means by which future air quality concentrations can be predicted for the period up to 2030. The work will need to take account of emissions from all sources that contribute to concentrations of NO_2, (and other relevant pollutants where justified). It will also inform work on noise, surface access and air traffic management.

Objectives

A1.4 The main objectives are to:

- review the technical and scientific robustness of air quality assessment work undertaken by the DfT for the purposes of the South East Regional Assessment Study (SERAS) public consultation on airport development options in 2002/3 and for the Air Transport White Paper;

- examine the adequacy of measurements of airborne pollutants from different sources around Heathrow for the purposes of compliance with standards and verification of models;
- examine the adequacy and reliability of source emission data available for the various contributing sources that will be used as modelling inputs;
- consider the suitability and adequacy of the models used to represent the dispersion of emissions around airports;
- identify and specify research and other work needed to improve understanding of air quality assessments; and
- agree the appropriate tools and data to be used in further air quality modelling undertaken by the Government in light of commitments made in the Air Transport White Paper.

Proposed approach

A1.5 The core issues specific to air quality are:

- dispersion modelling;
- ambient measurement; and
- emissions source data.

A1.6 Panels of independent experts, supported by officials, have been established to examine these topics. The composition and remit of each of the three panels are shown below.

A1.7 Progress will be reported to a wider range of stakeholders from time to time. DfT will institute an independent review process of the work of the panels.

PANEL 1 – DISPERSION MODELLING

General remit

A1.8 To examine the air quality modelling approach and tools supporting the SERAS/RAS analysis and the post-consultation modelling for the Air Transport White Paper and make recommendations for improvements for use in future modelling work.

Members

A1.9 Prof M Pilling, University of Leeds (Chairman)
Prof R Britter, University of Cambridge
Dr D Carruthers, Cambridge Environmental Research Consultants Ltd
D Carslaw, Institute for Transport Studies, University of Leeds
Prof B Fisher, Environment Agency
Prof D Laxen, Air Quality Consultants Ltd
Prof D Lee, Manchester Metropolitan University
Dr I McCrae, TRL Ltd
Prof A Robins, University of Surrey
S Beevers, Kings College London

P J Taylor, Atkins Ltd (formerly Halcrow Group Ltd)
Dr B Underwood, netcen (an operating division of AEA Technology plc)
Department for Transport
Department for the Environment, Food and Rural Affairs

Issues to be addressed

A1.10 Consider the suitability of the modelling approaches used previously at Heathrow to achieve best representation of the unique characteristics of airport emissions production.

A1.11 Consider what form of dispersion regime best represents the airport emissions situation. Examine EDMS/Aermod, Lasport and ADMS models and the pros and cons of the use of Gaussian and Lagrangian approaches.

A1.12 Specifically, consider issues surrounding the:

- suitability of emissions source representation using point/strips/volume;
- accuracy of representation of background emissions levels;
- characterisation of the initial dispersion of the plume;
- representation of near-roads dispersion; and
- NO_2/NO_X conversion now and later (ozone trend).

A1.13 Determine the work necessary to improve the modelling – including appropriate measurement requirements for required validation/verification data. Review the work to refine and improve the modelling, the output from any research specified and any model inter-comparison or validation activity.

PANEL 2 – AMBIENT MEASUREMENT

General remit

A1.14 To consider whether air quality monitoring in the vicinity of Heathrow Airport are adequate for the purposes of compliance testing and for verification of models. To determine what additional data may be required to meet these needs.

Members

A1.15 Prof D Laxen, Air Quality Consultants Ltd (Chairman)
V Beale, London Borough of Hillingdon
D Carslaw, Institute for Transport Studies, University of Leeds
B Creavin, BAA plc
R Gibson, London Borough of Hounslow
M Hackman, Highways Agency
S Moorcroft, Air Quality Consultants Ltd
K Morris, British Airways
S Beevers, Kings College London
P J Taylor, Atkins Ltd (formerly Halcrow Group Ltd)
Dr B Underwood, netcen (an operating division of AEA Technology plc)

Department for Transport
Department for the Environment, Food and Rural Affairs

Issues to be addressed

A1.16 Conduct an audit of current air quality monitoring activity around Heathrow, including the coverage, methods and data management and use. Identify any gaps in coverage and whether additional continuous monitoring data is required. Consider the adequacy of measurements of both airport-related and road traffic-related sources.

A1.17 Examine the potential for using existing specific measurement campaigns (such the BA transect study) to improve modelling aspects. Consider the need for supplementary or different measurement data through shorter-term study work - specifically to permit validation of a base year model.

A1.18 Review the output from measurement programmes or an expanded measurement network, maintaining contact with the modelling group to ensure data meets the needs of model validation activity.

PANEL 3 – EMISSIONS SOURCE

General remit

A1.19 To examine the quality and accuracy of emissions data, from the various sources at/ around airports. To consider in what areas additional or better data is needed and to suggest appropriate work to provide data sufficient to enable comprehensive modelling of current and predicted future emissions at Heathrow.

Members

A1.20 Dr D Raper, Manchester Metropolitan University (Chairman)
V Beale, London Borough of Hillingdon
B Creavin, BAA plc
C Eyers, QinetiQ plc
R Gibson, London Borough of Hounslow
M Hackman, Highways Agency
D Hutchinson, Greater London Authority
P Madden, Rolls Royce
Dr I McCrae, TRL Ltd
K Morris, British Airways
C Wilson, University of Sheffield
P J Taylor, Atkins Ltd (formerly Halcrow Group Ltd)
Dr B Underwood, netcen (an operating division of AEA Technology plc)
Department for Transport
Department for the Environment, Food and Rural Affairs
Department for Trade and Industry

Issues to be addressed

Aircraft (current):

A1.21 Examine the adequacy of aircraft emissions data drawn from the ICAO Aircraft Engine Emissions Databank together with knowledge for interpolation for operational power levels. Consider the needs for data for aircraft operations and power management to enable more precise representation of actual emissions levels for aircraft types and operations at Heathrow. Explore availability of reduced thrust / reverse thrust and roll data from LHR-based carriers. Consider the production of a range of emissions power profiles curves to support modelling needs.

Aircraft (future):

A1.22 Oversee acquisition of a comprehensive database of emissions for the future predicted performance of aircraft - accounting for prospective engine technology developments, covering the scenario timeframes.

Airside:

A1.23 Look at data available for APU use, engine testing, brake and tyre emissions and engine start-up phase emissions. Consider ways to acquire additional data to enable comprehensive modelling. Consider the prospective emissions performance for non-aircraft airside and landside airport specific emissions in the future.

Landside:

A1.24 Draw upon data and knowledge available to ensure that a suite of road traffic emissions performance data is adequate to represent emissions from local and national roads in the vicinity of Heathrow for the full timeframe of any future scenarios.

Annex 2
Previous assessments – description and shortcomings

Prior history

A2.1 The White Paper *Airports Policy* was published in June 1985 (DoT 1985). In 1990 the Government set up the Runway Capacity to Serve the South East (RUCATSE) Working Group, which reported in July 1993 (DoT 1993). However the enactment was stopped due to concerns about environmental damage. In May 1996 the House of Commons Transport Committee (1996) published a report on *UK Airport Capacity*, which recommended the preparation of a long-term White Paper.

A2.2 In March 1999 Government announced an intended study of airports and air services in the South East and East of England (SERAS). This study would complement the six regional studies announced in the 1998 White Paper *A New Deal for Transport: better for everyone* (DETR 1998).

A2.3 All previous assessments are published elsewhere. The key references are:

- South East and East of England Regional Air Services Study, Stage Two: Appraisal Findings Report – Supporting Documentation: Air Quality Appraisal, for DETR (Halcrow Group 2002);
- Air Quality Assessments Supporting the Government's White Paper *The Future of Air Transport* (DfT 2003);
- *Air Quality Modelling for Heathrow Airport 2002 - A report produced for BAA Heathrow* (Underwood et al. 2004e)
- *Air quality modelling for West London: Hillingdon, Hounslow, Spelthorne and Slough* (Williams and Girnary 2002)
- *British Airways Dispersion Modelling of Aircraft Movements at London Heathrow Airport – Summary of Phases 1-4 (2000-2003)* (ASK Consultants 2004)

SERAS 2000-2002

Limiting Principles

A2.4 The Government consulted on draft terms of reference for SERAS in September 1999, and commissioned an airports appraisal framework for use in the study. It is very important to note the basis upon which the SERAS air quality methodology was specified and developed: to compare options using relatively simple air quality key indicators (a form of AST (Appraisal Summary Table), rather than to provide a validated and accurate estimate of air pollution concentrations. Hence the focus was on the relative change between options, not the absolute.

A2.5 SERAS was fundamentally a decision making process for a long term strategy. It involved a number of stages. The principal focus of stage 1 was to develop and appraise options for capacity enhancement at individual existing airports and at the new sites which used judgement and simple screening methods. Stage 2 used air quality modelling to assess a large number of options at the principal South East airports, including new sites. For each main site this included:

- A base-case option, representing the option and its capacity currently envisaged in the land use planning system
- An option which represents maximum use of exiting runways, and
- Options which represent additional runway and terminal capacity at each airport

A2.6 The options at the main sites were then combined into a number of packages, where for each main airport option a 'representative case' has been defined. These representative cases formed the basis of the appraisal of each option.

A2.7 Where approximations and simplifications were introduced due to constraints, or where there were gaps in the knowledge base, the SERAS air quality methodology was designed to tend towards over-prediction rather than under-prediction. The resulting estimates were considered a reasonable basis for comparing the air quality impacts of packages/options, but the absolute numbers for any one case were subject to significant uncertainties and, based on the set-up, were more likely to be **overestimates** than underestimates.

A2.8 SERAS did not include a base year air quality model, for example 2000. This was removed from the original on the basis that the assessment was strictly relative and not absolute. The base case would normally be used to calibrate and validate the model (where feasible). Modelled years were 2015 and 2030.

A2.9 Further, the air quality assessment was required to be comparable to work undertaken in other regional airport studies, and this limited the ability to include certain factors, particularly site specific issues. The environmental terms of reference for SERAS also required that the appraisal method for air quality would not compromise the confidentiality of the study. The methodology reflects this limitation, and only used data generated within the SERAS team, or available from industry-available databases. This certainly prevented the use of airport specific data for many variables. This was particularly relevant for Heathrow where it was known that more relevant data existed. Illustrations of the effect of using such data can be readily seen in some of the SERAS sensitivity tests.

Modelling Approach

A2.10 Pollutant concentrations were modelled from two contributor sources: the contribution from those sources explicitly included in the dispersion modelling within a pre-defined study area; and the contribution from all other sources, included via a semi-empirical background model. Emission sources directly modelled included:

- aircraft-related emissions, including engine exhaust emissions in the landing and take-off (LTO) cycle, auxiliary power unit (APU) emissions, fugitive PM_{10} emissions from aircraft brake and tyre wear on landing;
- road-vehicle emissions on a major road network around the airport, including engine exhaust emissions and cold start emissions; and
- emissions from airside support vehicles.

A2.11 The Key Indicator for SERAS Stage 2 air quality was "the absolute number of people exposed to an exceedence of the air quality standard, weighted by the degree of exceedence". This used contours of pollution concentrations above the objectives, and population data for districts and wards.

Key Uncertainties

A2.12 The limiting principles of the work described above are the main source of uncertainty, especially when comparing this work to other studies of Heathrow with different more environmental impact assessment-like remits.

A2.13 Assumptions which led to over-estimates, but which were retained in all tests, included:

- Future aircraft fleet: as developed for noise modelling, and was not necessarily optimised for air emissions fleet mix;
- 100% take-off thrust;
- Near field (roadside) dispersion – simple representation only;
- Jet turbulence and plume rise – this was potentially significant but the data available on the expected effect was very limited;
- Surface access vehicle fleet (characteristics and emissions) – held constant against national fleet models available at the time. For example, no allowance for possible future Low Emission Zones or User Charging schemes; and
- Airside vehicles scope for reduced emissions – held constant, as data limitations restrict the definition of mitigation tests.

A2.14 The principal assumptions modified in the sensitivity tests are given in Table A2.1. The core assumptions were more likely to over-estimate than under-estimate local air quality impacts. The assumptions in sensitivity test 1 were considered to equate to the best available current technology in 2015. The assumptions in sensitivity test 2 were only likely to be realised as a result of the introduction of stringent government and airport operating policies, and at considerable expense to the airlines.

A2.15 Other uncertainties in the SERAS approach (compared to an EIA style air quality assessment) included:

- Criteria – The air quality objectives in SERAS were those in Air Quality Regulations at the time. Additional standards now exist, such as for PM_{10}, which are more difficult to achieve and have different compliance dates, especially 2010.
- Statistics – Conversion of annual mean to other air quality statistics used the former DETR Local Air Quality Management (LAQM) empirical relationships. These have been significantly revised since the SERAS work.
- Exposure – The data on the populations exposed and method was commensurate to the need for relative results only.
- NO_X/NO_2 – For near-road receptors, the relationship was taken from the DfT's Design Manual for Roads and Bridges at the time with a dependence on the distance from the road. This has been substantially revised, and the near-road relationship is much changed.
- Study area – The assessment was limited to the "area for detailed air quality assessment". The maximum study area explicitly modelled, made up of one or more airport zones, was 8 x 6 kilometre boxes centred on each runway. The definition comes from previous DfT airport assessments, and was simply a common approach with all regional studies.
- Airside – Emissions from airside support vehicles and plant in a given year were based on a very simple assumption of a fixed amount of pollutant per passenger throughput. This was due to the lack of usage and fleet data, for all airports.
- TOLR (take-off & landing roll) – The approach does not account for any airport-specific operational differences, for example, in the take-off weights for a given aircraft type which would greatly affect TOLR emissions.
- Near-field (aircraft) – The chosen initial dispersion parameters were more likely to underestimate than overestimate the near-field dispersion.
- Near-field (roads) – A volume source of depth of 3 metres, based on previous work. For the key road links, receptors may be very close to individual road links, and hence sensitive to the choice of initial dispersion.
- No specific representation of the potential plume rise of aircraft engine exhaust gases was included. This could lead to overestimation of the near-field concentration contribution from aircraft.
- Buildings – Modelling did not include specific representation of building wake effects. The presence of buildings on the airport was approximated by setting an effective roughness length only.

Table A2.1 Varied SERAS modelling assumptions

Technical Area	Core model runs	Sensitivity test 1	Sensitivity test 2
New aircraft/ engine combinations	Just meet CAEP/4 limit for Oxides of Nitrogen	All engines without certification would, by 2015, match the performance of current dual-annular combustors (DAC) engines, giving 20% lower emissions than CAEP/4	Based on aggressive use of ultra-low NO_Xtechnology. All aircraft using Heathrow must have LTO EI NO_X of no more than 45% of CAEP/4 limit.
% thrust on take-off	All aircraft at 100%	Reduced thrust (85%) for those main aircraft types in BA survey & analysis.	Reduced take-off thrust defined for all major jets
Reverse thrust on landing	All aircraft assumed to use full reverse thrust on landing	All aircraft assumed to use full reverse thrust on landing	All aircraft assumed to use reverse idle, rather than reverse thrust, on landing
APU emissions	Pre-Conditioned Air (PCA) is not used. APU usage for 90 minutes before departure for wide-bodied & 30 minutes for narrow-bodied aircraft & 15/20 minutes before arrival	All stands fitted with PCA & all aircraft with APUs use this facility. APU usage reduced to 15/10 minutes before departure & 5 minutes before arrival	All stands fitted with PCA and all aircraft with APUs use this facility. APU usage reduced to 15/10 minutes before departure & 5 minutes before arrival

- Background mapping – This was explicit, but only available to 2020. There was uncertainty in the degree of adjustment required for local effects.
- Modelled road network – nested set of different detail of modelling. Inner detailed simulation area very small. Extent of roads grid around airport could change.
- Traffic – Traffic flows were derived from a morning peak model only, and diurnal flow profiles (shape) are common to all model runs, irrespective of traffic volumes. The roads emission factor database has been considerably revised since SERAS.

Results Sensitivity

A2.16 With the main SERAS assumptions, airport-related sources account for between 55% and 80%, depending on the location, of pollution concentrations. Airport-related sources were dominated by aircraft emissions, and aircraft emissions were the largest contributor at each location. Inspecting the detailed results, the effect of runway location was evident, but the new runway itself did not dominate the results.

A2.17 In contrast, for the sensitivity tests, total airport sources generally contributed less than non-airport sources. Airport-related sources accounted for around 30% to 60% of pollution concentrations. The new runway taxiing and APU contributions were also reduced. The remaining exceedence areas were concentrated on the Harlington area and alongside the M4 corridor.

Table A2.2 Model specification for *The Future of Air Transport* White Paper (2002)	
Software	
i	Dispersion model software: CERC ADMS 3.1
ADMS setup	
i	Dry deposition: No. Judged as trivial
ii	Wet deposition: No. Judged as trivial
iii	Radioactive decay: N/A
iv	Gamma dose: N/A
v	Plume visibility: N/A
vi	Odours: N/A
vii	**Chemistry: No - post ADMS calculation. Conversion NO_x to NO_2 using empirical relationships: Laxen & Wilson method for 'near roadside' receptors FOR SENSITIVITY TEST ONLY and DEFRA where 'at background'**
viii	Buildings: Only included in model runs for airport boiler stacks (for CHP and T4 building heights set at typical values using subjective judgement), otherwise not included (judged as not important)
ix	Hills: No. Terrain is essentially flat in study area and is very unlikely to have any substantial influence on dispersion patterns
x	Coustline: N/A
xi	Puff: No. All releases are assumed to be continuous steady state
xii	Fluctuations: N/A
xiii	Site surface roughness: 0.2m as per Heathrow weather station, uniformly applied accross the study area
xiv	Site latitude (degrees)
Sources explicitly modelled in ADMS	
ia	Aircraft sources: Base volume sources. Source height 2.5m AGL (when on the ground) with volume depth of 30m and no plume rise. Source width 20m. Base volume sources off ground at heights 2m, 4m 8m ….1024m. Source dimensions off ground ??? Spacing of these base sources according to 'power-law rule' so that increases with height (25 sources between ground and 1000m with max spacing of 180m between uppermost 2)

Appendix AQ.1.8

ib	Emissions: NO_X and PM_{10}. PM_{10} emissions included fugitive emissions from aircraft brake and tyre wear (arrivals only requiring separate hourly weighting factors)
ic	**Time varying emission factors: No. Use of BAA BOSS database to determine hour-by-hour variations**
iia	Airside land based mobile sources: Base volume sources. Source height ?m AGL. Source width ?m
iib	Emissions: NO_x and PM_{10}
iic	**Time varying emission factors: No**
iiia	**Airside static point sources: Points representative of each source using data from T5 inquiry + 1m stack diameter assumption for Heathrow maintenance stack.**
iiib	Emissions: NO_x and PM_{10}. Efflux parameters given in Table 2.1
iiic	**Time varying emission factors: No**
iva	**Landside road sources: Base volume sources. Source height 1.5m AGL with volume depth of 3m. Source width 10m**
ivb	Emmisions: NO_x and PM_{10}
ivc	**Time varying emission factors: Yes, using relatively simple profile data by road type. Time varying within inner and middle nested roads areas**
ADMS Meteorology	
i	Met data: UK Met Office supplied for London Heathrow weather station for 10 year period. Statistical dataset used
ii	Minimum Monin-Obukhov length: 30m (applies to cities and large towns)
iii	Surface albedo: 0.23 (ADMS default = no snow covered ground)
iv	Priestly-Taylor parameter: 1 (ADMS default, appropriate for moist grassland
v	Precipitation at weather station: Assumed same
vi	Surface roughness at weather station: Assumed same
Model grids	
i	**Receptors: 20x20m grid**
Primary ADMS output	
i	Pollutants: All pollutants emitted
ii	Model output statistics: Annual means
iii	Units for output: ppb
Post-processing	
i	Background NO_x
ii	Background NO_2
iii	Background PM_{10}

Table A2.3 Air quality sensitivity tests in *The Future of Air Transport* White Paper

Rep case	Forecast year	Scenario	Sensitivity test parameters
Model changes applied to all sensitivity tests			- **new ERCD aircraft fleet mix data for forecast year** - **revised 2002 aircraft type base data** - **new road emission factors (EFDB2002)** - **revised background method (results for London region** - **revised idle for aircraft (where relevant)** - **reduced thrust for aircraft (where relevant)** - **Pre-Conditioned Air on all stand (reducing APU)** - **20% reduction in airport-related landside vehicle emissions** - **30% reduction in aircraft average holding times**
RC11 b1	2015	655k ATM, 3rd short runway to N	- better engine NO_X from Case 1 landing charge (equivalent to 'CAEP/4 –31%')
RC11 b2	2015	600k ATM, 3rd short runway to N	- better engine NO_X from Case 1 landing charge (equivalent to 'CAEP/4 –31%')
RC11 b3	2015	655k ATM, 3rd short runway to N	- delayed opening or 3rd runway - better engine NO_X performance ('CAEP/4 –40%')
RC1 b4	2015	480k ATM, max use of 2 runways	- better engine NO_X from Case 1 landing charge (equivalent to 'CAEP/4 –31%')
Model changes applied to all subsequent sensitivity tests			- **Laxen method for near-road NO_2/NO_X conversion ratios** - **Heathrow specific Landing Roll using A/C specific times rather than ERCD Group** - **air quality based optimised speed limits on M4 and M4 spur**
RC11 b5	2015	655k ATM, 3rd short runway to N	- better engine NO_X from Case 1 landing charge (equivalent to 'CAEP/4 –31%')

Rep case	Forecast year	Scenario	Sensitivity test parameters
Model changes applied to all subsequent sensitivity tests			- **50% reduction in airside emissions** - **23% reduction in employee-related vehicle trips to Heathrow** - **29% reduction in airport-related passenger trips from a £20 airport access charge** - **no growth in non-airport related traffic on M4 and M4 spur over current levels**
RC11 b6	2015	655k ATM, 3rd short runway to N	- better engine NO_X from Case 2 landing charge (equivalent to 'CAEP/4 –34%')
RC1 b7	2015	480k ATM, max use of 2 runways	- better engine NO_X from Case 1 landing charge (equivalent to 'CAEP/4 –31%')
RC11 b8	2015	600k ATM, 3rd short runway to N	- better engine NO_X from Case 2 landing charge (equivalent to 'CAEP/4 –34%')
RC11 b9	2015	655k ATM, 3rd short runway to N	- better engine NO_X from Case 2 landing charge (equivalent to 'CAEP/4 –34%')
Model changes applied to all subsequent sensitivity tests			- **reallocate all westerly departures from northern runway to southern runway, all westerly arrivals on the northern runway (all easterlies unchanged, respecting the Cranford Agreement)** - **airport related traffic scaled down using ratio of actual mppa**
RC11 b13	2015	550k ATM, 3rd short runway to N	- better engine NO_X from Case 2 landing charge (equivalent to 'CAEP/4 –34%')
RC11 b14	2020	600k ATM, 3rd short runway to N	- better engine NO_X from Case 2 landing charge (equivalent to 'CAEP/4 –40%')
RC11 b15	2015	550k ATM, 3rd short runway to N	- introduction of displaced start of roll on southern runway, by SPASM aircraft class
RC11 b16	2020	550k ATM, 3rd short runway to N	- introduction of rigorous EuroV/VI exhaust emission standards from road traffic - adjustment of aircraft fleet for later assessment year

Rep case	Forecast year	Scenario	Sensitivity test parameters
RC1 b17	2010	515k ATM, max use of 2 runways	- limited landing charge improvement in engine NO_X performance (equivalent to 'CAEP/4 –15%') - partial mixed mode operation, between 7am and 5pm
RC11 b18	2015	550k ATM, 3rd short runway to N	- zero emissions for M4 between M25 (J4A) and Cranford (M^3) (M4 and the spur placed in tunnel, with vent stacks which have scrubbers which are 100% effective at removing NO_X) - all emissions for the M4 spur (right into CTA) turned off (see above) - all southern runway westerly departures moved to a start of roll point at block 85 (Assumes southern runway extended 1km to west but retain easterly departures on the southerly runway at the existing SOR point)

AIR TRANSPORT WHITE PAPER 2003

A2.18 For the *The Future of Air Transport* White Paper, the same modelling approach was used as in SERAS, but improved, expanded and subjected to considerable sensitivity testing to aid understanding of uncertainty. Since the original work better information became available in a number of areas relevant to the modelling (e.g., revised aircraft fleets and updated road traffic emissions factors) and was reflected in the new work. Additionally, responses to the national consultation included some new or improved information (airline and operator proprietary) that was substituted.

A2.19 The intention of the White Paper work was to move the SERAS estimates, which were most likely to be overestimates, toward the 'best estimate' assessment of NO_2 impacts. As part of the best estimate, a review of all modelling parameters wasn undertaken, with the focus of any change being on those parameters with the largest effect. The work then also moves on from that 'best estimate' to see what scale of action might be needed to eliminate the predicted NO_2 problem.

A2.20 The tests undertaken and changes made are outlined in detail in published reports[1] (Halcrow Group 2002), and are not repeated here. The areas of modelling changed in the White Paper are shown in Tables A2.2 and A2.3. Table A2.2 summarises the components of the White Paper air quality model using the standard model specification structure, whilst Table A2.3 summarises the range of sensitivity tests undertaken and their main components.

1 Air Quality Assessments Supporting the Government's White Paper "The Future of Air Transport", DfT, December 2003

A2.21 The main changes from improved input data for Air Traffic Fleets, Aircraft Emissions Performance and Road Traffic were:

- Air traffic fleet data;
- Aircraft technology;
- Road traffic data;
- Basis and nature of sensitivity tests; and
- Representation of aircraft thrust and of emissions and their impact.

A2.22 The main modelling improvements were:

- Initial dispersion parameter uncertainties reflected in all sensitivity cases modelled using a range of values;
- Updated empirical relationships used to convert NO_X to NO_2 at near-road locations, referred to as the Laxen method;
- Specific operational differences in 'take-off and landing roll' parameters;
- Testing of uncertainty in SERAS 'near-field dispersion effects' within 30 metres of a major road (by varying volume source depth);
- Departure allocations improvements; and
- Euro V/VI exhaust emission standards for road vehicles.

A2.23 In addition, a wide range of mitigation tests were undertaken addressing technical Emissions Management and physical and operational mitigation measures:

- Aircraft emissions improvement driven by a theoretical emissions landing charge;
- Justification of 20% reduction in airport-related landside vehicle emissions (net effect of access limits, optimised speed limits);
- Reduction in airside emissions; and
- Landside vehicle emissions (airport and non-airport) – including more realistic staff access assumptions, Airport Access Charges: Passenger Trips, Non-Airport Traffic Road User Charging: Passenger Trips, forced growth rates for non-airport traffic).

Table A2.4 Model specification for BAA work (2004)

Software	
i	Dispersion model software: CERC ADMS 3.1
ADMS set-up	
i	Dry deposition: No. Judged as trivial
ii	Wet deposition: No. Judged as trivial
iii	Radioactive decay: N/A
iv	Gamma dose: N/A
v	Plume visibility: N/A
vi	Odours: N/A

vii	Chemistry: No - post ADMS calculation. Conversion NOx to NO2 using LAQM.TG(03) empirical relationships, with application of Laxen & Wilson method for 'near roadside' receptors and DEFRA where at 'background'
viii	Buildings: Only included in model runs for airport boiler stacks (for CHP and T4 building heights set at typical values using subjective judgement), otherwise not included (judged as not important
ix	Hills: No. Terrain is essentially flat in study area and is very unlikely to have any substantial influence on dispersion patterns
x	Coastline: N/A
xi	Puff: No. All releases are assumed to be continuous steady state
xii	Fluctuations: N/A
xiii	Site surface roughness: 0.2m as per Heathrow weather station, uniformly applied across the study area
xiv	Site latitude (degrees): ?
Sources explicitly modelled in ADMS	
ia	Aircraft sources: Base volume sources. Source height 2.5m AGL (when on the ground) with volume depth of 30m and no plumerise. Source width 20m. Base volume sources off ground at heights 2m, 4m 8m ….1024m. Source dimensions off ground ??? Spacing of these base sources according to 'power-law rule' so that increases with height (25 sources between ground and 1000m with max spacing of 180m between uppermost 2)
ib	Emissions: NO_X and PM_{10}. PM_{10} emissions included fugitive emissions from aircraft brake and tyre wear (arrivals only requiring separate hourly weighting factors)
ic	Time varying emission factors: Yes. Use of BAA BOSS database to determine hour-by-hour variations
iia	Airside land based mobile sources: Base volume sources. Source height ?m AGL. Source width ?m
iib	Emissions: NO_X and PM_{10}.
iic	Time varying emission factors: No.
iiia	Airside static point sources: Points representative of each source using data from T5 inquiry + 1m stack diameter assumption for Heathrow maintenance stack.
iiib	Emissions: NO_X and PM_{10}. Efflux parameters given in Table 2.1
iiic	Time varying emission factors: No. Uniform diurnal and seasonal profiles assumed
iva	Landside road sources: Base volume sources. Source height 1.5m AGL with volume depth of 3m. Source width 10m
ivb	Emissions: NO_X and PM_{10}

ivc	Time varying emission factors: Yes. Diurnal profile only (flat monthly profile judged as adequate). Separate profiles airport and non-airport related vehicles, each sub-divded into categories: cars and 'goods vehicles'. Profiles for non-airport traffic and airport HGV derived from national traffic statistics. Profiles for airport related vehicles (except HGV) dervide from passenger throughput data. Buses assigned same profiles as non-airport cars. For vehicles in car parks and taxis these were assigned same profiles as airport related cars
ADMS Meteorology	
i	Met data: UK Met Office supplied for London Heathrow weather station for 2002 in ADMS format. Data supplied are hourly sequential
ii	Minimum Monin-Obukhov length: 30m (applies to cities and large towns)
iii	Surface albedo: 0.23 (ADMS default = no snow covered ground)
iv	Priestly-Taylor parameter: 1 (ADMS default, appropriate for moist grassland)
v	Precipitation at weather station: Assumed same
vi	Surface roughness at weather station: Assumed same
Model grids	
i	Receptors: Study area 10km E-W, 7km N-S (SW corner 503000,173000). Regular grid 100 x 100m across study area + 10 x 10m grid 100m either side of explicitly modelled roads
Primary ADMS output	
i	Pollutants: All pollutants emitted
ii	Model output statistics: Annual means
iii	Units for output: ppb
Post-processing	
i	Background NO_X
ii	Background NO_2
iii	Background PM_{10}

BAA 2004

Kernel Improvements

A2.24 The BAA 2004 work was part of a large programme of work to improve representation of air quality at Heathrow, including creation of a much improved emissions inventory for 2002 and 2010, more disaggregate modelling of expected conditions in these years, and additional model verification against extra monitoring data.

A2.25 Whilst the modelling approach remained the Netcen kernel technique using ADMS3.1, many aspects were on an improved basis, as this work was for a different purpose, and so the methodology was not an evolution of the White Paper methodology. Changes included:

- Hourly Heathrow meteorological data for 2002;

- 2002 emission inventory for explicitly modelled sources (aircraft, airside vehicles, road network);
- Improved adaptation of the national empirical model for 'background';
- Simple parameterisation of near-field dispersion, with sensitivity tests of ideal values;
- Spatial distribution of aircraft emissions treated in more detail;
- Diurnal/monthly profiles of aircraft emissions treated in detail;
- Change-over of 'easterly'/'westerly' operation of runways modelled in detail;
- 10 metre receptor mesh near roads; 100 metre general mesh; and
- Empirical NO_X/NO_2 relationships improved.

A2.26 Table A2.4 summarises the components of the BAA air quality model using the standard model specification structure. This cannot be directly compared to the White Paper work, as the studies were for a different purpose and the level of input data available were thus at different degrees. The bold areas in Tables A2.2 and A2.3 are those which were significantly different in the BAA work compared to the work undertaken for the White Paper.

Results Summary

A2.27 Total NO_X – The total annual mean NO_X results showed a model bias towards overestimation (around 18%), with a fractional standard deviation of 31%. Analysis showed a difference in scale of overestimation between sites with large background components and sites with a large amount of explicit modelling.

A2.28 Roads – Further analysis showed that some sites were affected strongly by a contribution from the road network and others strongly by an aircraft contribution. Sites with a large modelled road-vehicle contribution had a larger than average ratio of modelled to measured total NO_X concentration – suggesting that modelling of the road traffic contribution close to the road over predicts. At near-road sites, typical overestimation is 30-50%. In both cases, tests were not able to distinguish between overestimation of emissions and underestimation of initial dispersion conditions as the root cause of differences.

A2.29 LHR2, at the airfield perimeter – A northerly/southerly directional analysis was used to identify road/aircraft contribution at LHR2. This indicated that **both** the road-vehicle and aircraft contributions at LHR2 are significantly overestimated, with the latter having a larger impact on total annual-mean NO_X. Again, tests were not able to distinguish between overestimation of emissions and underestimation of initial dispersion conditions. For the latter, a number of dispersion-related effects are important at LHR2 but less important at more distant receptors. These include near-field dispersion due to plume momentum and heat influenced by presence of the ground, plume rise, and jet displacement along the runway. However, increasing the initial dispersion parameter over a range of 30 metres to 100 metres, and scaling aircraft emissions by 0.54 both gave very similar improved model performance at LHR2. This is important, as different model changes that lead to the same degree of agreement at LHR2 (and with little effect at other monitors) would lead to significant differences in the NO_2 exceedence contour in nearby residential areas.

A2.30 Finally, for the first time model predictions were compared to new a monitoring transect across the airport. Results were highly correlated with measurements.

OTHER STUDIES

A2.31 Other models have been built in the last five years which include the Heathrow area. These are summarised here for completeness, but set-up, assumptions and shortcomings are not covered in as much detail as the main Heathrow-focused work described above.

CERC West London Model 2002

A2.32 A Stage 4 Review and Assessment of Air Quality was carried out in 2002, using ADMS-Urban, for four boroughs in the West London area: the London Boroughs of Hillingdon and Hounslow and the Boroughs of Spelthorne and Slough. Given the local air quality management (LAQM) context, the model only included a base year of 1999 and a forecast year of 2004/5.

A2.33 Current and future emissions data were taken from four different sources: the BAA emissions inventory for Heathrow, 1998; the London Atmospheric Emissions Inventory (LAEI) February 2002; the Surrey Traffic Model; and the February 2002 emissions inventory for Slough. Background concentration data, obtained from rural monitoring sites, and meteorological data from Heathrow were used in the modelling.

A2.34 Representation of aircraft emissions from Heathrow was improved over previous LAQM work by representing aircraft flight paths as a set of eight volume sources.

A2.35 All roads having a NO_X emission rate greater than 0.1g/km/s in 1999 were modelled explicitly, and the remainder as aggregated 1 square kilometres grid sources with a depth of 75 metre to represent initial vertical spread. The variation of traffic flow was reflected by applying a standard diurnal profile to the road emissions.

A2.36 The amount of emitted NO_X converted to NO_2 in the atmosphere was calculated using the Generic Reaction Set (GRS) of equations.

A2.37 The national Air Quality Strategy objective value for annual average NO_2 concentrations was predicted to be exceeded over most of the southern part of Hillingdon and along major roads in the north. Annual average PM_{10} concentrations were predicted not to exceed the AQS objective value anywhere within Hillingdon, whilst the 24-hour average percentile standard was predicted to be exceeded only along the M25 motorway. All modelled values were within a factor of two of the monitored values, with most slightly higher. For the annual average concentrations of NO_2 and PM_{10}, the square root of the normalised mean square error suggested an uncertainty of about 20%, and the normalised or fractional bias suggested overestimation by about 15%.

A2.38 Airport emissions contributed significantly to predicted ambient NO_X concentrations in the southern part of the Hillingdon Air Quality Management Area around the airport, but not in the northern part. Emissions from traffic on major roads were significant at all locations close to them.

British Airways 2003

A2.39 British Airways, for its own annual reporting and later extended to its own work for SERAS, commissioned dispersion modelling of aircraft movements at Heathrow. This was based on the EDMS/AERMOD model, and was for NO_X/NO_2 and PM_{10}. The work centred on the impact of British Airways aircraft sources **only**, including aircraft movements, APUs and engine testing/ground running, on ground level concentrations within 2-3 kilometres of the airport boundaries though this was extended to the whole of the air transport movements (ATMs) at Heathrow[2]. The majority of input data, as a result, was focussed on British Airways specific operations.

A2.40 Even with direct access to operational data, inputs still had a number of uncertainties related to non-British Airways aircraft operations. These included the NO_X emission indices at reduced thrust settings, and the proportion of take-offs at reduced thrust, for each aircraft type; movement schedules (or alternatively frequency profiles by hour of the day, day of the week and month of the year) for each aircraft type; and runway use for each hour of the year. To reflect British Airways specific operational practise, several workarounds were required to bypass EDMS default parameters which were characteristic of operations in the USA and did not reflect Heathrow conditions particularly well.

A2.41 The work made an attempt to reflect building wake effects using the AERMOD module BPIP, but with unsatisfactory results.

A2.42 NO_2 was estimated from NO_X using a relevant equation from the Netcen National Scale Empirical Model, as suggested by AQEG (2004). For Heathrow, this approach underestimates the role of primary NO_2 and hence the final resultant NO_2 concentrations.

A2.43 The study used EDMS 4.0. This version does not take account of results from USA aircraft plume LIDAR measurements, which in subsequent versions of EDMS have been used to account for plume rise and provide a more accurate initial vertical dispersion coefficient. As shown in this PSDH report, such issues are significant.

2 Whilst some modelling runs were for total ATM conditions at Heathrow, these still were based mostly on British Airways data (i.e., effective British Airways fleet and operations).

Annex 3

An analysis of changes to wind speed from the Met Office Heathrow site and development of a new data set

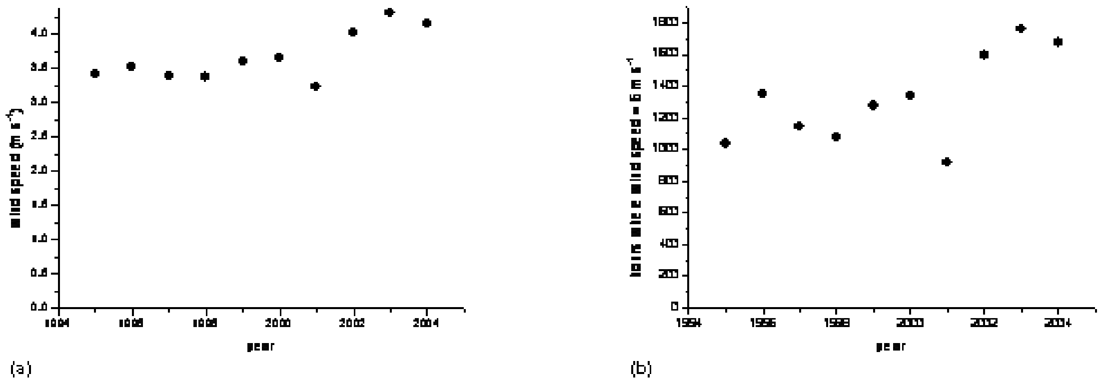
Context

A3.1 This annex summarises the analysis of wind speed measurements at the Met Office Heathrow site and the identification and remedy of problems associated with the data. In summary, it was found that data collected prior to September 2002 at the Met Office Heathrow site were associated with logger and instrument problems that led to measured wind speeds being too low.

Data Analysis

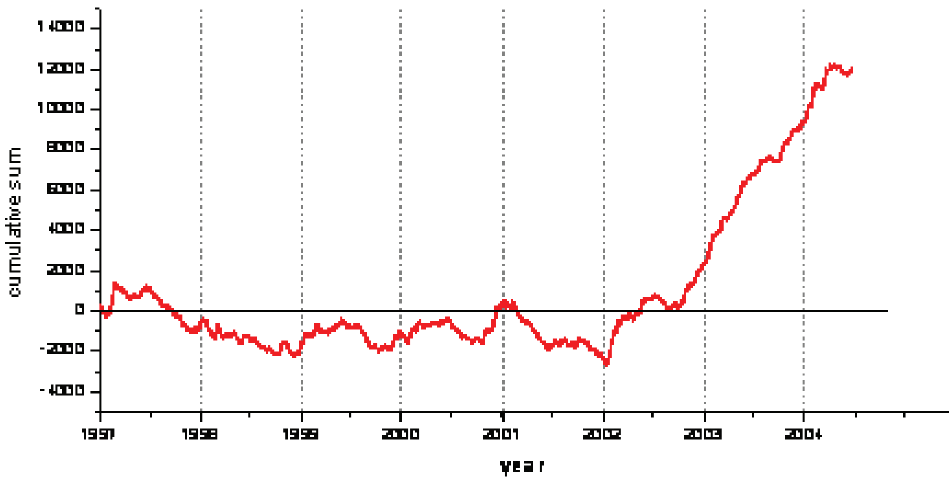
A3.2 A potential problem emerged with the wind speed data set while considering the proportion of time wind speeds are $>$ 6 m/s, which, as has been shown by the analyses of bivariate wind speed pollution roses, could be important conditions for the contribution made by aircraft jet plumes to ground level concentrations. Note that all data used in this analysis have been provided directly by the Met Office. Figure A3.1(a) indicates that annual mean wind speeds in 2002-2004 appear to be higher than in years prior to 2002. Mean wind speeds 2002-2004 are on average 21 % higher than the period 1995-2001. Furthermore, there also appears to be an increase in the number of hours where the wind speed is $>$ 6 m/s, as shown in Figure A3.1(b). Additional analysis conducted for Panel 1 by the Environmental Research Group at King's College London (ERG), shows that there has been a marked increase in the frequency of low wind speeds post 2001.

Figure A3.1 a) Annual mean wind speed, b) number of hours where the wind speed is > 6 m/s for the Met Office London Heathrow site (1995-2004).



A3.3 The plots shown in Figure A3.1 provide only indications of a possible change in wind speed. To further investigate this possibility, a cumulative sum (CUSUM) analysis was applied. A CUSUM analysis is frequently used for industrial processes as a means of determining whether something has 'gone out of control'. A CUSUM works by accumulating the differences between a measured value and a set limit in a time series and by doing so can rapidly highlight a systematic change to a process. Here, the mean wind speed for 1995-1996 was chosen as the set limit. The CUSUM was calculated on an hourly basis. If wind speeds remained on average the same as in 1995/6, the CUSUM plot would on average be zero.

Figure A3.2 CUSUM analysis of wind speed data at the Heathrow Met Office site.



A3.4 Figure A3.2 shows that there is some variation from 1997-2002 in the mean wind speed, which is entirely expected because of natural variations over different time scales. However, from a period within 2002, there is a clear departure from the mean. The constant slope of the line after 2002 indicates that the change has been systematic, indicating a possible step change in wind speed. The exact timing of the change is difficult to determine precisely because of the influence of the natural variation in wind speed. Two possible periods are indicated: at the beginning of 2002 and around September 2002.

A3.5 From a site history supplied by the Met Office (14 March 2005), several changes have occurred at the site in recent years:

1. A Vector Mk 6 anemometer was installed on 11/9/02, replacing a Munro Mk 5
2. The site moved (alt 32m, 508400, 175500) from previous location (alt 34m, 505100, 175700)
3. On 1/12/03 the Mk 6 was moved again (alt 34m, 507450, 176750)

A3.6 Analysis conducted by the Met Office for Panel 1 showed that at the London Heathrow site the wind speed instrument prior to September 2002 was directly associated with 2 issues affecting results - logger problems (including changes in software used), and an inability to correctly record low wind speed conditions (< 2 knots).

A3.7 Two attempts were made to re-calculate wind speeds for data prior to September 2002. The first was carried out by the Met Office using Wisley data (19 kilometres from Heathrow). Corrections were applied depending on the anemometer type used and by wind direction. Corrections were made by comparing coincident times e.g. Jan-June at one site with Jan to June at the other.

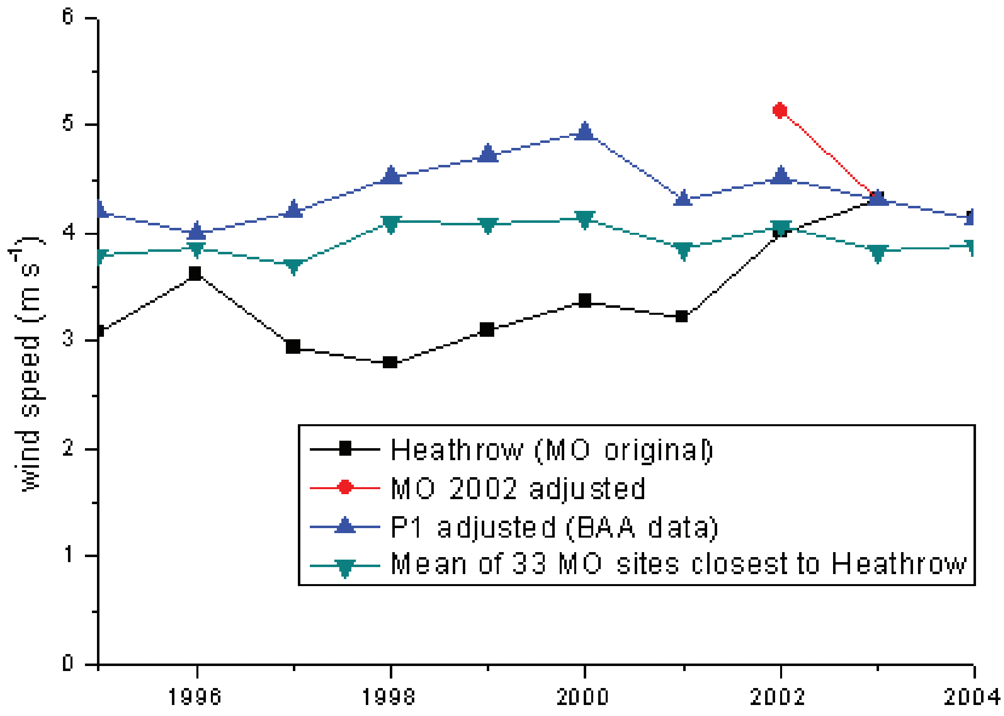
A3.8 The second method used data from BAA sites at Heathrow. The aim was to derive mean adjustment factors by comparing 2002/3 data at each site with the Met Office site, which could then be applied to pre-Sept. 2002 data. One site is located at LHR2 with data going back to 1993, using either a lightweight anemometer or a sonic anemometer (the latter since the end of 2002). Unfortunately, the data capture at this site for 2002 is poor. Another BAA site at Main Rd nurseries (about 1 km west of the airport) has had a sonic anemometer since 2001. It is at a height of 7 m. Data capture in 2002 was good at this site. For some reason, despite being a higher anemometer than LHR2 (7 cf. 4 m) a larger scaling factor was required for Main Rd when comparing 2003/4 data with Met Office data (1.74 cf. 1.20). Correction factors derived by comparing 2003/4 data with Met Office data were retrospectively applied to pre Sep. 2002 data. This differs from the Met Office coincident approach. However, no attempt was made to adjust wind speeds by direction. A times series from 1995-2004 was reconstructed using BAA data, based mostly on LHR2 data using the scaling factors above. However, for most of 2002, the Main Rd site was used.

A3.9 In addition the option to use data from another site was also considered – for Northolt (8 kilometres from Heathrow). However, analysis of the data for 2002 showed that this site had a very large fraction of calm conditions where no wind direction was available (> 20 % of the year). This site could not therefore be used either directly or for adjustment purposes.

A3.10 Subsequent analysis in deriving new wind speed pollution roses highlighted a potential problem with using BAA adjusted data for 2002. A closer inspection of 2003/4 data compared with the Met Office site showed poor wind speed correlation by direction.

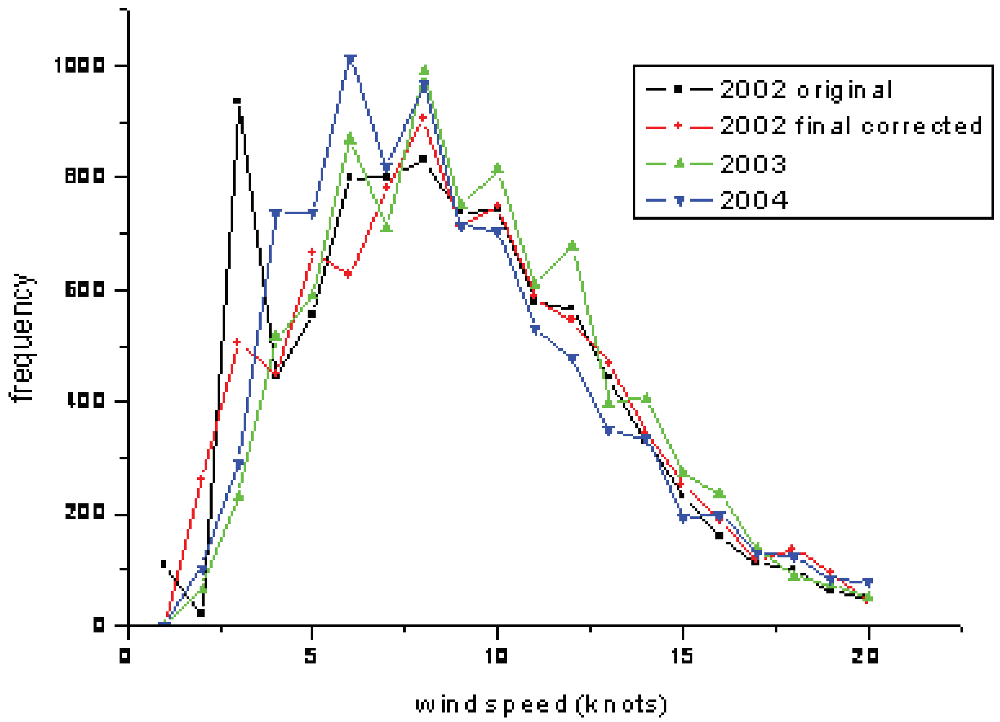
A3.11 Analysis of annual average wind speeds by the Met Office indicates that their reconstructed data for 2002 at Heathrow is probably too high (5.1 m/s) – see plot below. This can be seen when considering a large range of times series from around the UK. The re-construction using BAA data for 2002 appears to provide sensible results (4.4 m/s) on this basis. Note that the mean of 33 other MO sites are those within 100 kilometres of Heathrow. The plot highlights the problems associated with the original MO data, and the MO re-calculated 2002 data based on Wisley.

Figure A3.3 Plot showing the original (uncorrected) annual mean wind speed Met Office data, the mean of 33 Met Office site close to Heathrow, the P1 adjusted data using BAA data and the Met Office corrected 2002 data.



A3.12 The frequency distributions for the various data sets are shown below.

Figure A3.4 Frequency distributions of different hourly Met Office data sets.



A3.13 The most promising way forward was to use Met Office 2002 re-constructed data with an additional scaling factor applied such that the mean wind speed in 2002 is 4.4 m/s. This gave sensible hourly wind speeds by direction throughout 2002 and also ensured that 2002 ''sits'' properly in the time series since 1995. The latter point is important if in any subsequent air quality modelling a ''worst'' case met year is required. This final data set generated was the one used for the MIC work as reported in Panel 1.

Annex 4
Main source apportionment categories

Source type	Sub-division
Aircraft sources	Start-up Taxiing Holding Take-off roll Reduced thrust at take-off Initial climb, Climb-out to 1,000 feet Climb-out 1,000 feet to 3,000 feet Approach Landing roll Reverse thrust at landing Runway crossings Shut down APU emissions Ground running Brakes and tyres
Airport airside sources	Ground support vehicles – road going Ground support vehicles – specialist Ground support vehicles – LPG and hybrid Construction Runway maintenance, clearance, bird-scaring, etc Ground power units Fire training Fugitive PM_{10} emissions from aircraft CHP

Source type	Sub-division
Surface access sources	Airport related traffic and non-airport traffic: - weekday and weekend - variables by direction of travel - diurnal flows - diurnal speeds - diurnal traffic composition Vehicle fleet by purpose-based sub-fleets Airport-related traffic: - cars, taxis, coaches for air passengers - cars, buses for airport workers Non-airport-related traffic: - cars, LGVs, London taxis, OGV1, OGV2, local buses (red), other PSVs - HGVs split between rigid and articulated. Total vehicle-kilometres per grid-square Traffic queuing Airport employee-related trip ends Mode split passenger trip ends Long-term and short-term parking Non-engine vehicle sources (brake and tyre wear, road surface wear, re-suspended material)

Note: Apportionment does not differentiate between scenarios or forecast years

Annex 5
Key pollutants report

Background

A5.1 Following the SERAS study on the potential for airport expansion in the South East of England, uncertainty over compliance with the European Union annual mean limit value for Nitrogen Dioxide (NO_2) at Heathrow was a key factor persuading the Government not to support an additional runway at Heathrow straight away (DfT 2003a) The White Paper *The Future of Air Transport* published in December 2003 promised further work to see how best use could be made of existing runways at Heathrow, and whether a third runway could be added in due course, while still meeting key environmental conditions (DfT 2003b).

A5.2 As part of this work, the Department for Transport has set up technical Panels to review how air quality at Heathrow is assessed. Their remit is to review the data, knowledge and tools which underpinned the Government's assessments to date and to agree on a technically robust approach to assessing the air quality impacts of future options for development at Heathrow.

A5.3 One of the first tasks of the Panels was to determine which pollutants should be the focus of their work. Early discussions indicated a need to conduct a review outlining the pollutants of importance at Heathrow and justifying their inclusion/exclusion from the Panels' work programme (DfT 2004). This report aims to provide the basis for this.

Air quality standards

A5.4 The main driver for the air quality assessment of Heathrow Airport is compliance with the Air Quality Limit Values set by the European Union. These are legally binding limits on concentrations of a range of pollutants in ambient air. They are set out in Table A5.1 in this Annex.

A5.5 The Air Quality Strategy for England, Scotland, Wales and Northern Ireland (DETR 2000) sets air quality objectives for 7 pollutants that are included in regulations for the purposes of Local Air Quality Management:

- Benzene
- 1,3-butadiene
- Carbon monoxide

- Lead
- Nitrogen dioxide
- Particles (PM_{10})
- Sulphur dioxide

A5.6 In addition further objectives are set for the protection of human health, but which are not included in the regulations for the purposes of Local Air Quality Management:

- Ozone
- Benz-a-pyrene

The benz-a-prene is a marker for poly aromatic hydrocarbons (PAHs)

A5.7 Additional objectives for the protection of vegetation and ecosystems are also included in the strategy, however, these do not apply at Heathrow as it is within 20 kilometres of an urban agglomeration. These objectives cover nitrogen oxides and sulphur dioxide.

A5.8 The objectives for seven of the pollutants in the Air Quality Strategy have been adopted into UK law in the Air Quality Regulations 2000 and the Air Quality (Amendment) Regulations 2002. The objectives are set out in Table A5.2 at the end of this Annex. They are based on standards established by the Government's Expert Panel on Air Quality Standards and the EU limit values and targets.

Importance at airports

A5.9 Although compliance with air quality limit values and objectives is of primary importance, the Panels agreed that other pollutants that may be of particular significance at airports should also be considered, as the Panels' work is intended to inform air quality determinations at airports in the future when objectives may be different to today's. Other pollutants of potential significance at airports include:

- Volatile organic compounds (VOCs) - in addition to benzene and 1,3-butadiene.
- Poly aromatic hydrocarbons (PAHs) – including benzo(a)pyrene.

Benzene, 1,3-butadiene and other VOCs

A5.10 Few air quality modelling studies at airports include assessments of VOCs. VOC emissions data for aircraft are not readily available. For example, no emissions for any individual VOC species are recorded in the ICAO emissions databank (ICAO 2005). Modelling is further complicated by the involvement of VOCs in photo-chemical reactions.

A5.11 Measuring speciated VOCs is complex, particularly for continuous monitoring and relatively few automated monitoring sites for VOCs exist in the UK, and none of these are close to Heathrow.

A5.12 However, some transect measurements of benzene using diffusion tubes have been conducted at Heathrow (Clark 2005). These measurements indicate that annual mean concentrations of benzene across the airport site are well below the current Air Quality Strategy objective of 16.25 µg/m^3 (5ppb).

A5.13 Measurements of benzene (by diffusion tube) and other VOC species (by grab sampling) were also conducted at the LHR2 site in 2003 (Lampert et al. 2004). The annual mean concentration of benzene at Heathrow LHR2 was below the current Air Quality Strategy objective for benzene and is also below the objective for 2010 of 5 µg/m^3. Concentrations of benzene at LHR2 are lower than at the Marylebone Road central London roadside site. For other VOC species, the grab samples indicated that Heathrow annual mean concentrations were also lower than at the Marylebone Road site.

A5.14 Benzene and 1,3-butadiene are strongly correlated with road traffic emissions, in the absence of industrial sources such as chemical plants (for example, the Expert Panel on Air Quality Standards 1998 and 2002). Traffic is an important source of, benzene, 1,3-butadiene and VOCs within the Heathrow area but are not considered to be a priority area for the air quality Panels because levels are well below objectives, even close to busy roads.

PAHs (benz-a-pyrene)

A5.15 PAHs, in particular benz-a-pyrene, which is used as a marker compound for PAHs, have not been measured at Heathrow. The European Commission produced a position paper on PAHs in 2001, which reported that very few studies have been carried out on PAH emissions from aircraft, and of those carried out, most have been for military aircraft (European Commission 2001b). The Position Paper noted that PAH emissions are dependent on fuel composition (volatility) and on the power setting of the engine decreasing as the power setting increases, i.e. less important during take-off. It cites an average emission factors for an aircraft gas turbine engine as 1.24 mg per LTO (Landing–Take-off Cycle) for BaP. These emissions can be compared with typical LTO emissions for NO_X of 10-20 kg. In other words, PAH emissions are around 1×10^{-7} times those of NO_X. If aircraft are contributing around 30 µg/m^3 to NO_X concentrations at LHR2 (see main report), then a simple scaling would give a PAH contribution of 0.003 ng/m^3. The benz-a-pyrene contribution would be even smaller. The emissions of benz-a-pyrene are given as 3.53×10^{-8} times VOC (URS Corporation, 2003). As the non-methane HC emissions for aircraft are smaller than those of NO_X, then the benz-a-pyrene aircraft contribution at LHR2 would be around a factor of 10 lower, at around 0.0003 ng/m^3, which is well below the objective of 0.25 ng/m^3. This is consistent with the report that measurements of PAHs around Hamburg airport did not detect elevated concentrations (URS Corporation, 2003). The evidence is thus that aircraft are an insignificant source of PAHs.

A5.16 Road traffic is another source that contributes in the Heathrow area. The Addendum to the Air Quality Strategy (Defra 2003) discusses sources of PAHs and concentrations. This identifies that road traffic is a relatively minor source of PAHs in the UK, accounting for 8% of emissions and that concentrations near to roads do not exceed the benz-a-pyrene objective of 0.25 µg/m^3.

A5.17 The available evidence for PAHs indicate that levels at Heathrow are likely to be well below relevant health based standards and PAHs are not considered to be a priority area for the air quality Panels.

Carbon monoxide

A5.18 Carbon monoxide is extensively measured at a number of sites in the Heathrow area and has been included in some modelling studies. Modelling work related to the Terminal 5 development indicated that levels of CO at Heathrow are low.

A5.19 Similar modelling work using ADMS-Urban has been conducted as part of the air quality assessment for the 2^{nd} runway at Manchester airport.. This indicated that at airport sites aircraft contribute to 34-42% of modelled concentrations, reducing to 3-18% at sites in nearby residential areas. Modelled concentrations of CO for 2005 were less than 1 mg/m^3.

A5.20 Measurements of CO at sites in and around Heathrow airport show levels of CO well below the Air Quality Strategy objective of 11.6 mg/m^3 (10 ppm), as a maximum 8-hour mean, and these have been decreasing over the last decade (see for example London Borough of Hillingdon 2005; London Borough of Hounslow 2005).

A5.21 The available measurements and modelling for CO indicate that levels of CO at Heathrow are likely to be well below relevant health based standards and CO is not considered to be a priority area for the air quality Panels.

Lead

A5.22 Lead is generally not measured or modelled at airport sites. Following the elimination of lead from petrol there are no exhaust emissions of lead from vehicles on surrounding roads. Lead is also not added to aviation fuel. Lead is therefore not considered to be a priority area for the air quality Panels.

Oxides of nitrogen (NO_X)

A5.23 Uncertainty relating to predicted concentrations of nitrogen dioxide (NO_2) at Heathrow in the SERAS studies was one of the factors which persuaded the government to delay considering a further runway at Heathrow and which resulted in the creation of the air quality Panels to assess this issue.

A5.24 Nitrogen dioxide is produced by oxidation of nitric oxide (NO) (collectively NO and NO_2 are termed NO_X). NO_2 is also emitted as a primary pollutant by aircraft, although the majority of total aircraft NO_X emissions are as NO. NO_X is emitted from all combustion sources, including aircraft, auxiliary power units and ground support vehicles airside at airports and from heating plant and road traffic landside and in areas surrounding airports.

A5.25 The extensive modelling work carried out for the Terminal 5 and SERAS studies included assessment of NO_2 and NO_X. This indicated that it was not clear if compliance with Air Quality Strategy Objectives could be achieved at Heathrow. Uncertainties in the modelling process for NO_X and NO_2 are considerable and it is the work of the air quality Panels to reduce these as much as possible, so as to provide a more robust determination of future air quality at airports including Heathrow.

A5.26 Measurements of NO_2 and NO_X are routinely made by BAA using automated continuous monitoring equipment at the Heathrow LHR2 site and five sites around the airport. These are assessed in detail in the main report. Measurements at several of these sites indicate some current exceedences of the Air Quality Strategy annual objective for NO_2 of 40 $\mu g/m^3$ (21 ppb). No sites record exceedences of the 1 hour objective for NO_2 of 200 $\mu g/m^3$ (105 ppb).

A5.27 As current monitoring indicates the potential for exceedences of the objectives, and the available modelling has considerable uncertainties, it was concluded that the work of the air quality Panels should include assessment of NO_2 and NO_X.

Particles (PM_{10})

A5.28 Particles measured as PM_{10} are emitted by combustion sources including aircraft, auxiliary power units and ground support vehicles airside at airports and from heating plant and road traffic landside and in areas surrounding airports (Dore et al. 2005).

A5.29 Modelling at airports frequently includes assessment of PM_{10}, due to the importance of this pollutant for human health and because airports are perceived to be significant sources for particles. However, emissions of PM_{10} from aircraft are currently not well characterised. The ICAO emissions databank provides emissions data for difference aircraft in terms of smoke number but not PM_{10}. Modelling PM_{10} requires the use of methodologies to estimate aircraft PM_{10} emissions from the smoke number (see Report BAA/817 submitted to the Terminal 5, Heathrow Public Inquiry (Underwood et al. 1996)). The uncertainties associated with modelling PM_{10} are consequently greater than for some other pollutants such as carbon monoxide or NO_2.

A5.30 PM_{10} has been modelled at Heathrow to assess the implications for air quality of the Terminal 5 development (Underwood et al. 1996). This indicated that for the base year (1993) 49% of PM_{10} concentrations could be associated with aircraft increasing to 66% in 2016 for the case with construction of Terminal 5. Levels of PM_{10} were predicted to fall during the period 1993-2016 despite an increase in airport related PM_{10} emissions due to reductions in road traffic emissions over the period. The predicted annual mean concentration in 1993 for the LHR2 monitoring site was 21$\mu g/m^3$ which was in good agreement with measured data and well below the PM_{10} objective and limit value of 40 $\mu g/m^3$. Predicted concentrations at 7 sites around the airport perimeter varied between a maximum of 21.3 $\mu g/m^3$ for the 1993 base case to a minimum of 16.3 $\mu g/m^3$ for concentrations in 2016 with Terminal 5 (the modelling of PM_{10} has advanced considerably since this modelling).

A5.31 Measurements of PM_{10} are carried out at the Heathrow LHR2 site and several sites around the airport. These are assessed in detail in the main report. Concentrations of PM_{10} occasionally exceed the 24-hour objective level. In 2003 the 24-hour PM_{10} objective and limit value of 50 $\mu g/m^3$, not to be exceeded on more than 35 occasions, was exceeded on 39 occasions at LHR2 (Lampert et al. 2004) approximately 10% of the year.

A5.32 As current monitoring indicates the potential for exceedences of the objectives, and the available modelling has considerable uncertainties the work of the air quality Panels should include assessment of PM_{10}.

Particles ($PM_{2.5}$)

A5.33 There is now growing evidence that the finer particles are more significant in health terms. In response to this evidence, the European Commission has just (September 2005) issued a Thematic Strategy, which proposes to retain the existing PM_{10} limit values but supplementing them with a $PM_{2.5}$ cap of 25 $\mu g/m^3$ and an exposure-reduction target of 20% over the period 2010 and 2020. The exposure-reduction target applies to the average concentrations measured at urban background sites across a Member State.

A5.34 Little monitoring of $PM_{2.5}$ has been carried out in the UK, although as a general rule, concentrations may be taken to be around 60-70% of PM_{10} values. There has been some monitoring around the airport instituted as part of the Terminal 5 construction programme and data from these sites are provided in the main report.

A5.35 Given the current interest in $PM_{2.5}$ it was decided that information on measured concentrations should be collated, but that it was not appropriate at this point in time to attempt to model $PM_{2.5}$.

Sulphur Dioxide

A5.36 Emissions of sulphur dioxide from both aircraft engines and road vehicles are directly related to the sulphur content of the fuel. Aviation fuel is extremely low in sulphur and it is unlikely that aircraft will contribute to significant emissions of SO_2 at airports. The diesel now used by most road traffic is also low sulphur, however, other fuels used at airports, such as fuel oil in boiler plant and diesel for ground support vehicles, have higher sulphur contents.

A5.37 Few modelling studies at airports include assessment of SO_2 concentrations, due to the perceived limited emissions from aircraft and road transport. The limited modelling of SO_2 that has been carried out at Heathrow, has indicated that predicted concentrations of SO_2 at sites around the airport are below the Air Quality Strategy objectives.

A5.38 Sulphur dioxide is only measured at one site in the Heathrow area. The Hillingdon AURN site is close to the M4 motorway and to a limited extent will also be influenced by Heathrow emissions. There were no reported exceedences of any of the air quality objectives for SO_2 in 2003 (Lampert et al. 2004).

A5.39 Current modelling and monitoring suggest that concentrations of SO_2 at Heathrow are below current objectives. Fuel sulphur contents are not likely to increase and for some fuels, such as airside diesel may decrease. SO_2 concentrations at airports are therefore unlikely to increase in the future and SO_2 is not considered to be a priority area for the air quality Panels.

Ozone

A5.40 Ozone is a secondary pollutant, created in the atmosphere as a result of photochemical reactions involving hydrocarbons and nitrogen oxides (precursor pollutants). The immediate reaction close to sources of nitrogen oxides is for nitric oxide to react with the ozone to create nitrogen dixoide, and thus ozone concentrations are depressed close to fresh sources of emissions. On hot sunny summer days ozone can build up over several hours, as polluted air masses drift away from the emission sources and the ozone formation reactions take place. As a consequence the highest concentrations are usually found in rural areas several tens of kilometres downwind of the precursor emission. Ozone concentrations in south-east England are determined by emissions over a large area, including continental Europe. Modelling the impacts of these emissions is not straight forward. Furthermore, studies of the impact of urban emissions on downwind concentrations, suggest that changes in emissions from a small area such as Heathrow would not be expected to have a large impact on downwind concentrations.

A5.41 As noted above, the immediate effect of fresh emissions of nitrogen oxides it to cause nitric oxide to react with ozone, creating nitrogen dioxide. During the daytime there is also a back reaction whereby sunlight destroys nitrogen dioxide and recreates ozone and nitric oxide. There is thus a balance between nitrogen dioxide, nitric oxide and ozone, which varies with time of day and time of year, as well as varying from day to day. Nitrogen dioxide concentrations are thus linked to the amount of ozone in the atmosphere.

A5.42 Given the importance of ozone in the formation of nitrogen dioxide, it was decided that it would be appropriate to collate monitoring data for ozone within the study area. However, it is not considered a priority area to model the impact of Heathrow emissions on ozone concentrations.

Table A5.1 European Union Limit Values and Targets

Pollutant	Value	Measured as	To be achieved by
Benzene	5 $\mu g/m^3$	Annual Mean	1 January 2010
Carbon monoxide	10.0 mg/m^3	Maximum Daily 8-Hour Mean updated Hourly	1 January 2005
Lead	0.5 $\mu g/m^3$	Annual Mean	1 January 2005
Nitrogen Dioxide	200 $\mu g/m^3$ Not to be exceeded more than 18 times per year	1-Hour Mean	1 January 2010
	40 $\mu g/m^3$	Annual Mean	1 January 2010

Pollutant	Value	Measured as	To be achieved by
Nitrogen Oxides	(V) 30 µg/m^3	Annual Mean	19 July 2001
Ozone (Target)	120 µg/m^3 Not to be exceeded more than 25 times per year	Maximum Daily Running 8 hour Mean updated Hourly	1 January 2010
Particles (PM_{10}) (gravimetric)[a]	50 µg/m^3 Not to be exceeded more than 35 times per year	24-Hour Mean	1 January 2005
	40 µg/m^3	Annual Mean	1 January 2005
Sulphur dioxide	350 µg/m^3 Not to be exceeded more than 24 times per year	1-Hour Mean	1 January 2005
	125 µg/m^3 Not to be exceeded more than 3 times per year	24-Hour Mean	1 January 2005
	(V) 20 µg/m^3	Annual Mean	19 July 2001

(V) = applies to ecosystems. All other limit values apply to human health.

a Measured using the European gravimetric transfer sampler or equivalent.

Table A5.2 UK Objectives that Apply in England and Greater London

Pollutant	Objective	Measured as	To be achieved by
Benzene	16.25 µg/m^3	Running Annual Mean	31 December 2003
	5 µg/m^3	Annual Mean	31 December 2010
1,3-Butadiene	2.25 µg/m^3	Running Annual Mean	31 December 2003
PAHs (Benz-a-pyrene)	0.25 ng/m^3	Annual Mean	31 December 2010
Carbon monoxide	10.0 mg/m^3	Maximum daily running 8 Hour Mean	31 December 2003

Appendix AQ.1.8

Pollutant	Objective	Measured as	To be achieved by
Lead	0.5 µg/m^3	Annual Mean	31 December 2004
	0.25 µg/m^3	Annual Mean	31 December 2008
Nitrogen Dioxide[a]	200 µg/m^3 Not to be exceeded more than 18 times per year	1 Hour Mean	31 December 2005
	40 µg/m^3	Annual Mean	31 December 2005
Nitrogen Oxides	(V) 30 µg/m^3	Annual Mean	31 December 2000
Ozone	100 µg/m^3 Not to be exceeded more than 10 times per year	Daily maximum of running 8 hr mean	31 December 2005
Particles (PM_{10}) (gravimetric)[b]	50 µg/m^3 Not to be exceeded more than 35 times per year	24 Hour Mean	31 December 2004
	40 µg/m^3	Annual Mean	31 December 2004
Sulphur dioxide	266 µg/m^3 Not to be exceeded more than 35 times per year	15 Minute Mean	31 December 2005
	350 µg/m^3 Not to be exceeded more than 24 times per year	1 Hour Mean	31 December 2004
	125 µg/m^3 Not to be exceeded more than 3 times per year	24 Hour Mean	31 December 2004
	(V) 20 µg/m^3	Annual Mean	31 December 2000
	(V) 20 µg/m^3	Winter Mean (01 October - 31 March)	31 December 2000

a The objectives for nitrogen dioxide are provisional.

b Measured using the European gravimetric transfer sampler or equivalent.

µg/m^3 - micrograms per cubic metre

mg/m^3 - milligrams per cubic metre

(V) These objectives are adopted for the protection of vegetation and ecosystems. All of the remainder are for the protection of human health.

Table A5.3 UK provisional objectives for PM_{10} that apply in England and Greater London

Region	Objective	Measured as	To be achieved by
Greater London	50 µg/m^3 not to be exceeded more than 10 times per year	24-hour Mean	31 December 2010
Greater London	23 µg/m^3	Annual Mean	31 December 2010
Greater London	20 µg/m^3	Annual Mean	31 December 2015
Rest of England, Wales and Northern Ireland	50 µg/m^3 not to be exceeded more than 7 times per year	24-hour Mean	31 December 2010
Rest of England, Wales and Northern Ireland	20 µg/m^3	Annual Mean	31 December 2010

Annex 6
Investigation into the sources of air pollution

A data mining investigation into the sources of air pollution in the vicinity of Heathrow Airport

A Report to the Department for Transport

Final Report

David Carslaw

Institute for Transport Studies, University of Leeds

February 2006

Key points

DETECTION OF AIRCRAFT EMISSIONS

A6.1 A method has been developed based on approaches published in scientific literature to identify the aircraft contribution to NO_X and NO_2 concentrations measured in the vicinity of Heathrow Airport. This method has been further developed and refined for use at Heathrow. It is based on bivariate pollution rose plots that provide an effective graphical analysis of different emissions source types.

A6.2 The runway alternation pattern of aircraft activity at Heathrow provides a powerful means of distinguishing between aircraft sources of NO_X and other sources of NO_X (principally from road traffic sources).

A6.3 Aircraft contributions can be unambiguously detected to a distance of at least 2.8 km from a runway.

A6.4 Tests have been carried out to explore the importance of the choice of background site, used to subtract concentrations in the bivariate pollution rose plots. It is shown that the distribution of concentrations remains very similar in each case for any reasonable choice of background site. These results add weight to the conclusion that specific sources can be detected using these techniques and that the concentration patterns derived are not artefacts introduced during the background subtraction process.

A6.5 Aircraft emissions vary little by day of the week unlike road traffic emissions. This behaviour acts as another means of detecting aircraft emissions. On this basis, five out of seven monitoring sites close to Heathrow show an aircraft signal. The contribution detected at Slough Colnbrook and Main Road nurseries show a greater difference between weekdays and weekends, which indicates contributions from sources other than aircraft at these sites.

DISPERSION CHARACTERISTICS

A6.6 A distinctive feature of the dispersion of aircraft emissions (for aircraft on the ground) is that concentrations of NO_X increase with wind speed, or at least remain approximately constant. This feature contrasts with other ground-level emissions that tend to decrease with wind speed. This feature of the dispersion of aircraft emissions has characteristics of a buoyant plume.

A6.7 By considering the diurnal profile of NO_X by runway alternation at LHR2 and Harlington (LHR18), it is estimated that the aircraft contribution to NO_X concentrations decrease by a factor of approximately 10 between these two sites.

AIRPORT CONTRIBUTION TO NO_X CONCENTRATIONS

A6.8 Based on the bivariate pollution rose plot analyses it has been possible to estimate an upper limit of NO_X concentration due to the airport at different sites. At LHR2 it is estimated that about 32.8 $\mu g\ m^{-3}$ (28 % of the measured NO_X) is due to the airport. At Harlington and Hounslow 2 (LHR5) it is estimated that between 5.7-9.9 $\mu g\ m^{-3}$ (7-14 % of the measured NO_X) is due to airport sources. However, it is likely that the lower limits will be closer to the actual contributions at these sites due to the contribution of other sources between the airport and the measurement site. Sites to the south and east have a much lower contribution from the airport.

A6.9 Sites to the north-east of airport sources are likely to have a larger contribution from aircraft sources for two reasons. First, these locations are downwind of the prevailing wind direction. Second, these locations have a higher proportion of higher wind speeds than other directions. The latter point is important because of the larger contribution that aircraft make in high wind speed conditions compared with other sources such as roads.

NO_X–NO_2 CHEMISTRY

A6.10 The pattern of runway alternation allows an assessment of the amount of NO converted to NO_2 at different sites for different modes of runway operation. At LHR2 the difference in NO_X between northern and southern runway take-off is 60 $\mu g\ m^{-3}$, whereas the difference in NO_2 is 15 $\mu g\ m^{-3}$ (a ratio of 25 %).

A6.11 At Harlington, the NO_X and NO_2 difference is 4.7 and 2.3 $\mu g\ m^{-3}$, respectively; a ratio of about 50 %. As well as providing useful information on the contributions to NO_X and NO_2 that result from different runway operations, these results also provide some useful data for testing the chemistry routines/relationships within the different models.

PM_{10} EMISSIONS AND CONCENTRATIONS

A6.12 Aircraft PM_{10} emissions can be detected. It is calculated that the PM_{10}/NO_X emission ratio is 0.015 (on a mass basis). This ratio is lower than that for road traffic exhaust emissions, which are calculated to be 0.041 based on average vehicles emissions across the LAEI.

A6.13 It has not been possible to distinguish between exhaust emissions and emissions due to tyre wear from landing aircraft. $PM_{2.5}$ measurements could help in making the distinction between the two sources.

A6.14 Using the same methodology as for NO_X at LHR2 yields a contribution of 0.9 $\mu g\ m^{-3}$ due to the airport out of a total of 21.6 $\mu g\ m^{-3}$ (TEOM with no adjustment factor applied). The PM_{10} contribution at LHR2 due to the airport is therefore approximately 4.2 % of the total measured concentration.

A6.15 The wind speed dependence of PM_{10} concentrations is markedly different to that of NO_X at LHR2. These results suggest that there are different processes or sources that control PM_{10} and NO_X concentrations. There is some indication re-suspended PM_{10}, possibly from tyre and brake wear, is an important source.

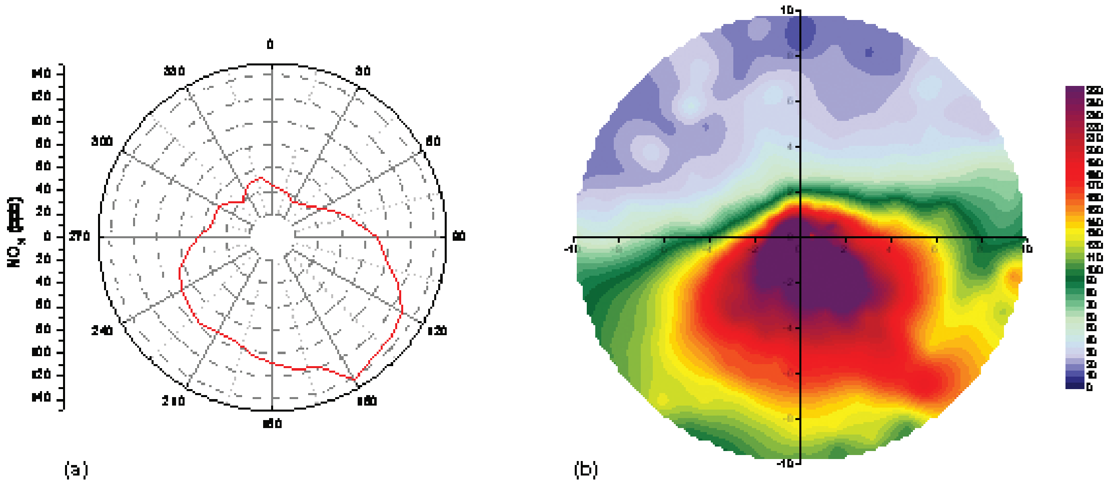
RELATIVE EMISSION RATES FOR AIRCRAFT

A6.16 By filtering ambient NO_X data at LHR2 and using NATS data for the movements of ‘‘medium’’ (e.g. Boeing 737) and ‘‘heavy’’ (e.g. Boeing 747) aircraft, and applying a multiple regression, it is estimated that heavy aircraft emit 3.1 ± 0.7 (at a 95 % confidence interval) times more NO_X than medium aircraft when taking off.

Source identification using bivariate pollution roses

A6.17 Pollution roses can be useful in exploring the influence of different sources of air pollution at a monitoring site. Usually the data are processed into average concentrations by wind direction as shown in Figure A6.1 a for the Hillingdon AURN site. The Hillingdon site is situated approximately 30-40 m north of the carriageway edge of the M4 motorway. The plot shows that the highest NO_X concentrations are observed when the wind is from the south or south-east i.e. blowing from the M4 towards the site. These results are entirely consistent with there being a relatively large source of NO_X to the south of the monitoring site i.e. the M4 motorway.

Figure A6.1 a) Conventional pollutant rose for concentrations of NO_X at the Hillingdon AURN site, b) bivariate pollution rose for the same data, which in addition show the effect of wind speed. Both plots are for data from Jan. 2000-Dec. 2004.



A6.18 The basic pollution rose approach can be developed further to include wind speed, which under many circumstances can provide more comprehensive information concerning the source types. Similar analyses have been carried out to delineate different source contributions to measured pollutant concentrations (e.g. Henry et al., 2002; Yu et al., 2004). Henry et al. (2002) used a nonparametric technique to identify different source types. The technique involved the use of kernel estimators to smooth the relationship between wind direction and pollutant concentration. Additionally they derived the 95^{th} percentile confidence interval by wind direction of the mean concentration. The additional statistics derived using the technique were useful in determining whether a peak in concentration was noise or not, and for providing a means of determining the error in the peak location i.e. the uncertainty in the direction in which a source is detected. The work of Henry et al. (2002) was extended by Yu et al. (2004) to additionally include wind speed and applied to the identification of airport sources of pollution. The addition of wind speed considerably enhanced the usefulness of the technique and allowed for further source differentiation. The technique therefore provided a more robust means of identifying source locations (and type) than could be achieved using simple pollution roses

A6.19 The approach adopted by Yu et al. (2004) has been modified here to develop a simplified screening technique for source apportionment around Heathrow. No attempt has been made to quantify the variance of concentrations by wind direction and wind speed and therefore no information is derived on the statistical robustness of the approach as in Yu et al. (2004). The technique has been simplified to provide a graphical means of determining likely source types and their direction. This has been achieved as follows:

1. Mean concentrations were derived for different wind speed and wind direction categories. For each 10° wind sector, the wind speed was split into ten categories (i.e. 0-1, 1-2 m s^{-1}… etc.) and the mean concentration of the pollutant was calculated. Wind speed/direction categories were ignored if there were less than 5 hourly concentration measurements, such as would be the case for some wind speed/direction combinations e.g. high wind speeds ($>$ 8 m s^{-1}) from an easterly direction. Ignoring sectors with few data points effectively ensured that the signal to noise ratio of the measurements in any one sector was high enough to ensure that the mean concentration was real and not noise. The choice of a minimum of 5 data points was determined by trial and error i.e. 5 or more points appeared to produce consistent results. Hourly meteorological data from the Met Office London Heathrow site were used throughout.

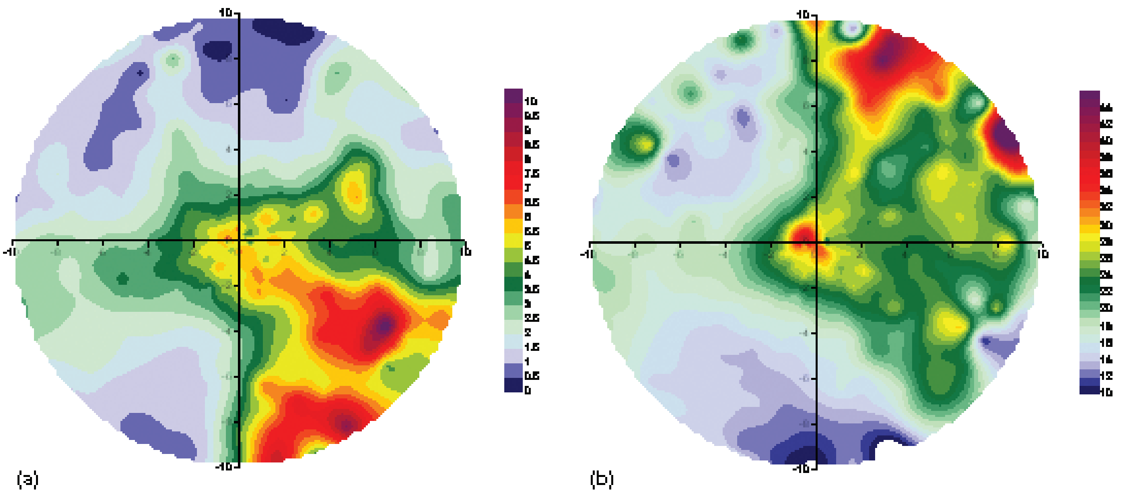
2. The data were then interpolated using a kriging technique (using Surfer 8.0 software) to produce a surface concentration map. The kriging technique is able to treat missing data such as those excluded because of a lack of data points. This ensured that the interpolation was carried out only on average concentration data that adequately represented the mean in any wind speed/direction sector.

3. The plots were converted from Cartesian to polar coordinates to produce pollution roses. Henry at al. (2002) did not favor plotting the data in polar coordinates because data are essentially compressed into a small space at low wind speeds, making it difficult to reveal the relationship with wind speed. However, as it will be shown, aircraft sources appear to be detected at higher wind speeds and the effect of this compression is less important. Overall, it was considered more beneficial to the interpretation of these plots if the wind direction was plotted in polar coordinates because the polar coordinate system is intuitively easy to understand for wind direction compared with the Cartesian system. Furthermore, with several air pollution sites available, polar plots can effectively highlight the locations of potential sources by ‘‘pointing’’ to their origin.

A6.20 Figure A6.1b shows the results of using this technique at the Hillingdon AURN site, using the same data as for Figure A6.1a. There are several points that should be noted. First, the highest concentrations are recorded when the wind blows from the south/south-east. This is entirely expected because the M4 is approximately 30 m south of the site. Second, as the wind speed increases from any direction, the concentration of NO_X decreases. This pattern of decrease is what would be expected from a ground level source where the concentration takes the form of a function that is inversely proportional to the wind speed i.e. as the wind speed increases there is more dilution of the plume. The results for the Hillingdon site indicate that concentrations of NO_X are dominated by a single ground-level source. The rate of decrease of a pollutant with wind speed also provides some indication of the proximity of the source to a monitoring site. There is some indication in the plot that another source may be present to the south-east. It should be noted that the concentrations shown in the middle of the plot $\leq 1\ m\ s^{-1}$ (and all subsequent plots shown) should be ignored because of a lack of reliable wind speed data. At more complex sites that are influenced by several different source types, a different and more revealing pattern of concentration emerges.

A6.21 The analysis described above has been applied to the Thurrock AURN background site to the east of London, to highlight how it can be used to identify individual sources of pollutants. The site is situated in an area that has a high amount of industrial activity and is therefore influenced by a complex mixture of sources. Figure A6.2 shows the pollution roses for SO_2 and PM_{10} and highlights a very different concentration distribution in both cases compared with the Hillingdon plot. For SO_2 there are three clear regions where a source has an influence (approximately 60, 120 and 160°). Unlike the Hillingdon plot (Figure A6.1b), the concentration of SO_2 actually *increases* with increasing wind speed. Increases in concentration with wind speed are indicative of a high-level source e.g. a chimney stack, where the plume is brought down to ground-level. At the Thurrock site therefore, it is likely that there are at least three stacks in the vicinity that have an influence on ground-level concentrations of SO_2 e.g. the peak at 120° is almost certainly the power station at Tilbury. It is also interesting to compare the SO_2 plot with that for PM_{10}. Figure A6.2b shows the same type of plot for PM_{10} and highlights sources at 20, 60 and 120°. At 120° the area of high PM_{10} concentration coincides with that for SO_2, which is indicative of a source that emits both PM_{10} and SO_2. The PM_{10} source at 120° is less distinct and might indicate a source that is an important emitter of SO_2 but less important for PM_{10}. Interestingly, the source at 20° is only a source of PM_{10} and not SO_2. The source at 20° also has an increasing PM_{10} concentration with wind speed, which might indicate a high-level source, but equally could be indicative of a wind-blown source where re-suspension becomes important at increasing wind speeds. These plots, together with some knowledge of the local emissions in the vicinity of a monitoring site, have the potential to highlight important individual source types.

Figure A6.2 a) Bivariate wind speed pollution rose for concentrations of SO_2 at Thurrock (ppb), b) for PM_{10}.



Comparison with the ADMS dispersion model

A6.22 The patterns of concentration shown in all the bivariate plots using observed ambient air pollution data can also be derived using a dispersion model. Using a dispersion model acts as a useful check to confirm whether the observed concentration distributions for different source types can be derived using a model that aims to treat the dispersion processes in a deterministic way. In fact, such an approach could potentially act as an effective means of validating a dispersion model. Four source types have been considered using the ADMS 3.1 model (Carruthers et al., 1997): an elevated point source, a road source, a stationary hot jet source and a volume source. The characteristics of these sources are shown in Table A6.3. It should be noted that the actual emission rate assumed in each case is not of interest because it is only the pattern of concentration that is relevant in the present analysis.

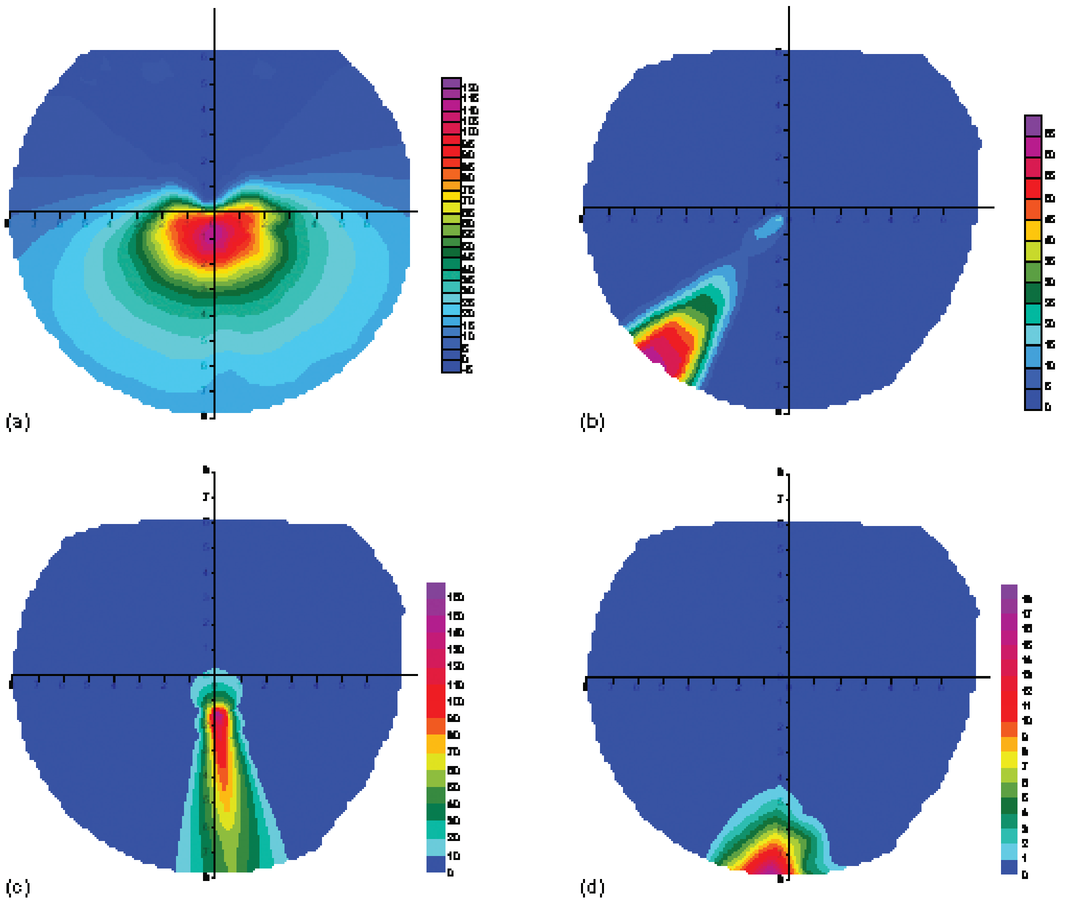
Table A6.3 Characteristics of different source types modelled using the ADMS 3.1 model.

Source description	Receptor details
Road source, infinite length, east-west orientation	100 m north, z = 0 m
Point source, H = 200 m, typical power station emission characteristics	3000 m NE, z = 0 m
Volume source, 80 m deep, centred at H = 40 m	500 m north, z = 0 m
Jet source, 280 °C, v = 375 m s^{-17}, H = 2 m, horizontal emission	500 m north, z = 0 m

H = height of source, v = exit velocity of emission and z = receptor height.

A6.23 The different sources shown in Table A6.3 were modelled using 1 year of hourly sequential meteorological data for 2001 from the Met Office Heathrow Airport site. The input (wind speed and direction) and output (concentration) data were processed to yield bivariate wind speed pollution roses. Figure A6.3 shows the wind speed pollution roses for the different source types. These results clearly demonstrate that very different concentration patterns are derived for different source types. The road source (Figure A6.3a) shows that concentrations are highest for low wind speed conditions and decrease with increasing wind speed. By contrast, the pattern from the chimney stack shows that concentrations increase with increasing wind speed when the wind is from the direction of the stack, as shown in Figure A6.3b. The volume source, despite being centred at a height of 40 m appears to display similar characteristics to the road source i.e. concentrations decrease with increasing wind speed. Finally, the jet source (Figure A6.3d) concentration pattern is very similar to the chimney stack i.e. concentrations increase with increasing wind speed.

Figure A6.3 a) Bivariate pollution rose for a road source, b) chimney stack, c) volume source and d) a jet source. Details of the source and receptor characterises are given in Table A6.3 as predicted by the ADMS 3.1 model.



A6.24 The plots shown in Figure A6.3(a-d) can also usefully be compared with observed data from ‘‘real’’ sources. For example, Figure A6.3a shares many of the similar characteristics to Figure A6.1b, which shows a plot dominated by a road source. In both plots, there is a clear decrease of concentration with wind speed. Figure A6.3b (stack source) also compares well with the SO_2 and PM_{10} plots at the Thurrock site that are known to be influenced by nearby tall stacks. In this case there is a clear increase in concentration with wind speed. The results from the analysis of ambient data and from the dispersion modelling of different source types indicate that the technique could be useful in identifying different sources of pollution, particularly in a complex setting where many different source types affect ambient concentrations.

Meteorological data

A6.25 Problems associated with the Met Office meteorological data collected at Heathrow Airport were identified as part of PSDH. These problems have been reported elsewhere and are not considered as part of the current report. To derive a time series of wind speed and wind direction from 1995 onwards, several data sets were used. For data post September 2002, unadjusted measurements from the Met Office site were used. For the rest of 2002, Met Office-adjusted data were used based on observations at a nearby site (Wisley). For pre-2002 data, data from the BAA LHR2 were used with an adjustment factor of 1.20 applied. A factor of 1.20 was based on an analysis of how coincident data from LHR2 and the Met Office site compared from 2003-2004.

NO_X concentrations

A6.26 Bivariate pollution roses have been calculated for air pollution monitoring sites close to Heathrow for NO_X. These have been calculated for daytime (assumed to be from 6 and to 10 pm) and nighttime (11 pm to 5 am). The daytime hours coincide with aircraft activity, where as at nighttime aircraft activity is minimal. By contrasting these two periods, some indication of the relative importance of aircraft sources can be made. All of these plots have a background concentration removed, as outlined in Table A6.4 below. It should be noted that the choice of background site was made based on highlighting the contribution from the direction of the airport in each case. Note that sites are generally referred to by their names rather than the codes shown in Table A6.4.

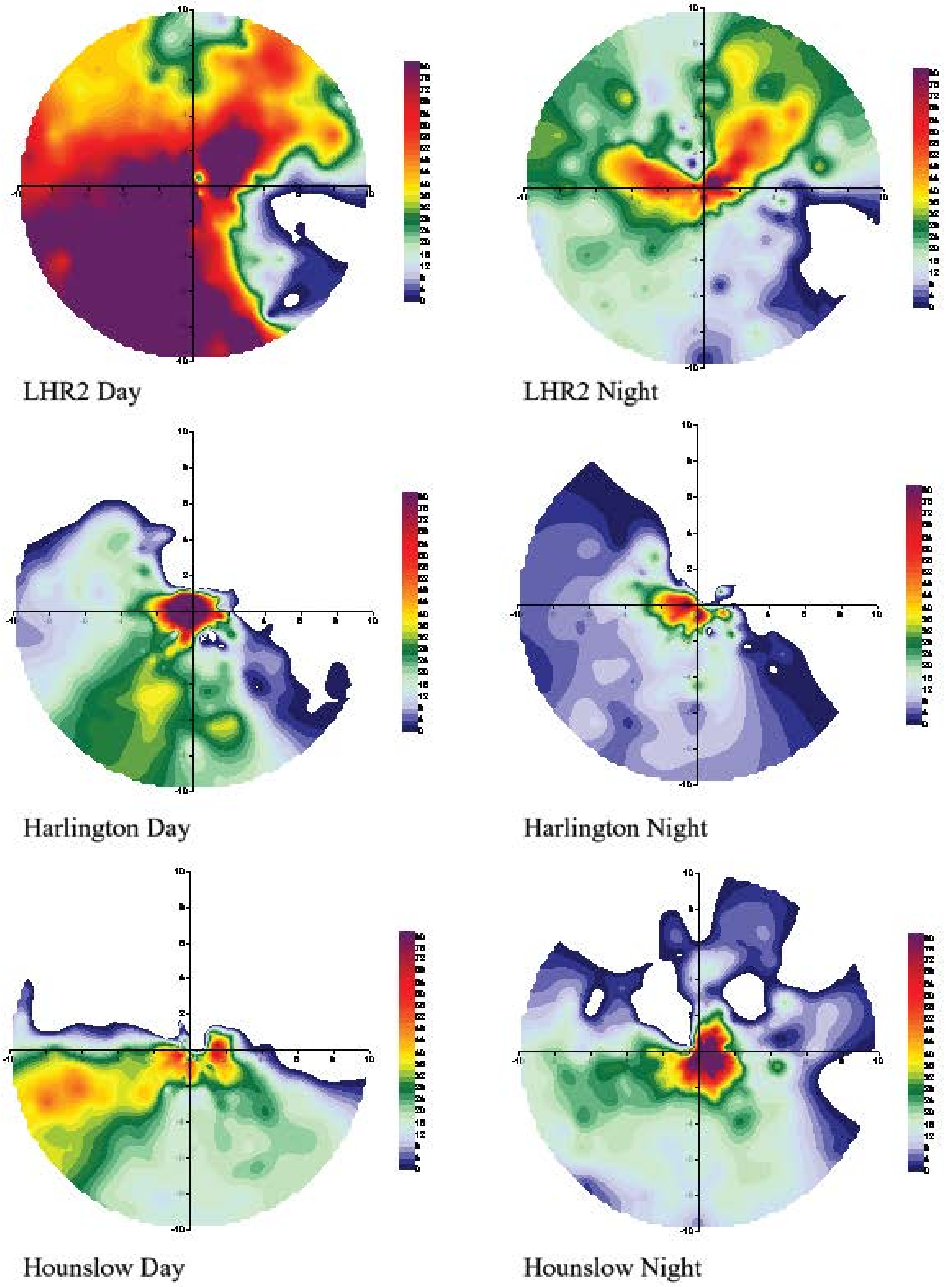
Table A6.4 Sites used for Bivariate pollution rose analysis, showing site used for background removal and period of data used.

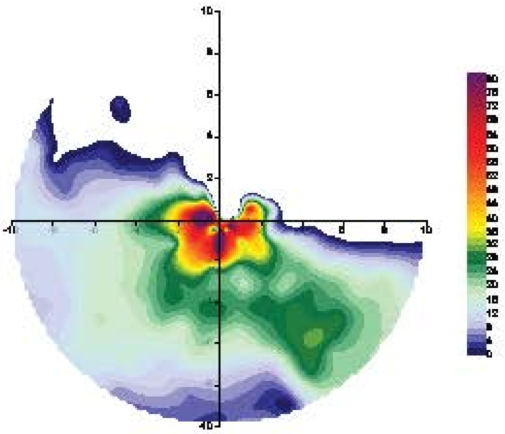
Site	Site code	Background site	Period
LHR2	LHR2	Oaks Road	July 2001-December 2004
Harlington	LHR18	Oaks Road	January 2004-December 2004
Hounslow	LHR5	Oaks Road	July 2001-December 2004
Green Gates	LHR15	Oaks Road	July 2001-December 2004
Main Road	LHR11	Oaks Road	July 2001-December 2004
Slough Colnbrook	LHR14	Hounslow	July 2001-December 2004
Oaks Road	LHR8	Green Gates	July 2001-December 2004
Hillingdon AURN	LHR16	Oaks Road	July 2001-December 2004

A6.27 The daytime plot for LHR2 shows a very clear source of NO_X to the south-west, consistent with the close proximity of aircraft sources. It is also apparent that there is a less significant source of NO_X to the north and in particular the north-east (i.e. the Northern Perimeter Road). At night, the road source and other sources to the north remain important, but the source to the south and south-west virtually disappears. This is consistent with the interpretation of an aircraft source to the south and south-west.

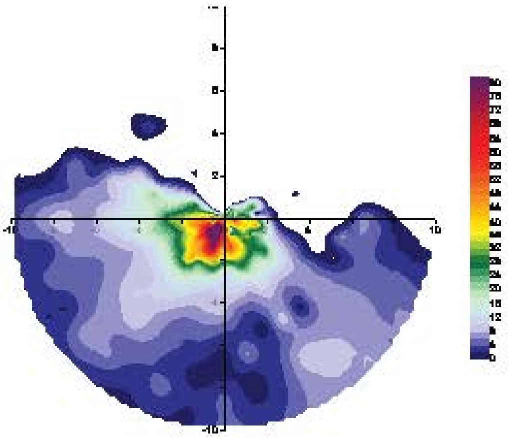
A6.28 The other plots also indicate sources at high wind speeds from the direction of Heathrow Airport. By contrast, the Hillingdon AURN site still shows a significant NO_X source at night, with a decreasing concentration with increasing wind speed.

Figure A6.4 Bivariate wind speed pollution roses for concentrations of NO_X for sites close to Heathrow. The data are split between daytime (left hand side, 6 am – 10 pm) and nighttime (right hand side, 11 pm – 5 am). Appropriate background concentrations have been removed in each case.

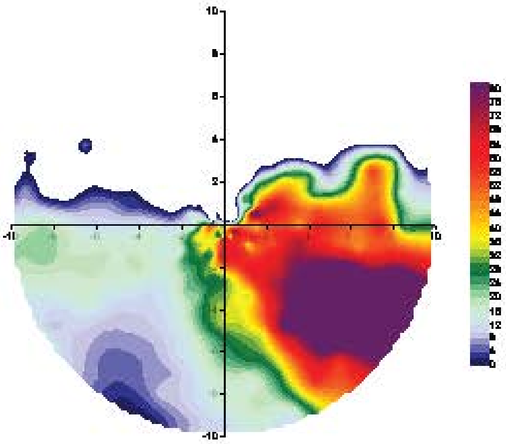




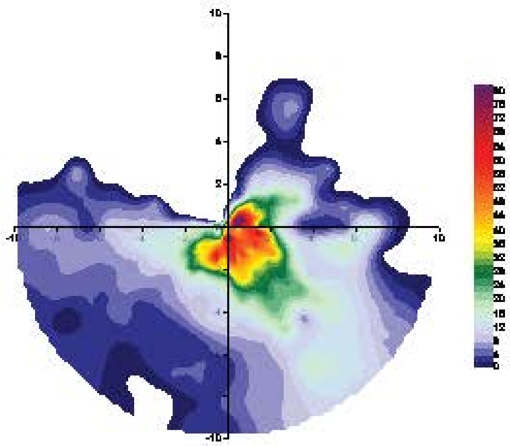
Green Gates Day



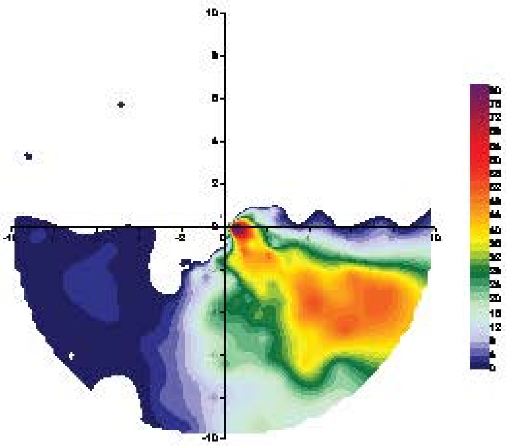
Green Gates Night



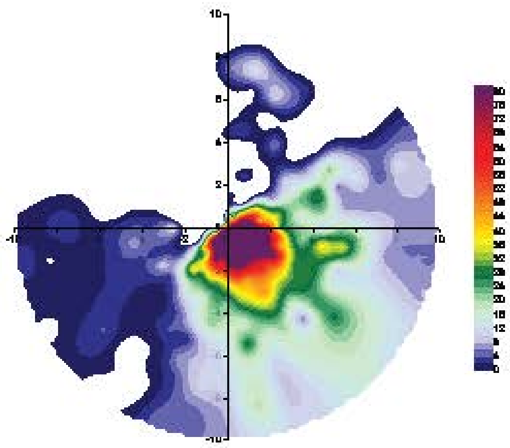
Main Road Day



Main Road Night

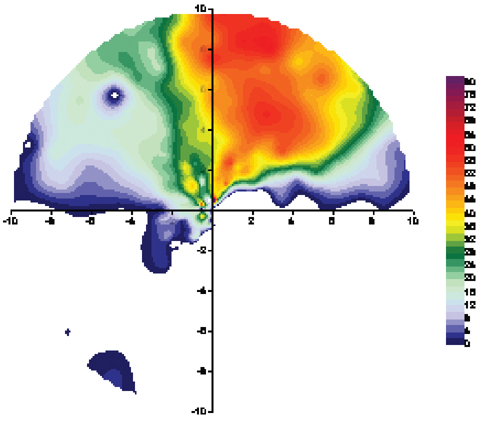


Slough Colnbrook Day

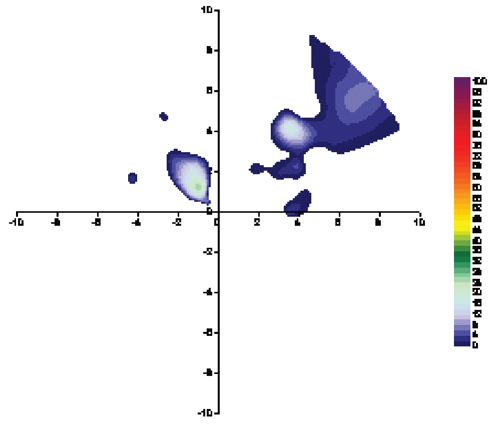


Slough Colnbrook Night

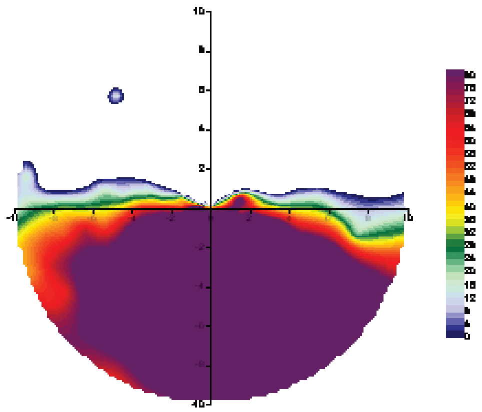
Appendix AQ.1.8



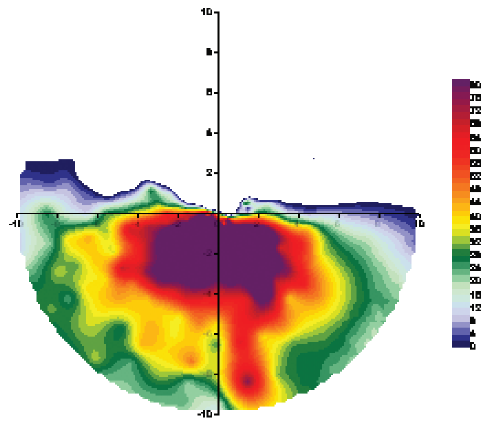
Oaks Road Day



Oaks Road Night



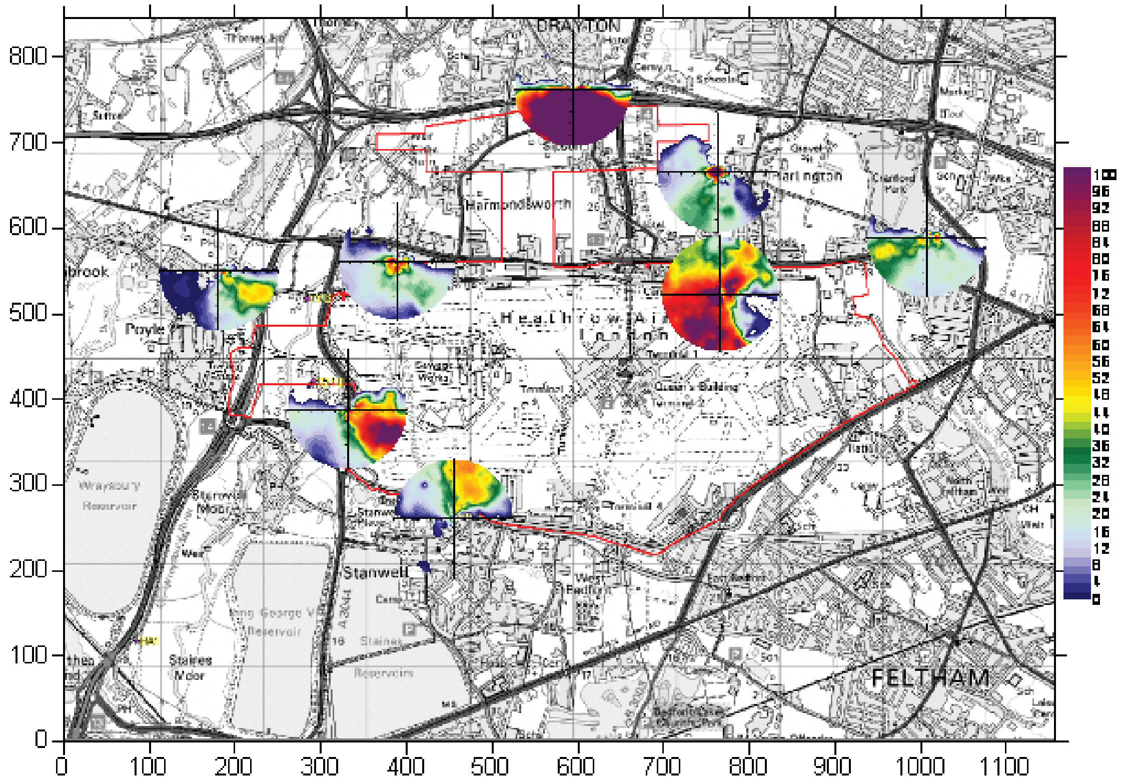
Hillingdon Day



Hillingdon Night

A6.29 These plots are not conclusive proof that aircraft or airport sources have been detected but taken together they do appear to strongly suggest that sources from the direction of Heathrow Airport can be detected. Figure A6.5 shows all the pollution roses in the vicinity of the airport spatially represented.

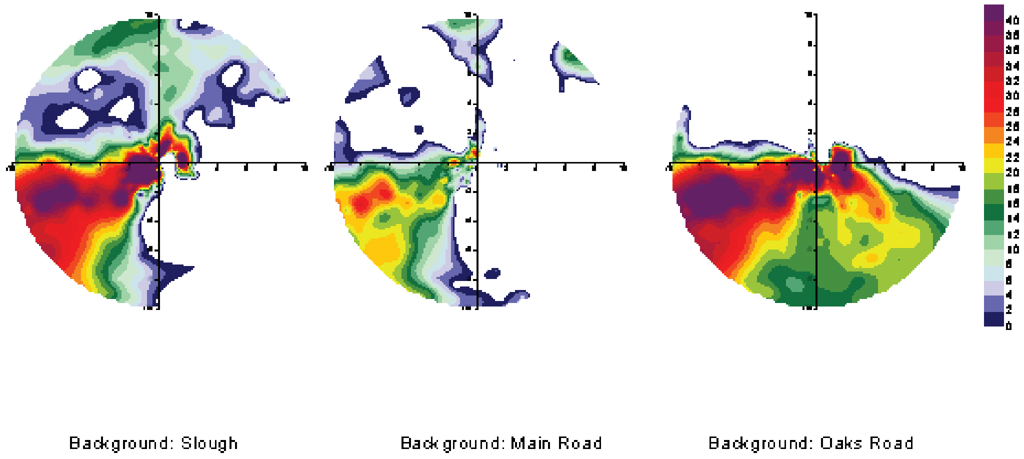
Figure A6.5 Map of wind speed pollution rose plots for NO_X (µg/m³), with background removed for daytime periods.



Effect of choice of background site

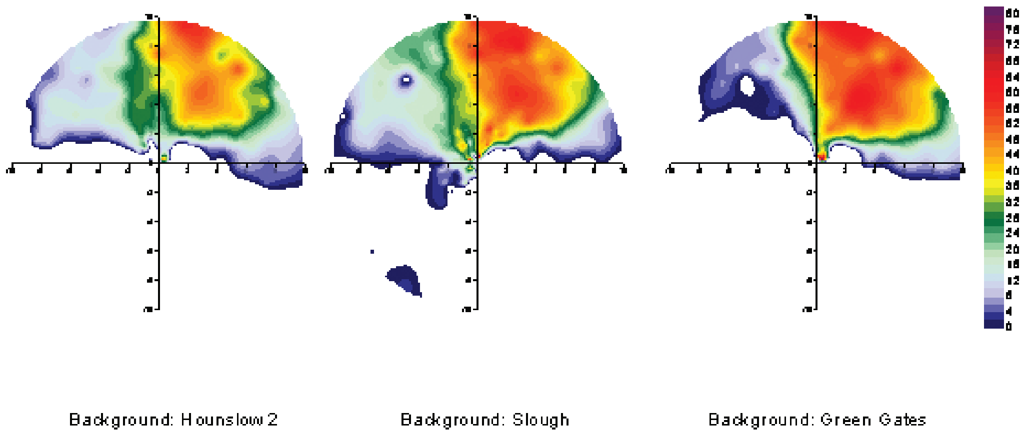
A6.30 The bivariate pollution rose plot analysis will depend on the choice of background site used. It is important to determine to what extent the pattern of concentration distribution at dependent on the choice of background site. Because there are several combinations of site available around Heathrow, it is possible to calculate bivariate pollution rose plots for several different combinations of background site.

Figure A6.6 Effect of choice of background site at Hounslow on NO_X concentrations ($\mu g\ m^{-3}$).



A6.31 Figure A6.6 shows the effect of the choice of background site at Hounslow 2. The Figure shows that the pattern of NO_X is essentially the same i.e. prominent source from the south-west. The absolute concentration does however, vary in each case. Using the Oaks Road or Slough Colnbrook sites result in a very similar concentration of NO_X. However, it appears that using Main Road for background subtraction results in a lower concentrations. This is probably due to the proximity of the M25 to the Main Road site.

Figure A6.7 Effect of choice of background site at Oaks Road on NO_X concentrations ($\mu g\ m^{-3}$).



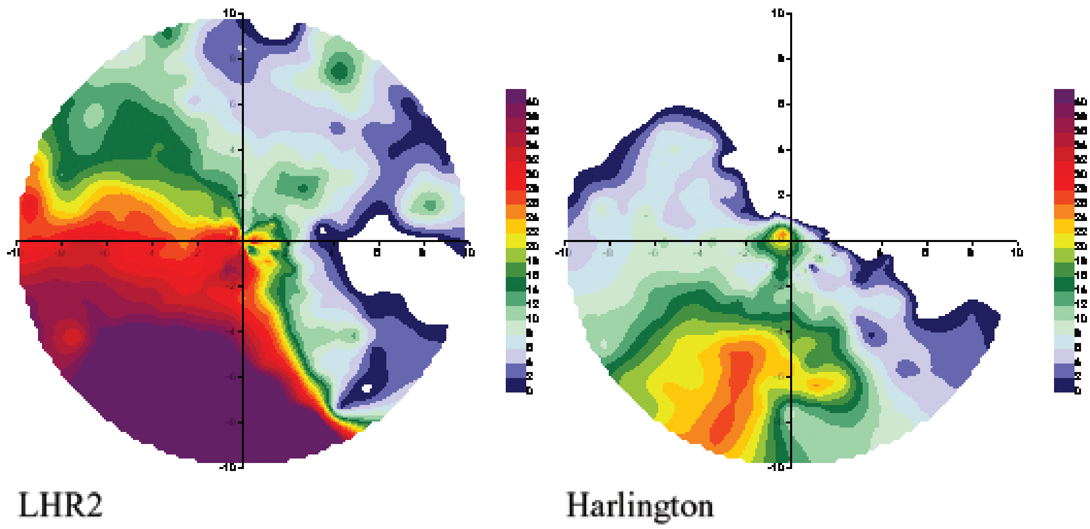
A6.32 Similar results were obtained for Oaks Road, where three different choices of background site were considered, as shown in Figure A6.7. Taken together, these results suggest that the overall pattern of concentration i.e. direction of source(s) with respect to a monitoring site is not very sensitive to the choice of background site. This finding adds strength to the conclusion that a robust method has been developed for the identification of different source types. The choice of background site remains important however, because there is some variation in the absolute magnitude of the NO_X signal detected. Based on these results, the choice of Main Road as a background site would probably lead to an underestimate of the source strength because of the likely influence of the M25.

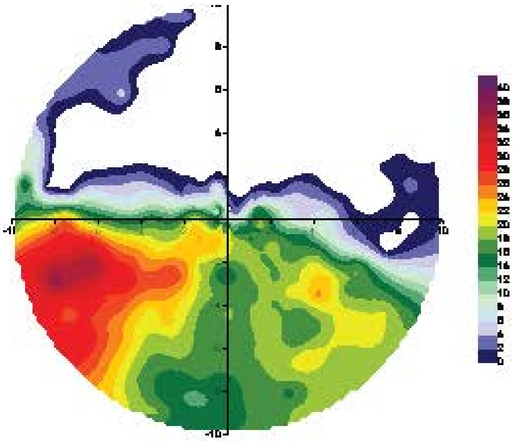
NO_2 concentrations

A6.33 Concentrations of NO_2 have also been calculated using the bivariate pollution rose technique, shown in Figure A6.8. These plots were calculated for daytime periods only. These plots tend to show a clearer pattern of concentration compared with the NO_X plots, but are also consistent in terms of the directions which are most important. One explanation for the increased clarity could be that the Heathrow sources of NO_X are generally a reasonable distance away from the measurement sites (a few hundred metres to several km). Over these distances there would generally be enough time for NO to be converted to NO_2 and these sources appear more characteristic of ''background'' sources. The effect of plotting NO_2 rather than NO_X would therefore diminish the importance of very local sources such as roads, but enhance the signature of more distant sources.

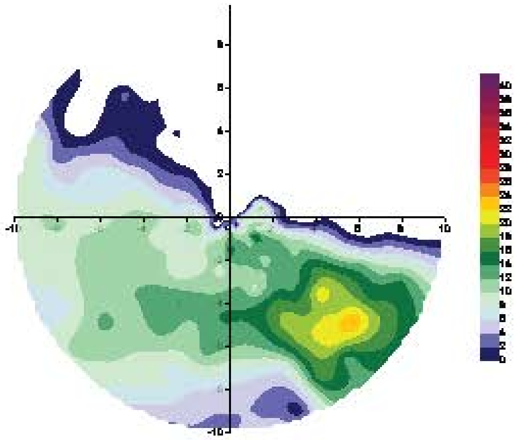
A6.34 The Green Gates plot does not show a very clear aircraft signal, despite its proximity to the runway. This is probably because an aircraft signal is only detected during easterly operation, when aircraft only land on the northern runway (09L). The more significant signal seen at Slough Colnbrook might be because other sources have been detected, as indicated earlier.

Figure A6.8 Bivariate wind speed pollution roses for concentrations of NO_2 for sites close to Heathrow. The data are for daytime periods (6 am – 10 pm) and have appropriate background concentrations removed.

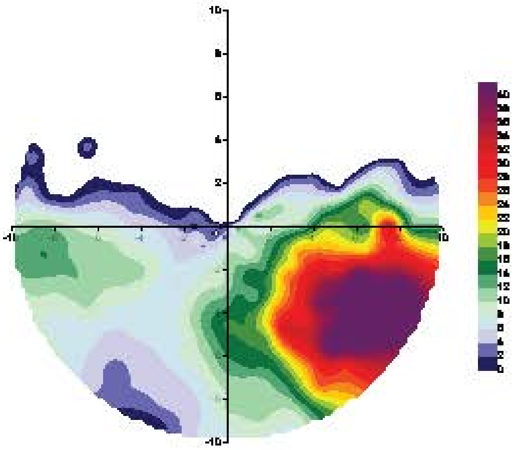




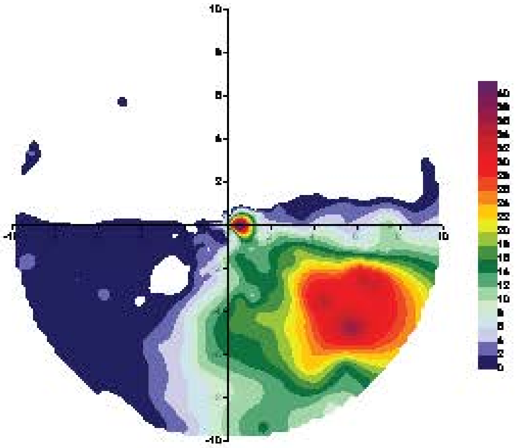
Hounslow



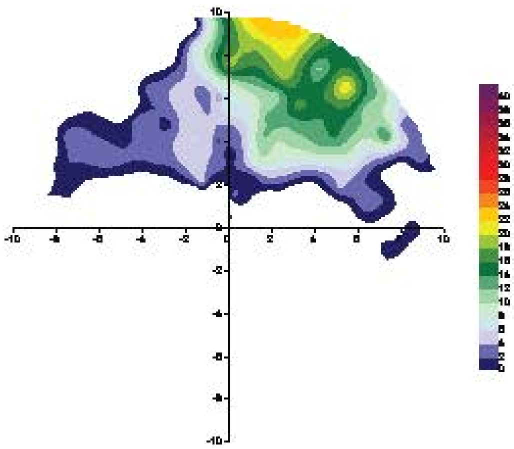
Green Gates



Main Road



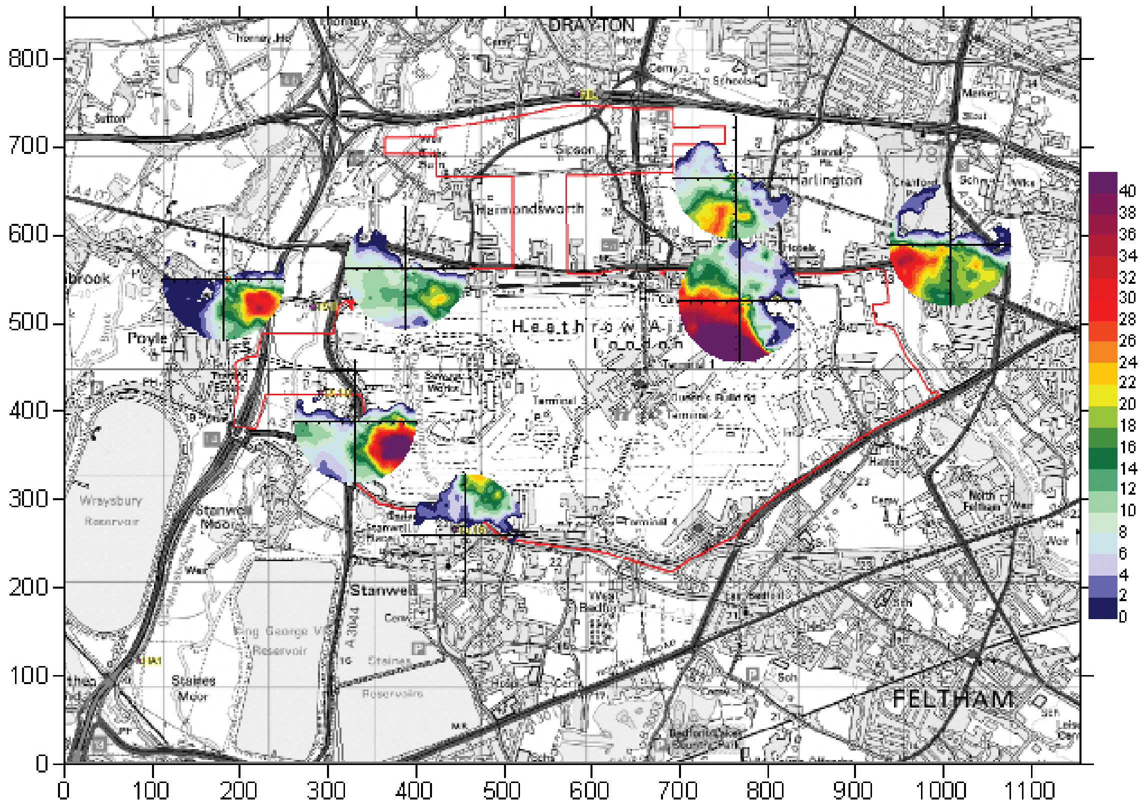
Slough Colnbrook



Oaks Road

A6.35 Figure A6.9 shows all the NO_2 pollution roses plotted spatially. This plot similarly suggests that sources from the direction of the airport can be detected.

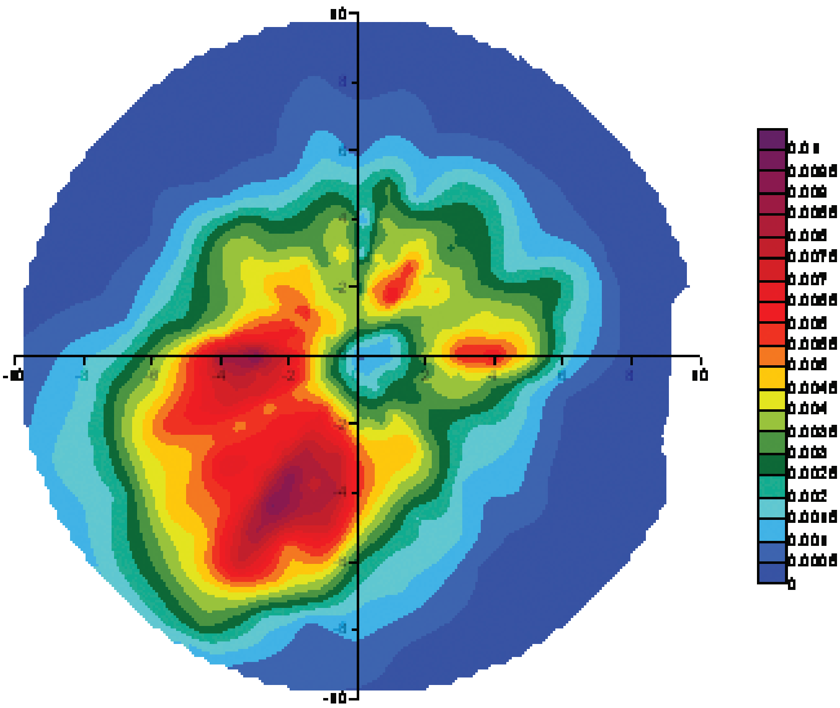
Figure A6.9 Map of wind speed pollution rose plots for NO_2 (µg/m^3), with background removed, for daytime periods



Estimating the airport contribution to measured NO_X and PM_{10} concentrations

A6.36 The bivariate pollution roses described above can be used to estimate an upper limit of airport sources to measured NO_X concentration at different monitoring sites. The contribution made by airport sources is determined by the frequency with which the wind is blowing from the airport to a particular monitoring site, minus a background contribution. Figure A6.10 shows a wind speed/direction joint probability plot, which has been derived by considering the number of hours over a period of time where the wind speed and wind direction are between different intervals, divided by the total number of hours. The Figure clearly shows the predominance of south-westerly winds measured at Heathrow. Another important feature of Figure A6.10 is the directions that have a high probability of higher wind speed conditions, because these appear to be important for detecting aircraft plumes. On this basis there is a higher chance of higher wind speeds from a south-westerly direction than other directions. These results suggest that for the dispersion of aircraft plumes the areas to the north-east of airport will register the largest contribution from aircraft; not only because of the prevailing wind direction, but also the higher fraction of higher wind speed conditions.

Figure A6.10 Wind speed/direction probability plot based on data from July 2001-December 2004.



A6.37 The data in Figure A6.10 can be multiplied with the bivariate wind speed pollution roses for NO_X that have background concentrations subtracted. Together with a selection of wind directions where the airport is likely to contribute to measured concentrations, an upper limit to the contribution to overall measured concentrations can be made. The estimate is an upper limit because in most cases there are other sources (mostly roads) between the airport and the measuring station. The exception is LHR2, where this method should provide a reasonably robust estimate of the airport contribution. For other sites, a range has been estimated based on selecting hours $> 3\ m\ s^{-1}$. The choice of $3\ m\ s^{-1}$ is based on a visual inspection of the bivariate pollution rose plots, where the effect of other road sources will be diminished, whereas the aircraft contribution would not be affected greatly. Clearly, this is an approximation, but it is likely that at many sites the lower limit will be closer to the actual contribution than the upper limit.

A6.38 The results of these calculations are shown in Table A6.5. For LHR2 it is estimated that the airport contributes around 32.8 $\mu g\ m^{-3}$ of the total measured NO_X (28.0 %). The sites to the east and south of the airport generally have a small contribution from the airport. The contributions made by the airport at Hounslow 2 and Harlington are similar (5.7-9.9 $\mu g\ m^{-3}$).

Table A6.5 Estimated airport contribution to measured NO_X concentrations.

Location	Measured NO_X (µg m^{-3})	Upper limit for airport contribution (µg m^{-3})	Upper limit for airport contribution (%)	Range (µg m^{-3})*	Direction range (degrees)
LHR2	116.6	31.5	28.0	21.5-**32.8**	150-260
Harlington	70.9	9.9	14.0	**5.7**-9.9	160-260
Hounslow 2	79.1	9.5	12.0	**5.7**-9.5	200-260
Green Gates	75.0	3.0	4.0	**1.1**-3.0	100-170
Main Road	81.0	7.1	8.8	**3.3**-7.1	100-170
Slough Colnbrook	68.8	1.8	2.6	**1.7**-1.8	100-170
Oaks Road	66.5	5.9	8.9	**2.2**-5.9	350-80

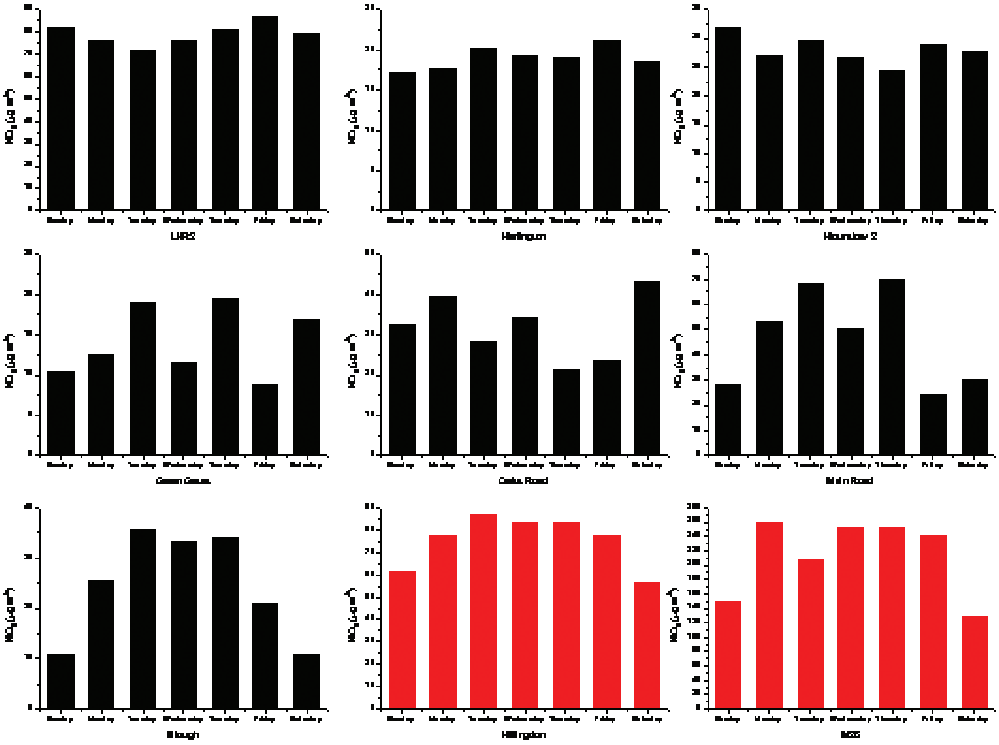
*Numbers in bold are estimated to be the closest to the actual contribution.

A6.39 Using the same methodology as above for PM_{10} (unadjusted data) at LHR2 yields a contribution of 0.9 µg m^{-3} due to the airport out of a total of 21.6 µg m^{-3} (TEOM with no adjustment factor applied). The PM_{10} contribution at LHR2 due to the airport is therefore approximately 4.2 % of the total measured concentration.

Day of week analysis

A6.40 A further check on whether aircraft plume are detected at nearby monitoring sites is to consider the day of the week variation in NO_X concentrations. Aircraft movements and emissions vary very little by day of the week. By contrast, road vehicle emissions are lower at weekends compared with weekdays. Figure A6.11 shows the day of the week variation at nine monitoring sites. The sites strongly influenced by road traffic emissions (Hillingdon and the M25, shown in red) show lower NO_X concentrations on Saturdays and Sundays, reflecting road traffic activity. The LHR2, Harlington, Green Gates and Oaks Rd sites show a relatively stable NO_X concentration by day of the week, suggesting a strong influence of aircraft sources. The Green Gates and Oaks Rd sites show more variation by day of the week because there are relatively few hours left after data filtering. The Main Rd and Slough Colnbrook sites appear to show more influence of road traffic sources. It is not certain therefore that the pollution roses shown for these two sites actually show a strong aircraft signal. However, it is also difficult to explain such high NO_X concentrations at high (6-10 m s^{-1}) wind speeds. Overall, the sites to the north, east and south of the airport show the strongest indication of aircraft sources, while those to the west show the least.

Figure A6.11 Day of the week variation in filtered NO_X concentrations at monitoring sites close to Heathrow Airport. Data were filtered by wind direction and had background concentrations subtracted as shown in Table A6.5. Wind speeds of > 4 m s^{-1} were also used.

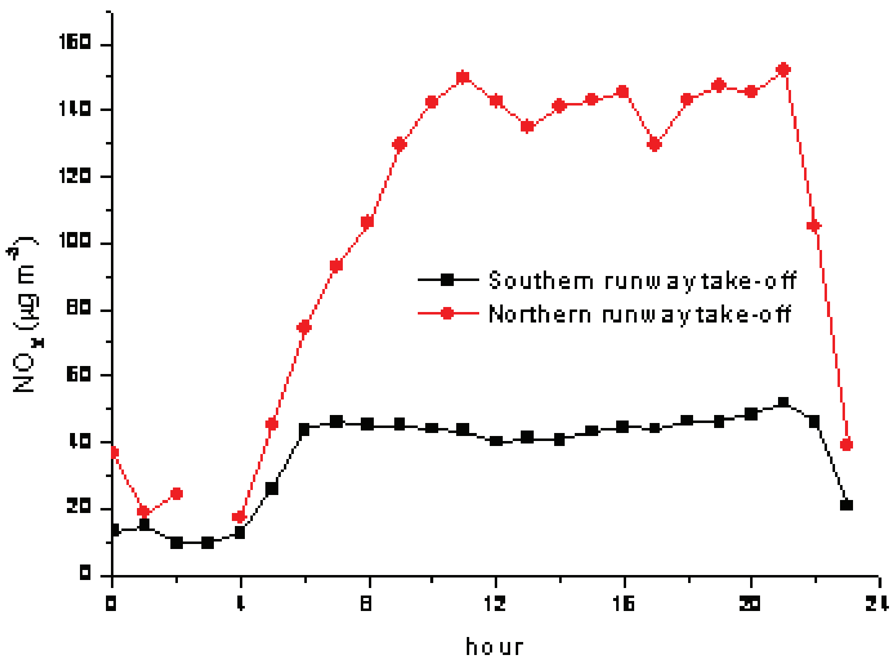


Runway operation analysis

A6.41 The hourly NATS data have been used to filter out conditions where aircraft take-off on either the northern and southern runways. The runway alternation pattern of aircraft activity is a distinctive feature of aircraft operation that provides an effective and robust way to identify aircraft sources.

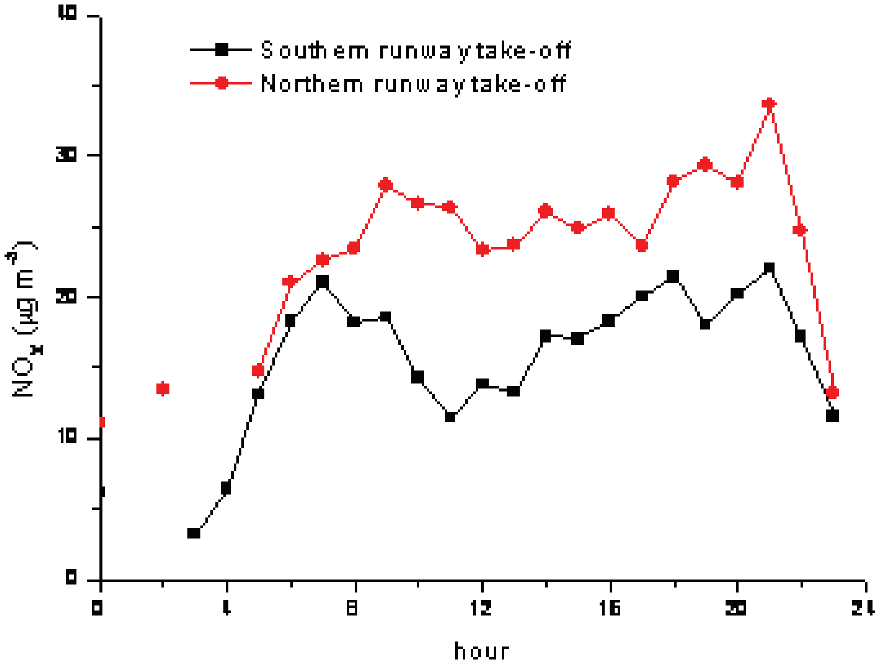
A6.42 Figure A6.12 shows the diurnal pattern of NO_X measured at LHR2 when the data are filtered by wind speed and direction. The filtering was undertaken by choosing wind speeds > 6 m s^{-1} (i.e. when ground level source effects are diminished and aircraft source are enhanced) and wind direction in a sector encompassing the airport only. Under these conditions, the contribution from aircraft sources should be clear. The Figure shows that there is a considerable difference in the NO_X concentration depending on whether aircraft are taking off on the northern or southern runways. Note that aircraft take off and land on the northern and southern runways during westerly operation, but only take off from the southern runway (and land on the northern runway) during easterly operation. This provides clear evidence of an aircraft contribution at this location. Several other features can also be noted. The diurnal pattern of measured NO_X concentration for aircraft taking off on the northern runway is very similar to the calculated emissions profile for aircraft. A distinctive feature of the plot is that concentrations remain high until 10 pm and then decline sharply.

Figure A6.12 Filtered NO_X concentration by runway use at LHR2. Data were filtered by wind direction and background concentrations subtracted according to the ranges shown in Table A6.5.



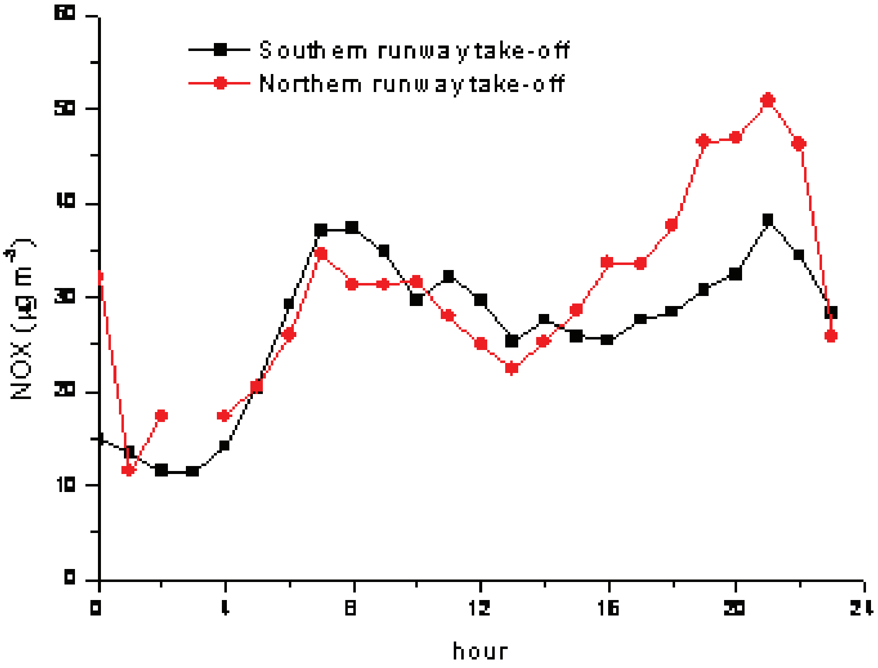
A6.43 Similar results were obtained for Harlington (Figure A6.13), although there was only 1 year of data available at this site.

Figure A6.13 Filtered NO_X concentration by runway use at Harlington. Data were filtered by wind direction and background concentrations subtracted according to the ranges shown in Table A6.5.



A6.44 The results at the Hounslow site, which is a similar distance away from the airport to Harlington, show a different diurnal pattern (Figure A6.14). There is less evidence of a difference between runway use before 12 pm, but there remains a clear difference during the afternoon and evening. Furthermore, the concentrations after 5 pm are also much higher than other periods of the day, which is not seen at LHR2 and Harlington. It appears therefore that aircraft emissions can be detected at Hounslow, but the diurnal pattern is very different to other sites.

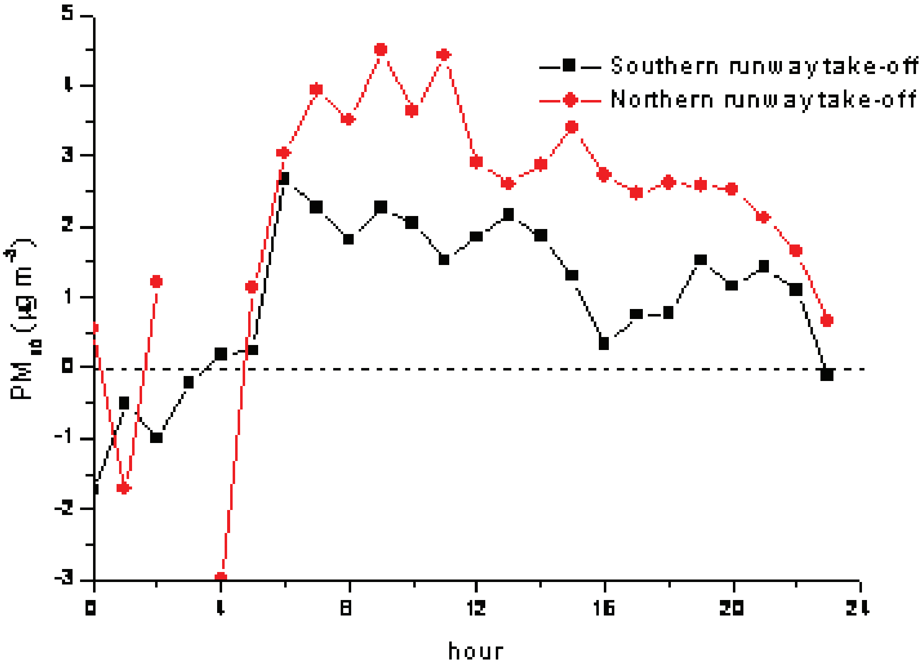
Figure A6.14 Filtered NO_X concentration by runway use at Hounslow 2. Data were filtered by wind direction and background concentrations subtracted according to the ranges shown in Table A6.5.



A6.45 The runway alternation analysis has also been carried out for PM_{10} at LHR2. Unadjusted (i.e. no 1.3 factor) TEOM data were used for this purpose. The same method was used as for NO_X, together with the same choice of background site. The results are shown in Figure A6.15. There is clearly a difference between northern and southern runway take-off, although the pattern is much less distinct than for NO_X. The overall contribution made by aircraft to PM_{10} concentrations is small, but can, however, be detected. It is useful to compare the PM_{10}/NO_X ratio calculated from these results because the ratio can be compared with that of road transport sources. The hours between 5 and 22 were used to estimate the mean PM_{10}/NO_X ratio of 0.015 (on a mass basis). This ratio is lower than that for road traffic exhaust emissions, which are calculated to be 0.041 based on average vehicles emissions across the LAEI for 2002. This is consistent with the interpretation that aircraft are a more important source of NO_X than PM_{10} compared with road traffic.

A6.46 It should be noted that the ratio of 0.015 for aircraft probably includes a contribution from exhaust emissions and tyre and brake wear. The PM_{10}/NO_X ratio for road traffic including tyre and brake wear is 0.061, highlighting the importance of these emissions for road traffic sources. It has not been possible to distinguish between exhaust emissions and emissions due to tyre wear from landing aircraft. $PM_{2.5}$ measurements could help in making the distinction between the two sources.

Figure A6.15 Filtered PM_{10} concentration by runway use at LHR2. Data were filtered by wind direction and background concentrations subtracted according to the ranges shown in Table A6.5.



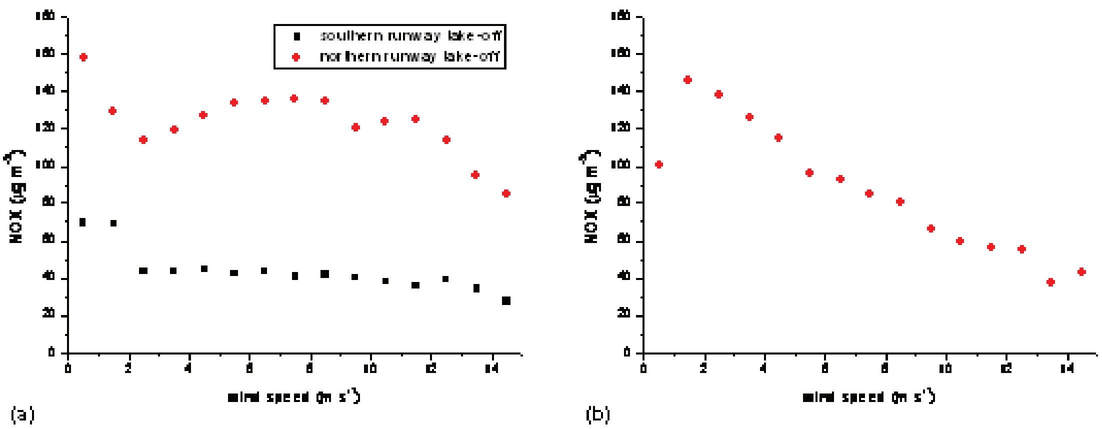
NO to NO_2 conversion

A6.47 The runway alternation pattern also provides some insights into the NO-NO_2-O_3 chemistry. At LHR2, the difference between northern and southern runway take-off is calculated to result in a difference in NO_X of 60 µg m^{-3}. The corresponding change in NO_2 was calculated to be 15 µg m^{-3} i.e. a NO_2/NO_X ratio of 25 %. At Harlington, the same calculations suggest a NO_X and NO_2 difference of 4.7 and 2.3 µg m^{-3}, respectively i.e. a ratio of 49 %. The difference in NO_X because of runway alternation decreases to only 7.8 % between LHR2 and Harlington, whereas that for NO_2 is 15.3 %. A more efficient conversion to NO_2 would be expected at Harlington for two reasons. First, there is more time available for the NO-O_3 reaction to take place and second, there will be fewer hours at Harlington that will be ozone-limited. At LHR2 there is likely to be a much greater proportion of hours that are ozone-limited because of the higher NO concentrations at that site due to the proximity of aircraft sources. These results could be beneficial for model validation of the NO_X-NO_2 chemistry.

Wind speed dependence

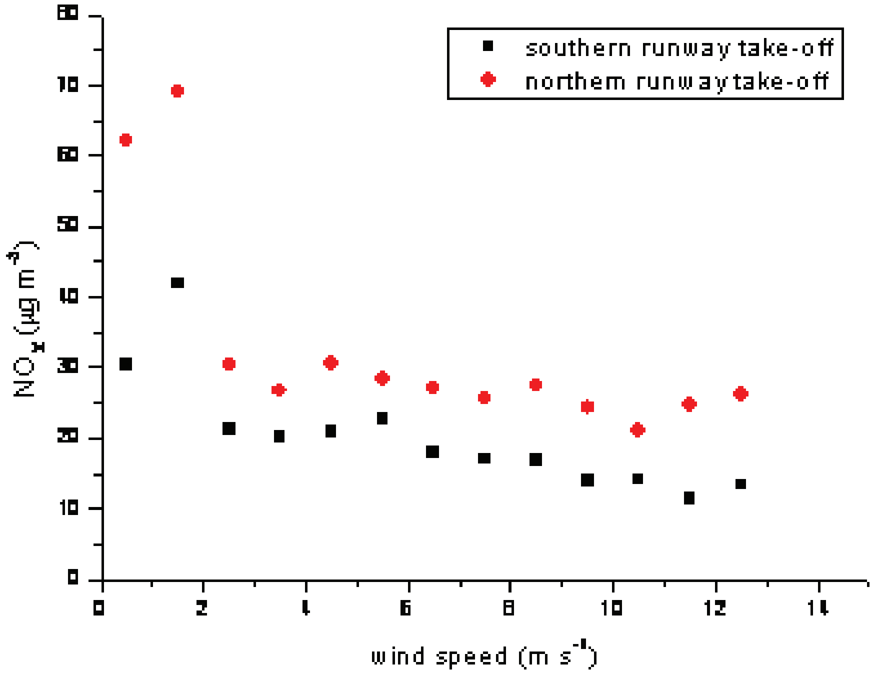
A6.48 NATS data were used to select hours where take-off was from either the northern or southern runway. Data from LHR2 were used and background values from Oaks Road were subtracted. Figure A6.16a shows the wind-speed dependence of NO_X concentrations by runway use. Figure A6.16b shows the wind speed dependence of NO_X concentrations at the Hillingdon site approximately 50 m from the M4. There are several important features shown by these plots that can be identified. First, concentrations at the Hillingdon site decrease smoothly with increasing wind speed. At LHR2 for northern runway take-off, concentrations decrease to about 2 m s^{-1}, then increase to around 8 m s^{-1}, before declining. For take-off on the southern runway, concentrations remain approximately constant across the wind speed range and only decline at little even at wind speeds of 15 m s^{-1}. These plots therefore highlight the very different dispersion characteristics of aircraft and road transport emissions. The increase followed by a decrease in concentration seen at the LHR2 site for northern runway take-off is characteristic of buoyant plume. Second, concentrations of NO_X for southern runway take-off are approximately one third that of northern runway take-off. The plot therefore provides some indication of how quickly aircraft plumes are dispersed.

Figure A6.16 a) Wind speed dependence of NO_X concentrations showing hours where take-off is from the northern and southern runways respectively at LHR2 b) for the London Hillingdon site. Both plots use the Oaks Road background data, which is subtracted.



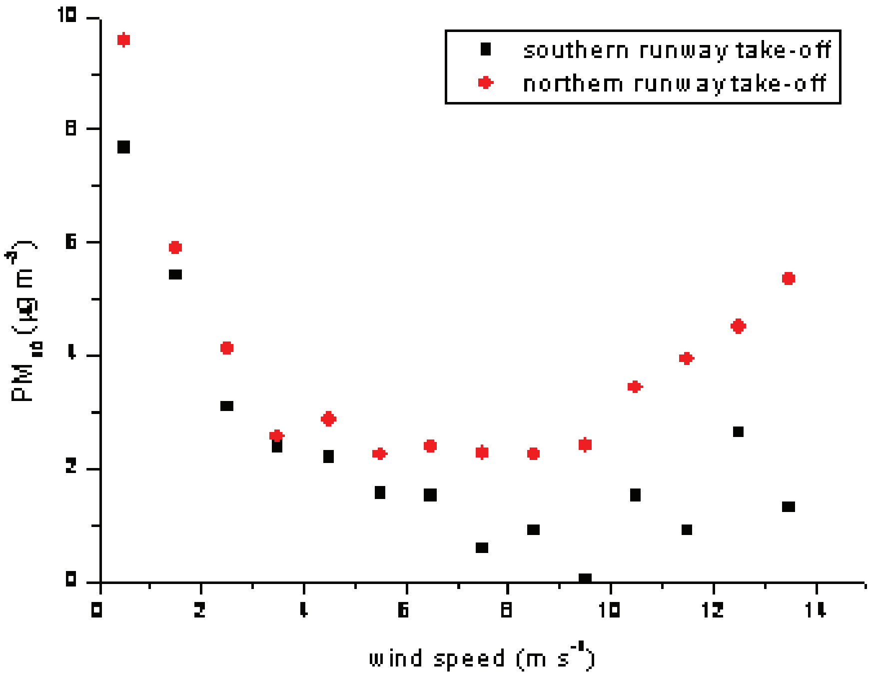
Appendix AQ.1.8

Figure A6.17 Wind speed dependence of NO_X concentrations showing hours where take-off is from the northern and southern runways respectively at Harlington.



A6.49 The wind speed dependence has also been calculated using the same approach for PM_{10} at LHR2, as shown in Figure A6.18. There is a distinct ''U'' shape in the relationship, which is markedly different to the relationship derived for NO_X (shown in Figure A6.16a). At low wind speeds below 5 m s^{-1}, there is little difference in the measured PM_{10} between northern or southern runway take-off. As the wind speed increases however, both the magnitude of the PM_{10} concentration and the difference between runway use also increase. The increasing PM_{10} with increasing wind speed is probably indicative of re-suspended particulate matter. However, it also appears that the combination of aircraft activity and high wind speeds results in higher concentrations of PM_{10}. These results might therefore indicate a more important role for re-suspended PM_{10} than exhaust emissions of PM_{10}. However, more work would be required to determine the factors that control the relationship shown in Figure A6.18.

Figure A6.18 Wind speed dependence of PM_{10} concentrations showing hours where take-off is from the northern and southern runways respectively at LHR2 using Oaks Road for background subtraction.



Aircraft emissions

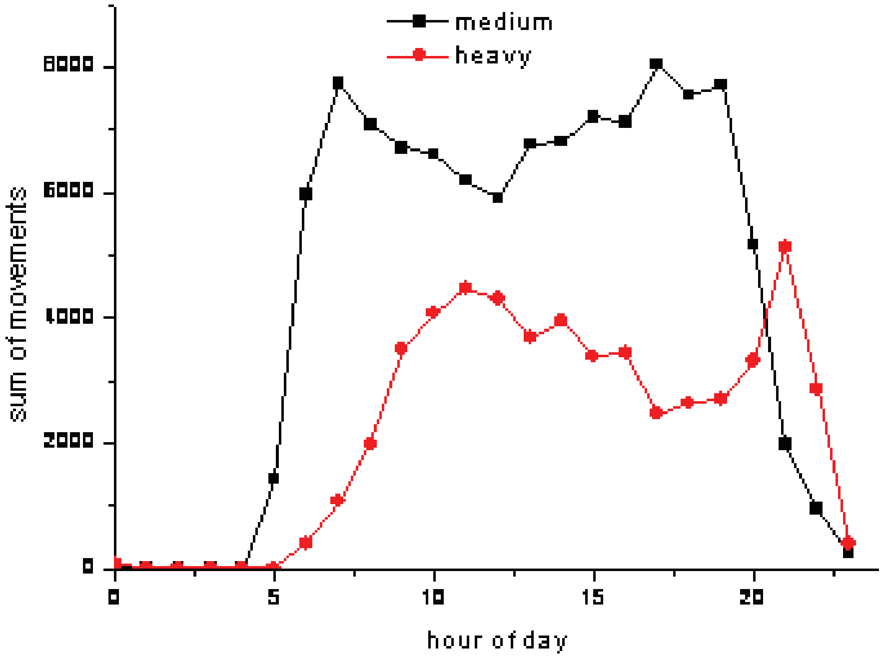
A6.50 The filtered diurnal profile of NO_X concentration shown in Figure A6.12 can be used together with aircraft movement data to estimate the relative importance of aircraft types to emissions of NO_X. Figure A6.19 shows the diurnal variation in aircraft movement by ''medium'' (e.g. Boeing 737) and ''heavy'' (e.g. Boeing 747) aircraft based on the analysis of NATS data. The filtered data shown in Figure A6.12 removed much of the variation due to meteorology because only high wind speed conditions have been used and the background concentration has been removed. This therefore allows a much more direct comparison between aircraft activity and measured concentration.

A6.51 A multiple regression was undertaken for the diurnal profiles such that:

$$[NO_X] = a.M_{(light)} + b.M_{(heavy)}$$

Where $[NO_X]_m$ is the measured (filtered) NO_X concentration, $M_{(light)}$ and $M_{(heavy)}$ are the movements of light and heavy aircraft and *a* and *b* are constants to be derived from the multiple regression. Data were additionally filtered to obtain the largest NO_X signal i.e. aircraft taking off on the northern runway (27R). The results suggest that heavy aircraft emit 3.1 $\pm$ 0.7 (at a 95 % confidence interval) times more NO_X than medium aircraft when taking off. The r^2 value for the regression was also high (0.97) with both medium and heavy planes making a statistically significant contribution.

Figure A6.19 Movements profiles of medium and heavy aircraft based on an analysis of NATS data.



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Henry, R. C., Y. S. Chang and C. H. Spiegelman (2002). Locating Nearby Sources of Air Pollution by Nonparametric Regression of Atmospheric Concentrations on Wind Direction. Atmospheric Environment 36(13): 2237-2244.

Yu, K. N., Y. P. Cheung, T. Cheung and R. C. Henry (2004). Identifying the Impact of Large Urban Airports on Local Air Quality by Nonparametric Regression. Atmospheric Environment 38(27): 4501-4507.

Annex 7
LIDAR study report

Air Quality at Heathrow Airport: Impact of Emissions from Aircraft in Ground Run and Flight

DfT Contract to Manchester Metropolitan University

First Technical Report

Angus Graham and David Raper

Manchester Metropolitan University

Simon Christie and Mike Bennett

University of Manchester

December 2005

Executive summary

A7.1 This report describes preliminary findings from a series of experiments performed at Heathrow in May 2005. The research was commissioned by the UK Department for Transport (DfT), as part of its ongoing Project for the Sustainable Development of Heathrow.

Objectives

a. To modify an existing rapid-scanning backscatter LIDAR, so that its beam will be eye safe and invisible, and thus suitable for use in the vicinity of an airport.

b. To undertake a two-week measurement programme at Heathrow Airport, in which the scanning LIDAR is used to image the dispersion of aircraft emissions.

c. To process the LIDAR data to yield backscatter images.

d. To analyse and interpret the processed LIDAR data, identifying scattering from aircraft emissions and parameterising the rise and spread of emissions that is revealed (according to airframe and engine characteristics; aircraft height and velocity; and meteorological conditions).

e. To identify and account for systematic differences in dispersion scales between emissions released at the various stages of ground run and flight.

Work Undertaken

- The LIDAR has been modified, with the laser now being frequency-tripled rather than frequency-doubled, yielding an eye-safe and invisible beam in the near ultraviolet (Objective *a*; Section 2).
- The LIDAR has been deployed at Heathrow in May 2005, and also subsequently at Manchester Airport, yielding images of backscattering from emissions in the wake of several hundred flights (Objectives *b* and *c*; Sections 2 and 3).
- Length, time and velocity scales of the dispersion of exhausts from aircraft engines during the take-off ground run have been systematically identified from images (Objective *d*; Section 4).
- Appropriate governing variables in the dispersion have been identified, according to the stage in the ground run considered, and the observed dispersive scales have been parameterised as a function of these variables (Objectives *d* and *e*; Section 4).

Findings

- The LIDAR system is well suited to studying the dispersion of emissions from aircraft in ground run and flight, over some 1-90 s from emission. Aerosols associated with exhausts from engines and tyre smoke generated on touchdown are observed.

- At the start of the ground run, once exhaust streams merge within a wingspan or so downstream of the aircraft, the flow forced by the thrust from engines may take the form of a wall jet. The jet extends downstream to a head, moving downstream at a speed scaling with $(F/\rho)^{1/4}/\tau^{1/2}$, where F is the pooled thrust from engines, ρ the density of the ambient air and τ the time since engines were powered up for take-off. The scaling coefficient is equal to 0.8 ± 0.1. The head is of width comparable to its downstream distance from the initial location of engines, and is of height, $18 \pm 4\%$ of this distance.
- The wall jet must ultimately break down under the action either of exhaust buoyancy or ambient wind shear. There is evidence of an enhanced vertical spreading, and possibly of some separation from the ground, for exhausts in light winds, up to $\sim 2\ m\ s^{-1}$ (at 10 m), as is consistent with the action of buoyancy.
- In the latter stages of the take-off ground run, exhausts may be drawn into a pair of plumes aligned with the runway and in excess of a wingspan apart. This is a consequence of a divergent flow below wings associated with the development of lift on the aircraft.

1. Introduction

A7.2 A series of experiments was performed recently at Heathrow with the University of Manchester's Rapid-Scanning LIDAR, as part of the Project for the Sustainable Development of Heathrow run by the UK Department for Transport (DfT). The LIDAR was used to study the dispersion of emissions from aircraft in their ground run and in flight. It comprises a pulsed ultraviolet beam that may be swept rapidly in either elevation or azimuth, allowing spatial maps of the backscattering from atmospheric aerosol to be built up. Enhanced concentrations of aerosol in the wake of aircraft, principally deriving from engine exhausts, may thus be imaged.

A7.3 As has been agreed with DfT, research presented here constitutes our first results and findings. Attention is given to characterising the initial distribution and dispersion of exhausts released while aircraft are in their take-off ground run. Characteristics are parameterised as a function of the forcing aircraft and meteorological variables. The aerosol in young exhausts is relatively concentrated, inducing the most marked excursions from ambient backscattering levels, and so images are fairly straight-forward to analyse. Such exhausts may impact greatly on air quality nearby.

A7.4 Findings on the dispersion of older exhausts, up to the age where their backscatter becomes indistinguishable from ambient, are deferred to the Final Report. These exhausts impact on air quality in much of the locality, but do so relatively weakly. Their diffuseness can lead to large errors in measurements of their scales, and some care is called for in their characterisation.

A7.5 The full range of images obtained will be surveyed in the Final Report. Measurements of exhausts from airborne aircraft, and emissions of tyre smoke released on touchdown, will also be described therein. Data from recent work with the LIDAR at Manchester Airport may be drawn upon to corroborate or extend the analysis, as necessary.

A7.6 Experimental details follow in Section 2. Observations are described in Section 3, and data are analysed in Section 4. Conclusions follow in Section 5.

2. Experiment

A7.7 The LIDAR comprises a Nd-YAG laser in a van, its beam steered using a rotating mirror and exiting from the roof of the vehicle at a height of 3 m. Beam divergence in the far field is approximately 1 mrad. Beam elevation is established from measured inclinations of the mirror relative to the elevation of a known target. Azimuthal angle is established through specifying the line of sight of a convenient fixed target, such as a tower or works chimney, a kilometre or so away. The compass orientation of this line may then be established from a suitable Ordnance Survey map or aerial photograph. An invisible and eye-safe beam was clearly a prerequisite for the work, and, in the months prior to the experiment, the laser was accordingly converted from a frequency-doubled implementation in the visible (λ=532 nm) to a frequency-trebled implementation in the near ultraviolet (λ=355 nm).

A7.8 Runways at Heathrow are aligned along 269.7°-89.7°, very nearly west-to-east, and are a little short of 4 kilometres long. The LIDAR was deployed at two airside sites beside runways, over a period of twelve days in May 2005, as shown in Fig. A8.1. One site lay 330 m south of the northern runway, 670 m west of its eastern end, at 51° 28' 28'' N, 0° 26' 35'' W, beside a de-icing bay at the end of Pier 3, Terminal One. The other lay 220 m south of the southern runway, 900 m east of its western end, at 51° 27' 46'' N, 0° 28' 30'' W, alongside cargo warehouses. Beam ranges in excess of I kilometres were achieved. It was thus possible to study aircraft emissions along the eastern half of the northern runway, and the western half of the southern runway.

A7.9 A purpose-built met. station was deployed from the roof of the LIDAR vehicle. Winds were measured 10 m from the ground using a cup anemometer and vane on a raised mast. Southerly winds were subject to flow distortion by nearby airport buildings. Air temperatures were measured by a thermistor, and shortwave insolation was measured with a pyranometer. Values were obtained over 10 s intervals. A humidity gauge was deployed but failed. Conditions were also measured at a Met. Office station to the north of the airfield (see Fig. A7.1).

A7.10 Supporting data on aircraft and carriers have been supplied by BAA. Contemporaneous, accurate and rapidly-updated records of aircraft position were essential for the LIDAR data to be interpreted correctly, so data from the Airport's ground radar, as operated by the National Air Traffic Service, have been utilised. Information from flight data recorders on flights operated by British Airways is also available. (Supporting film footage might well have been useful, but a short preparatory timescale and concerns as to the commercial sensitivity of such data meant this was not pursued.)

3. Observations

A7.11 A preliminary survey of the images obtained in LIDAR deployments at Heathrow and Manchester Airports may be found in the discussion document, 'Qualitative

Observations of Aircraft Plume Behaviour from LIDAR Measurements at Heathrow and Manchester', M. Bennett, September 2005. Discussion here is limited to observations of aircraft in the take-off ground run (see Section 1).

A7.12 Engine exhausts in the take-off ground run were studied thoroughly. They were never visible to the naked eye. Extinction of the beam energy when passing through the exhaust was always slight, never preventing near total passage of the beam through the plume. Images were built up over approximately a 2 s interval, the beam being swept upwards from a minimum elevation of about a degree. This was repeated at approximately 5 s intervals. The choice of azimuthal angle of the beam was constrained by an undertaking to avoid pointing at occupied buildings, so that a casual observer would not be needlessly exposed to the beam. Also, it was sought to study exhausts only where the beam was fully formed, some 200 m or more from the LIDAR. The decline of ambient backscattering levels with range arising as a result of geometric spreading, and extinction due to absorption and scattering, could then readily be allowed for.

A7.13 A specimen time series is shown in Fig. A7.2. The Airport was on easterly operations and the LIDAR was located at the southern site, the beam intersecting the runway axis obliquely at the western end of the runway. Surface winds were light, less than 2 m s^{-1} at 10 m, and north-easterly. Using data from the Airport's ground radar, it has been established that a B777 moved off on its ground run 9 s before the data acquisition of Fig. A7.2a was begun. This aircraft has two wing-mounted turbofan power plant 20 m apart. It joined the runway at the easternmost of the entry points to the southern runway shown in Fig. A7.1, and came to rest to await clearance for take-off with its engines some 450 m west of the LIDAR. A patch of enhanced backscattering is seen to develop in the images, extending down to the lowest elevation sampled, and, it may be supposed, associated with exhausts from engines from the time of power-up for take-off.

A7.14 On first observation (Fig. A7.2a), the patch extends to 600 m from the LIDAR. This corresponds to a location a distance 135 $\pm$ 40 m downstream (west) of the starting location of the aircraft's engines, and a distance 85 m laterally from the centre of the runway. The far end of the patch subsequently recedes at a decreasing speed, while rising and acquiring a front-like structure. From Fig. A7.2d onwards, there is evidence of an off-ground - if weak - peak in the strength of the enhanced backscatter, and thus in the concentration of scatterers, toward this end of the patch. The near end of the patch approaches the LIDAR. Over the course of time, the backscatter of the patch as a whole tends to approach ambient levels, consistent with a dilution of scatterers by the air around them.

A7.15 A second time series is shown in Fig. A7.3. Winds are stronger here, 7 m s^{-1} at 10 m. Data from the ground radar reveal an A321 commenced its ground run from the same location as in the case of Fig. A7.2, 12 s before the data acquisition of Fig. A7.3a was begun. The aircraft has two wing-mounted turbofans 11 m apart. Trends identified from Fig. A7.2 can also be observed in these images.

A7.16 The development of an off-ground peak in scatterer concentrations (Figs. A7.2 d–f) is consistent with the buoyancy of exhausts arising through their excess temperature over surroundings becoming dynamically active. The LIDAR data obtained at Heathrow do not, however, unambiguously show exhaust plumes to have separated from the ground. Separation might be expected when exhausts are of an age of order, F_e/B_e, where F_e is the thrust from an engine and B_e the buoyant force imparted to its exhausts per unit time. Supporting calculations show this age to be a minute or more.

A7.17 There were observational limitations at Heathrow in that the winds usually had a northerly component, while there were buildings to the south of both LIDAR sites. It was thus impossible to follow the plume very far downwind. On a single occasion, the plume was observed for a period of 90s, but in this case the wind was strong enough (3.9 m/s) to prevent it leaving the ground. On other occasions with lighter winds, elevated puffs could be observed towards the end of the series, after travel times of 30-60 s. It could not be absolutely excluded, however, that these arose as a result of the ambient wind shear detaching the head of a surface-based plume, rather than the plume as a whole rising as a result of buoyancy. Further analysis of such effects will depend on the results from Manchester.

A7.18 The thrust developed by engines when they are powered up for take-off may be expected to play a leading role in the initial stages of the dispersion of exhausts. Jets issuing from engines will merge downstream, this process likely accelerated through the agency of a Coanda effect, whereby jet axes are deflected toward one another and the ground. A region of integrated flows, and a common exhaust plume, might then extend downstream to terminate at a ‘‘head’’, wherein exhausts released as engines are powered up are concentrated. It may be the frontal structure of such a head that is seen in the images.

A7.19 With the passage of time from engine power-up, the head of the exhaust plume may be expected to spread laterally and upwards as it travels downstream, all at diminishing speeds. As speeds approach that of the wind at comparable height, the plume may become aligned with the wind toward its head. The head might easily cease to contribute to the patch of enhanced backscattering seen in images before it passes out of range. The concentration of scatterers at the head may thus approach ambient levels, or, in sufficiently strong a crosswind, the head could be advected out of the scanning plane of the beam.

A7.20 If the aircraft remained at its starting location, the end of the patch of enhanced backscattering nearest the LIDAR would be expected to remain at fixed mean range from the LIDAR, exhibiting a fixed mean backscatter. This end instead steadily approaches the LIDAR over time, as a consequence of the motion of the aircraft, and the passage into the beam of exhausts released after the aircraft moved off.

A7.21 Some supporting calculations may be made as to the initial forcing of the plume head. Consider the spreading turbulent jet arising when a source of mass and momentum (but not buoyancy) is introduced into a uniform still fluid. Where downstream distances are several times source scales or more, and jet mass flux exceeds source mass flux by at least an order of magnitude (as a result of the entrainment of ambient fluid), flow dimensions may be taken as independent of source scales and mass flux. Emissions of age, τ, old enough that this condition is realised then typically lie a downstream distance from the source modestly in excess of a length scale, $(F/\rho)^{1/4}\tau^{1/2}$, where F is the source force and ρ the fluid density (1.2 kg m^{-3} in the case of dry air at room temperature and pressure). This applies whether the source is introduced at a rigid plane boundary or far from boundaries, and whether the flow is that immediately after the force is applied or on equilibration. In the case of Fig A7.2a, for example, supposing the far end of the patch of enhanced backscattering, at a range of 600 m, delineates part of the head of the plume, the characteristic age of exhausts there may be taken as at least 9 s. The pooled maximum thrust from engines is equal to 748 kN. Thus, trace airborne emissions of the same age from a point source where the same force was applied might typically be found at a downstream distance from the source in excess of 84 m. This roughly tallies with an estimated downstream distance of the far end of the patch from the starting location of engines of 135 $\pm$ 40 m. It can also be seen that the requirement on minimum downstream distances for source scales and mass flux to be ignored is satisfied. (Limiting source scales might be taken as the span between outermost engines and the height of engines from the ground).

A7.22 As the far end of the patch of enhanced scattering in Fig. A7.2a lies 85 m from the centre of the runway, the putative plume head may then be supposed to extend at least 85 m laterally from the centre of the runway, and thus to be 170 m or more wide. Were it necessary to allow for the offset of the right (southernmost) engine from the centre of the runway, this would account for only 10 m of the 85 m measured. Similarly, any passive advection from the centre of the runway occurring as a result of crosswinds must be slight (less than 10 m at 10 m height in the 9 s since the aircraft moved off on its ground run), and, as will be seen, may in any case be suppressed. Plume width thus appears to be comparable to the downstream distance travelled, 135 $\pm$ 40 m. This is characteristic of a wall-jet flow (Launder and Rodi, 1983; Law and Herlina, 2002), rather than of a free jet, where the cross-stream span is less than half the downstream distance (see Turner, 1973). The marked lateral spread of the wall jet results from the shear stress at the wall, with lateral vorticity at the head of the jet twisted into streamwise vorticity upstream, as sketched in Fig. A7.4. Such a flow can arise only after a disruption of any local wind shear, and thus cannot be subject to a passive advection.

A7.23 When exhausts released from aircraft well into their take-off ground run are observed, a different scattering pattern is seen. A specimen time series is shown in Fig. A7.5. As in the earlier figures, the Airport was on easterly operations and the LIDAR located at its southern site. Here, the beam was directed to the northeast. Surface winds were light, 3 m s^{-1} at 10 m, and north-northeasterly (20°). Data from the Airport's ground radar reveal that a B747, 1 kilometres into its ground run, passed through the sweeping plane of the beam at a speed of 75 m s^{-1}, a few s before the data acquisition of Fig. A7.5a was begun. The aircraft has four wing-mounted turbofans and a wingspan of 64 m. The radar data show the aircraft to remain on the ground for at least 4 s after passing through the sweeping plane of the beam. While exhausts of given age are less concentrated than at engine power-up, presenting a weaker target to the LIDAR, it is nonetheless clear the scattering becomes organised into two principal clusters either side of the centre of the runway. It may therefore be inferred that exhausts from aircraft in the latter stages of their ground run may tend initially to be drawn into two parallel plumes straddling the runway.

A7.24 In Fig. A7.5a, two principal scattering clusters separated by some 150 m may be discerned. Allowing for the 27° viewing angle, this corresponds to two plumes 1.1 wingspans apart. In Fig. A7.5b, the two principal clusters are separated by 240 m, indicating that plumes are 1.7 wingspans apart. The scattering extends to a height of 25 m from the ground, or 0.4 wingspans. Backscattering strengths thereafter tail off, and each cluster spreads outwards and approaches the LIDAR, with an approach of the central location between clusters of about 90 m evident between Figs. A7.5b and A7.5d. The speed of plumes toward the LIDAR may be expected to scale with the wind speed at the mean height of plumes. Let directions be specified relative to the azimuthal line of the beam, positive, say, to its right. With the angle of the runway axis denoted α_r, and the angle from which surface winds blow denoted α_W, (both angles being relative to the LIDAR scanning azimuth) the following scaling coefficient should be anticipated,

$$\sin(\alpha_W - \alpha_r)/\sin\alpha_r.$$

A positive value corresponds to recession from the LIDAR. Setting $\alpha_r = 27°$ and $\alpha_W = -43°$, it follows that, taking plumes to have a mean height of 10 m (and with the wind speed there being equal to 3 m s^{-1}), plumes should approach the LIDARr at 6 m s^{-1}. Thus, over the 16 s between Figs. A7.5b and A7.5d, this amounts to a drift of 96 m, as tallies with the measured value.

A7.25 Another time series with the beam directed as in Fig. A7.5 is shown in Fig. A7.6. Aircraft parameters are unchanged, winds are the same speed but blow from the northwest. In Fig. A7.6a, a spike can be seen at the lowest elevation. Such spikes arise when the beam strikes the aircraft (providing a convenient means of synchronising LIDAR and radar time bases). The apparent scattering visible upstream of the aircraft strike is an artefact: the numerical analysis expects to fit a gentle exponential decay of scattering with distance. It is fooled by the very bright spike, followed by darkness, from a hard target. Thereafter, the same broad trends evident in Fig. A7.5 may be discerned. The fully-developed spacing between the two principal clusters is lower, however, some 150 m. This amounts to a spacing between plumes of 1.1 wingspans.

A7.26 The trend for exhausts to be drawn into two parallel plumes may arise through flows associated with the development of lift on the aeroplane. The pressure difference between lower and upper wing faces forces a divergent lateral flow below wings, as sketched in Fig. A7.7. Well away from the ground, this flow is associated with the rollup of a pair of persistent streamwise vortices, as mediated in the descent of the wake required by lift (from Newton's third law). Such vortices cap departure and arrival rates at busy periods at airports, their expected decay dictating the minimum separation between aircraft which can be deemed to be safe. When aircraft are within half a wingspan of the ground, however, vortex rollup is impeded. The outboard flow below wings forces the development of a shear layer at the ground, of opposing vorticity to that in the shed circulation above (see Fig. A7.7). If the shear layer separates from the ground and is drawn into the aircraft wake at lateral wake

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margins, little circulation may endure downstream. The steady diffusion of plumes in Figs. A7.5 and A7.6 does not suggest an underlying vortex structure. (A more prolonged divergence of plumes might, furthermore, be anticipated in the presence of vortices, through their coupling with ''image'' vortices, as arise from the condition of no flux of fluid into or out of the ground.)

A7.27 Lift in the take-off ground run can be significant prior to rotation of the aircraft, with a lift coefficient of 0.4 often correspondingly being assumed in calculations of take-off field length (Mair and Birdsall, 1992). Lift then rises rapidly on rotation. It is unlikely that aircraft were in rotation when passing through the plane of observation in the case of Figs. A7.5 and A7.6. It is, however, an open question as to whether exhausts were organised into two plumes during rotation further upstream, with the momentum from jets then causing the pair to be advected downstream through the beam.

4. Analysis

A7.28 The largest subset of the LIDAR data constitutes images of aircraft exhausts at the start of the take-off ground run. These images have been analysed, so that characteristics of the exhaust plumes may be determined as functions of the forcing variables. A set of 21 take-offs has been selected, on both runways, and as spanning the range of aircraft types and environmental conditions encountered. (The LIDAR was not operated at night or during rain). They are as specified in Table A7.1.

A7.29 The images show a patch of enhanced backscatter arising in the LIDAR beam shortly after aircraft engines are powered up for take-off (see Section 3). A means has been devised of characterising the distribution of scatterers at the far end of the patch, lying some 600 m from the LIDAR in the case of Fig. 7.2a, for example, or some 700 m in the case of Fig. A7.2d. This (horizontal) range is ascribed a characteristic value, r_p, and a linear fit along the upper edge of the patch is applied. The height of the point on the fitted line at a range equal to r_p is then the height ascribed to the far end of the patch, Δz_p. Height Δz_p may be converted to a height above the ground by adding 3 m, the height of the steering mirror of the LIDAR.

A7.30 Given time constraints, this has been undertaken by eye. Some subjective judgement has obviously been involved, and a computational scheme must ultimately be implemented. Such schemes bring new free parameters, as can rarely be set without some *ad hoc* prescription, but they nonetheless yield repeatable results, and must therefore be preferred.

A7.31 The height ascribed to the far end of the patch initially increases over successive images of the time series, but a decrease is then generally manifest. It is supposed this reflects a trend for horizontally-averaged scattering strengths in the patch to increase toward the ground (although, as shown in Section 3, scattering strengths in the vicinity of the far end itself may exhibit a weak off-ground maximum). Thus, as exhausts spread and concentrations approach ambient levels, the identified height may decline. The dispersive scales of exhaust plumes cannot then be inferred safely. Consequently, when the height first declines, the analysis is discontinued. This always happens within 20 s of the patch first being observed.

A7.32 Over such short time scales, the principal agent of dispersion may be expected to be the thrust from engines. Supporting calculations, and a difficulty in observing older plumes that have clearly separated from the ground in the experiment (see Section 3), indicate the buoyancy of exhausts is typically of secondary dynamical significance here. The action of the wind may also be supposed secondary. (Both suppositions will be revisited later in the section to check for consistency with findings). A null hypothesis is thus that the far end of the scattering patch delineates aircraft exhausts at the head of a jet (see Section 3). The jet forms downstream of the aircraft once exit streams from engines merge. Exhausts released as engines are powered up for take-off may be supposed to reside at the jet head.

A7.33 The downstream distance of the far end of the scattering patch from the initial location of the aircraft's engines on the runway, Δx_p, may be calculated. The associated lateral distance from the axis of the runway, Δy_p, may also be found. The ratio of these distances at the time of first observation of the patch has been established, and a histogram of such ratios built up over the set of take-offs analysed, as shown in Fig. A8.8. As the width of the jet head may be expected to be twice its lateral extent about the runway axis, and thus to be equal to at least $2\Delta y_p$, the histogram is consistent with a head characteristically of width comparable to the distance downstream from the initial location of release. This is indicative of a wall jet (see Section 3).

A7.34 Turbulent jets some way from their sources exhibit a mean speed whose dimensions follow from the source force, F, the ambient fluid density, ρ, and the downstream distance from the location of release, Δx. Thus, speeds scale with a term, $(F/\rho)^{½}/\Delta x$. In the case of the wall jet, however, the complete dependence on Δx is more complex than this. Flow speeds are not asymptotically insensitive to source scales, as the fractional momentum lost to the wall depends on Δx normalised on these scales. To first order, however, a dependence as $(F/\rho)^{½}/\Delta x$ may be presupposed, with a coefficient whose value reflects typical values of Δx normalised on source scales. On integrating the speed, it follows that the characteristic age at Δx of emissions from the source scales with a time scale, $\Delta x^2/(F/\rho)^{½}$. Thus, if the head of the jet forced by aircraft engines lies a distance, Δx_p, downstream of the initial location of release, then the time scale, $T \equiv \Delta x_p^2/(F/\rho)^{½}$, might be expected to scale with a characteristic time since engines were powered up for take-off.

A7.35 To calculate T, the pooled thrust from engines, F, must be estimated (ρ being taken simply as the density of dry air, 1.2 kg m^{-3} at the relevant temperatures and pressures). The fraction of maximum thrust utilised from engines during take-off depends on aircraft type and loading, runway length and meteorological conditions. The fraction may be established from the fuel consumption rate as logged in flight data recordings obtained during the experiment by British Airways plc (BA). The carrier was BA, however, in only three of the take-offs analysed. Thrust has thus been estimated simply as 90% of the maximum thrust, F_M (see Table A8.1), in the case of aircraft with two engines, and 85%, in the case of aircraft with four. (Twins typically draw greater fractions of maximum thrust to offset their fractionally greater loss of power on an engine failure). Actual percentages may be taken to lie between 75% and 100%.

A7.36 In Fig. A7.9, *T* is plotted against the time since aircraft moved off on their ground run (as adjudged from data from the Airport's ground radar). The plot is consistent with a linear relationship, within broad error limits. Points from the two aircraft size categories can be seen to overlap, although there is some suggestion that a line of higher gradient might better fit the lighter aircraft. A statistically significant difference cannot yet be safely inferred (or readily explained, for that matter).

A7.37 The speed of the head of a jet yielding the fit shown would scale with a term, $(F/\rho)^{1/4}/\tau^{1/2}$, where τ is the time since engines were powered up for take-off, and with the scaling coefficient being equal to 0.8 ± 0.1.With downstream distances being $O(10^2)$ times both the mean height and nozzle diameter of engines, a comparison may be made to laboratory observations on the turbulent discharge of a pipe flush with a plane wall, at $O(10^2)$ pipe diameters downstream (Law and Herlina, 2002). These data show the mean speed of the equilibrated flow to be of coefficient, 1.3 ± 0.1. Two factors may plausibly contribute to the slower speed identified here. Firstly, emissions issue from multiple sources, so the equivalent single source is wider than it is tall, and a greater fractional loss of momentum at given downstream distance may be anticipated. Secondly, the jet head may be expected to travel at a slower speed than the equilibrated flow at the same location. A head higher than the height of the equilibrated jet at the same location might then be expected, as addressed shortly.

A7.38 The *x*-intercept in Fig. A7.9 is equal to 16 ± 4 s. This may be taken as a characteristic time lag between the generation of take-off power and the aircraft moving sufficiently from its starting point for the motion to be picked up on the radar.

A7.39 A plot of Δz_p against Δx_p is shown in Fig A7.10. A linear fit is supported within the confines of errors, in the case of all but two points. Intriguingly, these derive from take-offs at the two lowest wind speeds studied. (Runs 14 and 19, images from the former as shown in Fig. A7.2). Exhaust buoyancy may thus be increasing the vertical spread in these cases. It may, furthermore, have gone on to cause these plumes to separate from the ground: individual puffs were indeed observed to separate from the ground towards the end of several runs. Research at to how plume characteristics depend on a correspondingly formulated plume Richardson number is ongoing, and will be presented in the Final Report.

A7.40 From the fit of Fig. A7.10, it may be inferred that the head of the jet is of a height characteristically about a sixth of the distance from the initial location of release. Tracers released at the source of an equilibrated wall jet diffuse to a height about a tenth of their downstream distance (Law and Herlina, 2002). The disparity may reflect an enhanced growth of the head arising from its depressed speed.

A7.41 Ambient winds may be expected to break up the wall jet and re-establish ambient stresses on the ground when the following quantity is sufficiently low,

$$(F/\rho)^{1/2} \Big/ (u_*^2 \tau),$$

where u_* is the friction velocity. A reference time scale, τ_r, may be calculated, running from the powering up of engines until the speed of the head of the jet falls to that of the wind at 10 m. This has been compared to the time span of each of the series of images analysed. Time spans never exceed τ_r by more than 4 s. This justifies an earlier assumption that winds are secondary in relation to jet thrust in mediating the dispersions studied.

5. Conclusions

A7.42 *a)* A LIDAR system incorporating a rapidly-swept beam has been modified for operation in the near ultraviolet, and used to image the backscatter from aerosol in the wake of aircraft at Heathrow. An enhanced backscatter arose as a result of exhausts from engines and tyre smoke on touchdown. Measurements on several hundred flights were made, covering a variety of aircraft size classes. Data were acquired in early, intermediate and advanced stages of the take-off ground run; from airborne aircraft in both departure and arrival; and on touchdown and over the landing ground run. Extensive data were obtained in conditions ranging from near calm to 8 m s^{-1} wind speed (at 10 m), neutral to moderately unstable; and in air temperatures of 10-15°.

A7.43 *b)* Generally, it was possible to observe the dispersion of emissions over time scales typically of up to 30 s and on occasion up to 90 s after their release. The maximum time scale reflects a decay of the concentration of aerosol to ambient levels, and appears sensitive to air temperature, with emissions observable for longer when it was colder. (The correlation with relative humidity may be stronger, but instrument failure prevented this from being measured). The maximum time scale also reflects the geometry of the LIDAR sites in relation to the eventual advection of the aircraft plumes by the wind.

A7.44 *c)* Observations made at the start of the take-off ground run, the beam being swept in the vertical and oriented at an oblique azimuthal angle to the runway, have been analysed. Once exhaust streams merge, as may be anticipated to occur within a wingspan or so downstream of aircraft, the common flow is found to assume the form of a wall jet. The jet comes to a head downstream, wherein aerosol released when engines are powered up for take-off may be supposed to reside. The head moves downstream at a speed scaling with $(F/\rho)^{1/4}/\tau^{1/2}$, where F is the pooled thrust from engines, ρ the density of the ambient air and τ the characteristic time since engines were powered up. The scaling coefficient is equal to 0.8 $\pm$ 0.1. The head is of width comparable its downstream distance from the initial location of engines, and is of height, 18 $\pm$ 4% of this distance.

A7.45 *d)* The wall jet may be taken ultimately to break down under the action either of exhaust buoyancy or ambient wind shear. It was difficult in this series of experiments to observe exhausts old enough to have unambiguously separated from the ground under the action of their buoyancy. There are, however, indications of an enhanced vertical spreading and possibly of lift-off in light winds, i.e. of < 2 m s^{-1} at 10 m. This would not be expected in the absence of buoyancy. Stronger winds may suppress buoyant action and separation.

A7.46 *e)* Observations made in the latter stages of the take-off ground run show exhausts may be drawn into a pair of plumes aligned with the runway and in excess of a wingspan apart. It is supposed this results from a divergent flow below wings associated with the development of lift on the aircraft. Well away from the ground, this flow generally leads to the rollup of a pair of persistent streamwise vortices in the wake. In the ground run, however, even in the presence of a significant lift, viscous interaction with the ground may prevent such vortices developing.

A7.47 *f)* It is not currently clear whether this flow divergence arises prior to the rotation of the aircraft on the runway. Lift (and drag) increase sharply with rotation, but lift prior to this can still be significant. With flaps and slats as typically extended for take-off (a setting of about 15°), the lift coefficient prior to rotation might be 0.3, with a maximum realisable value when airborne of 2.3. It follows that the lift just before rotation is about 15% of the aircraft weight - or some 60% of the pooled thrusts from engines (the enhanced drag within a civil turbofan at rotation is sufficient to depress thrusts by some 15-20% from static values).The wall jet that might be anticipated in the absence of lift may be particularly susceptible to disruption. It is associated with a convergent lateral flow at the ground, which the divergent flow associated with the lift will oppose.

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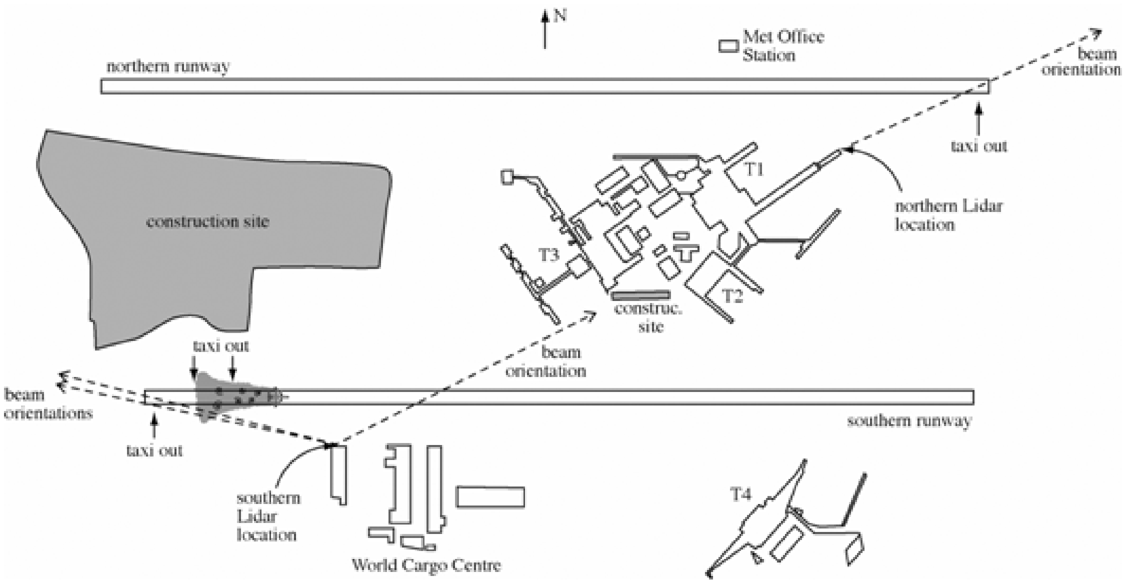
Table A7.1. Details of the set of take-offs selected for analysis. Each aircraft departs on its ground run at the corresponding fraction (in UTC) into the yearday specified, as has been discerned from data from the Airport's ground radar. Aircraft are of wingspan, b. Their power plant are established from airframe subtype and data on carriers, and are of pooled top thrust, F_M. Top fuel combustion rates, in kg s^{-1}, may be estimated to within 10% as equal to $9.5 \times 10^{-3} F_M$(kN). Surface-layer meteorology is established from instrumentation described in Section 2. Data are as averaged over 1 min periods, as centred on the centre time of the series of images analysed. Winds are of (10 m) speed, W_{10}, and direction, β_W. Air temperature (at 3 m) is denoted T, and the insolation, Q_i. Bounds show standard deviations, included when greater than the precision given. Monin-Obukhov length, L, is estimated from Q_i, W_{10} and a prescribed roughness length, according to the stability-class methodology of Turner (1969) and Golder (1972). For all runs except 21, airport buildings lie in excess of 1 kilometres upwind of the instruments, and a roughness length of 2 cm is thus appropriate (Stull, 1988). Friction velocity, u_*, is calculated on presupposing a shear in convective to neutral conditions as described by Stull (1988). Wind measurements made on run 21 are unreliable, as they were subject to local flow distortion by Airport buildings, and have been omitted.

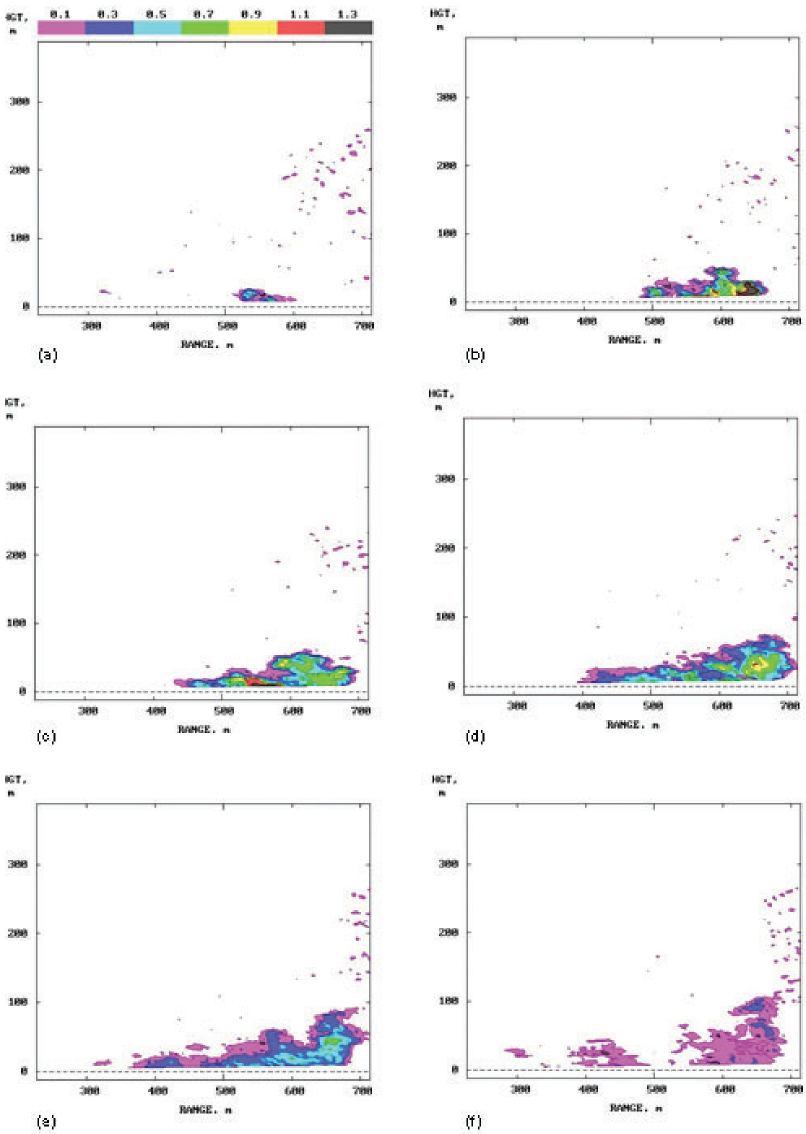
Run	Start (yearday 2005)	Aircraft	b (m)	F_M (kN)	W_{10} (m s^{-1})	β_W (°)	T (°C)	Q_i (W m^{-2})	L (m)	$u_*/W_{10} \times 10^{-2}$
1	134.4068	B777-200ER	60.9	800	6.2 ± 1.3	23 ± 10	11	191	∞	6.4
2	134.4769	B777-200ER	60.9	800	7.4 ± 0.6	46 ± 5	13	189	∞	6.4
3	134.4775	B747-400	64.4	1032	6.8 ± 1.2	44 ± 10	13	189	∞	6.4
4	134.4809	B767-300ER	47.6	534	7.6 ± 0.8	53 ± 7	13	183	∞	6.4
5	134.4851	B767-300ER	47.6	560	7.2 ± 0.9	33 ± 7	13	191	∞	6.4
6	134.5368	A319-100	34.1	210	6.9 ± 0.8	44 ± 7	14	206 ± 2	∞	6.4
7	134.5382	A321-200	34.1	276	6.8 ± 1.1	58 ± 8	14	200 ± 4	∞	6.4
8	134.5402	B777-200ER	60.9	800	6.5 ± 0.7	69 ± 5	14	188	∞	6.4
9	134.5915	A320-200	34.1	230	5.8 ± 0.3	72 ± 11	15	254 ± 3	∞	6.4
10	134.5943	B777-200ER	60.9	800	6.2 ± 0.5	66 ± 8	14	256	∞	6.4
11	137.5357	A320-200	34.1	230	3.5 ± 0.7	4 ± 12	10	189 ± 4	−20	7.3
12	137.5369	B777-200	60.9	658	3.8 ± 0.5	2 ± 5	10	292 ± 75	−20	7.3
13	137.5441	A320-200	34.1	230	4.2 ± 1.0	60 ± 8	11	402 ± 96	−20	7.3
14	137.5739	B777-200ER	60.9	748	1.6 ± 0.4	57 ± 14	10	240 ± 48	−30	7.1
15	137.5759	A321-100	34.1	280	4.3 ± 0.6	0 ± 7	11	171 ± 3	−30	7.1
16	137.5808	B747-400	64.4	1032	3.1 ± 0.4	305 ± 9	11	136 ± 2	−30	7.1
17	137.5826	A320-200	34.1	230	1.9 ± 0.2	295 ± 7	11	128 ± 2	−30	7.1
18	137.5850	A330-300	60.3	620	2.5 ± 0.5	274 ± 16	11	128 ± 2	−30	7.1
19	137.6844	A340-300	60.3	580	0.8 ± 0.3	320 ± 21	12	85	−30	7.1
20	137.6879	B747-200M	59.6	888	2.2 ± 0.3	7 ± 13	12	80	−30	7.1
21	138.6090	B767-300ER	47.6	560	-	-	16	163	-	-

Figure A7.1. Plan view of LIDAR-deployment scenarios at Heathrow. Beam orientations shown are those as holding over take-offs addressed in the Observations and Analysis. In easterly operations, as prompted by an easterly wind, take-offs were studied on the southern runway. Conversely, in westerly operations, as prompted by a westerly wind, take-offs were studied on the northern runway. Principal points of entry onto the runway during the studies are as marked. An aircraft is depicted in its ground run having powered up its engines and simultaneously accelerated away some 10 s beforehand. It initially joined the runway from the easternmost of the entry points shown.



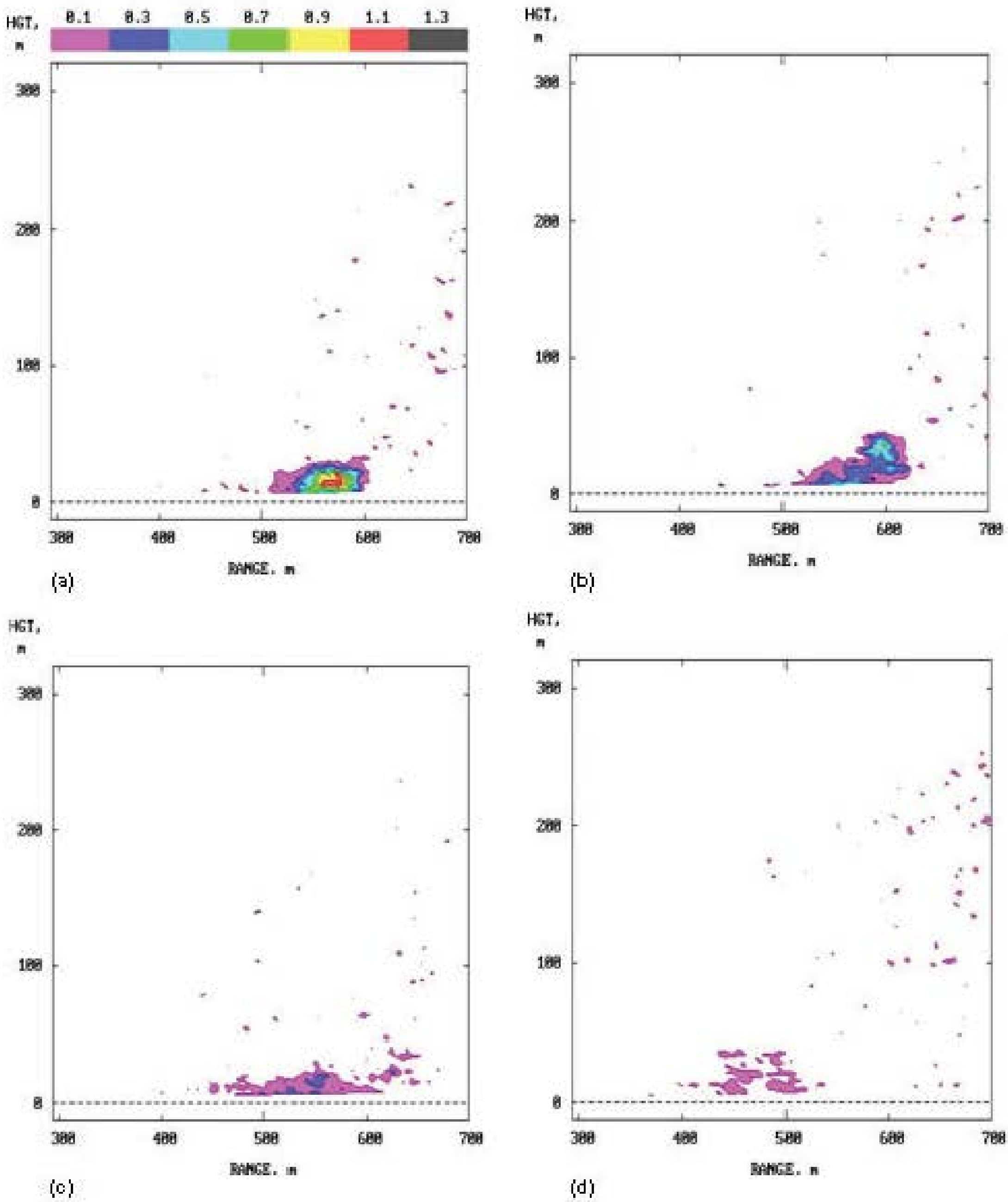
Appendix AQ.1.8

Figure A7.2. Time series of LIDAR images with the beam being swept in the vertical behind a B777-200ER commencing its take-off ground run (from rest), engines 450 $\pm$ 40 m west of the LIDAR at the starting location (as adjudged using data from the Airport's ground radar), a) 9 s after the aircraft moves off, b) 14 s after, c) 19 s, d) 24 s, e) 34 s, f) 44 s. Radial beam ranges are established from the return time of the pulse and the speed of light in air (0.03% slower than *in vacuo*). Range along the ordinate is the height above the effective beam origin (at the roof of the LIDAR vehicle, 3 m from the ground), range along the abscissa is the horizontal distance from the LIDAR (cropped so as to focus on the scattering of interest). The beam points toward 283°, intersecting the southern runway axis at 13°, 980 m from the LIDAR. The dashed line corresponds to the height of the beam origin. The colour bar calibrates the fractional enhancement in backscattering over ambient levels, the latter as deduced from a fitting procedure in which the medium is presupposed uniform along the beam. (The associated e-folding length scale of extinction due to absorption and scattering is treated as a free variable). Aircraft specifications and environmental conditions are as per run 14, Table A7.1 (see Analysis).



Appendix AQ.1.8

Figure A7.3. LIDAR images behind an A321-200 commencing its take-off ground run, beam swept upwards as per Fig. A7.2, and the aircraft also as starting therein, a) 12 s after the aircraft moves off, b) 17 s after, c) 22 s, d) 32 s. The beam points toward 282°, intersecting the southern runway axis at 12°, 1060 m from the LIDAR. Aircraft specifications and environmental conditions are as per run 7, Table A7.1.



Appendix AQ.1.8

Figure A7.4. Sketch of a wall jet, with putative coherent structure, a) in axial streamwise profile, with mean streamline, b) in plan view, c) in cross-section, on equilibration, with mean crossflows.

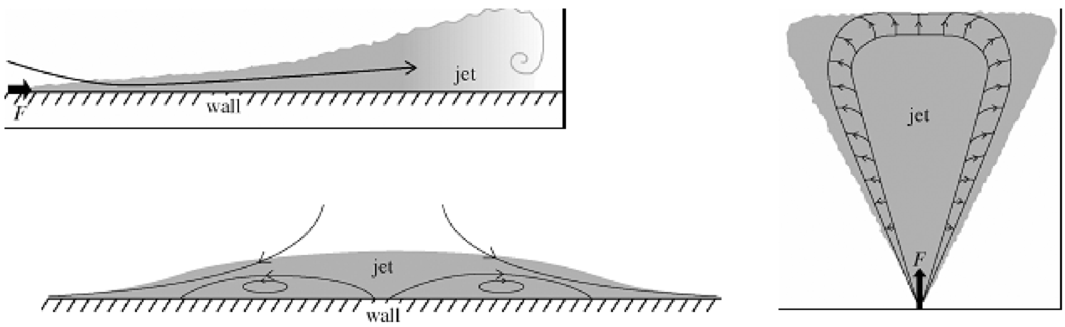


Figure A7.5. LIDAR images behind a B747-400, beam being swept upwards, a) a few s after the aircraft crosses the plane of the beam at 75 m s^{-1}, 1 kilometres into its ground run, b) 5 s after (a), c) 10 s after, d) 15 s after. The beam points toward 63°, intersecting the southern runway axis at 27°, 480 m from the LIDAR. Wind is 3 m s^{-1} at 10 m from 20°, air temperature is 12°C at 3 m, insolation is 30 W m^{-2}.

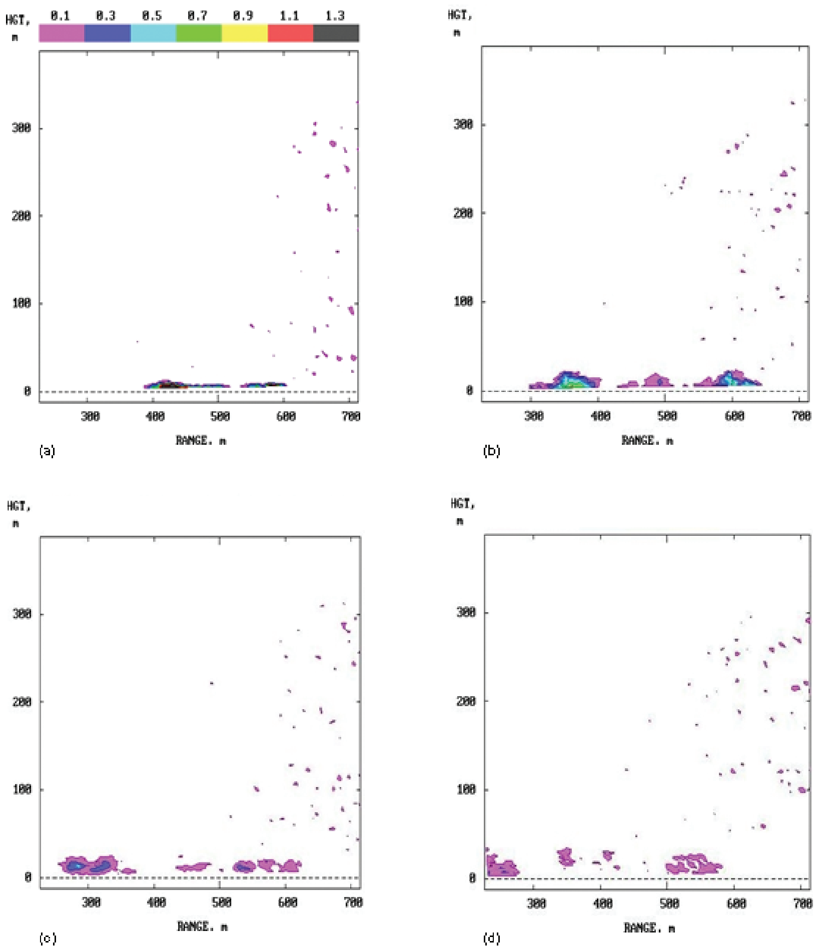
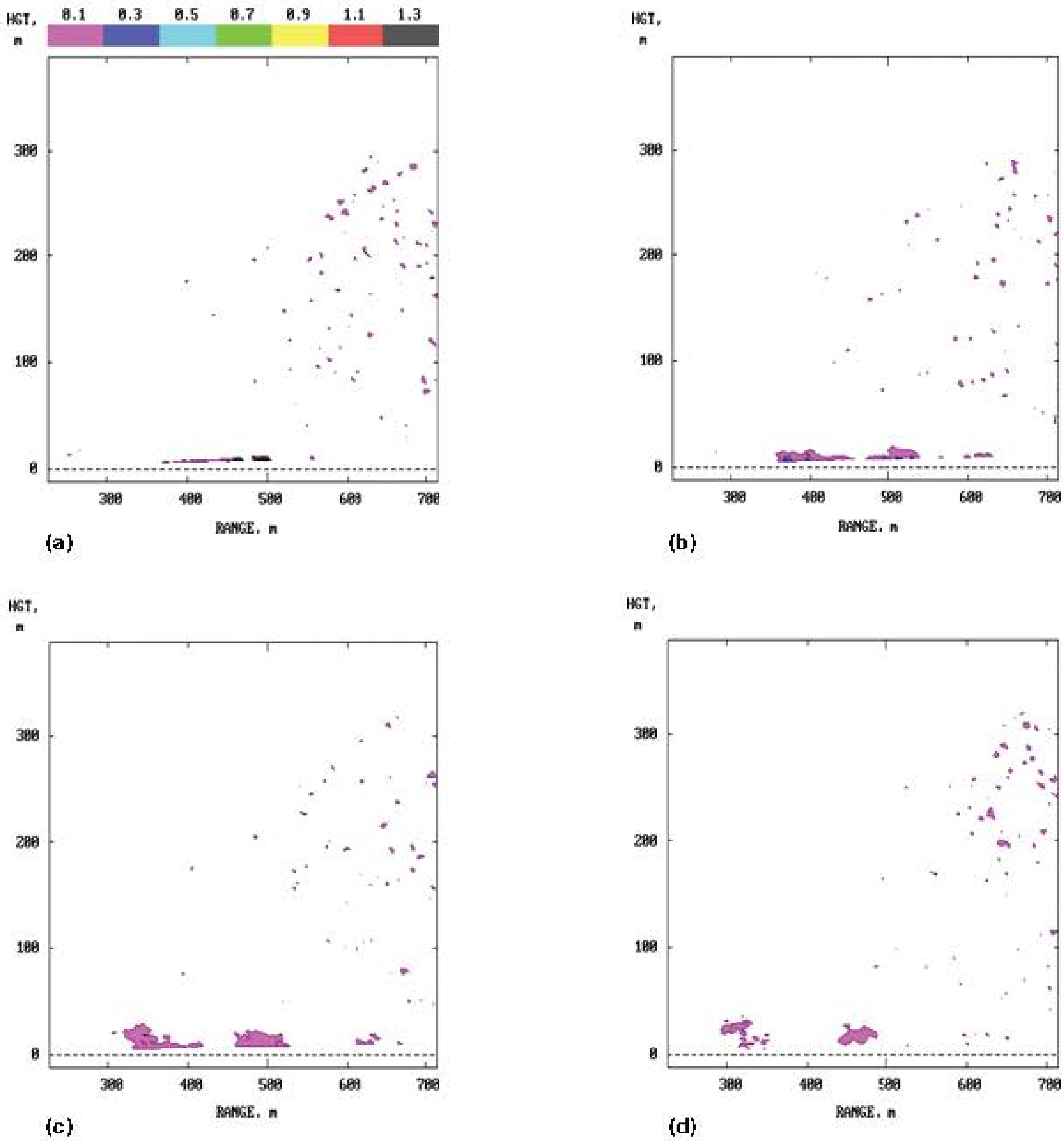


Figure A7.6. LIDAR images behind a B747-400, the sweeping and orientation of the beam as per Fig. A7.5, a) as the aircraft crosses the beam, at a speed and distance into its ground run as per Fig. A7.5(a), b) 5 s after (a), c) 11 s after, d) 21 s after. Wind is 3 m s^{-1} at 10 m from 300°, air temperature is 12°C at 3 m, insolation is 60 W m^{-2}.



Appendix AQ.1.8

Figure A7.7. Sketch of mean cross-flows in the near wake of an aeroplane, with ground-effect. The shear layer forced at the ground is shown shaded.

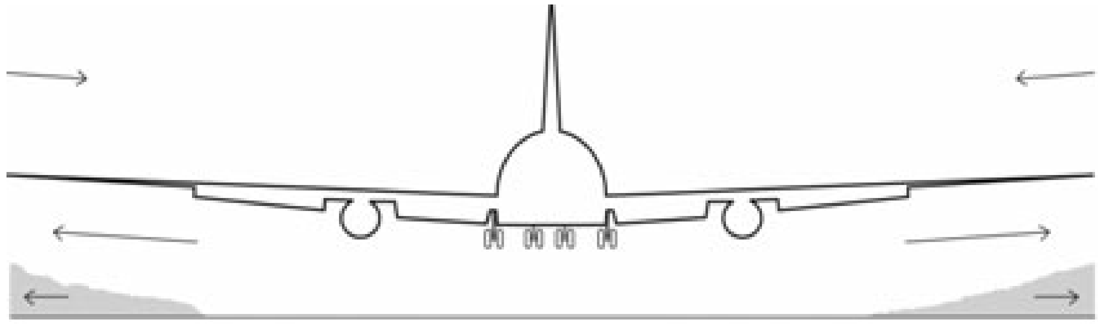


Figure A7.8. Histogram (21 samples) of lateral distance from the runway axis of the far end of the patch of enhanced backscattering, Δy_p, on first observation of the patch, and as expressed in ratio to the downstream distance of the far end from the initial location of engines on the runway, Δx_p. The left-hand dashed line shows the mean value obtained for aircraft of total maximum thrust 500 kN or more, 0.39; the right-hand line shows the mean value for aircraft of lower maximum thrust, 0.47; and the line between these shows the mean value for all aircraft, 0.42.

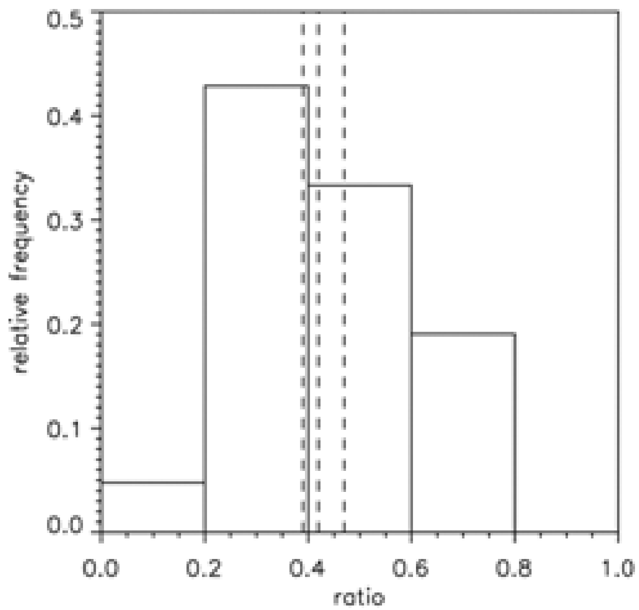


Figure A7.9. Plot of *T* (see Analysis) against time since aircraft moved off on their ground run, *t*. Crosses show values for aircraft of total maximum thrust less than 500 kN, asterisks those for aircraft of higher maximum thrust. Errors are shown shaded, for clarity, with lines of negative gradient delineating errors in the case of crosses, and lines of positive gradient delineating errors in the case of asterisks. The dashed line shows an error-weighted linear least-squares fit. It is of gradient, 2.6 $\pm$ 0.5, and *y*-intercept, 44 $\pm$ 4 s.

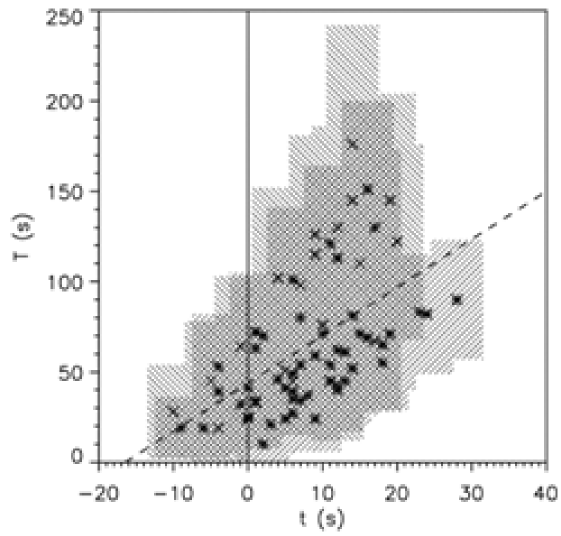
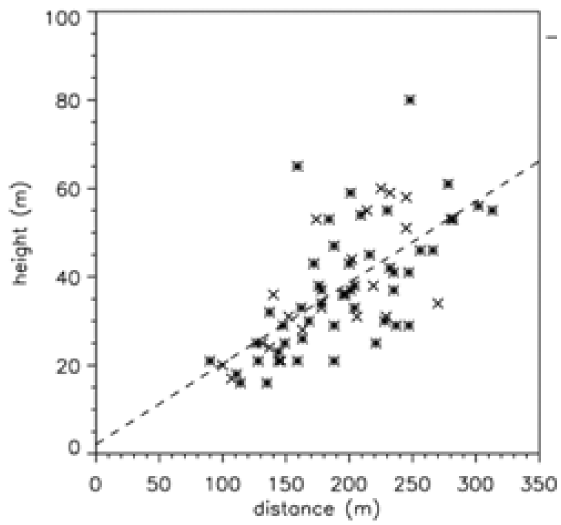


Figure A7.10. Plot of height ascribed to the far end of the patch of enhanced backscattering, Δz_p, against downstream distance of the far end from the initial location of engines, Δx_p. Symbols are as per Fig. A8.9. The top-right cross shows errors. The dashed line shows a linear least-squares fit, and is of gradient, 0.18 $\pm$ 0.04, and *y*-intercept, 2.1 $\pm$ 5.0 m.



Appendix AQ.1.8

Annex 8
Air quality monitoring around Heathrow

A8.1 This Annex provides information on the air quality monitoring sites in and near Heathrow Airport together with information on the ambient concentrations of nitrogen oxides (NO_X and NO_2), fine particulate matter (PM_{10}) and ozone

Table A8.1 Automatic monitoring sites at and near Heathrow

Table A8.2 Sources of the automatic monitoring data

Table A8.3 Annual mean nitrogen oxides concentrations 1996 to 2004

Table A8.4 Annual mean nitrogen dioxide concentrations 1996 to 2004

Table A8.5 Number of exceedences of 200 $\mu g/m^3$ as 1-hour mean nitrogen dioxide concentration 1996 to 2004

Table A8.6 Ratios of annual mean nitrogen dioxide to nitrogen oxides concentrations 1996 to 2004

Table A8.7 Annual mean PM_{10} concentrations 1996 to 2004

Table A8.8 Number of exceedences of 50 $\mu g/m^3$ as 24-hour mean PM_{10} concentration 1996 to 2004

Table A8.9 Annual mean $PM_{2.5}$ concentrations 1996 to 2004 (TEOM values unadjusted)

Table A8.10 Annual mean ozone concentrations 1996 to 2004

Table A8.1 Automatic monitoring sites at and near Heathrow

Site Code	Alternative Codes [a]		Site Names [a]			Site Type	NO_X / NO_2	PM_{10}	$PM_{2.5}$	O_3
LHR2	LH2	-	Heathrow LHR2	Heathrow Airport		A (R)	Y	Y	N	N
LHR3	EA7	-	Ealing 7	Southall		B	Y	Y	N	N
LHR4	HI3	-	Hillingdon 3	Oxford Avenue	Heathrow 2	R	Y	Y	N	N
LHR5	HS2	-	Hounslow 2	Cranford	Hounslow 2 – Cranford	B	Y	Y	N	N
LHR6	TD0	-	Teddington	-	-	B	Y	N	N	Y
LHR7	-	-	Myrtle Avenue	-	-	B	Y			
LHR8	T5-16	LH7	T5 – Oaks Road	BAA Land	Junction of Oaks Road and Russell Drive	B (R)	Y	Y	Y	N
LHR9[b]	-	-	Silwood Park, Ascot	-	-	B				
LHR10	HA1	LH9	M25 Staines	-	-	K/R	Y	Y	Y	Y
LHR11	T5-13	LH4	T5 – Main Road	Main Road Nurseries	Stanwell Moor Road	B	Y	Y	Y	Y
LHR12	T5-10	LH6	T5 – Bedfont Court	Fields adjacent to No. 13 Bedfont Court	Off Spout Lane	B	N	Y	Y	N
LHR13	T5-8	LH5	T5 – Moorbridge	Moorbridge Bungalow	Orchard Farm, Bath Road, Colnbrook	B	N	Y	Y	N
LHR14	SLH3	LH3	Slough Colnbrook	Slough Pippin School	T5 Colnbrook	B	Y	Y	N	N
LHR15	T5-24	LH8	T5 – Green Gates	Green Gates Meadow	Bath Road	B	Y	Y	Y	N
LHR16	HIL	HI0	London Hillingdon	Hillingdon AURN	-	S (R)	Y	Y	N	Y
LHR17	H12	-	Hillingdon 2	Hillingdon Hospital	Hillingdon 2 – Hillingdon Hospital	B (R)	Y	Y	N	N
LHR18	HRL	LH0	Harlington AURN	London Harlington	Harlington	B (R)	Y	Y	N	Y
LHR19	-	-	West End Lane	Heathrow 1	-	B	Y	N	N	N
LHR20	-	-	Heathrow Point West	Heathrow 2	Mondial Way	B (R)	Y	N	N	N

[a] A range of site codes and names have been used by different groups. [b] Site information and results for LHR9 did not become available to the Panel.

Site type Key: A – Airport; B – Background; K – Kerbside; R – Roadside; S – Suburban; (R) – Roadside influence.

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Table A8.2 Sources of the automatic monitoring data

Site Code	Site name	Data source
LHR2	Heathrow Airport	NO_X and NO_2 data www.heathrowairwatch.org.uk 13/9/05
LHR3	Ealing 7 – Southall	NO_X and NO_2 data www.londonair.org.uk 13/9/05
LHR4	Hillingdon 3	New site
LHR5	Hounslow 2 – Cranford	NO_X and NO_2 data www.heathrowairwatch.org.uk 13/9/05
LHR6	Teddington AURN	NO_X and NO_2 data www.airquality.co.uk 13/9/05
LHR7	Myrtle Avenue	New site
LHR8	T5 – Oaks Road	Data provided by BAA
LHR9	Silwood Park, Ascot	New site - Data not yet available
LHR10	M25 Staines	All data www.trl.co.uk 13/9/05
LHR11	T5 – Main Road	Data provided by BAA
LHR12	T5 – Bedfont Court	Data provided by BAA
LHR13	T5 – Moorbridge	Data provided by BAA
LHR14	Slough Colnbrook	NO_X and NO_2 data www.heathrowairwatch.org.uk 13/9/05
LHR15	T5 – Green Gates	Data provided by BAA
LHR16	Hillingdon AURN	NO_X and NO_2 data www.airquality.co.uk 13/9/05
LHR17	Hillingdon Hospital	NO_X and NO_2 data www.heathrowairwatch.org.uk 13/9/05
LHR18	Harlington AURN	NO_X and NO_2 data www.airquality.co.uk 13/9/05
LHR19	West End Lane	Data collected and provided by TRL for 2005
LHR20	Heathrow Point West	Data collected and provided by TRL for 2005

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Table A8.3 Annual mean nitrogen oxides concentrations 1996 to 2004

	NO_X Annual Mean (µg/m^3)								
Site Code	1996	1997	1998	1999	2000	2001	2002	2003	2004
LHR2	-	177.6	146.9	135.1	134.4	137.6	119.1	133.3	124.1
LHR3	-	-	-	-	-	-	-	-	-
LHR4	-	-	-	-	-	-	(91.5)[a]	-	-
LHR5	-	-	-	83.8	71.1	82.3	73.2	90.7	65.2
LHR6	-	70.8	51.4	50.1	44.3	52.5	38.6	43.9	36.5
LHR7	-	-	-	-	-	-	-	-	-
LHR8	-	-	-	-	-	-	62.7	74.8	60.2
LHR9	-	-	-	-	-	-	-	-	-
LHR10	387.8	332.5	223.2	276.2	246.8	196.1	196.1	209.1	-
LHR11	-	-	-	-	-	-	73.3	100.5	70.3
LHR12	-	-	-	-	-	-	-	-	-
LHR13	-	-	-	-	-	-	-	-	-
LHR14	-	-	-	-	-	73.8	70.5	85.4	59.4
LHR15	-	-	-	-	-	-	66.7	88.8	71.0
LHR16	-	209.3	181.5	-	140.2	130.9	112.9	129.4	112.1
LHR17	-	-	-	-	-	-	-	-	-
LHR18	-	-	-	-	-	-	-	-	71.5
LHR19	-	-	-	-	-	-	(75.9)[a]	-	-
LHR20	-	-	-	-	-	-	-	-	-

Data capture >75%

[a] Adjusted to 2002 annual mean equivalent from short-term un-verified 2005 data. Adjustment factors (1.404 for LHR4 and 1.313 for LHR19) calculated from measurements made at LHR2, LHR14 and the London Brent AURN following guidance in LAQM.TG(03) (Defra, 2003).

Table A8.4 Annual mean nitrogen dioxide concentrations 1996 to 2004

	NO_2 Annual Mean ($\mu g/m^3$)											
Site Code	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
LHR2	57.0	60.6	60.8	63.0	60.1	54.1	55.5	56.6	53.8	52.1	58.8	55.2
LHR3	-	-	-	-	-	-	-	-	-	-	-	-
LHR4	-	-	-	-	-	-	-	-	-	(39.0)[a]	-	-
LHR5	-	-	-	-	-	-	42.2	36.7	41.0	43.2	52.2	35.6
LHR6	-	-	-	-	35.3	31.9	31.9	27.7	28.9	25.3	28.1	24.5
LHR7	-	-	-	-	-	-	-	-	-	-	-	-
LHR8	-	-	-	-	-	-	-	-	-	31.8	38.6	33.4
LHR9	-	-	-	-	-	-	-	-	-	-	-	-
LHR10	-	-	-	57.2	49.5	38.6	46.5	40.9	39.8	39.2	54.7	-
LHR11	-	-	-	-	-	-	-	-	-	35.6	47.4	36.0
LHR12	-	-	-	-	-	-	-	-	-	-	-	-
LHR13	-	-	-	-	-	-	-	-	-	-	-	-
LHR14	-	-	-	-	-	-	-	54.2	35.2	36.1	42.3	30.9
LHR15	-	-	-	-	-	-	-	-	-	32.2	45.8	38.7
LHR16	-	-	-	-	-	-	-	-	-	45.2	53.7	47.2
LHR17	-	-	-	-	-	-	-	-	-	-	-	-
LHR18	-	-	-	-	-	-	-	-	-	-	-	38.2
LHR19	-	-	-	-	-	-	-	-	-	(35.5)[a]	-	-
LHR20	-	-	-	-	-	-	-	-	-	-	-	-

Data capture >75%

[a] Adjusted to 2002 annual mean equivalent from short-term un-verified 2005 data. Adjustment factors (1.152 for LHR4 and 1.087 for LHR19) calculated from measurements made at LHR2, LHR14 and the London Brent AURN following guidance in LAQM.TG(03) (Defra, 2003).

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Table A8.5 Number of exceedences of 200 μg/m³ as 1-hour mean nitrogen dioxide concentration 1996 to 2004

	NO_2 number of hourly exceedences of 200 μg/m³											
Site Code	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
LHR2	-	-	17	31	25	0	12	0	0	0	0	3
LHR3	-	-	-	-	-	-	-	-	-	-	-	-
LHR4	-	-	-	-	-	-	-	-	-	-	-	-
LHR5	-	-	-	-	-	-	0	0	0	0	1	-
LHR6	-	-	-	-	8	0	0	0	0	0	0	-
LHR7	-	-	-	-	-	-	-	-	-	-	-	-
LHR8	-	-	-	-	-	-	-	-	-	0	0	0
LHR9	-	-	-	-	-	-	-	-	-	-	-	-
LHR10	-	-	-	5	2	-	-	0	0	0	0	-
LHR11	-	-	-	-	-	-	-	-	-	-	9	0
LHR12	-	-	-	-	-	-	-	-	-	-	-	-
LHR13	-	-	-	-	-	-	-	-	-	-	-	-
LHR14	-	-	-	-	-	-	-	0	0	0	1	-
LHR15	-	-	-	-	-	-	-	-	-	0	1	0
LHR16	-	-	-	-	-	-	-	-	-	-	-	-
LHR17	-	-	-	-	-	-	-	-	-	-	-	-
LHR18	-	-	-	-	-	-	-	-	-	-	-	0
LHR19	-	-	-	-	-	-	-	-	-	-	-	-
LHR20	-	-	-	-	-	-	-	-	-	-	-	-

Data capture >90%

Appendix AQ.1.8

Table A8.6 Ratios of annual mean nitrogen dioxide to nitrogen oxides concentrations 1996 to 2004

Site Code	NO_2/NO_X ratio											
	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
LHR2	0.32	0.32	0.37	0.37	0.34	0.37	0.41	0.42	0.39	0.44	0.44	0.44
LHR3	-	-	-	-	-	-	-	-	-	-	-	-
LHR4	-	-	-	-	-	-	-	-	-	(0.43)	-	-
LHR5	-	-	-	-	-	-	0.50	0.52	0.50	0.59	0.58	0.55
LHR6	-	-	-	-	0.50	0.62	0.64	0.63	0.55	0.66	0.64	-
LHR7	-	-	-	-	-	-	-	-	-	-	-	-
LHR8	-	-	-	-	-	-	-	-	-	0.51	0.52	0.55
LHR9	-	-	-	-	-	-	-	-	-	-	-	-
LHR10	-	-	-	0.15	0.15	0.17	0.17	0.17	0.20	0.20	0.26	-
LHR11	-	-	-	-	-	-	-	-	-	0.49	0.47	0.51
LHR12	-	-	-	-	-	-	-	-	-	-	-	-
LHR13	-	-	-	-	-	-	-	-	-	-	-	-
LHR14	-	-	-	-	-	-	-	-	0.48	0.51	0.50	0.52
LHR15	-	-	-	-	-	-	-	-	-	0.48	0.52	0.55
LHR16	-	-	-	-	-	-	-	-	-	0.40	0.41	0.42
LHR17	-	-	-	-	-	-	-	-	-	-	-	-
LHR18	-	-	-	-	-	-	-	-	-	-	-	0.53
LHR19	-	-	-	-	-	-	-	-	-	(0.47)	-	-
LHR20	-	-	-	-	-	-	-	-	-	-	-	-

Table A8.7 Annual mean PM_{10} concentrations 1996 to 2004

	PM_{10} Annual Mean (gravimetric equivalent, $\mu g/m^3$)								
Site Code	1996	1997	1998	1999	2000	2001	2002	2003	2004
LHR2	-	35.8	30.3	29.5	27.4	29.3	27.7	31.1	27.1
LHR3	-	-	-	-	-	-	-	-	-
LHR4	-	-	-	-	-	-	-	-	-
LHR5	-	-	-	23.3	22.6	23.6	23.5	27.0	22.1
LHR6	-	-	-	-	-	-	-	-	-
LHR7	-	-	-	-	-	-	-	-	-
LHR8	-	-	-	-	30.0	32.4	19.1	(22.0)	(18.4)
LHR9	-	-	-	-	-	-	-	-	-
LHR10	40.5	35.1	28.1	28.9	27.6	27.3	29.9	27.6	-
LHR11	-	-	-	-	-	-	27.4	(33.8)	(27.3)
LHR12	-	-	-	-	-	-	22.6	(29.2)	(23.3)
LHR13	-	-	-	-	-	-	25.8	(25.5)	(21.2)
LHR14	-	-	-	-	-	23.4	23.9	26.8	-
LHR15	-	-	-	-	-	-	19.0	(23.1)	(20.2)
LHR16	-	-	-	-	-	25.7	25.0	29.8	25.8
LHR17	-	-	-	-	-	-	-	-	26.7
LHR18	-	-	-	-	-	-	-	-	24.8
LHR19	-	-	-	-	-	-	-	-	-
LHR20	-	-	-	-	-	-	-	-	-

Data capture >75%

(All data TEOM x 1.3)

Values in brackets are potentially affected by construction activities.

Table A8.8 Number of exceedences of 50 $\mu g/m^3$ as 24-hour mean PM_{10} concentration 1996 to 2004

	PM_{10} number of daily exceedences of 50 $\mu g/m^3$								
Site Code	1996	1997	1998	1999	2000	2001	2002	2003	2004
LHR2	-	48	29	28	20	21	15	39	12
LHR3	-	-	-	-	-	-	-	-	-
LHR4	-	-	-	-	-	-	-	-	-
LHR5	-	-	-	6	4	11	7	22	4
LHR6	-	-	-	-	-	-	-	-	-
LHR7	-	-	-	-	-	-	-	-	-
LHR8	-	-	-	-	-	23	1	(12)	(1)
LHR9	-	-	-	-	-	-	-	-	-
LHR10	90	54	22	25	17	26	-	-	-
LHR11	-	-	-	-	-	-	13	(67)	(22)
LHR12	-	-	-	-	-	-	9	(40)	(13)
LHR13	-	-	-	-	-	-	21	(24)	(0)
LHR14	-	-	-	-	-	8	9	26	-
LHR15	-	-	-	-	-	-	2	(16)	(2)
LHR16	-	-	-	-	-	12	12	-	13
LHR17	-	-	-	-	-	-	-	-	10
LHR18	-	-	-	-	-	-	-	-	11
LHR19	-	-	-	-	-	-	-	-	-
LHR20	-	-	-	-	-	-	-	-	-

Data capture >90%

Values in brackets are potentially affected by construction activities.

Results are gravimetric equivalent, based on TEOM x 1.3

Table A8.9 Annual mean $PM_{2.5}$ concentrations 1996 to 2004 (TEOM values unadjusted)

	$PM_{2.5}$ Annual Mean ($\mu g/m^3$)								
Site Code	1996	1997	1998	1999	2000	2001	2002	2003	2004
LHR2	-	-	-	-	-	-	-	-	-
LHR3	-	-	-	-	-	-	-	-	-
LHR4	-	-	-	-	-	-	-	-	-
LHR5	-	-	-	-	-	-	-	-	-
LHR6	-	-	-	-	-	-	-	-	-
LHR7	-	-	-	-	-	-	-	-	-
LHR8	-	-	-	-	-	-	-	(14.3)	(11.7)
LHR9	-	-	-	-	-	-	-	-	-
LHR10	-	-	-	15.4	14.4	13.6	12.5	15.2	-
LHR11	-	-	-	-	-	-	17.7	(19.5)	(17.0)
LHR12	-	-	-	-	-	-	-	(14.9)	(12.3)
LHR13	-	-	-	-	-	-	-	(14.8)	(12.7)
LHR14	-	-	-	-	-	-	-	-	-
LHR15	-	-	-	-	-	-	-	(14.7)	(12.3)
LHR16	-	-	-	-	-	-	-	-	-
LHR17	-	-	-	-	-	-	-	-	-
LHR18	-	-	-	-	-	-	-	-	-
LHR19	-	-	-	-	-	-	-	-	-
LHR20	-	-	-	-	-	-	-	-	-

Data capture >75% (Unadjusted)

Values in brackets are potentially affected by construction activities.

Appendix AQ.1.8

Table A8.10 Annual mean ozone concentrations 1996 to 2004

	O_3 Annual Mean (µg/m^3)								
Site Code	1996	1997	1998	1999	2000	2001	2002	2003	2004
LHR2	-	-	-	-	-	-	-	-	-
LHR3	-	-	-	-	-	-	-	-	-
LHR4	-	-	-	-	-	-	-	-	-
LHR5	-	-	-	-	-	-	-	-	-
LHR6	-	40	42	44	43	44	46	49	49
LHR7	-	-	-	-	-	-	-	-	-
LHR8	-	-	-	-	-	-	-	-	-
LHR9	-	-	-	-	-	-	-	-	-
LHR10	22.8	20.2	29.0	33.0	25.0	25.4	26.8	23.0	23.4
LHR11	-	-	-	-	-	-	34.5	32.2	32.6
LHR12	-	-	-	-	-	-	-	-	-
LHR13	-	-	-	-	-	-	-	-	-
LHR14	-	-	-	-	-	-	-	-	-
LHR15	-	-	-	-	-	-	-	-	-
LHR16	-	20	23	26	22	26	26	28	27
LHR17	-	-	-	-	-	-	-	-	-
LHR18	-	-	-	-	-	-	-	-	33
LHR19	-	-	-	-	-	-	-	-	-
LHR20	-	-	-	-	-	-	-	-	-

Data capture >75%

Annex 9
Data required from road traffic modelling

A9.1 This Annex includes the generic data requirements from road traffic modelling for use in air quality assessments at Heathrow. This should be read in conjunction with the section on surface access in Chapter 3.

TECHNICAL APPENDIX 3.1- P3.3 Generic Roads data requirements for air quality

For: Area1 HTM
Area: Area of Detailed Air Quality Assessment

Item		Specifics
ALL		All data below needed separately for each scenario & year tested.
A	Road traffic network	Data limited to those links modelled in 'HTM' which fall within the map area "detailed aq assessment" (i) Base case network + false nodes where new links associated with the 'option' only will connect in, so that links compared DM/DS are consistent.
		(ii) Road types, link refs, A & B nodes, road names + link lengths (kilometres) to be tabulated in Excel spreadsheet. (iii) Link lengths to be edited for those links extending outside the 'area'. (iv) All node co-ordinates to national Grid (6figureE, 6figureN) -to tie in to road geometry data. (v) Model network to be provided in format to enable import to GIS as layer (over base mapping). File format required is .dxf (vi) Road geometry for Part1 to be 'realistic' i.e., including false nodes for geometry. Taken from OSCAR (extract from relevant 5 kilometres tiles for relevant road type layers) ? (vii) Data to include details of new / changed links (to be provided as per above)
B	Traffic profiles	(i) To be representative of scenario tested (ie not fixed between forecast years or different schemes for same year) (ii) Profiles to represent 24hour average 7day, or separate for weekday and sat/sun (iii) Hourly flow profile preferred, alternatively timings and average flow for profile periods: a) night-time interpeak b) am peak c) daytime interpeak d) pm peak (iii) Profiles by specific roads preferred (e.g. profile for M11) or by road type (v) Profiles as dissaggregate as possible, preferably between airport and non-airport traffic (v) Profiles to be provided in Excel spreadsheets

For: Area1 HTM
Area: Area of Detailed Air Quality Assessment

Item		Specifics
C	Vehicle speed, composition, delay and queue length	(i) All data tabulated in Excel spreadsheet against link ref., coordinates and A & B nodes (ii) Data to be provided separately for the base-case and 'worst-case' option (iii) As a minimum, airport related traffic and non-airport related traffic provided as AADT flow data per link. (iv) Speed data to be dissaggregated as possible: minimum of AADT equivalent/link based on speed-flow curves for road types. Preferable hourly speed profiles by road type. (v) Speed data to be representative of scenario tested (ie not fixed between forecast years or different schemes for same year) (v) delay and queue length data only applies to HLTM modelled period. (vi) As a minimum, all other data to be provided as AADT equivalent per link.

	Part1 and Part2 Data																							Part1 only	
					AADT Flows (veh)		Flows by Time Period				Flows by Hour (1-24)				Speeds by Time Period				Speeds by Hour (1-24)				Data (average hour in period 07/10)	
Link Reference	Road Type	DM Flow AADT	Significance Indicator	AADT % HGV	Airport Flow	Non-airport Flow	Peak Hour	Shoulder	Inter-peak	Off-peak	1	2	.....	24	Peak Hour	Shoulder	Inter-peak	Off-peak	1	2	.....	24	Delay / vehicle (secs)	Ave. Queue at B Node
90706095490	15	9,082	0	14.9	0	4,023					28	20	.....	56					80	79	.....	79	11	1
90707095487	15	7,037	0	14.9	168	7,187					51	37	.....	103					80	79	.....	78	12	2
95054090707	15	2,304	0	14.9	13	1,984					14	10	.....	28					104	104	.....	104	0	0
95054095487	15	14,764	1	14.9	1,626	13,701					107	77	.....	215					91	89	.....	88	14	5
95380095485	5	3,330	0	7.7	3,954	1,211	537	443	331	91					73	74	76	79					50	0
95485095380	5	8,758	0	7.7	893	8,299	955	788	588	162					64	70	73	78					54	0
95485095486	16	8,624	1	11.9	5,944	4,916					65	43	.....	119					104	104	.....	104	18	4
95485097229	16	11,529	1	11.9	768	11,392					73	49	.....	134					104	104	.....	103	63	0
95486090706	15	1,475	0	14.9	0	769					5	4	.....	11					104	104	.....	104	0	0
95486095485	16	21,515	1	11.9	1,788	20,849					136	91	.....	249					80	80	.....	80	40	0
95486095490	15	7,412	1	14.9	5,956	4,159					71	51	.....	142					104	104	.....	104	13	3

For: Area2 2nd level HTM (if relevant)

Area: Area of Detailed Air Quality Assessment

Item		Specifics
ALL		All data below needed separately for each scenario & year tested.
A	Road traffic network	(i) Base case network + false nodes where new links associated with the 'option' only will connect in, so that links compared DM/DS are consistent. (ii) Road types, link refs, A & B nodes, road names + link lengths (kilometres) to be tabulated in Excel spreadsheet. (iii) Link lengths to be edited for those links extending outside the 'area'. (iv) All node co-ordinates to national Grid (6figureE, 6figureN) -to tie in to road geometry data. (v) Model network to be provided in format to enable import to GIS as layer (over base mapping). (vi) Data to include details of new / changed links (to be provided as per above)
B	Traffic profiles	(i) representative of forecast years tested (ii) Profiles to represent average 7day (iii) Period-based profiles: a) nighttime interpeak period b) am peak period c) daytime interpeak period d) pm peak period (iii) Profiles vary by road type (v) Profiles preferably between airport and non-airport traffic (v) Profiles to be provided in Excel spreadsheets
C	Vehicle speed, composition	(i) All data tabulated in Excel spreadsheet against link ref., coordinates and A & B nodes (ii) Data to be provided separately for the base-case and 'worst-case' option (iii) As a minimum, airport related traffic and non-airport related traffic provided as AADT flow data per link. (iv) Speed data to be dissaggregated as possible: minimum of AADT equivalent/link based on speed-flow curves for road types. Preferable period-based average speeds by link. (v) Speed data to be representative of forecast years tested

For:	Area3 - Other Roads (background model)	
Area:	Buffer Area for Air Quality Assessment + Area of Detailed Air Quality Assessment	
Item		Specifics
D	Total vehicle kilometres for each kilometres square	All data below needed for DM and DS separately. (i) VKM broken down by road type, separately for airport and non-airport LDV and HDV traffic (ii) For squares including Part1 and Part2, total VKM should be for 'other' roads only (ii) All data to be tabulated in Excel spreadsheet against link ref., A & B nodes, and coordinates (as National grid refs)

Centroid X Coordinate	Centroid X Coordinate	Grid Square	Road Type	Airport LDV	Airport HDV	Non-airport LDV	VKM Road	per Type
564500	231500	A1	9	1,351	79	6,505	380	8,315
564500	222500	A10	5	1,205	101	8,127	678	10,111
564500	221500	A11	3	1	0	222	16	238
564500	221500	A11	5	592	49	3,996	334	4,971
564500	221500	A11	9	15	1	14,819	862	15,692
564500	221500	A11	16	36	5	477	64	582
547500	231500	B1	9	569	33	2,741	160	3,503
547500	219500	B13	5	36	3	2,904	242	3,185
547500	219500	B13	9	37	2	2,785	162	2,986
547500	218500	B14	5	29	2	5,340	445	5,817
548500	222500	C10	9	0	0	94	5	99
548500	222500	C10	16	2,128	288	27,397	3,701	33,513
548500	221500	C11	3	40	3	8,752	619	9,414
548500	221500	C11	9	2,412	140	28,059	1,633	32,244
550500	230500	E2	15	624	109	27,674	4,845	33,252
550500	229500	E3	15	34	6	1,559	273	1,871
550500	225500	E7	9	4	0	3,621	211	3,836

For:	Area4 - AddOn Trip End Vehicle Emissions	
Area:	Area of Detailed Air Quality Assessment	
Item		Specifics
		All data below needed for DM and DS separately.
E	Trips by Mode Share	Passenger trips by driving trip mode (PnF, KnF)

	NR	DR	UG	Bus	P&F	K&F	Taxi	
	persons	persons	persons	persons	(veh)	(veh)	(veh)	Total Private
	Total passenger related trips to airport for period							
Trips	597	2581	2	1151	773	1923	869	**3565**
Mode Split	**8%**	**33%**	**0%**	**15%**	**10%**	**24%**	**11%**	**45%**
	Total passenger related trips from airport for period							
Trips	670	2895	2	1306	877	1923	986	**3787**
Mode Split	**8%**	**33%**	**0%**	**15%**	**10%**	**22%**	**11%**	**44%**
	Total input annual passengers to airport							
Mode Split	**6%**	**27%**	**0%**	**13%**	**18%**	**21%**	**15%**	**54%**

Appendix AQ.1.8

Annex 10
Glossary of terms

AADT Annual average daily traffic, i.e., the average number of vehicles per day.

Accuracy A measure of the closeness of the agreement between the result of a measurement and the true value (see also Uncertainty and Precision).

ACARE Advisory Council for Aeronautics Research in Europe.

ADMS Atmospheric Dispersion Modelling System. Proprietary name of dispersion modelling software developed and marketed by Cambridge Environmental Research Consultants.

Advect A horizontal movement of a mass of fluid, such as ocean or air currents. Can also refer to the horizontal transport of something, such as pollution, by such movement.

AERMOD US EPA (see below) air pollution dispersion model.

AIP Aeronautical Information Package. The official document used to publish Notifications required by the UK Air Navigation Order in accordance with the provisions of ICAO Annex 15.

Air pollution dispersion model A mathematical method for calculating air pollutant concentrations from emissions data under a set of known variables.

Air quality objective The UK Government has set target levels, expressed as a pollutant concentration in air, and dates for their achievement for nine air pollutants. These objectives are described in *The Air Quality Strategy for England, Scotland, Wales and Northern Ireland 2000*, and its amendment in 2002, and incorporated into legislation through the *Air Quality (England) Regulations 2000* and 2002.

ANMAC Aircraft Noise Monitoring Advisory Committee. A Department for Transport-chaired committee that advises the UK Government on aspects of aircraft noise monitoring at the three designated London airports.

Annual mean The average of the concentrations measured for each pollutant for one year. In the case of the air quality objectives this is for a calendar year.

Anthropogenic Caused or produced by humans.

AOC Air Operators Committee. A committee formed of operators of aircraft at each airport.

Approach The flight phase at the end of a flight from the holding beacon to touchdown on the runway. In the context of this report, it is used to define the section of the flight from 3000 feet above the airfield level to touchdown on the runway.

APU See Auxiliary Power Unit below.

Area source Emission sources that are too diffuse to identify individually, such as central heating boilers in houses and flats.

ARTEMIS Assessment and Reliability of Transport Emission Models and Inventory Systems. The objective of the 5th framework EU project was to develop a harmonised European emission model for road, rail, air and ship transport to provide consistent emission estimates at the national, international and regional level. The project was coordinated by TRL, and included 39 participants..

AST Appraisal Summary Table

ATC (1) Air Traffic Control. (2) Automatic traffic counts

ATM (1) Air transport movements, i.e., landings or take-offs of aircraft . (2) Air traffic management.

AURN Automatic Urban and Rural Network of air pollution measurement sites, managed by contractors on behalf of Defra and the devolved administrations.

Auxiliary power unit A small gas turbine engine normally situated in the tail of an aircraft and used to supply electrical and pneumatic power to the aircraft systems when not available from other sources.

Block Time The time elapsed from start of taxi out at origin to the end of taxi in at destination.

BOSS A BAA database containing information on aircraft movements.

CAEP Committee for Aviation Environmental Protection. The Committee within ICAO (see below) with responsibility for work related to the development of Standards, Recommended Practises and Procedures and/or guidance material dealing with the quality of the human environment.

Calibration (1) The process of multiplying the output of a model by a fixed correction factor to give, on average, a 1:1 relationship with measured data. (2) The process of reducing the uncertainty of monitoring data by controlled tests on the analyser, normally traceable to internationally accepted measurements standards.

Category B, C, D aircraft Speed related aircraft category as defined by ICAO (see below) Procedures for Air Navigation Services – Aircraft Operations (Doc 8168). Aircraft are divided into five speed categories, based on a nominal threshold speed defined as 1.3 times the stalling speed in the landing configuration at maximum certificated landing weight.

CERCCambridge Environmental Research Consultants Ltd

CFD Computational fluid dynamics

CHP See Combined heat and power below.

CLB, CLB1, CLB2 Fixed climb power settings (full climb and de-rates 1, 2, etc.), set by the FMC/FMS (see below) after the first power reduction during departure.

Climb-out A flight phase of the LTO cycle from take-off to (normally) 3000 feet.

CMS Continuous monitoring system

CNG Compressed natural gas. May be used as a vehicle fuel.

CO Carbon monoxide.

CO_2 Carbon dioxide

COBA COst Benefit Analysis. The Department for Transport's methodology for comparing the costs of providing road schemes with the benefits derived by road users (in terms of time, vehicle operating costs and accidents), and expressing the results in monetary terms.

Combined heat and power The combined production of electricity and usable heat. Steam or hot water which would otherwise be rejected when electricity alone is produced, is used for space or process heating.

Concentration The amount of a (polluting) substance in a volume (of air), typically expressed as a mass of pollutant per unit volume of air at standard conditions of temperature and pressure (for example, micrograms per cubic metre, $\mu g/m^3$) or as the ratio of the number of molecules of the pollutant to the total number of molecules in the volume of air (for example, parts per billion, ppb).

Corinair A programme to establish an inventory of emissions of air pollutants in Europe. It was initiated by the European Environment Agency Task Force and was part of the Corine (Coordination of information on the environment) work programme set up by the European Council of Ministers in 1985.

Correlation coefficient The fraction of the variability in one set of data that is proportional to the value of some other set of data.

COST 346 COST (COoperation in Science and Technology) Action 346 brings together interested parties across the EU to exchange and develop information on emissions and fuel consumption associated with heavy goods vehicles. The COST Action was coordinated by the Technical University of Graz.

Cranford Agreement A Ministerially approved noise mitigation undertaking given on 31 July 1952 at a meeting of the Cranford Residents' and District Amenities Association. The undertaking was a verbal statement of best endeavour that, as far as practicable, No. 1 runway (the northern runway) would not be used for landings or take-offs to the east, but it was accepted that there would be occasions when, for traffic reasons, both the No. 1 and No. 5 runway (the parallel southern runway) would have to be used.

Although this undertaking has not been formally recorded in the past, it is a well established measure that is published within the Manual for Air Traffic Services (1-1-11, Procedures for Easterly Operations) and in the Noise Abatement Notification for Heathrow, and any change or withdrawal of it would require prior consultation.

Data capture The percentage of all the possible measurements for a given period that were validly measured.

Daughter Directive Secondary European Union legislation, implementing a 'main' European Union Directive.

dB(A) 'A' weighted decibel. The Decibel (dB) is a unit of sound pressure level on a logorithmic scale. The A-weighting is a system of adjustment applied to sound of different frequencies to take account of the way the sensitivity of the human ear varies with sound frequency.

Defra Department for Environment, Food and Rural Affairs.

DETR The former Department of the Environment, Transport and the Regions. This Department has now been split into the Department for Transport (DfT), the Department for Environment, Food and Rural Affairs (Defra), and the Office of the Deputy Prime Minister (ODPM).

DfT Department for Transport.

D_P The mass of any gaseous pollutant emitted during the reference emissions landing and take-off cycle, for the ICAO individual aircraft engine emissions certification.

D_P/F_{00} The ICAO regulatory parameter for gaseous emissions, expressed as the mass of the pollutant emitted during the landing/take-off cycle divided by the rated thrust (maximum take-off power) of the engine.

ECS Environmental Control System. The ''air conditioning'' system on board aircraft.

EDMS Environmental Dispersion Modelling System required by the FAA (see below) for air quality assessments at US airports.

EI Emissions Index, defined as the mass of emission per unit fuel consumption, e.g. EINOx is the emissions index for NO_X emissions, and EIPM10, the same for PM_{10} emissions.

EIA Environmental impact assesment

Emission The amount of a (polluting) substance emitted in a certain amount of time, typically expressed as a mass of pollutant per unit time (for example, grams per second, or tonnes per year for a single source). May also be expressed per unit length of a road (for example, grams per second per metre), or per unit area of an urban area (for example, tones per annum per square kilometre).

Emissions inventory A quantification and compilation of emission sources by geography and time, usually including data covering one or several years.

Engine pressure ratio The ratio of the mean total pressure at the last compressor discharge plane of the compressor to the mean total pressure at the compressor entry plane, when the engine is developing its take-off thrust rating (in ISA sea-level static conditions).

ERCD Environmental Research & Consultancy Department of the Civil Aviation Authority

ERG Environmental Research Group at King's College London

EU Directive Europe-wide legislation which is incorporated into British law by Acts of Parliament or statutory instruments.

Euro I Europe-wide vehicle standard that required vehicles manufactured after 1992 to achieve set emissions limits. For petrol cars this was achieved by the fitting of three way catalysts.

Euro II, III, IV & V Europe-wide vehicle standards that are progressively stricter, for years 1996, 2000, 2006 and 2008 respectively.

European Commission This the body of the EU which proposes legislation (following requests by the Council and/or Parliament, or by own initiative). Most legislation is then amended and passed by the 25 governments in the Council of the Union, often with the

European Parliament. The Commission is then in charge of implementing the legislation. It is also enforces treaties and laws.

F_{00} Rated output. For engine emissions certification purposes, the maximum power/thrust available for take-off under normal operating conditions at ISA (see below) sea level static conditions without the use of water injection as approved by the certificating authority. Thrust is expressed in kilonewtons.

FAA Federal Aviation Administration

FDR Flight Data Recorder. A system on board aircraft for recording a large number of parameters regarding aircraft, engine and operational performance data. The FDR is a crash worthy recorder used in accident investigation. It is more common for data to be extracted from Quick Access Recorders (QAR), commonly installed on aircraft in addition to the FDR. QARs work in a similar manner to the FDR, but are not crash worthy and often record a greater range of parameters.

Fine particles Particulate matter in air with an equivalent aerodynamic diameter of ten microns or less. Also referred to as PM_{10}.

Flare The change in the flight path of an aircraft so as to reduce the rate of descent for touchdown.

FMC/FMS Flight Management Computer/Flight Management System. An on-board computer system that can be programmed by the pilot to fly complex trajectories and perform certain flight functions automatically.

g Gramme

Gas oil A medium oil used as a fuel in diesel (i.e., compression ignition) engines and burnt in central heating systems.

GIS Geographical Information System

Greater London The administrative area comprising 32 London Boroughs and the City of London.

HA Highways Agency.

HDV Heavy Duty Vehicle. Any road vehicle over 3.5 tonnes design gross weight.

HGV Heavy Goods Vehicle. A goods-carrying vehicle over 3.5 tonnes design gross weight.

HTM Heathrow Transport Model.

IATA International Air Transport Association. The international representative body for the aircraft operators.

ICAO International Civil Aviation Organisation (see also CAEP above).

ICCAIA International Coordinating Council of Aerospace Industry Associations. The international representative body for the aerospace industry.

Idle The lowest power at which an engine can operate. For aircraft it is the normal setting used when static and for taxiing operations.

ISA International Standard Atmosphere. A set of atmospheric temperature, pressure density, humidity conditions, etc. defined by ICAO (see above) to be used as a common datum.

Kernel technique This exploits the fact that the annual-mean air pollution concentration arising from a number of pollutant sources is the simple sum of the annual-mean concentrations from each source taken individually, provided the sources behave passively (i.e., one source does not change the turbulent environment in which another source is dispersing). Thus, for example, all ground-level sources with the same initial-dispersion parameters and the same diurnal/seasonal profiles are handled by performing a single ADMS model run for one such source and applying the resulting concentration field (termed a 'kernel') to each source with an appropriate shift of origin.

Kerosene Hydrocarbon fuel for jet aircraft.

kg Kilogramme.

kilo Used as a prefix to a scientific unit, this means 1000 times.

Knots Speed measured in nautical miles per hour.

LAEI See London Atmospheric Emissions Inventory below.

Landing and Take-Off (1) The ICAO reference emissions certification cycle obtained by running an isolated aircraft engine in a test cell at four power settings and times, and correcting the results to ISA at sea level, except that the reference absolute humidity shall be 0.00634 kg water/kg dry air. (2) Also used in this report to describe actual aircraft arrival and departure operations below a height of 3000 feet above the aerodrome level.

LDV Light Duty Vehicle. Any road vehicle not exceeding 3.5 tonnes design gross weight.

LGV Light Goods Vehicle. A goods-carrying vehicle not exceeding 3.5 tonnes design gross weight.

London Atmospheric Emissions Inventory An inventory of sources of air pollutants within Greater London prepared by the Greater London Authority.

Low emission zone A zone from which vehicles which fail to meet a specified emission standard (such as Euro III – see above) are excluded.

LPG Liquid petroleum gas. May be used as a vehicle fuel.

LTO See Landing and Take-Off above.

Mach number Speed divided by the local speed of sound.

Maximum hourly average The highest hourly reading of air pollution obtained during the time period under study.

Mean The average of a set of data.

MCERTS Monitoring Certification Scheme. The Environment Agency's scheme which provides a framework within which environmental measurements can be made in accordance with the Agency's quality requirements.

MES Main Engine Start. The part of the APU (see above) load cycle where air is bled off the APU to drive turbines to start the first main (propulsion) engine, and usually represents the highest load off-take. Subsequent main propulsion engines are normally started by cross bleeding air from this first main engine.

μg/m³ Micrograms per cubic metre of air. A unit for describing the concentration of air pollutants in the atmosphere, as a mass of pollutant per unit volume of air. A concentration of 1 $\mu g/m^3$ means that one cubic metre of air contains one microgram of pollutant.

mg/m³ Milligrammes per cubic metre of air. A unit for describing the concentration of air pollutants in the atmosphere, as a mass of pollutant per unit volume of clean air. This unit is one thousand times larger than the $\mu g/m^3$ unit listed above.

MIC Model Inter-Comparison study carried out for the Project for Sustainable Development of Heathrow

Microgramme (μg) One millionth of a gramme.

Minor roads Generally denotes non A-roads or motorways. In emission inventory terms refers to those not modelled explicitly.

MJ Magajoule. A unit of energy equal to 10^6 or 1 million joules, or to 0.2778 kilowatt hours.

MMU Manchester Metropolitan University

mppa Million passengers per annum (aircraft).

MTOW Maximum take-off weight

NAEI See National Atmospheric Emissions Inventory below.

National Atmospheric Emissions Inventory An inventory of sources of air pollutants for the whole of the UK.

NATS National Air Traffic Services, which provides air traffic control services to aircraft flying in UK airspace, and over the eastern part of the North Atlantic.

Natural gas is mainly comprised of methane (CH4) and is a conventional (fossil) fuel. It can significantly reduce emissions of NO_X and PM_{10} when used as a road vehicle fuel compared with diesel in certain applications. It is also a common fuel for domestic heating and used as a chemical feedstock.

Nautical mile Length of one minute of latitude, standardised to 6,080 feet. 1 nautical mile = 1.1515 statutory miles or = 1.8532 kiliometres.

Netcen National Environmental Technology Centre. An operating division of AEA Technology plc.

NEDC New European Driving Cycle. The combined chassis dynamometer test used for emission testing and certification of vehicles in Europe is composed of four ECE Urban Driving Cycles, simulating city driving, and one Extra Urban Driving Cycle (EUDC), simulating highway driving conditions. The cold-start version of the test, introduced in 2000, is also referred to as the New European Driving Cycle (NEDC).

ng/m³ Nanogrammes per cubic metre of air. A unit for describing the concentration of air pollutants in the atmosphere, as a mass of pollutant per unit volume of clean air. This unit is one thousand times smaller than the $\mu g/m^3$ unit listed above.

nm (1) Nautical mile, see above. (2) Nanometre, equal to 10^{-9} metre or one billionth part of a metre.

NMVOC Non-methane volatile organic compounds

NO Nitric oxide or nitrogen monoxide. Formed from nitrogen in the atmosphere during high temperature combustion.

NO_2 Nitrogen dioxide. Small amounts are formed from nitrogen in the atmosphere during high temperature combustion but the majority is formed in the atmosphere through the conversion of nitric oxide (NO) in the presence of ozone (O_3).

NO_X(1) Oxides of nitrogen, mainly nitric oxide or nitrogen monoxide (NO) and nitrogen dioxide (NO_2). (2) for ICAO (see above) certification, the sum of the amounts of the nitric oxide and nitrogen dioxide contained in a gas sample calculated as if the nitric oxide were in the form of nitrogen dioxide.

NPR Noise Preferential Route. These are departure routeings established to ensure that departing aeroplanes avoid over-flying noise-sensitive areas in the vicinity of an aerodrome as far as practicable. The rules for establishing NPR's are contained in ICAO Procedures for Air Navigation Services – Aircraft Operations (Doc 8168).

NTK Noise and Track-Keeping. The computer system used to monitor and record aircraft departure tracks, used to compile track-keeping statistics.

OGV1, OGV2 Classification of vehicles over 1.5 tonnes unladen weight according to their axle loads. OGV1 includes 2 and 3-axle rigid and articulated goods vehicles. OGV2 includes rigid and articulated goods vehicles with 4 or more axles.

OPR Overall Pressure Ratio. A measure of the ratio of the maximum air pressure reached in the engine relative to the engine inlet pressure. OPR is a selected engine design criteria.

Particle number A method of measuring air-borne particles. Instead of weight the actual number of particles per unit time are measured.

Particulate Mass Emission Index The number of grams of particulate matter generated in the exhaust per kg of fuel burned.

Particulate Number Emission Index The number of particles generated in the exhaust per kg of fuel burned.

PCU Passenger car unit A unit for measuring the volume of traffic in which the passenger car is adopted as the standard unit and other vehicles are assessed relative to passenger cars. In urban areas, motorcycles, scooters and mopeds are counted as 0.75 PCU and goods vehicles over 1.5 tonnes unladen weight as 2 PCUs.

Percentile A value that is the rank at a particular point in a collection of data. For instance, a 98th percentile of values for a year is the value that 98% of all the data in the year fall below, or equal.

PLTOW Performance Limited Take-Off Weight. The maximum take-off weight allowable for an aircraft based on performance limitations only. This is different from the Maximum Take-Off Weight (MTOW), which is based on structural limitations. The maximum allowable weight for the aircraft to operate at is the lesser of the PLTOW, and MTOW for the particular conditions.

Plume 1) The volume of mair emitted as a discrete body by an emission source 2) The region behind an aircraft containing the engine exhaust.

PM_{10} Particulate matter with an equivalent aerodynamic diameter of ten microns (10 µm) or less.

$PM_{2.5}$ Particulate matter with an equivalent aerodynamic diameter of 2.5 microns (2.5 µm) or less.

Point source A stationary location or fixed facility from which pollutants are discharged or emitted, this may include a number of stacks or a large plant.

ppb Parts per billion. A unit for describing the concentration of air pollutants in the atmosphere, as a volume ratio of pollutant per unit clean air, only suitable for gaseous pollutants (and hence not used as a unit for particles). This unit is one thousand times smaller than the ppm unit (see below).

ppm Parts per million. A unit for describing the concentration of air pollutants in the atmosphere, as a volume ratio of pollutant per unit clean air, only suitable for gaseous pollutants (and hence not used as a unit for particles).

Precision A measure of the closeness of the agreement between the results of successive measurements where the true value remains constant (see also Accuracy and Uncertainty).

Pressure ratio See *Engine pressure ratio* above.

Primary NO_2That part of engine NO_X emissions released directly from the exhaust as NO_2.

PSDH Project for Sustainable Development of Heathrow

PSTOPS & SSTOPS Variables available from SATURN (See below) providing information on the location of the back of a queue of traffic.

PSV Public Service Vehicle. A vehicle licensed to carry (normally 9 or more) fare-paying passengers.

Rated Output The maximum thrust available for take-off under normal operating conditions, as approved by the certificating authority.

Ratification Involves a critical review of all information relating to a data set, in order to amend or reject the data. When the data have been ratified they represent the final data to be used (see also Validation).

Relative humidity The ratio of the partial pressure of water vapor in an air parcel to the saturation pressure (usually over a liquid unless specified otherwise).

Rolling or running mean An average set for a specific time period (for example, eight hours) where the mean is continuously calculated for each hour over the year. For the running mean carbon monoxide value, expressed as the maximum eight-hour mean, this is calculated over all the consecutive eight-hour periods in a year, i.e., for (365 x 24) - 8 = 8,752 sets of eight-hour periods.

SATURN Simulation and Assignment of Traffic to Urban Road Networks. A traffic management modelling package, which is commonly used to model small-scale traffic flows, from junctions to towns.

SEA Strategic environmental assesment.

SERAS South East and East of England Regional Air Services study.

SFC Specific Fuel Consumption. The fuel used per unit thrust expressed as kilogrammes of fuel per kilogramme of thrust per hour.

SID Standard Instrument Departure. A designated instrument flight rule (IFR) departure route linking the aerodrome or a specified runway at that aerodrome with a specified significant point at which the en-route phase of a flight commences. The SID gives a set of instructions that should allow the operator of an aircraft to fly along an NPR (see above).

Statistical significance In normal English, "significant" means important, while in Statistics "significant" means probably true (not due to chance). A research finding may be true without being important. When statisticians say a result is "highly significant" they mean it is very probably true. They do not (necessarily) mean it is highly important.

SN Smoke Number. A dimensionless term quantifying smoke emissions developed by the Society of Automotive Engineers (SAE).

Surface Roughness A length-scale describing how the variation in land cover (forest, tall buildings etc) influences the development of turbulence in a flow of air above that surface.

Tb Temperature at the inlet of the engine combustion system.

TEOM Tapered element oscillating microbalance. Equipment used for measuring fine particulate matter such as PM_{10}.

TfL See Transport for London below

TIM Time in Mode. Defined as the time spent at a specific power setting, during each phase of the LTO cycle.

Transport for London (TfL) The body within the Greater London Authority Group with responsibility for managing London's main road network (other than motorways), the underground and bus services.

TRL Transport Research Laboratory.

True value The value of a concentration, for example, which is entirely consistent with the definition of the units in which it is given. This is the value that would be obtained by a perfect measurement.

UHC Unburned hydrocarbons.

Uncertainty A measure, associated with the result of a measurement, that characterizes the range of values within which the true value is expected to lie. Uncertainty is usually expressed as the range within which the true value is expected to lie with a 95% probability, where standard statistical and other procedures have been used to evaluate this figure. Uncertainty is more clearly defined than the closely related parameter *accuracy*, and has replaced it on recent European legislation.

UNECE United Nations Economic Commission for Europe, comprises EU Member States together with Central and Eastern European countries, the United States and Canada.

USEPA United States Environmental Protection Agency

V_1 Decision speed, up to which it should be possible to abort a take-off after failure of the critical engine and stop safely within the remaining runway length. After reaching V_1 the take-off must be continued

V_2 Take-off safety speed. The speed that must be achieved at the end of the take-off (at a height of 35 feet), following the failure of the critical engine at the critical point along the take-off roll.

Validation (1) General comparison of modelled results against monitoring data at relevant locations. (2) Screening monitoring data by visual examination to check for spurious and unusual measurements (see also Ratification).

V_{MCG} Minimum control speed on the ground.

VOC Volatile organic compound

V_{ZF} Zero-flaps minimum safe manoeuvring speed.

Annex 11
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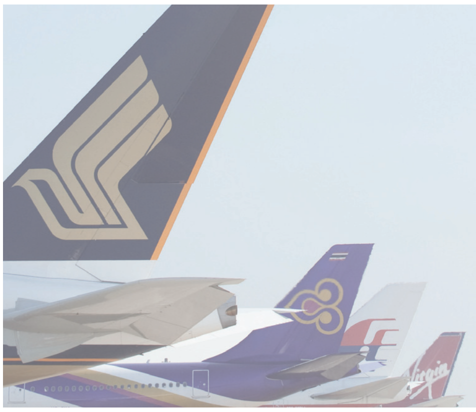
Appendix J

Heathrow Airport Air Quality Modelling for 2008/9: Results and Model Evaluation. Report by AEA Energy & Environment on behalf of BAA, July 2010. AEAT/ENV/R/2948/Issue 1



Heathrow
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Appendix AQ.1.15

Appendix AQ.1.15

AEA

Heathrow Airport Air Quality Modelling for 2008/9: Results and Model Evaluation

Report to BAA

AEAT/ENV/R/2948/Issue 1
July 2010

Appendix AQ.1.15

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AEA
The Breeze
2 Kelvin Close
Birchwood
Warrington
WA3 7PB

t: 0870 190 6929
f: 0870 190 6933

AEA is a business name of AEA Technology plc

AEA is certificated to ISO9001 and ISO14001

Author	Name	B Y Underwood, C T Walker and M J Peirce
Approved by	Name	B Y Underwood
	Signature	[redacted]
	Date	29th July 2010

Appendix AQ.1.15

Executive Summary

E.1 In 2009, BAA commissioned AEA to carry out an air quality study for Heathrow with three components:

(a) to compile an inventory of atmospheric emissions arising from airport operations for the 12-month period from 1st April 2008 to 31st March 2009, including the pollutants NO_x (oxides of nitrogen), PM_{10} (particulate matter with an aerodynamic diameter less than 10 microns) and $PM_{2.5}$ (particulate matter with an aerodynamic diameter less than 2.5 microns);
(b) to carry out a dispersion-modelling study to quantify the contributions from airport sources and from road-vehicle emissions on the major road network around Heathrow to airborne concentrations in residential areas close to the airport; to combine these contributions with the estimated contribution from all other sources to give a view of total airborne concentrations around Heathrow in 2008/9;
(c) to evaluate the performance of the model using monitoring data collected around Heathrow in 2008/9.

E.2 This report presents the results of the model evaluation, then goes on to provide best estimates of the 2008/9 spatial distribution of concentrations of the designated pollutants around Heathrow. Separate reports are available on the compilation of the airport emission inventory and on the methodology used for the dispersion-modelling study.

E.3 The air quality around Heathrow is of continuing concern. The annual mean NO_2 concentration in some residential areas near the airport is close to or above the national objective, which should have been met by 2005. Thus, there is a vital interest in understanding how much airport operations contribute to pollutant concentrations in the vicinity of the airport. Although monitoring provides spot checks on the situation at specific locations, modelling is required to give a fuller appreciation of the spatial variation in airborne concentrations. It is also needed to allow the relative contributions to the concentration at key locations from various sources on the airport to be identified and to provide a basis for forecasting the air quality impact of operational changes on the airport.

E.4 This work updates the air quality modelling carried out to provide the evidence base for the last government's consultation on 'Adding Capacity at Heathrow', which followed the recommendations of the expert panels set up under the Project for the Sustainable Development of Heathrow (PSDH). The air quality work underpinning the consultation (referred to below as the PSDH work) was based on an airport emission inventory for 2002.

E.5 The PSDH work included an evaluation of the performance of the model, comparing modelled values for 2002 with measured values obtained for the same period from monitoring stations around the airport. This showed that annual-mean NO_x and NO_2 concentrations across the set of nine monitoring sites included in the comparisons were predicted with no significant average bias. Compilation of the 2008/9 emissions inventory and the associated dispersion modelling study have been carried out using a methodology very similar to that used for the PSDH work, so the conclusions drawn from the PSDH study are still relevant.

E.6 However, there are a few differences in the methodology for the 2008/9 study compared to that used for the PSDH work, including differences in the calculation of the contribution from sources beyond the airport and near-Heathrow major road network and a different approach to deriving NO_2 concentrations from NO_x concentrations. Moreover, the aircraft fleet operating at the airport and the distribution of engine technologies in the traffic on the roads around Heathrow are constantly evolving, and it is important to check that the modelling continues to give an unbiased view of concentrations around the airport as the relative contributions from various sources change. In addition, a number of monitoring sites around the airport have come into operation since 2002, including Sipson*, Harmondsworth,

* These are the short names of monitoring sites, introduced for convenience in the discussion – fulll site details are given in Section 2 of the report

Harlington, Oxford Avenue, Hatton Cross and Hayes. Except for Hayes, the sites are expected to have a significant airport contribution to annual-mean NO_x concentrations, and thus provide the opportunity for a more detailed test of the modelling of airport sources than possible with 2002 data.

E.7 Given the current situation around Heathrow in relation to national objectives and limits for NO_2, the evaluation places particular emphasis on this pollutant. However, NO_2 concentrations are derived from NO_x concentrations, so separate evaluations are made of the modelling for NO_x concentrations and the methodology for deriving NO_2 concentrations from NO_x concentrations. Evaluation of the modelling methodology for PM_{10} and $PM_{2.5}$ is limited by the characteristics of the available monitoring data.

E.8 The focus of attention in this study is to assess how well the model predicts concentrations in residential areas around the airport, in particular at locations strongly influenced by sources related directly to the operation of the airport. This includes receptors that are appreciably influenced by emissions arising within the airport perimeter itself but also receptors influenced strongly by road traffic emissions, where the traffic itself has a major airport-related component. Thus, concentrations are calculated within a 9 km square area, centred on the airport, with not only total concentrations presented in the area but also the separate contributions from key source categories. The area is very similar to that used in the PSDH work, which aids comparisons between the two studies. The 2008/9 model evaluation has been based on comparisons with continuous data obtained at 12 monitoring sites within the area, all having continuous NO_x/NO_2 analysers, 10 having continuous PM_{10} analysers and 3 with continuous $PM_{2.5}$ analysers.

E.9 A number of the data sets used have a data capture (fraction of hours in the 2008/9 period with valid data) less than 90% - usually taken as a lower limit when using data to test compliance with annual mean objectives - but nevertheless situated in important locations from a model evaluation perspective. For model evaluation purposes, however, the data-capture constraint can be loosened, given that the results of the dispersion modelling are available on an hourly basis. Thus, for model-monitoring comparisons at a particular site, the model results have been based on those hours of met data for which valid concentration measurements are available.

E.10 The results and conclusions of the study are summarised by pollutant below.

NO_x

E.11 Total period-mean NO_x concentrations are predicted with an average fractional discrepancy, defined as *(modelled value-measured value)/measured value*, of -5.2% (i.e. the model under-predicts on average by 5.2% across the sites), with a standard deviation of 12.2% (12 sites), where the latter is a measure of the site-to-site variability in the measured values that has not been captured by the model. Assuming the measurement uncertainty (one standard deviation) for long-period average NO_2 concentrations from continuous analysers to be around 5%, the observed bias is highly unlikely to be explained by statistical measurement fluctuations for a finite sample of 12 sites. Similarly, a large fraction of the unexplained site-to-site variability is unlikely to be attributable to measurement uncertainties. Thus, the model is slightly biased towards under-prediction of total period-mean NO_x concentrations.

E.12 The three sites with the largest contribution from emissions on the road network have significant negative values of the fractional discrepancy, suggesting that there is a systematic underestimation of this contribution, which is offset by an overestimation of other contributions across the sites leading to a quite small average fractional discrepancy.

Airport Sources

E.13 A comparison of measured and modelled NO_x concentration differences between sites north of the airport and Oaks Rd (south of the airport) for selected wind directions indicates that the model has no significant tendency either to overestimate or to underestimate the contribution of airport sources* to the period-mean NO_x concentrations at receptors in the residential areas north of the airport, to the level of accuracy allowed by measurement uncertainties. In particular, it represents well the variation in the airport concentration contribution with distance from the principal sources on the airport and the variation with east-west location in relation to the ends of the northern runway.

E.14 This gives confidence that the model provides a good basis for investigating the potential impact on residential areas of operational changes on the airport that affect the magnitude and spatial distribution of NO_x emissions, for example the abandonment of the Cranford agreement (which would then allow departures on runway 09L) and the construction of a third runway north of the current runways. It also indicates that the model tendency to underestimate total period-mean NO_x concentrations is unlikely to arise from the modelling of airport sources.

E.15 A breakdown of the concentration differences across the airport by wind speed indicates a tendency for the model to overestimate at low wind speed and underestimate at high wind speed. Thus the remarkable level of agreement (for sites north of the airport) between modelled and measured values of the airport contribution to period-mean NO_x concentration is partly fortuitous, arising from a compensation between the two tendencies, and may not be maintained to the same extent if the met data in a given year exhibited a markedly different wind speed distribution to that in 2008/9. Nevertheless, given that the agreement is reasonably good in every wind-speed range, it would require a major shift in wind-speed frequency distribution to generate a significant discrepancy. The observed trend with wind speed could point to inaccuracies in the plume-rise modelling for aircraft sources, but the evidence from comparisons involving little influence from aircraft sources indicates that this cannot be the full explanation.

E.16 At Oaks Rd, close to the southern boundary of the airport, concentration-difference comparisons indicate that the modelling overestimates the contribution from airport sources by around 3 $\mu g/m^3$ (for a total airport contribution of 17 $\mu g/m^3$). The apparent greater overestimation of the airport contribution at Oaks Rd than at sites north of the airport may derive partly from the tendency noted above for the model to overestimate at low wind speeds, which has a greater effect south of the airport due to the greater probability of low wind speeds for northerly winds than for southerly winds. Nevertheless, the discrepancy at Oaks Rd is only of comparable size to the judged uncertainty in measured differences in period-mean concentrations.

E.17 Given the evidence that the modelling is a reliable basis for predicting the spatial variation of the contribution from airport sources to period-mean NO_x concentrations around the airport, contours of this contribution have been derived from model results on a spatial grid of receptor points. These indicate that NO_x contributions from airport sources above 30 $\mu g/m^3$ in 2008/9 were confined to areas within the airport boundary, with the contribution in the nearest residential areas in the range 10-20 $\mu g/m^3$. The modelled contribution from airport sources falls to at most 6.3 $\mu g/m^3$ at the M4 motorway, but varies in an east-west direction along the motorway as a result of the contour shape, which is governed by the prevalence of south-westerly winds coupled with the spatial distribution of sources on the airport. Contour shapes show some differences from those calculated for 2002 in the PSDH work, partly as a result of the opening of T5 and partly due to a greater frequency of westerly winds in 2008/9 than in 2002.

E.18 A detailed comparison of the 2008/9 modelled values of the airport contribution at 13 representative sites with corresponding values from the PSDH work shows that the 2008/9 values are broadly comparable to those for the PSDH 2002 and 2010SM cases, which is in line with the magnitude of the estimated airport emissions for the three cases. There are some detailed differences from the PSDH results not related to emission differences that principally reflect differences in the wind rose between 2008/9 and 2002.

* Defined to include all sources within the airport perimeter plus elevated (LTO) aircraft sources, although the latter make a small contribution to ground-level concentrations once they are above a few hundred metres in height.

Road Network Sources

E.19 Comparison of concentration differences for pairs of sites with one of the sites (Hillingdon, LHR2, Hayes, Oxford Avenue) strongly affected by a nearby road indicates that the modelling underestimates the contribution to period-mean NO_x concentrations from emissions on the major road network around Heathrow; this reinforces the evidence provided by an examination of the discrepancies in total period-mean concentrations. The extent of the underestimation is significantly greater than can be attributed solely to measurement errors.

E.20 It would be premature to view this as evidence for a systematic under-prediction of road vehicle NO_x emissions using the current emissions methodology, given that the basic traffic data used in the emissions quantification have not been fully evaluated. There is evidence that modelled total traffic flow on the M4 motorway adjacent to the Hillingdon site is well represented by the traffic model, but there is no information on how realistic are the predictions of Heavy Duty Vehicles (bus/coach and Heavy Goods Vehicle) fraction and vehicle speed, parameters that are particularly important from an emissions perspective. For the M25, it appears that, in addition, total flows are underestimated.

E.21 There is some evidence from the concentration-difference comparisons that a key contributor to the discrepancies at near-road receptors relates to network intersections or other areas of flow disturbance, which lead to traffic queues, flow breakdown or changes in speed. It is possible to account for queues in the emissions methodology if they are explicitly recognised in the traffic data, but in the set of data available for the 2008/9 inventory any link delays were absorbed into effective link speeds, thereby not allowing the spatial distribution of queuing emissions to be represented. It is recommended that this deficiency is removed in future traffic data sets generated for air quality assessment purposes. With reference to speed data, it may not be enough to provide hourly-averaged speed if this speed is the net effect of periods of smooth flow interspersed with periods of flow breakdown.

E.22 There appears to be an additional discrepancy between modelling and measurements at Green Gates, not attributable to airport sources and not readily explained in terms of under-prediction of the contribution from the major road network around Heathrow. This may point to a local source not included in the modelling, although measurement uncertainties for concentration differences may also have played a part. Although large point sources have been modelled individually, it cannot be ruled out that the 1-km spatial resolution of emissions from medium-sized point sources in the LAEI may be having an influence on the accuracy of modelled concentrations close to Green Gates.

E.23 There are also additional discrepancies in NO_x concentrations at Hayes that cannot be explained in terms of under-prediction of the road network contribution. Hayes has a particularly large contribution from area sources representing emissions from the London Atmospheric Emissions Inventory (LAEI) and the National Atmospheric Emissions Inventory (NAEI), including a substantial contribution from the Great Western railway line. However, there is not enough information to determine if the discrepancy arises from sources local to the site or is more widespread in Hayes.

E.24 The observed discrepancies point to the need for a more detailed evaluation of traffic model outputs and how these are used to calculate emissions. It may be advantageous to defer that work until a traffic model is available that has been calibrated and validated with particular reference to those traffic characteristics that are key to the quantification of road traffic emissions and to the estimation of the road-network contribution to airborne pollutant concentrations.

E.25 In the interim, in order to generate a ‘best-estimate’ modelled NO_x concentration field around the airport, the road-network NO_x contribution was scaled everywhere by a constant factor (1.21), chosen so that the average discrepancy between modelled and measured period-mean NO_x concentrations across the 12 monitoring sites is reduced to zero. This simple procedure has the merit of increasing the concentrations more in absolute terms in areas where the road network makes a large contribution, reflecting the evidence from the monitoring data, but is unlikely to remove all the discrepancy relating to the road network at sites such as Hayes and LHR2 (although at least some of the discrepancy at these sites may be due to features specific to the site and not necessarily generalisable to other receptors). Also, the scaled NO_x concentration field may still underestimate concentrations at near-road receptors that are strongly influenced by traffic queuing at junctions or are situated close to areas of the network subject to other types of flow disruption.

E.26 Although the average discrepancy across the sites has been reduced to zero, it is likely that there is a residual tendency towards overestimation at receptors immediately south of the airport because of an over-prediction of the contribution from airport sources in northerly winds. Similarly, for receptors to the (north) west of the airport there may be a systematic residual underestimation because of the under-prediction of the contribution from the M25.

E.27 The contour plot of period-mean NO_x concentration based on the set of 2008/9 results that include the road-network scaling factor is much closer in appearance to the equivalent plot for the PSDH 2002 case than for the PSDH 2010SM case. However, the NO_x 75 µg/m^3 contour in the 2008/9 results (approximately equivalent to the NO_2 40 µg/m^3 contour) does not extend as far from the airport boundary into Harlington as in the 2002 results; also, a smaller area of Hayes between the railway line and the M4 is above the 75 µg/m^3 level.

E.28 A more detailed comparison of results for 13 representative sites shows that the average total NO_x concentration from the 2008/9 study is much closer to the equivalent PSDH average for 2002 case than for the forecast 2010SM case, with the average 3.8% lower than for the 2002 PSDH case and 29.3% higher than for the 2010SM case.

NO_2

E.29 The availability of ozone measurements at three of the monitoring sites included in the analysis allows a separate test of the component of the methodology for deriving NO_2 concentrations from NO_x concentrations that predicts the total oxidant (sum of O_3 and NO_2) concentration from the background oxidant and the local NO_x concentrations. The modelled values agreed with measured values within the level of accuracy of the measurements, with an average fractional discrepancy between modelled and measured values of 6% (overestimation).

E.30 A comparison of modelled and measured period-mean NO_2 concentrations at the 13 monitoring sites included in the study – using the modelled NO_2 concentrations derived from NO_x concentrations that include the road-network scaling factor – gives an average fractional discrepancy of 1.6% (i.e. the model overestimates by on average 1.6%), with a standard deviation of 9.7%. For comparison, using NO_x concentrations that do not include the road-network scaling factor, the average fractional discrepancy in period-mean NO_2 concentrations is -1.8% (i.e. an underestimation of 1.8%), with a standard deviation of 9.7%. Neither of the two values of average fractional discrepancy can be interpreted as a significant model bias.

E.31 The performance of the Jenkin approach for deriving period-mean NO_2 concentrations from period-mean NO_x concentrations can be separated from the performance of the modelling for NO_x concentrations to some extent (though not fully) by comparing NO_2/NO_x ratios. Using the NO_x results that include the road-network scaling, the average fractional discrepancy in the NO_2/NO_x ratios is 2.1% (i.e. the model on average overestimates the ratio by 2.1%) with a standard deviation of 5.5%. For comparison, without the road-network scaling factor, the average fractional discrepancy is 4.1% with a standard deviation of 6.0%. This level of agreement is within what is expected from the semi-empirical (Jenkin) methodology used for this study, judging from the scatter on the data points used to derive the underlying $[NO_2]/[OX]$ relationship. Thus, the results indicate that the Jenkin methodology does not introduce any significant bias into the model results, so that once the bias in NO_x concentrations has been removed no further model adjustment is necessary.

E.32 The NO_2 concentration results on a grid of receptors have been used to generate contours of period-mean NO_2 concentration in 2008/9. Areas of exceedence of the annual-mean limit (40 µg/m^3) extend out into residential areas from the airport boundary, from the motorways and from the Great Western railway line, in accord with the areas of highest emission density. The grid results may not have the spatial resolution to determine if individual receptors close to the contour are within or outside the exceedence area, which would require closer investigation on a receptor-by-receptor basis. It should be borne in mind that the NO_2 contours presented should be viewed as 'interim' on the grounds that they have been derived from NO_x values based on the interim traffic model results, adjusted using the simple road-network scaling factor.

E.33 Comparing the 2008/9 NO_2 contour plot with the equivalent 2002 PSDH plot shows that the exceedence areas extend further out from the motorway and railway line into residential areas in 2008/9, despite the NO_x concentrations in 2008/9 being on average similar to or slightly lower than in the 2002 PSDH results at a given location, implying that the NO_2/NO_x ratios are higher in 2008/9. On the other hand, the exceedence area in 2008/9 does not extend as far north into Harlington from the airport boundary as in the 2002 PSDH case, reflecting the lower modelled NO_x concentrations in this area in 2008/9. The increase in NO_2/NO_x ratios can be traced primarily to the higher average primary NO_2 fraction* in 2008/9 compared to that in the 2002 analysis, principally resulting from the higher fractions now associated with road-traffic NO_x emissions.

E.34 Examining the changes from the PSDH results in more detail at 13 representative receptors shows that the average modelled NO_2 concentration across these sites for 2008/9 is 4.7% higher than for the 2002 PSDH case, whereas the average NO_x concentration is 3.8% lower. Thus, the modelled NO_2/NO_x ratios for 2008/9 are on average 7.9% higher than for the 2002 PSDH case, whereas they are lower than for the PSDH 2010SM case by on average 11.6%.

PM_{10}

E.35 Based on the data from the ten continuous PM_{10} analysers in the study area, the average fractional discrepancy between modelled to measured total period-mean PM_{10} concentration is -0.4 %, with a standard deviation of 17.5%. The measured value at Harmondsworth is an outlier, suggesting either an instrumental problem or the influence of a local source not included in the modelling. It is worth noting that the instrument at Harmondsworth is a BAM (Beta Attenuation Monitor), whereas the instruments at the other sites (except Hayes) are of the TEOM (Tapered Element Oscillating Micro-balance) type.

E.36 Excluding Harmondsworth, the average fractional discrepancy is 4.3% (i.e. the model overestimates by 4.3% on average), with a standard deviation of 9.5%. The average fractional discrepancy both with and without Harmondsworth is lower than the accuracy of the measurement technique, so the comparison is able to demonstrate only that any model bias for total period-mean concentrations is less than the uncertainty in the measurements.

E.37 The modelled contribution from the designated road network and airport sources is on average only 2.3 $\mu g/m^3$ (maximum 5.2 $\mu g/m^3$, at LHR2) compared to a modelled background contribution of 17.2 $\mu g/m^3$, so the model-monitoring comparisons of total period-mean concentration mainly assess the background contribution. Furthermore, the smallness of the modelled contribution from airport and road-network sources highlights the difficulty of evaluating the performance of the modelling for these sources even using difference analysis, given that the expected differences are only comparable to 'natural' variation in the background (i.e. site-to-site variations in the background that are not captured by the modelling) and less than measurement uncertainties.

Airport Sources

E.38 Comparison of modelled and measured PM_{10} concentration differences between LHR2 and Oaks Rd and between Harlington and Oaks Rd indicates that the underestimation or overestimation of the contribution from airport sources to period-mean PM_{10} concentrations, if any, is less than estimated measurement uncertainties.

* The fraction of NO_x that is released in the form of NO_2 (prior to the further generation of NO_2 by gas-phase reactions)

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E.39 For LHR2, the model appears to overestimate the contribution from emissions on the runway (principally from brake and tyre wear), which could result from inaccuracies in the spatial distribution of the emissions rather than in the magnitude of the total emissions. At Harlington, there is good agreement between the modelled and measured concentration difference in a wind direction range giving a dominant contribution from airport sources. However, the absolute differences are less than 1 $\mu g/m^3$, which is less than the estimated measurement uncertainties.

E.40 The measured PM_{10} concentration difference between Green Gates and Oaks Rd for wind directions giving an an airport contribution at Green Gates is negative whereas the modelled difference is positive, although small in magnitude in both cases. This emphasises the difficulty in interpreting such small concentration differences.

E.41 Thus, there is no significant evidence that the contribution from airport sources is either overestimated or underestimated within the limits set by measurement uncertainties. Based on the model results, the contribution from airport sources to total period-mean PM_{10} concentration in 2008/9 was between 0.1 and 1.0 $\mu g/m^3$ in the residential areas just north of the airport (out of a total of around 20 $\mu g/m^3$), reaching around 2 $\mu g/m^3$ at the airport perimeter.

E.42 Comparing the 2008/9 model results for the contribution from airport sources (to period-mean PM_{10} concentrations) with equivalent results from the PSDH for the 2002 and 2010SM cases shows that at a given location the contributions are broadly comparable, as expected from the magnitude of airport emissions for the three cases. The principal differences in the 2008/9 results can be related to differences in meteorology.

Road-Network Sources

E.43 The three sites with the largest modelled road-network contribution to period-mean PM_{10} concentration are LHR2, Oxford Avenue and Hayes. None of these sites is close to a motorway. Comparison of modelled and measured concentration differences for LHR2-Harlington shows a missing modelled contribution to period-mean PM_{10} concentrations at LHR2 deriving from a narrow range of north-easterly wind directions, similar to that found for NO_x at LHR2. In the NO_x case, the peak was judged most likely to arise from traffic perturbations at the junction of the Northern Perimeter Road with Neptune Rd, and this is judged also the most likely origin of the peak for PM_{10}. The total contribution to the period-mean concentration represented by the missing peak, however, is less than 1 $\mu g/m^3$.

E.44 The comparisons chosen to highlight the road-network contribution suggest that it may be under-predicted (with a compensating over-prediction of the background or LAEI/NAEI contributions). However, the evidence is not strong, given the small magnitude of concentration differences compared to measurement uncertainties and the potential for un-modelled site-to-site variability in the background contribution. In addition, there is a question of how generalisable are the results for these three sites to the network as a whole, particularly to near-motorway receptors, given that the fidelity of the traffic data close to the sites has not been evaluated. Furthermore, discrepancies at LHR2 and Hayes may relate to localised flow perturbations at junctions. Thus, the information provided by the PM_{10} evaluation is an inadequate basis for making a whole-network adjustment to modelled concentrations, so no adjustment factors have been applied to the model results on the grid of receptors used for generating contour plots. However, the potential for model underestimation close to junctions and to other regions of flow disturbance should be noted.

E.45 Contour plots based on the modelling results show that off-airport values above the 40 $\mu g/m^3$ limit value for annual mean PM_{10} concentration within the study area in 2008/9 were confined to areas within the road margins of the M4 and other major roads and within about 30 m of the centre of the M25 (with concentration values east of the M25 road centre higher than those west). Off-airport values above the surrogate annual mean value of 31.5 $\mu g/m^3$, used to test the limit on 24-hour mean concentrations, were principally confined to areas within about 30 m from the centre of the M4 and about 50 m from the centre of the M25, although also extended 10-20 m from the centre of a few non-motorway road links. These areas should be taken as indicative of areas vulnerable to exceedence of the relevant limit, but the grid results may not have the spatial resolution to determine if individual receptors close to the relevant contour are within or outside the exceedence area, which would require closer investigation on a receptor-by-receptor basis.

E.46 The data used in the evaluation for PM_{10} does not provide a good test of the model at distances of a few tens of metres from a major motorway, so the predicted areas of exceedence close to the margins of the M4 and M25 should be treated with caution. There is some tentative evidence that the modelled 2008/9 PM_{10} concentrations close to the margins of these motorways are overestimates.

E.47 A comparison of the 2008/9 values for total PM_{10} concentration with equivalent values for the PSDH 2002 and 2010SM cases, using 13 representative receptor locations, shows that the 2008/9 values are on average closer to the PSDH results for the 2010SM case than to the results for the 2002 PSDH case, principally reflecting the fall in the background contribution since 2002.

$PM_{2.5}$

E.48 There were only three $PM_{2.5}$ monitoring sites operating in the study area in 2008/9 (Oaks Rd, Green Gates and Harmondsworth). In the modelling, the background component is the dominant contributor (9.6 $\mu g/m^3$) at these sites, with the airport and road network sources together contributing at most 1.2 $\mu g/m^3$.

E.49 The agreement between measured and modelled values is within the expected measurement uncertainty for Oaks Rd and Green Gates but there is significant over-prediction at Harmondsworth, by 41% (3.4 $\mu g/m^3$)*. The average fractional discrepancy between modelled and measured values is 17% and the average absolute discrepancy is 1.5 $\mu g/m^3$.

E.50 Even leaving aside measurement uncertainties, the comparison between modelled and measured total period-mean $PM_{2.5}$ values is unable to provide any detailed information on the performance of the modelling for airport and road network sources, given that their combined contribution is smaller than the uncertainty in the modelled contribution from all other sources (principally the background contribution).

E.51 Similarly, comparisons of $PM_{2.5}$ concentration differences are unable to provide any detailed information on the contribution from airport and road network sources, given that the modelled differences are smaller than the site-to-site variability in the contribution from other sources that is not captured by the model (and smaller than expected measurement uncertainties on concentration differences). The different measurement technique used at Harmondsworth further complicates the interpretation of differences involving that site. Thus, no source-specific model evaluation is possible for $PM_{2.5}$, and the comparisons of total period-mean concentrations are able only to confirm that the predicted total concentrations are within the range expected based on the monitoring data and its uncertainties.

E.52 Contour plots of total period-mean $PM_{2.5}$ concentration indicate that, according to the modelling, the values above 25 $\mu g/m^3$ limit/objective (coming into force in 2020/2015 respectively) were confined largely to areas within about 30 m of the M25. The caveats placed earlier on modelled PM_{10} concentrations at such close proximity to the M4 and M25 motorways apply to $PM_{2.5}$ also.

* It is worth noting that the instrument at Harmondsworth is of the light-scattering type, whereas the other two sites have TEOM instruments

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Abbreviations

ADMS	Atmospheric Dispersion Modelling System
AEA	A business name of AEA Technology plc
APU	Auxiliary Power Unit
AQEG	Air Quality Expert Group
AQMA	Air Quality Management Area
AQS	Air Quality Strategy for England, Scotland, Wales and Northern Ireland
AQSR	Air Quality Standards Regulations
ATWP	Air Transport White Paper
AURN	Automatic Urban and Rural Network
BAM	Beta Attenuation Monitor
CERC	Cambridge Environmental Research Consultants
CTA	Central Terminal Area
DC	Data Capture
EU	European Union
FDMS	Filter Dynamic Measurement System
HGV	Heavy Goods Vehicle
IQR	Inter-Quartile Ratio
LAQN	London Air Quality Network
LDV	Light Duty Vehicle
LHR	London Heathrow Airport
LTO	Landing and Take-Off
NAEI	National Atmospheric Emission Inventory
NO_x	Nitrogen Oxides ($NO+NO_2$)
NPR	Northern Perimeter Road
OS	Ordnance Survey
OSIRIS	Optical Scattering Instantaneous Respirable Dust Indication System
OX	Oxidant (sum of O_3 and NO_2)
PCM	Pollution Climate Mapping
PM_{10}	Particulate Matter with aerodynamic diameter less than 10µm[*]
$PM_{2.5}$	Particulate Matter with aerodynamic diameter less than 2.5µm
PSDH	Project for the Sustainable Development of Heathrow
QA/QC	Quality Assurance/Quality Control
SD	Standard Deviation
SM	Segregated Mode
T5	Terminal 5
TEOM	Tapering Element Oscillating Microbalance
(US)EPA	(US) Environmental Protection Agency
VCM	Volatile Correction Model

[*] To be precise, particles that pass through the selective size inlet of a specified measuring instrument with 50% efficiency at 10µm (2.5 µm for $PM_{2.5}$) aerodynamic diameter, where the 'aerodynamic diameter' of a particle is the diameter of a spherical particle of unit relative density that would have the same gravitational settling velocity as the particle of interest.

Appendix AQ.1.15

1 Introduction

Background

1.1 London Heathrow Airport (Heathrow) is the world's busiest international airport, serving around 65 million passengers in 2008, and is a key component of the UK's transport infrastructure. The airport lies close to residential areas, however, and the off-site air quality impacts of its operations are kept under review by both the airport operator, BAA, and by the local authorities in the administrative areas surrounding the airport. This review process draws on measurements made at a number of automatic monitoring sites around the airport, and also includes the periodic updating of an airport emission inventory accompanied by a dispersion modelling study. These aim to inform airport stakeholders of the evolving contribution of the airport to local airborne pollutant concentrations.

1.2 In 2009, BAA commissioned AEA to carry out an air quality study for Heathrow with three components:

(a) to compile an inventory of atmospheric emissions arising from airport operations for the 12-month period from 1st April 2008 to 31st March 2009, including the pollutants NO_x (oxides of nitrogen), PM_{10} (particulate matter with an aerodynamic diameter less than 10 microns) and $PM_{2.5}$ (particulate matter with an aerodynamic diameter less than 2.5 microns);
(b) to carry out a dispersion-modelling study to quantify the contributions from airport sources and from road-vehicle emissions on the major road network around Heathrow to airborne concentrations in residential areas close to the airport; to combine these contributions with the estimated contribution from all other sources to give a view of total airborne concentrations around Heathrow in 2008/9;
(c) to evaluate the performance of the model using monitoring data collected around Heathrow in 2008/9.

1.3 This report presents the results of the model evaluation, then goes on to provide best estimates of the 2008/9 spatial distribution of concentrations of the designated pollutants around Heathrow. Separate reports are available covering the compilation of the airport emission inventory[1] and the methodology used for the dispersion-modelling study (including the estimation of the contribution from sources not included explicitly via dispersion modelling)[2]. The former will be referred to as 'the 2008/9 inventory report' and the latter as the '2008/9 modelling methodology report'.

1.4 The Heathrow inventory feeds into the London Atmospheric Emission Inventory (LAEI)[3] and the National Atmospheric Emission Inventory (NAEI)[4] via the normal updating cycle for these inventories, although there may be a delay due to a phasing mismatch*. The inventory and modelling study also provide information to the local authorities in administrative areas around Heathrow to assist them in discharging their responsibilities under Part IV of the Environment Act 1995, whereby they are required to review periodically the concentrations of designated pollutants within their areas against air quality objectives set at the national level in the Air Quality Strategy for England, Scotland, Wales and Northern Ireland (AQS)[5]. Where it is expected that an objective cannot be met by the required date, the local authority is required to declare an Air Quality Management Area (AQMA) and to bring forward an Air Quality Action Plan to reduce concentrations, to the extent that the sources responsible for the failure to meet objectives are within its control.

1.5 The air quality around Heathrow is of continuing concern. The annual mean NO_2 concentration in some residential areas near the airport is close to or above the AQS objective (40 µg/m^3), which should have been met by 2005. The air quality modelling work underpinning the government consultation 'Adding Capacity at Heathrow' forecast that there would be exceedences of the EU limit value (40 µg/m^3) in 2010 (the date when compliance with the limit becomes mandatory). Although there are forecast to be widespread exceedences of the limit value in London in 2010[6] – for which the government is likely to

* The 2008/9 Heathrow inventory was not finished in time to be included in the 2008 version of the London Atmospheric Emissions Inventory.

seek a time extension from the European Commission – the Mayor's draft air quality[6] strategy notes that the limit has been met consistently since 1999 at non-roadside monitoring locations in outer London, except around Heathrow airport. The boroughs around Heathrow* have all declared an AQMA for NO_2.

1.6 Similarly, in its *'Future of Air Transport'* White Paper (ATWP)[7] the last government's support of a third runway at Heathrow was provisional on it being confident that the air quality limits (as well as a noise condition) could be met, which led to the setting up of the Project for the Sustainable Development of Heathrow to examine the technical basis for developing the required confidence. After consulting on the evidence base relating to the environmental conditions[8], the (then) Secretary of State announced his support for a third runway[9], again emphasising in the decision document the need to meet air quality limits. In the responses to the consultation[10], a majority did not believe that the air quality criterion could be met if a third runway was built.

1.7 In light of the above, there is a vital interest in understanding how much airport operations contribute to pollutant concentrations in the vicinity of the airport. Although monitoring provides spot checks on the situation at specific locations, modelling is required to give a fuller appreciation of the spatial variation in airborne concentrations. It is also needed to identify the relative contributions from various sources on the airport to the concentration at key locations and to provide a basis for forecasting the air quality impact of operational changes on the airport.

1.8 Prior to the current programme of work, the last published Heathrow inventory based on actual airport activity data was for the calendar year 2002. An inventory for that year was first compiled in 2004[11] in the context of the periodic updating process noted above. The long gap between that inventory and the 2008/9 inventory can be traced partly to the decision to await the final recommendations of the Project for the Sustainable Development of Heathrow (PSDH)[12] before the next inventory update. However, as part of the air quality work underpinning the government consultation on 'Adding Capacity at Heathrow', the 2002 inventory was revised[13] using a methodology that implemented the PSDH recommendations. Air quality modelling was then carried out by Cambridge Environmental Research Consultants (CERC) using this 2002 inventory and a number of forecast airport inventories. The results of this modelling provided the evidence base relating to the air quality test for Heathrow expansion set by the ATWP, which was a key component of the 'Adding Capacity at Heathrow' consultation. As a shorthand in the remainder of this report, the air quality work underpinning the consultation will be referred to as the 'PSDH work'.

1.9 The PSDH work included an evaluation of the performance of the model by CERC, comparing modelled values for 2002 with measured values obtained for the same period from monitoring stations around the airport[14]. This established that the model gave a good estimate (within 10%) of the airport contribution to total NO_x concentrations at the monitoring site close to the northern runway (LHR2) and a good account of how this contribution changes as the distance from from the centre of gravity of airport sources increases. It also showed that annual-mean NO_x and NO_2 concentrations across the set of 9 monitoring sites were predicted with no significant average bias, and allowed quantification of the site-to-site variability in concentrations not accounted for by the model. The 2008/9 emissions inventory was compiled using a methodology very similar to that used for the 2002 inventory, and the 2008/9 dispersion modelling used the ADMS-Airport[15] code, developed by CERC for the PSDH work and licensed to AEA for use in the 2008/9 work. Thus, the modelling methodology for the 2008/9 work has, to an extent, been already evaluated.

1.10 However, there are a few differences in the methodology for the 2008/9 study compared to that used for the PSDH work, including differences in the calculation of the contribution from sources beyond the airport and near-Heathrow major road network and a different approach to deriving NO_2 concentrations from NO_x concentrations. Besides, the aircraft fleet operating at the airport and the distribution of engine technologies in the traffic on the roads around Heathrow are constantly evolving, and it is important to check that the modelling continues to give an unbiased view of concentrations around the airport as the relative contributions from

* London Borough of Harlington, London Borough of Hounslow, Spelthorne Borough Council, Slough Borough Council

various sources change.

1.11 In addition, a number of monitoring sites around the airport have come into operation since 2002, including Sipson*, Harmondsworth, Harlington, Oxford Avenue, Hatton Cross and Hayes. Except for Hayes, the sites are expected to have a significant airport contribution to annual-mean NO_x concentrations, and thus provide the opportunity for a more detailed test of the modelling of airport sources than possible with 2002 data.

1.12 Finally, it is anticipated that the 2008/9 inventory and modelling will form the baseline for an investigation of the response of concentrations around the airport to potential operational changes on the airport, and it is common practice to 'verify' the model using current data before moving on to forecast potential future changes.

Scope

1.13 As noted above, ambient air quality in the UK is managed by reference to the Air Quality Strategy (AQS) for England, Scotland, Wales and Northern Ireland[5], which sets objectives for airborne concentrations of specified pollutants†, together with target dates for their achievement. In addition, air quality limit values and associated introduction dates set by EU Directives have been taken into English law‡ through the Air Quality Standards Regulations[16](AQSR). Although there is considerable overlap between the AQS and AQSR, there are some differences in detail, particularly in relation to dates of applicability.

1.14 Of the key pollutants of interest from a human health standpoint, this study focuses on NO_2, PM_{10} and $PM_{2.5}$. The justification for this choice is given in the 2008/9 inventory report and will not be repeated here. In view of the current situation around Heathrow in relation to the annual mean NO_2 objective and limit value, the evaluation places particular emphasis on this pollutant. However, given that NO_2 concentrations are derived from NO_x concentrations, there is separate, detailed evaluation of the modelling for NO_x concentrations and the methodology for deriving NO_2 concentrations from NO_x concentrations. The objectives and limit values for the pollutants of interest are shown in Table 1.1.

1.15 The 2008/9 modelling methodology report defines a 'study area' 9 km square, centred on the airport (shown in Fig 2.1), within which detailed concentrations are predicted. The choice of this area is explained in the latter report and will not be repeated here. The model evaluation is carried out using monitoring data obtained at sites operating continuous analysers within this area, as explained in Section 2. Comparisons with NO_2 diffusion-tube measurements in the area is not included within the scope of the current study.

1.16 It is not sufficient in the model evaluation to show that total concentrations are predicted with reasonable accuracy at the set of monitoring sites. A large contribution to total concentration within the study area derives from sources outside the area, including sources a long way from it, which generate a concentration field only slowly varying across the study area. Thus systematic errors in modelling the contribution from local sources could be compensated by an error in the longer-range component, with such a compensation not necessarily persisting into the future as the balance between sources changes. For this reason, it is important to be able to isolate – or at least enhance – the contribution from particular local source groups, to allow separate evaluation of the modelling for those sources. The strategy used to achieve this enhancement is explained in Section 3, but relies on having hourly concentration averages from continuous analysers.

1.17 It is important to bear in mind that, even when the concentration contribution from particular source groups can be isolated, comparison with monitoring data tests jointly the emissions methodology and dispersion modelling. Generally, there is no independent check on emissions other than via their influence on concentrations. This raises the possibility of fortuitous cancellation of errors in emissions quantification and dispersion modelling, which may not persist into the future as meteorology and the spatial distribution of emissions

* These are the short names of monitoring sites, introduced for convenience in the discussion – fulll site details are given in Section 2 of the report
† Sulphur dioxide (SO_2), nitrogen dioxide (NO_2), particulate matter (PM_{10} and $PM_{2.5}$), benzene, 1,3-butadiene, ozone, carbon monoxide (CO), lead and polycyclic aromatic hydrocarbons (PAHs)
‡ The $PM_{2.5}$ limit value has not yet been taken into UK law.

changes. Thus, the evidence on model performance is cumulative, as the modelling is tested in a variety of source configurations and meteorology. The air quality methodology used to calculate concentrations for the PSDH model evaluation was very similar to that used here, but for a different aircraft fleet mix and for different meteorology, gave good agreement in the airport contribution at LHR2 derived from modelling and measurement. Together, the studies increase confidence that good agreement between model and measurements has not resulted from cancellation of major errors.

1.18 It is worth noting that the emissions on the near-Heathrow major road network for 2008/9 were derived from an 'interim' traffic model, for which only limited tests of the model outputs had been reported. As discussed in Section 3, it is likely that some of the discrepancy between measured and modelled concentrations close to roads derives from inaccuracies in characterising the traffic data, rather than from emission-factor or dispersion-modelling inaccuracies, but it was outside the scope of the present study to investigate how much of the discrepancy might be attributable to the traffic data.

Report Structure

1.19 Section 2 of the report describes the monitoring data used in the comparisons; Section 3 discusses the comparison between model results and monitoring data; and Section 4 draws conclusions.

2 Monitoring Data

2.1 Site Selection

2.1.1 The focus of attention in this study is to assess how well the model predicts concentrations in residential areas around the airport, in particular at locations strongly influenced by sources related directly to the operation of the airport. This includes receptors that are appreciably influenced by emissions from within the airport perimeter itself but also receptors influenced strongly by road traffic emissions, where the traffic itself has a major airport-related component. Of course, there is no sharp boundary to this region, but the modelling methodology report defines a 9 km square 'study area', centred on the airport, within which concentrations are calculated in detail - not only total concentrations but also the separate contributions from key source categories*. This study area is very similar to that used in the PSDH work to present predicted concentrations around Heathrow, which helps in comparing results from the two studies.

2.1.2 Within the study area, 12 sites with continuous monitoring data for the 2008/9 period were identified, with all the sites having continuous NO_x/NO_2 analysers, 10 having continuous PM_{10} analysers and 3 with continuous $PM_{2.5}$ analysers: the model evaluation was based on comparison with monitoring data at this set of sites. The M25 site at Staines lies just outside the area so, arguably, could have been included in the evaluation, but this site was rejected in the PSDH model evaluation: it is situated much closer to the carriageway than is relevant to outdoor public exposure and the interpretation of its data proved problematic. Thus, the site has not been included in the current study (although its PM_{10} concentrations are mentioned in Section 3). The extent of the study area and the set of sites used in the evaluation are shown in Fig 2.1.

2.1.3 There are a large number NO_2 diffusion tube sites in the area, some belonging to the national network of diffusion tube sites and others belonging to local authority networks. NO_2 diffusion tubes have lower-precision than continuous NO_x/NO_2 analysers, although they play a valuable role in mapping spatial variations in NO_2 concentrations in areas with few (or no) continuous analysers. The present study has focused on a detailed assessment of the model predictions for separate source contributions, which is the principal driver of spatial variations in total concentrations. A comparison of the modelling results with NO_2 diffusion tube measurements in the period, although potentially interesting, was outside the scope of the study.

2.1.4 Table 2.1 presents relevant characteristics of the monitoring sites, including a short name that will be used in the discussions in the remainder of the report, the site OS co-ordinates and the range of pollutants monitored at the site. It also gives a brief description of the environment local to the site, and these descriptions are supplemented by Google satellite images in Figs 2.2 (a)-(l), at a spatial resolution chosen to show the principal local features. It is common for monitoring sites to be given a classification (rural, urban background, roadside etc) relating to the type of environment that the site can be taken to represent. For sites potentially affected significantly by airport sources, this classification scheme is less useful. From a model-evaluation perspective, the key distinguishing feature amongst sites is the extent to which they are influenced by various sources of emissions. The monitoring sites included in this evaluation span a useful range from this perspective, from sites where the sources on the airport have a major influence (such as LHR2), sites where emissions from a nearby road have a dominant influence (such as Hillingdon and Hayes) and sites located within residential areas with an appreciable (but not dominant) airport contribution and/or nearby road contribution (for example, Sipson, Harlington, Harmondsworth, Oxford Avenue, Cranford and Hatton Cross).

2.1.5 The changing pattern of source contributions across the sites is used to advantage in the analysis by taking concentration differences between sites, which highlight the contribution

* This breakdown is not given for NO_2 because of the non-linear relationship between NO_x and NO_2 concentrations

from specific sources. In this context, Oaks Rd serves a particular function in the evaluation, given that for a range of southerly wind directions it receives no contribution from the airport sources and little contribution from the major road network around the airport, so acts as a 'background' site when taking concentration differences for selected ranges of wind direction (see Section 3).

2.1.6 For the sites that are close enough to the nearest links of the road network to receive a significant contribution from them (for example, LHR2, Hillingdon, Hayes and Oxford Avenue), the co-ordinates of the site have been adjusted in the dispersion modelling to ensure that the site sits the correct distance from the modelled road (which may not perfectly coincide with the actual road, given the finite tolerance of the spatial representation of the road network in the dispersion modelling).

2.1.7 Table 2.1 also specifies if the site belongs to either the LAQN[17] (London Air Quality Network) or AURN[18] (Automatic Urban and Rural Network). This identification is included mainly in relation to the QA/QC (Quality Assurance/Quality Control) provisions under which the site operates. Sites not affiliated to either network may nevertheless be operated to a QA/QC standard equivalent to that of one of these networks. Oaks Rd, Green Gates, Colnbrook and Sipson are operated to the AURN QA/QC standards. The Hillingdon sites not not explicitly part of the LAQN network are nevertheless operated to LAQN QA/QC standards. The essential features of the QA/QC procedures for both networks have been summarised by Laxen *et al*[19].

2.2 Data Characterisation

NO_x and NO_2

2.1.8 Table 2.2 (a) and (b) give some characteristics of the NO_x and NO_2 data sets used in the analysis, with the first column identifying the website from which the data were downloaded. All the analysers included are of the chemiluminescence type, which is the EU reference method for NO_2. The EU sets an accuracy objective of ±15% at the 95% confidence level for NO_x/NO_2 continuous analysers[20], and the AQEG report on nitrogen dioxide in the UK[21] states that it is likely that the great majority of UK national network measurements meet this uncertainty requirement. For sites operated to LAQN standards, a working uncertainty of 10% (at 2 standard deviations) has been suggested[22], based on observation and analysis. Technical guidance for air quality review and assessment[23] suggests that the overall uncertainty of the measurements (considering both accuracy and precision) from a continuous analyser is expected to be about ±10% (2 standard deviations) for long-period averages that are well above the instrument detection limit, provided that appropriate QA/QC methods are applied.

2.1.9 The tables give the ratification status of the data at the time of the analysis reported here. Most of the data sets were fully ratified at the time, but with a few exceptions, as detailed in the table. Provisional data is subject to adjustment on ratification, but it is not expected that the changes (if any) will have an appreciable effect on the analyses reported in Section 3.

2.1.10 Table 2.2 also gives the data capture (DC), the fraction of hours in the twelve-month period with valid data. It is normal to set a lower limit of 90% on DC when monitoring data are being used to check compliance with air quality objectives and limit values for annual mean values[23]. Clearly, for 2008/9 there are a number of sites with DC less than 90% but nevertheless situated in important locations from a model evaluation perspective. In the context of a model evaluation exercise, however, the constraints on DC may be loosened. Given that the results of the dispersion modelling are available on an hourly basis, it is possible to include in the dispersion modelling for a particular site only those hours of met data for which valid concentration measurements are available, thereby allowing like-for-like comparison of modelled and measured values.

2.1.11 Of course, there is still a requirement that the range of meteorological conditions in the hours with valid data be reasonably representative of the full range experienced over twelve months, but this perspective does allow sites with DC less than 90% to be used in the evaluation, whereas they might be rejected in testing for compliance with limits. The lowest DC for NO_x/NO_2 is 81.5% (Hatton Cross). Table 2.2 also gives the longest continuous run of missing data, showing that in the case of Green Gates most of the missing hours occurred in a single period (Aug/Sep 2008), whereas they were distributed amongst several gaps for the other sites with low DC. However, even Green Gates was judged to have a sufficient representation of combinations of meteorological variables to be used in an evaluation of model performance for long-period average concentrations. Thus, all sites have been included in the analysis, albeit taking account explicitly of the data gaps as explained above.

2.1.12 Table 2.2 (a) and (b) give, respectively, the period-mean NO_x and NO_2 concentrations, defined as the simple arithmetic average of concentrations in all hours with valid data. In this report, the term 'period mean' will be used for averages over the 2008/9 twelve-month period. This reserves the term 'annual mean' to refer to average over a calendar year, which is the metric used for air quality objectives and limits. Also given in the Table 2.2 is the maximum hourly value, to give some idea of the dynamic range of the hourly measurements. The highest hourly NO_x value at Sipson (3719 $\mu g/m^3$) looks anomalous: in fact there were two consecutive hours with high values (3719 $\mu g/m^3$ and 2815 $\mu g/m^3$), with the next highest value in the period only 724 $\mu g/m^3$. The Sipson data set, however, was fully ratified, so no data values were rejected. The two high values contribute 0.75 $\mu g/m^3$ to the total period-mean NO_x concentration.

2.1.13 The period-mean NO_x concentrations over the 12 sites span an appreciable dynamic range, from 56.1 $\mu g/m^3$ to 124.8 $\mu g/m^3$, indicating the potential for testing the influence of local sources on NO_x concentrations. The values for period-mean NO_2 concentration span a smaller range (from 32.0 $\mu g/m^3$ to 54.9 $\mu g/m^3$), reflecting the non-linear relationship between NO_2 and NO_x concentrations. Nevertheless, NO_2 range is still substantial from a model-evaluation perspective.

2.1.14 Table 2.2 (a) for NO_x also presents the 25th and 75th percentile of the hourly concentration values, together with their ratio (the inter-quartile ratio, IQR). This ratio has significance in the methodology for deriving period-mean NO_2 concentrations from period-mean NO_x concentrations, as described in the modelling methodology report. Generally, other purely statistical parameters of the distribution of hourly values do not provide much additional insight, although they may be useful for data consistency checking. On the other hand, averages taken for particular wind directions and wind speeds give more information on the key sources influencing the concentrations, and are the principal metrics used in the analysis in Section 3.

2.1.15 For NO_2, Table 2.2 (b) also gives the number of hours in the period with hourly-average concentration above 200 $\mu g/m^3$, which is relevant to the short-period NO_2 objective/limit that there should be fewer than 18 values above 200 $\mu g/m^3$ in a (calendar) year. In the present context, the values in the table can be used to test the methodology in which a surrogate annual mean NO_2 concentration of 60 $\mu g/m^3$ is used to test for compliance with the short-period limit (see the 2008/9 modelling methodology report). Clearly the data in Table 2.2 (b) are consistent with the assumption that if the annual mean is less than 60 $\mu g/m^3$ it is unlikely that the short-period limit will be exceeded. However, given that the period-mean values are well below 60 $\mu g/m^3$, the data do not provide a sensitive test of the assumption.

2.1.16 Bearing in mind missing data, an alternative way of expressing the short-period criterion is that the 99.79th percentile of hourly concentrations should be less than 200 $\mu g/m^3$. Table 2.2 (b) gives the relevant values, again showing that the short-period limit was satisfied at all the sites in 2008/9.

2.1.17 From Table 2.2 (b) it can be seen that the 2008/9 period-mean NO_2 concentration was above 40 $\mu g/m^3$ for 5 of the sites. However, for sites with data capture below 90%, such as Green Gates, the value can only be taken as indicative of the 12-month mean concentration, given the potential influence of missing data.

PM_{10}

2.1.18 Tables 2.2 (c) provides characteristics of the data sets used for the PM_{10} analysis in Section 3, in a similar manner to those provided for NO_x and NO_2, although some data columns are specific to PM_{10}.

2.1.19 It is noteworthy that the data capture for Hatton Cross is particularly low (70.1%), with most of the missing hours confined to a single period from October 2008 to February 2009. Given that most of the winter period is therefore missing, this raises the concern that low temperatures and low values of surface heat flux will be under-represented in the meteorological data set relevant to the hours with valid concentration measurements, so additional caution may be warranted in using the Hatton Cross PM_{10} data.

2.1.20 Eight of the ten PM_{10} sites have TEOM (Tapering Element Oscillating Microbalance) analysers, as noted in Table 2.1. It is standard practice to adjust concentration measurements from this type of instrument for the loss of volatile components (for example ammonium nitrate) resulting from the heated inlet. Tests reported in the AQEG report on particles[24] have shown that there is variability in the relationship between concentrations measured by co-located TEOM and reference instruments, but an interim adjustment factor of 1.3 was proposed for the UK. Recently, however, a more accurate method of correcting TEOM measurements (using the Volatile Correction Model[25]) has been devised for use with UK TEOM data. The model relies on data from the network of FDMS* (Filter Dynamics Measurement System) instruments established in the last few years; in general data from 2007 onwards can be corrected in this way. Equivalence to the EU reference method for PM_{10} can be demonstrated for the FDMS instrument[23].

2.1.21 For the TEOM sites, Table 2.2 (c) gives both the uncorrected period-mean concentration and the VCM-corrected period mean. For sites belonging to the LAQN the data was already available in VCM-corrected form (with uncorrected data also available); for the remaining sites, the VCM correction was carried out for the present study, using the VCM web portal[25]. The process of VCM correction has the potential to further lower the data capture if the FDMS sites themselves have missing data; the additional data loss, however, was less than 1%. Data capture values shown in the table relate to the final VCM-corrected data.

2.1.22 Uncertainties relating to the correction of TEOM data to to gravimetric-equivalent values add to the measurement uncertainty for these instruments: the results cited in the AQEG report suggest than an accuracy of better than 15% (at the 95% confidence level) should not be expected.

2.1.23 For the remaining two sites (Harmondsworth and Hayes) the instrument is a BAM (Beta Attenuation Monitor). For specific versions of the BAM (with unheated inlet) it is possible to demonstrate equivalence to the EU reference method[23], with raw data corrected to gravimetric equivalent by dividing by 1.21. As downloaded from the Hillingdon website, the data for Harmondsworth and Hayes were already corrected to gravimetric equivalent.

2.1.24 It will be noted later that measured period-mean given by the Harmondsworth BAM data is an outlier compared to other measured values in the area and compared to model results. This may signal an instrument problem, but the data were not discarded before the stage of comparing measurements with modelling results. The data for Harmondsworth were not ratified for the Jan-Mar 2009 period, but the values were consistently high throughout the 12-month period.

2.1.25 Harmondsworth also has an OSIRIS (Optical Scattering Instantaneous Respirable Dust Indication System) analyser, which operates on the principle of light scattering. Equivalence between this type of analyser and the EU reference method has not been shown. Technical guidance[23] suggests that this type of instrument, suitably calibrated, may be useful for indicative or screening purposes but not for detailed air quality assessments. The 2008/9 period-mean PM_{10} value from the Harmondsworth OSIRIS instrument is shown in Table

* The FDMS TEOM is a modified version of the TEOM designed to tackle the problem of loss of volatile components.

2.2(c) for information, but is not used further in the evaluation exercise.

2.1.26 The objective/limit on shorter-period PM_{10} concentrations – that there be less than 35 exceedences per year of a 24-hour mean value of 50 $\mu g/m^3$ - is recognised to be more onerous generally than the annual-mean objective. As discussed in the 2008/9 modelling methodology report, compliance with this objective is judged using a surrogate annual-mean concentration, as recommended in technical guidance for local authority air quality review and assessment[23], which gives

No. 24-hour mean exceedences = -18.5 + 0.00145 x annual mean^3 + (206/annual mean)

2.1.27 According to this, there will not be more than 35 exceedences of a 24-hour mean value of 50 $\mu g/m^3$ if the annual mean is less than 31.5 $\mu g/m^3$, so it has become common practice in air quality review and assessment to use the latter as a surrogate for the short-period limit when testing compliance using modelling results, on the grounds that model results for long-period averages are less uncertain than for short-period averages. The use of this surrogate annual-mean value can be subjected to a local test using the PM_{10} monitoring data around Heathrow for the 2008/9 period, and Table 2.2 (c) gives the number of daily exceedences at each of the monitoring sites. For all the sites with period-mean less than 31.5 $\mu g/m^3$, the number of daily exceedences is less than 35. For Harmondsworth (BAM), with a period-mean of 34.7 $\mu g/m^3$, the number is greater than 35 (45). Although these results are consistent with the use a limit of 31.5 $\mu g/m^3$ on the annual mean as a surrogate for the short-period limit, they do not provide a sensitive test, given that all except one of the period-mean values are well below 31.5 $\mu g/m^3$.

2.1.28 Table 2.3 shows the number of daily exceedences predicted by the above relationship compared to the measured value. This shows agreement between measurement and prediction within the associated level of uncertainty in the relationship (estimated from the scatter on the data used to develop the relationship), bearing in mind possible deviations for sites with low data capture. This adds confidence in the use of the use of an annual-mean surrogate.

2.1.29 An alternative way of testing the short-period limit for measurements with missing data is to test that the 90.41th percentile of daily means throughout the period is less than 50 $\mu g/m^3$. This metric is also shown for the monitoring sites in Table 2.2 (c), confirming that the value was indeed less than 50 $\mu g/m^3$ at all sites except Harmondsworth, as expected.

$PM_{2.5}$

2.1.30 Table 2.2 (d) give some characteristics of the data for the 2008/9 period from the three $PM_{2.5}$ analysers included in the evaluation. The Green Gates and Oaks Rd instruments are of the TEOM type, with appropriate size-selecting inlet. Standard correction methods for TEOM annual-mean $PM_{2.5}$ measurements, based on comparisons with UK gravimetric measurements, have not yet been proposed, but the instruments are conventionally set up with an (US) EPA default adjustment protocol (TEOM reading*1.03 + 3 $\mu g/m^3$). Equivalence with the EU reference method for $PM_{2.5}$ has not been shown for the standard TEOM instrument.

2.1.31 The Harmondsworth measurements are from the OSIRIS instrument at the site, and similar comments apply for $PM_{2.5}$ as those made above for PM_{10}.

2.1.32 The data capture of the two TEOM analysers was high for the period (>95%). Although lower at Harmondsworth (87%), it is still adequate for model evaluation purposes, as explained earlier in the discussion for NO_x.

Ozone

2.1.33 As explained in Section 3 (NO2), local ozone measurements can be used to check the calculation of total oxidant concentrations (sum of O_3 and NO_2 concentrations) that form part of the methodology for deriving NO_2 concentrations from NO_x concentrations. Ozone is measured (by ultraviolet absorption) at three of the sites in the study area (Harlington, Hillingdon and Cranford) and some data characteristics of the ozone data for the 2008/9 period are shown in Table 2.2 (e).

2.1.34 The data capture is high at Harlington and Hillingdon (around 99%), but low at Cranford, which will be borne in mind when the data are put to use in Section 3.

3 Results and Discussion

3.1 NO_x

Total Period Mean

3.1.1 The key aim in the model evaluation exercise is to assess how well the combined emission quantification and dispersion modelling methodologies are able to predict annual mean NO_x and NO_2 concentrations. In the context of the present 2008/9 study, therefore, the focus of attention is on concentrations averaged over the twelve-month period, termed the period-mean concentration, as explained in Section 2.

3.1.2 In a detailed comparison between model predictions and measured values at monitoring sites, it is important to consider the impact of missing data. If the modelling is to be carried out using a full year of hourly meteorological (met) data, there is usually a requirement that the data capture (fraction of hours with valid data) in the measurements be at least 90%; even then it would be preferable if the data gaps were distributed over the year rather than focused in one period, to avoid bias. In the 2008/9 case, there are a number of sites with data capture (DC) less than 90% (see Section 2) but nevertheless situated in important locations from a model evaluation perspective.

3.1.3 Given that the results of the dispersion modelling are available on an hourly basis, it is possible to include in the dispersion modelling for a particular site only those hours of met data for which valid concentration measurements are available, thereby allowing like-for-like comparison when the DC falls below 90%. Of course, there is still a requirement that the range of meteorological conditions in the hours with valid data be reasonably representative of the full range experienced over the twelve months, but this perspective does allow sites with DC less than 90% to be used in the evaluation, whereas they might be rejected in testing for compliance with limits.

3.1.4 The lowest DC for NO_x amongst the sites used in the assessment was 81.4% (Hatton Cross). Having set up the procedure to make like-for-like comparisons for sites with DC<90%, it was extended to sites even with DC>90%, to put all sites on an equal footing in the analysis. Of course, the concentration contour plots and results at specific receptors generated after the model evaluation will be based on model results that include all hours of the period. For convenience in the discussion below, concentrations averaged over the hours with valid measurements will be termed 'period-mean' concentrations and those averaged over all hours of the period will be termed 'all-hours period-mean' concentrations.

3.1.5 Table 3.1 compares the modelled total period-mean NO_x concentrations at the continuous NO_x/NO_2 analysers with the measured values, and gives the breakdown of the model total by source category. It is worth noting that the rural background contribution varies from site to site in this table only because a different selection of hours (with valid measurements) is being taken in each case, not because there is any spatial variation in the model contribution over the study area. The average of the modelled values is 73.1 $\mu g/m^3$, whereas the average over the measurements is 78.9 $\mu g/m^3$.

3.1.6 It is judged more appropriate to discuss model-monitoring differences in terms of fractional discrepancies (*(modelled-measured)/measured*) rather than absolute discrepancies (*modelled-measured*), and the corresponding values are shown in Table 3.1. Thus the average fractional discrepancy (also referred to below as the bias) is -5.2%, i.e. the model underestimates on average by 5.2% across the set of sites, with a standard deviation of 12.2% (12 sites), where the latter is a measure of the site-to-site variability in the measured values that has not been captured by the model. Taking the measurement uncertainty (one standard deviation) for long-period averages to be around 5% (Section 2) indicates that the observed bias is highly unlikely to be explained by statistical measurement fluctuations for a finite sample of 12 sites. Similarly, a large fraction of the site-to-site variability not explained by the model is unlikely to be attributable to measurement uncertainties.

3.1.7 There are alternative ways of presenting the comparison between the two data sets. For example, the model 'explains' 76% of the variance in the measured values about their mean, i.e. the reduction in the variance (mean square absolute discrepancy) when the measurements are referred to the model values compared to the variance when they are referred to their arithmetic average is 76%. Fig 3.1 presents a scatter plot of modelled versus measured period-mean values. The correlation coefficient for the two data sets (which measures the extent to which they are linearly related) is 0.89.

3.1.8 For interest, Table 3.2 shows the difference between the period-mean concentrations and the all-hours period-mean concentrations, to indicate the influence of missing hours. The differences range from -0.45 to 2.4 $\mu g/m^3$ at the period-mean level, with the largest difference at Green Gates; differences may be larger in particular wind-direction ranges.

3.1.9 For convenience, the following terminology for source groups will be used in the discussions below:

(a) 'airport' emissions refers to sources on the airport[*] and does not include airport-related road-vehicles on the landside road network; the term is a little loose in that it includes all aircraft emissions in the LTO cycle, including elevated emissions that may arise beyond the airport perimeter (although the contribution from emissions above a few hundred metres in height is small at the receptors of interest);
(b) 'runway' emissions, which includes aircraft emissions from take-off roll, initial climb, final approach and landing roll;
(c) 'apron emissions', which includes APU emissions and airside vehicle/plant emissions; these may be lumped together sometimes because their modelled spatial distributions overlap, making it difficult to separate out their individual contributions by the directional analysis of monitoring data.

3.1.10 For the three sites with the highest total contribution from airport sources, LHR2, Hatton Cross and Oaks Rd. the fractional discrepancy is –4.8%, 16.3% and 13.1% respectively. For the three sites with the largest road network contribution, Hillingdon, LHR2 and Hayes, the fractional discrepancy is -10.8%, -4.8% and -27.4% respectively, suggesting that there is a systematic underestimation of the road contribution. This highlights the importance of evaluating the model separately for the various source contributions, given that the balance between contributions may change in the future. This is the objective of the more detailed analysis described below.

3.1.11 For comparison, in the model evaluation carried out by CERC (for 2002) in the PSDH work, the modelled annual-mean concentration averaged across 8 monitoring sites[†] was 76.2 $\mu g/m^3$ compared to a average of 77.6 $\mu g/m^3$, a fractional discrepancy of only -1.8%. It should be noted that the set of 8 sites used in the PSDH comparison did not include as many sites close to the airport as in the set available for the 2008/9 evaluation.

3.1.12 Excluding the three 'road' sites mentioned above, the average of the modelled concentrations is 64.8 $\mu g/m^3$ whereas the average of the measured values is 66.6 $\mu g/m^3$. Even these nine sites have an appreciable contribution from the modelled road network, typically 14 $\mu g/m^3$, so would be subject to some underestimation if there was a systematic underestimation of the road-vehicle contribution that persisted beyond the immediate vicinity of the road (as would be the case if emissions are being underestimated).

3.1.13 Table 3.1 shows that all sites have a major combined contribution from the LAEI/NAEI area sources and the rural background, which is fairly constant across the set of sites (except at Hayes), so inaccuracies in this contribution could act to partly offset inaccuracy in the contributions from airport and road-network sources. Again, this emphasises the importance of evaluating the performance of the modelling of airport and road vehicle sources separately

[*] Aircraft (including main engines, APUs and engine testing), airside vehicles/plant, car parks and taxi queues, heating plant and the fire-training ground.
[†] Excluding LHR10, the Staines near-M25 site, which was considered an outlier.

from that of the LAEI/NAEI/background contributions.

3.1.14 The availability of monitoring results from the Oaks Rd site, upwind of the airport along the principal south-westerly wind direction, presents the opportunity to isolate the contribution from airport sources by taking concentration differences between a monitor north of the airport and Oaks Rd, focusing on wind directions that point to and from the two sites. A similar type of analysis was carried out (for Heathrow) by CERC for the PSDH work[14]. In taking concentration differences, the assumption is made that the rural background contribution does not have a significant concentration gradient between the two monitors. Similar difference analyses can enhance the evaluation of the road network contribution at near-road sites.

3.1.15 As described in the 2008/9 modelling methodology report, the dispersion modelling results were obtained separately for each hour of the period, allowing average concentration differences to be calculated for selected wind direction (and wind speed) ranges. It is important to bear in mind when comparing concentration *differences* that the under/overestimation of the difference may have a contribution from the over/underestimation of the concentration being subtracted. Thus, there is benefit in using 'clear' differences, i.e. in situations where the sources of interest have a much larger contribution at one site than at the other.

3.1.16 The 1 km spatial resolution of the area sources (LAEI and NAEI) in the study area restricts the angular resolution of model results from these sources, which is a limitation (compared to the 10° angular resolution set by the meteorological data) for the squares within a few km of any given receptor. However, the source categories represented in the area emissions (such as domestic and commercial combustion) are not highly focused spatially (and the emission densities are not large), so the limited spatial resolution is not likely to be a significant limitation (but it should be borne in mind in the angular comparisons presented below).

3.1.17 The measurement errors associated with concentration differences cannot be ignored. If the measurement biases of the analysers are uncorrelated, then the error in the (absolute) difference is greater than the error in the value at each site (taken to be around 5%). However, if the sites belong to the same network or are operated to the same QA/QC procedures it is expected that there will be some correlation between the systematic errors at each site. It is judged unlikely that the uncertainty in period-mean differences for the sites around Heathrow will be less than 2 $\mu g/m^3$ or higher than 5 $\mu g/m^3$ (at 1 standard deviation), although these estimates have not been based on any specific data or analysis.

Evaluation of the Modelling for Airport Sources

LHR2-Oaks Rd

3.1.18 The LHR2-Oaks Rd concentration difference was given particular attention in the model evaluation undertaken by the PSDH[14]. LHR2 is only 180 m from the centre-line of the northern runway (27R), so receives a major contribution from runway sources, offering the potential for a good test of the 'moving-jet' module in ADMS-Airport (see the 2008/9 modelling methodology report). In addition, there are no major sources immediately upwind of Oaks Rd for the range of angles over which the wind blows airport sources towards LHR2, so the difference is 'clear'.

3.1.19 A form of presentation of the concentration differences that has proved useful in other similar analyses is to plot the mean concentration as a function of wind direction (i.e. with all hours of the period sorted by wind sector* and the concentration then averaged over the hours for a given sector), which will be termed a 'concentration difference rose'. This is displayed as a 'radar' plot in Fig 3.2, in which the angle in the plot corresponds to wind sector and the radial distance is the mean concentration for the sector†. This figure shows remarkably good

* Wind direction in the met data is already digitised into 10° sectors, which are labelled by the mid-angle of the sector

† It is important to note that in this form of presentation the concentration for a given wind sector has not been weighted by the relative probability that the wind blows in that sector. This avoids making the comparisons for sectors with low frequency difficult to read. However, it is important to recognise that discrepancies in some angular ranges have much less impact on the period-mean than in others. Table 3.3, on the other hand, includes the frequency weighting, as do the figures showing contribution as a function of wind speed.

agreement in the modelled and measured differences in the angular range 120° to 270°, when the wind blows from the airport towards LHR2 – the present focus of attention - although the model underestimates the concentration difference when the wind blows from some northerly directions.

3.1.20 For angles above about 180°, LHR2 ‘sees’ emissions from a major part of the take-off roll on the nearby runway 27R (westerly operation) and also from other parts of the airfield including the CTA (Central Terminal Area), T5 (Terminal 5) aprons and runway 27L (although the contribution from these sources is significantly smaller than that from 27R). Thus, the good agreement persists over a major part of the spatial distribution of airport sources.

3.1.21 A particular feature of Fig 3.2 is the peak in the monitoring difference for NE winds that is not reflected in the model difference, but discussion of this feature will be deferred to the section below on the analysis for road-network emissions.

3.1.22 The comparison for LHR2-Oaks Rd differences can now be made quantitative, by evaluating the contribution to the total period-mean concentration difference from wind directions that give a significant airport contribution at LHR2, choosing sectors 170° to 270° inclusive; this range of angles is marked on Fig 3.3. Although sectors 120° to 160° also point from the runway to LHR2, aircraft generally depart on the southern runway (09R) for this range of angles, so the contribution to period-mean concentrations is small. The LHR2-Oaks Rd entry in Table 3.3 gives the modelled and measured contributions from the selected sectors to the period-mean concentration difference, showing a discrepancy of only 2.9% (model overestimation) on a contribution of around 35 $\mu g/m^3$.

3.1.23 Table 3.4 shows the breakdown by source category of the modelled contribution to the period-mean NO_x concentration difference in the 170° to 270° range. The airport accounts for 88% of the model difference. Clearly, aircraft sources dominate the airport contribution, and ancillary model results show that take-off roll accounts for around 65% of the aircraft contribution.

3.1.24 A further level of evaluation can be carried out by investigating how the concentration contribution from the selected angular range is distributed as a function of wind speed. For this purpose, the hours for which the wind direction lies in the chosen range are partitioned amongst a set of wind speed categories separated by around 0.5 m/s[*], with averages then taken for each category; the mean concentration for a given category is multiplied by the fraction of all hours in the year for which the wind lies in the given speed category (and angle range) to generate the contribution to the total period-mean concentration difference from the category.

3.1.25 The resulting set of values are shown in Fig 3.4, which will be termed a ‘contribution/wind speed’ plot. The figure demonstrates a good level of agreement across the major part of the wind speed range, but does indicate a tendency for the model to overestimate at low wind speeds and underestimate at high wind speeds, which was also found in the PSDH model evaluation[14]. Thus the remarkable level of agreement in the total contribution from this angle range is partly fortuitous, arising from a compensation between these two tendencies, and may not be maintained to the same extent if the met data in a given year showed a markedly different wind speed distribution. Nevertheless, given that the agreement is reasonably good in every wind-speed category, it would require a major shift in wind-speed frequency distribution to generate a significant overall discrepancy.

Filtering by Westerly Departure Runway

3.1.26 One of the indicators of model performance devised for the PSDH model evaluation involved determining the difference in average concentrations at LHR2 between hours when 27R (close to LHR2) was used for departures and hours when 27L (far from LHR2) was used for

[*] Wind speed in the met data is given in terms of a discrete set of values, which are the m/s equivalent of a whole number of knots. In the analysis, hours with reported wind speed of zero or 0.5 m/s were assigned to a single bin with representative speed 0.75 m/s in line with the procedure in ADMS-Airport in which wind speeds of less than 0.75 m/s are set to 0.75 m/s, with the wind direction set to that in the previous hour (or the latest preceding hour with speed above 0.75 m/s).

departures. This was one way of testing the ability of the model to predict the fall-off in the concentration contribution from aircraft on the runway as a function of distance from the 'centre-of-gravity' of airport sources (critical to predicting the aircraft contribution in residential areas north of the airport). In fact, the test is made more stringent by comparing average concentrations separately for each hour of the day. The resulting comparison is displayed in Fig 3.5, which shows the mean LHR2-Oaks Rd NO_x concentration difference (for wind direction within the range 170° to 270° inclusive) by hour of day, separately for hours with departures on 27R and 27L.

3.1.27 Clearly, the average change in concentration between hours when aircraft take off on 27R and hours when they take off on 27L is well reproduced by the model, giving confidence that the model is representing the behaviour of the aircraft contribution as a function of distance from the key airport sources. In addition, during the daytime, the hour-of-day concentration profile when aircraft take off on 27R is fairly well reproduced by the model. The dip in concentration around 15:00 hours (local time) reflects the fact that departures switch between runways at this time (in westerly operation), but complete change-over may not occur at precisely 15:00 every day, so hours near the change-over time may have departures on both 27R and 27L. In the analysis for Fig 3.5, hours were assigned to either the 27R or the 27L categories depending on the which runway had the maximum number of departures in the hour. The comparison in the night hours is not very useful since many hours have departures on neither 27R or 27L, so the concentration is an average for only a few hours and the natural variability in concentration is therefore greater.

3.1.28 Integrating over all hours and normalising appropriately gives the total contribution to the period-mean NO_x concentration difference from the selected sector range for each of the operating modes. Table 3.5 gives the comparison between modelled and measured values for this contribution, showing a remarkable level of agreement, with a fractional discrepancy of less than 4% for departure on 27R (overestimation) and a fractional discrepancy of around 5% (underestimation) for departure on 27L.

3.1.29 Since the PSDH (2002) analysis, additional continuous NO_x/NO_2 sites have become operational in residential areas north of the airport (Harlington, Hillingdon Harmondsworth and Sipson), offering the potential to examine directly the model performance for on-airport sources at receptors further than LHR2 from the runway. However, it should be borne in mind that the wind angles that bring pollutant from sources on the airport to these sites also bring pollutant from the A4 and Northern Perimeter Road, potentially complicating the interpretation, so the 27R/27L comparison remains a valuable additional model test on variation with distance from airport sources.

Bi-Polar Plot

3.1.30 The PSDH model evaluation demonstrated a visually appealing way of presenting concentration differences jointly as a function of wind direction and speed, as a bi-variate polar plot (bi-polar plot for short). Figs 3.6 (a) and 3.6(b) show the LHR2-Oaks Rd NO_x concentration differences presented in this way, with Fig 3.6(a) showing modelling results and Fig 3.6(b) showing monitoring data. The plots are generated by assigning the hourly concentration differences to the set of joint wind sector and speed categories, then taking the average over the set of hours within each joint category.

3.1.31 The set of average LHR2-Oaks Rd concentration differences for the joint categories are then represented on a polar plot in which the radial distance represents wind speed[*], the angle clockwise from the *y* (up-down) direction on the page represents wind angle (the direction from which the wind blows, clockwise from north) and the colour represents a concentration range. The plots have been smoothed to make the visual comparisons easier[†]. Although the plots give a good visual impression of major features of the concentration distribution, it is important not to over-interpret them. Some of the joint categories contain few hours and the concentrations from them are therefore subject to greater sampling fluctuations. Under the

[*] It is important to keep in mind when interpreting the plots that radial distance represents wind speed not spatial distance. All concentrations on a given plot relate to the specific locations of the monitoring sites.
[†] The smoothing is applied only for presentational purposes in this type of figure. All numerical analyses are carried out with un-smoothed data.

action of the smoothing algorithm, concentration outliers may generate localised spatial features which, although visually striking, may simply reflect a sampling fluctuation. However, broad features of the plot reflect the results from many hours and are thus more reliable.

3.1.32 A key feature of both plots is that the concentration difference is large and positive for winds blowing from the SW quadrant, which point from airport sources towards LHR2. Difference concentrations are above 50 $\mu g/m^3$ across most of the quadrant, both in the measurement and the model results. The plots again demonstrate the model overestimation at low wind speeds and underestimation at high wind speeds noted earlier. Although the colour coding focuses the eye on these systematic differences, it is important to recognise that the difference in concentration is generally much less than a factor of two across the whole speed range.

3.1.33 The relatively high concentration at high wind speeds is considered diagnostic of an elevated source, so in this instance reflects the influence of plume rise for hot engine exhaust plumes. However, the comparison in Fig 3.6 cannot be interpreted as showing that the plumes are elevated according to measurement but at ground-level according to modelling. Ground-level plumes generally lead to a rapid decline in concentration with increasing wind speed, whereas both monitoring and modelling plots show concentration remaining high up to the highest wind speeds. A contribution to the difference in the plots, nevertheless, may arise from inaccuracies in the modelling of plume rise, with an indication that the model gives too little plume rise at low wind speed and too much at high wind speed. Generally, the heights of rise are of order tens of metres, and even quite small differences in plume height can have a significant impact on ground-level concentrations.

3.1.34 Furthermore, there is a need for caution in interpreting the variation of concentration with wind speed as simply related to plume elevation: other factors may be at work. For example, emissions may not arise equally in all wind speeds (because of a difference in average wind speed for hours of the day with quite different emission rates) and the distribution of atmospheric ‘stability’ conditions (which affect the rate of dispersion) may not be the same at each wind speed. In addition, the influence of sampling fluctuations needs to be borne in mind for the highest wind speeds, which are relatively infrequent.

3.1.35 It is worth bearing in mind that the concentrations in the bi-polar plot are not weighted by the relative number of hours in the bin, whereas high wind speeds are relatively infrequent. Thus, the contribution to period-mean concentrations from the highest wind speeds is relatively small, as shown in the difference/wind speed plot (Fig 3.5).

3.1.36 The discrepancy in the difference concentration for wind directions in the NE quadrant is clearly visible in the bi-polar plot, and will be discussed in the section below relating to the road network contribution.

Sipson-Oaks Rd

3.1.37 As noted earlier, additional continuous NO_x/NO_2 sites have become operational in residential areas north of the airport (London Harlington, Hillingdon Harmondsworth and Hillingdon Sipson) since the PSDH 2002 analysis, offering the potential to examine directly the model performance for airport sources at receptors further than LHR2 from the runway.

3.1.38 Fig 3.7 shows the difference rose for Sipson-Oaks Rd. Focusing first on wind directions pointing from airport sources to the Sipson monitoring site (with sectors 120° to 240° inclusive accounting for most of the airport contribution), the figure shows good agreement between model results and monitoring data across the range of sectors. The relevant entry in Table 3.3 compares the modelled and measured contribution to the period-mean concentration difference from this range of angles, confirming the good level of agreement, with the model value only 9% lower than the measured value (i.e. a difference of 1.2 $\mu g/m^3$). Table 3.6 gives the breakdown by source category of the contribution from this angle range to the period-mean concentration difference, showing that the airport accounts for 80% of the concentration difference according to the model.

3.1.39 In contrast to the situation for LHR2-Oaks Rd, the modelled contribution from apron emissions is comparable to that from the runway emissions because at the wind angles for which Sipson 'sees' take-off roll emissions from departures on 27R (generally greater than 180°) the emission density on the runway is already low (with many aircraft already airborne by the time they pass Sipson)*. Thus the comparison at Sipson tests a quite different airport source mix than that at LHR2.

3.1.40 For angles greater than 230°, where there is a relatively small contribution from the runway, there is a hint of model underestimation. At these angles, there is a contribution at Sipson from the road complex (including the M25 west of the airport): the road network contribution will be further discussed in the section on road-network sources.

3.1.41 Figure 3.8 gives the contribution/wind speed plot for the sector range 120° to 240°, again showing that the good agreement in the total contribution has resulted from a cancellation of the model overestimation at low wind speeds and underestimation at high wind speeds, but the discrepancy over the middle speed range (which contributes most to the total contribution) is generally better than 20%. The influence of the 'outlier' high measured concentrations (for 2 hours only), discussed in Section 2, can be seen in the comparison for wind-speed categories around 8 m/s.

3.1.42 The bi-polar plots in Fig 3.9 are an alternative way of displaying the features discussed above. Focusing first on the areas of green, which represent a positive difference between Sipson and Oaks Rd for winds blowing from the S-SW (i.e. from the airport). The model reproduces well the measured concentration-difference magnitude, angular range and distribution as a function of wind speed. Again, the influence of the 'outlier' values can be seen for angles around 210° (and wind speed around 8 m/s), with the 'smoothing' routine used for this particular form of presentation spreading the peak to neighbouring joint angle/speed categories.

Harlington–Oaks Rd

3.1.43 Monitoring data from the Harlington site were not available for the PSDH 2002 model evaluation. The Harlington-Oaks Rd difference rose is displayed in Fig 3.10, with airport sources contributing principally over the sectors 160° to 240° inclusive. Although wind angles a little greater than this point from western end of the northern runway, the concentration contribution is small because departures will be on 27R (the eastern end of the northern runway) for these angles and there will be little emission density at the western end.

3.1.44 The wind directions pointing from the airport to the Harlington site will also carry pollutants from road vehicles on the Northern Perimeter Road and on the A4, but the breakdown of the difference by source contribution (Table 3.7) shows that the road network contributes only 11% of the total difference in period-mean concentrations, whereas airport sources contribute 87%, according to the modelling, with runway emissions accounting for a large fraction (around 70%) of this. Thus the Harlington-Oaks Rd difference provides a good test of the modelling for the airport contribution to NO_x concentrations in the residential areas of Harlington.

3.1.45 In contrast to the situation for Sipson, some wind angles that correspond to departures on 27R point to Harlington from parts of the runway that still have significant NO_x emission density from take-off roll, so the airport contribution in Harlington is comparatively large despite the site being further from the runway.

3.1.46 The Harlington-Oaks Rd entry in Table 3.3 shows that the model overestimates the contribution from sectors 160° to 240° by 20%, which is equivalent to 1.6 $\mu g/m^3$, which is less that the expected uncertainty in concentration differences. The contribution/wind speed plot for this range of angles is displayed in Fig 3.11, showing overestimation in a medium range of wind speeds and generally good agreement above 4 m/s. The five wind speed bins

* In fact, Sipson receives a larger contribution from initial climb than from take-off roll.

from 1.5 m/s to 4.1 m/s contribute 4.2 µg/m^3 (out of 9.5 µg/m^3) to the period-mean concentration difference according to the modelling whereas they contribute 2.8 µg/m^3 (out of a total of 7.9) according to the measurements, which represents a model overestimation by 50%. The contribution from the remaining wind speed bins is much the same in the modelling and monitoring data (5.3 µg/m^3 modelled versus 5.1 µg/m^3 measured).

Harmondsworth-Oaks Rd

3.1.47 The Harmondsworth-Oaks Rd difference rose is displayed in Fig 3.12, with airport sources contributing principally over the sectors 110° to 190° inclusive. Harmondsworth, being further west than Sipson or Harlington, has a relatively small airport contribution despite being closer than Harlington to the runway. Wind directions that lead to departures on 27R - which generate the highest emission density on the northern runway – do not point from the runway to the Harmondsworth site: for the range of angles pointing from airport sources to the site, aircraft currently depart from the southern runway (09R). In addition, wind directions that do point from the major part of the northern runway towards Harmondsworth are relatively infrequent. These features are reflected in the source breakdown of the contribution from the 110° to 190° sector range to the period mean concentration, as given in Table 3.8, which shows that the contribution from apron emissions is larger than the contribution from runway emissions. The comparison of modelled and measured contributions to the period-mean from this range of sectors is shown in Table 3.3, with the model underestimating in this case by 24%, equivalent to 1.0 µg/m^3. Monitoring data from the Harmondsworth site were not available for the PSDH 2002 model evaluation.

3.1.48 In Fig 3.12 the agreement between model and measurement is good over the range 110° to 150°, which includes most of the runway and CTA sources. Between 150° and 190°, airport sources are still a major contributor, with about 40% deriving from runway sources and 60% from apron (T5) sources, but here the model under-predicts the difference, which may indicate an under-prediction of the contribution from the T5 aprons. However, the absolute difference in the contribution to the total period-mean concentration difference is only around 1 µg/m^3. For angles greater than 190°, the road network gives the largest contribution from local sources, and the model underestimates the difference by around a factor of two.

Green Gates-Oaks Rd

3.1.49 There is particular interest in the Green Gates site because annual-mean NO_2 concentrations there have been not far below the limit value for a number of years, raising concerns that the opening of T5 may have a significant impact in the Longford area.

3.1.50 The Green Gates-Oaks Rd difference rose is shown in Fig 3.13, with airport sources mainly contributing for wind sectors 100° to 180°. The total NO_x contribution to period-mean concentrations from airport sources is relatively small, for similar reasons to those given above for Harmondsworth, with aircraft mainly taking off on the southern runway when the wind blows from airport sources to the site. The breakdown by source of the contribution to the period-mean concentration difference from these sectors is given in Table 3.9, with airport sources accounting for 95% of the total difference; aircraft (main engines), APUs and airside vehicles contribute comparable amounts to the relatively small airport total.

3.1.51 The modelled difference shows a peak in concentration in the 120° sector, for which the wind points to Green Gates from apron sources in the CTA, and here the model value is a little higher than the measured value, whereas for angles around 160°, which point from T5 aprons to Green Gates, the model value is a little less than the measured value.

Oxford Avenue-Oaks Rd

3.1.52 The Oxford Avenue site receives a substantial contribution to period-mean NO_x concentrations from airport sources, being downwind of major airport sources along the dominant wind direction. In addition, it lies quite close to the A4.

3.1.53 Fig 3.14 shows the Oxford Avenue-Oaks Rd difference rose, with airport sources mainly contributing over the 210° to 260° sector range. Elevated concentration differences are shown over this sector range in both the modelling and monitoring results, with the model difference a little less than the measured difference. Table 3.10 gives the breakdown by source of the contribution to the period-mean concentration difference from these sectors, showing that airport sources account for 69.5% of the total, with the road network accounting for 30.3%. The Oxford Avenue-Oaks Rd entry in Table 3.3 shows a larger absolute discrepancy between modelled and measured values (4.2 $\mu g/m^3$) than for the other sites selected for their airport contribution. This can be attributed to the larger road-network contribution, given the evidence (discussed later) of systematic under-prediction of the road network contribution across the study area. Nevertheless, the fractional discrepancy between the two values is still less than 20%.

Oaks Rd-Harlington (Sipson, Harmondsworth)

3.1.54 It is also possible to test the modelling for airport sources by taking differences between Oaks Rd and a site north of the airport for northerly wind sectors. The model-monitoring comparison is more difficult to interpret in this case because the concentrations include a substantial contribution from the road network at both sites, but they provide useful additional information.

3.1.55 An appropriate range of sectors to capture the airport contribution at Oaks Rd is 330° to 90° and the differences between Oaks Rd and three northerly sites, Harlington, Harmondsworth and Sipson, are examined over this range. Table 3.3 shows the relevant comparison of modelled and measured differences, indicating that the model overestimates the difference, on average by 3.4 $\mu g/m^3$. From Table 3.1, it can be seen that the modelling over-predicts the total period-mean concentration at Oaks Rd (by 6.4 $\mu g/m^3$), for which the overestimation of the airport contribution therefore provides a partial explanation.

3.1.56 The general features of the comparisons are similar for all three northerly sites, so only the Oaks Rd-Harlington differences will be examined in more detail. In a sense, the difference rose can deduced by reversing the signs of the concentrations in Fig 3.10, but because of the nature of the polar plot this is difficult to read for northerly quadrants, so is re-plotted with signs reversed in Fig 3.15.

3.1.57 This reveals a significant over-prediction for wind angles around 320° to 350°: these sectors point to Oaks Rd from the T5 aprons, which are the principal airport contributors in this range. The runway gives little contribution for these sectors since, in principle, aircraft should be taking off from 27L/27R for these wind directions (although the correlation between wind direction and change of runway operation is not exact). The over-prediction of the difference in the 320° to 350° range might indicate an overestimation of the T5 contribution at Oaks Rd, but caution is needed, given that the modelled contribution at Harlington from these directions (which has a significant road network contribution) may be underestimated. Evidence will be presented below that there is a general under-prediction of the contribution from the road network across the study area. There is a smaller model overestimation of the concentration difference (by 14%) for the sector range 10° to 60°, which includes contributions from take-off roll on the southern runway and from CTA apron emissions.

3.1.58 Fig 3.16 gives the contribution/wind speed comparison for the whole 330° to 90° range, showing even more strongly than in the differences for southerly winds (e.g. Fig 3.4) that model overestimation at low wind speed is partly offset by an underestimation at higher wind speeds. In this instance, the overestimation at low wind speeds has a greater effect on period-mean concentrations because the probability of low wind speeds is higher for northerly winds than it is for southerly winds, as illustrated in Fig 3.17. In the discussion of the LHR2-Oaks Rd differences, it was speculated that underestimation of plume rise at low wind speed for main engine exhaust emissions (and overestimation at high wind speed) may be contributing to the discrepancy. In a similar vein, the lack of plume rise modelling for APU emissions on the aprons may also be playing a part. It is worth noting that the frequency of northerly winds is relatively low and quite strongly angle-dependent (see wind rose in the 2008/9 modelling methodology report). Thus, uncertainties in the met data for wind direction may contribute to modelling-monitoring differences.

3.1.59 From the three comparisons for Oaks Rd in Table 3.3, the modelling overestimates the contribution to the concentration difference by around 3 $\mu g/m^3$. If this is attributed solely to overestimation of the airport contribution at Oaks Rd, it would account for about one half of the total overestimation of the the period-mean NO_x contribution at Oaks Rd (6.4 $\mu g/m^3$).

Summary for Airport Sources

3.1.60 It is useful to summarise the position for airport sources before moving on to comparisons for the road-network contribution.

3.1.61 Referring to Table 3.3, the values of the contribution to period-mean concentration difference for sectors dominated by airport sources range over an order of magnitude across six sites north of the airport (from 3.2 $\mu g/m^3$ to 34.4 $\mu g/m^3$), and the average (absolute) discrepancy between modelled and measured values at the six sites is only -0.6 $\mu g/m^3$, with a standard deviation of 1.8 $\mu g/m^3$. Expressed in fractional terms, the mean fractional discrepancy is -5.4% (underestimation), with a standard deviation of 15.5%. This level of discrepancy is small compared to the uncertainties in concentration difference measurements, so provides no evidence that the modelling for airport sources either overestimates or underestimates significantly.

3.1.62 The comparisons presented above together indicate that the model gives a good account of the impact of airport sources on period-mean NO_x concentrations at receptors in the residential areas north of the airport. In particular, it represents well the variation in the airport concentration contribution with distance from the principal sources on the airport and the variation with east-west location in relation to the ends of the northern runway. This gives confidence that the model provides a robust basis for investigating the potential impact on residential areas of operational changes on the airport that affect the magnitude and spatial distribution of NO_x emissions, for example the abandonment of the Cranford agreement (which would then allow departures on runway 09L) and the construction of a third runway north of the current runways.

3.1.63 At Oaks Rd, close to the southern boundary of the airport the difference comparisons indicate that the modelling overestimates the contribution from airport sources by around 3 $\mu g/m^3$ (for a total airport contribution of 17 $\mu g/m^3$), although this discrepancy is only of comparable size to the judged uncertainty in measured differences in period-mean concentrations.

3.1.64 These comparisons jointly test the methodology for quantifying airport emissions and the dispersion modelling methodology that translates emissions into airborne concentrations. This raises the possibility that significant errors in emissions quantification may be fortuitously cancelling errors in dispersion modelling, an issue that was discussed in Section 1. The good agreement found above, however, applied in situations where different source groups (runway, apron, etc) were dominant, so any fortuitous cancellation would have to apply across a range of sources.

Concentration Contours for the Airport Contribution to Period-Mean NO_x concentrations

3.1.65 The above tests gives confidence in the model's ability to predict the spatial variation of the airport contribution to total NO_x concentrations in the residential areas around the airport. To show this variation, concentration contour plots have been generated based on the model values at a set of grid points, as described in the modelling methodology report. The basic receptor grid is a square grid with 100 m spacing, aligned with the OS grid axes. In addition, for the modelling of aircraft sources on the runway, the 'intelligent gridding' option in ADMS-Airport was used, which creates additional receptors at a finer spatial resolution close to the runway. These additional points help to capture the large spatial gradients close to the runway in the contribution from runway sources to period-mean NO_x concentration, although the base 100 m grid is adequate to capture the spatial gradients in the residential areas around the airport.

3.1.66 As noted earlier, the contour plots are based on calculated concentration values that are averages over all hours of the 2008/9 period (termed earlier the 'all hours' period-mean concentration), in contrast to the values used in the comparisons with measurements discussed above, which took into account missing data in the measurements.

3.1.67 Fig 3.18 gives the contour plot for period-mean contribution from 'airport' sources (as defined earlier). The shape of the contours reflects the spatial distribution of NO_x emissions on the airport - with particularly high emission intensity at the eastern end of the northern runway – coupled with the strongly anisotropic wind rose (with its south westerly dominance). The current restriction of departures on runway 09L (the western end of the northern runway) adds to the anisotropy of the contours. Values of the airport contribution to the period-mean NO_x concentration above 30 $\mu g/m^3$ are restricted to within the main body of the airport, with values in the nearest residential communities typically within the range 10-20 $\mu g/m^3$. At the M4 motorway, the contribution from airport sources (as defined earlier) is at most around 6.3 $\mu g/m^3$ (at an easting of around OS 508800), falling to around 3.5 $\mu g/m^3$ where the M4 intersects the eastern edge of the study area (OS 512000) and around 1.5 $\mu g/m^3$ where it intersects the western edge (OS 503000).

Comparison with PSDH Results for 2002 and 2010SM

3.1.68 Fig 3.19 shows the same information as in Fig 3.18 but using colour bands for concentration ranges. The colour coding has been chosen to correspond to that used in the PSDH air quality report, to facilitate visual comparison with equivalent results for the 2002 PSDH case (Fig 10.3 in the CERC report[14]) and the 2010SM (Segregated Mode) case (Fig 10.12 in the CERC report). It should be noted that the PSDH work used a slightly different definition of 'airport' sources, which included a few landside road links and the tunnel to the CTA, but this does not have a major impact on the shape of the contours. It should also be noted that, although the colour coding has been continued to high values of NO_x close to sources on the airport, the modelling has not been optimised to represent detailed concentration variations close to airport buildings; the spatial resolution of emissions and receptors has been chosen principally with a view to predicting off-airport concentrations. However, the high-concentration colour bands in the interior of the airport provide a valuable means of checking the spatial distribution of the underlying emissions.

3.1.69 Concentration results from the PSDH work were also presented at a series of specific receptors that included the monitoring sites operating at the time and a number of other key locations. For the present discussion, a set of 13 specific receptors have been chosen to compare results from the PSDH with those from the present work, including continuous NO_2/NO_x monitoring sites common to the two sets of results plus four other sites (HD56,t HD57, HD58 and HD60) selected to represent key areas of interest not covered by the monitoring sites; the sites are marked on Fig 3.20.

3.1.70 Prior to presenting the concentration comparisons, Table 3.11 summarises relevant emissions information, showing that the 2008/9 and 2002 PSDH cases have comparable ground-level airport emissions, with the forecast 2010SM emissions somewhat higher. Table 3.12 compares the contributions to period-mean concentrations from airport sources at the selected sites,for the three cases. The set of sites span an order-of-magnitude range in total airport contribution to period mean NO_x concentrations from less than 3 $\mu g/m^3$ to greater than 30 $\mu g/m^3$.

3.1.71 At a given site, the contributions from a given category of airport sources for the three cases are broadly comparable, as expected from the magnitude of total emissions. However, there are subtle differences from one case to another that relate to differences in the spatial distribution of emissions between the cases and differences in meteorology. For example, the relatively larger aircraft contribution at Hatton Cross in 2008/9 is partly due to the significantly higher frequency in 2008/9 than in 2002* of the wind blowing in the 270° wind

* The 2008/9 wind rose is shown in Fig 3.1 in the 208/9 modelling methodology report, and the PSDH wind rose is Fig 2.1 in the CERC report for the PSDH[14].

sector*. Only wind directions in a relatively narrow range of angles around 270° bring runway emissions to the Hatton Cross site. Similarly, the relatively large contribution at Oaks Rd from non-aircraft airport emissions (principally airside vehicle emissions) is partly due to the higher frequency in 2008/9 than in 2002 of winds blowing in sectors 40° to 60° (pointing from the CTA aprons to Oaks Rd). It is worth noting that the wind blows relatively infrequently in some ranges of wind sectors, and there is much higher variability from year to year in the frequency associated with these sectors.

Evaluation of the Modelling for the Road Network Contribution

3.1.72 Road vehicle emissions on the road network around Heathrow play an important role in determining the total concentration of NO_x in residential areas close to the airport, so concentration differences were analysed separately with a focus on the road-network contribution. In the discussion below, it is important to keep in mind the 'interim' nature of the traffic model, which is discussed in the 2008/9 inventory report.

Hillingdon-Harmondsworth; Hillingdon-Harlington

3.1.73 The Hillingdon site is 40 m north of the nearest lane of the M4, so receives a major contribution from the motorway when the wind blows from southerly directions. Over part of the range of southerly wind sectors, the site also receives a contribution from the airport, but at this distance the modelled contribution is small. By choosing a 'difference' site that is also north of the airport (and without a large airport contribution), the potentially confounding effect of differences in non-road contributions can be reduced: Harlington and Harmondsworth are appropriate 'difference' sites.

3.1.74 Fig 3.21 gives the Hillingdon-Harmondsworth difference rose. Both the modelled and measured concentration differences are large for southerly winds, typically around 60-80 $\mu g/m^3$ from modelling and 80-100 $\mu g/m^3$ from measurement, but it is clear that the model systematically underestimates the concentration difference over the whole range of sectors for which the motorway is expected to give a major contribution, in particular for south-easterly wind directions. An underestimation of this magnitude is very unlikely to be attributable to measurement uncertainty alone. Table 3.13 (which serves as a master table of comparisons relating to the road network) compares the measured and modelled differences for the sector range 100° to 270°, showing that the model underestimates the contribution to the period-mean concentration difference by 20%, a discrepancy of 9.2 $\mu g/m^3$ on a measured total of 46.4 $\mu g/m^3$. Table 3.14 gives the breakdown by source of the contribution to the period-mean concentration difference from these sectors, showing that airport sources account for less than 2% of the total difference, with the road network accounting for 93%.

3.1.75 Fig 3.22 shows the contribution/wind-speed comparison for the 100° to 270° sector range. Although there is an under-prediction in the total area, in line with the discrepancy in the difference rose, it can be seen that if the model values are re-normalised to the same total as from the monitoring there would be overestimation at low wind speed and underestimation at high wind speed. This tendency, therefore, is displayed not only for aircraft sources, so some component of it, at least, is generic to the dispersion modelling as a whole.

3.1.76 Fig 3.23 gives the Hillingdon-Harlington difference rose, which has similar features to those for Hillingdon-Harmondsworth. In this case, the fractional discrepancy between modelled and measured values for the contribution from sectors 100° to 270° to the period-mean concentration is a 37% under-prediction, a discrepancy of 18.5 $\mu g/m^3$ out of a measured total of 49.7 $\mu g/m^3$. The smaller amount of under-prediction when Harmondsworth is used as the 'difference' site may result from its location closer to the M25 and M25/M4 interchange, given the evidence discussed later in this section of under-prediction of the concentration contributions from the M25. Model underestimation of the road network contribution at Harmondsworth would increase the model difference and reduce the discrepancy between

* Also, the overall frequency of departures in westerly operation was higher in 2008/9 (71.7%) compared to in 2002 (68.8%), which would put more of the emissions at the eastern end of the runway.

Appendix AQ.1.15

modelled and measured differences.

3.1.77 There is major interest currently in whether or not the present methodologies for quantifying NO_x road vehicle emissions are leading to systematic under-prediction of traffic-related emissions, and it is tempting to interpret the above results for the Hillingdon site in this light. However, before conclusions can be drawn from these results about the current set of emission factors, it is necessary to evaluate the basic traffic data used in the emissions quantification. The report on the interim traffic model[26] shows there is good agreement between traffic model output and measured total two-way flow between Junction 4 and 4b, with the comparison in the three model time periods shown in Table 3.15. However, this comparison does not provide any information on the HDV (bus/coach and HGV) fraction in the traffic, which is particularly important from an emissions perspective. It addition it does not give any information on the accuracy of modelled traffic speed, also a parameter of key importance for emissions. In relation to the latter, hourly average speed may not be enough to characterise the traffic state in relation to emissions if there are periods of flow breakdown and queuing.

3.1.78 In this context, the measured concentration difference in Fig 3.23 shows a peak at around 120°-140°, which could result from traffic slowing or queuing to exit the M4 eastbound at Junction 4, but this level of detail is not represented in the traffic data used in the modelling. A contribution to the peak may also arise from emissions on the section of the M4 Spur south of its junction with the M4, with the increased discrepancy at these angles then reflecting a modelling deficiency in the representation of this contribution.

3.1.79 In conclusion, it will be necessary to carry out a more detailed evaluation of traffic model outputs for links close to air quality monitors before conclusions can be drawn regarding the accuracy of the current set of NO_x speed-emission curves (as discussed in detail in the inventory report). It may be preferable to wait until a revised, fully calibrated traffic model becomes available before carrying out this detailed examination.

Green Gates-Oaks Rd (Road Network Contribution)

3.1.80 As noted earlier, there is particular interest in the NO_x and NO_2 concentrations at Green Gates because total NO_2 concentrations have been running close to the limit value of 40 $\mu g/m^3$ in recent years. In relation to the road network contribution, the Green Gates–Oaks Rd difference rose (Fig 3.13) indicates significant discrepancies for northerly and westerly sectors.

3.1.81 It is difficult to identify a 'clear' difference for the road network contribution at Green Gates. For angles giving a significant network contribution at the site, most other sites also have a significant network contribution. However, the key wind direction quadrants at Green Gates from this perspective are westerly (bringing pollutant from the M25 and the A3044), so the Green Gates-Oaks Rd difference itself can be used if the sector range is restricted to around 200° to 290°: at greater angles Oaks Rd starts to 'see' the nearby southern perimeter road and the various junctions with the A3044 and the M25 (J14); at smaller angles Green Gates starts to 'see' airport sources. Table 3.16 gives the breakdown by source of the modelled contribution to the period-mean concentration difference from these sectors, showing that the road network accounts for 69% of the total difference; the relevant entry in Table 3.13 gives the model-monitoring comparison for this sector range, showing that the model contribution to the period-mean concentration difference is only 40% of the measured contribution, equivalent to a discrepancy in period-mean concentration difference of 7.4 $\mu g/m^3$. The discrepancy over this sector range can account for more than 50% of the total discrepancy in period-mean NO_x concentration at Green Gates (Table 3.1).

Harmondsworth-Colnbrook

3.1.82 It is important to identify if the discrepancy at Green Gates in westerly winds arises from a source very local to the site or relates to the contribution from the western parts of the road network in general. To shed light on this, concentration differences were taken between Harmondsworth and Colnbrook for westerly wind sectors, restricting the (northerly) angular range to reduce the contribution at Colnbrook from the M4 (and A4). The range 200° to 290° was selected, for which the road network accounts for 71% of the modelled contribution to the period-mean concentration difference. Fig 3.24 presents the difference rose for this pair of sites, showing that the model under-predicts the difference over the pertinent angular range. The relevant entry in Table 3.13 compares the modelled and measured values of the contribution to the period-mean concentration from this sector range, showing that the model underestimates the contribution by a factor of two, equivalent to an under-prediction of 5.4 $\mu g/m^3$.

3.1.83 Again, before conclusions can be drawn about the emission factors in current use, the fidelity of the traffic data has to be considered. The report on the interim road model[26] gives a comparison of modelled and observed flows on the M25 from J15 to J14 (only anticlockwise flows are available in the report), as shown in Table 3.15, with total flows under-predicted by 8%,13% and 19% in the morning-peak, inter-peak and afternoon-peak traffic model periods respectively. As with the M4 comparisons discussed earlier, no information is provided on the accuracy of the predicted HDV (bus/coach and HGV) fraction or traffic speed. Thus, it would be premature to draw conclusions from the present NO_x concentration comparisons about the performance of current methodologies for estimating road-vehicle emissions in situations where the traffic is well characterised from an emissions perspective.

Green Gates-Harmondsworth

3.1.84 There are other, more puzzling discrepancies associated with Green Gates for winds from northerly sectors, which can be examined most effectively using Green Gates-Harmondsworth differences. Fig 3.25 presents the difference rose for this site pair. The discrepancy in the westerly sectors has been discussed above using other differences, but it is striking that in the sectors 0° to 90° the model difference in Fig 3.25 is effectively zero whereas the measured difference is around 15-20 $\mu g/m^3$ in all sectors. Thus, this sector range contributes around 3.4 $\mu g/m^3$ to the total measured period-mean concentration difference, but virtually nothing to the total modelled period-mean concentration difference. The Green Gates monitoring data are fully ratified for the period and measurement uncertainties are unlikely to account for a discrepancy of this magnitude.

3.1.85 In this angle range, the site is too far from the A4 (around 200 m at closest point) and from the M4 (1.5 km) to expect a significant difference contribution from the road network. The nearby Bath Rd (nearest edge is 16 m from the monitor), although not included specifically in the modelled major road network, carries little traffic and is unlikely to be the origin of the excess concentration.

3.1.86 One possible explanation relates to the spatial resolution of the emissions taken from the LAEI. Although large point sources have been modelled individually, it cannot be ruled out that the 1-km spatial resolution of emissions from medium-sized point sources in the LAEI may be having an influence on the accuracy of modelled concentrations close to Green Gates. Alternatively, there are (so far unconfirmed) reports of some (house) construction activity on the Bath Rd close to the monitoring site at around the relevant period, but the duration and extent of any such activity is not currently known. However, at the present time the origin of the concentration excess at Green Gates in these sectors is unclear.

Oxford Avenue-Oaks Rd (Road Network Contribution)

3.1.87 As noted earlier, besides receiving a substantial contribution to period-mean NO_x concentration from airport sources, Oxford Avenue is located close to the A4 and receives a moderate contribution from the road network. Choosing the sector range from 90° to 180° avoids the major airport sources (although includes the long-stay car park south of Oxford Avenue). Table 3.17 shows that the road network accounts for 96% of the modelled contribution to period-mean concentration difference for this range of sectors.

3.1.88 The relevant entry in Table 3.13 shows that the model accounts for only 40% of measured contribution from this range of sectors (an under-prediction of 60%) equivalent to an under-prediction of 3.2 $\mu g/m^3$. Taken together with results quoted earlier for Oxford Avenue-Oaks

Rd (200°-260°), this suggests that the underestimation of the contribution from the road network for southerly wind sectors (which includes the contribution from the nearby A4) can account for around 6 μg/m^3 of the 12 μg/m^3 discrepancy in total period-mean concentrations at Oxford Avenue (Table 3.1), with the remainder deriving from neither the airport nor the A4.

3.1.89 It is worth remembering that information on the accuracy of the traffic model outputs for the A4 was not provided in the traffic model report.

LHR2-Harlington

3.1.90 As noted in the earlier discussion of the difference rose for LHR2-Oaks Rd, the measured concentration difference shows a strong peak for wind sectors around 40°, which requires further investigation. LHR2-Oaks Rd is not the best site pair for examining these wind sectors, given that Oaks Rd receives a substantial airport contribution from the relevant sectors, which complicates the interpretation. Thus, a difference site north of the airport is preferable for investigating the contribution from northerly sectors to the period-mean concentration at LHR2. Harlington was chosen for this purpose, and Fig 3.26 gives the LHR2-Harlington difference rose, showing clearly the excess contribution localised around 40°. For the sector range 270° to 100° (for which the road network dominates the contribution to the period-mean concentration difference), Table 3.13 shows that the model underestimates the difference contribution by 36%, equivalent to an under-prediction of 10.9 μg/m^3. This underestimation of the road network contribution is more than enough to account for the under-prediction in total period-mean NO_x at LHR2 shown in Table 3.1.

3.1.91 The narrow angular range associated with the excess contribution and the fact that it does not appear for other monitoring sites suggests that it derives from a local source. Although there are a number of potential sources immediately north east of LHR2, including car parks and the taxi feeder park, the most likely candidate is traffic on the Northern Perimeter Road (NPR), around the (signalised) junction with Neptune Rd (see Fig 2.2(a)). Fig 3.27 presents a (Google) satellite image at higher spatial resolution, showing the road layout near the site, including the location of the traffic signals.

3.1.92 As discussed in the 2008/9 inventory report, traffic queues were not explicitly recognised in the traffic data set available for the 2008/9 inventory. In previous airport studies (except for the PSDH*), AEA used a methodology in which junction delay times output by the traffic model were used to derive queue lengths and queuing emissions, but in the traffic data provided for the 2008/9 inventory junction delays were incorporated into the effective speed associated with the road link. This procedure does not necessarily lead to underestimation of total emissions on the link, but it does redistribute any increased emissions arising at/near junctions along the whole link. In the case of LHR2, this would reduce the modelled concentrations at the site. Such considerations indicate that detailed model-monitoring comparisons at sites close to road junctions require particular attention to how junction delays are to be represented from an air quality perspective.

3.1.93 It is worth remembering that information on the accuracy of the traffic model outputs for the NPR was not provided in the traffic model report.

Hayes-Cranford

3.1.94 Data from the Hayes kerbside monitoring site were not available for the PSDH model evaluation, with the site only becoming operational in 2008 (April). Table 3.1 showed a large discrepancy between modelled and measured period-mean NO_x concentrations at the site (34.4 μg/m^3). To investigate the road network contribution to this discrepancy, concentration differences between the Hayes and Cranford sites were examined. A site north of the airport was (marginally) preferred to Oaks Rd as the difference site because of the north/south gradient in the LAEI/NAEI contribution, although it restricts the angular range available to avoid the airport contribution at Cranford.

* AEA compiled the PSDH inventories for airport sources, but CERC quantified the emissions on the road network as part of the ADMS-Airport modelling task.

3.1.95 Fig 3.28 gives the Hayes-Cranford difference rose, showing that the model significantly underestimates the difference for southerly sectors, when the wind blows from the adjacent A437 towards the monitoring site. Restricting attention to sectors less than 220° to avoid the airport contribution at Cranford, Table 3.13 compares the modelled and measured contribution to the period-mean concentration difference from the sectors 90° to 210°, for which the road network contributes 87% of the total. The model underestimates the contribution by 44%, equivalent to 9.6 $\mu g/m^3$. It can be inferred, therefore, that the under-prediction of the contribution from all southerly sectors broadly speaking accounts for around 2/3 of the total discrepancy in period-mean concentration at Hayes, with the remainder 1/3 deriving from northerly sectors.

3.1.96 The location of the Hayes monitor is challenging from an air quality modelling perspective, situated at the kerbside of the A437 (N Hyde Rd) and on the junction with N Hyde Gardens (not part of the modelled network). There is no information on the fidelity of the modelled traffic flows, speeds and composition on the A437, and earlier comments about the modelling of junction delays apply here also (although the junction is not signalised). Thus it is not possible to draw general conclusions about current emissions factors from the comparisons presented here, but the airborne concentrations at the site would be worth re-analysing when traffic data that are well characterised from an air quality perspective are available.

3.1.97 Turning attention to northerly sectors, it is clear from Fig 3.28 that the model underestimates the concentration difference from these directions also. Table 3.1 shows that there is an especially high contribution to the period-mean concentrations at Hayes from the LAEI/NAEI sources, and ancillary modelling information shows there is an important component (around 12 $\mu g/m^3$) from rail emissions on the Great Western line. According to the modelling, the contribution to the Hayes-Cranford period-mean concentration difference from sectors 270° to 80° is 10.5 $\mu g/m^3$ whereas the measured contribution is 25.5 $\mu g/m^3$, revealing an underestimation by 15 $\mu g/m^3$. It is not possible to say from the data at one site how much of this discrepancy is local to the Hayes site or more widespread within the Hayes area. It is worth noting that there is an industrial estate north west of the site, including the Nestle plant. The latter has been modelled as a stack release (see the 2008/9 modelling methodology report), but contributes <1 $\mu g/m^3$ at the Hayes site according to the modelling.

Road Network Scaling Factor for NO_x

3.1.98 One aim of the modelling study, besides evaluating model performance, is to generate contours of total period-mean NO_2 concentration in order to gauge the spatial extent of any residential areas in which the concentration exceeded the limit value of 40 $\mu g/m^3$. If the model reproduces well the concentrations at the monitoring sites, this process can be viewed as an 'intelligent' way of interpolating and extrapolating from the measured data, guided by an understanding of source contributions, to generate the best estimate of the overall spatial distribution of concentration.

3.1.99 The difficulty that arises in the present study, therefore, is the evidence for a consistent underestimation of the contribution from the road network. Concentration contours derived from the raw modelling results, therefore, will underestimate NO_x concentrations and thus the extent of any NO_2 exceedence area.

3.1.100 As noted above, the observed discrepancies point to the need for a more detailed evaluation of traffic model outputs and how these are used to calculate emissions. It may be advantageous to defer that work until a traffic model is available that has been calibrated and validated with particular reference to those traffic characteristics that are key to the quantification of road traffic emissions and to the estimation of the road network contribution to airborne pollutant concentrations.

3.1.101 In the interim, however, a procedure has been devised that seeks to make best use of the information currently available to estimate the NO_x concentration field within the study area. This procedure attributes the non-zero average fractional discrepancy across the monitoring sites entirely to a underestimation of the road network contribution everywhere within the area. Thus, a scaling factor is applied uniformly to the road network contribution at all points, with the magnitude chosen so that the average fractional discrepancy in total period-mean NO_x concentrations across the continuous monitoring sites reduces to zero. Applying an adjustment in this form automatically generates a larger absolute change in concentrations at sites close to roads, which is consistent with the results of the evaluation.

3.1.102 The required factor is found to be 1.212, i.e. the modelled road network contribution is increased by 21.2% everywhere in the study area. The resulting period-mean concentrations at the monitoring sites are shown in Table 3.18 and the revised scatter plot is shown in Fig 3.29. After application of the scaling factor, the correlation between modelled and measured values increases marginally from 0.89 to 0.90. The standard deviation of the model-monitoring discrepancy remains at around 12%. It cannot be ruled out that this adjustment of the road network contribution may be partly compensating for a systematic over- or under-prediction of the LAEI/NAEI/background contribution, given that the combined contribution from these components is only slowly varying across the study area so cannot be readily evaluated by difference analysis. However, this additional uncertainty is intrinsic to the simple scaling approximation.

3.1.103 Although the average discrepancy across the sites has been reduced to zero, this does not imply that there cannot be a systematic spatial variation in the residual discrepancy across the study area. It is likely that at receptors immediately south of the airport the period-mean concentrations are overestimated because of an over-prediction of the contribution from airport sources in northerly winds. Similarly, for receptors to the (north) west of the airport there may be a systematic residual underestimation because of the under-prediction of the contribution from the M25.

3.1.104 The above simple scaling process is unlikely to remove all the discrepancy relating to the road network at sites such as Hayes and LHR2, but at least some of the discrepancy at these sites is likely to be due to features specific to the site and not necessarily generalisable to other receptors. Nevertheless, the scaled NO_x concentration field may underestimate concentrations at near-road receptors that are strongly influenced by traffic queuing at junctions or are situated close to areas of the network subject to other types of flow disruption. Also a simple scaling of this type is unable to compensate fully for the 'missing' contribution at Green Gates (from north-easterly winds), so could lead to an underestimation of concentrations in Longford unless the missing source is very local to the monitoring site. Similarly, it is unable to compensate for the discrepancy at Hayes from northerly wind sectors, which will similarly lead to an underestimation of concentrations in Hayes unless the reason for the discrepancy is very local to the monitoring site.

Contours of Total Period-Mean NO_x Concentration

3.1.105 Contours of total (all-hours) period-mean NO_x concentration after applying the road network scaling factor discussed above are shown in Fig 3.30, in a colour-coded form using the same coding scheme as in the PSDH work, for ease of comparison[*]. As will be seen in the following section, the NO_2 limit value of 40 $\mu g/m^3$ corresponds to NO_x values within the range 70-80 $\mu g/m^3$, for the current set of results[†], so there is particular interest in the off-airport areas shown in dark green, yellow and warmer colours. Fig 3.31 shows the equivalent results without applying the road network scaling factor, to enable the impact of the scaling to be visualised.

3.1.106 It should be noted that the spatial representation of sources has been judged in relation to the impact on off-airport concentrations, so spatial variations within the body of the airport are less reliable. In particular, the chosen spacing of the discrete jet sources on the runway and taxiways should be borne in mind. Also, the density of the grid receptor points results from a compromise between model run time and the smoothness of contours, so that some features of the contour shapes at the sub-100 m scale may be artefacts of the finite

[*] The lower concentration bands, however, have been shown hatched so that parts of the base map show through, to help locate the boundaries between colours on the map.
[†] There is not a fixed period-mean NO_x value corresponding to a given period-mean NO_2 value in the Jenkin methodology if there are site-to-site differences in the total oxidant concentration, which in turn depends on how much primary NO_2 is associated with the total NO_x concentration.

resolution of the grid.

3.1.107 Fig 3.30 can be compared with the equivalent figures in the CERC report for 2002 (Fig 10.1) and 2010SM (Fig 10.10). It is clear that the 2008/9 results for total NO_x concentration are much closer to the equivalent 2002 PSDH results than to the 2010SM results. However, the 75 µg/m^3 contour in the 2008/9 results does not extend as far from the airport boundary into Harlington as in the 2002 results, and a smaller area of Hayes between the Great Western railway line and M4 is above 75 µg/m^3.

Comparison with PSDH at Specific Receptors

3.1.108 It is easier to make detailed comparisons with the PSDH results by focusing on a representative set of specific receptors. Table 3.19 compares the 2008/9 results (including the road network scaling factor) for (all hours) period-mean NO_x concentration with the equivalent 2002 PSDH and 2010SM results at the 13 specific receptors introduced earlier. For the non-airport contribution, the 2008/9 results are much closer to the 2002 PSDH results than to the 2010SM results, with the average over the 13 sites 3.5% lower for 2008/9 than for the 2002 PSDH case and 42% higher than for the PSDH forecast 2010SM case. Although the calculated 2008/9 value of the total NO_x emissions on the designated road network is around 30% lower than that quoted for the 2002 PSDH case (for a closely equivalent network – see 2008/9 emission inventory report), the scaling up of the road network contribution by 21% described above has brought the calculated NO_x concentrations for 2008/9 close to the corresponding 2002 values. The PSDH forecast 2010SM NO_x concentrations are significantly lower, principally as a result of the fall in the road vehicle contribution that was expected to occur by 2010.

3.1.109 As discussed earlier, the contribution from the ‘airport’ sources is similar across the three cases, with the result that the total modelled NO_x concentrations for 2008/9 are similar to those for the 2002 PSDH case and higher than those for the 2010SM case. The average total NO_x concentration across the 13 sites for the 2008/9 case is 3.8% lower than for the 2002 PSDH case and 29.3% higher than for the 2010SM case.

3.2 NO_2

Total Oxidant

3.2.1 The ‘Jenkin’ methodology for deriving annual mean NO_2 concentrations from annual mean NO_x concentrations, described in the 2008/9 modelling methodology report, has two components: (a) the relationship between annual mean total oxidant (sum of O_3 and NO_2 concentrations) and annual mean total NO_x concentration and (b) the fraction of the total oxidant that is NO_2, as a function of NO_x concentration.

3.2.2 Given that there are ozone measurements at some of the near-Heathrow monitoring sites (Cranford, Harlington and Hillingdon), it is possible to carry out a limited test of the (a) component separate from an evaluation of (a) and (b) together (which yield annual-mean NO_2 concentrations). Table 3.20 compares the total oxidant at the three sites derived from measurement with the value derived using the Jenkin relationship

$$[OX] = B + A\,[NO_x] \qquad (1)$$

where [OX] is the annual mean oxidant concentration (ppb), *B* is the background oxidant (discussed in the modelling report, and assigned the value 33.5 ppb for the Heathrow region in 2008/9), *A* is the weighted-average primary NO_2 fraction for the site derived from the modelling[*] and $[NO_x]$ is the annual mean NO_x concentration at the site. It should be noted from Table 2.2(e) that the data capture for the ozone measurements at Cranford was poor in the 2008/9 period.

[*] The values of *A* used here are those derived after using the roads scaling factor, but are little different from those derived without the scaling.

3.2.3 Equation (1) is a relationship between twelve-month mean values, and is applied in the current context to period-mean concentrations. Missing data in the measurements must not be forgotten, but from the perspective of Equation (1) the measured period-mean concentrations are viewed simply as an approximation to the all-hours period-mean concentrations, with the additional uncertainty caused by missing data borne in mind at the comparison stage. (The key metric being evaluated for NO_2 is the NO_2/NO_x ratio, which is judged to be relatively insensitive to the missing data at the sites of interest.) The right-hand side of Equation (1) has been calculated using the measured value of $[NO_x]$, thus making the comparison principally a test of the values of *B* and *A*.

3.2.4 Table 3.20 shows reasonable agreement at the three sites, although the [OX] values derived from the right-hand side of (1) are on average 6% higher than the sum of the measured O_3 and NO_2 concentrations, which is within the uncertainty in the measurements. Given that there is some uncertainty in the value of *B*, there would be justification for treating it as an adjustable parameter, within the range of uncertainty, to improve the fit of modelled period-mean NO_2 concentrations with measurements. However, an adjustment of this type was not judged necessary, given the level of agreement obtained with the baseline estimate (see below).

Period-Mean NO_2 Concentrations

3.2.5 Table 3.21 compares the modelled and measured period-mean NO_2 concentrations (with the former derived from the modelled period-mean NO_x concentrations using the values of *B* and *A* appropriate to the whole twelve month period). The model results are shown both with and without the application of the NO_x road network scaling factor discussed earlier.

3.2.6 Before applying the roads scaling factor, the average fractional discrepancy (defined as *(modelled-measured)/measured*) is -1.8% (with a standard deviation, SD, of 9.7%), i.e. the model underestimates on average by 1.8%. After applying the roads scaling factor, the average fractional discrepancy is 1.6% (SD 9.7%). Neither of these values of average fractional discrepancies can be interpreted as a significant model bias.

3.2.7 Fig 3.32 shows a scatter plot of modelled versus measured period-mean NO_2 concentrations, both with and without the application of the road-network scaling factor. The correlation coefficient is 0.87 without application of the road-network scaling factor and 0.88 including the factor.

NO_2/NO_x Ratios

3.2.8 Of course, the NO_2 comparison reflects partly the underlying NO_x comparison, whereas a comparison of NO_2/NO_x ratios provides a more specific test of the Jenkin methodology for deriving period-mean NO_2 concentrations from period-mean NO_x concentrations (although this test does not remove entirely the dependence on the absolute NO_x values because of the non-linearity of the relationship). Table 3.21 shows the modelled and measured values of this ratio, both with and without the road-network scaling factor. The measured ratios range from 0.44 to 0.63 across the sites, with the modelled ratio ranging from 0.46 to 0.61 before applying the roads scaling and 0.45 to 0.60 after applying the scaling.

3.2.9 Without the road-network scaling factor, the average fractional discrepancy in the NO_2/NO_x ratios is 4.1% (i.e. the model on average overestimates the ratio by 4.1%) with a SD of 6.0%. After applying the roads scaling factor, the average overestimation reduces to 2.1% (SD 5.5%). This level of agreement is within what is expected from the (semi-empirical) Jenkin methodology, judging from the scatter on the data points used to derive the underlying $[NO_2]/[OX]$ relationship. Thus, the results indicate that the Jenkin methodology does not introduce any significant bias into the model results, so that once the bias in NO_x concentrations has been removed no further model adjustment is necessary.

Jenkin Category III versus Category II

3.2.10 It was noted in the modelling methodology report that the inter-quartile ratio of hourly monitoring values at Oaks Rd and Hatton Cross would in principle put them into Jenkin Category III rather than II (which has been used for all the results in Table 3.21), but Category II was retained on the grounds that the higher value was more likely related to the airport contribution than to a road network contribution. Table 3.22 shows the NO_2 values and the NO_2/NO_x ratios obtained using the Category III rather than Category II relationship.

3.2.11 At Oaks Rd, using the Category III relationship would lead to an under-prediction of the NO_2 concentration there. The NO_2/NO_x ratio is already underestimated compared to that from modelling using the Category II relationship (partly because NO_x is overestimated), and using the Category III relationship increases the level of underestimation of the ratio. Thus the retention of the Category II relationship at Oaks Rd is justified. At Hatton Cross, the overestimation of period-mean NO_2 concentration derives from the overestimation of period-mean NO_x and changing from Category II to Category III does not have a major impact on this overestimation, although it reduces it a little.

3.2.12 In the modelling methodology report, it was noted that the inter-quartile ratio of the hourly monitoring data at the Colnbrook site was anomalously high and, using the Jenkin category boundaries would have placed the site in category III. As seen in Table 3.22, using the Category III relationship would bring the modelled value closer to the measured value (a discrepancy of 2.1 $\mu g/m^3$ reduced to a discrepancy of 0.5 $\mu g/m^3$), but not by a significant amount.

3.2.13 In summary, there is no strong reason to depart from using the Category II relationship across the whole study area when calculating NO_2 concentration contours.

Contour Plots

3.2.14 As noted earlier for NO_x, although the primary purpose of the 2008/9 modelling study was to provide a basis for model evaluation, a subsidiary aim was to provide a more complete picture of the spatial variation in near-airport concentrations in 2008/9 than available from monitoring data alone. It is recognised that the annual-mean NO_2 objective and limit value are defined for concentrations averaged over a calendar year. However, the model values for the 2008/9 period are indicative of the potential for the 40 $\mu g/m^3$ objective to have been exceeded in 2008.

3.2.15 Fig 3.33 shows contours of modelled period-mean NO_2 concentration on a map background, with the NO_2 concentrations derived from NO_x results that include the road network scaling factor. The same colour-coding scheme has been used as in the reporting of the PSDH work[14], for ease of comparison, so areas where the limit value of 40 $\mu g/m^3$ is exceeded are shown in yellow (and 'warmer' colours). The lower concentration bands have been shown hatched so that parts of the base map can be seen, to help locate the boundaries between concentration bands on the map. For completeness, Fig 3.34 shows the equivalent results based on the NO_x concentration values without the road-network scaling factor, but only the results including the scaling factor will be discussed further below.

3.2.16 Areas of exceedence extend out into residential areas from the airport boundary, from the motorways and from the Great Western railway line, in accord with the areas of highest emission density. It should be borne in mind that these NO_2 results should be viewed as 'interim' on the grounds that they have been derived from NO_x values based on the interim traffic model results, adjusted using the simple road network scaling factor.

3.2.17 The 40 $\mu g/m^3$ contour should be taken as indicative of areas vulnerable to exceedence, but the grid results may not have the spatial resolution to determine if individual receptors close to the contour are within or outside the exceedence area, which would require closer investigation on a receptor-by-receptor basis. The limitations of the NO_2 contour plots in relation to spatial resolution are similar to those discussed earlier for the NO_x contours. In addition, when judging the risk of exceedence for near-road properties, care has to be taken to ensure that an individual receptor is located at the correct distance from the modelled road (which may differ from the position of the actual road, within the tolerance of the model's representation of the road network).

3.2.18 Areas at risk of exceeding the short-period NO_2 limit value (using a period-mean of 60 $\mu g/m^3$ as a surrogate) are marked in red and 'hotter' colours in Fig 3.33. Period-mean concentrations above the surrogate limit are confined to areas within about 30-40 m of the centre of the M4 motorway. For the M25, period-mean concentrations above the 60 $\mu g/m^3$ surrogate limit are confined to a distance of around 40-50 m west of the M25 centre-line and about 80-90 m east of the centre-line. The caveats about spatial resolution noted above for the 40 $\mu g/m^3$ limit apply here also. It is outside the scope of the present study to determine whether or not there is relevant public exposure in the portions of these exceedence areas that lie outside the road margins.

3.2.19 As noted earlier, the site-to-site variability in the period-mean NO_2 concentrations not captured by the model has a standard deviation of around 10%. Some of this may be due to measurement uncertainties, but it is likely that a major fraction of it relates to modelling uncertainty. Thus, even if the model is unbiased on average, at any particular site there is a significant probability of measuring a 10% higher or lower period-mean concentration. Fig 3.35[*] presents an alternative view of the modelling results from this perspective, showing separately the areas with period-mean concentrations 36-40 $\mu g/m^3$ and 40-44 $\mu g/m^3$.

Comparison with PSDH Results

3.2.20 Comparing Fig 3.33 with the equivalent 2002 PSDH results (Fig 10.2) shows that the exceedence areas extend further out from the motorway and railway line into residential areas, despite the NO_x concentrations in 2008/9 being on average similar to or slightly lower than in the 2002 PSDH results at a given location (as discussed earlier). This implies that the NO_2/NO_x ratios are higher near roads in 2008/9, and this will be examined further below. On the other hand, the exceedence area in 2008/9 does not extend as far into Harlington from the airport boundary as in the 2002 PSDH case, reflecting the lower NO_x concentrations in this area in 2008/9.

3.2.21 These differences can be examined further using the set of 13 specific receptors introduced earlier, as shown in Table 3.23. The average modelled NO_2 concentration across these 13 sites for 2008/9 is 4.7% higher than for the 2002 PSDH case, whereas the average NO_x concentration is 3.8% lower. This shows that the modelled NO_2/NO_x ratios for 2008/9 are on average 7.9% higher than for the 2002 PSDH case, whereas they are on average 11.6% lower than for the 2010SM. The 2008/9 NO_2 concentrations in Table 3.23 are on average 14.8% higher than for the 2010SM case.

3.2.22 The largest changes in NO_2 concentrations between 2002 and 2008/9 values are at Oaks Rd and Hatton Cross, where meteorological factors play a significant part in generating changes in NO_x concentrations. It should be borne in mind, however, that the 2008/9 modelled NO_x concentration for Hatton Cross showed a significant residual overestimation compared to the measured value.

3.2.23 More insight into the differences in NO_2/NO_x ratios for the three cases can be gained by looking at the values of *B* (the background oxidant level) and *A* (the NO_x-weighted average value of the primary NO_2 fraction) that appear in the Jenkin methodology. Although CERC did not use the Jenkin methodology for the PSDH work[†], effective values of *A* and *B* can be estimated from the data they provide.

3.2.24 An effective value of *B* for 2002 in the PSDH work can be derived as the sum of the rural O_3 concentration (in ppb) and NO_2 concentration (in ppb), with a reduction for the primary NO_2 associated with the rural NO_x concentration (taken to be 9.3% of the NO_x in 2002, as in Jenkin's work). This yields 32.1 ppb, only 4% below the value used in the 2008/9 work (33.5 ppb). For 2010, the primary NO_2 fraction associated with the rural NO_x is taken to be 14%,

[*] Fig 3.35 was prepared using the FAST software, a user-friendly tool for displaying the results of a modelling study and allowing scenario testing, licensed to BAA by AEA; the particular functionality used to generate the figure allows colour-coding of concentration contour areas without obscuring the underlying base map.
[†] CERC preferred to use the chemistry module provided within ADMS-Airport.

reflecting the increase in primary NO_2 fractions associated with road transport emissions. This also leads to an effective values of *B* of 32.1 ppb, using the forecast concentrations of O_3, NO_2 and NO_x given by CERC. Thus, differences in the assumed background oxidant level are not likely to be the principal source of the observed differences in NO_2/NO_x ratios.

3.2.25 For the 2002 PSDH case, most sources were assigned a primary NO_2 fraction of 10%, whereas in the 2008/9 work the weighted-average value of primary NO_2 fraction (*A*) is around 14% throughout the study area. Table 3.23 gives the modelled values at the 13 sites, which range from 13.5% to 15.3%, with higher values tending to arise at sites where the road network contribution is large. Similarly, for the 2010SM case in the PSDH work, NO_x emissions on the major road network around Heathrow were assigned a primary NO_2 fraction of 16.5% and NO_x emission on major roads in the rest of London were assigned a primary NO_2 fraction of 19.1%. This indicates that a major part of the difference in NO_2/NO_x fractions for the 3 cases derives from differences in primary NO_2 fractions. This conclusion is in line with the consensus that has emerged in the last few years that NO_2 concentrations in urban areas are not falling as expected ten years ago principally because of the increased primary NO_2 associated with road-vehicle NO_x emissions[27].

3.2.26 As noted earlier, the PSDH work did not use the Jenkin approach, so some of the differences between the NO_2/NO_x ratios for 2008/9 and those for the two PSDH cases will derive from the difference in basic methodology. Some insight into this can be gained from Fig 3.36. If *A* is artificially fixed at a constant value (rather than varying somewhat over the area, as the balance of source contributions change), then for a fixed value of *B* the Jenkin formulation yields a single curve of NO_2 concentration versus NO_x concentration (assuming all sites have been assigned to a single Jenkin Category, in this case Category II). Fig 3.36 plots this curve for three values of A, namely 5%, 10% and 15%, and also plots the modelled NO_2 and NO_x values for the three cases for the 13 sites used in Table 3.23. Clearly, the 2008/9 values all lie close to the 15% line, as expected from the *A* values in Table 3.23. The 2002 PSDH values are reasonably consistent with the 10% line although on average falling a little below it, as might be expected from the slightly lower effective value of *B*; the 2010SM values lie generally above the 15% line, consistent with an average value of *A* of around 17%. This suggests that most of the differences in average NO_2/NO_x ratios for the three cases derives from the difference in primary NO_2 fractions rather than from a change in methodology.

3.2.27 Fig 3.36 also gives an indication of how the NO_x value at which the NO_2 limit value of 40 $\mu g/m^3$ is reached varies with primary NO_2 fraction. For *A*=5%, the corresponding NO_x value (using this simple representation) is around 87 $\mu g/m^3$; for *A*=10%, it is around 80 $\mu g/m^3$; and for *A*=15% it is around 72 $\mu g/m^3$.

3.3 PM_{10}

Total Period Mean

3.3.1 Table 3.24 compares the modelled total period-mean PM_{10} concentrations at the continuous PM_{10} analysers with the measured values, and also shows the breakdown of the modelled total by source category. The average fractional discrepancy between modelled and measured total period-mean PM_{10} concentration is -0.4%, with a standard deviation of 17.5% (10 sites). Fig 3.37 shows a scatter plot of modelled versus measured period-mean PM_{10} concentrations. The correlation coefficient including all data points is only 0.15, but excluding Harmondsworth is 0.68.

3.3.2 The discrepancy at Harmondsworth is an outlier compared to the values at other sites, suggesting either an instrumental problem or the influence of a local source not included in the modelling. However, the large discrepancy is found at for all wind directions, suggesting that it does not result from a local source. It is worth noting that the instrument at Harmondsworth is a BAM (Beta Attenuation Monitor), whereas the instruments at the other sites (except Hayes) are of the TEOM type. The data from Harmondsworth have not been used in any further detailed modelling-monitoring comparisons.

3.3.3 Excluding Harmondsworth, the average fractional discrepancy is 4.3% (i.e. the model overestimates by 4.3% on average across the sites), with a standard deviation of 9.5%. The model overestimation is particularly large at Green Gates (25.7%), where the measured value is actually lower than the background value (as calculated from rural monitoring data). The average fractional discrepancy both with and without Harmondsworth is lower than the accuracy of the measurement technique (see Section 2), so the comparisons are able to demonstrate only that any model bias for total period-mean concentrations is less than the uncertainty in the measurements.

3.3.4 The modelled contribution from the designated road network and airport sources is on average only 2.3 $\mu g/m^3$ (maximum 5.2 $\mu g/m^3$, at LHR2) compared to a background level of 17.2 $\mu g/m^3$. This shows that the above comparison of total period-mean concentrations essentially evaluates only the prediction of the background contribution.

3.3.5 There is the possibility that concentration-difference comparisons may be able to add additional information on model performance for airport and road-network sources. However, PM_{10} concentration differences will be subject to systematic differences in measurement accuracy from one analyser to another. For analysers that use the same measurement technique and are part of the same network, some sources of inaccuracy are expected to cancel out. For example, all the TEOM analysers have been VCM-corrected using the same set of FDMS data. Nevertheless, systematic differences will remain, and are expected to be greater when the type of analyser is different. It is judged that the measurement uncertainties in differences are unlikely to be less than 2-3 $\mu g/m^3$ even for instruments of the same type, although this judgement is not based on any specific analysis. Only if measured concentration differences within a range of angles selected to highlight particular source groups are significantly greater than measurement uncertainties will it be possible to extract additional information on model performance from difference comparisons.

3.3.6 Besides measurement uncertainties, it is also necessary to keep in mind the possibility of 'natural' variations in the background (i.e. site-to-site variations in the background that are not captured by the modelling), which may mask differences in the concentration contributions from local sources.

3.3.7 Nevertheless, difference analysis may be able to set limits on the accuracy of the modelling for specific sources, and has been carried out for sites with the potential to yield the largest concentrations differences.

Concentration Differences for Airport Sources

LHR2-Oaks Rd

3.3.8 Fig 3.38 presents the PM_{10} concentration difference rose for LHR2-Oaks Rd. Focusing on the range of sectors bringing airport emissions to LHR2, there is a marked peak in the modelled concentration differences around 180° and a smaller peak in the measured differences at a similar angle. Table 3.25 gives the breakdown by source of the contribution to total period-mean concentration from the 150° to 270° range of sectors, showing that airport sources account for 83% of the modelled difference. Subsidiary model information shows that 87% of the modelled aircraft contribution in Table 3.25 is from brake and tyre wear emissions.

3.3.9 Tyre wear emissions have been distributed on a relatively short section of the runway (50 m long) in the touchdown zone, which for arrivals on 27R is not far from due south of the LHR2 monitor. LHR2 'sees' these emissions for a relatively narrow range of wind sectors. At smaller angles, aircraft will be arriving principally at the western end of the runway (09L), for which the touchdown zone is a long way from LHR2, and at larger angles the wind does not blow emissions on the relevant portion of the runway towards LHR2.

3.3.10 The measured concentration differences in Fig 3.38 for angles around 180° are around 4 $\mu g/m^3$, so are just about significant in relation to measurement uncertainties. Table 3.26

Appendix AQ.1.15

compares the modelled and measured values of the contribution to the total period-mean PM_{10} concentration difference from the 150° to 270° sector range, showing that the model overestimates by 42%, equivalent to a discrepancy of 0.7 $\mu g/m^3$. Taking into account measurement uncertainty, it is possible that the modelling is actually underestimating the period-mean concentrations, but taking the uncertainty on period-mean concentration difference as 3 $\mu g/m^3$ would imply that the underestimation of the airport contribution at LHR2 is unlikely to be more than a factor of two (for a modelled contribution of 2.3 $\mu g/m^3$).

3.3.11 The much larger peak in the modelling results does not necessarily imply that total emissions from runway sources have been overestimated: they may have been distributed over a section of the runway that is displaced from where the bulk of the emissions actually arise, thereby spuriously enabling wind directions giving rise to westerly operation to carry pollutant to the monitor. Similarly, the emissions may have been restricted to too small a length of runway. Inaccuracies in the spatial distribution of emissions along the runway may have a major effect at LHR2, but are likely to have a smaller effect at off-airport receptors at greater distance from the runway.

3.3.12 Fig 3.39 gives the concentration difference/wind speed comparison for the 150° to 270° sector range, showing that the model tends to overestimate at lower wind speed, as was found for NO_x. However, the agreement at wind speeds above 3 m/s is good and, even at lower wind speed, the agreement is reasonably good (typically around a factor-of-2 agreement), considering the smallness of the actual concentration differences. It is worth noting that no plume rise is associated with the brake and tyre wear emissions - the principal source contributing to the model results in Fig 3.39 - so these results reduce the likelihood that the overestimation at low wind speeds (and underestimation at high speeds) in the equivalent NO_x comparisons for airport sources can be attributed solely to inaccuracies in plume rise modelling.

3.3.13 The interpretation of the comparison in Fig 3.38 for northerly winds is complex, given that Oaks Rd receives an airport contribution for these wind sectors. The road network contribution at LHR2 will be examined later using an alternative ‘difference’ site.

Harlington–Oaks Rd

3.3.14 Fig 3.40 presents the difference rose for the Harlington-Oaks Rd PM_{10} concentration differences. Focusing on the range of sectors bringing airport emissions to Harlington (160° to 240°), the modelled and measured differences are similar, but they are both small (typically around 1-2 $\mu g/m^3$ in any particular sector), so the significance of the measured differences in relation to measurement uncertainties is questionable. Table 3.27 shows that airport sources account for 83% of the contribution to the period-mean PM_{10} concentration difference from this sector range, with aircraft and airside vehicles of comparable importance.

3.3.15 As shown in Table 3.26, the measured and modelled values of the contribution to the period-mean PM_{10} concentration difference from the 160° to 240° are in agreement, but this could be fortuitous given the small values involved. The model results show a small peak at 180°, deriving from brake and tyre wear emissions on the runway, whereas the monitoring results have a hint of a peak around 210°, which points from CTA apron sources towards Harlington. This suggests that the good agreement in the measured and modelled contributions from airport sources at Harlington may result from an overestimation of the contribution from runway sources balanced by an underestimation of the contribution from apron sources. However, it is important not to over-interpret the evidence from such small concentration differences (as evidenced by the Green Gates results below), bearing in mind measurement uncertainties.

Green Gates-Oaks Rd

3.3.16 The Green Gates-Oaks Rd difference rose is presented in Fig 3.41, and serves to emphasise the note of caution made earlier about over-interpreting small differences. According to the modelling, concentration differences in the sectors blowing from airport sources to Green Gates are around 2 μg/m^3, whereas in the monitoring they are around -2 μg/m^3 to -1 μg/m^3 (i.e. concentrations at Oaks Rd are higher than at Green Gates)! There is a clear peak in the modelling results in the sector range 100° to 180°, but this amounts to a contribution to the period-mean concentration difference of only around 0.2 μg/m^3, virtually all from airport sources, with comparable contributions from aircraft and airside vehicles. In the monitoring data, there is also a hint of peak pointing towards airport sources, but the magnitude of the contribution to the total period mean difference has been cancelled by a large negative contribution to the difference.

3.3.17 A clue to what is happening is given by the total period-mean concentration results given in Table 3.24, which shows that the measured total is well below the modelled total at Green Gates, and is even below the modelled ‘background’ contribution. Leaving aside the possibility of instrumental problems at Green Gates – all the PM_{10} data for the site used in the analysis were ratified - this either indicates a spatial variation in the period-mean background contribution, not captured by the model and large enough to offset any contribution from the airport and local road network, or is the manifestation of uncertainties in concentration difference measurements.

3.3.18 No other difference pair provide clear information about airport sources. For Oxford Avenue-Oaks Rd, the modelled contribution from the road network is significantly larger than that from airport sources in the relevant sector range. The concentration differences between Harmondsworth and any of the other PM_{10} sites is so large that no meaningful conclusions about airport sources can be drawn, probably as a result of measurement inaccuracies.

3.3.19 On the basis of the comparisons available, there is no evidence that the contribution from airport sources to period-mean PM_{10} concentrations in residential areas around the airport is being underestimated nor that it is being overestimated by a large factor, but the conclusions drawn cannot be more definitive because of the small concentration differences involved.

Concentration Contours for the Airport Contribution to Period-Mean PM_{10} concentrations

3.3.20 Based on the above, Fig 3.42 shows contours of the contribution from airport sources to total period-mean PM_{10} concentration generated from the (all-hours) model results on the grid of receptors, without any model adjustment. The contribution is between 0.1 and 1.0 μg/m^3 in the residential areas just north of the airport, reaching around 2 μg/m^3 at the airport perimeter.

Comparison with PSDH Results for 2002 and 2010SM

3.3.21 Prior to comparing concentrations, Table 3.28 gives a brief summary of relevant emissions (the 2008/9 emissions report gives greater detail), showing that all three cases have similar ground-level aircraft emissions. The ‘other airport’ emissions (principally from airside vehicles and car parks) in the 2008/9 inventory are a little higher than for the 2002 PSDH case and near a factor of two higher than for the 2010SM PSDH case.

3.3.22 Table 3.29 compares the contributions to period-mean concentrations from airport sources for the three cases. The set of sites span an order-of-magnitude range in total airport contribution to period mean NO_x concentrations from less than 0.1 μg/m^3 (Colnbrook) to 2.0 μg/m^3 (LHR2). At a given site, the contributions from a given category of airport sources for the three cases are broadly comparable, as expected from the magnitude of total emissions. However, there are case-to-case variations that relate to differences in the spatial distribution of emissions and differences in meteorology. For example, the relatively large 2008/9 aircraft contribution at Hatton Cross has been explained earlier in the NO_x discussions as due partly due to the significantly higher frequency in 2008/9 than in 2002 of the wind blowing in the 270° wind sector. The impact is greater for PM_{10} than for NO_x because brake and tyre wear emissions on the runway are not subject to plume rise. Similarly, the relatively large contribution at Oaks Rd from non-aircraft airport emissions (principally airside vehicle emissions) is partly due to the higher frequency in 2008/9 than in 2002 of winds blowing in sectors 40° to 60° which point from the CTA aprons to Oaks Rd.

Concentration Differences for Road Network Sources

3.3.23 Of the sites with PM_{10} measurements, the three sites with the largest modelled road-network contribution to period-mean PM_{10} concentration are LHR2, Oxford Avenue and Hayes. None of these sites is close to a motorway.

LHR2-Harlington

3.3.24 The peak in the measured LHR2-Oaks Rd concentration-difference rose (Fig 3.38) for winds from north-easterly sectors was noted earlier, but Oaks Rd is not the best site for examining LHR2 for northerly wind sectors because it receives a major contribution from airport sources. Choosing a difference site north of the airport, Fig 3.43 presents the PM_{10} concentration difference rose for LHR2-Harlington. Focusing on the northerly range of sectors, there is a measured excess concentration at LHR2 of over 4 $\mu g/m^3$ over a wide range of sectors, which is not surprising given the proximity of the Northern Perimeter Road (NPR) to LHR2, with a particular peak around 30° to 40°, similar to the peak found for NO_x concentrations. In the NO_x case, the peak was judged most likely to arise from traffic perturbations at the junction of the NPR with Neptune Rd, and this is judged also the most likely origin of the peak for PM_{10}. There are modelled differences of comparable magnitude to measured differences in some sectors, but the additional peak is missing.

3.3.25 For the sector range 270° to 100° (for which the road network accounts for essentially all of the modelled contribution to the period-mean concentration difference), Table 3.30 shows that the model underestimates the difference contribution by 24%, equivalent to an under-prediction of 0.5 $\mu g/m^3$. Table 3.24 shows that there is good agreement between modelled and measured values of total period-mean PM_{10} concentration at LHR2, so the under-prediction in the road network contribution offsets the over-prediction in the contribution from airport sources discussed earlier. This does not imply that the combined contribution from airport and road network sources has been perfectly predicted by the model. Even leaving aside measurement uncertainties, site-to-site differences in the background contribution (and in the LAEI/NAEI contribution) that have not been captured by the model may be offsetting an inaccuracy in the modelled value for the combined contribution from airport and road network sources. Nevertheless, the evidence indicates that any inaccuracy in the modelled contribution from airport and road network sources at LHR2 is not greater than the site-to-site variability in concentrations that has not been captured by the model (which has a standard deviation of around 2 $\mu g/m^3$, according to Table 3.24).

Oxford Avenue-Cranford

3.3.26 The site at Oxford Avenue is fairly close to the A4, so can in principle give information on the road-network contribution to PM_{10} concentrations, provided sectors are chosen that do not include a significant contribution from airport sources. A ‘difference’ site north of the airport is selected to reduce the risk of gradients in the background contribution affecting the differences: Fig 3.44 gives the PM_{10} concentration difference rose for Oxford Avenue-Cranford. Clearly, the modelling underestimates the concentration difference for southerly sectors, for which the wind blows from the road to monitoring site, with the discrepancy around 4 $\mu g/m^3$, which may be significant compared to measurement uncertainties. It is important to bear in mind that the traffic model outputs for the A4 were not been evaluated in the report on the interim traffic model, so it is not clear how much of the model-monitoring discrepancy derives from emissions quantification and/or dispersion modelling rather than from traffic model uncertainties.

3.3.27 Focusing on the sector range 90° to 180° to avoid the airport contribution at both sites, Table 3.30 shows that the model accounts for only 26% of the measured contribution to the period-mean PM_{10} concentration difference from this sector range, a discrepancy of 0.55 $\mu g/m^3$. If this level of underestimation was maintained over all southerly sectors, the total amount of under-prediction from the road-network contribution would be around 1.0-1.5 $\mu g/m^3$. Table 3.24 shows that the total period-mean PM_{10} concentration at Oxford Avenue is under-predicted by 1.4 $\mu g/m^3$, so the under-prediction of the road-network contribution could account for the discrepancy in total period-mean concentration. However, the predicted contributions from the airport and road network sources are smaller than the potential site-to-site variation in the background contribution, so it is important not to over-interpret the results. In a similar analysis using Oaks Rd as the difference site (and the same sector range), the model accounts for 54% of the measured contribution, a discrepancy of 0.21 $\mu g/m^3$, giving some hint of the un-modelled site-to-site variability.

Hayes-Cranford

3.3.28 Hayes is the only kerbside site used in the model evaluation. Selecting Cranford as the difference site for reasons outlined earlier for Oxford Avenue, Fig 3.45 gives the PM_{10} concentration difference rose for Hayes-Cranford. As was the case for Oxford Avenue, the modelling clearly underestimates the concentration difference for southerly sectors, for which the wind blows from the road towards the monitoring site, with the discrepancy up to around 5 $\mu g/m^3$. Again, it is important to bear in mind that the traffic model outputs for the A437 were not been evaluated in the report on the interim traffic model, so it is not clear how much of the model-monitoring discrepancy may derive from emissions quantification and/or dispersion modelling. In addition, it should be noted that the Hayes instrument is a BAM (Beta Attenuation Monitor), so there additional measured concentration differences may arise from systematic inter-analyser differences.

3.3.29 Focusing on the sector range 90° to 210° to avoid the airport contribution at Cranford, Table 3.30 shows that the model accounts for around one half of the measured contribution to the period-mean PM_{10} concentration difference from this sector range, a discrepancy of 0.9 $\mu g/m^3$. If this level of underestimation was maintained over all southerly sectors, the total amount of under-prediction from the road-network contribution would be around 3 $\mu g/m^3$. Table 3.24 shows that the total period-mean PM_{10} concentration at Hayes is under-predicted by only 1.0 $\mu g/m^3$, so other contributions at Hayes must be overestimated to result in this level of agreement. However, these differences are small compared to measurement uncertainties.

Concentration Contours for Total Period-Mean PM_{10} Concentrations

3.3.30 On average, total period-mean PM_{10} concentrations are not under-predicted across the sites (discounting Harmondsworth) – Table 3.24 – but the comparisons presented above suggest there may be under-prediction of the road-network contribution (which is compensated by an over-prediction of the background (or LAEI/NAEI) contribution). However, the evidence is not strong, given the small magnitude of concentration differences compared to measurement uncertainties and the potential for un-modelled site-to-site variability in the background contribution. In addition, there is a question of how generalisable are the results for these three sites to the network as a whole, particularly to near-motorway receptors, given that the fidelity of the traffic data close to the sites has not been evaluated. Furthermore, discrepancies at LHR2 and Hayes may relate to localised flow perturbations at junctions. In consequence, therefore, the information provided by the PM_{10} evaluation is an inadequate basis for making a whole-network adjustment to modelled concentrations, so no adjustment factors have been applied to the (all-hours) model results on the grid of receptors used for generating contour plots. However, the potential for model underestimation close to junctions and to other regions of flow disturbance should be noted.

3.3.31 Fig 3.46 shows contours of modelled total period-mean PM_{10} concentrations, using the same colour coding for concentration as in the PSDH contour plots for 2002[*] (Fig 10.6 in the PSDH PSDH air quality report), for ease of comparison. Red and 'warmer' colours in the figure denote areas with period-mean PM_{10} concentration above 40 $\mu g/m^3$ (the limit value for annual-mean PM_{10} concentration). It is recognised that the annual-mean PM_{10} objective and limit value are defined for concentrations averaged over a calendar year. However, the model values for the 2008/9 period are indicative of the potential for the 40 $\mu g/m^3$ limit to have been exceeded in 2008. Off-airport values above 40 $\mu g/m^3$ are confined to areas within the road margins of the M4 and within about 30 m of the centre of the M25 (with

[*] PM_{10} contour plots were given for only the 2002 case in the PSDH air quality report.

concentration values east of the road centre higher than those west). Yellow (and warmer colours) in Fig 3.46 denotes values above 30 μg/m^3, so the contour for 31.5 μg/m^3 (the surrogate for the 24-hour limit) will be slightly inside the margins of the yellow area. Values above 31.5 μg/m^3 in 2008/9, according to the model, were confined to areas within about 30 m from the centre of the M4 and about 50 m from the centre of the M25. It is outside the scope of the present study to determine whether or not there is relevant public exposure in the narrow portions of these exceedence areas that lie outside the road margins.

3.3.32 It should be noted that the elevated concentration close to the northern runway are less prominent in Fig 3.46 than in the equivalent PSDH figure, principally because tyre-wear emissions have been confined to a smaller area of the runway in the 2008/9 modelling than in the PSDH work (and show up as small areas of higher concentration on the runway); brake-wear emissions have been distributed along the landing roll, as in the PSDH work.

3.3.33 The yellow and red areas on the contour plot should be taken as indicative of areas vulnerable to exceedence of the relevant limit, but the grid results may not have the spatial resolution to determine if individual receptors close to the relevant contour are within or outside the exceedence area, which would require closer investigation on a receptor-by-receptor basis. The spatial limitations of the PM_{10} contour plots are similar to those discussed earlier for the NO_x contours. In addition, when judging the risk of exceedence for near-road properties, care has to be taken to ensure that an individual receptor is located at the correct distance from the modelled road (which may differ from the position of the actual road, within the tolerance of the model's representation of the road network).

3.3.34 It is unfortunate that there were no near-motorway monitoring data available for PM_{10} comparisons, given that the model gives period-mean concentrations above the limit value close to the edge of the carriageway for sections of the M25 and M4. However, the Hillingdon PM_{10} monitor (40 m from the edge of the carriageway) was operational up to October 2007. The period-mean gravimetric-equivalent (TEOM*1.3) value for the last full twelve month period was 27.3 μg/m^3 and the value in the calendar year 2006 was 29.3 μg/m^3. If the gravimetric-equivalent value in 2008/9 was also 27.3 μg/m^3, the VCM-corrected value is likely to have been around 23.5 μg/m^3, judging from the range of corrections at other nearby sites, which is comparable to the modelled value of 23.2 μg/m^3. It is likely, however, that the measured value in 2008/9 would have been lower than in 2007, given the trend from previous years, so the model may be over-predicting by a few μg/m^3 in 2008/9 at this site.

3.3.35 The Staines M25B site operated by the Highways Agency/TRL is outside the study area and, as noted in Section 2, is so close to the motorway that it is sensitive to fine details of the spatial representation of emissions on the motorway that are beyond the spatial resolution of the modelling. Nevertheless, the south-west corner of the study area includes part of the same stretch of the M25 (J13 to J14) as that adjacent to the monitor, so a cross-check on the concentration at an equivalent distance from the modelled road was judged worthwhile. The annual-mean PM_{10} concentration at the site in 2008 (calendar year) was 26.3 μg/m^3 (TEOM*1.3), which is likely to yield a lower value when VCM-corrected. The monitoring site is 30 m from the centre-line of the motorway, close to the clockwise hard shoulder. According to the modelling, the period-mean concentration at this distance from the road is around 30 μg/m^3 which, although below the surrogate limit value of 31.5 μg/m^3, is higher than the measured value. This may indicate that concentrations very close to the M25 are overestimated, although the concentration gradients are steep this close to the road and the model may not overestimate at a few tens of metres further from the motorway.

3.3.36 In conclusion, in the absence of further opportunities for model evaluation close to motorways, the predicted areas of exceedence for PM_{10} close to the margins of the M4 and M25 should be treated with caution.

Comparison with PSDH Results for Total Period-Mean PM_{10} Concentration

3.3.37 Table 3.31 compares the modelled period-mean PM_{10} concentrations for 2008/9 with equivalent values for the 2002 PSDH and 2010SM cases. The contributions from airport sources have been compared earlier. The non-airport total cannot be broken down further

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because the PSDH split between road-network sources and other LAEI sources is different from that in the 2008/9 modelling.

3.3.38 The total non-airport contribution in the 2008/9 results is on average closer to the PSDH value for the 2010SM case than for the 2002 PSDH case, as expected from the dominant influence of the rural background contribution. In turn, this leads to total PM_{10} concentrations that are on average closer to the PSDH results for the 2010SM case than to the results for the 2002 PSDH case.

3.4 $PM_{2.5}$

3.4.1 Three sites with $PM_{2.5}$ data were identified in Section 2 for inclusion in the comparison exercise, namely Oaks Rd, Green Gates and Harmondsworth. The Harmondsworth data were obtained using an OSIRIS system (see Section 2) and the data for Oaks Rd and Green Gates using a TEOM instrument. Further discussion of the limitations of the $PM_{2.5}$ monitoring data is given in Section 2.

3.4.2 Table 3.32 compares measured and modelled values of total period-mean $PM_{2.5}$ concentrations at the three sites*, and gives a breakdown of the modelled value by source. Clearly, the background component is the dominant contributor (9.6 μg/m^3), with the airport and road network sources together contributing at most 1.2 μg/m^3.

3.4.3 The agreement between measured and modelled values is within the expected measurement uncertainty for Oaks Rd and Green Gates, but there is significant over-prediction at Harmondsworth, by 41% (3.4 μg/m^3). The average fractional discrepancy between modelled and measured values is 17% and the average absolute discrepancy is 1.5 μg/m^3.

3.4.4 Even leaving aside measurement uncertainties, the comparison between modelled and measured total period-mean $PM_{2.5}$ values is not likely to provide any detailed information on the performance of the modelling for airport and road-network sources, given that their combined contribution is smaller than the uncertainty in the modelled value for the contribution from all other sources (principally the background contribution). The comparisons can indicate only that the combined contribution from the airport and the road network is not being under-predicted by a large factor (because then it would become apparent, despite uncertainties in the modelled background) but cannot indicate if the combined contribution is being over-predicted. The upper bound on the combined contribution is loosened further when measurement uncertainties are taken into account.

3.4.5 Similarly, for $PM_{2.5}$, concentration differences will be unable to provide any detailed information on the contribution from airport and road network sources – even leaving aside measurement uncertainties - given that the differences will be smaller than the expected site-to-site variability in the contribution from other sources that is not captured by the model. The different measurement technique used at Harmondsworth would further complicate the interpretation of differences involving that site.

3.4.6 Thus, in conclusion, no source-specific model evaluation is possible for $PM_{2.5}$, and the comparisons of total period-mean concentrations are able only to confirm that the predicted total concentrations are within the range expected based on the monitoring data and its uncertainties.

3.4.7 Fig 3.47 shows contours of modelled total period-mean $PM_{2.5}$ concentration. The 25 μg/m^3 level, shown in magenta, is of interest because of the objective (and limit) value for $PM_{2.5}$ (see Table 1.1), although this does not come into force until 2020 (2015). According to the modelling, values above 25 μg/m^3 were confined to areas within about 30 m of the centre-line of the M25 and within the road margins of a few other links of the major road network. The 20 μg/m^3 level is also of interest in terms of the Stage 2 indicative limit value (from 2015, subject to review by 2013). Areas with values above 20 μg/m^3 are shown in red (and

* For $PM_{2.5}$, the distinction between 'period-mean' and 'all-hour period mean' was ignored.

magenta) on Fig 3.47.

3.4.8 Although no detailed evaluation of the model predictions for the airport and road vehicle contributions has been possible, it is important to recognise that concentrations of $PM_{2.5}$ and PM_{10} are not unrelated. For combustion sources, it is likely that the contribution to PM_{10} concentration is very similar to the contribution to $PM_{2.5}$ concentrations (i.e. the particles that make up most of the PM_{10} mass are small enough that they also make up most of the $PM_{2.5}$ mass). This is not necessarily the case for fugitive emissions from brake and tyre wear, but the differences even for these sources is unlikely to be much more than a factor of two. Thus any observations made about the performance of the modelling for PM_{10} are likely to apply largely to $PM_{2.5}$. Thus, it is unlikely that the contribution to $PM_{2.5}$ concentrations from aircraft sources is being underestimated by a more than a factor of two, and areas close to motorways with predicted period-mean concentrations above 20 or 25 $\mu g/m^3$ should be treated with caution.

4 Conclusions

NO_x

4.1 Total period-mean NO_x concentrations are predicted with an average fractional discrepancy (defined as *(modelled value-measured value/measured value)*) of -5.2% (i.e. the model under-predicts on average by 5.2% across the sites), with a standard deviation of 12.2% (12 sites), where the latter is a measure of the site-to-site variability in the measured values that has not been captured by the model. Assuming the measurement uncertainty (one standard deviation) for long-period average NO_2 concentrations from continuous analysers to be around 5%, the observed bias is highly unlikely to be explained by statistical measurement fluctuations for a finite sample of 12 sites. Similarly, a large fraction of the unexplained site-to-site variability is unlikely to be attributable to measurement uncertainties. Thus, the model is slightly biased towards under-prediction of total period-mean NO_x concentrations.

4.2 The three sites with the largest contribution from emissions on the road network have significant negative values of the fractional discrepancy, suggesting that there is a systematic underestimation of this contribution, which is offset by an overestimation of other contributions across the sites leading to a quite small average fractional discrepancy.

Airport Sources

4.3 A comparison of measured and modelled NO_x concentration differences between sites north of the airport and Oaks Rd (south of the airport) for selected wind directions indicates that the model has no significant tendency either to overestimate or to underestimate the contribution of airport sources[*] to the period-mean NO_x concentrations at receptors in the residential areas north of the airport, to the level of accuracy allowed by measurement uncertainties. In particular, it represents well the variation in the airport concentration contribution with distance from the principal sources on the airport and the variation with east-west location in relation to the ends of the northern runway.

4.4 This gives confidence that the model provides a good basis for investigating the potential impact on residential areas of operational changes on the airport that affect the magnitude and spatial distribution of NO_x emissions, for example the abandonment of the Cranford agreement (which would then allow departures on runway 09L) and the construction of a third runway north of the current runways. It also indicates that the model tendency to underestimate total period-mean NO_x concentrations is unlikely to arise from the modelling of airport sources.

4.5 A breakdown of the concentration differences across the airport by wind speed indicates a tendency for the model to overestimate at low wind speeds and underestimate at high wind speeds. Thus the remarkable level of agreement (for sites north of the airport) between modelled and measured values of the airport contribution to period-mean NO_x concentration is partly fortuitous, arising from a compensation between the two tendencies, and may not be maintained to the same extent if the met data in a given year exhibited a markedly different wind speed distribution to that in 2008/9. Nevertheless, given that the agreement is reasonably good in every wind-speed bin, it would require a major shift in wind-speed frequency distribution to generate a significant discrepancy. The observed trend with wind speed could point to inaccuracies in the plume-rise modelling for aircraft sources, but the evidence from comparisons involving little influence from aircraft sources indicates that this cannot be the full explanation.

4.6 At Oaks Rd, close to the southern boundary of the airport, concentration-difference comparisons indicate that the modelling overestimates the contribution from airport sources by around 3 $\mu g/m^3$ (for a total airport contribution of 17 $\mu g/m^3$). The apparent greater

[*] Defined to include all sources within the airport perimeter plus elevated (LTO) aircraft sources, although the latter make a small contribution to ground-level concentrations once they are above a few hundred metres in height.

overestimation of the airport contribution at Oaks Rd than at sites north of the airport may derive partly from the tendency noted above for the model to overestimate at low wind speeds, which has a greater effect south of the airport due to the greater probability of low wind speeds for northerly winds than for southerly winds. Nevertheless, the discrepancy at Oaks Rd is only of comparable size to the judged uncertainty in measured differences in period-mean concentrations.

4.7 Given the evidence that the modelling is a reliable basis for predicting the spatial variation of the contribution from airport sources to period-mean NO_x concentrations around the airport, contours of this contribution have been derived from model results on a spatial grid of receptor points. These indicate that NO_x contributions from airport sources above 30 $\mu g/m^3$ in 2008/9 were confined to areas within the airport boundary, with the contribution in the nearest residential areas in the range 10-20 $\mu g/m^3$. The modelled contribution from airport sources falls to at most 6.3 $\mu g/m^3$ at the M4 motorway, but varies in an east-west direction along the motorway as a result of the contour shape, which is governed by the prevalence of south-westerly winds coupled with the spatial distribution of sources on the airport. Contour shapes show some differences from those calculated for 2002 in the PSDH work, partly as a result of the opening of T5 and partly due to a greater frequency of westerly winds in 2008/9 than in 2002.

4.8 A detailed comparison of the 2008/9 modelled values of the airport contribution at 13 representative sites with corresponding values from the PSDH work shows that the 2008/9 values are broadly comparable to those for the PSDH 2002 and 2010SM cases, which is in line with the magnitude of the estimated airport emissions for the three cases. There are some detailed differences from the PSDH results not related to emission differences that principally reflect differences in the wind rose between 2008/9 and 2002.

Road-Network Sources

4.9 Comparison of concentration differences for pairs of sites with one of the sites (Hillingdon, LHR2, Hayes, Oxford Avenue) strongly affected by a nearby road indicates that the modelling underestimates the contribution to period-mean NO_x concentrations from emissions on the major road network around Heathrow; this reinforces the evidence provided by an examination of the discrepancies in total period-mean concentrations noted earlier. The extent of the underestimation is significantly greater than can be attributed solely to measurement errors on concentration difference.

4.10 It is tempting to interpret the these results as confirmation of recent evidence that NO_x emissions factors for road vehicles are being underestimated. However, it would be premature to draw such conclusions before the basic traffic data used in the emissions quantification have been fully evaluated. There is evidence that modelled total traffic flow on the M4 motorway adjacent to the Hillingdon site is well represented, but there is no information on how realistic are the predictions of HDV (bus/coach and HGV) fraction and vehicle speed, parameters that are particularly important from an emissions perspective. For the M25, it appears that, in addition, total flows are underestimated.

4.11 There is some evidence from the concentration differences that a key contributor to the discrepancies at near-road receptors relates to network intersections or other areas of flow disturbance, which lead to traffic queues, flow breakdown or changes in speed. It is possible to account for queues in the emissions methodology if they are explicitly recognised in the traffic data, but in the set of data available for the 2008/9 inventory link any delays were absorbed into effective link speeds, thereby not allowing the spatial distribution of queuing emissions to be represented. It is recommended that this deficiency is removed in future traffic data sets generated for air quality assessment purposes. With reference to speed data, it may not be enough to provide hourly-averaged speed if this speed is the net effect of periods of smooth flow interspersed with periods of flow breakdown.

4.12 There appears to be an additional discrepancy between modelling and measurements at Green Gates, not attributable to airport sources and not readily explained in terms of under-prediction of the contribution from the major road network around Heathrow. This may point to a local source not included in the modelling, although measurement uncertainties for concentration differences may also have played a part. Although large point sources have been modelled individually, it cannot be ruled out that the 1-km spatial resolution of emissions from medium-sized point sources in the LAEI may be having an influence on the accuracy of modelled concentrations close to Green Gates.

4.13 There are also additional discrepancies in NO_x concentrations at Hayes that cannot be explained in terms of under-prediction of the road network contribution. Hayes has a particularly large contribution from area sources representing emissions from the LAEI and NAEI inventories (including a substantial contribution from the Great Western railway line). However, there is not enough information to determine if the discrepancy arises from sources local to the site or is more widespread in Hayes.

4.14 The observed discrepancies point to the need for a more detailed evaluation of traffic model outputs and how these are used to calculate emissions. It may be advantageous to defer that work until a traffic model is available that has been calibrated and validated with particular reference to those traffic characteristics that are key to the quantification of road traffic emissions and to the estimation of the road-network contribution to airborne pollutant concentrations.

4.15 In the interim, in order to generate a 'best-estimate' modelled NO_x concentration field around the airport, the road-network NO_x contribution was scaled everywhere by a constant factor (1.21) chosen so that the average discrepancy between modelled and measured period-mean NO_x concentrations across the 12 monitoring sites reduced to zero. This simple procedure has the merit of increasing the concentrations more in absolute terms in areas where the road network makes a large contribution, reflecting the evidence from the monitoring data, but is unlikely to remove all the discrepancy relating to the road network at sites such as Hayes and LHR2 (although at least some of the discrepancy at these sites may be due to features specific to the site and not necessarily generalisable to other receptors). Also, the scaled NO_x concentration field may still underestimate concentrations at near-road receptors that are strongly influenced by traffic queuing at junctions or are situated close to areas of the network subject to other types of flow disruption.

4.16 Although the average discrepancy across the sites has been reduced to zero, it is likely that there is a residual tendency towards overestimation at receptors immediately south of the airport because of an over-prediction of the contribution from airport sources in northerly winds. Similarly, for receptors to the (north) west of the airport there may be a systematic residual underestimation because of the under-prediction of the contribution from the M25.

4.17 The contour plot of period-mean NO_x concentration based on the set of 2008/9 results that include the road-network scaling factor is much closer in appearance to the equivalent plot for the PSDH 2002 case than for the PSDH 2010SM case. However, the NO_x 75 $\mu g/m^3$ contour in the 2008/9 results (approximately equivalent to the NO_2 40 $\mu g/m^3$ contour) does not extend as far from the airport boundary into Harlington as in the 2002 results; also, a smaller area of Hayes between the railway line and the M4 is above 75 $\mu g/m^3$.

4.18 A more detailed comparison with the PSDH results for 13 representative sites shows that the non-airport contribution in 2008/9 is much closer to the equivalent PSDH contribution for 2002 than for the 2010SM cases, with the average over the 13 sites 3.5% lower for 2008/9 than for the 2002 PSDH case and 42% higher than for the PSDH forecast 2010SM case. Although the calculated 2008/9 value of the total NO_x emissions on the designated road network is around 30% lower than that quoted for the 2002 PSDH case (for a closely equivalent network), the scaling up of the road network contribution by 21% largely offsets this reduction. Combining the airport and non-airport contributions, the average total NO_x concentration across the 13 sites for the 2008/9 case is 3.8% lower than for the 2002 PSDH case and 29.3% higher than for the 2010SM case.

NO_2

4.19 The availability of ozone measurements at three of the monitoring sites included in the analysis allows a separate test of the component of the methodology for deriving NO_2 concentrations from NO_x concentrations that predicts the total oxidant (sum of O_3 and NO_2) concentration from the background oxidant and the local NO_x concentrations. The modelled values agreed with measured values within the level of accuracy of the measurements, with an average fractional discrepancy between modelled and measured values of 6% (overestimation).

4.20 A comparison of modelled and measured period-mean NO_2 concentrations at the 13 monitoring sites included in the study – using the modelled NO_2 concentrations derived from NO_x concentrations that include the road-network scaling factor – gives an average fractional discrepancy of 1.6% (i.e. the model overestimates by on average 1.6%), with a standard deviation of 9.7%. For comparison, using NO_x concentrations that do not include the road-network scaling factor, the average fractional discrepancy in period-mean NO_2 concentrations is -1.8% (i.e. an underestimation of 1.8%), with a standard deviation of 9.7%. Neither of the two values of average fractional discrepancy can be interpreted as a significant model bias.

4.21 The performance of the Jenkin approach for deriving period-mean NO_2 concentrations from period-mean NO_x concentrations can be separated from the performance of the modelling for NO_x concentrations to some extent (though not fully) by comparing NO_2/NO_x ratios. Using the NO_x results that include the road-network scaling, the average fractional discrepancy in the NO_2/NO_x ratios is 2.1% (i.e. the model on average overestimates the ratio by 2.1%) with a standard deviation of 5.5%. For comparison, without the road-network scaling factor, the average fractional discrepancy is 4.1% with a standard deviation of 6.0%. This level of agreement is within what is expected from the semi-empirical (Jenkin) methodology used for this study, judging from the scatter on the data points used to derive the underlying $[NO_2]/[OX]$ relationship. Thus, the results indicate that the Jenkin methodology does not introduce any significant bias into the model results, so that once the bias in NO_x concentrations has been removed no further model adjustment is necessary.

4.22 The NO_2 concentration results on a grid of receptors have been used to generate contours of period-mean NO_2 concentration in 2008/9. Areas of exceedence of the annual-mean limit (40 $\mu g/m^3$) extend out into residential areas from the airport boundary, from the motorways and from the Great Western railway line, in accord with the areas of highest emission density. The grid results may not have the spatial resolution to determine if individual receptors close to the contour are within or outside the exceedence area, which would require closer investigation on a receptor-by-receptor basis. It should be borne in mind that the NO_2 contours presented should be viewed as ‘interim’ on the grounds that they have been derived from NO_x values based on the interim traffic model results, adjusted using the simple road-network scaling factor.

4.23 Comparing the 2008/9 NO_2 contour plot with the equivalent 2002 PSDH plot shows that the exceedence areas extend further out from the motorway and railway line into residential areas, despite the NO_x concentrations in 2008/9 being on average similar to or slightly lower than in the 2002 PSDH results at a given location, implying that the NO_2/NO_x ratios are higher in 2008/9. On the other hand, the exceedence area in 2008/9 does not extend as far into Harlington from the airport boundary as in the 2002 PSDH case, reflecting the lower NO_x concentrations in this area. The increase in NO_2/NO_x ratios can be traced primarily to the higher average primary NO_2 fraction in 2008/9 compared to that applicable to the 2002 analysis, principally resulting from the higher fractions now associated with road-traffic NO_x emissions.

4.24 Examining the changes from the PSDH results in more detail at the 13 representative receptors shows that the average modelled NO_2 concentration across these sites for 2008/9 is 4.7% higher than for the 2002 PSDH case, whereas the average NO_x concentration is 3.8% lower. as noted above. Thus, the modelled NO_2/NO_x ratios for 2008/9 are on average 7.9% higher than for the 2002 PSDH case, whereas they are lower than for the PSDH

2010SM case by on average 11.6%.

PM_{10}

4.25 Based on data from the ten continuous PM_{10} analysers in the study area, the average fractional discrepancy between modelled to measured total period-mean PM_{10} concentration is -0.4 %, with a standard deviation of 17.5%. The measured value at Harmondsworth is an outlier, suggesting either an instrumental problem or the influence of a local source not included in the modelling. It is worth noting that the instrument at Harmondsworth is a BAM (Beta Attenuation Monitor), whereas the instruments at the other sites (except Hayes) are of the TEOM type.

4.26 Excluding Harmondsworth, the average fractional discrepancy is 4.3% (i.e. the model overestimates by 4.3% on average), with a standard deviation of 9.5%. The average fractional discrepancy both with and without Harmondsworth is lower than the accuracy of the measurement techniques, so the comparison is able to demonstrate only that any model bias for total period-mean concentrations is less than the uncertainty in the measurements.

4.27 The modelled contribution from the designated road network and airport sources is on average only 2.3 $\mu g/m^3$ (maximum 5.2 $\mu g/m^3$, at LHR2) compared to a modelled background contribution of 17.2 $\mu g/m^3$, so the model-monitoring comparisons of total period-mean concentration mainly assess the background contribution. Furthermore, the smallness of the modelled contribution from airport and road-network sources highlights the difficulty of evaluating the performance of the modelling for these sources even using difference analysis, given that the expected differences are only comparable to 'natural' variation in the background (i.e. site-to-site variations in the background that are not captured by the modelling) and less than measurement uncertainties.

Airport Sources

4.28 Comparison of modelled and measured PM_{10} concentration differences between LHR2 and Oaks Rd and between Harlington and Oaks Rd indicates that the underestimation or overestimation of the contribution from airport sources to period-mean PM_{10} concentrations, if any, is less than estimated measurement uncertainties.

4.29 For LHR2, the model appears to overestimate the contribution from emissions on the runway (principally from brake and tyre wear), which could result from inaccuracies in the spatial distribution of the emissions rather than in the magnitude of the total emissions. Taking the measurement uncertainty on the period-mean concentration difference as 3 $\mu g/m^3$ would imply that any underestimation of the airport contribution at LHR2 is at most a factor of two (for a modelled contribution of 2.3 $\mu g/m^3$). At Harlington, there is good agreement between the modelled and measured concentration difference in a wind direction range giving a dominant contribution from airport sources. However, the differences are less than 1 $\mu g/m^3$, which is less than the estimated measurement uncertainties.

4.30 The measured PM_{10} concentration difference between Green Gates and Oaks Rd for wind directions giving an an airport contribution at Green Gates is negative whereas the modelled difference is positive, although small in magnitude in both cases. This emphasises the difficulty in interpreting such small differences.

4.31 Based on the model results, the contribution from airport sources to total period-mean PM_{10} concentration in 2008/9 was between 0.1 and 1.0 $\mu g/m^3$ in the residential areas just north of the airport (out of a total of around 20 $\mu g/m^3$), reaching around 2 $\mu g/m^3$ at the airport perimeter.

4.32 Comparing the 2008/9 model results for the contribution from airport sources to period-mean PM_{10} concentrations with equivalent results from the PSDH for the 2002 and 2010SM cases shows that at a given location the contributions are broadly comparable, as expected from the magnitude of airport emissions for the three cases. The principal differences in the 2008/9 results can be related to differences in meteorology.

Road-Network Sources

4.33 The three sites with the largest modelled road-network contribution to period-mean PM_{10} concentration are LHR2, Oxford Avenue and Hayes. None of these sites is close to a motorway. Comparison of modelled and measured concentration differences for LHR2-Harlington shows a missing modelled contribution to period-mean PM_{10} concentrations at LHR2 deriving from a narrow range of north-easterly wind directions, similar to that found for NO_x at LHR2. In the NO_x case, the peak was judged most likely to arise from traffic perturbations at the junction of the NPR with Neptune Rd, and this is judged also the most likely origin of the peak for PM_{10}. The total contribution to the period-mean concentration represented by the missing peak, however, is less than 1 $\mu g/m^3$.

4.34 The comparisons chosen to highlight the road-network contribution suggest that it may be under-predicted (with a compensating over-prediction of the background or LAEI/NAEI contributions). However, the evidence is not strong, given the small magnitude of concentration differences compared to measurement uncertainties and the potential for un-modelled site-to-site variability in the background contribution. In addition, there is a question of how generalisable are the results for these three sites to the network as a whole, particularly to near-motorway receptors, given that the fidelity of the traffic data close to the sites has not been evaluated. Furthermore, discrepancies at LHR2 and Hayes may relate to localised flow perturbations at junctions. Thus, the information provided by the PM_{10} evaluation is an inadequate basis for making a whole-network adjustment to modelled concentrations, so no adjustment factors have been applied to the model results on the grid of receptors used for generating contour plots. However, the potential for model underestimation close to junctions and to other regions of flow disturbance should be noted.

4.35 Contour plots based on the modelling results show that off-airport values above the 40 $\mu g/m^3$ limit value for annual mean PM_{10} concentration within the study area in 2008/9 were confined to areas within the road margins of the M4 and other major roads and within about 30 m of the centre of the M25 (with concentration values east of the M25 road centre higher than those west). Off-airport values above the surrogate annual mean value of 31.5 $\mu g/m^3$, used to test the limit on 24-hour mean concentrations, were principally confined to areas within about 30 m from the centre of the M4 and about 50 m from the centre of the M25. These areas should be taken as indicative of areas vulnerable to exceedence of the relevant limit, but the grid results may not have the spatial resolution to determine if individual receptors close to the relevant contour are within or outside the exceedence area, which would require closer investigation on a receptor-by-receptor basis.

4.36 The data used in the evaluation for PM_{10} does not provide a good test of the model at distances of a few tens of metres from a major motorway, so the predicted areas of exceedence close to the margins of the M4 and M25 should be treated with caution. There is some tentative evidence that the modelled 2008/9 PM_{10} concentrations close to the margins of these motorways are overestimates.

4.37 A comparison of the 2008/9 values for total PM_{10} concentration with equivalent values for the PSDH 2002 and 2010SM cases, using 13 representative receptor locations, shows that the 2008/9 values are on average closer to the PSDH results for the 2010SM case than to the results for the 2002 PSDH case, principally reflecting the fall in the background contribution since 2002.

$PM_{2.5}$

4.38 There were only three $PM_{2.5}$ monitoring sites operating in the study area in 2008/9 (Oaks Rd, Green Gates and Harmondsworth). In the modelling, the background component is the dominant contributor (9.6 $\mu g/m^3$) at these sites, with the airport and road network sources together contributing at most 1.2 $\mu g/m^3$.

4.39 The agreement between measured and modelled values is within the expected measurement uncertainty for Oaks Rd and Green Gates but there is significant over-prediction at Harmondsworth, by 41% (3.4 μg/m^3)*. The average fractional discrepancy between modelled and measured values is 17% and the average absolute discrepancy is 1.5 μg/m^3.

4.40 Even leaving aside measurement uncertainties, the comparison between modelled and measured total period-mean $PM_{2.5}$ values was unable to provide any detailed information on the performance of the modelling for airport and road network sources, given that their combined contribution is smaller than the uncertainty in the modelled contribution from all other sources (principally the background contribution).

4.41 Similarly, comparisons of $PM_{2.5}$ concentration differences are unable to provide any detailed information on the contribution from airport and road network sources, given that the modelled differences are smaller than the site-to-site variability in the contribution from other sources that is not captured by the model (and smaller than expected measurement uncertainties on concentration differences). The different measurement technique used at Harmondsworth (OSIRIS) further complicates the interpretation of differences involving that site. Thus, no source-specific model evaluation was possible for $PM_{2.5}$, and the comparisons of total period-mean concentrations were able only to confirm that the predicted total concentrations are within the range expected based on the monitoring data and its uncertainties.

4.42 Contour plots of total period-mean $PM_{2.5}$ concentration indicate that, according to the modelling, the values above 25 μg/m^3 limit/objective (coming into force in 2020/2015 respectively) were confined largely to areas within about 30 m of the M25. The caveats placed earlier on modelled PM_{10} concentrations at such close proximity to the M4 and M25 motorways apply to $PM_{2.5}$ also.

* It is worth noting that the instrument at Harmondsworth is of the OSIRIS (light-scattering) type, whereas the other two sites have TEOM instruments

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Tables and Figures

Table 1.1 Relevant air quality strategy objectives and EU limit values for selected pollutants

Pollutant	Objective	Metric[a]	Date[b]	European obligations	Date[b]
Nitrogen dioxide (NO_2)	200 µg/m^3 not to be exceeded more than 18 times per year	1 hour mean	31.12.2005	200 µg/m^3 not to be exceeded more than 18 times per year	1.1.2010
	40 µg/m^3	annual mean	31.12.2005	40 µg/m^3	1.1.2010
Particles[c] (PM_{10})	50 µg/m^3 not to be exceeded more than 35 times a year	24 hour mean	31.12.2004	50 µg/m^3 not to be exceeded more than 35 times a year	1.1.2005
	40 µg/m^3	annual mean	31.12.2004	40 µg/m^3	1.1.2005
Particles[d] ($PM_{2.5}$)	25 µg/m^3	annual mean	2020	Limit value 25 µg/m^3	1.1.2015
		annual mean		Stage 2 indicative limit value of 20 µg/m^3	1.1.2020[e]
				Exposure concentration obligation of 20 µg/m^3	1.1.2015[e]
	Target of 15% reduction in concentrations at urban background	annual mean	between 2010 and 2020	Exposure reduction target relative to the 2010 AEI[f] (0% to 20% reduction)	2020

[a] Averaging period
[b] Date to be achieved by and maintained thereafter
[c] The objectives given here for PM_{10} do not apply in Scotland.
[d] AQS objectives for $PM_{2.5}$ have not been included in Regulations for the purpose of Local Air Quality Management. (The limit value given here for $PM_{2.5}$ does not apply in Scotland.)
[e] Will be reviewed by the European Commission by 2013
[f] The three-year running annual mean or AEI is calculated from the $PM_{2.5}$ concentration averaged across all urban background locations in the UK (ie. the AEI for 2010 is the mean concentration measured over 2008, 2009 and 2010).

Table 2.1 Monitoring site information

Site name	Short name	Easting	Northing	Network	Pollutants	Location
Heathrow LHR2	LHR2	508393	176742	LAQN	NO, NO_2, PM_{10} (TEOM), O_3, CO	Within boundary fence of airport. Approx. 180 m north of runway 27R centre-line, 500 m from the end. Approx. 19 m south of centre of Northern Perimeter Road, near junction with Neptune Road. Fig 2.2 (a)
Heathrow Oaks Road	Oaks Rd	505729	174496	Airport	NO, NO_2, PM_{10} (TEOM), $PM_{2.5}$, O_3	Alongside residential road in residential area adjacent to parkland. Approx. 200 m south of Southern Perimeter Road. Fig 2.2 (b)
Heathrow Green Gates	Green Gates	505185	176922	Airport	NO, NO_2, PM_{10} (TEOM), $PM_{2.5}$	In parkland adjacent to residential area, approx. 400 m north of west end of runway 09L. Fig 2.2 (c)
Slough Colnbrook	Colnbrook	503542	176827	Slough	NO, NO_2, PM_{10} (TEOM)	In grounds of Pippins primary school, between residential and industrial areas. Approx. 500 m west of the M25. Fig 2.2 (d)
London Hillingdon Harmondsworth	Harmondsworth	505561	177661	Hillingdon	NO, NO_2, PM_{10} (BAM), PM_{10} (Osiris), $PM_{2.5}$ (Osiris), PM_1 (Osiris), TSP (Osiris)	Alongside minor road on outskirts of Harmondsworth village, adjacent to residential and commercial areas and parkland. Approx 900 m north of airport perimeter road. Fig 2.2 (e)
London Hillingdon	Hillingdon	506945	178609	AURN	NO, NO_2, O_3, SO_2, CO	At end of Sipson Road cul-de-sac, in a residential area bounded on the south by the M4. Approx. 40 m north of the nearest lane of the M4. Fig 2.2 (f)
Hillingdon Sipson	Sipson	507325	177280	Hillingdon	NO, NO_2	At the end of Ashby Way, a cul-de-sac in a residential area adjacent to parkland. Approx. 300 m north of the A4 (T) Bath Road. Fig 2.2 (g)
London Harlington	Harlington	508299	177809	AURN	NO, NO_2, PM_{10} (TEOM), $PM_{2.5}$, O_3, CO	Alongside minor road amidst farmland, approx. 300 m west of outskirts of Harlington and 1 km north of airport perimeter road. Fig 2.2 (h)
London Hillingdon 3 Oxford Avenue	Oxford Ave	509551	176974	LAQN	NO, NO_2, PM_{10} (TEOM)	In residential area, approx. 10 m from centre of residential road Oxford Avenue, and approx. 30 m north of centre of A4 Bath Road. Approx. 300 m north-east of Northern Perimeter Road. Fig 2.2 (i)
Hillingdon Hayes	Hayes	510283	178905	Hillingdon	NO, NO_2, PM_{10} (BAM)	On the corner of busy A437 North Hyde Road and side-road North Hyde Gardens in mixed residential, commercial and industrial area. Approx. 10 m from edge of North Hyde Road, approx. 1 m from kerb of North Hyde Gardens. Fig 2.2 (j)
Hounslow 2 - Cranford	Cranford	510371	177198	LAQN	NO, NO_2, PM_{10} (TEOM), O_3, SO_2	In residential area adjacent to parkland. Fig 2.2 (k)
Hounslow Hatton Cross	Hatton Cross	509332	174997	LAQN	NO, NO_2, PM_{10} (TEOM)	At end of Myrtle Grove cul-de-sac, adjacent to parkland. Approx. 100 m south-east of A30 (T) Great South West Road. Fig 2.2 (l)

Appendix AQ.1.15

Table 2.2 (a) Data characteristics for NO_x

Short name	Data source[a]	Ratification status[b]	Data capture (%)	Longest run of missing data (hours)	Period mean (µg/m^3)	Max hourly average (µg/m^3)	25th %ile of hourly averages (µg/m^3)	75th %ile of hourly averages (µg/m^3)	IQR[c]
LHR2	HAW	R	99.1	24	115.3	993.0	48.0	160.0	3.33
Oaks Rd	HAW	R	92.5	356	58.7	592.0	17.0	82.0	4.82
Green Gates	HAW	R	85.4	1205	75.2	894.0	29.0	88.0	3.03
Colnbrook	HAW	R	99.5	27	56.1	722.0	15.0	69.0	4.60
Harmondsworth	HA	P 1/1/09-31/3/09	93.2	399	63.6	672.0	23.0	74.0	3.22
Hillingdon	HAW	R	82.1	1224	108.1	861.0	40.0	145.0	3.63
Sipson	HAW	R	99.6	4	68.4	3719.0	27.0	82.0	3.04
Harlington	HAW	R	88.9	802	62.7	810.0	25.0	74.0	2.96
Oxford Ave	LA	P 1/9/08-31/3/09	90.8	439	83.7	785.4	36.1	106.6	2.95
Hayes	HAW	R	84.3	733	124.8	1207.0	53.0	157.0	2.96
Cranford	LA	P 27/2/09-31/3/09	81.7	424	64.0	793.3	25.0	74.7	2.99
Hatton Cross	LA	P 20/2/09-31/3/09	81.4	897	66.7	704.6	21.6	85.7	3.97

[a] HAW= www.heathrowairwatch.org.uk; LA = www.londonair.org.uk; HA = www.hillingdon-air.info
[b] R= ratified; P=provisional between dates shown, ratified otherwise
[c] IQR: Inter-quartile ratio= 75th percentile value/25th percentile value

Appendix AQ.1.15

Table 2.2 (b) Data characteristics for NO_2

Short name	Data source[a]	Ratification status[b]	Data capture (%)	Longest run of missing data (hours)	Period mean (µg/m^3)	Max hourly average (µg/m^3)	Number of hours >200 µg/m^3	99.8th %ile of hourly values
LHR2	HAW	R	99.1	24	52.4	168.0	0	139
Oaks Rd	HAW	R	92.5	356	36.9	160.0	0	127
Green Gates	HAW	R	85.4	1205	40.7	166.0	0	128
Colnbrook	HAW	R	99.5	27	32.0	160.0	0	121
Harmondsworth	HA	P 1/1/09-31/3/09	93.2	399	34.3	124.0	0	107
Hillingdon	HAW	R	82.1	1224	50.8	178.0	0	143
Sipson	HAW	R	99.6	4	38.9	592.0	2	122
Harlington	HAW	R	88.9	802	34.9	147.0	0	112
Oxford Ave	LA	P 1/9/08-31/3/09	90.8	439	43.8	146.0	0	120
Hayes	HAW	R	84.3	733	54.9	204.0	4	180
Cranford	LA	P 27/2/09-31/3/09	81.7	424	36.2	151.9	0	117
Hatton Cross	LA	P 20/2/09-31/3/09	81.4	897	34.4	150.1	0	115

[a] HAW= www.heathrowairwatch.org.uk; LA = www.londonair.org.uk; HA = www.hillingdon-air.info
[b] R= ratified; P=provisional between dates shown, ratified otherwise

Appendix AQ.1.15

Table 2.2 (c) Data characteristics for PM_{10}

Short name	Data source[a]	Ratification status[b]	Data capture (%)	Longest run of missing data (hours)	Raw period mean (µg/m^3)	Corrected period mean[c] (µg/m^3)	Maximum hourly mean (µg/m^3)	Number of 24-hour periods >50 µg/m^3	90th %ile of 24-hour means (µg/m^3)
LHR2	HAW	R	96.8	70	20.8	23.9	122.1	13.0	44.9
Oaks Rd	HAW	R	93.3	406	16.6	19.7	114.1	7.0	37.2
Green Gates	HAW	R	98.0	70	13.8	16.8	95.1	1.0	32.4
Colnbrook	HAW	R	98.0	70	16.2	19.2	134.7	5.0	36.6
Harmondsworth (BAM)	HA	P 1/1/09-31/3/09	86.0	565	42.0	34.7	678.0	45.0	57.0
Harmondsworth (Osiris)	HA	P 1/1/09-31/3/09	86.9	971	25.8	-	157.0	13.0	45.8
Harlington	HAW	R	87.3	562	17.9	21.0	126.5	8.0	38.5
Oxford Ave	LA	P 30/3/09-31/3/09	94.3	154	20.9	22.9	257.5	2.0	39.4
Hayes	HAW	R	83.0	733	27.3	22.5	135.0	4.0	39.0
Cranford	LA	P 4/3/09-31/3/09	88.3	467	17.7	18.9	91.7	1.0	33.3
Hatton Cross	LA	P 20/2/09-31/3/09	70.1	2397	18.7	20.7	156.1	0.0	34.2

[a] HAW= www.heathrowairwatch.org.uk; LA = www.londonair.org.uk; HA = www.hillingdon-air.info
[b] R= ratified; P=provisional between dates shown, ratified otherwise
[c] Correction depends on type of analyser: TEOM data have been corrected using VCM method; BAM corrected by dividing by 1.2

Table 2.2 (d) Data characteristics for $PM_{2.5}$

Short name	Data source[a]	Ratification status[b]	Data capture (%)	Longest run of missing data (hours)	Period mean (µg/m^3)	Maximum hourly mean (µg/m^3)
Oaks Rd	HAW	R	95.3	356	11.6	50.0
Green Gates	HAW	R	98.6	5	11.0	50.0
Harmondsworth (Osiris)	HA	P 1/1/09-31/3/09	86.9	971	8.3	84.0

[a] HAW= www.heathrowairwatch.org.uk; HA = www.hillingdon-air.info
[b] R= ratified; P=provisional between dates shown, ratified otherwise

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Table 2.2 (e) Data characteristics for ozone

Short name	Data source[a]	Ratification status[b]	Data capture (%)	Longest run of missing data (hours)	Period mean (µg/m^3)
Hillingdon	HAW	R	99.1	27	29.0
Harlington	HAW	R	98.9	27	33.7
Cranford	LA	P 4/3/09-31/3/09	77.0	623	32.9

[a] HAW= www.heathrowairwatch.org.uk; LA = www.londonair.org.uk
[b] R= ratified; P=provisional between dates shown, ratified otherwise

Table 2.3 Comparison of predicted and measured number of daily of exceedence of 50 µg/m^3 PM_{10}

Site	Period mean (µg/m^3)	Number of days >50 (µg/m^3)	
		Predicted	Measured
LHR2	23.9	10.0	13
Oaks Rd	19.7	3.0	7
Green Gates	16.8	0.6	1
Colnbrook	19.2	2.5	5
Harmondsworth	34.7	47.9	45
Harlington	21.0	4.7	8
Oxford Avenue	22.9	7.9	2
Hayes	22.5	7.2	4
Cranford	18.9	2.2	1
Hatton Cross	20.7	4.3	0

Table 3.1 Comparison of modelled period-mean NO_x concentrations[a] with measured values for continuous NO_x/NO_2 analysers[b]

Site	Modelled period-mean NO_x concentrations (µg/m³)										Measured (µg/m³)	FD[d]
	Airport					Off-airport				Grand total (µg/m³)		
	Aircraft	APU	Airside vehicles	Other airport[c]	Airport sub-total	Road traffic	LAEI/NAEI	Background	Off-airport sub-total			
LHR2	25.13	3.27	3.63	0.94	32.98	35.22	25.47	14.31	75.00	107.98	115.26	-6.3
Oaks Road	8.99	3.62	3.49	1.00	17.10	9.90	23.82	14.27	47.99	65.09	58.68	10.9
Green Gates	1.38	1.19	1.38	0.36	4.31	16.09	26.03	14.92	57.04	61.35	75.20	-18.4
Colnbrook	1.10	0.35	0.46	0.15	2.06	13.53	24.23	14.31	52.06	54.13	56.12	-3.5
H'worth	1.22	0.85	1.02	0.25	3.35	14.37	26.52	13.90	54.78	58.13	63.59	-8.6
Hillingdon	1.95	0.85	0.84	0.31	3.95	48.44	29.63	13.92	91.99	95.95	108.15	-11.3
Sipson	5.51	2.17	2.26	0.70	10.64	13.24	27.53	14.24	55.01	65.65	68.39	-4.0
Harlington	5.53	1.36	1.47	0.53	8.88	13.64	29.80	14.49	57.94	66.81	62.74	6.5
Oxford Ave	9.68	1.27	1.46	1.00	13.42	17.21	26.76	14.14	58.12	71.54	83.66	-14.5
Hayes	2.52	0.50	0.57	0.33	3.92	31.08	40.54	14.84	86.47	90.39	124.81	-27.6
Cranford	4.54	0.86	0.93	0.91	7.23	12.75	28.81	14.94	56.49	63.72	64.04	-0.5
Hatton Cross	11.35	2.65	2.82	1.63	18.45	18.54	25.33	14.25	58.12	76.57	66.66	14.9
Average										73.11	78.94	-5.2
SD										16.57	23.79	12.2

[a] These values are prior to applying the road-network scaling factor
[b] All values shown to two decimal places to avoid the accumulation of rounding errors in forming ratios and sub-totals, but this is not indicative of the precision of either the model or measured values
[c] Includes car parks and stationary sources
[d] Fractional Discrepancy=100*(model-measured)/measured

Table 3.2 Comparison of period-mean NO_x concentrations and all-hours period-mean NO_x concentrations

Site	NO_x DC (%)	Period mean ($\mu g/m^3$)	All- hours period mean ($\mu g/m^3$)	Diff[a] ($\mu g/m^3$)
LHR2	99.1	107.98	107.98	0.00
Oaks Road	92.5	65.09	63.63	1.46
Green Gates	85.4	61.35	58.96	2.40
Colnbrook	99.5	54.13	54.10	0.03
Harmondsworth	93.2	58.13	58.45	-0.32
Hillingdon	82.1	95.95	94.01	1.94
Sipson	99.6	65.65	65.79	-0.14
Harlington	88.9	66.81	66.41	0.41
Oxford Ave	90.8	71.54	71.84	-0.30
Hayes	84.3	90.39	89.16	1.23
Cranford	81.7	63.72	62.53	1.20
Hatton Cross	81.4	76.57	77.02	-0.45

[a] Diff=(Period mean-All hours period mean)

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Table 3.3 Comparison of model and measured contributions to the period-mean difference in NO_x concentration between pairs of analysers, for sector ranges chosen to highlight the airport source contribution

(a) southerly wind sectors

Difference selected	Sector range (deg)[a]	NO_x concentration contribution (µg/m^3)		Disc[b] (µg/m^3)	FD[c] (%)
		Modelled	Measured		
LHR2-Oaks Rd	170-270	35.36	34.35	1.01	2.9
Sipson-Oaks Rd	120-240	12.47	13.67	-1.20	-8.8
Harlington-Oaks Rd	160-240	9.51	7.94	1.57	19.8
Harmondsworth-Oaks Rd	110-190	3.26	4.27	-1.02	-23.8
Green Gates-Oaks Rd	100-180	3.04	3.19	-0.15	-4.8
Oxford Avenue-Oaks Rd	200-260	17.75	21.93	-4.18	-19.1

[a] Angle is the direction from which the wind blows, clockwise from north; sector ranges are inclusive
[b] Disc (absolute discrepancy)=modelled-measured
[c] Fractional Discrepancy=100*(modelled-measured)/measured

(b) northerly wind sectors

Difference selected	Sector range (deg)[a]	NO_x concentration contribution (µg/m^3)		Disc[b] (µg/m^3)	FD[c] (%)
		Modelled	Measured		
Oaks Rd-Harlington	330-90	11.91	9.16	2.75	30.0
Oaks Rd-Harmondsworth	330-90	12.41	9.47	2.95	31.1
Oaks Rd-Sipson	330-90	12.46	7.98	4.48	56.0

[a] Angle is the direction from which the wind blows, clockwise from north; sector ranges are inclusive
[b] Disc (absolute discrepancy)=modelled-measured
[c] Fractional Discrepancy=100*(modelled-measured)/measured

Table 3.4 Breakdown by source category of the contribution to the period-mean LHR2-Oaks Rd NO_x concentration difference from wind direction sectors 170° to 270° inclusive

Site	Airport contribution (μg/m³)					Off-airport contribution (μg/m³)			Grand total (μg/m³)
	Aircraft	APU	Airside vehicles	Other airport[a]	Airport sub-total	Road traffic	LAEI/ NAEI	Off-airport sub-total	
LHR2	23.60	3.33	3.57	0.56	31.07	5.76	4.80	10.56	41.63
Oaks Rd	0.00	0.00	0.00	0.00	0.00	1.71	4.55	6.26	6.26
Difference	23.60	3.33	3.57	0.56	31.07	4.05	0.25	4.30	35.36

[a] Includes car parks and stationary sources

Table 3.5 Comparison of modelled and measured contributions to LHR2-Oaks Rd concentration difference (from wind direction sectors 170° to 270° inclusive) for hours selected by mode of runway operation

Mode	Concentration contribution (μg/m³)[a]	
	Modelled	Monitored
Dep 27R/Arr 27L	22.85	22.00
Dep 27L/Arr 27R	9.78	10.28

[a] The two contribution do not sum to the total in Table 3.3
because there are other contributions from easterly operation and from hours with departures on both runways

Table 3.6 Breakdown by source category of the contribution to the period-mean Sipson-Oaks Rd NO_x concentration difference from wind direction sectors 120° to 240° inclusive

Site	Airport contribution (μg/m³)					Off-airport contribution (μg/m³)			Grand total (μg/m³)
	Aircraft	APU	Airside vehicles	Other airport[a]	Airport sub-total	Road traffic	LAEI/ NAEI	Off-airport sub-total	
Sipson	5.24	2.09	2.11	0.56	10.00	3.23	3.84	7.07	17.06
Oaks Rd	0.00	0.00	0.00	0.01	0.01	0.81	3.78	4.59	4.60
Difference	5.24	2.09	2.11	0.55	9.99	2.42	0.05	2.48	12.47

[a] Includes car parks and stationary sources

Table 3.7 Breakdown by source category of the contribution to the period-mean Harlington-Oaks Rd NO_x concentration difference from wind direction sectors 160° to 240° inclusive

Site	Airport contribution (µg/m³)					Off-airport contribution (µg/m³)			Grand total (µg/m³)
	Aircraft	APU	Airside vehicles	Other airport[a]	Airport sub-total	Road traffic	LAEI/ NAEI	Off-airport sub-total	
Harlington	5.14	1.33	1.39	0.40	8.25	1.65	3.23	4.88	13.14
Oaks Rd	0.00	0.00	0.00	0.00	0.00	0.65	2.98	3.63	3.63
Difference	5.14	1.33	1.39	0.40	8.25	1.00	0.26	1.25	9.51

[a] Includes car parks and stationary sources

Table 3.8 Breakdown by source category of the contribution to the period-mean Harmondsworth-Oaks Rd NO_x concentration difference from wind direction sectors 110° to 190° inclusive

Site	Airport contribution (µg/m³)					Off-airport contribution (µg/m³)			Grand total (µg/m³)
	Aircraft	APU	Airside vehicles	Other airport[a]	Airport sub-total	Road traffic	LAEI/ NAEI	Off-airport sub-total	
Harmondsworth	1.08	0.67	0.82	0.19	2.75	0.72	1.92	2.64	5.39
Oaks Rd	0.00	0.01	0.00	0.03	0.04	0.34	1.75	2.10	2.13
Difference	1.08	0.66	0.81	0.16	2.71	0.38	0.17	0.54	3.26

[a] Includes car parks and stationary sources

Table 3.9 Breakdown by source category of the contribution to the period-mean Green Gates-Oaks Rd NO_x concentration difference from wind direction sectors 100° to 180° inclusive

Site	Airport contribution (µg/m³)					Off-airport contribution (µg/m³)			Grand total (µg/m³)
	Aircraft	APU	Airside vehicles	Other airport[a]	Airport sub-total	Road traffic	LAEI/ NAEI	Off-airport sub-total	
Green Gates	1.06	0.84	0.99	0.20	3.07	0.47	1.71	2.18	5.25
Oaks Rd	0.02	0.02	0.02	0.11	0.17	0.40	1.64	2.05	2.22
Difference	1.04	0.81	0.97	0.09	2.90	0.07	0.06	0.13	3.04

[a] Includes car parks and stationary sources

Table 3.10 Breakdown by source category of the contribution to the period-mean Oxford Avenue-Oaks Rd NO_x concentration difference from wind direction sectors 200° to 260° inclusive

Site	Airport contribution (µg/m³)					Off-airport contribution (µg/m³)			Grand total (µg/m³)
	Aircraft	APU	Airside vehicles	Other airport[a]	Airport sub-total	Road traffic	LAEI/ NAEI	Off-airport sub-total	
Oxford Avenue	9.13	1.28	1.40	0.53	12.33	6.47	3.02	9.49	21.82
Oaks Rd	0.00	0.00	0.00	0.00	0.00	1.09	2.98	4.07	4.07
Difference	9.13	1.28	1.40	0.53	12.33	5.38	0.04	5.42	17.75

[a] Includes car parks and stationary sources

Table 3.11 Emissions summary pertinent to Table 3.11 concentration comparisons

Case	Ground-level NO_x emissions (tonne/year)	
	Aircraft[a]	Other airport[b]
2008/9	1637.41	278.91
2002 PSDH	1661.63	263.49
2010SM	2126.15	184.07

[a] Includes APUs and engine testing
[b] Excludes heating plant

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Table 3.12 Comparison of 2008/9, 2002 PSDH and 2010SM contributions from airport sources to period-mean NO_x concentrations

Site	PSDH name	Easting	Northing	Contribution to period-mean NO_x concentrations (µg/m^3)								
				Aircraft+APU+engine testing			Other airport			Total airport		
				2008/9	2002 PSDH	2010SM	2008/9	2002 PSDH	2010SM	2008/9	2002 PSDH	2010SM
LHR2	LHR2	508399	176744	28.5	31.2	37.1	4.6	6.5	3.6	33.1	37.7	40.7
Oxford Avenue	LHR4	509550	176997	11.0	12.5	14.1	2.6	3.0	2.3	13.6	15.5	16.4
Cranford	LHR5	510370	177195	5.7	6.3	7.4	1.9	1.9	1.2	7.7	8.2	8.6
Hatton Cross	LHR7	509333	175002	14.2	10.7	13.3	4.8	3.4	1.7	19.0	14.1	15.0
Oaks Rd	LHR8	505739	174497	11.8	7.5	10.4	4.4	1.8	1.6	16.2	9.3	12.0
Colnbrook	LHR14	503535	176829	1.5	2.1	2.7	0.6	0.5	0.5	2.1	2.6	3.2
Green Gates	LHR15	505185	176922	2.9	3.6	5.7	1.8	1.2	1.8	4.7	4.8	7.5
Hillingdon	LHR16	506945	178609	2.6	3.7	4.8	1.1	1.2	0.9	3.6	4.9	5.7
Harlington	LHR18	508279	177792	6.7	8.5	10.5	2.0	2.7	1.5	8.7	11.2	12.0
HD60	HD60	505736	177752	2.1	3.2	4.6	1.3	1.1	1.1	3.3	4.3	5.7
HD58	HD58	508414	177125	13.1	16.3	19.0	3.2	4.5	2.4	16.3	20.8	21.4
HD57	HD57	508758	177718	7.7	9.3	11.2	2.0	2.5	1.5	9.7	11.8	12.7
HD56	HD56	509798	178634	3.9	5.0	6.1	1.2	1.3	0.8	5.0	6.3	6.9
Average				8.6	9.2	11.3	2.4	2.4	1.6	11.0	11.7	12.9

Table 3.13 Comparison of model and measured contributions to the period-mean difference in NO_x concentration between pairs of analysers, for selected sector ranges chosen to highlight the road network source contribution

Difference selected	Sector range (deg)[a]	NO_x concentration contribution (µg/m^3)		Disc[b] (µg/m^3)	FD[c] (%)
		Modelled	Measured		
Hillingdon-Harmondsworth	100-270	37.20	46.37	-9.17	-19.8
Hillingdon-Harlington	100-270	31.18	49.71	-18.53	-37.3
Green Gates- Oaks Rd	200-290	4.82	12.17	-7.35	-60.4
Harmondsworth-Colnbrook	200-290	5.18	10.58	-5.40	-51.1
Oxford Avenue-Oaks Rd	90-180	2.16	5.38	-3.22	-59.9
LHR2-Harlington	270-100	19.81	30.74	-10.93	-35.6
Hayes-Cranford	90-210	12.37	21.97	-9.59	-43.7

[a] Angle is the direction from which the wind blows, clockwise from north; sector ranges are inclusive
[b] Disc (absolute discrepancy)=modelled-measured
[c] Fractional Discrepancy=100*(modelled-measured)/measured

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Table 3.14 Breakdown by source category of the contribution to the period-mean Hillingdon-Harmondsworth NO_x concentration difference from wind direction sectors 100° to 270° inclusive

Site	Airport contribution (µg/m³)					Off-airport contribution (µg/m³)			Grand total (µg/m³)
	Aircraft	APU	Airside vehicles	Other airport[a]	Airport sub-total	Road traffic	LAEI/ NAEI	Off-airport sub-total	
Hillingdon	1.95	0.85	0.84	0.30	3.95	40.01	10.09	50.10	54.06
Harmondsworth	1.15	0.89	1.00	0.25	3.30	5.33	8.23	13.56	16.86
Difference	0.80	-0.03	-0.16	0.05	0.66	34.68	1.86	36.54	37.20

[a] Includes car parks and stationary sources

Table 3.15 Comparison of measured and modelled traffic flows on the M4 between Junctions 4 and 4b[26]

(**a) two-way flows on M4 between Junctions 4 and 4b**

Model period		Flow (PCU[a]/hour)	
		Observed	Modelled
Morning peak	0800-0900	12392	12645
Inter peak	1000-1600	9894	9571
Evening peak	1700-1800	11942	11834

[a] PCU – Passenger Car Units

(b) one way flows on M25 between Junctions 15 and 14

Model period		Flow (PCU[a]/hour)	
		Observed	Modelled
Morning peak	0800-0900	8626	7910
Inter peak	1000-1600	7236	6377
Evening peak	1700-1800	7345	5943

[a] PCU – Passenger Car Units

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Table 3.16 Breakdown by source category of the contribution to the period-mean Green Gates-Oaks Rd NO_x concentration difference from wind direction sectors 200° to 290° inclusive

Site	Airport contribution (µg/m^3)					Off-airport contribution (µg/m^3)			Grand total (µg/m^3)
	Aircraft	APU	Airside vehicles	Other airport[a]	Airport sub-total	Road traffic	LAEI/ NAEI	Off-airport sub-total	
Green Gates	0.02	0.07	0.08	0.04	0.20	6.05	7.46	13.51	13.71
Oaks Rd	0.02	0.00	0.00	0.00	0.02	2.75	6.13	8.87	8.89
Difference	0.00	0.07	0.08	0.04	0.18	3.31	1.33	4.64	4.82

[a] Includes car parks and stationary sources

Table 3.17 Breakdown by source category of the contribution to the period-mean Oxford Avenue-Oaks Rd NO_x concentration difference from wind direction sectors 90° to 180° inclusive

Site	Airport contribution (µg/m^3)					Off-airport contribution (µg/m^3)			Grand total (µg/m^3)
	Aircraft	APU	Airside vehicles	Other airport[a]	Airport sub-total	Road traffic	LAEI/ NAEI	Off-airport sub-total	
Oxford Avenue	0.13	0.00	0.00	0.31	0.44	2.68	3.17	5.85	6.29
Oaks Rd	0.12	0.14	0.09	0.36	0.72	0.61	2.80	3.41	4.13
Difference	0.00	-0.14	-0.09	-0.04	-0.28	2.06	0.37	2.44	2.16

[a] Includes car parks and stationary sources

Table 3.18 Comparison of (scaled) modelled period-mean NO_x concentrations with measured values for continuous NO_x/NO_2 analysers[a]

Site	Modelled period-mean NO_x concentrations ($\mu g/m^3$)										Measured ($\mu g/m^3$)	FD[c]
	Airport					Off-airport				Grand total ($\mu g/m^3$)		
	Aircraft	APU	Airside vehicles	Other airport[b]	Airport sub-total	Road traffic	LAEI/NAEI	Background	Off-airport sub-total			
LHR2	25.13	3.27	3.63	0.94	32.98	42.68	25.47	14.31	82.46	115.44	115.26	0.2
Oaks Road	8.99	3.62	3.49	1.00	17.10	12.00	23.82	14.27	50.09	67.19	58.68	14.5
Green Gates	1.38	1.19	1.38	0.36	4.31	19.50	26.03	14.92	60.45	64.76	75.20	-13.9
Colnbrook	1.10	0.35	0.46	0.15	2.06	16.39	24.23	14.31	54.93	56.99	56.12	1.6
H'worth	1.22	0.85	1.02	0.25	3.35	17.41	26.52	13.90	57.83	61.18	63.59	-3.8
Hillingdon	1.95	0.85	0.84	0.31	3.95	58.71	29.63	13.92	102.26	106.21	108.15	-1.8
Sipson	5.51	2.17	2.26	0.70	10.64	16.04	27.53	14.24	57.82	68.45	68.39	0.1
Harlington	5.53	1.36	1.47	0.53	8.88	16.53	29.80	14.49	60.82	69.70	62.74	11.1
Oxford Ave	9.68	1.27	1.46	1.00	13.42	20.86	26.76	14.14	61.77	75.18	83.66	-10.1
Hayes	2.52	0.50	0.57	0.33	3.92	37.67	40.54	14.84	93.05	96.97	124.81	-22.3
Cranford	4.54	0.86	0.93	0.91	7.23	15.45	28.81	14.94	59.19	66.42	64.04	3.7
Hatton Cross	11.35	2.65	2.82	1.63	18.45	22.47	25.33	14.25	62.05	80.50	66.66	20.8
Average										77.42	78.94	0.0
SD										18.78	23.79	12.0

[a] All values shown to two decimal places to avoid the accumulation of rounding errors in forming ratios and sub-totals, but this is not indicative of the precision of either the model or measured values
[b] Includes car parks and stationary sources
[c] Fractional Discrepancy=100*(model-measured)/measured

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Table 3.19 Comparison of model results for period-mean NO_x concentrations: 2008/9 (including road network scaling), 2002 PSDH and 2010SM

Site	PSDH name	Easting	Northing	Period mean NO_x concentrations ($\mu g/m^3$)								
				Airport			Non-airport			Total		
				2008/9	2002 PSDH	2010SM	2008/9	2002 PSDH	2010SM	2008/9	2002 PSDH	2010SM
LHR2	LHR2	508399	176744	33.1	37.7	40.7	82.3	70.9	50.3	115.4	108.6	91.0
Oxford Avenue	LHR4	509550	176997	13.6	15.5	16.4	62.0	62.4	43.1	75.6	77.9	59.5
Cranford	LHR5	510370	177195	7.7	8.2	8.6	57.5	59.3	40.8	65.1	67.5	49.4
Hatton Cross	LHR7	509333	175002	19.0	14.1	15.0	62.0	62.0	42.0	81.0	76.1	57.0
Oaks Rd	LHR8	505739	174497	16.2	9.3	12.0	49.4	49.4	34.0	65.7	58.7	46.0
Colnbrook	LHR14	503535	176829	2.1	2.6	3.2	54.9	61.1	41.5	57.0	63.7	44.7
Green Gates	LHR15	505185	176922	4.7	4.8	7.5	57.5	57.7	39.0	62.2	62.5	46.5
Hillingdon	LHR16	506945	178609	3.6	4.9	5.7	99.9	119.9	71.9	103.6	124.8	77.6
Harlington	LHR18	508279	177792	8.7	11.2	12.0	60.6	60.2	42.0	69.3	71.4	54.0
HD60	HD60	505736	177752	3.3	4.3	5.7	59.4	58.3	39.5	62.7	62.6	45.2
HD58	HD58	508414	177125	16.3	20.8	21.4	55.2	58.2	41.2	71.5	79.0	62.6
HD57	HD57	508758	177718	9.7	11.8	12.7	66.1	67.9	47.4	75.7	79.7	60.1
HD56	HD56	509798	178634	5.0	6.3	6.9	66.5	76.0	54.9	71.5	82.3	61.8
Average				11.0	11.7	12.9	64.1	66.4	45.2	75.1	78.1	58.1

Table 3.20 Comparison of measured and calculated period-mean total oxidant at sites with ozone measurements

Site	Calculated oxidant				Measured oxidant			FD[c] (%)
	B (ppb)	*A*[a]	$[NO_x]$[b] (ppb)	$[OX]_{calc}$ (ppb)	$[O_3]$ (ppb)	$[NO_2]$ (ppb)	$[OX]_{meas}$ (ppb)	
Cranford	33.5	0.138	33.62	38.12	16.45	19.00	35.45	7.5
Harlington	33.5	0.138	32.94	38.04	16.86	18.32	35.18	8.1
Hillingdon	33.5	0.153	56.77	42.17	14.50	26.66	41.16	2.5
Average								6.0

[a] *A* – calculated for all hours of the period
[b] Measured NO_x value used here
[c] Fractional Discrepancy=100*(calculated-measured)/measured

Appendix AQ.1.15

Table 3.21 Comparison of period-mean NO_2 concentrations and NO_2/NO_x ratios

	Without roads scaling factor						With roads scaling factor					
	Period-mean NO_2 concs (µg/m^3)		FD[a]	NO_2/NO_x			Period-mean NO_2 concs (µg/m^3)		FD[a]	NO_2/NO_x		
Site ID	Modelled	Measured	(%)	Modelled	Measured	Ratio[a]	Modelled	Measured	%	Modelled	Measured	FD[a]
LHR2	49.92	52.39	-4.7	0.46	0.45	1.7	51.91	52.39	-0.9	0.45	0.45	-1.1
Oaks Road	37.08	36.94	0.4	0.57	0.63	-9.5	37.87	36.94	2.5	0.56	0.63	-10.5
Green Gates	35.77	40.66	-12.0	0.58	0.54	7.8	37.09	40.66	-8.8	0.57	0.54	6.0
Colnbrook	32.85	31.96	2.8	0.61	0.57	6.6	34.05	31.96	6.5	0.60	0.57	4.9
H'worth	34.45	34.30	0.4	0.59	0.54	9.9	35.68	34.30	4.0	0.58	0.54	8.2
Hillingdon	47.80	50.79	-5.9	0.50	0.47	6.1	50.91	50.79	0.2	0.48	0.47	2.1
Sipson	37.25	38.89	-4.2	0.57	0.57	-0.2	38.29	38.89	-1.5	0.56	0.57	-1.6
Harlington	37.60	34.91	7.7	0.56	0.56	1.2	38.67	34.91	10.8	0.55	0.56	-0.3
Oxford Ave	39.48	43.76	-9.8	0.55	0.52	5.2	40.74	43.76	-6.9	0.54	0.52	3.3
Hayes	45.46	54.86	-17.1	0.50	0.44	14.4	47.46	54.86	-13.5	0.49	0.44	11.4
Cranford	36.49	36.19	0.8	0.57	0.57	1.3	37.51	36.19	3.7	0.56	0.57	0.0
Hatton Cross	41.20	34.38	19.8	0.54	0.52	4.3	42.50	34.38	23.6	0.53	0.52	2.4
Average			-1.8			4.1			1.6			2.1
SD			9.7			6.0			9.7			5.5

[a] Fractional Discrepancy= 100*(modelled-measured)/measured

Table 3.22 Effect of assigning sites to Jenkin Category III rather than Category II

	NO_2 concentration (µg/m^3)			NO_2/NO_x ratio		
	Modelled		Measured	Modelled		Measured
Site	Category II	Category III		Category II	Category III	
Oaks Rd	37.87	35.95	36.94	0.56	0.54	0.63
Colnbrook	34.05	32.48	31.96	0.60	0.57	0.57
Hatton Cross	42.50	40.18	34.38	0.53	0.50	0.52

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Table 3.23 Comparison of model results for period-mean NO_2 concentrations: 2008/9 (including road network scaling), 2002 PSDH and 2010SM

Site	PSDH name	A	NO_2 ($\mu g/m^3$)			NO_x ($\mu g/m^3$)			NO_2/NO_x		
			2008/9	2002 PSDH	2010SM	2008/9	2002 PSDH	2010SM	2008/9	2002 PSDH	2010SM
LHR2	LHR2	0.143	52.4	47.7	45.7	115.4	108.6	90.9	0.45	0.44	0.50
Oxford Avenue	LHR4	0.143	40.9	39.8	36.9	75.6	77.9	59.5	0.54	0.51	0.62
Cranford	LHR5	0.138	37.1	36.0	32.5	65.1	67.4	49.4	0.57	0.53	0.66
Hatton Cross	LHR7	0.143	42.7	36.7	32.9	81.0	76.0	57.0	0.53	0.48	0.58
Oaks Rd	LHR8	0.135	37.1	31.5	28.9	65.7	58.6	46.1	0.57	0.54	0.63
Colnbrook	LHR14	0.140	34.0	34.4	30.0	57.0	63.7	44.7	0.60	0.54	0.67
Green Gates	LHR15	0.140	36.1	34.0	31.0	62.2	62.6	46.5	0.58	0.54	0.67
Hillingdon	LHR16	0.153	50.0	47.3	40.5	103.6	124.7	77.6	0.48	0.38	0.52
Harlington	LHR18	0.138	38.6	38.3	35.3	69.3	71.4	54.0	0.56	0.54	0.65
HD60	HD60	0.137	36.2	34.1	30.5	62.7	62.7	45.1	0.58	0.54	0.68
HD58	HD58	0.141	39.4	41.5	39.1	71.5	79.1	62.6	0.55	0.52	0.62
HD57	HD57	0.140	40.9	39.9	36.9	75.7	79.8	60.0	0.54	0.50	0.62
HD56	HD56	0.136	39.3	41.2	37.5	71.5	82.3	61.9	0.55	0.50	0.61
Average		0.141	40.3	38.6	35.2	75.1	78.1	58.1	0.55	0.51	0.62

Table 3.24 Comparison of modelled and measured period-mean PM_{10} concentrations[a]

Site	Modelled period-mean NO_x concentrations (µg/m^3)										Measured (µg/m^3)	FD[c]
	Airport					Off-airport				Grand total (µg/m^3)		
	Aircraft	APU	Airside vehicles	Other airport[b]	Airport sub-total	Road traffic	LAEI/NAEI	Background	Off-airport sub-total			
LHR2	1.58	0.07	0.30	0.06	2.00	3.19	1.52	17.28	21.99	23.99	23.94	0.20
Oaks Road	0.26	0.07	0.29	0.05	0.67	1.01	1.52	17.33	19.86	20.53	19.69	4.25
Green Gates	0.11	0.02	0.12	0.03	0.27	1.55	1.55	17.76	20.86	21.13	16.82	25.68
Colnbrook	0.04	0.01	0.04	0.01	0.09	1.27	1.72	17.26	20.24	20.33	19.18	6.01
H'worth (BAM)	0.04	0.02	0.08	0.02	0.16	1.29	1.57	16.66	19.53	19.69	34.67	-43.22
Harlington	0.15	0.03	0.12	0.03	0.33	1.54	1.76	17.19	20.49	20.82	20.96	-0.68
Oxford Ave	0.26	0.03	0.13	0.05	0.46	2.08	1.48	17.44	20.99	21.46	22.87	-6.18
Hayes	0.06	0.01	0.05	0.02	0.14	2.53	1.88	16.99	21.40	21.54	22.54	-4.43
Cranford	0.13	0.02	0.08	0.03	0.26	1.32	1.51	17.75	20.57	20.83	18.92	10.11
Hatton Cross	0.37	0.04	0.22	0.06	0.69	1.76	1.39	17.69	20.84	21.52	20.67	4.12
Average										21.19	22.03	-0.41
SD										1.15	4.92	17.50

[a] All values shown to two decimal places to avoid the accumulation of rounding errors in forming ratios and sub-totals, but this is not indicative of the precision of either the model or measured values
[b] Includes car parks and stationary sources
[c] Fractional Discrepancy=100*(model-measured)/measured

Table 3.25 Breakdown by source category of the contribution to the period-mean LHR2-Oaks Rd PM_{10} concentration difference from wind direction sectors 150° to 270° inclusive

Site	Airport contribution (µg/m^3)					Off-airport contribution (µg/m^3)			Grand total (µg/m^3)
	Aircraft	APU	Airside vehicles	Other airport[a]	Airport sub-total	Road traffic	LAEI/ NAEI	Off-airport sub-total	
LHR2	1.49	0.07	0.30	0.04	1.90	0.54	0.43	0.97	2.87
Oaks Rd	0.00	0.00	0.00	0.00	0.00	0.19	0.38	0.57	0.57
Difference	1.49	0.07	0.30	0.04	1.90	0.35	0.05	0.40	2.30

[a] Includes car parks and stationary sources

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Table 3.26 Comparison of model and measured contributions to the period-mean difference in PM_{10} concentration between pairs of analysers, for selected sector ranges chosen to highlight the airport source contribution

Difference selected	Sector range (deg)[a]	PM_{10} concentration contribution (μg/m³)		Disc[b] (μg/m³)	FD[c] (%)
		Modelled	Measured		
LHR2-Oaks Rd	150-270	2.30	1.62	0.68	42.1
Harlington-Oaks Rd	160-240	0.43	0.44	-0.01	-2.7

[a] Angle is the direction from which the wind blows, clockwise from north; sector ranges are inclusive
[b] Disc (absolute discrepancy)=modelled-measured
[c] Fractional Discrepancy=100*(modelled-measured)/measured

Table 3.27 Breakdown by source category of the contribution to the period-mean Harlington-Oaks Rd PM_{10} concentration difference from wind direction sectors 160° to 240° inclusive

Site	Airport contribution (μg/m³)					Off-airport contribution (μg/m³)			Grand total (μg/m³)
	Aircraft	APU	Airside vehicles	Other airport[a]	Airport sub-total	Road traffic	LAEI/ NAEI	Off-airport sub-total	
Harlington	0.14	0.03	0.12	0.03	0.32	0.18	0.25	0.43	0.74
Oaks Rd	0.00	0.00	0.00	0.00	0.00	0.09	0.22	0.31	0.31
Difference	0.14	0.03	0.12	0.03	0.32	0.09	0.02	0.11	0.43

[a] Includes car parks and stationary sources

Table 3.28 Emissions summary pertinent to Table 3.29 concentration comparisons

Case	Ground-level PM_{10} emissions (tonne/year)	
	Aircraft[a]	Other airport[b]
2008/9	36.34	23.08
2002 PSDH	36.85	20.12
2010SM	37.73	13.33

[a] Includes main engines, APUs, engine testing and aircraft brake and tyre wear
[b] Excludes heating plant

Table 3.29 Comparison of 2008/9, 2002 PSDH and 2010SM contributions from airport sources to period-mean PM_{10} concentrations

Site	PSDH name	Easting	Northing	Contribution to period-mean PM_{10} concentrations (µg/m³)								
				Aircraft+APU+engine testing			Other airport			Total airport		
				2008/9	2002 PSDH	2010SM	2008/9	2002 PSDH	2010SM	2008/9	2002 PSDH	2010SM
LHR2	LHR2	508399	176744	1.63	1.22	1.32	0.36	0.46	0.25	2.00	1.68	1.57
Oxford Avenue	LHR4	509550	176997	0.29	0.26	0.22	0.18	0.20	0.13	0.46	0.46	0.35
Cranford	LHR5	510370	177195	0.15	0.14	0.12	0.12	0.12	0.07	0.26	0.26	0.19
Hatton Cross	LHR7	509333	175002	0.43	0.24	0.23	0.30	0.23	0.11	0.74	0.47	0.34
Oaks Rd	LHR8	505739	174497	0.30	0.16	0.17	0.34	0.13	0.12	0.64	0.29	0.29
Colnbrook	LHR14	503535	176829	0.05	0.05	0.05	0.05	0.03	0.04	0.09	0.08	0.09
Green Gates	LHR15	505185	176922	0.14	0.11	0.15	0.14	0.08	0.14	0.28	0.19	0.29
Hillingdon	LHR16	506945	178609	0.06	0.11	0.13	0.08	0.08	0.06	0.14	0.19	0.19
Harlington	LHR18	508279	177792	0.18	0.25	0.26	0.16	0.18	0.10	0.33	0.43	0.36
HD60	HD60	505736	177752	0.06	0.11	0.14	0.10	0.08	0.08	0.16	0.19	0.22
HD58	HD58	508414	177125	0.45	0.50	0.51	0.24	0.31	0.17	0.70	0.81	0.68
HD57	HD57	508758	177718	0.21	0.24	0.24	0.15	0.17	0.10	0.36	0.41	0.34
HD56	HD56	509798	178634	0.09	0.12	0.11	0.08	0.09	0.06	0.18	0.21	0.17
Average				0.31	0.27	0.28	0.18	0.17	0.11	0.49	0.44	0.39

Table 3.30 Comparison of model and measured contributions to the period-mean difference in PM_{10} concentration between pairs of analysers, for selected sector ranges chosen to highlight road-network emissions

Difference selected	Sector range (deg)[a]	PM_{10} concentration contribution (µg/m³)		Disc[b] (µg/m³)	FD[c] (%)
		Modelled	Measured		
LHR2-Harlington	270-100	1.64	2.15	-0.52	-24.0
Oxford Avenue-Cranford	90-180	0.19	0.74	-0.55	-74.5
Hayes-Cranford	90-210	0.81	1.69	-0.87	-51.7

[a] Angle is the direction from which the wind blows, clockwise from north; sector ranges are inclusive
[b] Disc (absolute discrepancy)=modelled-measured
[c] Fractional Discrepancy=100*(modelled-measured)/measured

Appendix AQ.1.15

Table 3.31 Comparison of 2008/9, 2002 PSDH and 2010SM period-mean PM_{10} concentrations

Site	PSDH name	Easting	Northing	Period mean NO_x concentrations (µg/m^3)								
				Airport			Non-airport			Total		
				2008/9	2002 PSDH	2010SM	2008/9	2002 PSDH	2010SM	2008/9	2002 PSDH	2010SM
LHR2	LHR2	508399	176744	2.00	1.68	1.57	21.87	24.01	20.88	23.87	25.69	22.45
Oxford Avenue	LHR4	509550	176997	0.46	0.46	0.35	20.79	23.60	20.63	21.25	24.06	20.98
Cranford	LHR5	510370	177195	0.26	0.26	0.19	20.07	23.58	20.60	20.33	23.84	20.79
Hatton Cross	LHR7	509333	175002	0.74	0.47	0.34	20.74	23.60	20.57	21.48	24.07	20.91
Oaks Rd	LHR8	505739	174497	0.64	0.29	0.29	19.69	23.07	20.27	20.33	23.36	20.56
Colnbrook	LHR14	503535	176829	0.09	0.08	0.09	20.19	23.44	20.48	20.28	23.52	20.57
Green Gates	LHR15	505185	176922	0.28	0.19	0.29	20.30	23.36	20.46	20.58	23.55	20.75
Hillingdon	LHR16	506945	178609	0.14	0.19	0.19	23.09	25.89	22.03	23.23	26.08	22.22
Harlington	LHR18	508279	177792	0.33	0.43	0.36	20.41	23.77	20.84	20.75	24.20	21.20
HD60	HD60	505736	177752	0.16	0.19	0.22	20.22	23.56	20.65	20.38	23.75	20.87
HD58	HD58	508414	177125	0.70	0.81	0.68	20.00	23.57	20.68	20.70	24.38	21.36
HD57	HD57	508758	177718	0.36	0.41	0.34	21.04	24.00	20.94	21.40	24.41	21.28
HD56	HD56	509798	178634	0.18	0.21	0.17	20.24	24.21	21.15	20.41	24.42	21.32
Average				0.49	0.44	0.39	20.66	23.82	20.78	21.15	24.26	21.17

Table 3.32 Comparison of modelled and measured period-mean $PM_{2.5}$ concentrations[a]

Site	Modelled period-mean NO_x concentrations (µg/m^3)										Measured (µg/m^3)	FD[c]
	Airport					Off-airport				Grand total (µg/m^3)		
	Aircraft	APU	Airside vehicles	Other airport[b]	Airport sub-total	Road traffic	LAEI/NAEI	Background	Off-airport sub-total			
Oaks Road	0.17	0.06	0.25	0.05	0.53	0.62	1.04	9.63	11.29	11.83	11.58	2.2
Green Gates	0.07	0.02	0.10	0.02	0.22	1.00	1.07	9.63	11.70	11.92	10.96	8.8
H'worth	0.03	0.02	0.07	0.01	0.13	0.85	1.11	9.63	11.60	11.73	8.33	40.9
Average					0.30	0.82				11.83	10.29	17.3
SD										0.10	1.73	20.71

[a] All values shown to two decimal places to avoid the accumulation of rounding errors in forming ratios and sub-totals, but this is not indicative of the precision of either the model or measured values
[b] Includes car parks and stationary sources
[c] Fractional Discrepancy=100*(model-measured)/measured

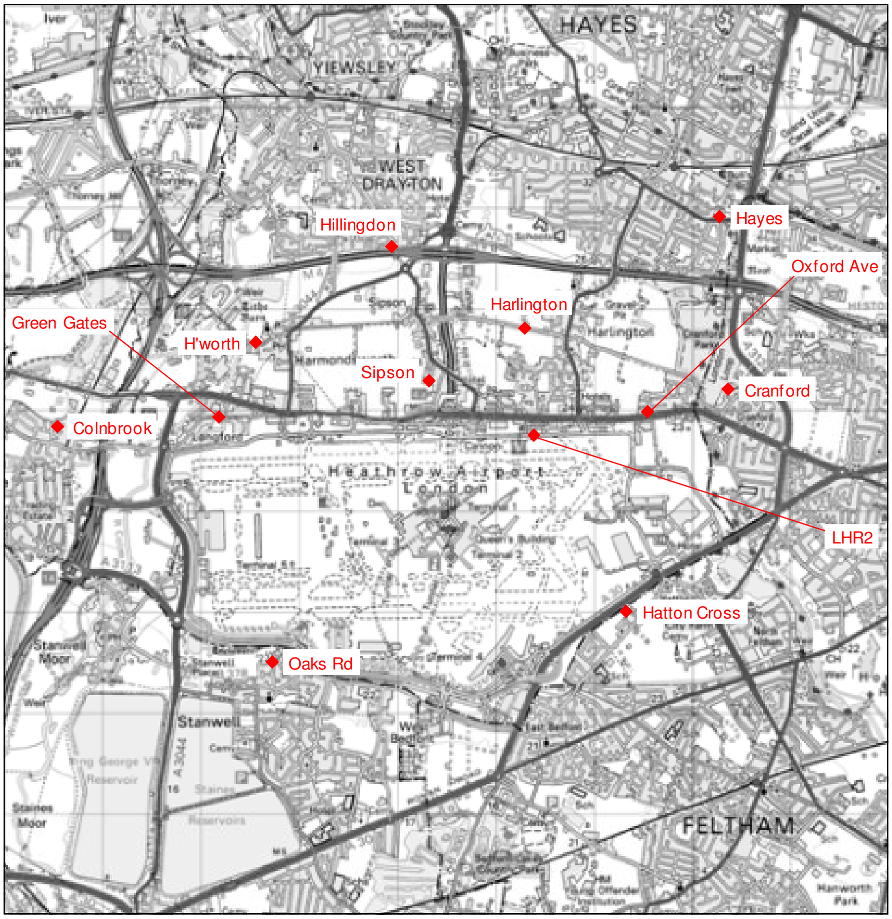

Fig 2.1 Location of monitoring sites used in the study

Appendix AQ.1.15

Fig 2.2 (a) LHR2 (Extent of picture: 170 m × 110 m approx.)

Fig 2.2 (b) Oaks Road (Extent of picture: 170 m × 110 m approx.)

Appendix AQ.1.15

Fig 2.2 (c) Green Gates (Extent of picture: 340 m × 220 m approx.)

Fig 2.2 (d) Colnbrook (Extent of picture: 340 m × 220 m approx.)

Appendix AQ.1.15

Fig 2.2 (e) Harmondsworth (Extent of picture: 170 m × 110 m approx.)

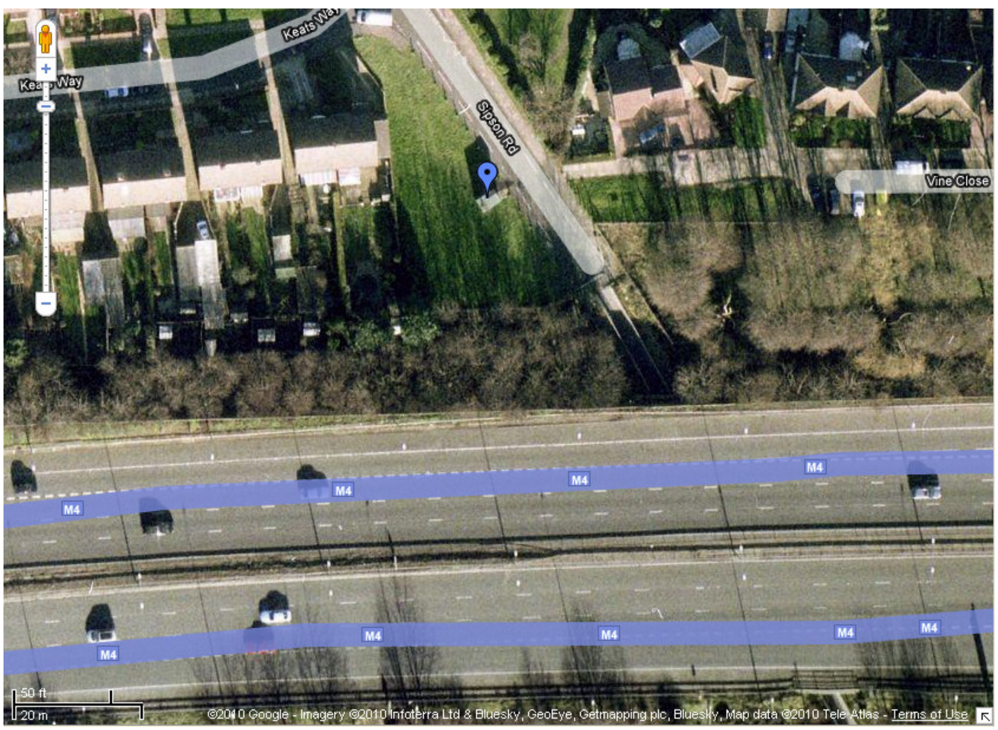

Fig 2.2 (f) Hillingdon (Extent of picture: 170 m × 110 m approx.)

Appendix AQ.1.15

Fig 2.2 (g) Sipson (Extent of picture: 170 m × 110 m approx.)

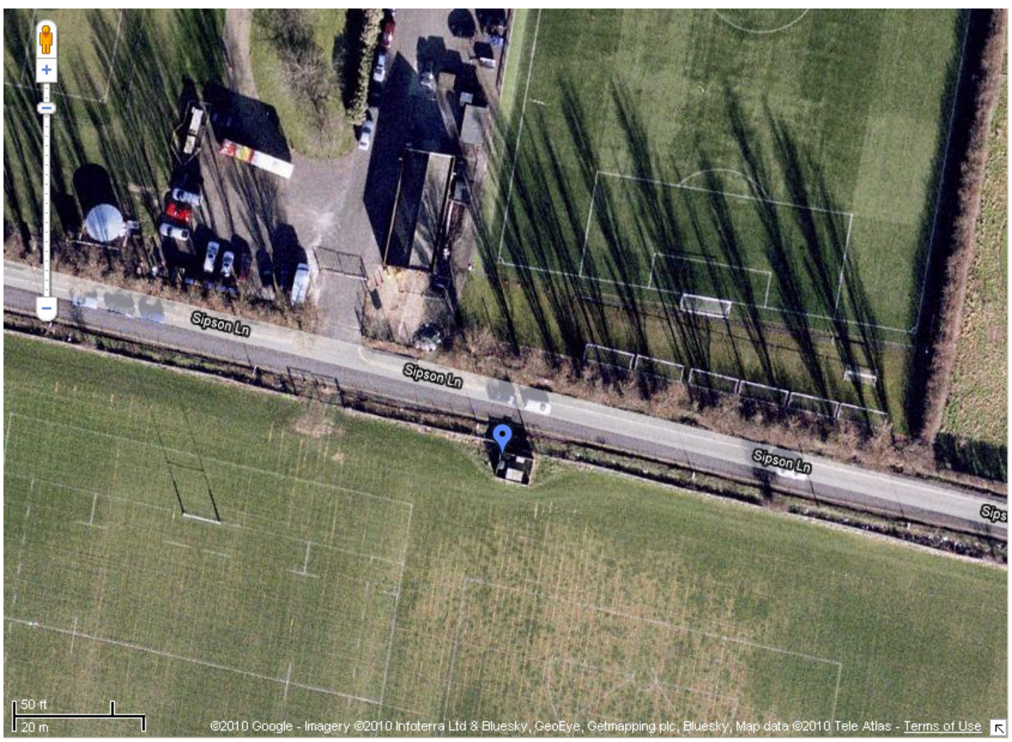

Fig 2.2 (h) Harlington (Extent of picture: 170 m × 110 m approx.)

Appendix AQ.1.15

Fig 2.2 (i) Oxford Avenue (Extent of picture: 170 m × 110 m approx.)

Fig 2.2 (j) Hayes (Extent of picture: 170 m × 110 m approx.)

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Fig 2.2 (k) Cranford (Extent of picture: 340 m × 220 m approx.)

Fig 2.2 (l) Hatton Cross (Extent of picture: 340 m × 220 m approx.)

Appendix AQ.1.15

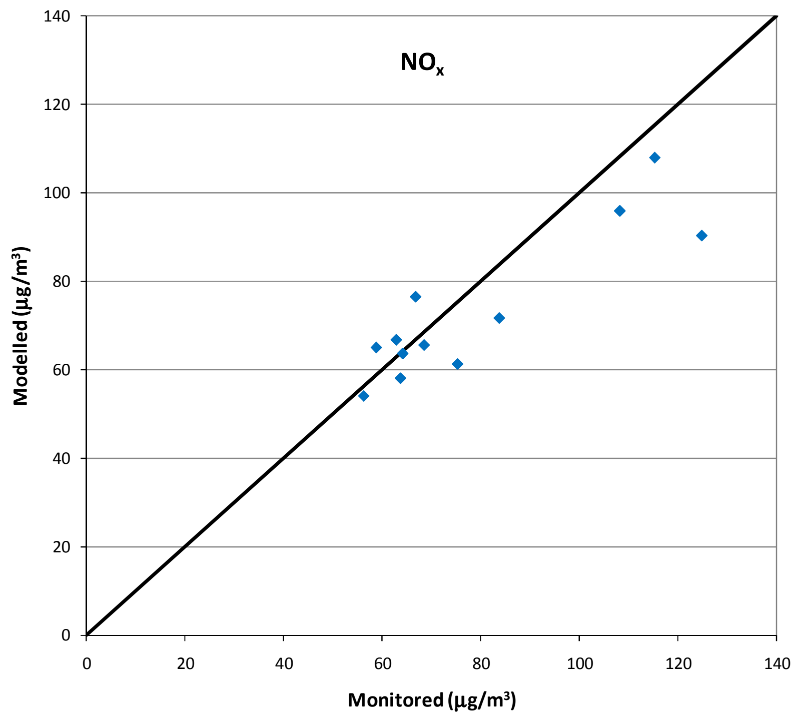


Fig 3.1 Scatter plot of modelled versus measured period-mean concentration (also shows the 1:1 line)

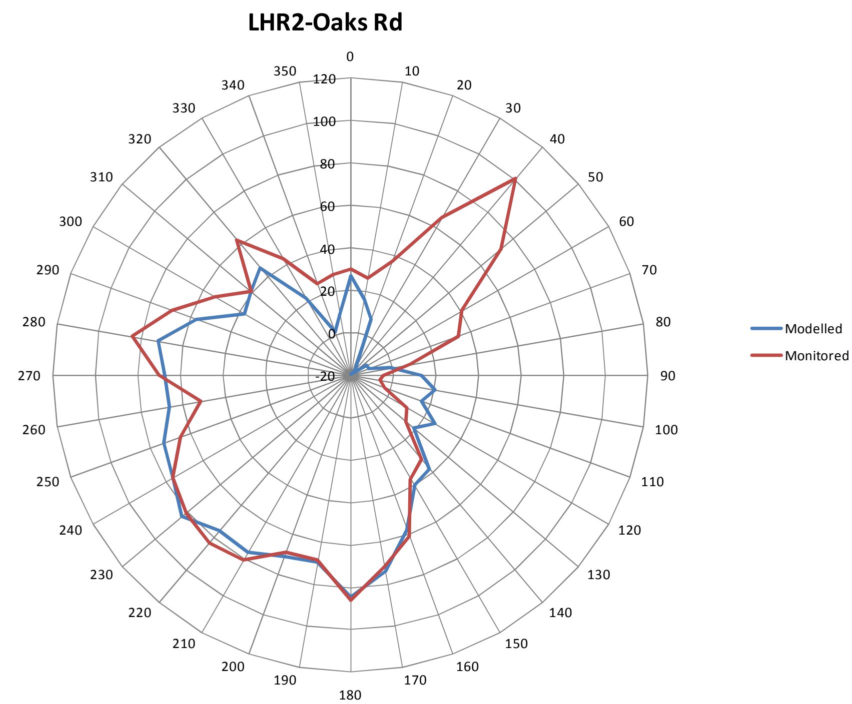


Fig 3.2 The average difference in NO_x concentration ($\mu g/m^3$) between LHR2 and Oaks Rd as a function of wind direction

Appendix AQ.1.15

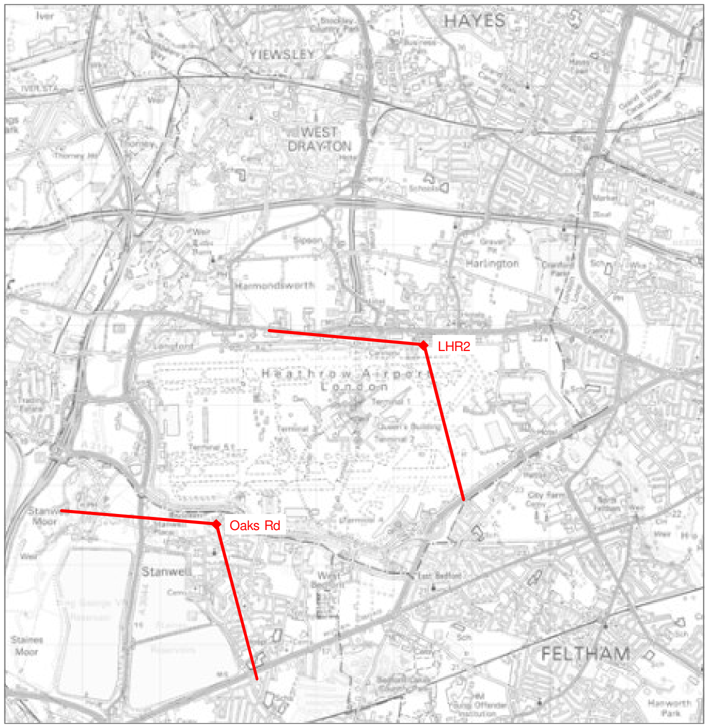


Fig 3.3 Shows the 170° to 270° sector range as seen from LHR2 and Oaks Rd (NB: each sector is assumed to spans a ±5° about its mid-line)

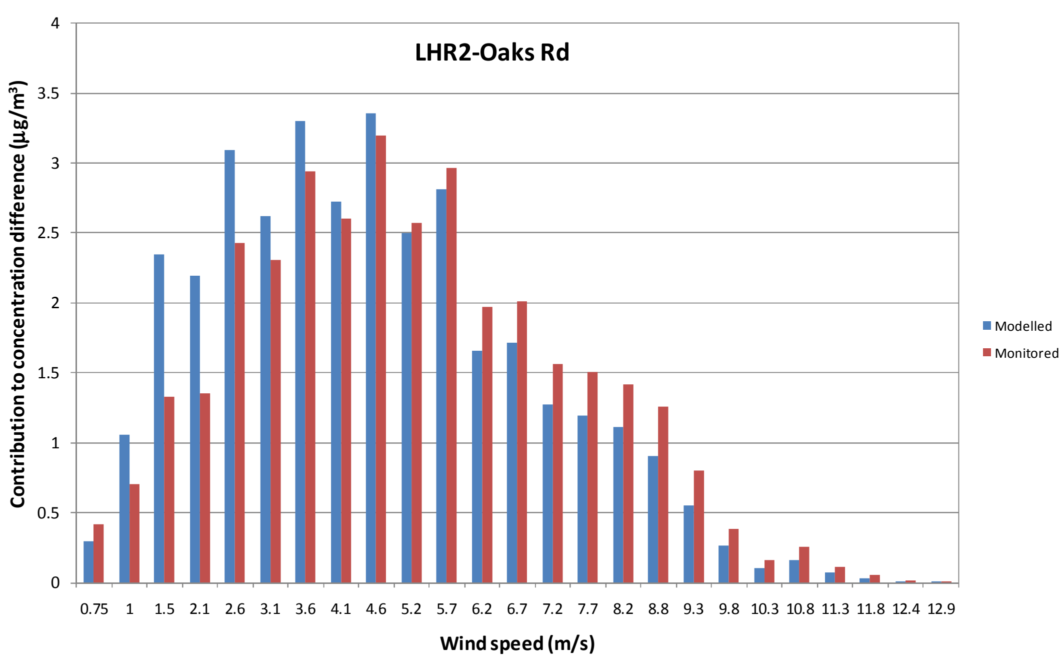


Fig 3.4 LHR2-Oaks Rd concentration difference contribution from wind sectors 170° to 270° inclusive as a function of wind speed

Appendix AQ.1.15

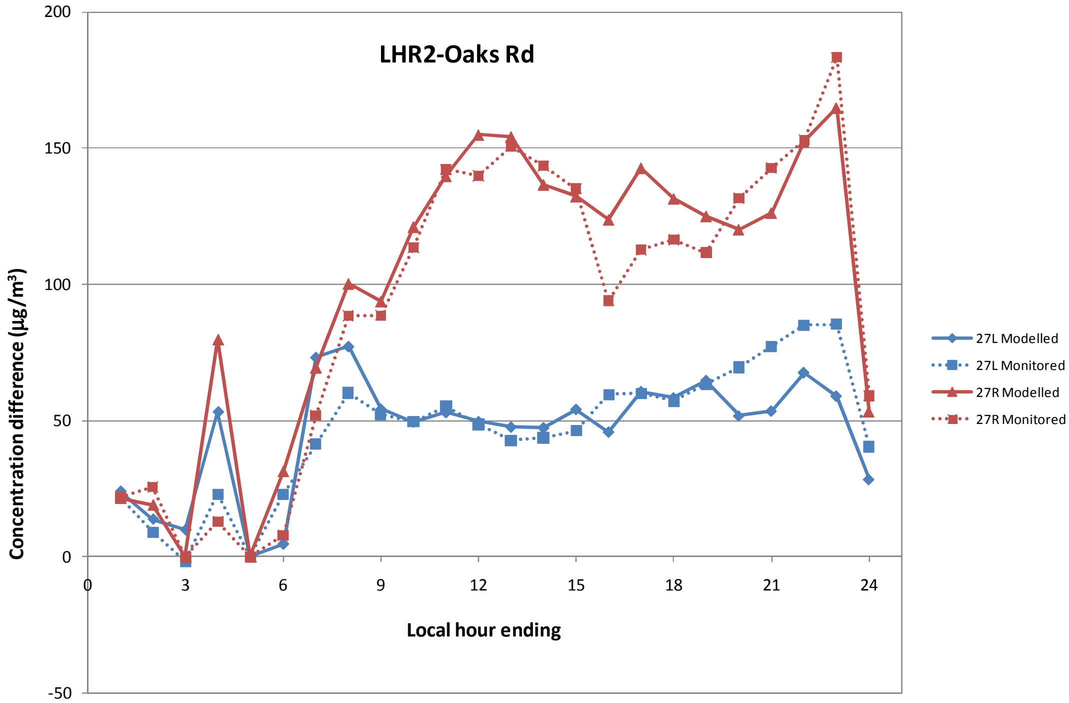
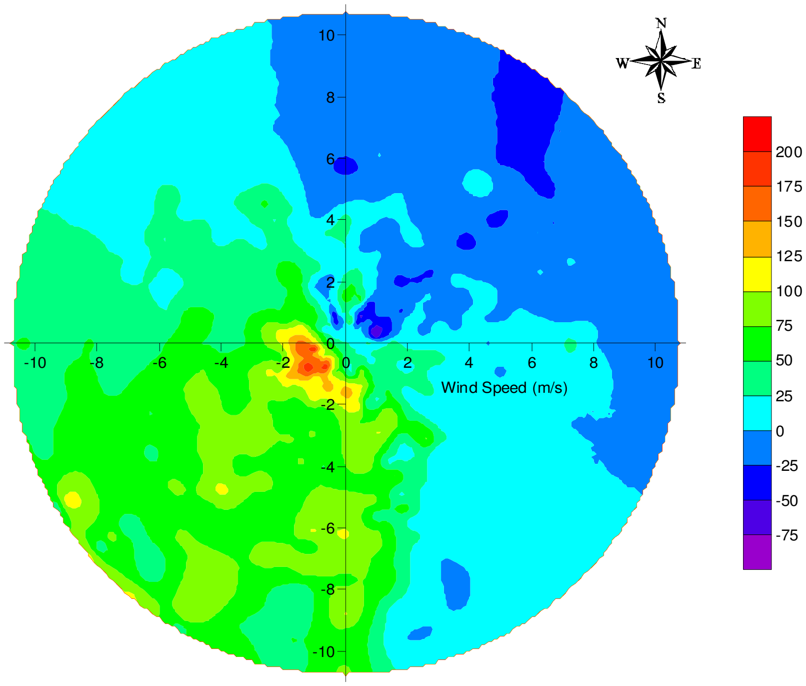
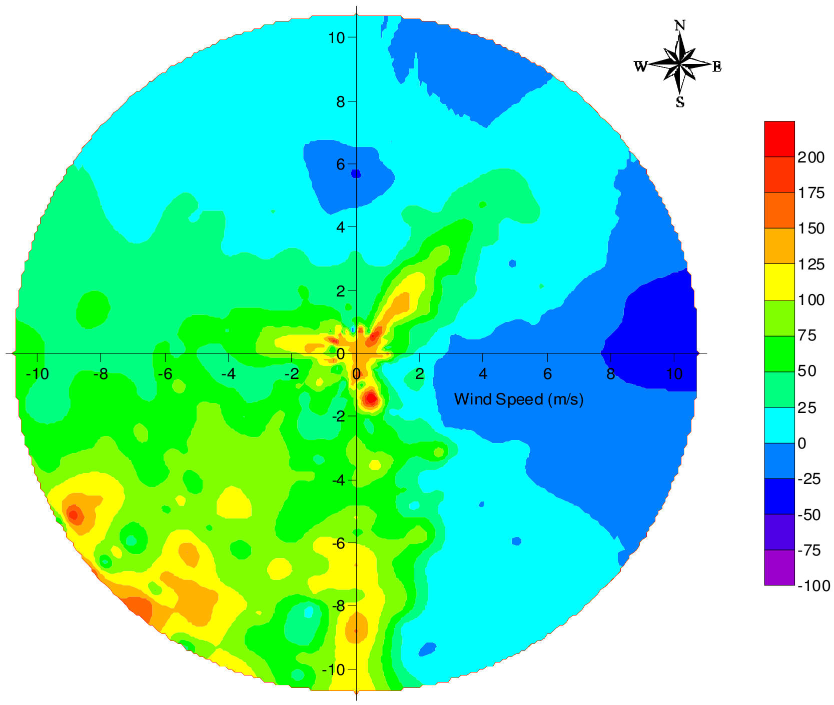


Fig 3.5 LHR2-Oaks Rd NO_x concentration difference by departure runway and hour of day

Appendix AQ.1.15



(a) modelling



(b) monitoring

Fig 3.6 Bi-polar plots for LHR2-Oaks Rd

Appendix AQ.1.15

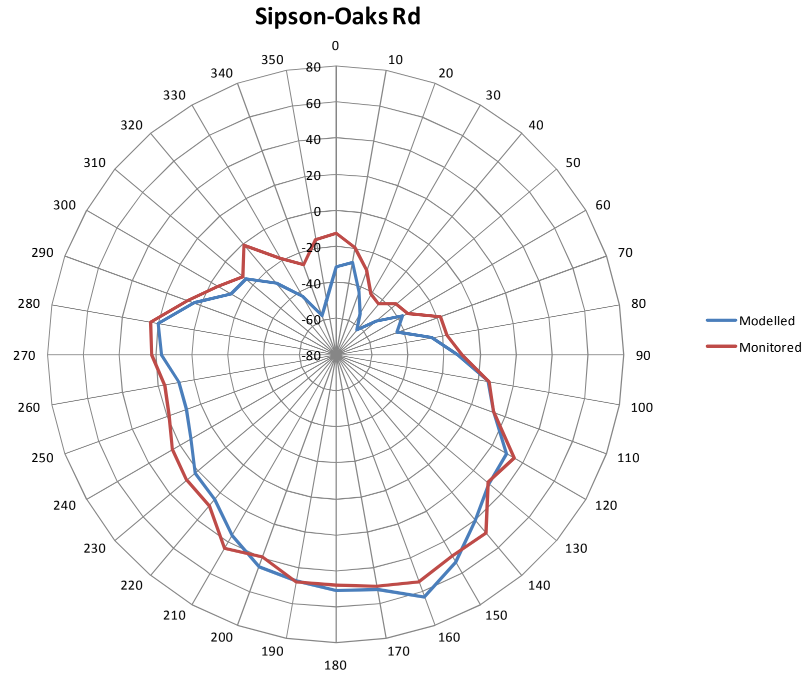


Fig 3.7 The average difference in NO_x concentration (µg/m^3) between Sipson and Oaks Rd as a function of wind direction

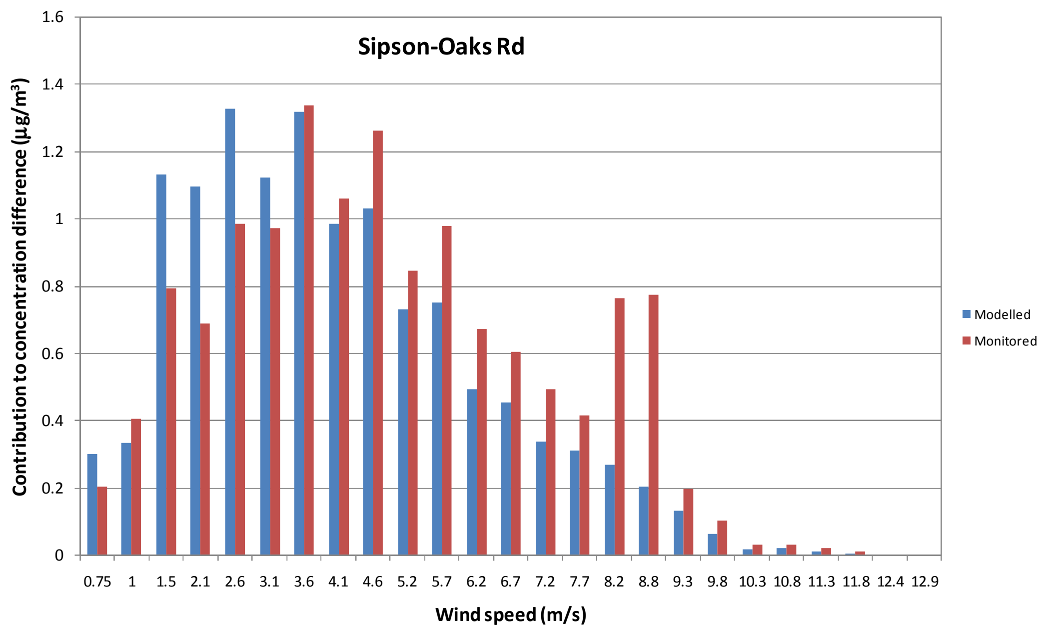
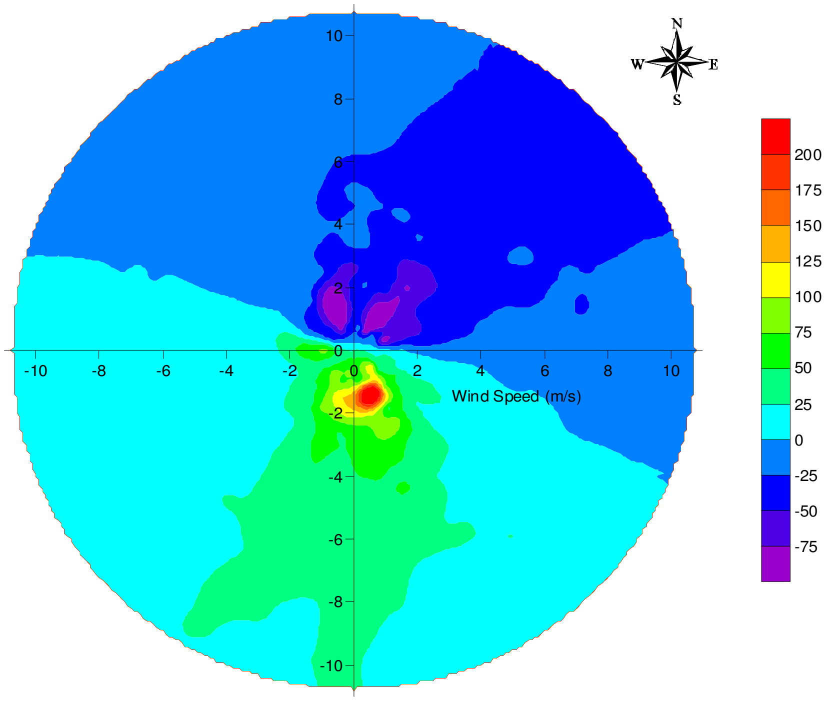
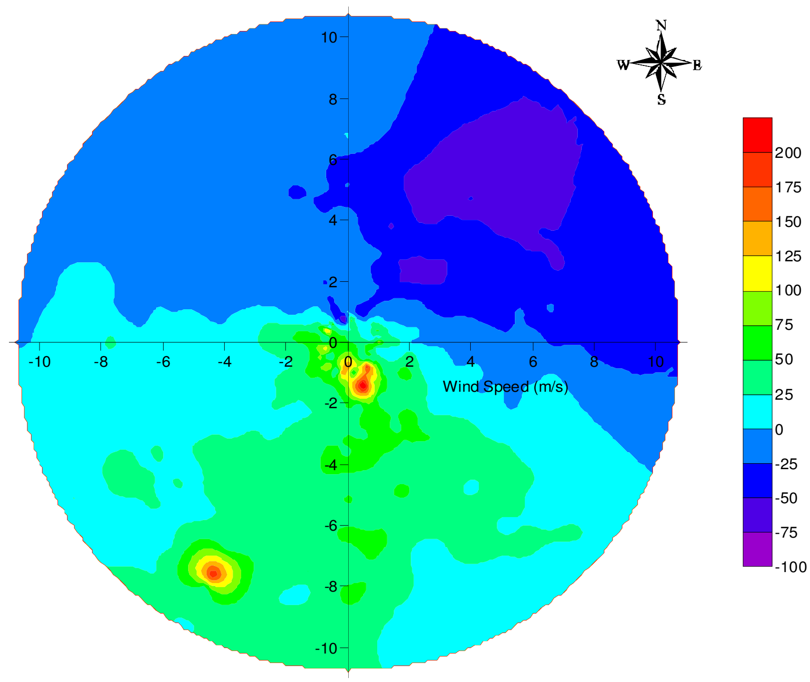


Fig 3.8 Sipson-Oaks Rd concentration difference contribution from wind sectors 120° to 240° inclusive as a function of wind speed



(a) modelling



(b) monitoring

Fig 3.9 Bi-polar plots for Sipson-Oaks Rd

Appendix AQ.1.15

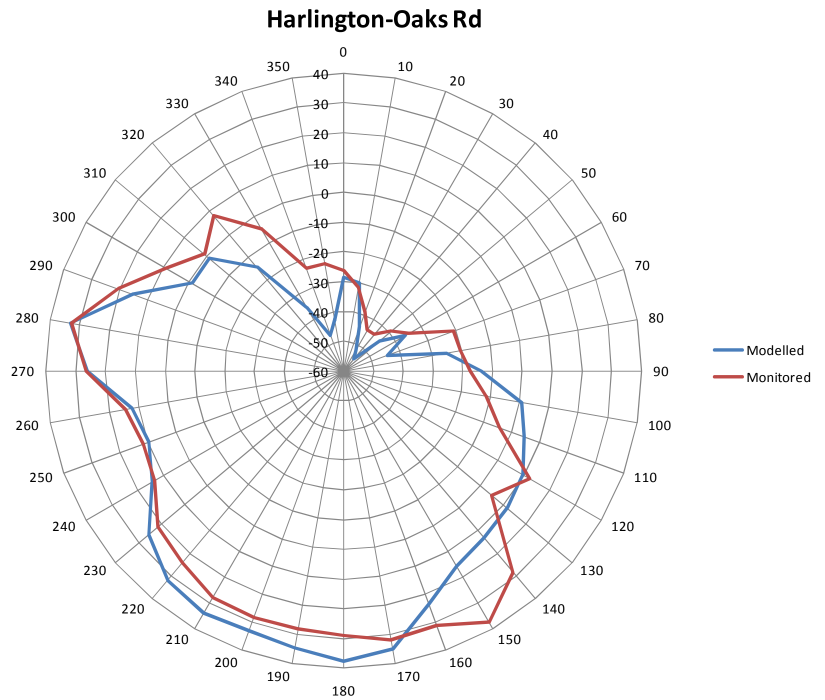


Fig 3.10 The average difference in NO_x concentration (µg/m^3) between Harlington and Oaks Rd as a function of wind direction

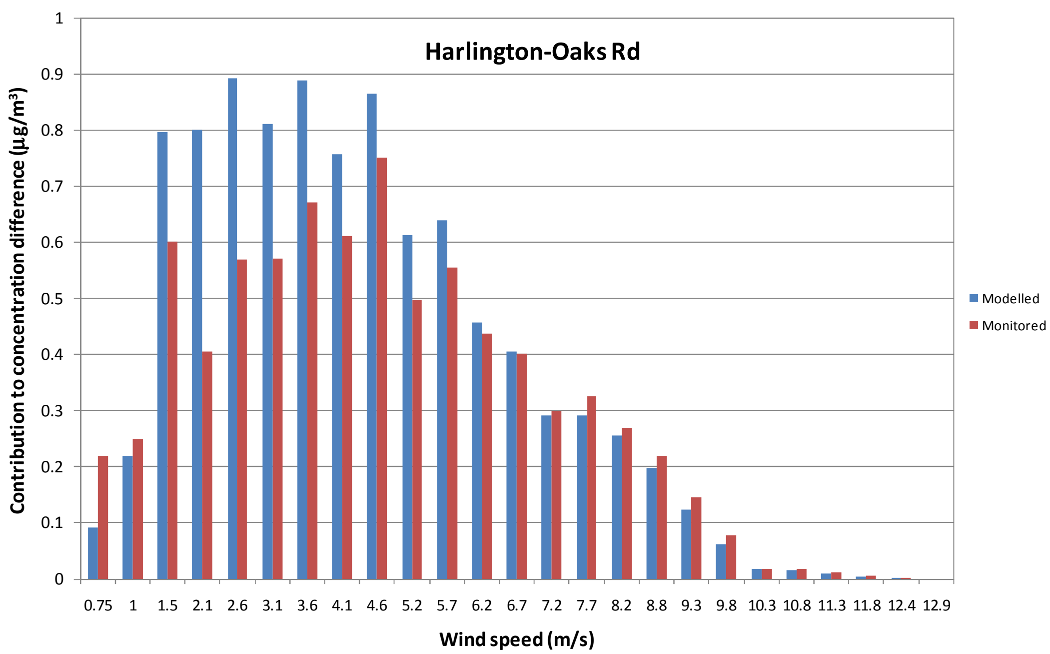


Fig 3.11 Harlington-Oaks Rd concentration difference contribution from wind sectors 160° to 240° inclusive as a function of wind speed

Appendix AQ.1.15

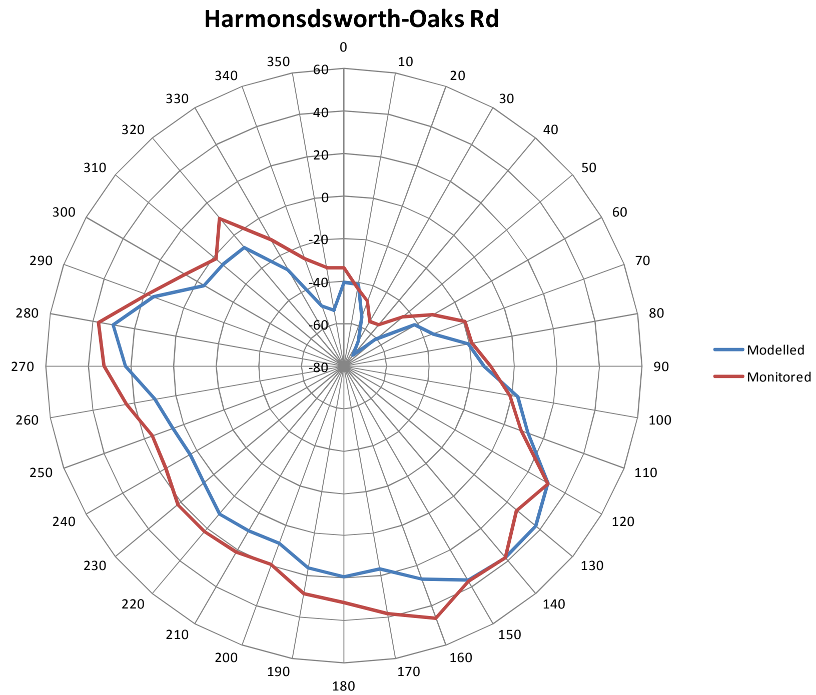


Fig 3.12 The average difference in NO_x concentration (µg/m^3) between Harmondsworth and Oaks Rd as a function of wind direction

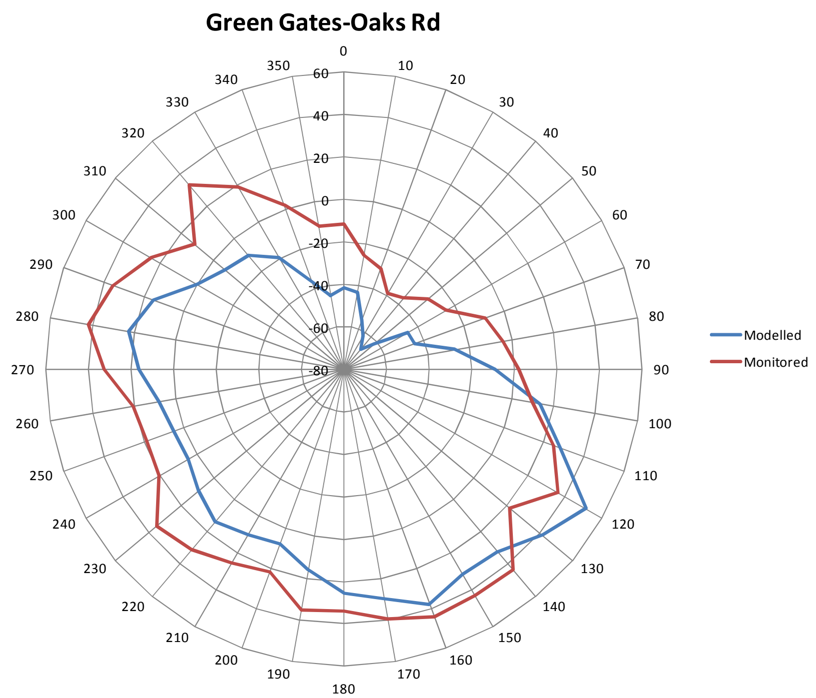


Fig 3.13 The average difference in NO_x concentration (µg/m^3) between Green Gates and Oaks Rd as a function of wind direction

Appendix AQ.1.15

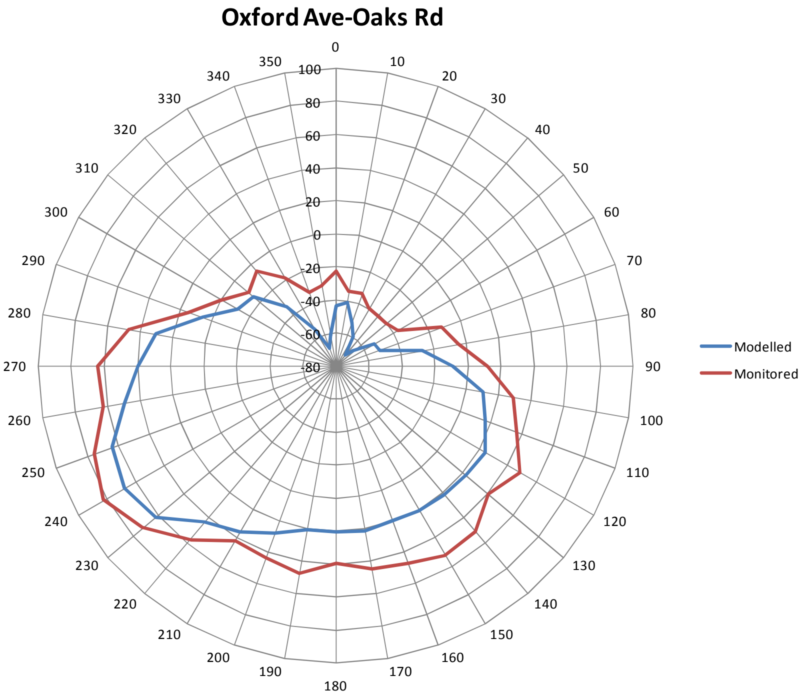


Fig 3.14 The average difference in NO_x concentration (µg/m^3) between Oxford Avenue and Oaks Rd as a function of wind direction

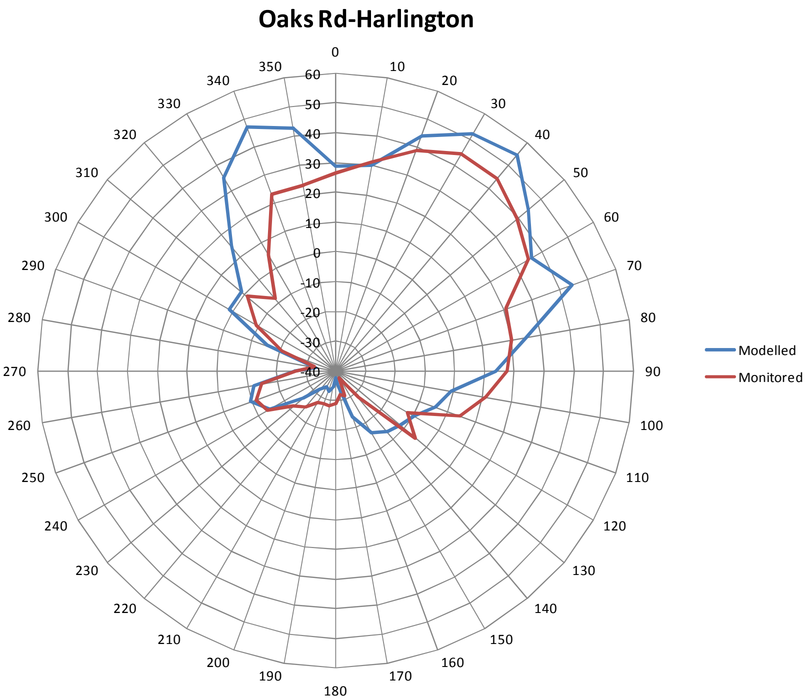


Fig 3.15 The average difference in NO_x concentration (µg/m^3) between Oaks Rd and Harlington as a function of wind direction

Appendix AQ.1.15

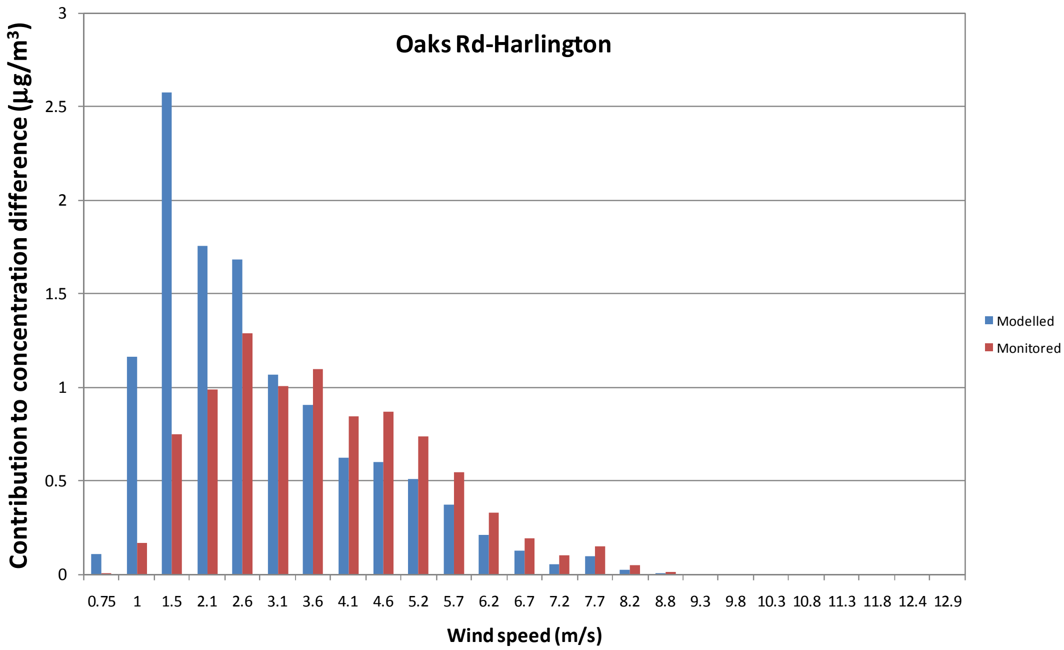


Fig 3.16 Oaks Rd-Harlington concentration difference contribution from wind sectors 330° to 90° inclusive as a function of wind speed

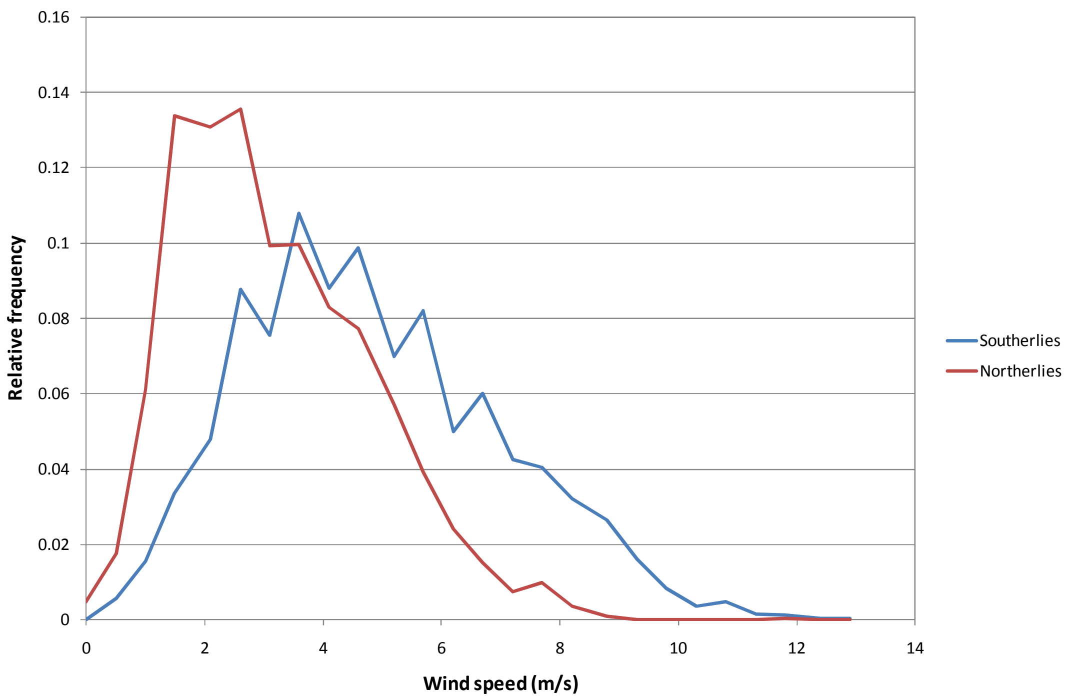


Fig 3.17 Wind speed frequency distribution shown separately for southerly (170°-270°) and northerly (330°-90°) sectors

Appendix AQ.1.15

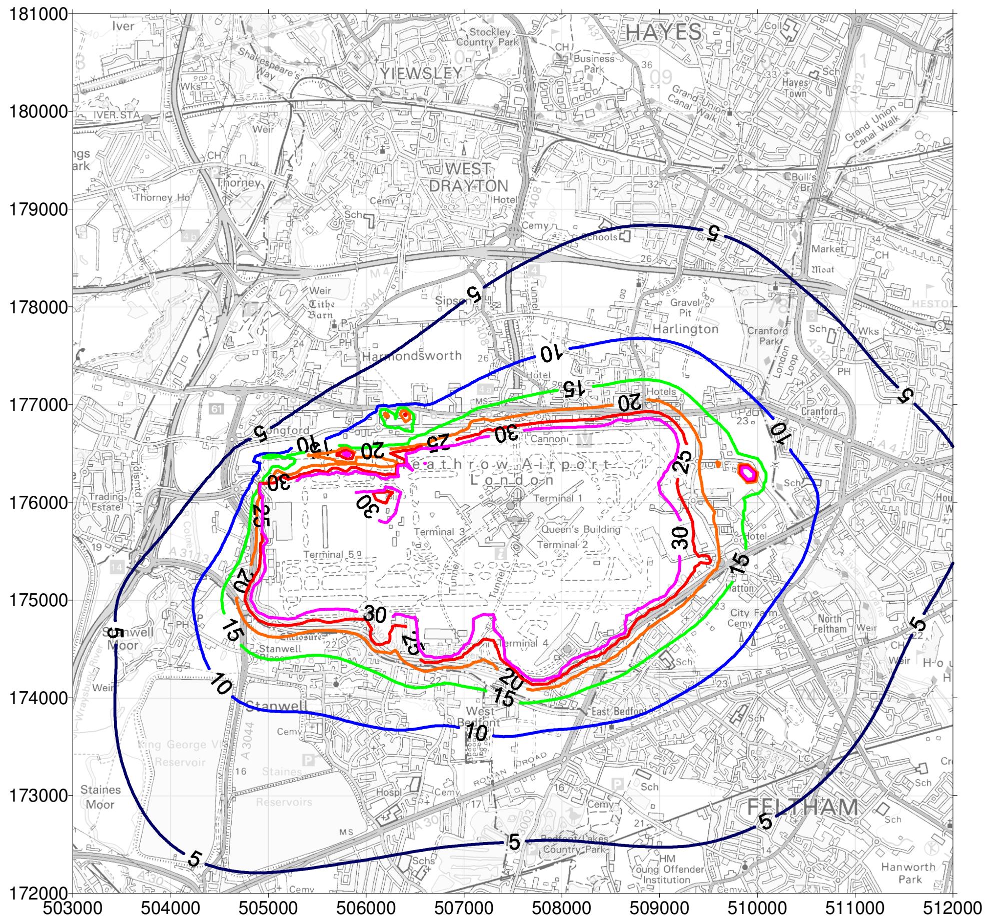


Fig 3.18 Airport contribution to 2008/9 period-mean NO_x concentrations: contours shown for 5 μg/m^3 to 30 μg/m^3

Appendix AQ.1.15

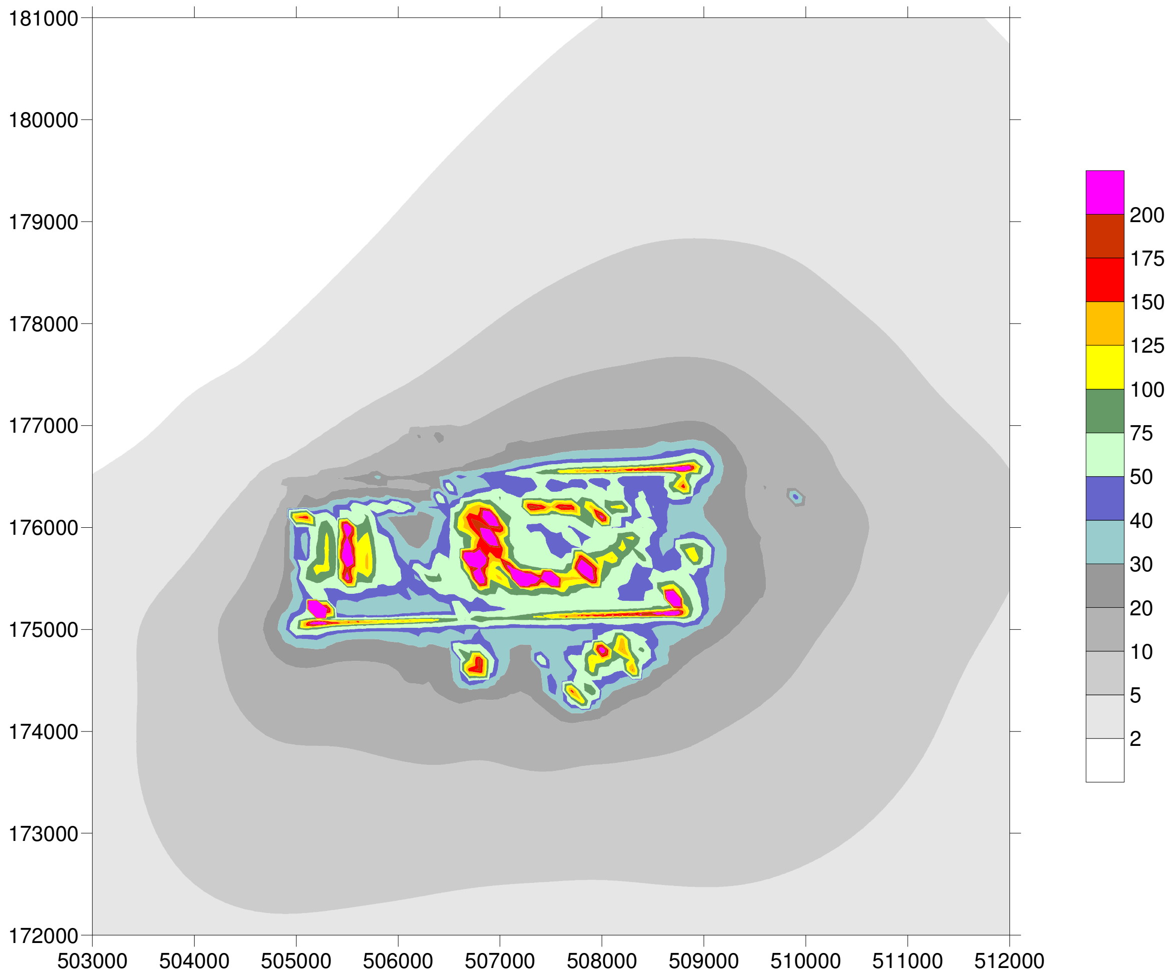


Fig 3.19 Airport contribution to 2008/9 period-mean NO_x concentrations, with PSDH colour coding

Appendix AQ.1.15

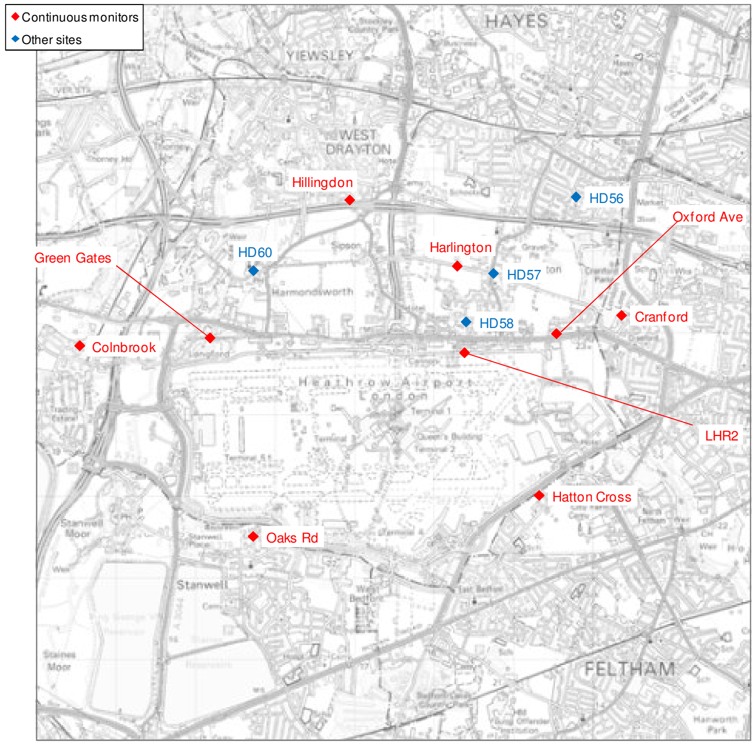


Fig 3.20 Set of receptor points used for comparisons with PSDH results

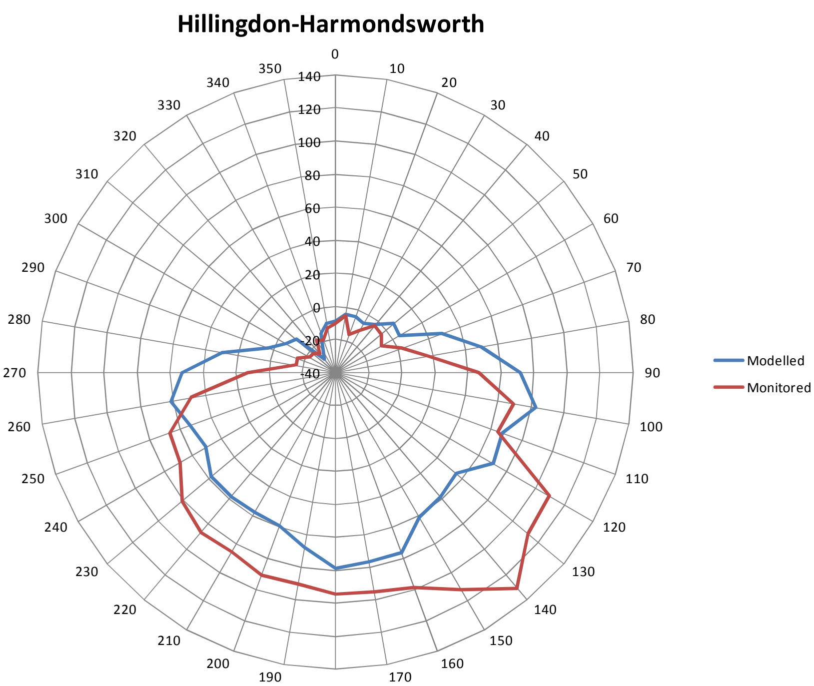


Fig 3.21 The average difference in NO_x concentration (µg/m^3) between Hillingdon and Harmondsworth as a function of wind direction

Appendix AQ.1.15

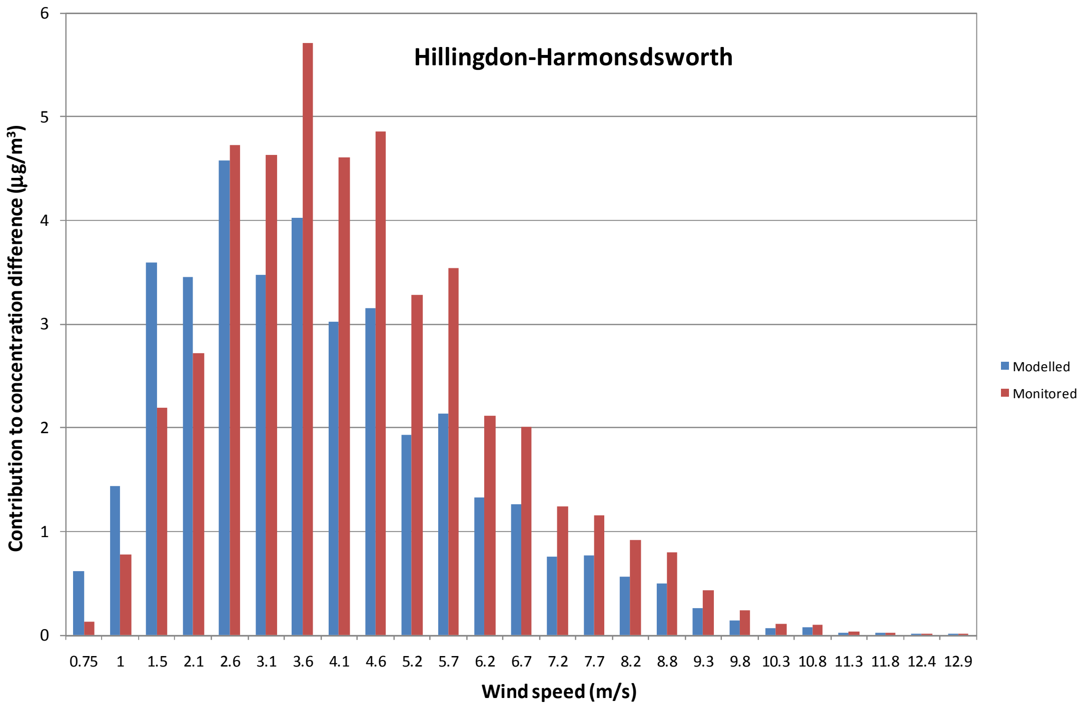


Fig 3.22 Hillingdon-Harmondsworth concentration difference contribution from wind sectors 100° to 270° inclusive as a function of wind speed

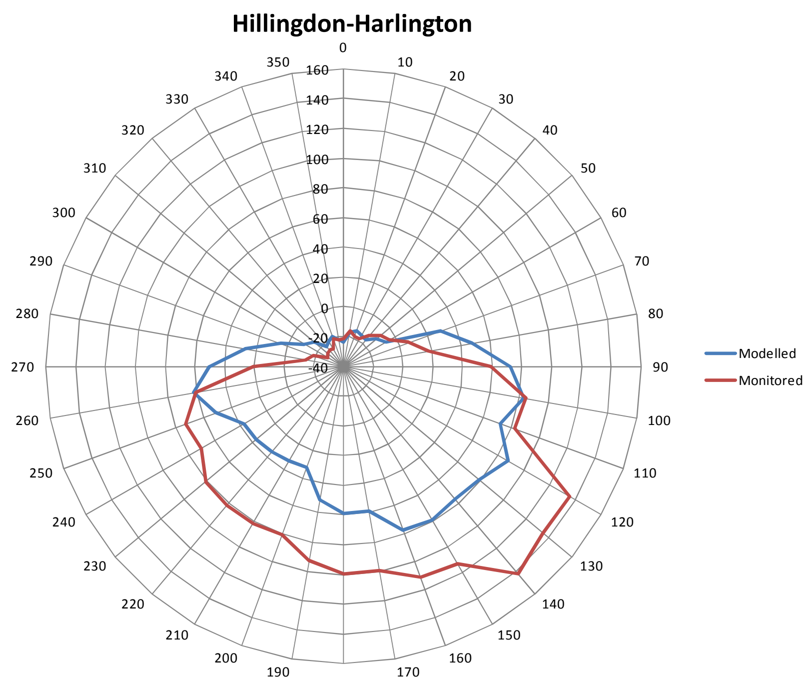


Fig 3.23 The average difference in NO_x concentration ($\mu g/m^3$) between Hillingdon and Harlington as a function of wind direction

Appendix AQ.1.15

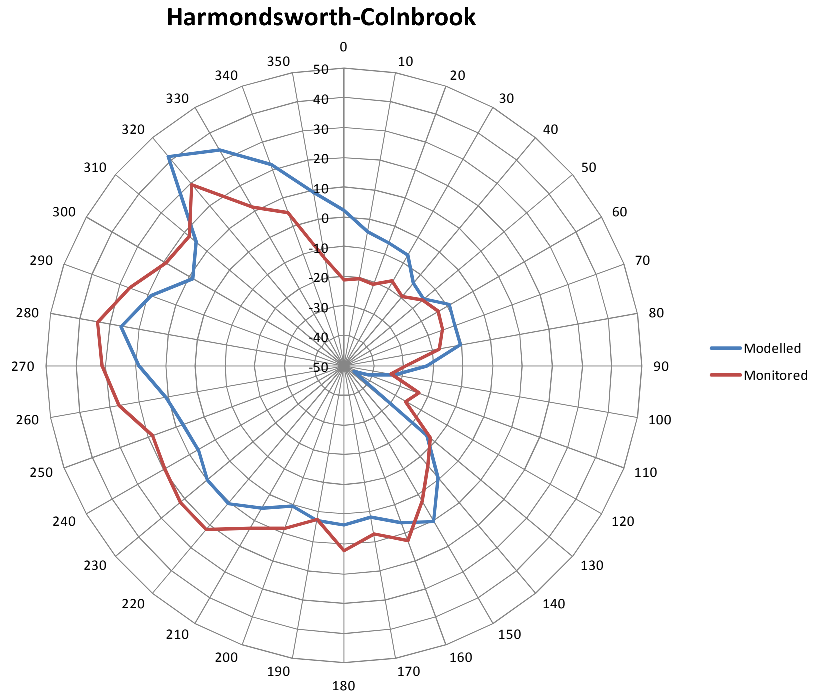


Fig 3.24 The average difference in NO_x concentration (μg/m^3) between Harmondsworth and Colnbrook as a function of wind direction

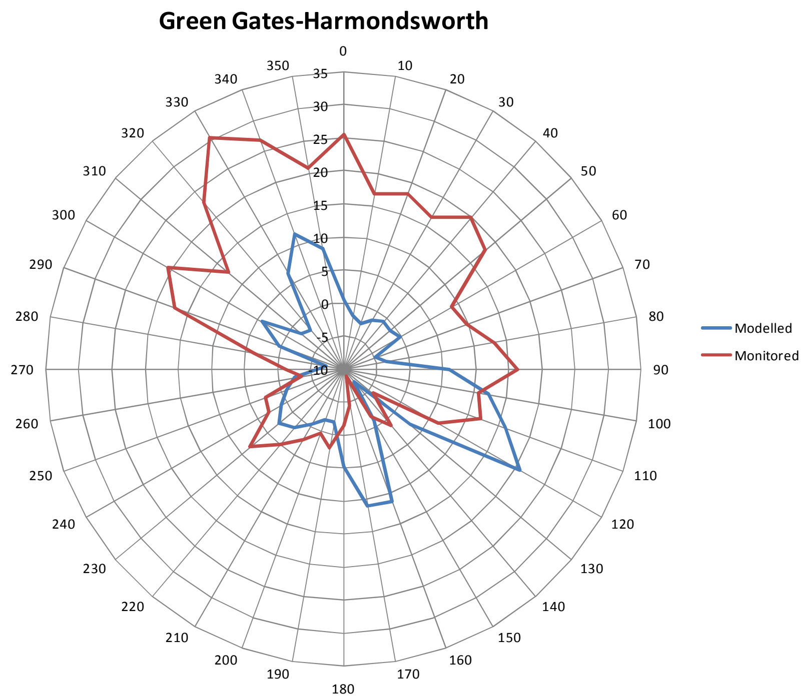


Fig 3.25 The average difference in NO_x concentration (μg/m^3) between Green Gates and Harmondsworth as a function of wind direction

Appendix AQ.1.15

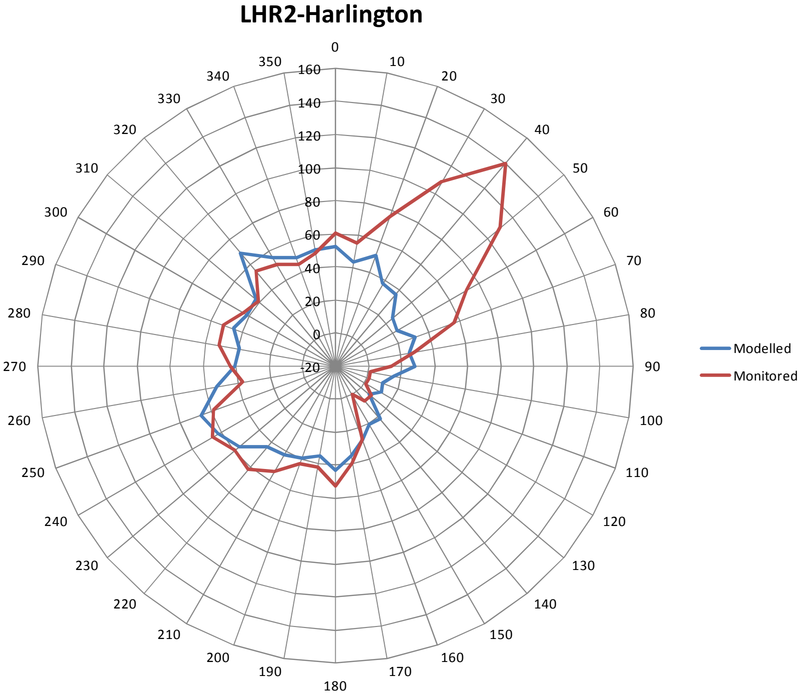


Fig 3.26 The average difference in NO_x concentration (µg/m^3) between Green Gates and Harmondsworth as a function of wind direction

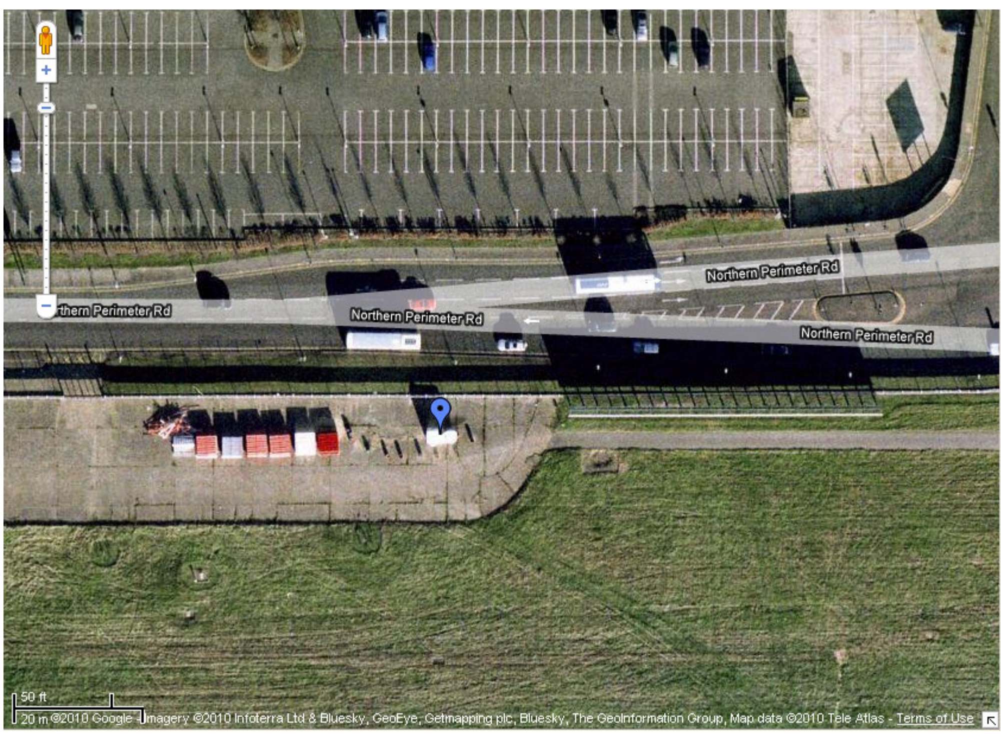


Fig 3.27 Google satellite image showing LHR2 in relation to junction of Northern Perimeter Rd with Neptune Rd . (Extent of picture: 170 m × 110 m approximately)

Appendix AQ.1.15

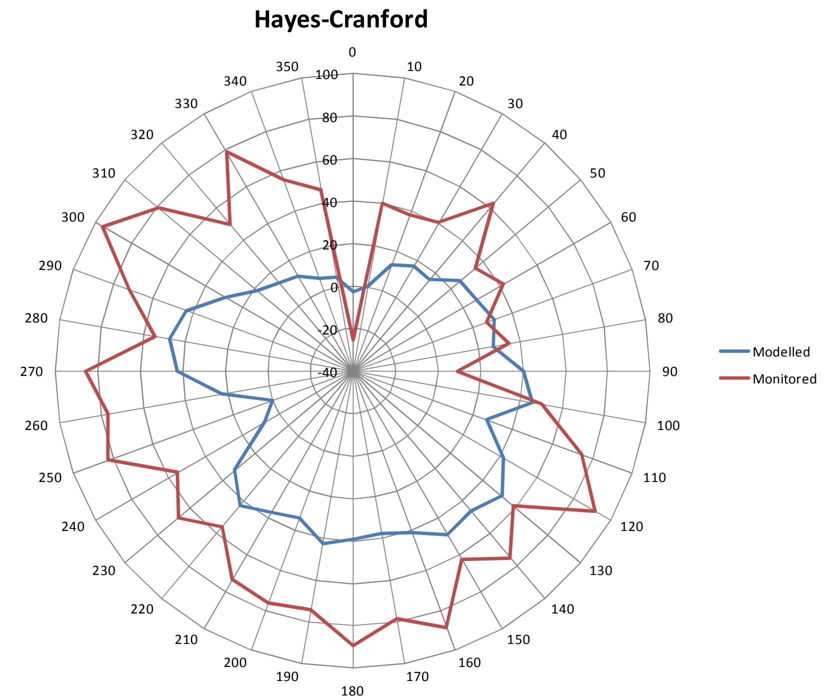


Fig 3.28 The average difference in NO_x concentration (µg/m^3) between Hayes and Cranford as a function of wind direction

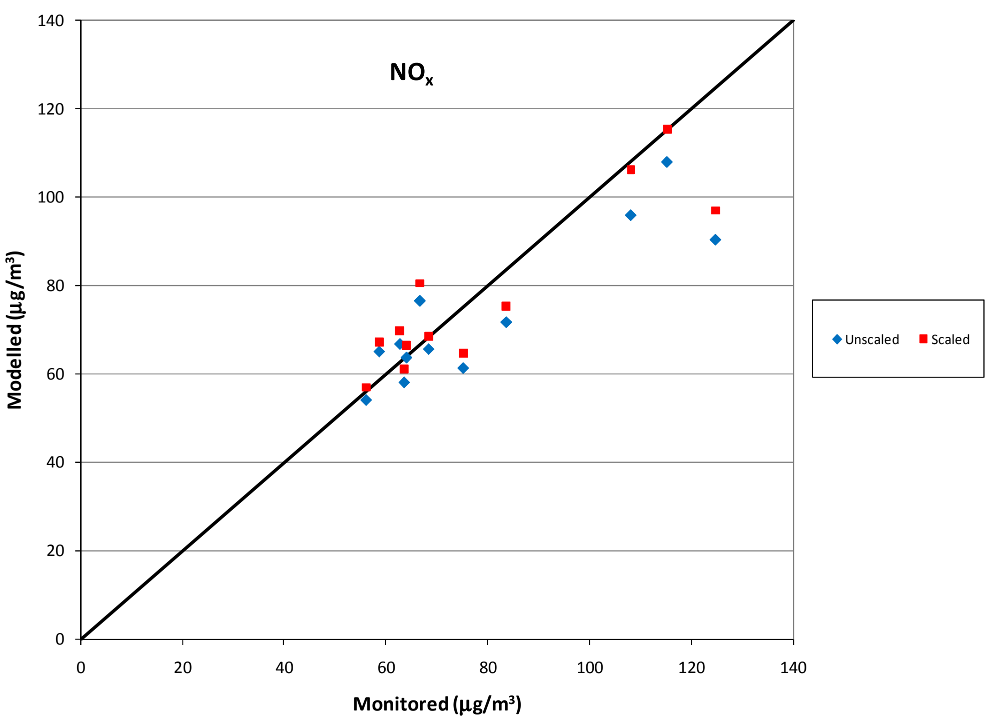


Fig 3.,29 Effect on NO_x scatter plot of including the road network scaling factor

Appendix AQ.1.15

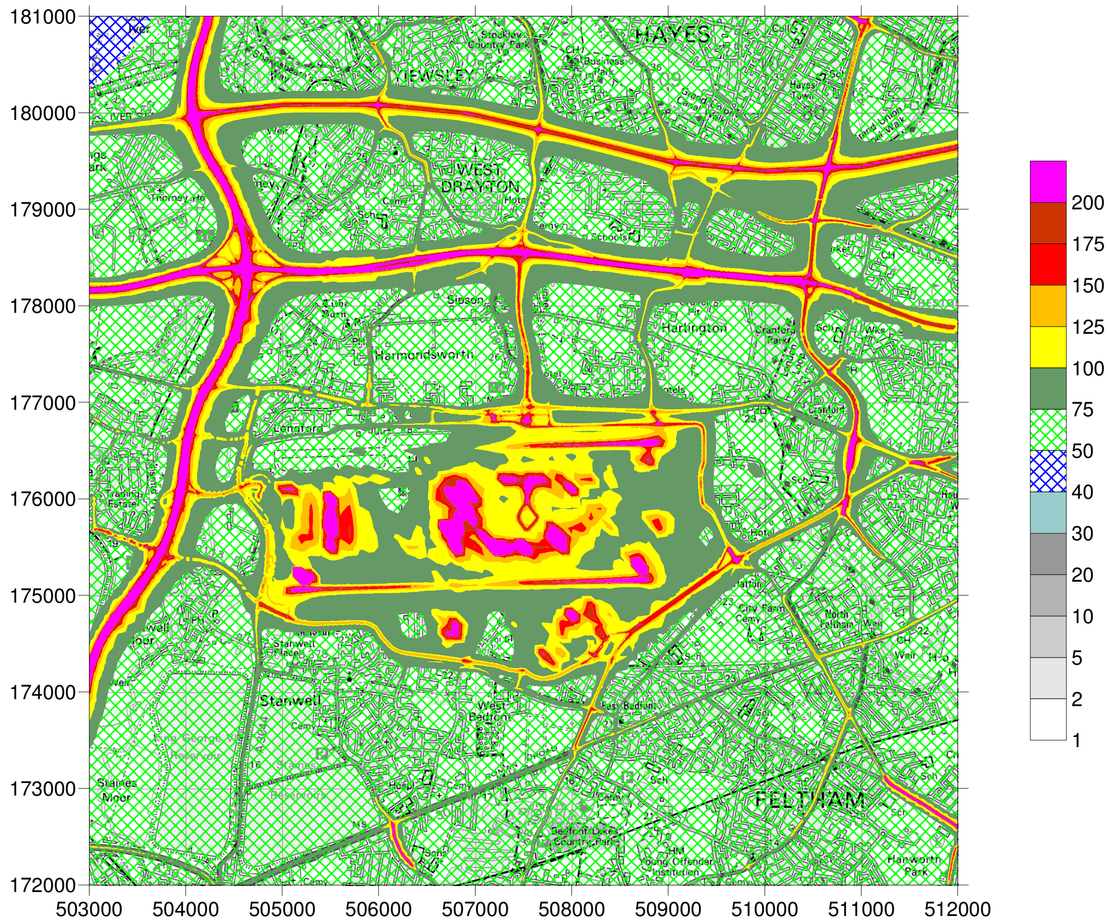


Table 3.30 Modelled total period-mean NO_x concentration ($\mu g/m^3$) in 2008/9 (with scaled road network contribution)

Appendix AQ.1.15

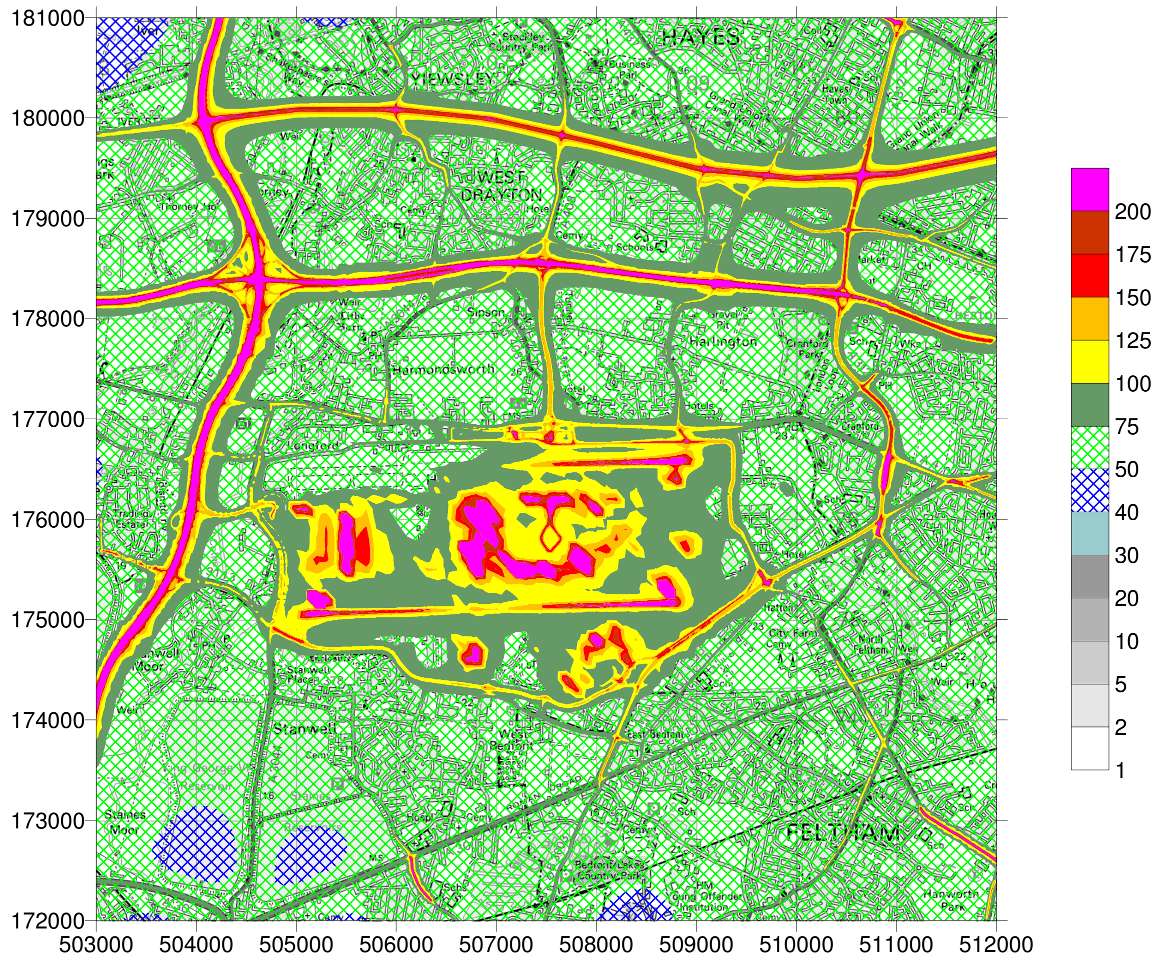


Table 3.31 Modelled total period-mean NO_x concentration ($\mu g/m^3$) in 2008/9 (with non-scaled road network contribution)

Appendix AQ.1.15

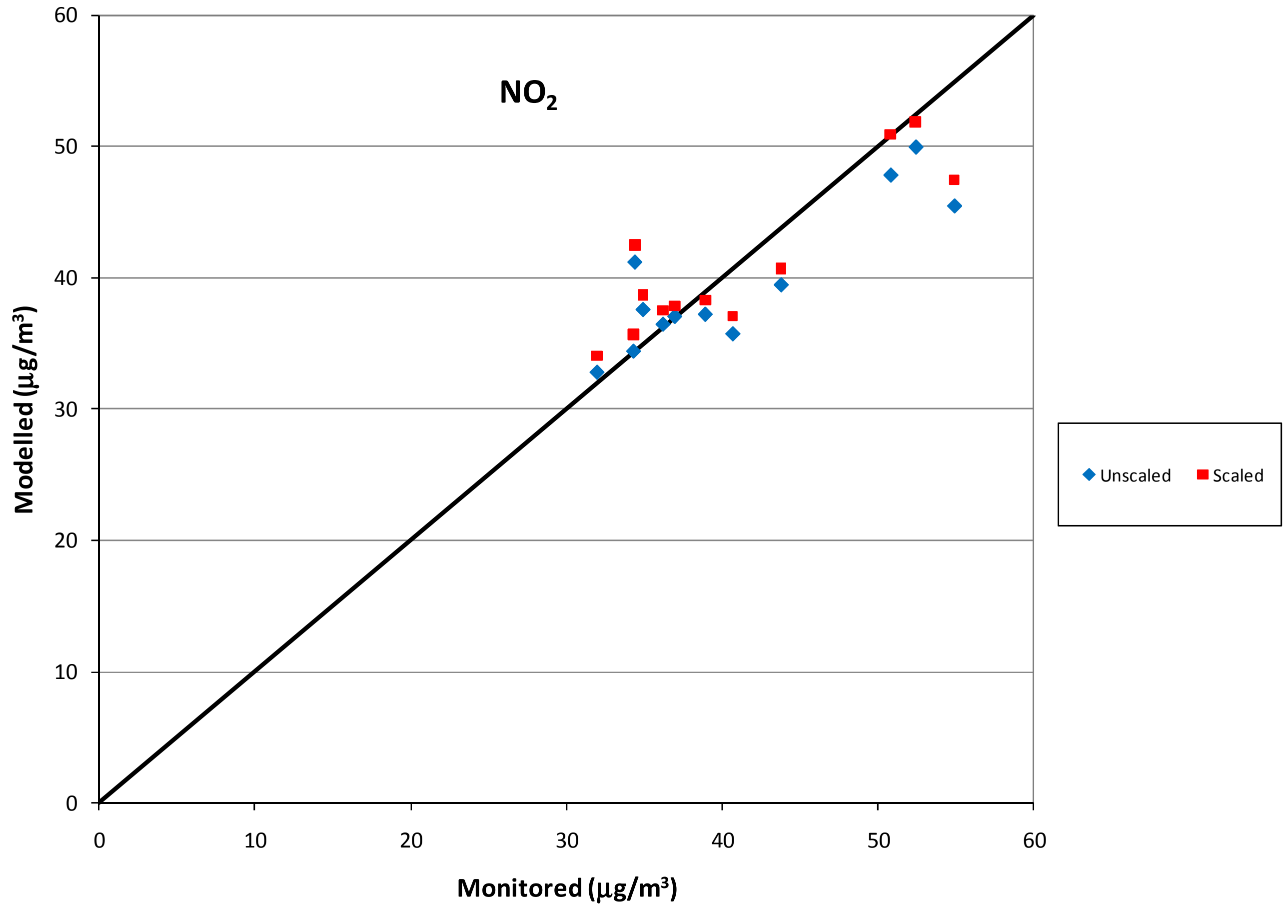


Fig 3.32 Scatter plot of modelled and measured period-mean NO_2 concentrations, before and after applying road-network NO_x scaling factor

Appendix AQ.1.15

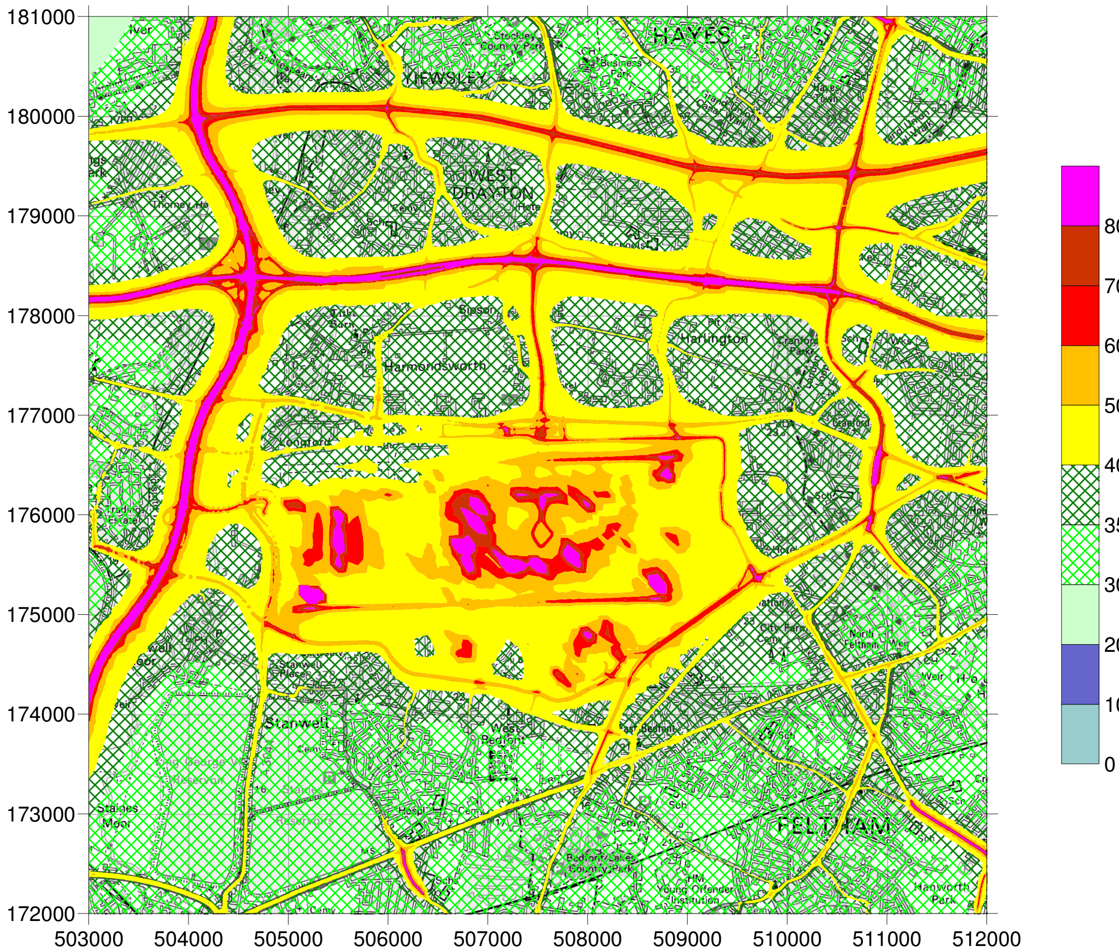


Table 3.33 Modelled total period-mean NO_2 concentration (μg/m^3) in 2008/9 (using scaled road-network NO_x contribution)

Appendix AQ.1.15

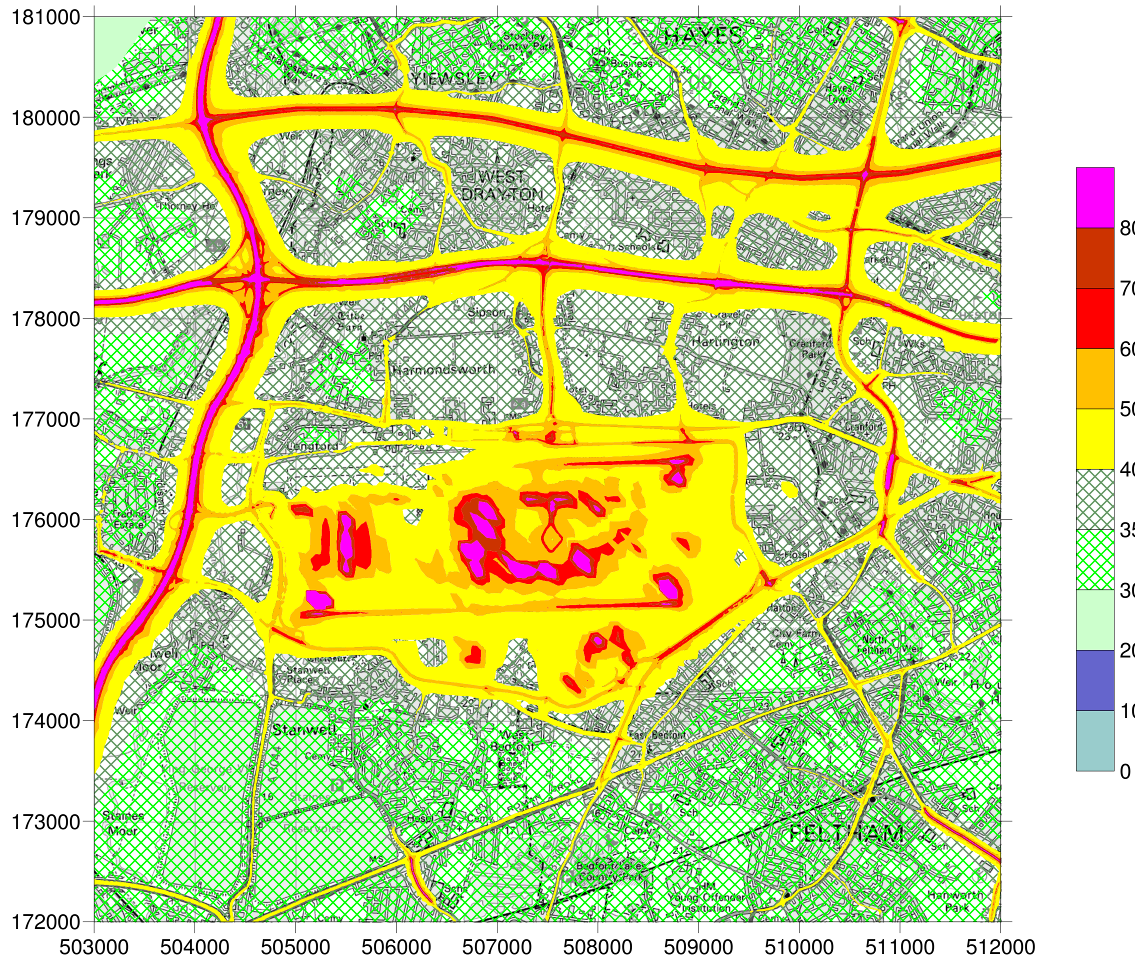


Table 3.34 Modelled total period-mean NO_2 concentration ($\mu g/m^3$) in 2008/9 (using non-scaled road-network NO_x contribution)

Appendix AQ.1.15

Fig 3.35 Modelled period-mean NO_2 concentrations: orange 36-40 µg/m^3; red 40-44 µg/m^3; purple >44 µg/m^3

Appendix AQ.1.15

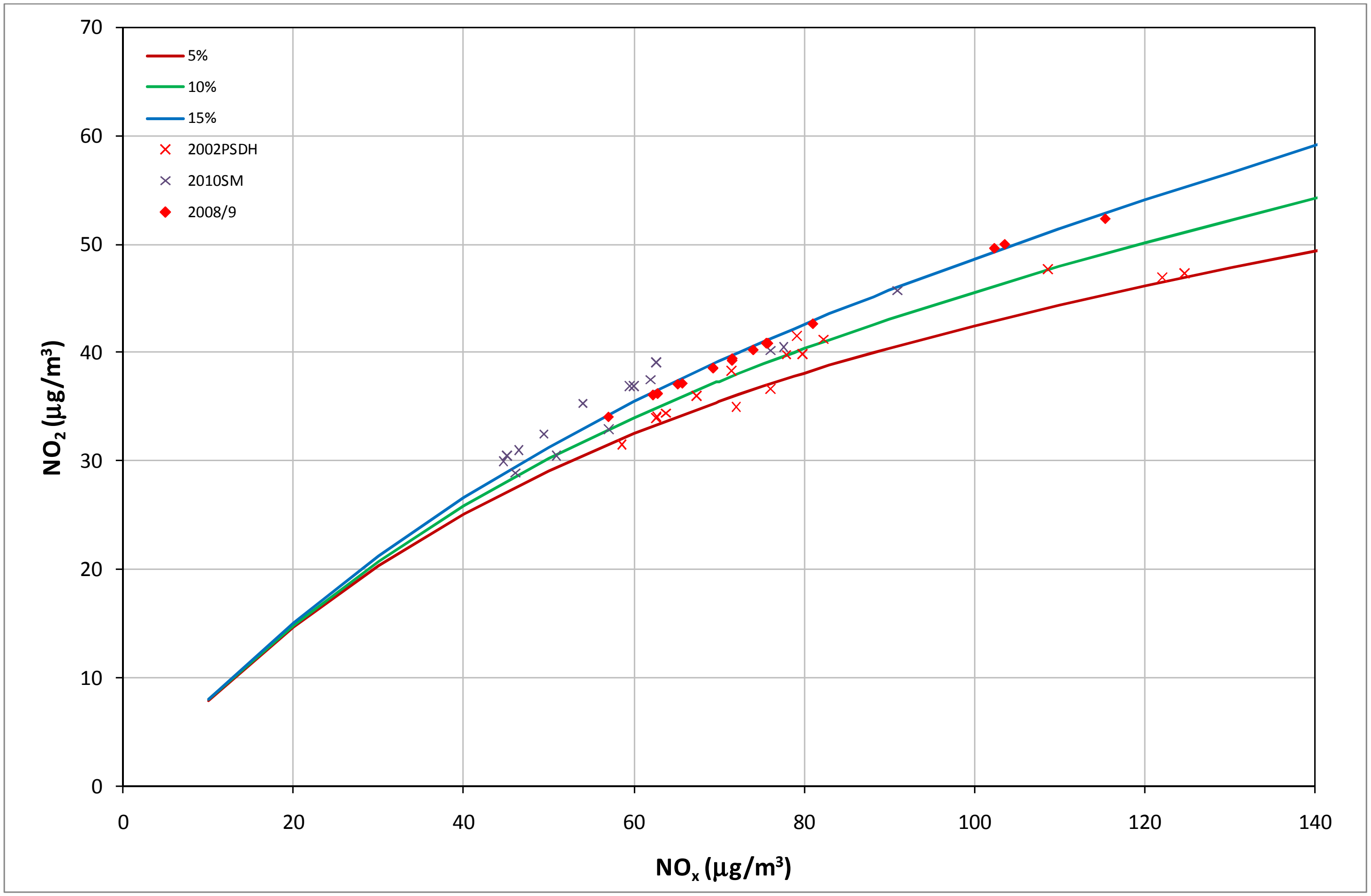
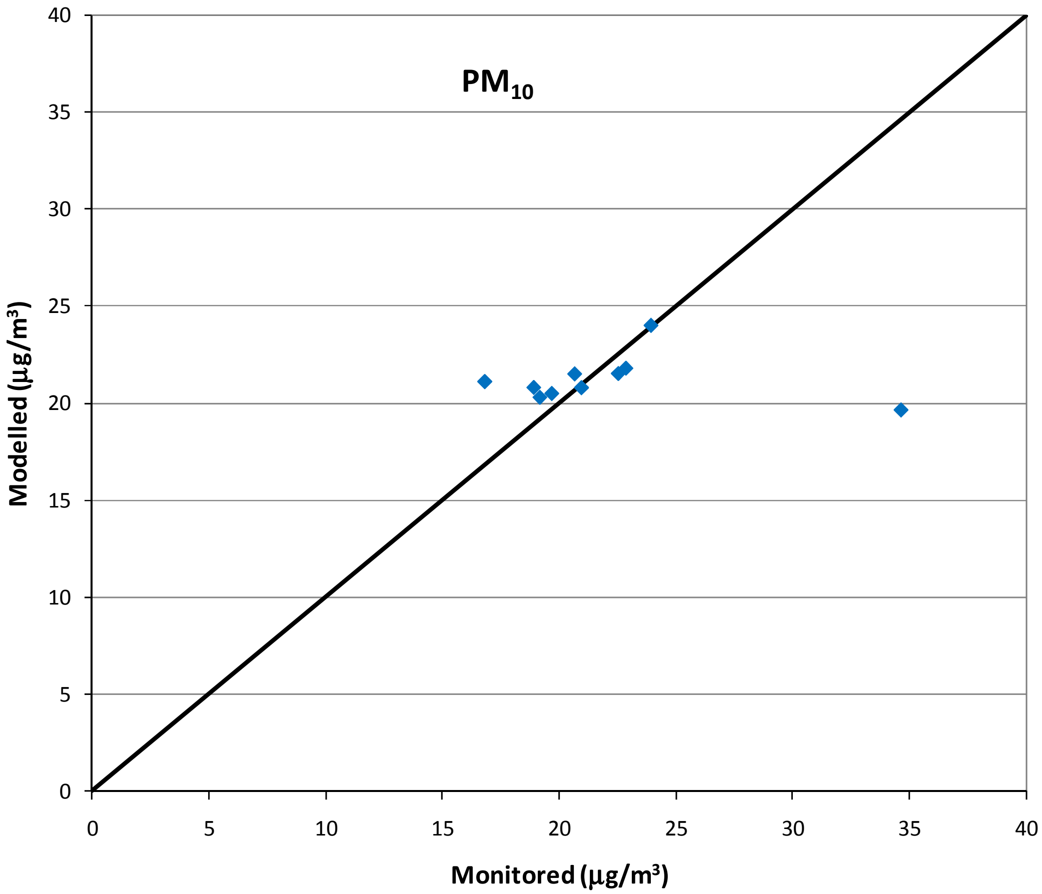


Fig 3.36 Comparison of NO_2/NO_x ratios. Solid curves are given by the Jenkin methodology for fixed values of A (primary NO_2 fraction) and B-33.5 ppb.

Appendix AQ.1.15



ig 3.37 Scatter plot of modelled and measured period-mean PM_{10} concentration

Appendix AQ.1.15

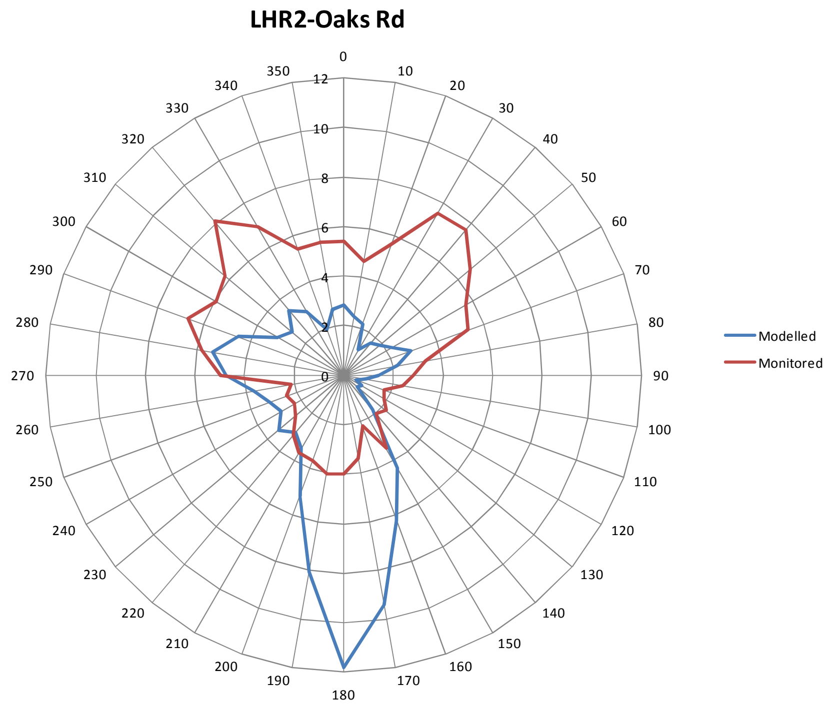


Fig 3.38 The average difference in PM_{10} concentration (µg/m^3) between LHR2 and Oaks Rd as a function of wind direction

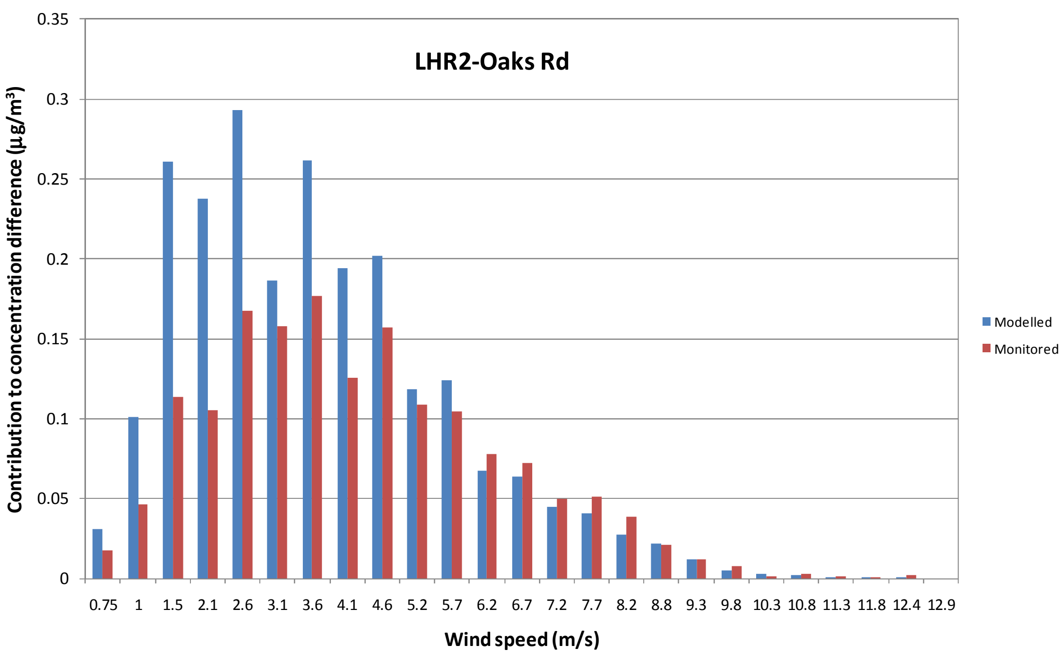


Fig 3.39 LHR2- Oaks Rd PM_{10} concentration difference contribution from wind sectors 150° to 270° inclusive as a function of wind speed

Appendix AQ.1.15

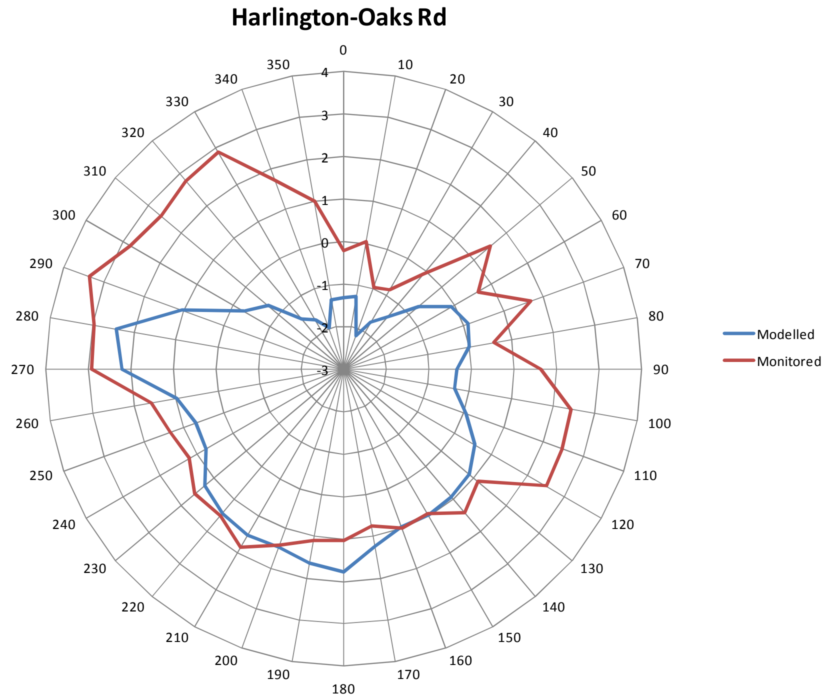


Fig 3.40 The average difference in PM_{10} concentration (µg/m^3) between Harlington and Oaks Rd as a function of wind direction

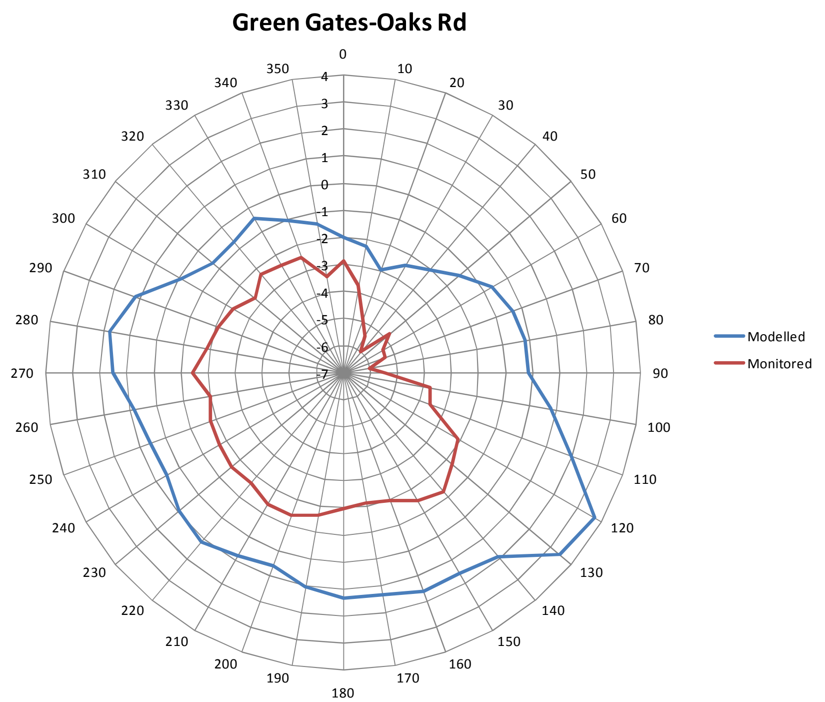


Fig 3.41 The average difference in PM_{10} concentration (µg/m^3) between Green Gates and Oaks Rd as a function of wind direction

Appendix AQ.1.15

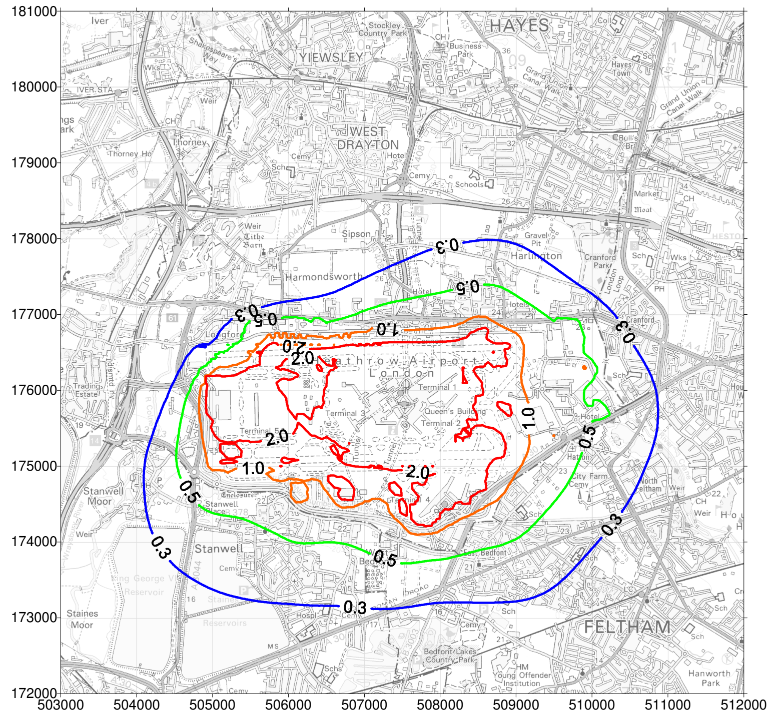


Fig 3.42 Airport contribution to 2008/9 period-mean PM_{10} concentrations: contours shown for 0.3, 0.5, 1.0 and 2.0 µg/m^3

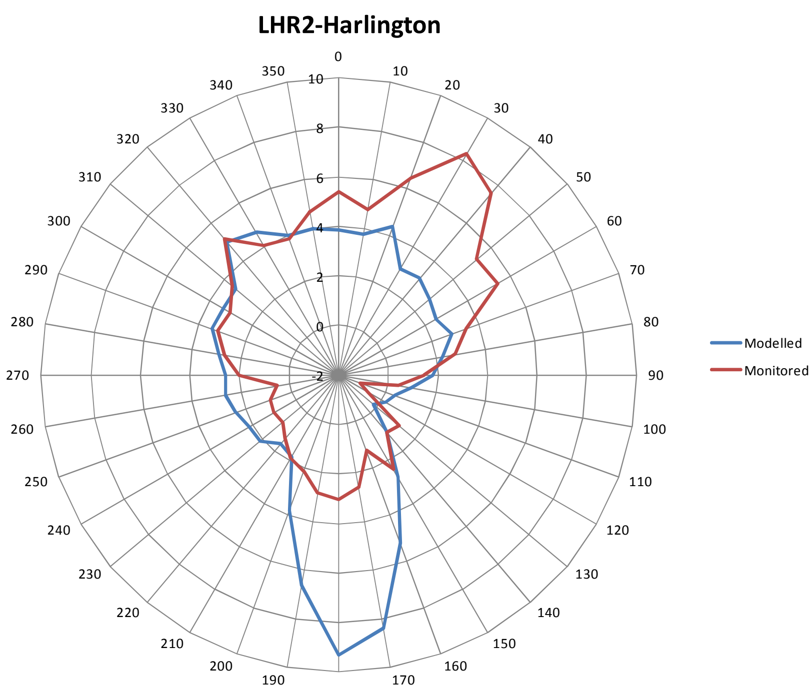


Fig 3.43 The average difference in PM_{10} concentration (µg/m^3) between LHR2 and Harlington as a function of wind direction

Appendix AQ.1.15

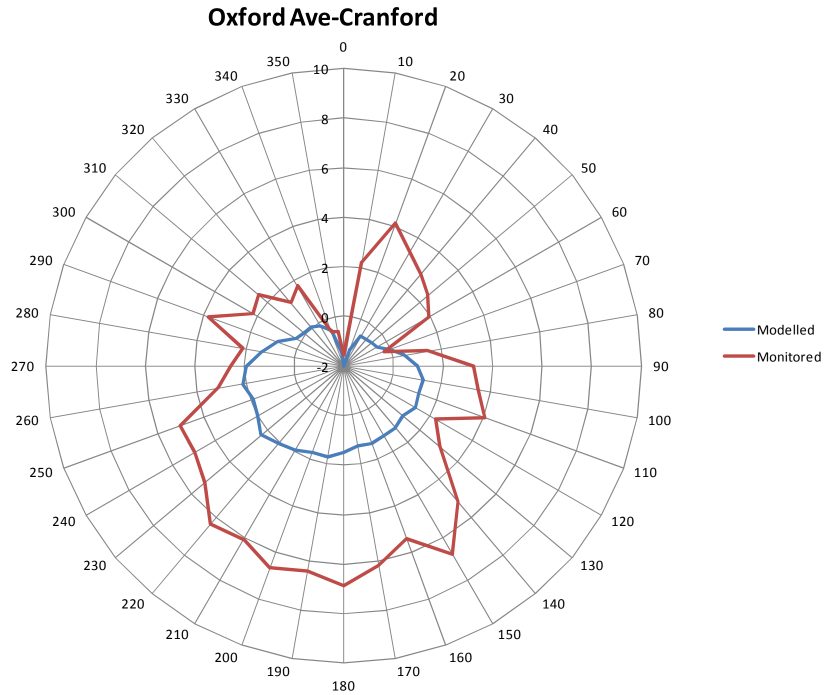


Fig 3.44 The average difference in PM_{10} concentration (µg/m^3) between Oxford Ave and Cranford as a function of wind direction

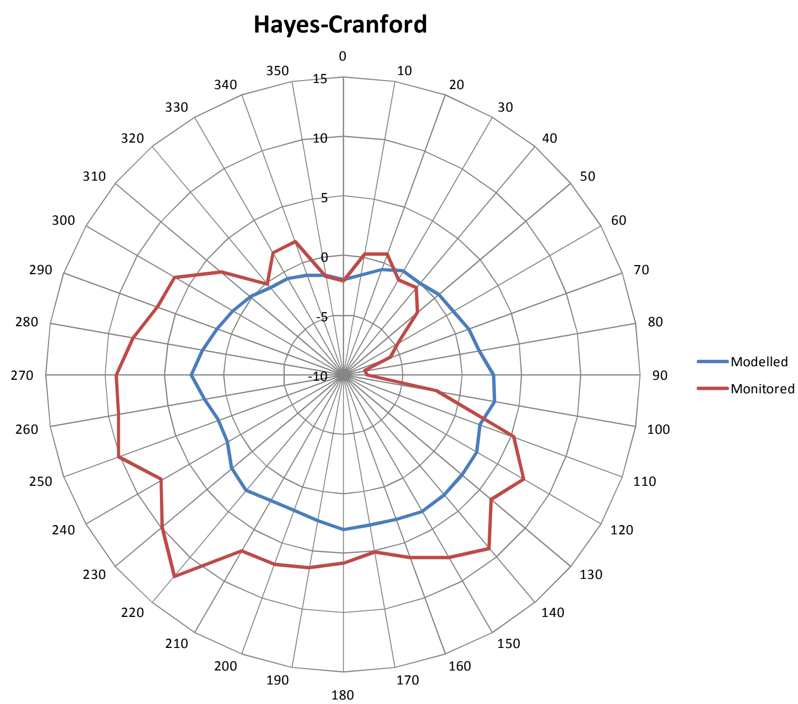


Fig 3.45 The average difference in PM_{10} concentration (µg/m^3) between Hayes and Cranford as a function of wind direction

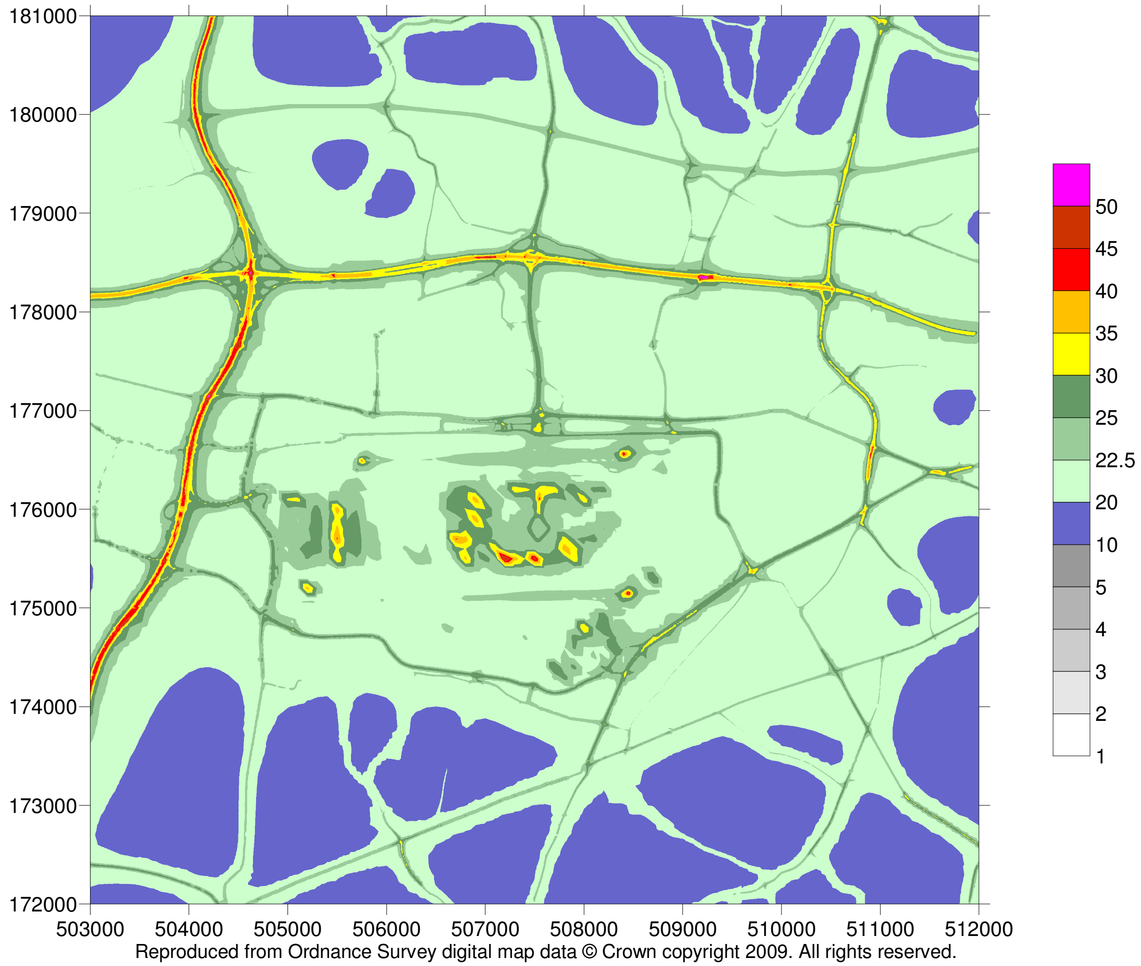


Fig 3.46 Modelled total (all hours) period-mean PM_{10} concentrations for 2008/9

Appendix AQ.1.15

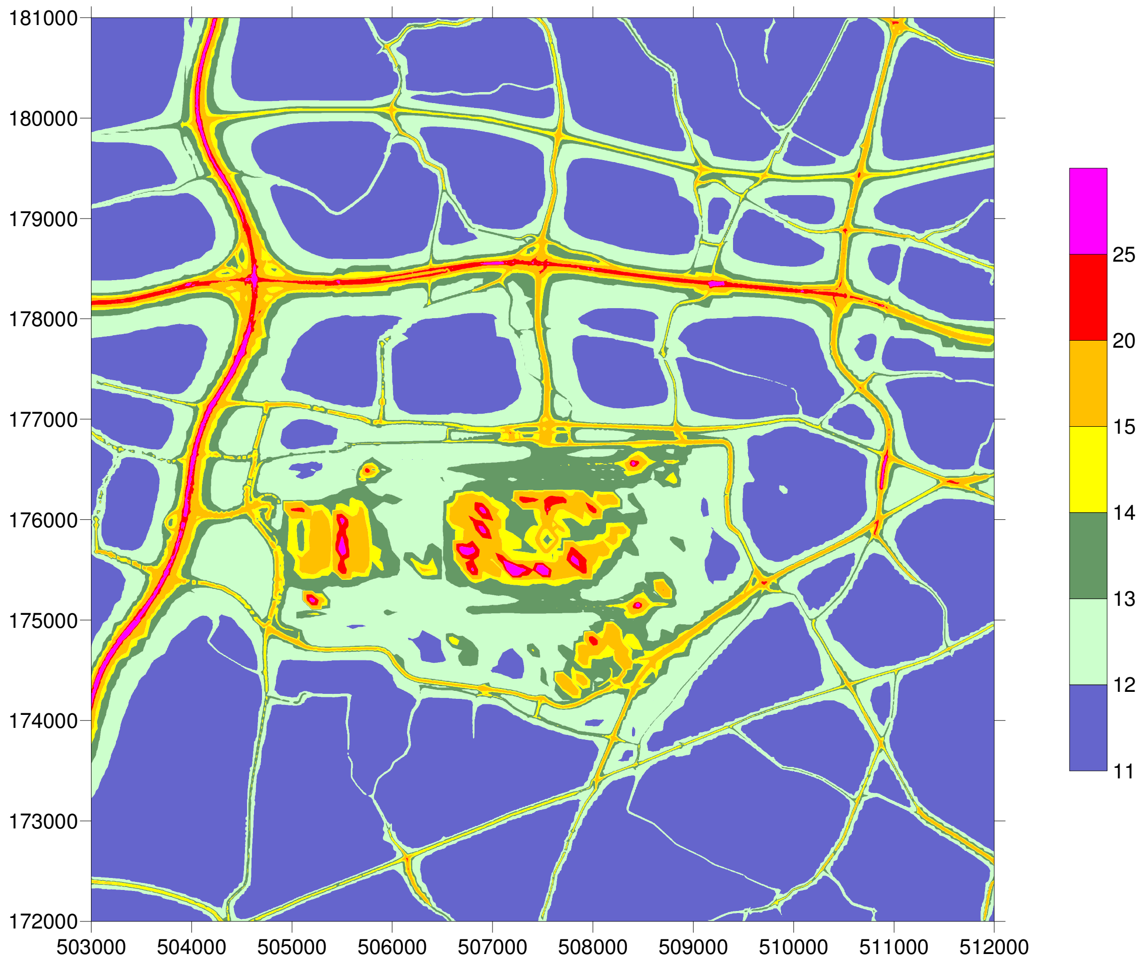


Fig 3.47 Modelled total (all hours) period-mean $PM_{2.5}$ concentration for 2008/9

Appendix AQ.1.15

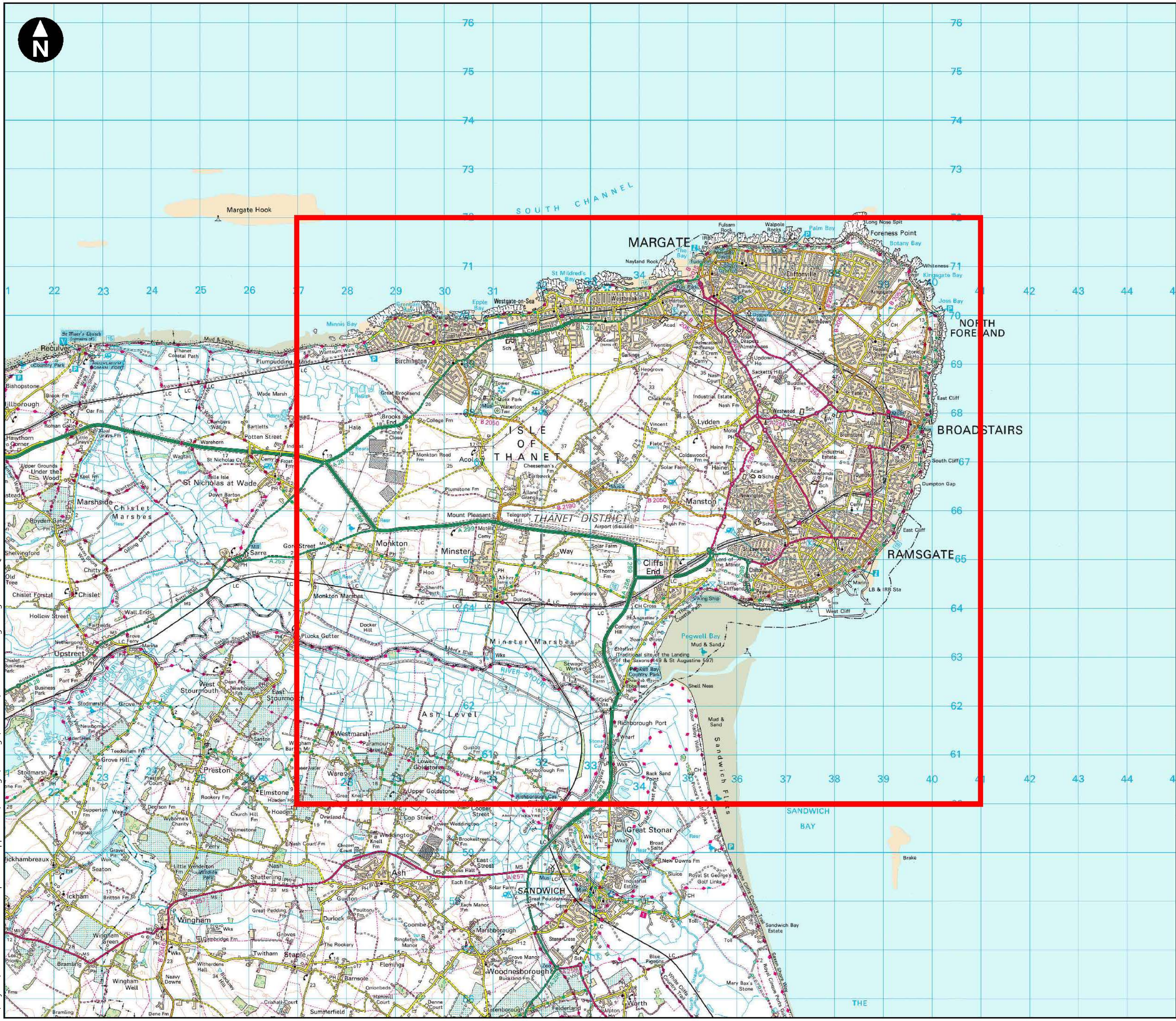
Appendix AQ.1.15

AEA

AEA group
329 Harwell
Didcot
Oxfordshire
OX11 0QJ

Tel: 0870 190 6929
Fax: 0870 190 6933

Appendix AQ.1.15



Key

Study area

0 m 4000 m

Scale 1:75,000 @ A3

Client

RSP

Manston Airport DCO

Study Area

January 2019

wood.

R:\Projects\40820 STH Manston Airport Post Application\D Design\Drawings\AutoCAD\40820-Lon13.dwg Originator: JACQUI.PARKIN

Appendix AQ.1.20

Existing view

Proposed wireline view

RPS	**Manston Airport DCO**	Date of photography: 13/09/2017 Lens: 50mm (35mm format)	Distance to site: 0km OS reference: 633315, 166524	Direction to site: east Viewpoint height: 40m AOD	Horizontal field of view: Approx. 75° Viewing distance: 300mm @ A3	**Viewpoint 1: RAF Manston Museum Carpark** **Figure: 1**

Ref: 10772-0003-005

Appendix CA.1.4

RPS **Manston Airport DCO**	Date of photography: 13/09/2017 Lens: 50mm (35mm format)	Distance to site: 0km OS reference: 633315, 166524	Direction to site: southeast Viewpoint height: 40m AOD	Horizontal field of view: Approx. 75° Viewing distance: 300mm @ A3	**Viewpoint 1: RAF Manston Museum Carpark** **Figure: 2**

Ref: 10772-0003-005

Appendix CA.1.4

Ref: 10772-0003-005

RPS

Manston Airport DCO	Date of photography: 13/09/2017 Lens: 50mm (35mm format)	Distance to site: 0km OS reference: 633315, 166524	Direction to site: south Viewpoint height: 40m AOD	Horizontal field of view: Approx. 75° Viewing distance: 300mm @ A3	Viewpoint 1: RAF Manston Museum Carpark Figure: 3

Appendix CA.1.4

Ref: 10772-0003-005

RPS	Manston Airport DCO	Date of photography: 13/09/2017 Lens: 50mm (35mm format)	Distance to site: 0km OS reference: 634032, 167145	Direction to site: south-south east Viewpoint height: 47m AOD	Horizontal field of view: Approx. 75° Viewing distance: 300mm @ A3	**Viewpoint 2: Manston Road** **Figure: 4**

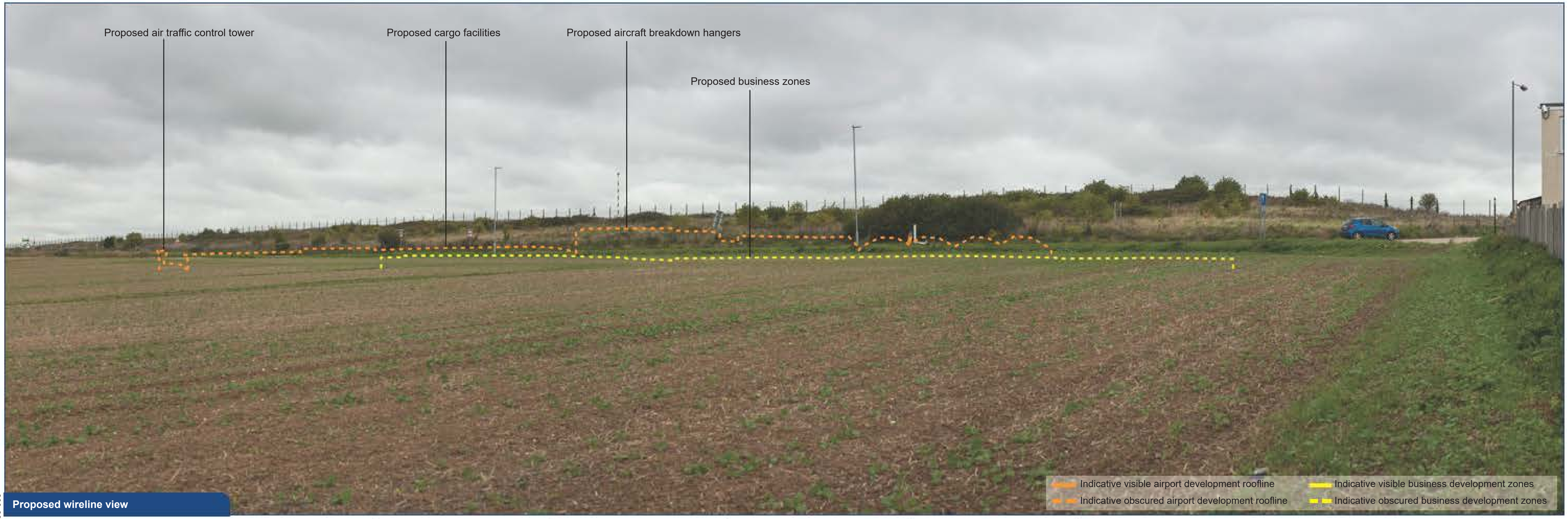
Appendix CA.1.4

Ref: 10772-0003-005

RPS	**Manston Airport DCO**	Date of photography: 13/09/2017 Lens: 50mm (35mm format)	Distance to site: 0km OS reference: 634032, 167145	Direction to site: south Viewpoint height: 47m AOD	Horizontal field of view: Approx. 75° Viewing distance: 300mm @ A3	**Viewpoint 2: Manston Road** **Figure: 5**

Appendix CA.1.4


Existing view



Proposed wireline view

Ref: 10772-0003-005

RPS	Manston Airport DCO	Date of photography: 14/09/2017 Lens: 50mm (35mm format)	Distance to site: 0.1km OS reference: 634366, 165089	Direction to site: northwest Viewpoint height: 39m AOD	Horizontal field of view: Approx. 75° Viewing distance: 300mm @ A3	**Viewpoint 3: Canterbury Road West PRoW** **Figure: 6**

Appendix CA.1.4

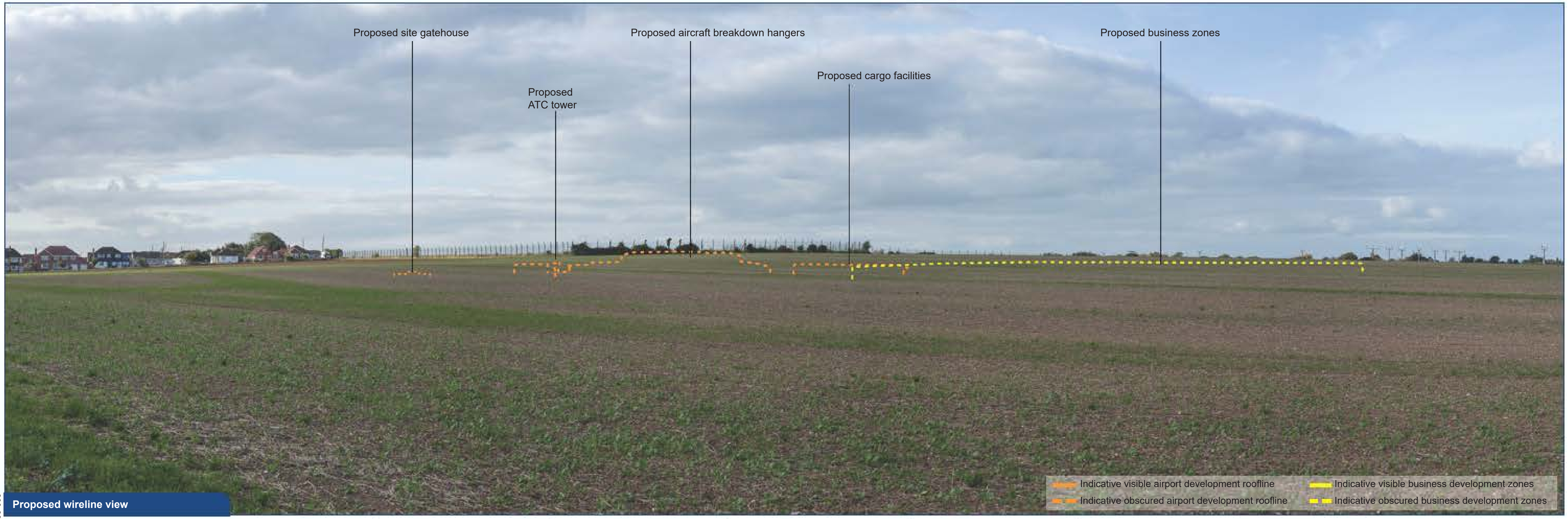
Existing view

Proposed wireline view

Ref: 10772-0003-005

RPS	Manston Airport DCO	Date of photography: 13/09/2017 Lens: 50mm (35mm format)	Distance to site: 0.6km OS reference: 631122, 16585	Direction to site: east Viewpoint height: 52m AOD	Horizontal field of view: Approx. 75° Viewing distance: 300mm @ A3	Viewpoint 4: B2190, Minster Road Figure: 7

Appendix CA.1.4



Ref: 10772-0003-005

RPS

Manston Airport DCO	Date of photography: 03/10/2017 Lens: 50mm (35mm format)	Distance to site: 0.6km OS reference: 635205, 165114	Direction to site: northwest Viewpoint height: 40m AOD	Horizontal field of view: Approx. 75° Viewing distance: 300mm @ A3	**Viewpoint 5: A256 Haine Road** **Figure: 8**

Appendix CA.1.4

Ref: 10772-0003-005

RPS **Manston Airport DCO**	Date of photography: 14/09/2017 Lens: 50mm (35mm format)	Distance to site: 0.3km OS reference: 634619, 166204	Direction to site: west Viewpoint height: 49m AOD	Horizontal field of view: Approx. 75° Viewing distance: 300mm @ A3	**Viewpoint 6: B2050 western edge of Manston** **Figure: 9**

Appendix CA.1.4

Existing view

Proposed wireline view

Ref: 10772-0003-005

RPS	Manston Airport DCO	Date of photography: 14/09/2017 Lens: 50mm (35mm format)	Distance to site: 0.3km OS reference: 634619, 166204	Direction to site: west Viewpoint height: 49m AOD	Horizontal field of view: Approx. 75° Viewing distance: 300mm @ A3	Viewpoint 6: B2050 western edge of Manston Figure: 10

Appendix CA.1.4

Ref: 10772-0003-005

RPS **Manston Airport DCO**	Date of photography: 14/09/2017	Distance to site: 0.5km	Direction to site: southwest	Horizontal field of view: Approx. 75°	**Viewpoint 7: Vincent Road near Fleet Farm**
	Lens: 50mm (35mm format)	OS reference: 634481, 167555	Viewpoint height: 48m AOD	Viewing distance: 300mm @ A3	**Figure: 11**

Appendix CA.1.4

Ref: 10772-0003-005

RPS **Manston Airport DCO**	Date of photography: 14/09/2017 Lens: 50mm (35mm format)	Distance to site: 0.9km OS reference: 632564, 167096	Direction to site: southeast Viewpoint height: 37m AOD	Horizontal field of view: Approx. 75° Viewing distance: 300mm @ A3	**Viewpoint 8: Woodchurch Road, southern edge of Woodchurch** **Figure: 12**

Appendix CA.1.4

Ref: 10772-0003-005

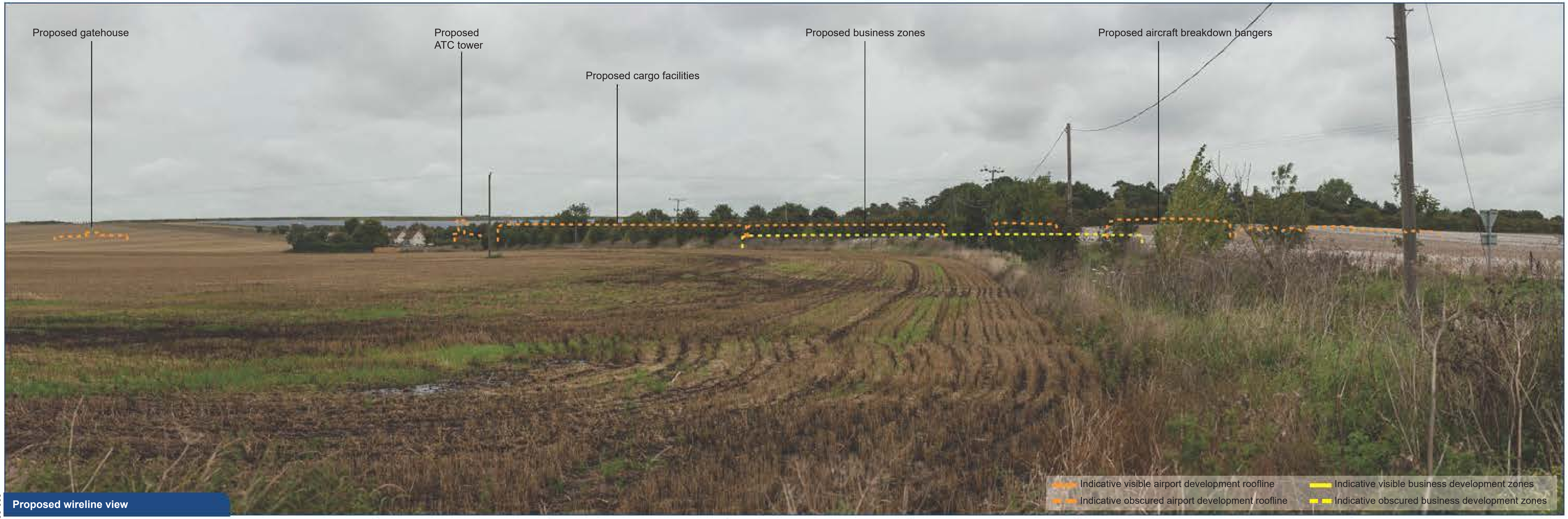
RPS	**Manston Airport DCO**	Date of photography: 14/09/2017 Lens: 50mm (35mm format)	Distance to site: 1.2km OS reference: 630872, 166840	Direction to site: west Viewpoint height: 30m AOD	Horizontal field of view: Approx. 75° Viewing distance: 300mm @ A3	**Viewpoint 9: Minster Road, Acol** **Figure: 13**

Appendix CA.1.4

Ref: 10772-0003-005

RPS	**Manston Airport DCO**	Date of photography: 14/09/2017 Lens: 50mm (35mm format)	Distance to site: 1.4km OS reference: 631819, 167446	Direction to site: southwest Viewpoint height: 31m AOD	Horizontal field of view: Approx. 75° Viewing distance: 300mm @ A3	**Viewpoint 10: Pumping station south of Quex Park** **Figure: 14**

Appendix CA.1.4



Ref: 10772-0003-005

RPS	Manston Airport DCO	Date of photography: 14/09/2017 Lens: 50mm (35mm format)	Distance to site: 1.1km OS reference: 633107, 164479	Direction to site: northeast Viewpoint height: 16m AOD	Horizontal field of view: Approx. 75° Viewing distance: 300mm @ A3	**Viewpoint 11: Viking Coastal Trail, Cottington Road** **Figure: 15**

Appendix CA.1.4

Ref: 10772-0003-005

RPS **Manston Airport DCO**	Date of photography: 14/09/2017 Lens: 50mm (35mm format)	Distance to site: 1.1km OS reference: 633790, 164232	Direction to site: north Viewpoint height: 21m AOD	Horizontal field of view: Approx. 75^0 Viewing distance: 300mm @ A3	**Viewpoint 12: A256, Cottington Road Bridge** **Figure: 16**

Appendix CA.1.4


Existing view

Proposed wireline view

RPS **Manston Airport DCO**	Date of photography: 14/09/2017 Lens: 50mm (35mm format)	Distance to site: 2.1km OS reference: 635654, 168600	Direction to site: southwest Viewpoint height: 36m AOD	Horizontal field of view: Approx. 75° Viewing distance: 300mm @ A3	**Viewpoint 13: Nash Court, Nash Road, Margate** **Figure: 17**

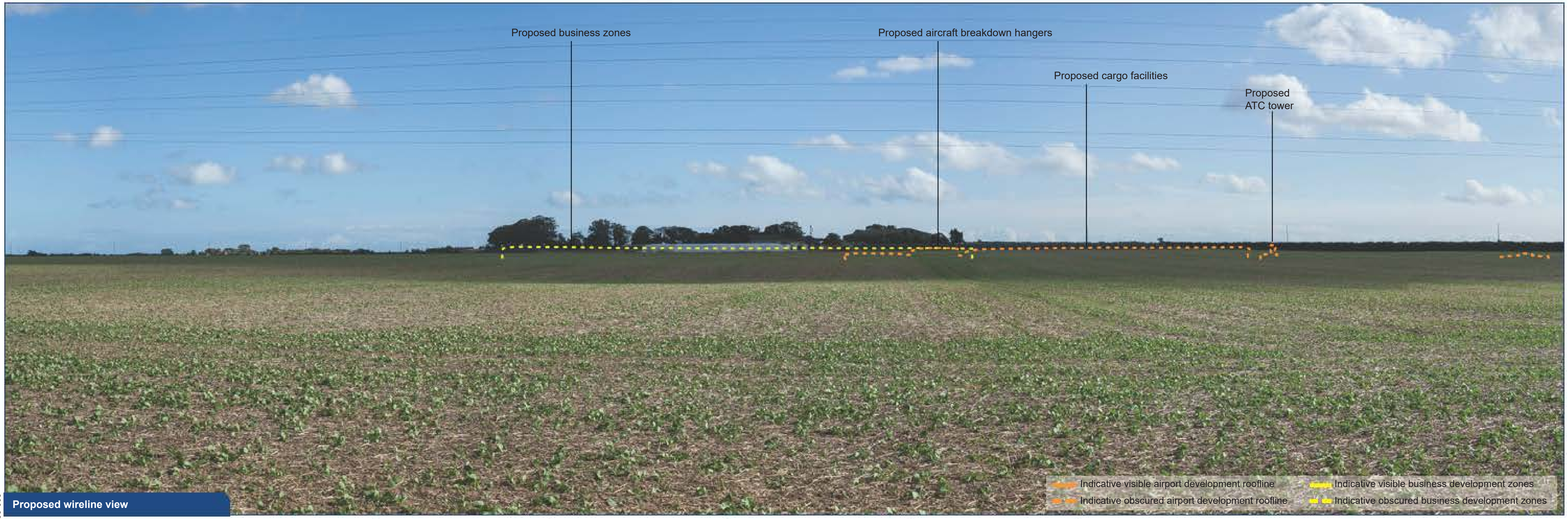
Ref: 10772-0003-005

Appendix CA.1.4

Ref: 10772-0003-005

RPS	Manston Airport DCO	Date of photography: 14/09/2017 Lens: 50mm (35mm format)	Distance to site: 1.8km OS reference: 633511, 168850	Direction to site: south Viewpoint height: 29m AOD	Horizontal field of view: Approx. 75° Viewing distance: 300mm @ A3	**Viewpoint 14: Junction of High Street and Shottendane Road, southern Garlinge** **Figure: 18**

Appendix CA.1.4



Ref: 10772-0003-005

RPS **Manston Airport DCO**	Date of photography: 13/09/2017 Lens: 50mm (35mm format)	Distance to site: 2.1km OS reference: 632531, 168633	Direction to site: south Viewpoint height: 29m AOD	Horizontal field of view: Approx. 75° Viewing distance: 300mm @ A3	**Viewpoint 15: PRoW, Shottenden Road** **Figure: 19**

Appendix CA.1.4

Ref: 10772-0003-005

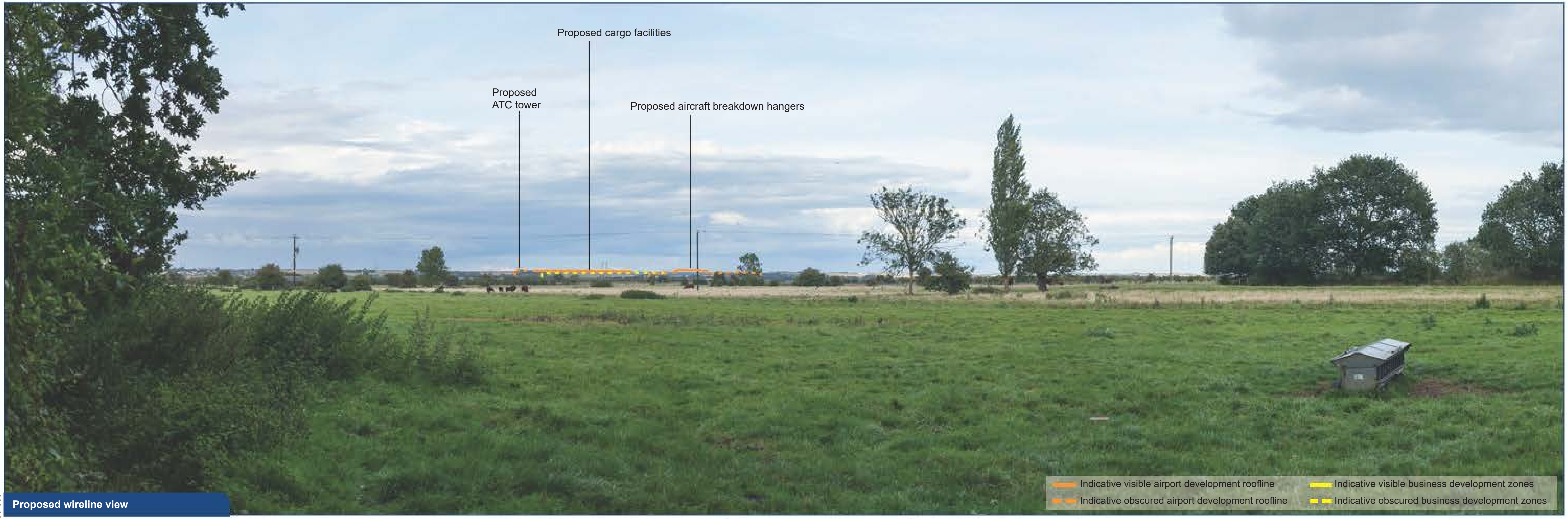
RPS	**Manston Airport DCO**	Date of photography: 14/09/2017 Lens: 50mm (35mm format)	Distance to site: 2.0km OS reference: 634328, 163120	Direction to site: north Viewpoint height: 6m AOD	Horizontal field of view: Approx. 75° Viewing distance: 300mm @ A3	**Viewpoint 16: Northern side of Pegwell Country Park** **Figure: 20**

Appendix CA.1.4

Ref: 10772-0003-005

RPS Manston Airport DCO	Date of photography: 14/09/2017 Lens: 50mm (35mm format)	Distance to site: 3.0km OS reference: 631780, 162767	Direction to site: northeast Viewpoint height: 5m AOD	Horizontal field of view: Approx. 75° Viewing distance: 300mm @ A3	Viewpoint 17: South Saxon Way alongside River Stour Figure: 21

Appendix CA.1.4



Ref: 10772-0003-005

Manston Airport DCO	Date of photography: 14/09/2017 Lens: 50mm (35mm format)	Distance to site: 5.1km OS reference: 629443, 161275	Direction to site: northeast Viewpoint height: 3m AOD	Horizontal field of view: Approx. 75° Viewing distance: 300mm @ A3	**Viewpoint 18: Goldstone Drove PRoW, west of Lower Goldstone** **Figure: 22**

Appendix CA.1.4

Ref: 10772-0003-005

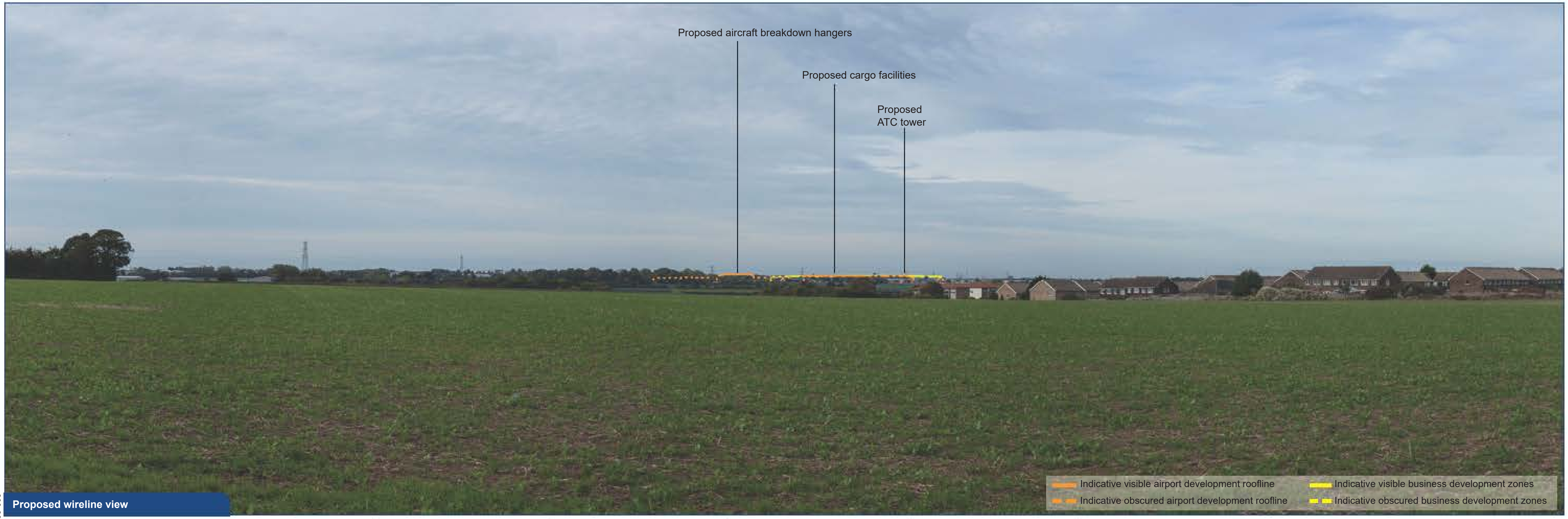
RPS **Manston Airport DCO**	Date of photography: 03/10/2017 Lens: 50mm (35mm format)	Distance to site: 4.9km OS reference: 626863, 166205	Direction to site: east Viewpoint height: 24m AOD	Horizontal field of view: Approx. 75° Viewing distance: 300mm @ A3	**Viewpoint 19: Eastern edge of St Nicholas at Wade** **Figure: 23**

Appendix CA.1.4

Ref: 10772-0003-005

RPS Manston Airport DCO	Date of photography: 03/10/2017 Lens: 50mm (35mm format)	Distance to site: 5.3km OS reference: 626980, 163458	Direction to site: northeast Viewpoint height: 4m AOD	Horizontal field of view: Approx. 75° Viewing distance: 300mm @ A3	**Viewpoint 20: North side of bridge at Plucks Gutter** **Figure: 24**

Appendix CA.1.4



Ref: 10772-0003-005

RPS **Manston Airport DCO**	Date of photography: 03/10/2017 Lens: 50mm (35mm format)	Distance to site: 4.6km OS reference: 637905, 169846	Direction to site: southwest Viewpoint height: 49m AOD	Horizontal field of view: Approx. 75° Viewing distance: 300mm @ A3	**Viewpoint 21: St Michael's Avenue, Northdown** **Figure: 25**

Appendix CA.1.4

Ref: 10772-0003-005

RPS Manston Airport DCO	Date of photography: 14/09/2017 Lens: 50mm (35mm format)	Distance to site: 5.2km OS reference: 632440, 160311	Direction to site: north Viewpoint height: 13m AOD	Horizontal field of view: Approx. 75° Viewing distance: 300mm @ A3	**Viewpoint 22: PRoW, north of Richborough Castle** **Figure: 26**

Appendix CA.1.4

Aviation capability

December 2017

Appendix CA.1.14

Strong HSSE culture
Beyond Zero Program

- Our clients place strong emphasis on safe work performance and well- established health & safety management systems
- **Beyond Zero** means zero harm every minute of every day, whatever we do, at work or home

TRIR*
0.23
10.5M hrs

LTIR*
0
10.5M hrs

EMR*
0.53
E&IS US

*YTD Q3 2017

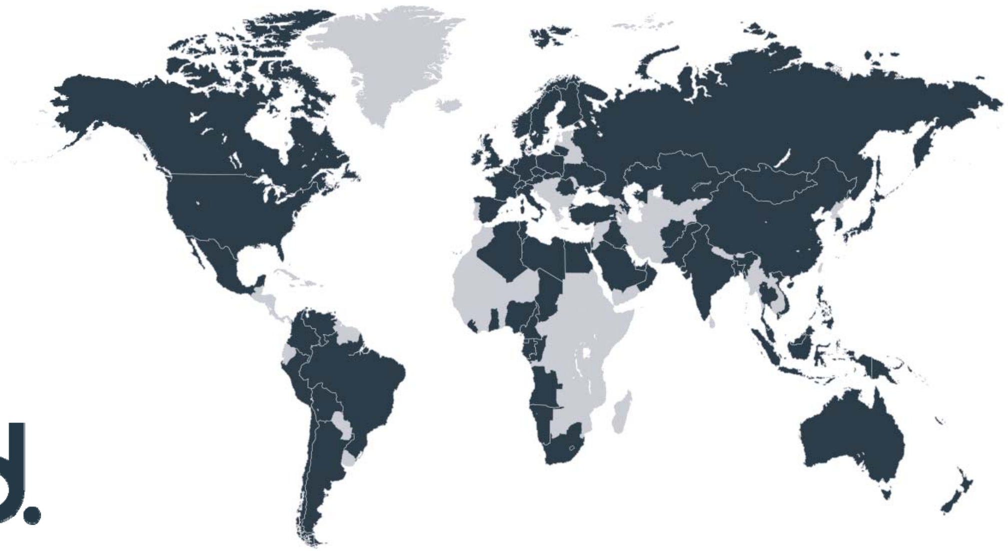
BEYOND ZERO

always take care
follow the rules
do a risk assessment
you must intervene
manage any change
wear the correct ppe

Appendix CA.1.14

Amec Foster Wheeler is now Wood

- ► A new global leader in technical, engineering and project services
  - ► Over $11 billion combined revenue (Wood Group & Amec Foster Wheeler)
  - ► Operating in more than 60 countries
  - ► 55,000 people in 400+ offices worldwide
  - ► Over 160 years experience



Appendix CA.1.14

Environment & Infrastructure Solutions

Appendix CA.1.14

About E&IS
At a glance

- E&IS leads our environmental engineering and consulting business and a wide range of infrastructure-related service capabilities
- Technical experts across the US, Canada, UK, Europe, Australia and Latin America
- Providing full consulting, engineering and construction services to our clients in the oil/gas/chemicals, power, mining, industrial, pharmaceutical, government, transportation and water sectors

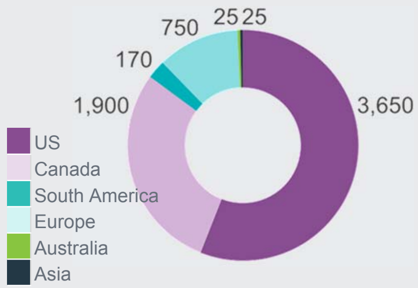
Results
2016

Sales
$1.5 billion

Revenue
$1.3 billion

Offices
175

Employees
6,500



Appendix CA.1.14

About E&IS

The sectors we work in

Government

- Environmental remediation
- Architecture/engineering services
- Energy efficiency
- Construction services
- Military fueling systems
- Program management

Transportation

- Roads and bridges
- Rail and transit
- Ports
- Airports
- Alternate delivery models

Industrial

- Aerospace/defense
- Automotive
- Chemical
- Electronics and metals
- Food & beverage

Power & Clean Energy

- Fossil fuels
- Renewables
- Nuclear
- Transmission & distribution

Oil and gas

- International
- National
- Independent
- Midstream
- Capital projects
- Operational projects

Mining

- Junior exploration
- Junior producer
- Intermediate producer
- Senior producer

Pharmaceutical

- Bulk API
- Biopharmaceuticals
- Fill finish
- R&D/labs
- Packaging/warehousing

Water

- Water resources
- Industrial process water
- Storm water
- Facilities Engineering/Design/ Construction

Appendix CA.1.14

About E&IS

Integrated services across the full asset lifecycle

Technical skill sets matched to customer environmental and engineering needs

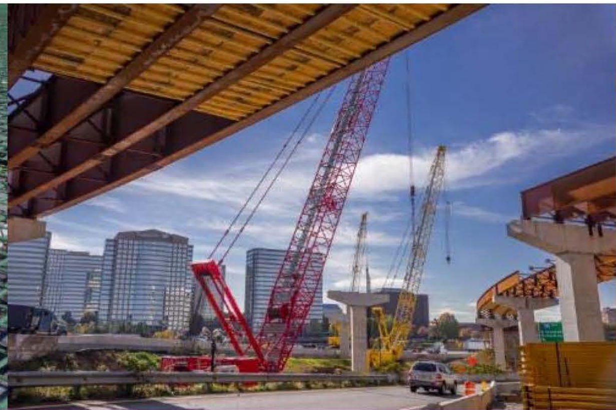
Lifecycle services

- Environmental Remediation
- Permitting and Compliance
- Environmental Sciences
- Public Infrastructure
- Geotechnical and Materials
- Facility Operations

Appendix CA.1.14

Transportation Services Overview

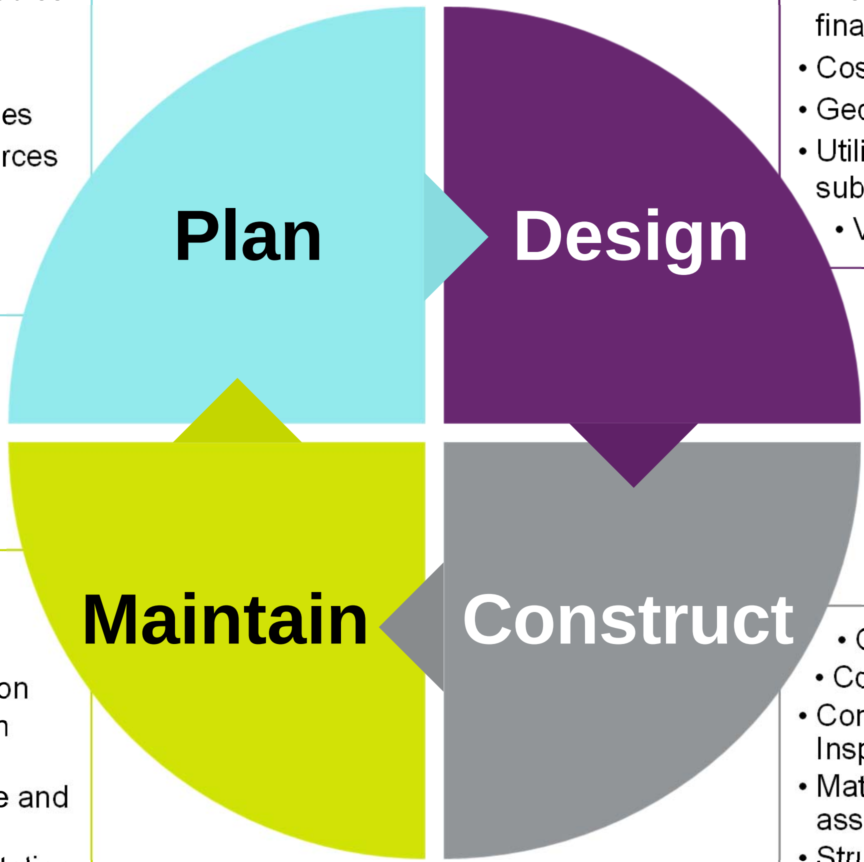
amec foster wheeler



Appendix CA.1.14

Transportation lifecycle services

- Feasibility and location studies
- Environmental reviews
- Traffic studies
- Air and water quality studies
- Natural and cultural resources investigations
- Grant writing
- Market analysis



- Preliminary engineering and final design
- Cost estimates
- Geotechnical engineering
- Utility coordination and subsurface utility engineering
- Value engineering

- Owner's engineer
- Construction administration
- Construction Engineering Inspection (CEI)
- Materials testing and quality assurance
- Structural steel inspection

- Pavement consulting and engineering
- Bridge and structural inspection and rehabilitation
- Road Weather Information Systems (RWIS)
- Environmental compliance and permitting
- Tunnel evaluation/rehabilitation
- Design to extend useful life

Appendix CA.1.14

Transportation client base

- Design-Build and PPP clients
- Federal, state, provincial and municipal governments
- Railroads and transit agencies
- Port, harbor and marine authorities
- Toll highway authorities
- Airports and aviation agencies
- Mining, oil, gas and private industry

Airport services

Accomplishing more than 700 airport projects in the past 17 years, Amec Foster Wheeler has effectively served the needs of airports across the globe by creatively addressing construction, engineering, and environmental challenges. For more than 50 years, we have proven that we have the combination of knowledge, resources, and "cutting edge" skills to deliver cost-effective, efficient, and sustainable solutions.

- We develop reliable airside and landside programs that efficiently accommodate current and future demands
- We create effective points of transfer between landside and airside traffic
- We seamlessly integrate existing terminal infrastructure into a design plan that improves operations, passenger service and safety
- We develop programs that deliver optimal performance for airport operations, runways that keep air traffic moving effectively, and improved traffic flows to keep ground transportation moving
- Our consulting team address any and all environmental related airport issues from cradle to grave
- We have total design/project management capability to support airport projects
- Our experts prepare construction plans, specifications, bid documents, and cost estimates for a broad scope of FAA-funded projects
- Our environmental assessment and permitting group is world class leading on projects such as at Heathrow where the challenges are significant

Airport services

- Airport planning
- Air quality, noise and vibration studies
- Archaeology and cultural heritage surveys
- Architecture, structural, MEP and fire protection
- Biodiversity and water quality investigations
- Contaminated land/land quality
- Construction management
- Contracts development and administration
- Construction management and other services
- Design and engineering services
- Development planning
- Energy management
- Environmental Impact Assessment
- Facility asset management
- Fuel/de-icing facilities development
- Geotechnical engineering
- Landscape and visual assessments
- Landside roadways and parking facilities
- LEED-certified professionals
- Master planning inputs
- Materials testing and structural steel inspection
- Pavement management and rehabilitation
- Passenger and cargo terminal design
- Project Management
- Quality Assurance/Quality Control
- Regulatory compliance
- Runway, taxiway and airport design
- Sustainability appraisal
- Sustainable solutions
- Stormwater management and pollution prevention

Appendix CA.1.14

Key Airport Services in the UK

- Navigating the planning and environmental permitting processes – lessons learnt from our global experience;
- Public consultation – debunking myths, improving communication and understanding;
- Noise modelling- using our noise assessment tool (ListenIN) to create a 3D soundscape bringing to life one of the most technical EIA topics;
- Adding value to airport infrastructure by implementing multi-purpose mitigation solutions- integrating blue/green infrastructure into airport planning;
- Minimising environmental impacts through integration with the design process- for example micro-design of taxiways, soundscape design, carbon and waste reduction strategies.

Appendix CA.1.14

Current and Recent UK Airport Projects

Heathrow Expansion Program

Customer: Heathrow Airport, Ltd.
Location: London, UK

£15+ B, 3.5-km third runway at Europe's busiest airport. The complex planning & consultation process is being performed by an Integrated Design Team (IDT), which is delivering the Masterplan Design & Development Consent Order application material. As a member of the IDT, we are acting as lead on key technical services including environmental impact assessment and sustainability, engineering surveys, river and flood engineering, consultation, and Program Management services (cost control, programming and innovative information management solutions). 2017 fees to date approximately £8 M.

Manston Airport DCO GT3

Customer: RiverOak Strategic Partners
Location: Kent, UK

Leading the EIA for a Development Consent order for the Reopening of Manston Airport in Kent. The project involves the development of a freight and passenger facility with associated business park developments. Wood was appointed by Riveroak Strategic partnership to provide a full multi-disciplinary EIA service including noise, air quality, biodiversity, major accidents and disasters, transport etc. The DCO application was submitted in 2018 and is currently being examined by PINS.

Bristol International Airport, TCPA Application

Customer: Bristol Airport Limited
Location: Bristol, UK

Ongoing advice to Bristol Airport including an application for 10 and now 12mmpa. Application includes upgraded terminals, car parking, a new admin building and local road improvements. A new EIA is currently being prepared and will be submitted alongside the planning application in late 2018.

Luton Airport, Noise Advice and S73 Application

Customer: London Luton Airport
Location: Luton, UK

All of the UK airport projects we are involved in necessitate the provision of noise advice. We are currently working with Luton airport on a Section 73 (amended planning conditions) application to allow increase the area of the daytime noise contour. Wood are leading the application process as well as providing noise and environmental advice.

Appendix CA.1.14

Slide 14

GT3	NIck Hilton has some text from Dublin bid that can go in here. Gibbs, Toby, 16/02/2018

Relevant experience

London Heathrow Airport

- Key member of the design team delivering services to the Airport's expansion program / R3 – Leadership on the engineering surveys, water services, and all environmental and sustainability studies
- Full runway alternation enabling works – EIA, expert witness
- Heathrow East Terminal (T2A) - EIA, planning support, environmental technical studies
- Terminal 5 – Environmental advisor, air quality, employment, expert witness, waste minimisation strategy

Appendix CA.1.14

Manston Airport

- DCO Application submitted to PINS this year
- Reopening of Airport in East Kent, with an anticipated 1,400,000 passenger movements/year.
- Surface access strategy
  - Also undertaking EIA, ecology, heritage, water, noise, air quality,
  - Public transport
  - PROW
  - Access strategies
- Travel plans
- Masterplan development
- Junction design

Appendix CA.1.14

Relevant experience
UK airports

Bristol International Airport

- ▶ Masterplanning
- ▶ EIA and planning
- ▶ Sustainability studies

Newquay Cornwall Airport (RAF St. Mawgan)

- ▶ CAA licensing
- ▶ Environmental support
- ▶ Planning support

Relevant experience

US airports

Portland International Jetport Terminal Expansion

Services included construction inspection, construction administration, project design, BIM, City of Portland and user interface, for the mechanical, plumbing, fire protection, structural, electrical, civil, permitting, and geothermal design services to Gensler Architects. This project will obtain LEED Gold certification.

2010-2011 • $75M construction

Port of Seattle: Seattle Tacoma International Airport Infrastructure Upgrades during Capital Improvements Program

AMEC provided asbestos surveys, abatement design, specification development, construction management, constructability review, and construction oversight services for the upgrade of the mechanical, electrical, communications, security infrastructure systems throughout Seattle-Tacoma International Airport.

2001-2009 • $85M construction

Hartsfield-Jackson Atlanta International Airport Expansion

Providing construction services including cost engineering, scheduling, construction engineering and inspections, testing of soil, cement and aggregates. In addition provided evaluation of radiographic testing for fuel tanks and piping structure.

1974-Current • $1B construction

JFK, LaGuardia and Newark International Airport Construction and Engineering Services

Construction services including construction management, engineering and construction inspection related services for terminal, airside and landside assets. Also provided on-call services for various facilities including JFK, LGA, EWR as well as bridges and tunnels.
1990-Current

Relevant experience

Seattle-Tacoma International Airport (STIA)
CIP – Regulated Materials Abatement Program

$2.7 B Capital Improvement Program (CIP)

Operated as lead consultant of the $100 M Regulated Materials Abatement Program for CIP including:

- Mechanical infrastructure
- Electrical infrastructure
- Communications infrastructure
- Seismic Improvements
- Tenant renovation projects

- Performed over 300 projects during program including:
  - Asbestos surveys
  - Abatement designs
  - Contractor documents
  - Construction management

Relevant experience

Seattle-Tacoma International Airport (STIA)

Amec Foster Wheeler performed as a lead program consultant during the Capital Improvement Program (CIP)

Key program achievements:

- Managed airport infrastructure program in CIP
- Six consulting firms from local area
- Liaison between Program Manager, Sea-Tac Engineering, Port Construction Services regarding abatement impacts
- Developed project development flow to include asbestos review of every project
- Developed airport wide “asbestos fireproofing drawings” to aid in asbestos program awareness
- Developed feasibility studies full abatement vs. spot abatement
- Developed GIS Conflict Resolution Tool for Project Management Team
- Developed alternative means of compliance for Asbestos Drywall Mud following earthquake
- Developed standardised formats for abatement design drawings and specifications
- Provided peer review of other consultant abatement project designs

Relevant experience

Miami South Terminal expansion

Quality control and materials testing inspection for civil, electrical, mechanical, structural engineering and architecture on the following elements:

- Special Low-Voltage systems
- Conveyor equipment systems
- RF engineering
- Roofing
- Structural steel and welding

Relevant experience

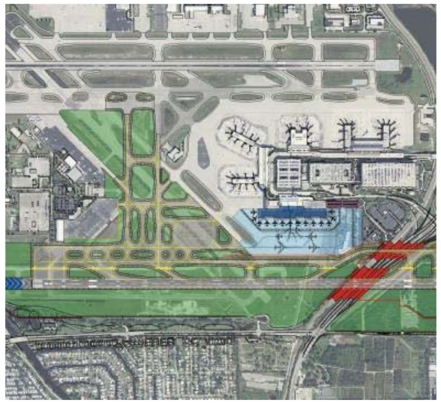
Fort Lauderdale-Hollywood runway 9R-27L

Client: Broward County Aviation Department
Location: Fort Lauderdale-Hollywood Airport (FLL)

$800 M expansion of Runway 9R-27L

- Largest project in Broward County history
- Improvements include taxiway pavements, runway/taxiway structures over roadways, perimeter road modifications, water and sanitary main improvements, and airport exit roadways

Amec Foster Wheeler providing Construction Project Management services, including:



- Environmental management
- Regulatory agency coordination
- Permitting monitoring
- Inspection services
- QA/QC coordination
- QA materials testing and inspection coordination
- Project engineering

Relevant experience

Atlanta pavement management and rehabilitation

On-call planning contract
(5 years)

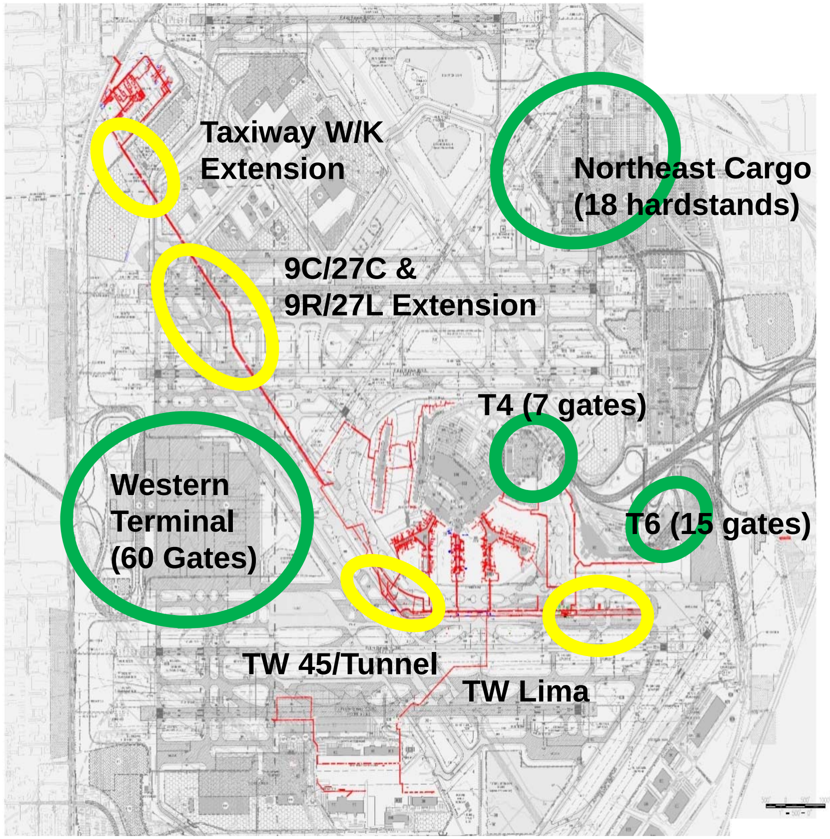
On-call engineering contract
(5 years)

Anticipated projects:

- ► Sixth runway
- ► Air cargo zone relocation
- ► Next generation ATC upgrades
- ► Alternative / reliever airport

Relevant experience

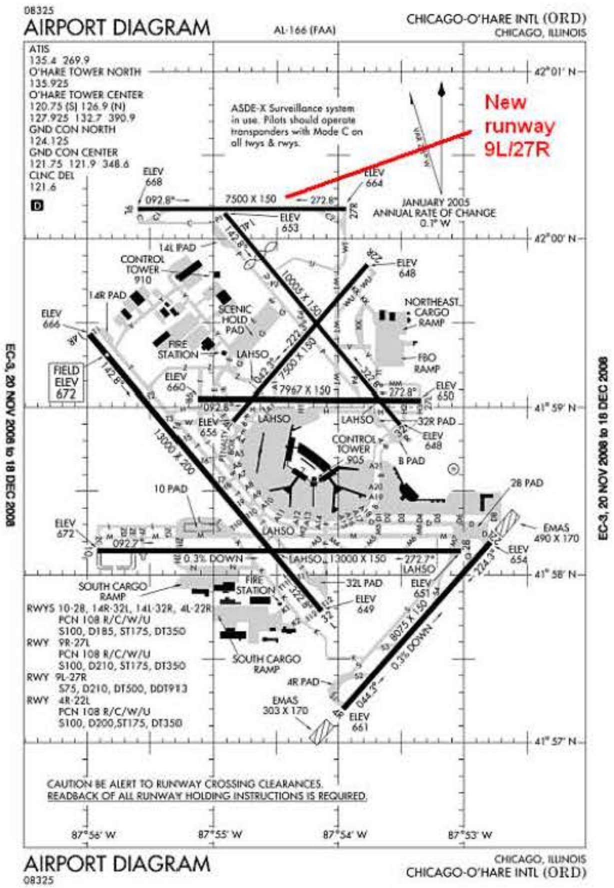
Chicago O'Hare Willow-Higgins creek relocation



- Willow-Higgins creek relocation
- Pavement management
- Facility inspection assistance and follow up
- UST removal, updates
- Jet-A fuel storage tank upgrade, AST farm design
- Title V Air Permit
- NPDES storm water permitting services
- Stormwater Pollution Prevention Plan development, implementation and update
- Runway deicing fluid facility improvements
- O'Hare Reserve Station environmental site assessment

Relevant experience

Chicago O’Hare Willow-Higgins creek relocation



Appendix CA.1.14

Relevant experience
Phoenix Sky Harbor various assignments

- Runway Reconstruction Project – Quality Control Program development and implementation
- Construction phase testing and monitoring of all materials and construction operations
- Performed Quality Acceptance testing of Portland cement concrete pavement (PCCP) and asphalt concrete paving

Relevant experience

Seattle-Tacoma SeaTac environmental contract

Wide range of engineering and environmental services over decades

- Airport parking garage construction Quality Assurance / Quality Control (QA/QC)
- Runway overlay construction inspection
- Airport exit drive aignment feasibility study
- Terminal expansion – mechanical, electrical and structural planning

Photo courtesy of WSDOT

Relevant experience

Reno South Terminal apron design / engineering

- Geotechnical
- Rehabilitation alternatives analysis
- Life-cycle cost analyses
- Engineering reports and PS&E for demolition of old asphalt concrete ramp area
- Design / construction of new concrete pavement apron

Relevant experience

PANY/NJ NY & Newark Airports – pavement management

JFK Airport solarroadways.com

Newark Airport panynj.com

- Terminal apron and gate pavement assessments
- Pavement evaluations, pavement designs, and pavement engineering on an ongoing basis
- Airport Pavement Management System update to develop a five-year plan for maintenance and rehabilitation (M&R) of airside and landside pavement networks

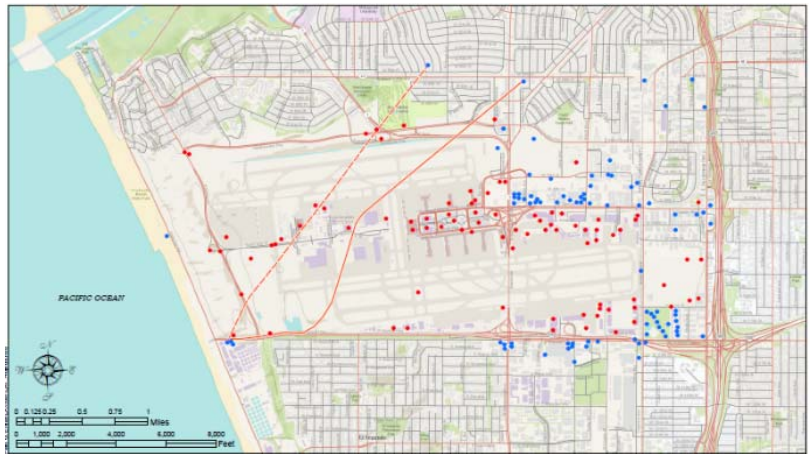
Relevant experience

Los Angeles World Airports

Amec Foster Wheeler is currently performing inspection services for the City of Los Angeles, Los Angeles World Airports under an on-call agreement for specialty inspection and materials testing.

Current new construction at LAX includes several projects:

- $1.45B+ Bradley West modernisation – largest public works project in Los Angeles City history; will double size of current 1M-sf Tom Bradley International Terminal
- $438M Central Utility Plant replacement
- ~$300M in aircraft taxi lane improvements
- $270M in elevator/escalator replacements
- $600M+ for in-line baggage handling and screening systems in all terminals
- $636M in improvements throughout Terminals 4, 5 and 6



Relevant experience

San Diego International

Main runway and taxiway pavement rehabilitation – Quality Assurance testing and inspection

Materials engineering, testing and inspection

- Concrete and masonry
- Steel
- Asphalt
- Concrete
- Aggregate
- Geotechnical, non-destructive testing
- Geotechnical testing

Relevant experience
John Wayne Airport

Pavement engineering

Geotechnical engineering and construction materials inspection

- Terminal C and NCHR building pads
- South runway
- New central utility plant
- Pavement condition survey

Environmental consulting

- Parking structure B and access tunnels soil and groundwater monitoring

Design/Build oversight

- New central utility plant

Relevant experience
US Department of Defense

Nellis AFB (NV)

Creech AFB (NV)

Bergstrom AFB (TX)

Scott AFB (IL)

Eglin AFB (FL)

Andrews AFB (MD)

International

- ► Cold Lake, Alberta, Canada – Environmental, Geotechnical, Materials, CA services
- ► Goose Bay, Labrador, Canada – environmental, groundwater modeling, pavement engineering
- ► Afghanistan – master planning, various airfields
- ► Saudi Arabia
- ► Others

Other International Airport Projects

Lisbon New Airport

Customer: Heathrow Airport, Ltd.
Location: London, UK

£15+ B, 3.5-km third runway at Europe's busiest airport. The complex planning & consultation process is being performed by an Integrated Design Team (IDT), which is delivering the Masterplan Design & Development Consent Order application material. As a member of the IDT, we are acting as lead on key technical services including environmental impact assessment and sustainability, engineering surveys, river and flood engineering, consultation, and Program Management services (cost control, programming and innovative information management solutions). 2017 fees to date approximately £8 M.

Rome Airport

GT3

Customer: RiverOak Strategic Partners
Location: Kent, UK

Leading the EIA for a Development Consent order for the Reopening of Manston Airport in Kent. The project involves the development of a freight and passenger facility with associated business park developmens. Wood was appointed by Riveroak Strategic partnership to provide a full multi-disciplinary EIA service including noise, air quality, biodiversity, major accidents and disasters, transport etc. and we expect to submit the DCO application in Q1 2018.

Central European Governments

Customer: Seattle-Tacoma International Airport
Location: Seattle, USA

The undertaking of programme management services for the Airports $2.7Bn Capital Improvement Programs. This required management of 40 individual projects of varying types across the airport. In doing this the development of management systems and provision of technical assistance

Jomo Kenyatta Airport, Nairobi

Customer: European Investment Bank
Location: Nairobi, Kenya

Wood. was appointed by the European Investment Bank as Environmental Technical Advisors to provide Kenya Airports Authority with advice and training in relation to Environmental Impact Assessment requirements and construction/ demolition associated with proposals for expanding Jomo Kenyatta International Airport.

Appendix CA.1.14

Slide 34

GT3 NIck Hilton has some text from Dublin bid that can go in here.
Gibbs, Toby, 16/02/2018

Appendix CA.1.14

Relevant experience

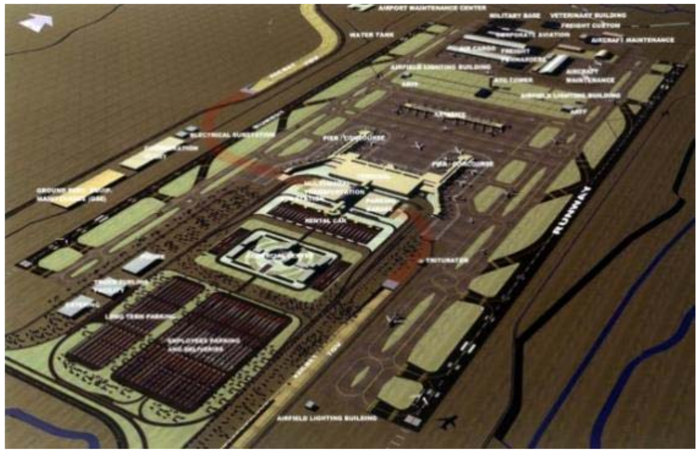
International airports

Jomo Kenyatta International Airport, Nairobi, Kenya

- ► Environmental
- ► Management technical assistance and support

New Lisbon Airport, Portugal

- ► EIA technical advisor support and assistance



TRACECA

- ► Environmental aviation advice to governments in Eastern Europe

OSPREY
CONSULTING SERVICES

1 February 2019

OSPREY CONSULTING SERVICES LTD CORPORATE RESUME

Introduction

Osprey Consulting Services Limited (Osprey) is an independent specialist aviation consultancy with the breadth of experience and capabilities that are required to provide the detailed and expert aviation advice to the Manston Airport project.

Such expertise does not only resides within our specialist Airports and Airspace Team, which comprises individuals with experience as Air Traffic Controllers, Aviators, Operations Staff and Safety Engineers, but equally in our Platforms and Air Systems Team which has an in-depth understanding of aircraft capabilities, our Air Traffic Management Systems Team which has a detailed technical understanding of airport systems and our highly specialised Instrument Flight Procedure (IFP) Design Team who develop flight procedures to international regulatory and safety standards.

Company Background

Osprey was formed in 2006 and has developed an outstanding reputation in both the civil and military aviation communities for reliability, value for money and the quality of our output. The Company comprise 40 staff in 4 UK offices; it is ISO 9001:2015 accredited and CyberEssentials Plus approved. Where required, in areas such as IFP Design, Osprey holds the appropriate individual and company accreditations from the Civil Aviation Authority (CAA).

In terms of performance, Osprey has received official recognition through awards such as the Airport Operators Association's (AOA) Aviation Consultancy of the Year 2016 and the Institute of Engineering and Technology (IET) award for Innovation in Safety. We also have extensive experience of delivering a range of high-profile airport and airspace projects and are equally well regarded across the Regulatory community; a number of our staff have previously worked in the CAA and therefore have a unique insight into what the regulator may require or accept. Osprey has also completed a number of projects contracted to the CAA itself.

Finally, Osprey regularly works at governmental level, be that conducting due diligence or operational trials, assisting with the development of policy and regulation, or delivering major airport projects such as those on behalf of the Welsh Government under a broad Framework Agreement for the provision of 'Specialist Aviation Services'.

Osprey's Capabilities

Whilst divided into 4 delivery Teams, Osprey's capabilities can be described as follows:

- Air/Space Vehicles & Systems
  - Osprey provides clients with high quality, technical and operational airworthiness expertise across a range of Air and Space Vehicles and Systems.
  - We provide support to both civil and military clients, and have a proven track record of achieving regulatory approval of systems, maintaining certification and providing engineering advice to understand risks associated with chosen solutions.
  - We can assist in development of processes and procedures and Safety Management Systems (SMS) in accordance with International Civil Aviation Organization (ICAO) SMS Guidance.
  - In this capability area we employ highly experienced staff from a variety of backgrounds including Aircraft Systems Engineers, Safety Engineers and Flight Operations and Maintenance Experts.
  - Osprey is a member of the Aerospace Defence and Security (ADS) group.
- Airports & Airspace
  - Osprey has helped more than 25 airports achieve their growth targets.
  - We are able to support, or lead, the development of the full range of airport capabilities. This is frequently achieved through the use of multi-disciplinary teams.
  - Through a robust requirements capture process, Osprey is able to offer a comprehensive procurement process for airport systems and services in accordance with UK and EU regulation.
  - We are able to offer safety case development for both airport systems and processes including a range of 'first of type' systems.
  - In terms of airspace development, Osprey can offer a unique 'end to end' capability in terms of the application of the CAA Airspace Change process including IFP Design.
  - A thorough understanding of every aspect of airport operations ensures that Osprey is able to provide detailed advice based on extensive practical experience of the sector.
  - Osprey is already providing support to a range of projects which are directly comparable in terms of scale and scope to that of Manston Airport.
- Defence
  - Osprey supports a number of different military clients in the provision of Airworthiness, Safety, Systems Engineering and Operational support. This includes support across multiple Air and Land platforms to enhance efficiency and safety such as a major Airspace Change project for RAF Brize Norton.

- Osprey has a diverse Defence capability on a range of platforms, equipment, systems and services. This demands the highest levels of competence and confidence in the support it provides.
  - We equally provide support to prime contractors within the defence sector in areas such as Airworthiness and Engineering together with Operational and Safety support.
- Renewables
  - Over the last 12 years, Osprey has assisted over 700 wind farms address their issues on aviation, and in one year alone they saw projects which would generate 6,200 MW gain planning consent; enough electricity to power 3.5 million homes per year.
  - We also have extensive experience in windfarm mitigation be that from an operational or a technical perspective which will prove invaluable in the Manston Airport project.

Summary

In summary, as a well-established and well-regarded specialist aviation consultancy, Osprey is able to offer RSP the full range of specialist aviation support required to ensure that the Development Consent Order submission remains aligned to current and anticipated aviation regulations and that the project can subsequently be implemented in a seamless manner to the satisfaction of the CAA.

Osprey's staff have extensive practical experience in both the airports and airspace sectors, but equally in the regulatory community. Such capabilities are demonstrated through our support to a wide range projects which have direct relevance to the Manston Airport project. This proven track record, combined with our reputation for independence and technical excellence, has equally seen us selected by a number of Government departments and regulators to undertake projects on their behalf. This includes a range of services to the Welsh Government Aviation Team.

However, Osprey's particular strength is not only the depth of airport and airspace expertise that we can bring to bear, but equally the breadth of our capabilities. This allows us to also consider issues from a number of perspectives including the performance or capability of an aircraft or operator, or from a systems or safety perspective. As a result, Osprey's support to the Manston project is comprehensive and authoritative.

AVIATION

Our sector expertise

rpsgroup.com

MAKING COMPLEX EASY

Appendix CA.1.14

As air travel brings people and places closer together, rising demandfor this form of transport increases the pressure on our aviation infrastructure.

Innovation for aviation

Airport maintenance, upgrades and expansions can be disruptive, while new airport developments can be complex and costly to execute.

RPS has decades of experience in aviation projects delivered both airside and landside, and we're passionate about deliveringcost-effective, high-performance air infrastructure solutions. From technical services for the upgrade of terminal facilities, to advisory services to support the strategic growth of the world's busiest airports, our focus is maximising project value whileminimising downtime and disruption.

CONTENTS:

HOME

MEETING YOUR CHALLENGES

Economic development is underpinned by the global trade of products and services. The aviation sector continues to make a significant contribution in driving this growth in passenger traffic and transportation of goods. Economic analysis shows that the aviation industry will play an important role to support growth of national economies and industry for the foreseeable future.

Airports are the bridge between the ground and the air, where users and operators meet. They provide a central pillar to a nation's sustainable economic growth and the requirement to maintain global aviation links. Airports need to develop and evolve to assist in driving economic growth for that country or region in which they are located. A balance must be achieved between the economic benefits, the cost of construction and the environmental effects – particularly carbon emissions, air quality and noise.

How can we help?

RPS provides a unique blend of town planning, architectural and engineering design, project management, health and safety and environmental services for every stage of an aviation project. We make every service offer bespoke to the individual client's needs to provide efficient, tailored solutions, based on our strategic purpose, promise and behaviours.

Examples include:

- At the masterplanning and subsequent planning stage we are able to offer strategic planning advice including advising on relevant consenting regimes working within the aviation planning policy framework, including applications for Development Consent Order and managing the environmental impact assessment (EIA) process.
- In conjunction with our airport planning and EIA teams, we provide specialist technical services including: health impact assessment, air quality, noise, flood risk, ecology, site investigation and landscape and visual impact assessments.
- Our design experience covers: airside/landside infrastructure, airfield ground lighting, airfreight facilities, business aviation facilities, cargo/passenger terminals and maintenance hangars. These incorporate architectural, civil and structural engineering, building services and airfield planning services.
- We are able to provide extensive health and safety compliance support, including; fire risk, legionella/water quality and asbestos consultancy.
- Our combined approach allows our teams to offer tailored solutions, helping airports balance their commercial goals with their responsibilities to the environment, health and safety and local communities.

EXPERIENCE

GATWICK

Since 2013 we have provided a wide range of design, environmental and planning services to Gatwick. We were strategic advisors on the development of its second runway proposal and we continue to support sustainable growth through the Design Framework.

Challenge

For the second runway scheme (R2) we worked in a lead role as part of a team of aviation expert advisors. The challenge was to develop the R2 scheme design through optioneering and assessment to provide a more sustainable solution for expansion than at Heathrow, delivering economic benefit with less environmental and community impact. Under the Design Framework we are providing a multi-disciplinary service for a series of overlapping projects to improve operational performance, in a period of targeted investment by the new owners.

Solution

Using our unique blend of experience from similar projects such as Heathrow Airport Terminal 5, 2008 Stansted Airport second runway application and our work at other airports, we assisted Gatwick at every stage of the process on planning, environmental issues and the consultation process.

Our architecture and engineering design teams have been working collaboratively on building and airfield related projects. The architectural led projects within both terminals have improved passenger experience. Other projects have included airfield schemes to improve airport operations and resilience plus landside car park schemes to provide more customer choice. Our collaborative approach with the Airport has allowed our design teams to produce efficient and effective design which has been well received by the relevant airport project teams.

Services provided

- Airfield planning
- Air quality advisor
- Architecture
- Biodiversity advisor
- Building services
- Civil and structural engineering
- Environmental coordinator
- Health impact assessment
- Strategic planning advisor
- Sustainability advisor

Client

Gatwick Airport

Completion date

Ongoing

HOME

North Terminal and Airfield - Gatwick Airport

AVIATION EXPERIENCE

TAG Farnborough Airport

Planning and environmental advisors for planning application to increase aircraft movements. Assisted the development of airport's Low Emission and Carbon Neutral Strategy.

- Planning, environmental, expert evidence

Cambridge Airport

Outline design and procurement management for a new Engine Ground Facility. Project included a 20m high steel frame structure for noise attenuation and a link taxiway.

- Airfield planning, civil & structural engineering, building services

Guernsey Airport

Scoping study, masterplanning and detail design for £62m scheme to rehabilitate the entire airside.

- Planning, EIA, stakeholder engagement, transport assessment, airfield planning, detailed design, site supervision, project management

London City Airport

Lead environmental and sustainability consultant supporting Airport's £500m development programme. Included completing EIA, ES, HIA, CEMP and Sustainability strategy.

- Environmental, sustainability, technical assessments, expert evidence

Monarch MRO Hangar

Development of a new £10m, 110,000ft² state of the art aircraft maintenance facility.

- Architecture, civil & structural engineering, building services, planning, principal designer

DHL Facility

Development of a new cargo sortation facility forming a World hub at East Midlands Airport. Scheme included cargo warehouse, offices, aircraft stand , access roads and associated infrastructure.

- Architecture, civil & structural engineering, highways, airfield planning, planning

AVIATION EXPERIENCE

Dublin Airport

Development of plans for a new runway. Detailed design for rehabilitation of runway, Terminal 1 extension and airside and landside infrastructure.

- Project management, architecture, civil & structural engineering, airfield planning, highways, planning and environmental

Southend Airport

Terminal layout and detail design for new passenger terminal.

- Architecture, civil & structural engineering, airfield planning

Stansted Airport

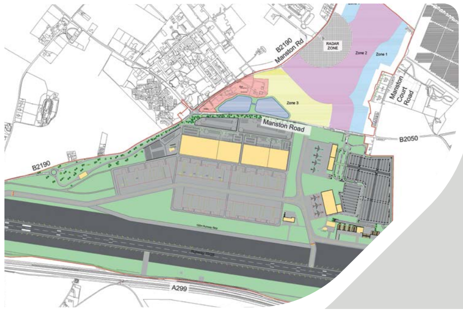
Lead consultant supporting planning application for increasing runway capacity. Coordinated EIA process including preparing ES, HIA and HRA and outline CEMP. Helped secure granting of planning permission. Also undertook landside masterplan.

- Project management, EIA, HIA , HRA, masterplanning

British Airways

Compliance Management Framework providing Fire safety assessments, legionella and water quality, asbestos management, air quality, H&S audits and noise assessments.

- Hangar inspections, lift engineering, building services



Manston Airport

Masterplanning for reopening of the airport and planning support for DCO application.

- Planning, masterplanning, airfield planning, architecture, civil & structural engineering and utilities

Luton Airport

Business aviation client facilities including hangars, Fixed Base Operations and aprons.

- Architecture, civil & structural engineering, building services engineering

ABOUT RPS

Founded in 1970, RPS is a leading global professional services firm of 5,600 consultants and service providers. Located in 125 countries across all six continents, RPS define, design and manage projects that create shared value for a complex, urbanising and resource scarce world.

We deliver a broad range of services across the asset lifecycle in: property, energy, transport, water, defence & government services and resources. We provide services in project & programme management, design & development, water services, environment, advisory & management consulting, exploration & development, planning & approvals, health, safety & risk, oceans & coastal, laboratories, training and communication & creative services. The stand out for our clients is that we use our deep expertise to solve problems that matter, making them easy to understand and we're easy to work with – Making complex easy.

Our expertise:

- Advisory and management consulting
- Communications and creative services
- Design and development
- Environment
- Exploration and development
- Health, safety and risk
- Laboratories
- Oceans and coastal
- Planning and approvals
- Project and program management
- Training
- Water services

rps MAKING COMPLEX EASY

Northpoint Aviation Services Ltd

Capability Statement

Northpoint Aviation is a boutique professional services firm specialising in aviation, travel and tourism, but with expertise that also encompasses economic appraisal, urban development, government affairs and academic research.

Northpoint's two Principals, Chris Cain and Basil O'Fee, are both Oxbridge educated and have direct hands-on experience of running a UK regional airport (Newquay Cornwall) and a UK airline (Highland Airways) respectively. In addition, they have developed wide ranging knowledge of the aviation, tourism, transport, property and infrastructure sectors, accumulated as a result of periods working for both local and Central Government, for private companies and large consultancies and as a consequence of fostering strong collaborative ties with academic institutions and a network of consultancy firms with complementary expertise.

Northpoint's six core staff and 14 Associates are able to provide advice ranging across strategy and policy, business and land use planning, route development and airport masterplanning, programme and stakeholder management, commercial and economic appraisal, state aid applications and major infrastructure and property investment.

Since its inception in 2011 Northpoint has grown to become a widely recognised brand in the UK aviation sector, with c200 clients across the public and private sectors, both within and outside the UK. Northpoint has worked in:

- the USA, Canada and Australia,
- Scandinavia and Baltic bloc countries,
- Germany, Croatia and Ireland
- the UK and its Crown Dependencies

In so doing it has worked for both national Governments and the smallest island communities, the largest airports to the smallest airlines.

The company’s Head Office is in Inverness and heads up work in Scotland, Ireland, the Crown Dependencies and Europe; but there are also offices in Cornwall (serving the South West and Wales) and Kent (London, the South East, the rest of England and North America).

Its website can be found at: https://www.northpointaviation.com

Northpoint’s contribution to the Manston Project is being run through its South East regional office and it is to there any inquiries should be directed.

South East Regional Office
14 Monarch Terrace
Kings Hill
West Malling
Kent
ME194NP

VISCOUNT AVIATION

Viscount Aviation Limited ("Viscount") provides advisory and interim management services to the wider aviation industry.

Customers from both private and public sectors include:

- Argyll and Bute Council
- Department of Arts, Heritage and the Ghaeltacht, Ireland
- Dundee City Council
- Hanseatic City of Lübeck
- Highlands and Islands Airports
- Infratil Airports
- Northpoint Aviation Services
- Regional & City Airports
- RiverOak Strategic Partners
- West Dunbartonshire Council

The managing director and principal of Viscount is Tom Wilson.

An accomplished aviation veteran, he entered the industry in 1992 and held senior executive and board positions in public and private sectors. He has held the position of Most Senior Executive / Accountable Manager for 4 airports (Prestwick, Manston, Lübeck and City of Derry).

From 2010 to mid 2014, Tom was CEO of Infratil Airports Europe (Prestwick and Manston) and latterly Executive Chairman of Prestwick Airport, a role which he undertook whilst transitioning Prestwick into the public sector. The CEO role required the minimisation of holding costs while the airports were prepared for sale and marketed. Working closely with Infratil's advisors (PwC) he managed the preparation of a data-room and made presentations to prospective interested parties. Meantime, he restructured staffing at both locations resulting in a 15% cost reduction. At Manston he oversaw an increase in both passenger and freight traffic. Ultimately Manston was sold and Prestwick was acquired by the Scottish Government. Tom was closely involved in both processes including directly interfacing with the respective principals.

Tom spent some 12 years at Prestwick Airport (1992 – 2004) the last 7 of which as Managing Director; during the period of his leadership, Prestwick was regularly the fastest growing airport in the UK (and sometimes Europe) with passenger volumes increasing from under 500,000 to over 2,000,000 and freight doubling from 20,000MT to over 40,000MT. He authored Prestwick's submission for the Government's 2003 White Paper successfully arguing Prestwick's 2030 forecast up from the initial DfT figures of 2.8m to 6.0m passengers per annum.

Leaving the position at Prestwick in 2004, he set up his own business providing advisory and interim management services to the industry and public sector. Examples of this include:

- Fulfilling the role of Geschäftsführer of Lübeck Airport (2007 – 2009), Germany, Tom drove considerable growth taking Lübeck from loss to profit and doubling passenger numbers. During 2009, the coalition of SPD, Green and Communist parties were returned to power in the Lübeck Parliament and sought to have the airport closed as a consequence of Infratil (the private owner of 90% of the shares) announcing its intention to "put" the airport back to the City of Lübeck. He worked directly with the Mayor and a Bürgerentscheid (Citizens' Referendum) was initiated which supported the continuation of the airport in public ownership. Lübeck Airport is still open today and in new private ownership. During his tenure at Lübeck, he managed a highly complex planning application to expand the airport which yielded a successful outcome; that expansion is now being implemented. The process involved public consultation, negotiations with environmental parties and the regulator (the State of Schleswig-Holstein).

- Performing due diligence work for airport acquisitions including successful bids for Manston and Lübeck.

- Running the tender and subsequent audit of the PSO contract for the Aran Islands air services. This is a public service contract to provide lifeline air connections between mainland Ireland and the Islands.

- Undertaking a detailed review of Dundee Airport for Dundee City Council. This resulted in Tom's recommendation that the airport be taken over by Highlands and Islands Airports being implemented.

- Providing recruitment advice and interviewing for regional airports.

- Providing interim support to City of Derry Airport as the Accountable Manager for a period of 2 years. During the period, the airport ran a PSO tender process for a London service and ultimately bmi regional commenced a double daily Stansted service.

Tom's experience has covered many areas including:

- The construction and development of 2 airport connected railway stations.

- Rapid low cost passenger and freight growth with relationships at CEO level with airlines.

- Tight cost control and close management of airports keeping many traditionally outsourced functions "in house" to maximise retained value and operational flexibility.

- Developing new passenger facilities and retail outlets.

- Developing large scale MRO facilities resulting in a few hundred jobs.

- Managing the design and construction of air freight handling facilities.

- Reintroducing a disused runway back into full H24 operation including airfield ground lighting and navigational aids.

- Setting up and running an Air Navigation Services Providers licence.

- Relicensing a closed civil airport.

- Procuring and introducing a new radar (primary and secondary) system.

Tom was a director of Ayrshire Chamber of Commerce and Industry and President (2003 – 2005). Prior to joining the aviation industry in 1992, he worked in the electronics and computer industry in Scotland, Europe and the USA in both technical and managerial positions.

An honours graduate in Electrical & Electronic Engineering from Strathclyde University (Glasgow) and a chartered engineer with European registration, Tom was born and brought up in the West of Scotland.

MANSTON AIRPORT DEVELOPMENT CONSENT ORDER (TR020002)

RESPONSE TO FIRST WRITTEN QUESTIONS

CA.1.32

Statutory Undertakers

Provide a schedule of all Statutory Undertakers referenced in the Book of Reference showing whether a representation under s127 of PA2008 has been made, the stage at which negotiations leading to a possible removal of that objection and the currently forecast likely outcome.

Response:

The schedule below identifies the statutory undertakers referenced in the Book of Reference (**APP-0014**) and provides the information requested by question CA.1.32.

Statutory undertaker	**Representation made under section 127 Planning Act 2008?**	**Current status of negotiations with statutory undertaker regarding representation**	**Current forecast likely outcome**
South Eastern Power Networks plc (**SEPN**)	No	Although SEPN has not made a representation for the purposes of section 127 of the Planning Act 2008, the Applicant has engaged with SEPN in order to seek to agree the form of protective provisions to be included in the dDCO (**APP-006**) in favour of SEPN. The Applicant is currently discussing the form of an agreement with SEPN's legal advisers which includes protective provisions.	The Applicant intends that the discussions ongoing with SEPN will result in a fully agreed statement of common ground, including as to protective provisions.

Appendix CA.1.32

		The initial statement of common ground with SEPN (**TR020002/D3/SOCG/SEPN**) contains further information about the status of current negotiations, including matters which the Applicant has not yet agreed with SEPN.	
UK Power Networks Services (South East) Limited (**UKPN**)	No	South East Power Networks plc has advised the Applicant that all interests recorded as belonging to UK Power Networks Services (South East) Limited in the Book of Reference should in fact be in the name of South East Power Networks plc and has recently provided the Applicant with further land ownership information in the form of an asset register. An SoCG is therefore not being progressed with UK Power Networks at this stage whilst the Applicant reviews the new information provided by South Eastern Power Networks plc.	See comment opposite.
Southern Gas Networks plc (**SGN**)	Yes dated 20 September 2018	The Applicant is in discussions with SGN's legal advisers and is actively negotiating protective provisions. The initial statement of common ground with SGN (**TR020002/D3/SOCG/SGN**) contains further information about the status of current negotiations, including matters which the Applicant has not yet agreed with SGN.	The Applicant intends that the discussions ongoing with SGN will result in the removal of its representation under section 127 Planning Act 2008.
Network Rail Infrastructure Limited (**NRIL**)	Yes dated 8 October 2018	The Applicant received on 18 January 2018 a draft framework agreement from NRIL which includes NRIL's proposed protective provisions in addition to a deed of grant in respect of the rights required by the Applicant for the project.	The Applicant intends that the discussions ongoing with NRIL will result in the removal of its representation under section 127 Planning Act 2008.

		The Applicant is currently in discussions with NRIL over the appropriate protections NRIL's infrastructure. The initial statement of common ground with NRIL (**TR020002/D3/SOCG/NR**) contains further information about the status of current negotiations, including matters which the Applicant has not yet been able to agree with NRIL.	
Southern Water Services Limited (**SW**)	No	Although SW has not made a representation for the purposes of section 127 of the Planning Act 2008, the Applicant has sought to agree the form of protective provisions with SW. The Applicant is currently waiting to hear from SW with comments on the protective provisions included in the dDCO (**APP-006**). The Applicant has provided a draft SoCG to SW. The Applicant intends that a SoCG with SW will be submitted at Deadline 4, subject to engagement from SW on the content of the SoCG.	The Applicant intends that the discussions ongoing with SW will result in a fully agreed statement of common ground, including as to protective provisions.
BT Group plc (**BT**)	No	Although BT has not made a representation for the purposes of section 127 of the Planning Act 2008, the Applicant has sought to agree the form of protective provisions with BT. The Applicant is currently waiting to hear from BT with comments on the protective provisions included in the dDCO (**APP-006**).	The Applicant intends that the discussions ongoing with BT will result in a fully agreed statement of common ground, including as to protective provisions.

Appendix CA.1.32

		The Applicant has been in discussions with BT regarding the production of an SoCG. The Applicant has sent a draft SoCG to BT. The parties will continue to work together to provide an agreed SoCG by Deadline 4.	
Nemo Link Limited (**Nemo Link**)	No	Although Nemo Link has not made a representation for the purposes of section 127 of the Planning Act 2008, the Applicant has sought to agree the form of protective provisions with Nemo Link. The Applicant is currently waiting to hear from Nemo Link with comments on the protective provisions included in the dDCO (**APP-006**) The initial statement of common ground with Nemo Link (**TR020002/D3/SOCG/Nemo**) contains further information about the status of current negotiations, including matters which the Applicant has not yet agreed with Nemo Link.	The initial statement of common ground with Nemo Link (**TR020002/D3/SOCG/Nemo**) confirms that Nemo Link does not object to the Development and has no comments on the protective provisions included in the dDCO (**APP-006**).

Appendix CA.1.32

Met Office Hadley Centre

CEH

University of Reading

Developing H++ climate change scenarios for heat waves, droughts, floods, windstorms and cold snaps

Adaptation Sub-Committee

October 2015

Appendix CC.1.2

Authors:
Steven Wade, Michael Sanderson, Nicola Golding, Jason Lowe and Richard Betts, Met Office
Nick Reynard, Alison Kay, Lisa Stewart and Christel Prudhomme, Centre for Ecology and Hydrology (CEH)
Len Shaffrey, Ben Lloyd-Hughes and Ben Harvey, University of Reading

Internal reviewers:
Simon Brown (Met Office); Helen Hanlon (Met Office)

This report has been produced by the Met Office, University of Reading and CEH for the Adaptation Sub-Committee and to support the second Climate Change Risk Assessment (CCRA).

Acknowledgements
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In addition, members of the Project Steering Group have provided useful inputs throughout the project: Amanda Charles (GO-Science), Claudette Thompson (Cabinet Office), Edward Foale (Cabinet Office), David Ramsbottom (HR Wallingford), Tracey Dunford (Natural Resources Wales), Zhong Zhang (Natural Resources Wales), Paul Dunhill (Welsh Government), Melanie Harrowsmith (Met Office), Helen Balmforth (Health and Safety Laboratory), Ken Wright (DECC), Mike Thompson (Environment Agency), Zebedee Nii-Naate (Defra), Patrick Cowdy (Welsh Government), Ragne Low (Edinburgh University), Helen Reeves (BGS), Simon Sharpe (FCO), Tim Reeder (Environment Agency), Glenn Watts (Environment Agency), Rosalind West (Defra), Kathryn Humphrey (CCC), Manuela DiMauro (CCC), Daniel Johns (CCC) and Steve Smith (CCC).

Contents

Appendix CC.1.2

Summary

This report describes the results of a project to investigate the development of plausible high-end climate change scenarios for potential use in the 2016 UK Climate Change Risk Assessment (CCRA) Evidence Report. It covers the following climate hazards: heat waves, cold snaps, low and high rainfall, droughts, floods and windstorms. The scope of the project does not extend into defining the consequences of these hazards such as mortality, property damage or impacts on the natural environment.

The scenarios created for this report are referred to as H++ scenarios, and are typically more extreme climate change scenarios on the margins or outside of the 10th to 90th percentile range presented in the UKCP09 projections (Murphy et al., 2009). For each hazard considered, H++ information is presented alongside selected indicators from UKCP09 or a range of possible changes from selected global models from the Climate Model Inter-comparison Project (CMIP5) archive (Table S1 and Sections 2 to 8).

The 2016 CCRA Evidence Report is being delivered to the UK Government by the Adaptation Sub Committee of the Committee on Climate Change. In 2012, the previous CCRA Evidence Report (Wade et al., 2012) described the potential impacts of climate change based largely on the UKCP09 projections. Although it considered High emissions scenarios[1], it did not include H++ scenarios. In some sections and in the overall summary of risks the report focused only on the Medium emissions scenario[2].

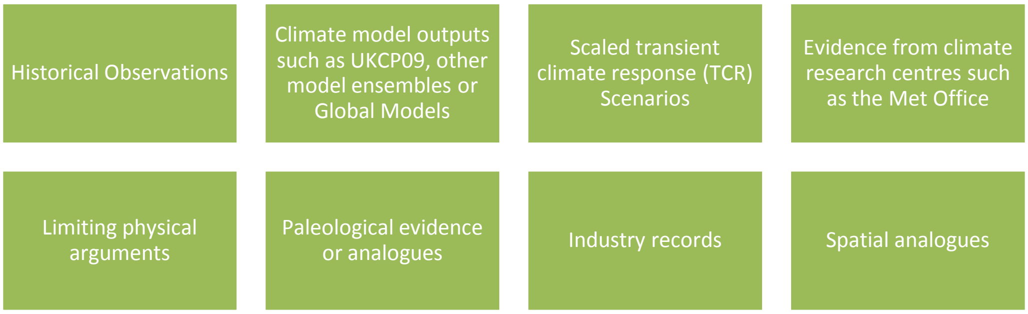
In the context of the second CCRA, H++ scenarios can help to more fully explore the potential consequences of climate change and flexibility of current and future adaptation plans. This consideration of low probability, high impact risks is a fundamental component of good risk management, and this applies as much to climate change as it does to other types of risks (King et al., 2015)[3]. These kinds of scenarios can be used for sensitivity testing different adaptation options against an extreme level of risk, which

[1] The CCRA considered Low (SRES B1), Medium (SRES A1B) and High (SRES A1FI) Emissions and the 10 % to 90 % probability levels to define upper and lower limits of possible changes as well as range of population scenarios.
[2] The key summary 'onset plots' of threats and opportunities used the Medium emissions scenario, whereas the more detailed 'scorecards' considered the full range.
[3] This report prepared jointly by experts representing the UK, US, China and India recommends that the general principles of risk assessment should be applied to climate change risk assessments. These include, among other things, "finding out more about the worse-case scenarios in relation to long-term changes as well as short-term events, and assessing the full range of probabilities, bearing in mind that a low-probability event may correspond to a very high risk, if the impact is catastrophic".

is useful for long term climate change adaptation planning[4]. These more extreme scenarios cannot be ruled out based on current understanding and may occur at some point in the future. They are often not tied to a specific time frame (e.g. 2080s), or a given level of global temperature rise from a defined baseline (e.g. 6ºC).

The H++ scenarios developed in this report are based on information from different evidence sources. Some were based on simply looking further into the tails of the uncertainty distributions of UKCP09 than was the case in CCRA1, but many also include evidence from historical observations, global and regional climate models, and/or consideration of limiting physical arguments. They all include some expert opinion, if only on the choice of evidence strands to include.

Evidence sources considered for the development of H++ scenarios



The best example of the use of H++ scenarios for adaptation planning to date is the Thames Estuary 2100 project[5]. It used a H++ sea level rise and storm surge scenario to help policy makers to think in more detail about flexible adaptation strategies and to support engineers to implement plans that will help protect London from any plausible increase in coastal flood risk up to 2100 (Ranger, Reeder and Lowe, 2013). This project is the first step in a feasibility study to consider extending the idea of the H++ scenario from the original work done for sea level rise and storm surge to other types of climate hazards.

Guidance on the use of H++ scenarios

Including information on plausible but extreme risks is an important component of robust risk management practice (King et al., 2015). We advocate using H++ scenarios in climate change risk assessments to help to provide a high impact, low likelihood event to

[4] Typically the upper end of a H++ scenario has a low probability but it is difficult and often impossible to reliably quantify this probability.
[5] This is written up in the UKCP09 Marine Projections and available on the UKCP09 web site http://ukclimateprojections.metoffice.gov.uk/media.jsp?mediaid=87906&filetype=pdf

compare against more likely outcomes. In making their assessment, decision makers need to consider the full range of possibilities, and then consider their own specific appetite for risk in making a decision on what actions to take. This means that H++ scenarios should not be used in isolation. Instead they should be used alongside estimates of the more likely range of future outcomes, for instance from the likely range or 10^{th} to 90^{th} percentile range of UKCP09 or CMIP5 models as well as information on impacts, adaptation and vulnerability.

H++ scenarios can be useful scenarios for identifying a wide range of adaptation options or adaptation pathways and discovery of the 'limits to adaptation'. They may help to identify specific types of adaptation, for example flexible plans that can be adjusted if rates of warming are greater or less than anticipated or used to highlight the importance of monitoring to understand trends or rates of change. They could be useful for screening risks or to set the boundaries for more detailed sensitivity analysis, impacts assessment or risk assessment studies. Further work is needed to explore how H++ might be used alongside a range of existing decision making approaches.

Summary of H++ scenarios

The following table summarises the H++ scenarios for each hazard and compares it with selected indicators covering a more likely range of possible outcomes. Some of scenarios relate to 30 year average conditions, whereas others relate to single years or events (long droughts). The type of scenario is indicated in Table S1 and explained in the relevant chapter. Following feedback we also use the term L-- specifically for the 'cold snap' scenario to emphasise that it is at the opposite end of the scale to the extreme warm summer temperatures in H++ and linked to Low emissions. The methodologies and conceptual framing for H++ and L-- are similar.

Some of these changes, such as summer heat waves, are much more extreme than is currently experienced and at the margins or beyond the 2080s UKCP09 High Emissions projections. Other scenarios, such as long droughts, have magnitudes that are more in line with current experience. The choice of H++ scenarios reflects the best evidence available and limitations of current climate models; it is possible that ongoing projects, such as the current NERC Drought programme, identify more extreme plausible scenarios and these should not be ruled out based on this assessment.

Table S1: A summary of the H++ scenarios presented in this report and comparisons to selected indicators from UKCP09, selected CMIP5 models or the Climate Change Risk Assessment 2012. (Event based or annual average scenarios are marked with the symbol:✷. All other scenarios relate to 30 year means).

Hazard	Scenario	Scenario description	Main basis
Heat waves	✷H++	✷ Annual average summer maximum temperatures exceeding 30°C over most of the UK and 34°C over much of central and southern England. ✷ Hottest days would exceed 40°C in some locations, with 48°C being reached in extreme cases.	Historical data, particularly anomalies related to the hot summers of 1976 and 2003; UKCP09 High emissions scenario, 90% probability level. *Explicit consideration of the Urban Heat Island effect was excluded.*
	UKCP09 High Emissions	Average summer maximum temperatures in most of England and Wales are around 14 to 22 °C (1961-1990). Under the UKCP09 2080s High emissions scenario, at the 90% probability level and regional scale, summer 30-year mean maximum temperatures are projected to be 8-9°C warmer than 1961-1990. (22 to 31 °C in most of England and Wales), but the hottest day could be 10-12°C warmer (24 to 34 °C in most of England and Wales).	UKCP09 Trends Report Figure 2.12 gridded data. UKCP09 projections (This report Section 3.3) administrative regions http://ukclimateprojections.metoffice.gov.uk/23673?emission=high
Low rainfall	✷H++	✷ A 6 month duration summer drought with rainfall deficits of up to 60% below the long term average (1900-1999). ✷ Longer dry periods spanning several years with rainfall deficits of up to 20% below the long term average (1900-1999) across all of England and Wales, similar to the most severe and extensive long droughts in the historical record.	Historical data, particularly the UK regional precipitation series (HadUKP); selected Coupled Model Inter-comparison Project (CMIP5) climate models; calculation of rainfall deficits over a range of time periods from 6 months to 5 years. *See note below on interpretation of these deficits.*
	CMIP5 range	✷ The CMIP5 baseline indicates maximum 6 month summer rainfall deficits across England and Wales of 50% below normal. CMIP5 future projections indicate a wide spread in possible 6 month summer drought severities. These may increase up to a maximum reduction of 60% below normal, or decrease to a maximum reduction of 30% below normal. No change in winter or longer duration droughts. UKCP09 does not provide drought indices.	England and Wales Precipitation (EWP). See Figure 4.4. Selected CMIP5 models. See Section 4 and Figure 4.10. *The baseline is 1900-1999 rather than 1961-90. These scenarios cannot be compared directly to deviations from a 1961-1990 baseline or data for smaller areas or maps with gridded data. A large average deficit across England and Wales indicates the potential for much larger local deficits.*
Low river flows	✷H++	✷ A 40-70 % reduction in 'low flows' (Q95) in England and Wales in a single summer. ✷ For multi-season droughts, including 2 summers, a 20 to 60 % reduction in low flows in England and Wales.	Historical data; selected Coupled Model Inter-comparison Project 5 (CMIP5) climate models used for low rainfall; use of case studies and sensitivity analysis to estimate impacts of rainfall deficits on flows. *The baseline is 1900-1999 rather than 1961-90.*
	CCRA1/ UKCP09 High Emissions	In Anglian Region for 2080s High emissions scenario, changes in annual Q95 from -38% to -70% with less severe reductions elsewhere, e.g. -13% to 33% in Orkney and Shetland.	Based on the results of water company studies (using a 1961-1990 baseline). *The H++ scenarios cannot be compared directly to results from smaller areas or different baselines.*
High	H++	A 70%-100% increase in winter rainfall	Historical data; UKCP09 High

Appendix CC.1.2

Hazard	Scenario	Scenario description	Main basis
rainfall		(Dec to Feb) in a single winter (from a 1961-1990 baseline). An up to five-fold increase in frequency and 60% to 80% increase in heavy daily and sub-daily rainfall depths, for both summer and winter events (all year round).	emissions; high resolution climate modelling; physical processes i.e. the Clausius-Clapeyron relationship between temperature and rainfall.
	UKCP09 High Emissions	A 6% to 58% increase in winter rainfall (Dec, Jan, Feb) for London (1961-1990 baseline) with greater increases elsewhere. *Note that UKCP09 did not indicate increases in heavy summer rainfall.*	UKCP09 10% to 90% probably levels. See UKCP09 web site: http://ukclimateprojections.metoffice.gov.uk/23674?emission=high
High river flows	H++	A 60% to 120% increase in peak flows at the 'lower end' of the H++ scenarios for some regions in England and Wales. The upper limit for any region is a 290% increase in peak flows (1961-1990 baseline). *The scenarios are based on the average response of "Enhanced-high" catchments, which are particularly sensitive to increases in rainfall.*	Historical data; Flood Estimation Handbook; UKCP09 High emissions; based on detailed hydrological modelling completed for the Environment Agency. Scenarios are presented for all major UK river basins.
	UKCP09	A 5% to 70% increase in peak flows in the River Thames basin (1961-1990 baseline). (The typical 'change factor' used in flood risk studies was +20%, see Section 7.2)	Analysis using UKCP09 sampled data. Low Emissions 10% probability level to High Emissions 90% probability level (Kay, *pers. comm*.)
Wind storms	H++	A 50-80% increase in the number of days per year with strong winds over the UK (1975-2005 baseline). *A strong wind day is defined as one where the daily mean wind speed at 850 hPa, averaged over the UK (8W-2E, 50N-60N), is greater than the 99th percentile of the historical simulations.*	Historical data, selected Coupled Model Inter-comparison Project 5 (CMIP5) climate models; UKCP09. *The caveat is that CMIP5 climate model simulations contain biases in the position of North Atlantic storm track and systematically under-represent the number of intense cyclones.*
	CMIP5	A change in number of days per year with strong winds over the UK between -20% to +40%.	Analysis using a sub-set of CMIP5 models and estimating 10% and 90% probability levels for RCP4.5 emissions. Baseline is 1975-2005.
Cold snaps	✷L--	✷ In the 2020s, UK average winter temperatures (December, January and February) of 0.3°C and for the 2080s, UK average winter temperatures would be around -4°C. ✷In the 2020s, UK average temperatures on the coldest day would be -7^{o}C in some locations. UK average temperature of the coldest day would be around -11°C.	Historical data, particularly the cold winter of 1962/63; UKCP09 Low emissions scenario 10% probability level; a slowdown or collapse of the Atlantic Meridional Ocean Circulation by 2080s and reductions in solar output. *Short-term cooling due to volcanic activity was excluded.* (Section 8).
	UKCP09 Low Emissions	Annual average winter temperatures for most of England and Wales are around +2 to +4 ^{o}C (1961-1990). Under the Low emissions scenario, at the 10 % probability level and regional scale, 30-year average winter (Dec-Jan-Feb) warming is 0.2 to 0.5 ^{o}C in the 2020s and 1.0 to 1.4^{o}C in 2080s above 1961-90.	UKCP09 Trends Report Figure 2.3 gridded data UKCP09 projections (This report Section 2.3) administrative regions. http://ukclimateprojections.metoffice.gov.uk/23672?emission=low

Chapter 1 Introduction

This report describes the development of H++ scenarios for use in the UK Climate Change Risk Assessment Evidence Report, which is being delivered by the Adaptation Sub Committee. It covers heat waves, cold snaps, low and high rainfall, droughts, floods and windstorms.

This chapter provides some background to the project and outlines the concept and use of H++ scenarios. Subsequent chapters present the analysis and description of each H++ scenario for the climate hazards considered. The evidence used is based on historical observations, climate model outputs, limiting physical factors that constrain future changes and, in some cases, key thresholds that are important for impacts and adaptation.

1.1 Project background

Prior to this project, two specific studies have advanced the idea of H++ scenarios. Firstly, a H++ scenario for sea level rise and tidal surge was included as an output in the 2009 UK Climate Projections and then used for the Thames Estuary (TE2100) project. Secondly, regional H++ peak flow scenarios were developed by the Environment Agency and included in advice for flood risk managers[6].

The first Climate Change Risk Assessment (CCRA) published in 2012, made reference to the H++ scenarios for sea level rise and tidal surge but did not use this in its assessment of coastal flooding, or extend the idea of an H++ scenario to other extreme events such as river and surface water flooding, drought, heat waves and cold snaps.

1.2 What is the H++ concept?

A H++ scenario can be envisaged as a 'high end' range of a change in the frequency, intensity or magnitude of a particular climate metric or hazard. In this project it is typically beyond both the likely range and 10^{th} to 90^{th} percentile range of climate futures described by the UKCP09 approach. The H++ scenario has an evidential basis that

[6] Environment Agency. Advice for Flood and Coastal Erosion Risk Management Authorities. September 2011. See https://www.gov.uk/government/publications/adapting-to-climate-change-for-risk-management-authorities

cannot be ruled out based on current understanding *and that may occur at some point in the future, and may or may not be tied to a specific time frame (e.g. 2020s, 2050s or 2080s*) (Table 1.1). With the exception of cold snaps, the high end scenarios are associated with the High Emission scenarios, which typically do not consider climate mitigation policy and have emissions growing into the future. Such scenarios typically do not have precise probabilities associated with them but are at the extreme end of the range and are assumed to be of very low probability. The difficulty in assigning a probability is partly due to gaps in understanding how the climate system works and also due to uncertainty in which emissions future will be followed. The H++ scenario can be considered to consist of both the numerical information on future change, and the narrative information on why certain strands of evidence have been chosen and the confidence in that evidence. Expert judgement is a key part of the H++ scenario development. The existence of H++ has encouraged policy makers to think in more detail about flexible adaptation strategies and limits to adaptation (Ranger, Reeder and Lowe, 2013). In particular, in the context of the second CCRA consideration of H++ scenarios can help to fully explore the consequences of extreme events outside of the ranges considered in the first assessment (Wade et al., 2012). Following feedback we also use the term L-- to describe the cold snap scenario, in order to emphasise that it is at the opposite end of the scale to the extreme warm summer temperatures in H++. The methodologies and conceptual framework for H++ and L-- are similar and they are often both referred to as H++ type events.

There will always be uncertainty associated with projections of future climate variability and change. Techniques (such as the ASK method[7] or UKCP09[8] approach) can be used to estimate some of the uncertainty by comparing model outputs against observations, and by comparing the outputs of different models against each other. This uncertainty can then be described by means of a formal probability distribution, which allows risk based decision making to be considered.

The starting point for considering H++ scenarios is often to look further into the tails of the distributions from available climate model projections, such as looking beyond the 90th percentile in UKCP09. However, there are reasons to believe that some models may not be reliable in these more extreme regimes, for instance because of limitations in the

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[7] The likelihoods of future changes are estimated by scaling the response to historical climate forcings as simulated by a model and using the scaling factors to adjust the future predictions by the same model. The basic assumption is that if a climate model under/overestimates the response to past climate forcings as compared with observed climate changes, then it will also under/overestimate the response to future forcings provided the forcings remain similar. For example see Allen et al (2000)

[8] Further background on UKCP09 is available from: http://ukclimateprojections.metoffice.gov.uk/21678

range over which components of the climate models have been designed to operate or because of known or unknown missing processes. While the models provide useful information the H++ and L-- approach also considers other strands of evidence, such as palaeo results, to give a range of high-end or low-end estimates. The number and choice of different evidence strands used will be dictated by data availability and the expert judgement of the scientists constructing the scenario. Where available information on the confidence of different evidence streams is available it may also be used as part of the process.

What H++ is	What H++ is not
• A range of values in the tail of the uncertainty distribution	• A projection of the likely future outcome
• A range suitable for sensitivity testing and investigation of no-regrets options	• A single value
• A process for combining information from different sources (not from just a single model framework)	• The maximum value possible or worst case scenario
• A tool to encourage planners and practitioners to think about their risk appetite and where crossing a specific threshold has a large impact	• Typically although H++ is known to be in the tail of the uncertainty distribution it is usually not possible to specify a precise probability for components of H++

Table 1.1: Explaining H++ scenarios

1.3 Guidance on using H++

Including information on extreme risks is an important component of robust risk management practice. Very often, climate change risk assessments in the past in the UK (including CCRA1) have focussed on a central estimate of potential future change, and ignore the tails of the uncertainty distribution. Consequently, this means that low likelihood, high impact events are not considered in decision making related to adapting to climate change. In comparison, other assessments such as the Cabinet Office's National Risk Assessment deliberately focus on a low likelihood, high impact event, specifically *"the maximum scale, duration and impact, that could reasonably be expected to occur"*, but do not consider the longer time periods of importance to CCRA2.[9]

[9] https://www.gov.uk/risk-assessment-how-the-risk-of-emergencies-in-the-uk-is-assessed

During the Thames Estuary 2100 (TE2100) project the H++ scenario range was used alongside UKCP09 scenarios. In this case "H+" and "H++" scenarios were developed and used to explore and select the best options for long term flood risk management. The final strategy was flexible; a selected programme of work was designed to protect London against floods risks under central climate change estimates to beyond 2100 (to cover the full design life of structures) but these options can be adapted to protect London from the H++ scenario (Ramsbottom, *pers. comm*.).

To bring climate change risk management more in line with other types of risk management (King et al, 2015), H++ type scenarios should therefore be used in climate change risk assessments to help to provide a high impact, low likelihood event to compare against more likely outcomes. In making their assessment, decision makers need to consider the full range of risk, and then consider their own specific appetite for risk in making a decision on what actions to take to manage the risk. This means that H++ scenarios should not be used in isolation. Instead they should be used alongside estimates of the more likely range of future outcomes, for instance from the likely range or 10th to 90th percentile range of UKCP09 or CMIP5 models as well as information on impacts, adaptation and vulnerability.

The specific benefits of H++ scenarios will depend on the adaptation planning methods in different sectors, however, in general:

- They can be useful scenarios for exploring long term climate change, identifying a wide range of adaptation options or adaptation pathways and discovery of the 'limits to adaptation'.
- They may help to identify specific types of adaptation, for example flexible plans that can be adjusted if rates of warming are greater or less than anticipated or used to highlight the importance of monitoring to understand trends or rates of change.
- They could be useful for screening risks or to set the boundaries for more detailed sensitivity analysis, impacts assessment or risk assessment studies.

An important issue for users of H++ is to consider what early warning could be put in place to detect if the real world climate is deviating from the likely projected range and heading towards the H++ or L-- values. In some cases the change may result from abrupt events and so the amount of early warning may be limited but still potentially useful. In many cases the onset might be much slower. For some H++ cases existing observing systems, for instance for temperature or sea level, might be utilised.

The H++ type scenarios outlined in this report only consider changes in climate hazards; i.e. the frequency, intensity or magnitude of a weather-related event. It has not been possible with the resources available to extend these scenarios into describing the consequences of such events such as the impact on mortality, property damage or impacts on the natural environment. Further work to consider these consequences would be useful to give a fuller picture of the impact of such scenarios. In particular, some consideration of consequences is needed by the authors of the CCRA2, to give a sense of how they compare to more likely outcomes. Some of this work has been carried out in two of the other research projects funded to input into CCRA2 that are available alongside this report, on projections of flood risk, and projections of future water availability.

Finally we note that a key part of future planning is communication, both of the threats and opportunities of climate variability and change and of the decisions that are made when developing adaptation plans. We strongly recommend where possible that the H++ and L-- scenarios are communicated alongside the likely range and following a clear discussion of the concepts of low probability high impact events. The purpose of including these scenarios should be made clear to all involved stakeholders. Limitations and caveats related to the use of H++ concepts are discussed in Annex 1, which also includes further draft guidance on their use in the CCRA and elsewhere.

1.4 Approach

In this feasibility study of developing H++ type scenarios we first decided on a structured approach for including a range of different types of evidence. This was based on experience from developing the earlier sea level H++ scenarios and expert judgement of the science leads in the project. The strands of evidence considered are summarised in the diagram below (Figure 1.1). Expert judgement forms a key ingredient in both selecting the evidence sources and ensuring data sources are used sensibly, and providing a means of combining evidence or dealing with conflicting evidence. If a confidence level can be assigned to the evidence strands this can form part of the H++ type scenario. The scale of confidence ratings is guided by that of the IPCC (Mastrandea et al, 2010), where very high confidence corresponds to their being both robust evidence and agreement between sources and very low confidence means there is either limited evidence or poor agreement between evidence.

Historical Observations	• This aims to identify the 'biggest known events' in the historical record (magnitude, location, extent, duration). It also forms a key communications tool for H++ type scenarios and provides a sanity check on all other evidence sources.
UKCP09, other model ensembles or Global Models	• UK Climate Projections (UKCP09) distribution tails - while most focus has been on the full distribution here we recommend looking in the tails of the probability distribution and local outliers of the regional climate model (RCM) simulations. If using the sample data product the largest number of samples should be used. • Other Global Models, especially the Coupled Model Intercomparison Project (CMIP5) range up to 2100 - these are structurally different to the Met Office HadCM3 model used in UKCP09 and so may perform differently. However, the ensemble has not been set up to sample uncertainty so should be used with caution. This also includes experiments designed to test particular physical mechanisms, such as a collapse of the AMOC.
Scaled TCR Scenarios	• This involves translation of CMIP5 extended Representative Concentration Pathway (RCP) experiments as an analogue for higher Transient Climate Response (TCR) or greater radiative forcing. Upper limits for TCR will be taken from multiple evidence strands in the IPCC 5th assessment.
Evidence from Met Office & other climate research centres	• These often involve single simulations of high resolution climate or impact models or creation of new datasets, for example Kendon et al 2014.
Limiting physical arguments	• There may be limiting physical arguments which bound the extent of potential future outcomes. Consideration of these will also serve to provide a sanity check on the rest of the analysis.
Paleo evidence or analogues	• We will include evidence from studies of tree rings, lake sediments and evidence of coastal or river erosion where these are relevant.
Industry records	• Some industries such as energy, transport and water may hold valuable independent records relevant to this analysis. Access to these will be sought where relevant.
Spatial analogues	• For some analyses, consideration of spatial analogues may be useful to provide context. However, issues of consistency will need to be taken into account, e.g. analogues based on temperature alone may select weather regimes with very different conditions to the UK under current and future conditions.

Figure 1.1: Structured approach - consideration of data sources

Each Hazard was then assigned to a lead scientist who was asked to apply the H++ methodology as they understood it, and as time allowed. For each hazard the leads were each asked to consider:

- The most appropriate source(s) of data for scenario generation, e.g. UKCP09 or CMIP5 models

- Existing research, particularly impacts modelling and links with other projects funded by the ASC to inform the CCRA (on water resources, floods and ecological impacts) to ensure consistency in the approaches used
- Information on relevant thresholds that are important for impacts assessment (where possible)

Each source of evidence has been reviewed and evaluated in terms of its contribution to the development of the H++ scenario. Where climate models are the primary source of information, an assessment was made of their level of skill and where appropriate caveats are highlighted at the beginning of each section.

Chapter 2 Heat waves

2.1 Summary of the High++ Hot Day and Heat Wave Scenarios

The H++ hot day and heat wave scenarios span a range of time scales (1 day to a season) and encompass the entire UK. The time scales of the H++ scenarios are relevant for a variety of purposes. Mortality is elevated during heat waves, especially among the elderly (Hajat et al., 2014). Infrastructure can be affected by hot temperatures – for example, buckling of railway tracks (Dobney et al., 2009). Periods of very high temperatures are also often accompanied by little or no rainfall, leading to drought conditions and placing even greater demand on the water supply system (Chapter 5).

Future summers, heat waves and hot temperatures in the UK are likely to be hotter and last longer than present day events. Under the UKCP09 2080s High Emissions scenario at the 90$^{\%}$ probability level and regional scale, 30-year average UK regional summer temperatures are 6.0^{o}C to 8.1^{o}C warmer than the 1961-1990 baseline[10]. These changes were considered along with data from the 1976 and 2003 hot summers/heat waves to derive H++ scenarios for hot summers, heat waves and hottest days of the summer.

Under these H++ scenarios average summer maximum temperatures would exceed 30°C over most of the UK, and would exceed 34°C over much of central and southern England. Temperatures of the hottest days would exceed 40°C, with 48°C being reached in London.

The H++ scenarios were developed using historical extreme heat waves and days with record high temperatures, and modelled changes in summer temperatures from the UKCP09 projections. The H++ methodology involved calculating summer average baseline temperatures for the UK using observed daily maximum temperatures for the period 1961-1990. Anomalies for the hottest days, hottest heat wave and hottest summer relative to that baseline period were also calculated[11].

[10] http://ukclimateprojections.metoffice.gov.uk/23673?emission=high

[11] This approach was adopted following peer review and is simpler than the work previously presented in the first draft report, which was based on analysis of the Met Office Hadley Centre Regional Climate Model and included information on the extension of heat wave durations.

As for the cold H++ scenarios, this approach is subject to a number of caveats. First, it assumes that the anomalies of the 1976 summer and 2003 heat wave average and hottest days from a long term mean can be added to future summer mean temperatures. Secondly, the calculation does not explicitly consider the urban heat island (UHI) effect, assuming that this is captured in the anomalies of these two events[12]. Thirdly, in the presentation of gridded data (Figure 2.2) it adopts the spatial patterns of anomalies observed in previous events when future heat waves could be centred differently and have larger (or smaller) spatial extents. Finally, all changes were calculated at the scale of the climate model (25 km) and temperatures at some individual locations are likely to be hotter still[13].

The assumptions adopted here have been accepted in other peer reviewed studies (e.g. Schoetter et al., 2014) and the results are also consistent with other studies over Europe (Russo et al., 2014) and the UK (Brown et al., 2014), albeit producing slightly higher maximum temperatures. There will be dynamical and thermodynamic limits on how high temperatures in the UK could become in the future, but is not known what those limits are. The temperatures of very hot summers are controlled by several different factors, of which the most important are the synoptic patterns. For example, during August 2003, very hot air was transported from continental Europe to the UK which led to the record temperatures. Droughts exacerbate the temperatures, since there will be little or no cooling of the land via evaporation of water from the soils. These physical limits are discussed in more detail in section 2.5.

2.2 Historical data

There are several different data sources which can be studied to examine how periods of warm weather have changed in the past and provide guidance on suitable H++ scenarios. Northern hemisphere annual average temperatures have been estimated using a wide range of proxy data, such as tree ring widths, composition of lake sediments and pollen samples. Some of these proxy records cover the past 2000 years. The Central England Temperature record (CET; Parker et al., 1992) dates back to 1659, and is the longest instrumental series of this kind in the world. Monthly mean temperatures are available over the entire series. Gridded temperatures based on weather station records are available from 1910 (Perry and Hollis, 2005). Briefly, data

[12] Refer to Annex 7 of the UKCP09 climate projections report http://ukclimateprojections.metoffice.gov.uk/22530

[13] A comparison of the gridded temperatures at the 5 km and 25 km spatial scales showed that the 5 km data can be up to 3-4°C hotter than the 25 km data.

from the UK weather and climate station network were gridded by regression and interpolation to a 5 km × 5 km grid, taking into account factors such as latitude, longitude, coastal proximity and local topography (Perry and Hollis, 2005; Perry et al., 2009). These data have been aggregated to the 25 km × 25 km grid used by the UKCP09 climate projections. Monthly data are available from 1910, and daily data from 1960.

Historical northern hemisphere mean temperatures

Annual average temperatures for all or part of the northern hemisphere for the last 2000 years have been reconstructed using a wide range of proxy data (Masson-Delmotte et al., 2013). These reconstructions show that annual temperatures were anomalously warm between about 950 and 1250, a period referred to as the Medieval Climate Anomaly (or Medieval Warm Period). They also indicate that any 30 or 50 year average temperature was very likely cooler during the past 800 years than the 1983-2012 or 1963-2012 instrumental temperatures (Masson-Delmotte et al., 2013). Some reconstructions for the first millennium suggest that some 30 or 50 year periods may have been as warm as 1963-2012. Confidence in this finding is low as there are fewer proxy records and less independence among the reconstructions (Masson-Delmotte et al., 2013).

The record-breaking summer of August 2003 in Europe is the hottest for Europe in the instrumental record (which begins in 1850[14]). Record temperatures from this heat wave have not been reached or exceeded since in many countries. This heat wave claimed many lives, mostly among the elderly. However, an analysis of a new source of proxy data (grape harvest dates between 1444 and 2011) in Switzerland suggests that the late spring and early summer (April to July) of 1540 may have been even hotter than 2003 (Wetter and Pfister, 2013). An exceptionally long drought occurred during 1540 which contributed to the unusually high temperatures (Wetter et al., 2014). Temperature anomalies for 1540 were estimated to be between 4.7°C and 6.8°C hotter during April-July than the 1901-2000 mean temperature for April-July in the Alpine region. The same late spring-early summer period in 2003 was only 2.86°C hotter. Other historical reports show that temperatures were still anomalously warm in Switzerland ("like April") in winter

[14] Measurements of temperature are available at a small number of locations before 1850 in Europe. For example, temperatures at four European stations are available from 1721 (Jones and Moberg, 2003), but none of these stations indicate temperatures between 1721 and 1850 were as warm as those in 2003. The number of sites prior to 1850 is probably too small to estimate Europe-wide temperatures.

1540/1541, and no frost or snow covered the ground (Wetter and Pfister, 2013). Kington (2010) states that Britain was affected by a severe drought between 1538 and 1541, with the Thames so low that salt water flowed as far upstream as London Bridge. He also suggests that the summer of 1540 was probably one of the warmest on record. The study of Wetter and Pfister (2013) suggests a heat wave much hotter than that of 2003 is possible in a single country even without any effects of anthropogenic warming.

Warm Summers in the Central England Temperature Record

Summer (June, July and August) mean temperature anomalies (relative to the 1961-1990 average) between 1660 and 2014 from the CET are shown in Figure 2.1. Summer temperatures at the beginning of the series (up to about 1700) were generally colder than average, as this period is at the end of the Little Ice Age. Summers between 1700 and 1810 tended to be warmer than average, followed by a second period of cooler summers (1810 to 1930).

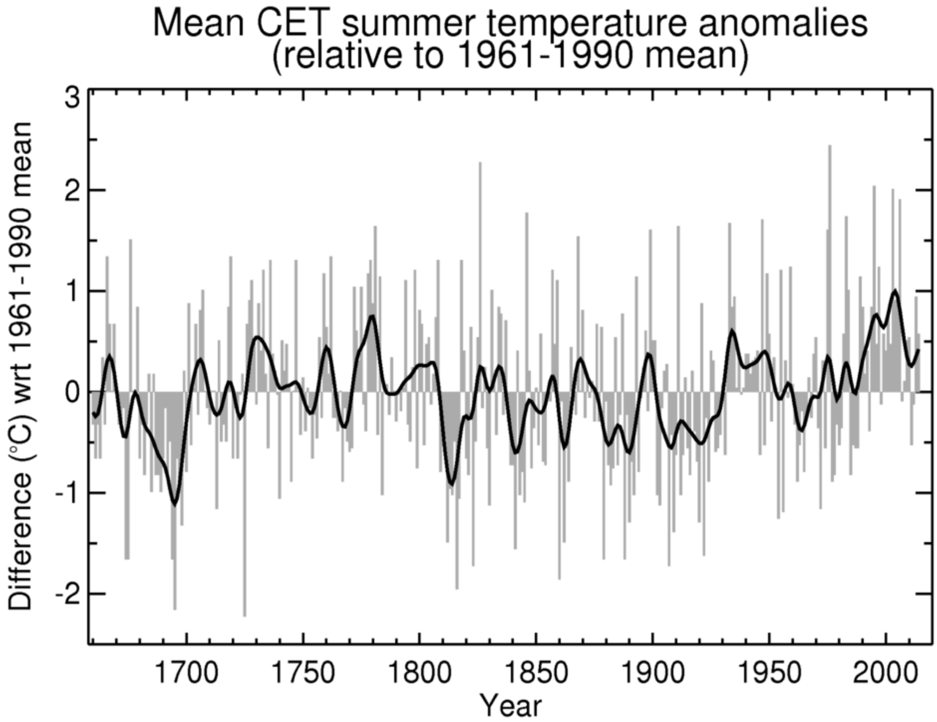


Figure 2.1. Summer mean temperature anomalies for the years 1660-2014 relative to the 1961-1990 annual mean. The grey bars show individual anomalies for each year. The black line is a smoothed version created with a 21-term binomial filter (Parker, 2009).

As always, there are exceptions; the summer of 1826 is the second warmest in the CET, only the summer of 1976 is warmer. Other notable warm summers are 1995, 2003 and 2006. There has been an unusually long run of warm summers since 1990. A positive trend of 0.075 ± 0.050°C per decade in summer mean temperatures exists between

1900 and 2014. An analysis by eye of the summer temperature anomalies shown in Figure 2.1 suggests that the coldest summers have warmed by about 1°C since 1950. Temperatures of the warmest summer anomalies have also increased, from about 1.3°C during the 18th century to around 1.7°C in the late 20th and 1.9°C in the early 21st century.

UK hot temperature records

The hottest days and nights in the UK have been identified from weather stations by the NCIC, and the hottest days and nights for each part of the UK are shown in Table 2.1. Many of the record hot temperatures occurred during the heat waves of 1976, 1990 and 2003. Interestingly, none of these records occurred during the hot summer of 2006, when temperatures in excess of 36°C were recorded near London. Very warm temperatures were recorded on the 1st July 2015 at many stations across the UK, but they did not exceed the absolute records in Table 2.1

Table 2.1. UK record hot temperatures from weather stations, which date back to the 1850s

UK Region	Hottest Daily Maximum / °C	Date	Hottest Daily Minimum / °C	Date
Scotland	32.9	09.08.2003	20.5	02.08.1995
England	38.5	10.08.2003	23.9	03.08.1990
Northern Ireland	30.8	30.06.1976 12.07.1983	20.6	31.07.1868
Wales	35.2	02.08.1990	22.2	29.07.1948

Historical changes in hot days and heat waves

Della-Marta et al. (2007) analysed a data set of 54 high-quality homogenized daily maximum temperature series from western Europe for the period 1880-2005. A hot day was defined as any day whose maximum temperature exceeded the 95th percentile of summer (June, July and August) daily maximum temperatures for the period 1906-1990. A heat wave was the longest number of consecutive hot days in any given year. Della-Marta et al. (2007) concluded that over the period 1880 to 2005 the length of summer heat waves over western Europe had doubled and the frequency of hot days had almost tripled. Heat waves had also become 1.6 ± 0.4°C hotter over this period.

The Intergovernmental Panel on Climate Change (IPCC) Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) concluded that there was medium confidence that the length and/or number of heat waves had increased globally since the middle of the 20th century and that it was very likely that the length, frequency, and/or intensity of these events would increase over most land areas by the end of the 21st century (Seneviratne et al., 2012). These conclusions were reiterated and strengthened by the IPCC Fifth Assessment Report (AR5; Hartmann et al., 2015).

Heat waves in the UK were identified and analysed using 5 km gridded daily maximum temperatures for the period 1960 – 2013 (Perry and Hollis, 2005; Perry et al., 2009). A simple heat wave definition was used, where a threshold temperature of 30°C had to be exceeded on 3 or more consecutive days (Perkins and Alexander, 2013). This threshold is arbitrary but a day when maximum temperatures reached or exceeded 30°C would be considered to be a very hot day (Schoetter et al., 2014). This threshold was exceeded in all of the major heat waves of the twentieth and early twenty-first century (Burt, 2004). The most extreme heat wave was then identified using a variety of definitions: (a) highest temperatures reached, (b) longest consecutive period with daily maximum temperatures at or above 30°C, and (c) largest area of the UK where 3 or more consecutive days reached or exceeded 30°C.

Heat waves in the UK vary considerably in their characteristics. The most extreme heat wave identified depends on the definition used. The highest temperatures occurred in 2003, where 38.1°C is present in the gridded data (note that the highest actual temperature measured during 2003 was 38.5°C at Faversham in Kent on 10th August). The longest heat wave occurred in 1976, where sixteen consecutive days were at or above 30°C at 12 locations around the UK. The total number of days where 30°C was reached or exceeded in one or more locations was twenty in both 1976 and 1990. The largest total land area in the UK where 3 or more consecutive days were above 30°C at some point during the summer months was 81,000 km^2 during 1976, closely followed by 73,000 km^2 in 1995. For comparison, the areas in 2003 and 2006 were 32,400 and 68,000 km^2 respectively.

These results illustrate that characteristics of historical heat waves can be very different. For example, record high temperatures were recorded during the 2003 heat wave, but the longest heat wave, greatest spatial extent of a heat wave and hottest summer all occurred in 1976. These results are dependent on the threshold used to define a heat wave. The use of a lower or higher threshold would change the lengths and numbers of heat waves identified. However, the broad findings above are unlikely to change drastically.

2.3 UKCP09

In the UKCP09 projections all areas of the UK warm, more so in summer than in winter (Murphy et al., 2009). For the Medium emissions scenario changes in 30-year summer mean temperatures for the 2050s are greatest in parts of southern England (up to 4.2ºC (2.2 to 6.8ºC))[15] and least in the Scottish islands (just over 2.5ºC (1.2 to 4.1ºC))[16].

Under the UKCP09 2080s High emissions scenario, at the 90% probability level and regional scale, UK regional 30-year mean summer temperatures are 6.0^{o}C to 8.1^{o}C warmer than the 1961-1990 baseline[17]. Gridded data for this specific scenario are included in the calculation of H++ scenarios in Section 2.5.

30-year average mean daily maximum temperatures increase everywhere. Increases in the summer average are up to 5.4ºC (2.2 to 9.5ºC) in parts of southern England and 2.8ºC (1 to 5ºC) in parts of northern Britain (Murphy et al., 2009). Modelled changes in the 30-year average warmest day of summer from the UKCP09 projections (using the 90% probability data) are larger than changes in summer mean maximum temperatures. For example, around London summer average 30-year mean maximum temperatures are projected to be 8-9°C warmer, but the hottest day could be 10-12°C warmer. These results suggest that the highest temperatures will warm at a faster rate than mean temperatures during the summer months (see physical limits section).

UKCP09 did not consider potential future changes in the Urban Heat Island (UHI) effect, although this is discussed in Annex 7 of the climate projections report (Murphy et al., 2009).

2.5 Physical limits

Miralles et al. (2014) investigated the physical processes underlying recent extreme heat waves using satellite and balloon measurements of land and atmospheric conditions from the summers of 2003 in France and 2010 in Russia. They found that these extreme heat waves could only occur with very dry soils, advection of heat and the presence of a

[15] Central estimates of change (those at the 50% probability level) followed, in brackets, by changes which are very likely to be exceeded, and very likely not to be exceeded (10 and 90% probability levels, respectively).
[16] Based on the summary report http://ukclimateprojections.metoffice.gov.uk/22530
[17] The range represents different rates in different UKCP09 administrative regions http://ukclimateprojections.metoffice.gov.uk/23673?emission=high

high pressure system nearby; similar conclusions were reached by Quesada et al. (2012). During daytime, heat was supplied by large-scale horizontal advection, warming of an increasingly dry land surface and enhanced entrainment of warm air into the atmospheric boundary layer. Overnight, the heat generated during the day was preserved in an anomalous kilometres-deep atmospheric layer located several hundred metres above the surface. This layer then re-entered the atmospheric boundary layer during the next diurnal cycle. These processes resulted in a progressive accumulation of heat over several days, which enhanced soil desiccation and led to further escalation in air temperatures. Miralles et al. (2014) suggested that the very hot temperatures observed during extreme heat waves can be explained by the combined multi-day memory of the land surface and the atmospheric boundary layer. Miralles et al. (2014) noted that the length and severity of heat waves is ultimately determined by the synoptic conditions. Rainfall deficits leading to dry soils are not a necessary requirement, and soil desiccation may not play a role in determining the duration of the heat wave.

2.4 Other evidence

Several recent papers have considered the impacts of climate change on heat waves. Russo et al. (2014) developed a new heat wave metric, which accounts for both magnitude and duration of heat waves. Using this metric, they studied extreme heat waves which occurred worldwide between 1980 and 2012, and projected changes in spatial extents and severity of heat waves under a range of emissions scenarios. However, this new metric does not seem to have identified the severe heat wave which occurred in Australia between 25th January and the 9th February 2009 (Australian Government, 2009).

Russo et al. (2014) noted that the CMIP5 models do not reproduce heat waves as severe as that of August 2003 during the historical period. Heat waves similar to August 2003 were projected to become the norm in Europe after 2070 under the high emissions scenario (RCP8.5). Very extreme heat waves (worse than 2003) were only projected under the RCP8.5 scenario during the period 2068-2100, and occurred 1-2 times per year. Stott et al. (2004) used a different climate model (HadCM3) and greenhouse gas emission scenario (SRES A2) and projected that summers like 2003 could be normal as early as 2040, and would even be considered cool by 2060.

Brown et al. (2014) used extreme value analysis together with emulated climate model data to estimate the future 1 in 50 year summer daily maximum temperature for London.

This estimate was made for 1961-1990 and a 20 year period centred on 2050 using the A1B emissions scenario. The 1 in 50 year temperature for 1961-1990 was 35.7°C, and for 2040-2060 was estimated to lie between 35.9°C and 42.1°C (10th – 90th percentiles). The estimated maximum temperatures for H++ scenarios for London on the two hottest days in Figure 2.2 (lower panels) are 46.1°C and 48.1°C, which are higher than the estimates of Brown et al. (2014). However, Brown et al. (2014) used the medium emissions scenario (A1B). If a high emissions scenario had been used (e.g., A1FI, A2, RCP8.5), and the estimate was made for the end of the 21st century instead of 2050, the estimated 1 in 50 year temperatures would be higher.

2.6 H++ scenarios

The summer of 1976 is the hottest in the UK instrumental record, and also contains the heat wave which lasted the longest (16 days) and had the greatest spatial extent. The 2003 heat wave is the hottest (so far) to occur in the UK. During the period 3rd - 12th August temperatures exceeded 30°C over some or most of the UK (Burt, 2004). The hottest two days were the 9th and 10th of August. On the 9th August temperatures exceeded 30°C over almost all of the UK, and temperatures in south-east England reached around 37°C in many locations. On the 10th August 2003, a slow moving cold front was bringing cooler conditions to most of the UK, but the highest temperatures of the heat wave (exceeding 38°C) were recorded in south-east England on this day. The 12th August was the last day when temperatures were at or above 30°C over south-east England. By the 15th August temperatures had returned to near normal (Burt, 2004).

The daily maximum temperature anomalies for the 9th and 10th August 2003 (the two hottest days of the heat wave) were compared with the projected changes in the 30-year average hottest day of summer from the UKCP09 projections at the 90th probability level (Murphy et al., 2009). Although the spatial distributions of the temperatures differed, the magnitudes were very similar. This result suggests that the hottest days of the August 2003 heat wave could be indicative of the typical hottest day of summer at the end of the 21st century (i.e. the 30 year average).

The data in Table 2.2 were used to construct a H++ summer, a H++ heat wave and two H++ hottest days. Maps illustrating the four H++ scenarios are shown in Figure 2.2. First, a new baseline was created, which is the sum of the 1961-1990 average and the UKCP09 30-year average change in summer mean maximum temperature (90th probability level). The H++ summer is the sum of the new baseline and the summer 1976 mean anomalies. The August 2003 heat wave anomalies were then added to the new baseline summer temperatures to create the H++ heat wave. Finally, temperature anomalies associated with the two record hottest days (9th and 10th August 2003) were added to the new baseline to create two possible H++ hottest summer days. These scenarios are therefore event based and describe hot conditions over specific time periods.

The maps shown in Figure 2.2 show that average temperatures in the H++ summer and heat wave are very similar. A H++ summer could be considered to be a continuous heat wave, and so would last around 90 days.

Table 2.2 Data used to create the H++ scenarios for summer, a heat wave and hottest days.

Variable	Description	Type
Baseline	1961-1990 summer mean of daily maximum temperatures	Gridded
Change in summer mean maximum temperature	UKCP09 2080s (2070-2099), high emissions scenario, 90% probability level	Gridded
Hottest summer average temperature anomalies	Summer 1976	Gridded
August 2003 heat wave mean anomaly	Average maximum temperature anomaly for the period 3rd-12th August 2003	Gridded
August 9th 2003 anomaly	Daily maximum temperature anomaly for the 9th August 2003	Gridded
August 10th 2003 anomaly	Daily maximum temperature anomaly for the 10th August 2003	Gridded

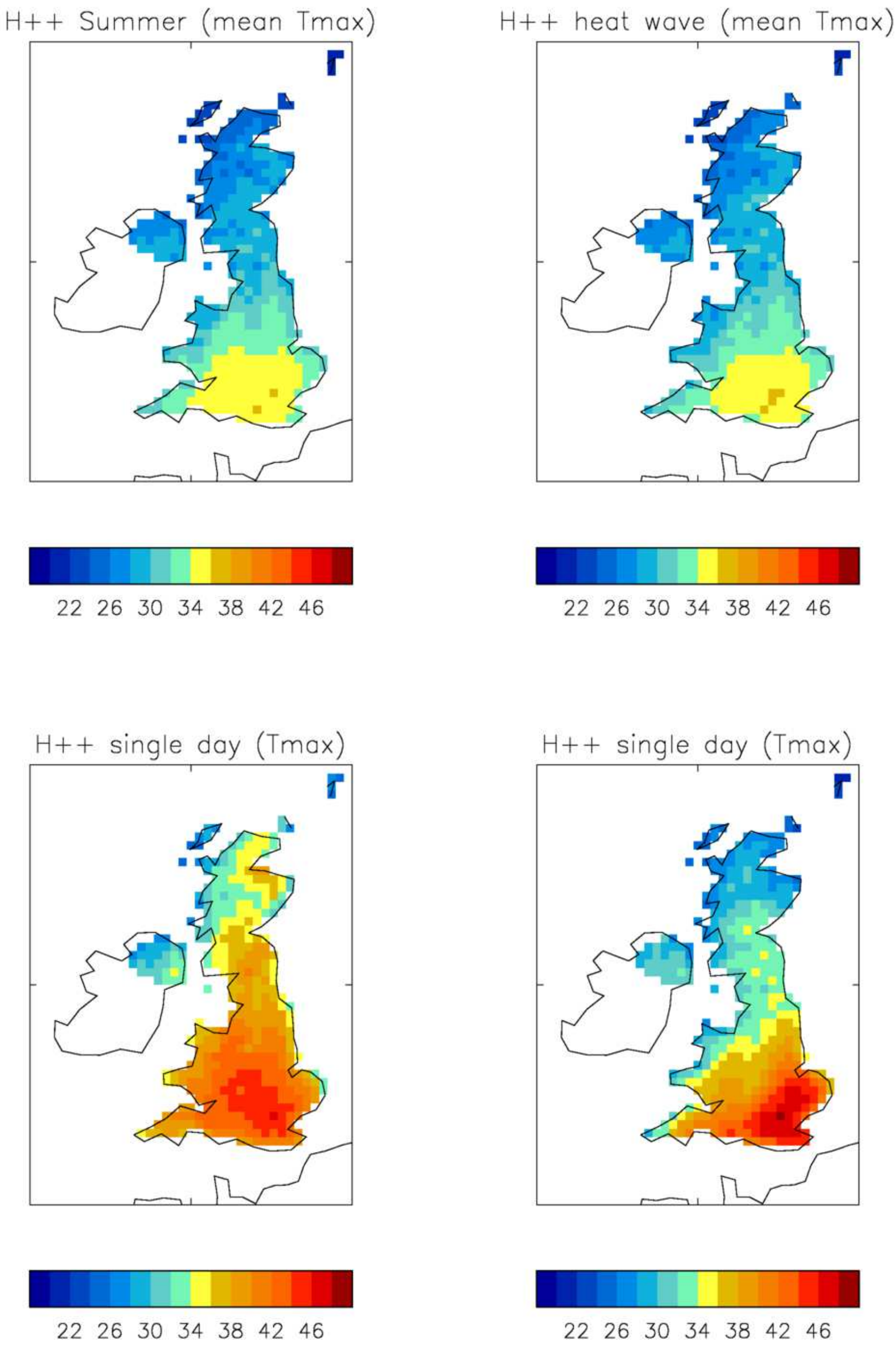


Figure 2.2 H++ scenarios for summer, a heat wave, and two possible hottest days. All temperatures are in °C.

The approach used here assumes that the anomalies of the 1976 summer and 2003 heat wave average and hottest days from a long term mean can be added to future 30-year average summer mean temperatures. Schoetter et al. (2014) studied changes in heat waves in the CMIP5 ensemble. They found that a shift in the temperature distribution towards higher temperatures was more important for the increase in heat wave severity than any changes in the width of the distribution. This result suggests that adding observed anomalies to changes in average summer temperatures is reasonable. There will be dynamical and thermodynamic limits on how high temperatures in the UK could become in the future, but is not known what those limits are.

All changes shown in Figure 2.2 were calculated at the scale of the climate model (25 km) and are based on projections of a 30-year average change rather than changes for single years, which would be higher in some cases. Temperatures at individual locations are therefore likely to be hotter still. A comparison of the gridded temperatures at the 5 km and 25 km spatial scales showed that the 5 km data can be up to 3-4°C hotter than the 25 km data. Finally the calculation does not consider potential future changes in the urban heat island effect, which raises temperatures by 1 to 2 °C even under current conditions[18].

Under the H++ scenarios average summer (JJA) maximum temperatures would exceed 30°C over most of the UK, and would exceed 34°C over much of central and southern England. Temperatures of the hottest days would exceed 40°C, with 48°C being reached in London.

The anomalies for the hottest days (from observations) were compared with projected changes in the hottest day of summer from the UKCP09 projections. The magnitudes of the observed and modelled anomalies were very similar. The observed anomalies could be considered as representative of future very hot days. Projected changes in mean summer maximum temperatures from the UKCP09 projections were added to the baseline along with the anomalies for the hottest days and heat wave to create the H++ scenarios. The reported temperatures are the highest that can be estimated from the models and observations.

A summary of the data sources used to estimate the H++ scenarios is given below.

- Palaeo. Reconstructed northern hemisphere annual average temperatures for 30 and 50 year periods over the past 2000 years suggest present-day temperatures have not been reached or exceeded in the past 800 years. However, one recent

[18] Refer to Annex 7 of the UKCP09 climate projections report http://ukclimateprojections.metoffice.gov.uk/22530

reconstruction suggested the late spring and early summer of 1540 in central Europe was much hotter than 2003. It is not clear whether the UK also experienced extreme hot temperatures during the same period.

- Historic. The CET shows that 1976 was the hottest summer overall, although individual months were hotter in other years. The CET also shows that temperatures of the coldest and warmest summers have become higher, and there has been a series of warm summers since 1990.
- UKCP09. These climate projections all suggest that summers will be hotter in the future. Modelled increases in the temperature of the hottest day of summer are larger than changes in summer mean temperatures.
- CMIP5. Analyses of European temperature changes all suggest that summers in the future will be hotter and heat waves will be more severe. The CMIP5 models do not simulate heat waves as severe as 2003, and so may underestimate future heat wave severity. Very few of the published studies of future heat waves specifically consider the UK.

Chapter 3 Low rainfall

3.1 Summary of the High ++ low rainfall scenarios

The High ++ low rainfall scenarios span a range of time scales (6 to 60 months) and three major UK regions (England & Wales, Scotland, and Northern Ireland).

Future summer meteorological droughts in England and Wales could be more or less severe. Severe short drought (6 months) and long multi-season drought (of three years or more) are of particular interest to users in specific sectors, for example:

a) Agriculture – short period droughts (6 months in either winter or summer) with little/no rainfall. These may also be associated with extremes in temperature (hot summer, cold winter).

b) Water supply systems - long period droughts (multi-season, 3 years or more) as these can have a significant impacts on public water resources systems designed to cope with shorter drought periods.

The H++ scenarios were developed using a credible set of climate models selected from the UKCP09 and CMIP5 archives.

The H++ methodology for low rainfall involved computing changes in the probability of precipitation deficits of a given magnitude over a range of accounting periods. The reported changes in probability are the largest (in terms of a move toward drier conditions) that can be estimated from the models (7 member subset from CMIP5 archive) under the most pessimistic emissions pathway (RCP8.5).

Drought can be initiated either by a reduction in delivery (e.g. fewer cyclones) and/or the suppression of precipitation (more anticyclones). Competing physical factors influence periods of low rainfall in the UK and one important caveat is that climate models do not simulate all these features effectively. However a consideration of these competing influences indicates changes that are broadly consistent with the empirical findings from the climate models analysed.

A characteristic of UK drought is low frequency variability (see Figure 3.1). This means that the relatively short UKCP09 reference period (1961-1990) is inadequate for a reliable assessment of baseline drought probabilities and thus UKCP09 is not considered to be appropriate for the analysis of low rainfall. For this reason this chapter places greatest emphasis on the use of historical data and CMIP5 model outputs.

The H++ low rainfall scenario is for a significant increase in 6 month duration summer drought with deficits up to 60%. Climate models suggest no significant change in winter droughts; however, the possibility remains of some longer dry periods across the whole of England and Wales with rainfall deficits of up to 20% lasting 3 to 5 years similar to the most severe long droughts on record.

Where direct observations are available this study uses the full instrumental record. The reference period for climate models is 1900-1999 and the future is 2070-2099. The data sources used are described in Annex 2.

Box 3.1 Low rainfall scenarios and drought risks

Droughts have severe impacts on societies, economies, agriculture and ecosystems. The multi-annual 1975-76 UK drought had a devastating effect on the UK economy causing an estimated £3,500M loss to agriculture, £700M of subsidence damage to buildings and a £400M cost to the water industry (figures adjusted for inflation, (Rodda and Marsh 2011)).

Low rainfall is closely related to the concept of drought and shares many of the difficulties which complicate a precise definition of the peril (Lloyd-Hughes 2014). The primary difficulties are the choice of starting point and accounting period over which precipitation deficits are accrued. The approach of this study is to consider accumulated precipitation totals computed at the end of the winter (April) and summer (October) half years for a wide range of accounting periods: 6, 12, 24, 30, 36, 42, 48, 54, and 60 months. This provides the necessary granularity to inform on the credible impacts of climate change on two distinct drought scenarios of interest (see above).

3.2 Historical data and methods

For this scenario the observational data is used mainly for context setting and filtering models based on historical performance.

HadUKP - UK regional precipitation series

HadUKP (Alexander and Jones 2000) is a series of datasets of UK regional precipitation, which incorporates the long-running England & Wales Precipitation (EWP) series beginning in 1766, the longest instrumental series of this kind in the world. The map (Figure 3.1) shows the regions that are available.

Figure 3.1 HadUKP precipitation regions.

HadUKP incorporates a selection of long-running rainfall stations to provide the best available long term average precipitation across a large area (Alexander and Jones, 2001)[19]. The monthly EWP series goes back to 1766, whereas the monthly series for the sub-regions of England and Wales begin in 1873. The monthly series for Scotland (and sub-regions) and Northern Ireland begin in 1931.

Methodology
Accumulated precipitation totals have been computed, as measured at the end of the winter (April) and summer (October) half years, for the set accounting periods: 6, 12, 24, 30, 36, 42, 48, 54, and 60 months for each of the HadUKP (Alexander and Jones 2000) regional time series and for equivalent regional time series extracted from the CMIP5 models. The accumulated totals have been converted into time series of anomalies by subtraction of the long term running mean total for relevant accounting period and time

[19] The data and a description of how it was created are available on the Met Office web site http://www.metoffice.gov.uk/hadobs/hadukp/

Appendix CC.1.2

of year. Anomalies for model projections of the future 2070-2099 are relative to a reference period defined as 1900-1999. An example time series of 36-month accumulations for the EWP region is shown in Figure 3.2.

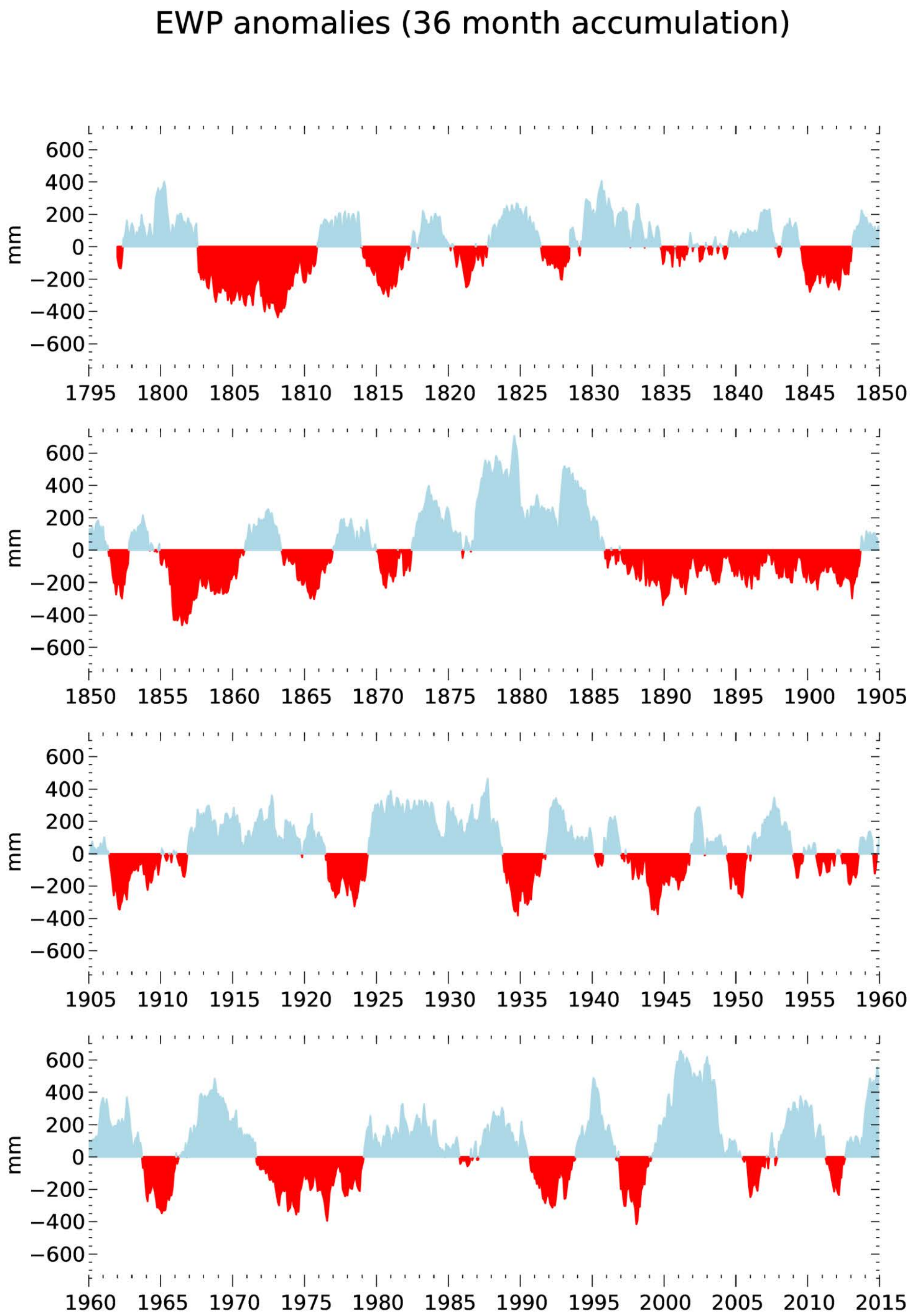


Figure 3.2 Time series of 36 month precipitation anomalies for EWP (England and Wales Precipitation). The anomalies are departures of precipitation relative to long term averages for that time of year. Red (blue) shading indicates periods of time when conditions were drier (wetter) than average.

Appendix CC.1.2

Selection of credible models

The fidelity of the dynamics emerging from the CMIP5 models has been analysed in detail by McSweeney et al. (2014). Accepting only those models identified as 'satisfactory' for all indicators across Europe and eliminating those with 'significant biases' elsewhere resulted in a candidate pool of 11 models. Since climate models do not attempt to reproduce the time sequencing of events in recent climate (they are uninitialized) models are evaluated using probability distributions. Synthetic 6-month accumulated precipitation anomalies from the candidate models were compared with observations for each of the HadUKP regions for the summer and winter half years for all years 1900-1999. A model was deemed to be 'credible' if the empirical cumulative distributions of the modelled data were consistent with the observations at the 10% significance level as measured by the Kolmogorov–Smirnov (K-S) test. A total of 7 models were found to produce realistic looking droughts over the EWP region. These are listed in table 3.1 with p-values for the Kolmogorov–Smirnov (K-S) test, where P values higher 0.1 (10%) indicate a good fit between the observed and modelled data. If the model and observations are sampled from identical distributions then the p-value gives the probability of the K-S statistic being as large or larger than calculated. An example visual comparison of modelled versus observed accumulated distributions is shown in Figure 3.3 for the ACCESS1-0 model for the summer half year. Thus we conclude there is some limited skill in the model at presenting EWP values.

Table 3.1 Model performance as measured by the distributional adequacy of 6-month precipitation anomalies for the EWP region 1900-1999.

Model	K-S *p*-value Summer	K-S *p*-value Winter
ACCESS1-0	0.22	0.32
CMCC-CM	0.22	0.22
CNRM-CM5	0.10	0.22
GFDL-CM3	0.15	0.22
GFDL-ESM2M	0.32	0.10
HadGEM2-ES	0.15	0.15
MPI-ESM-MR	0.22	0.10

It is notable that no credible models could be identified for the HadUKP regions beyond the EWP region (and even here models are only just credible, see for example the lower tails of Figure 3.3 where the distributions only just overlap at the 95% level of confidence). The relatively small geographical extents of these regions increases the relative importance of local scale effects on the variability of the precipitation totals to an extent that cannot be matched by the spatio-temporal resolution of the current generation of climate models. In contrast, the characteristics of simulated droughts at the

European scale are found to be in excellent agreement with observations (Lloyd-Hughes et al. 2013).

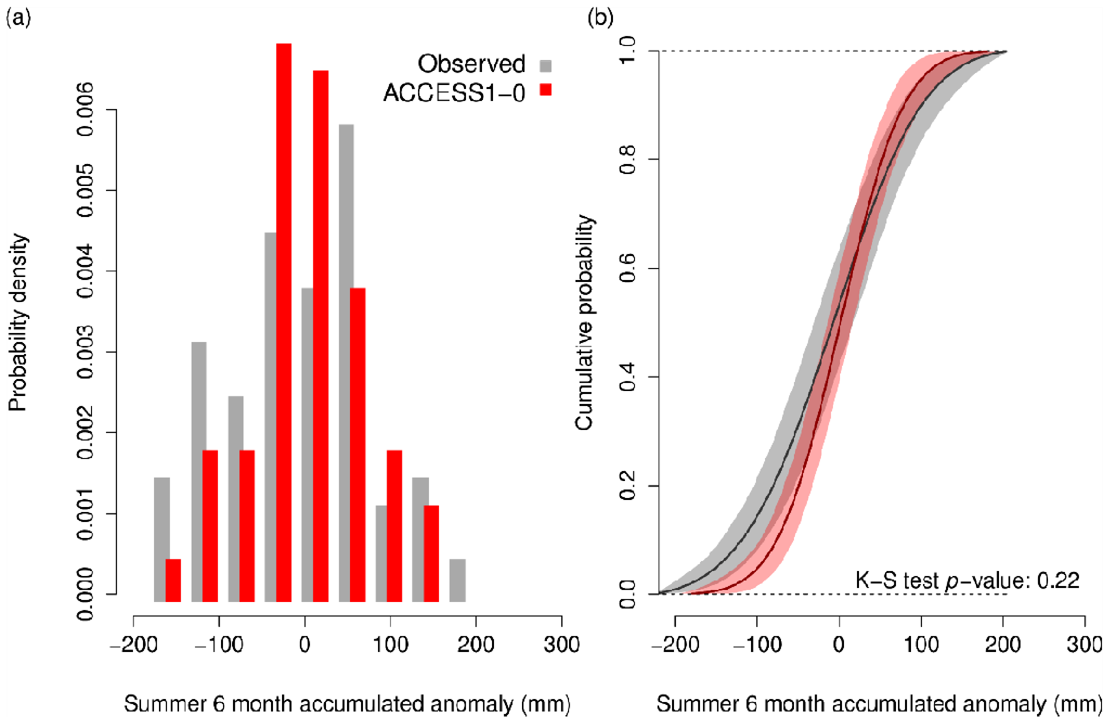


Figure 3.3 Comparison of distributions (a) histogram and (b) maximum entropy estimates of the cumulative distribution function of modelled (red) and observed (grey) accumulated precipitation anomalies for EWP in summer 1900-1999. The shading on the cumulative curves represents the 95% confidence interval.

Historical droughts

Drought is quasi-regular feature of the UK climate and a significant event is to be expected every 5 to 10 years (as can be inferred from Figure 3.1; a detailed analysis of probability is provided below). The Centre for Ecology & Hydrology (CEH) have published reports on the most notable recent events including 1976 (Rodda and Marsh 2011), 1984 (Marsh and Lees 1985), 1988-1992 (Marsh et al. 1994), 2003 (Marsh 2004), and 2010-2012 (Marsh et al. 2013). A discussion of major drought events for England and Wales since 1800 is provided by Marsh, Cole, and Wilby (2007a). Of particular note, are the changes in variance (heteroskedasticity) seen in Figure 3.1 and similar plots of drought intensity. Such variability gave rise to the ‘Long Drought’ of the nineteenth century which would represent a considerable challenge to the water industry across England and Wales (Watts et al. 2012).

UK droughts are typically associated with large scale blocking high pressure systems and rarely exist in isolation; a characterisation of recent historical droughts on a European scale, using indicators of both rainfall and river flows is provided by Hannaford et al. (2011).

Historical probabilities (baseline risk)

The UK has some of the longest precipitation records in the world in the form of the HadUKP time series (Alexander and Jones 2000). These provide an excellent basis for the assessment of baseline probabilities for precipitation deficits. Upper estimates of these are presented in Figures 3.4, 3.5 and 3.6 for the England and Wales Precipitation (EWP), Scotland Precipitation (SP) and Northern Ireland Precipitation (NIP) regions respectively. These figures show probabilities in the format of a pair of matrices (one for each half year; winter (April) and summer (October))[20]. The columns correspond to the time period over which the precipitation anomaly is measured (e.g. 6 month total, 12 month, etc.). The rows correspond to the severity of the deficit expressed as a percent of the total which can be expected at this time of year for the given accumulation period under the current climate (as estimated from observations of the recent climate; 1900-1999 for EWP; 1931-1999 for SP and NIP). Therefore the H++ values for low rainfall can be taken directly from these figures and the differences between the observed period and the future can also be assessed. For example, the most severe EWP summer rainfall deficit over 6 months based on observed data was 50% (Figure 3.4, lower pane) and the H++ EWP summer rainfall deficit over the same period is 60% (Figure 3.10, lower pane). The choice of accumulation period and deficit measure facilitates the direct comparison with the Low Flows section of this report (Section 4).

[20] The quoted probabilities represent the upper bound of a 95% confidence interval (c.i.) of probabilities derived from the data. The probabilities themselves were estimated by repeatedly fitting a maximum entropy distribution to each of 1000 bootstrap resamples taken from the data. Maximum entropy (MaxEnt) is a non-parametric method for statistical inference about the probability density function of a given sample of data which estimates the least biased distribution among all others that satisfy the constraining moments from the sample. A detailed description of MaxEnt procedure is provided by (Petrov, Soares, and Gotovac 2013).

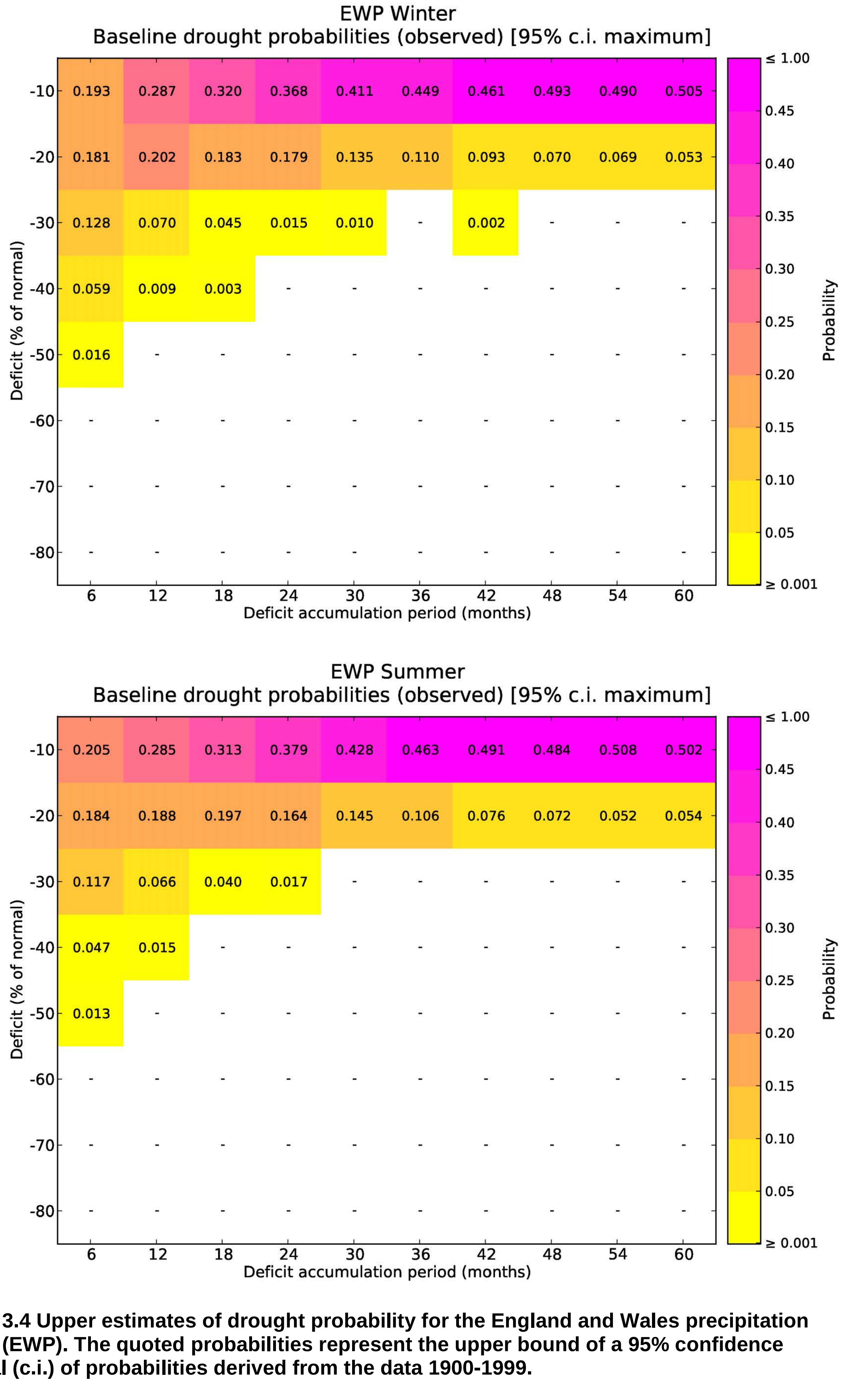
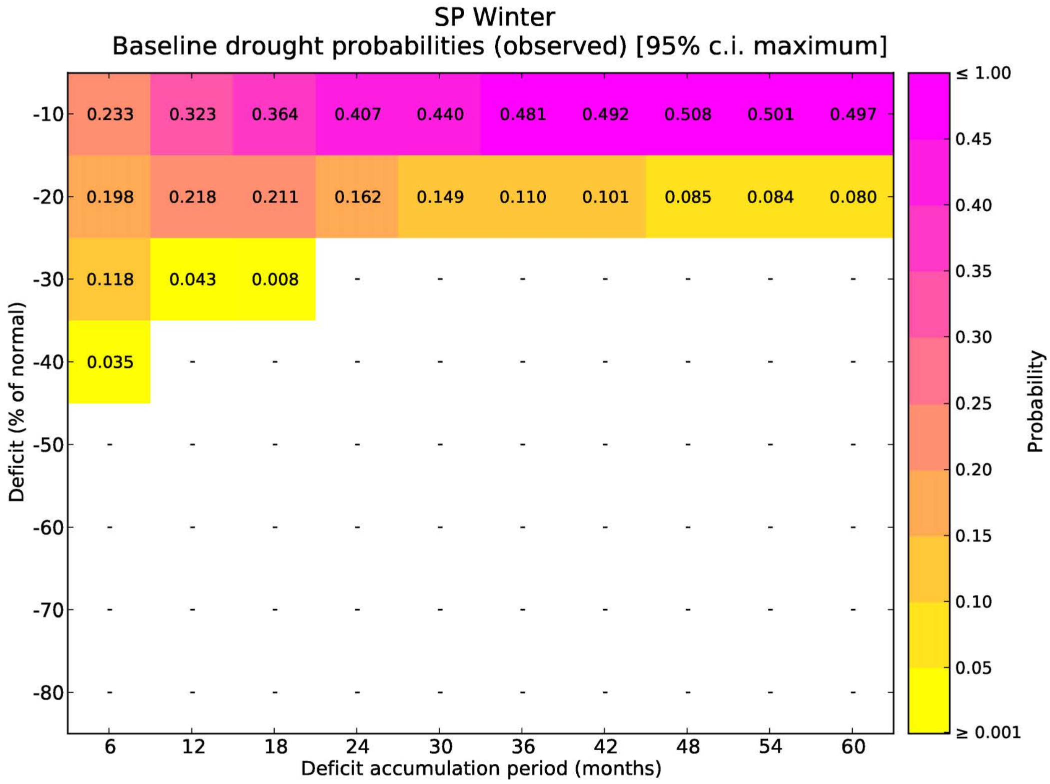


Figure 3.4 Upper estimates of drought probability for the England and Wales precipitation region (EWP). The quoted probabilities represent the upper bound of a 95% confidence interval (c.i.) of probabilities derived from the data 1900-1999.

Appendix CC.1.2



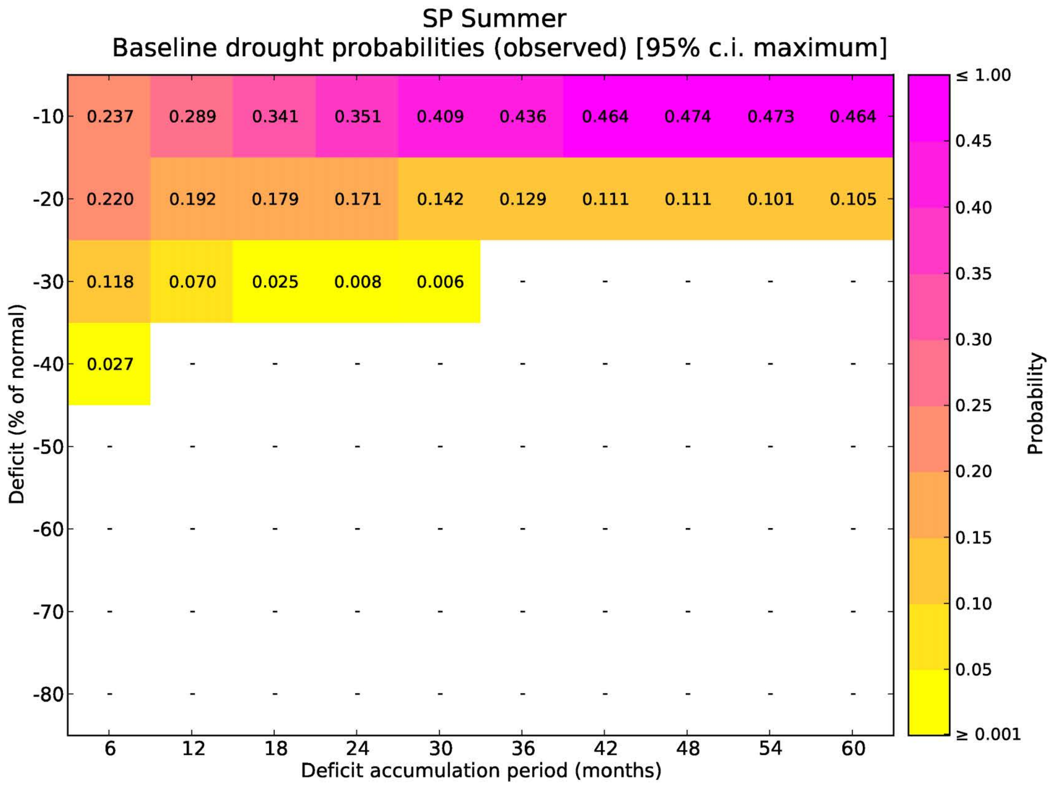
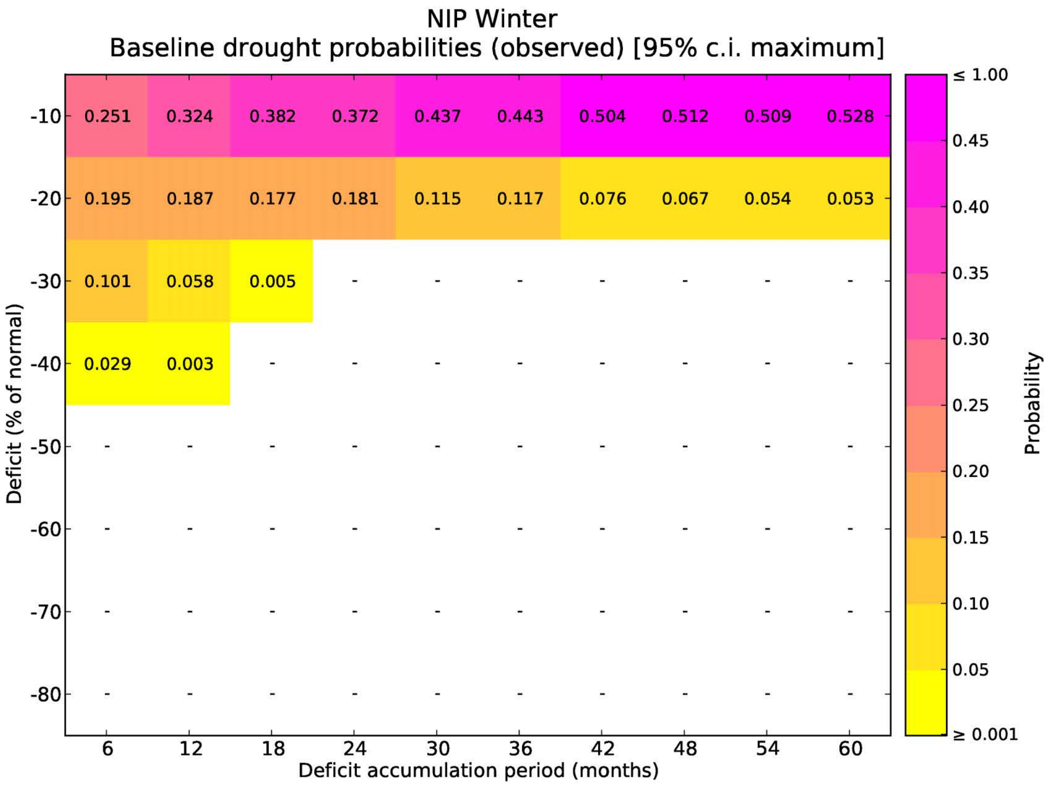


Figure 3.5 Upper estimates of drought probability for the Scottish precipitation region (SP). The quoted probabilities represent the upper bound of a 95% confidence interval (c.i.) of probabilities derived from the data 1931-1999.



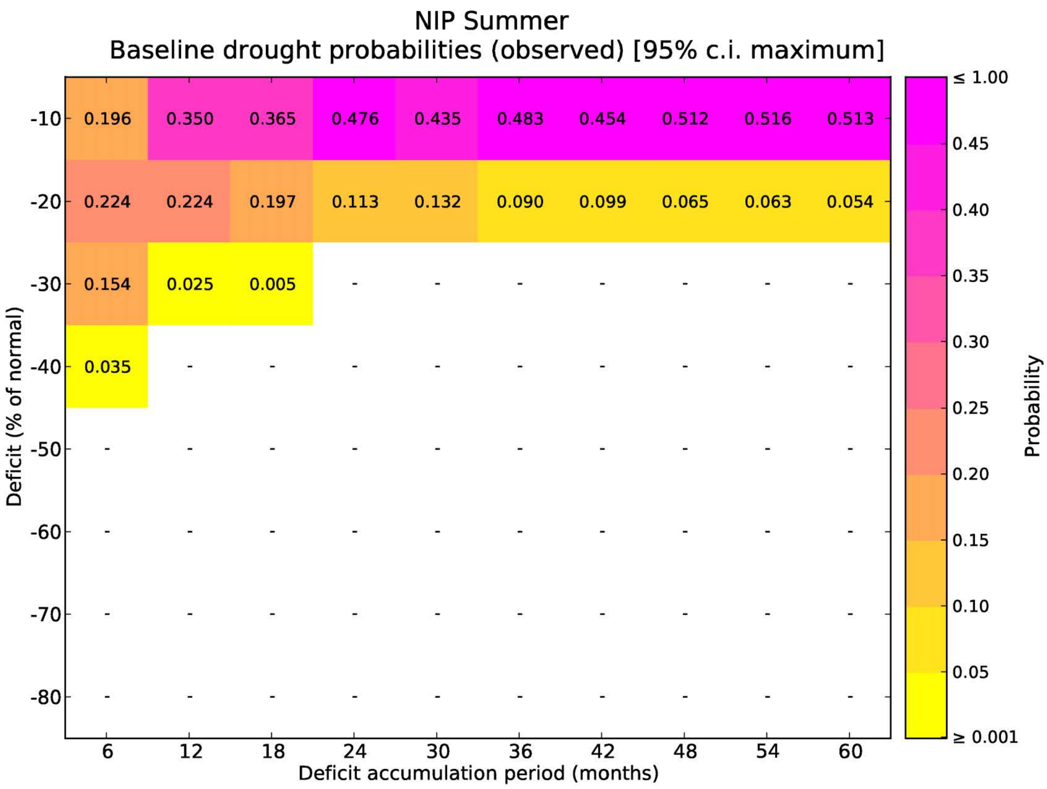


Figure 3.6 Upper estimates of drought probability for the Northern Ireland precipitation region (NIP). The quoted probabilities represent the upper bound of a 95% confidence interval (c.i.) of probabilities derived from the data 1931-1999.

Appendix CC.1.2

3.3 UKCP09

Whilst UKCP09 is not suitable for the analysis of low precipitation accumulated over extended time periods (multi-year droughts) it does provide some information on changes at the seasonal timescale. Figure 3.7 shows projected changes in winter (left) and summer (right) precipitation totals expected by 2070-2099 under the UKCP09 high emissions scenario. The upper panels represent changes at the 10% probability (i.e. driest) level of the probabilistic range. The lower panels represent changes at the 90% probability (i.e. wettest) level. The overall pattern is a move toward wetter winters and drier summers. The range of the projected changes varies considerably across the probability ranges from almost no change through to shifts of greater than 70% of the 30-year average value. Geographically there is some indication that the largest reductions in summer precipitation are biased toward central and southern regions. However, these shortfalls may be compensated for through the enhanced winter rainfall projected for the same regions.

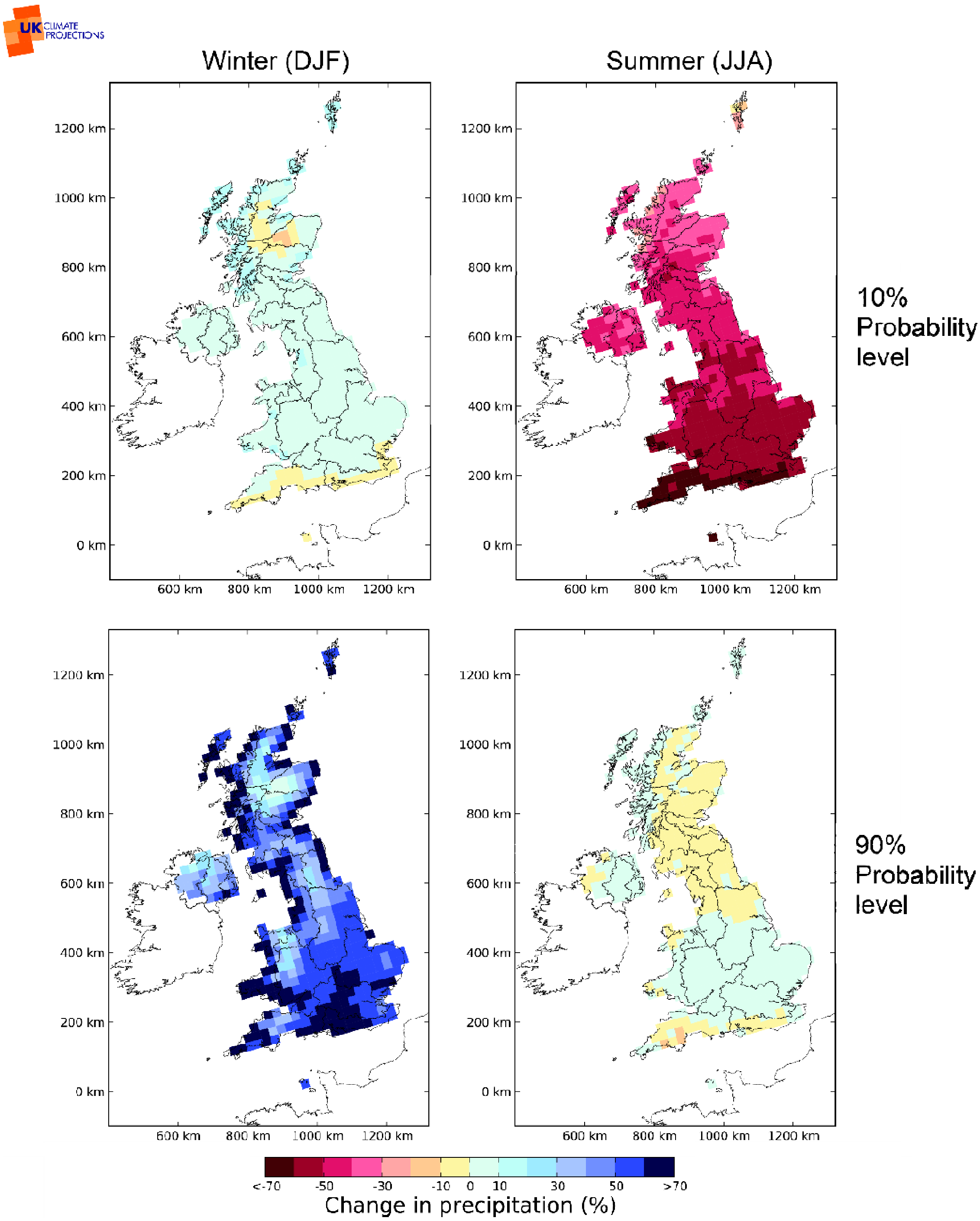


Figure 3.2 Projected changes in winter (left) and summer (right) precipitation totals expected by 2070-2099 under the UKCP09 high emissions scenario. The upper panels represent changes at the 10% probability (i.e. driest) level of the probabilistic range. The lower panels represent changes at the 90% probability (i.e. wettest) level.

3.4 Evidence from CMIP5 climate models

CMIP5 (Taylor, Stouffer, and Meehl 2012) represents the current state-of-the-art in GCMs and earth system models (ESMs) that have been submitted to the World Climate Research Programme. A subset of 35 models was used in this study (based on availability at the time of writing).

The magnitudes of projected changes in precipitation are shown in Figure 2.8 for the 35 CMIP5 models (orange lines) the 11-member Met Office regional climate model (black crosses) and the seven credible[21] CMIP5 models identified above (red circles). The values vary dramatically from model to model and from summer to winter. Whilst the pattern is noisy, the majority of the models projects a move toward wetter winters and drier summers, a result that is consistent with the projections of UKCP09 (Jenkins et al. 2009) and UKCIP02 (Hulme et al. 2002). It is notable that degree of spread is largely similar irrespective of the model subset.

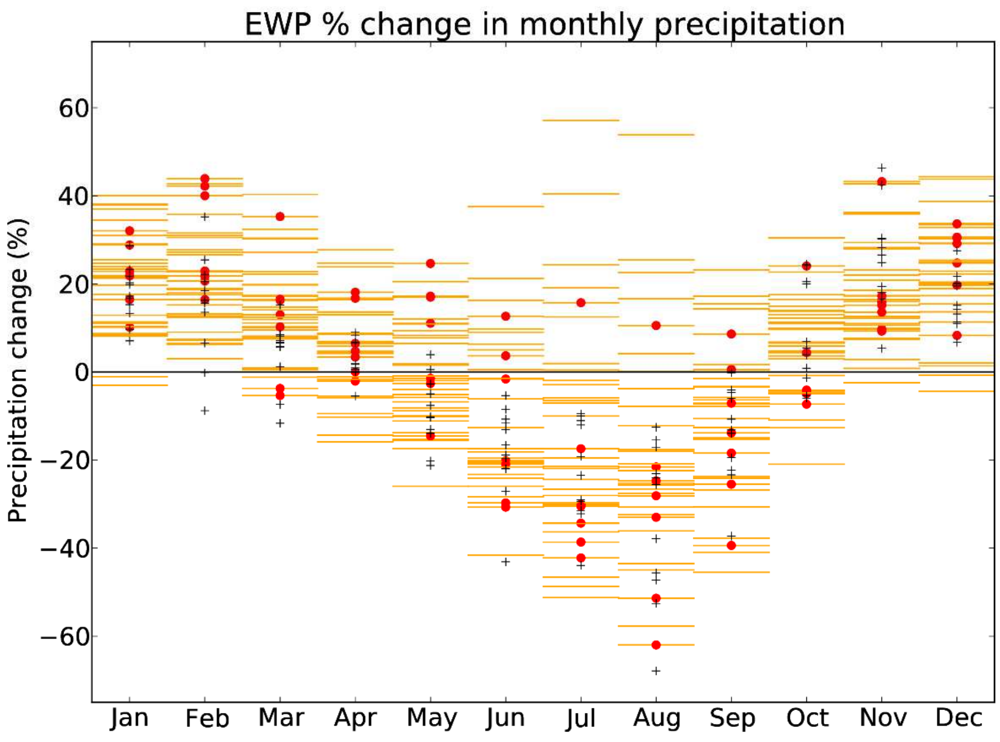


Figure 3.8 Projected changes (% difference from the 1900-1999 baseline) in expected monthly precipitation totals for 2070-2099 by month for each of the 35 CMIP5 models (orange lines), 11 UKCP09 regional models (black crosses) and the seven credible models (red dots).

[21] Credible models based on the K-S test described earlier in the section (Table 3.1)

Appendix CC.1.2

Since credible models (albeit only marginally credible) of low precipitation exist for the EWP region for the reference period (1900-1999) it is reasonable to examine their projections for the future (2070-2099) under the H++ scenario. The mixed pattern of changes in the average monthly precipitation totals lead to a mixed pattern of changes in the precipitation anomalies accumulated over longer time scales. In general, wetter winters tend to ameliorate the effects of summer droughts and serve to break up the longest sequences of below normal rainfall. Thus, the risk of multi-annual droughts might be thought to decrease. However, the risk of a dry winter in a particular year or series of years, whilst reduced, still remains, and when a particular occurrence is coupled with a dry summer, a severe long-period drought can still emerge. Such a mixture of effects can be seen in Figure 3.9 which compares the distribution of dry run lengths (consecutive negative precipitation anomalies for 6-monthly accumulations) between the reference period and the projected future. The shape of the distribution shifts to favour the probability of short period droughts whilst the risk of long period events remains.

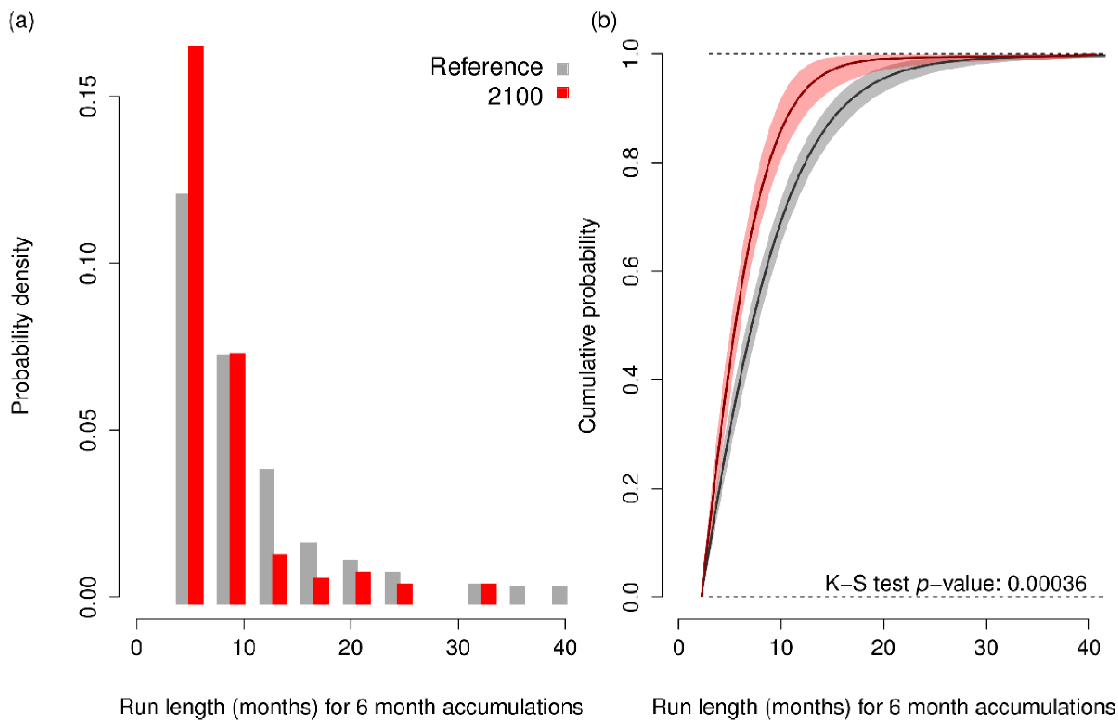


Figure 3.9 Comparison of distributions of dry run lengths (consecutive negative precipitation anomalies for 6-monthly accumulations) between the reference period and the projected future (by 2100). The grey bars in panel (a) show the histogram of run lengths (drought durations) under the present climate. The red bars are model estimates for the climate in 2100. Panel (b) shows the same data as cumulative distributions with a 95% confidence interval (shaded).

A similar pattern is seen in the changes in probability of low rainfall over short and long durations for England and Wales between the baseline and future periods; that is with the largest changes for 6 month durations, while the possibility of longer drought remains. These are presented for summer and winter droughts in Figures 3.10 and 3.11 respectively. The figures indicate credible ranges on the probabilities expected by 2100. The changes in probability are computed on a cell by cell basis. Minimal (optimistic) estimates are computed by applying the minimum shift (in terms of a move toward drier conditions) from the 7 credible models to the lower bound of the 95% confidence interval of the present day probabilities (estimated from the full observed EWP time series). Likewise, maximal (pessimistic) estimates are computed by applying the maximum shift from the 7 models to the upper bound of 95% confidence interval of the present day probabilities (i.e. by shifting the probabilities shown in Figure 3.3). Comparison of the baseline figures to the minimal and maximal future figures provides information on the possible changes in future periods of low rainfall. For example for England and Wales 6 month summer rainfall there was 1.3% chance of a 50% rainfall deficit for the baseline period (Figure 3.4 lower pane), which changes to a 0.2% to 13.4% chance of a 50% rainfall deficit in future periods (Figure 3.10). For England and Wales winter rainfall there is a 1% chance of 30% rainfall deficit over 30 months for the baseline period (Figure 3.4, upper pane), which becomes less likely changing to a zero to 1% chance in future (Figure 3.11).

In the context of developing H++ scenarios for short and longer droughts, these results suggest:

- Future summer meteorological droughts in England and Wales could be more or less severe; **the largest changes suggest the possibility of significant increases in the probabilities of severe 6 month duration summer droughts. The chance of encountering deficits of up to 60% of the expected precipitation (under the current climate) increases from 0% to 5%.**
- No significant change in winter droughts; however, the possibility remains of some longer dry periods lasting several years **similar to the most severe long droughts on record.**

The current generation of global climate models are not capable of synthesising realistic droughts for regions as small as Scotland and Northern Ireland and little can be inferred about the change in risk over these regions.

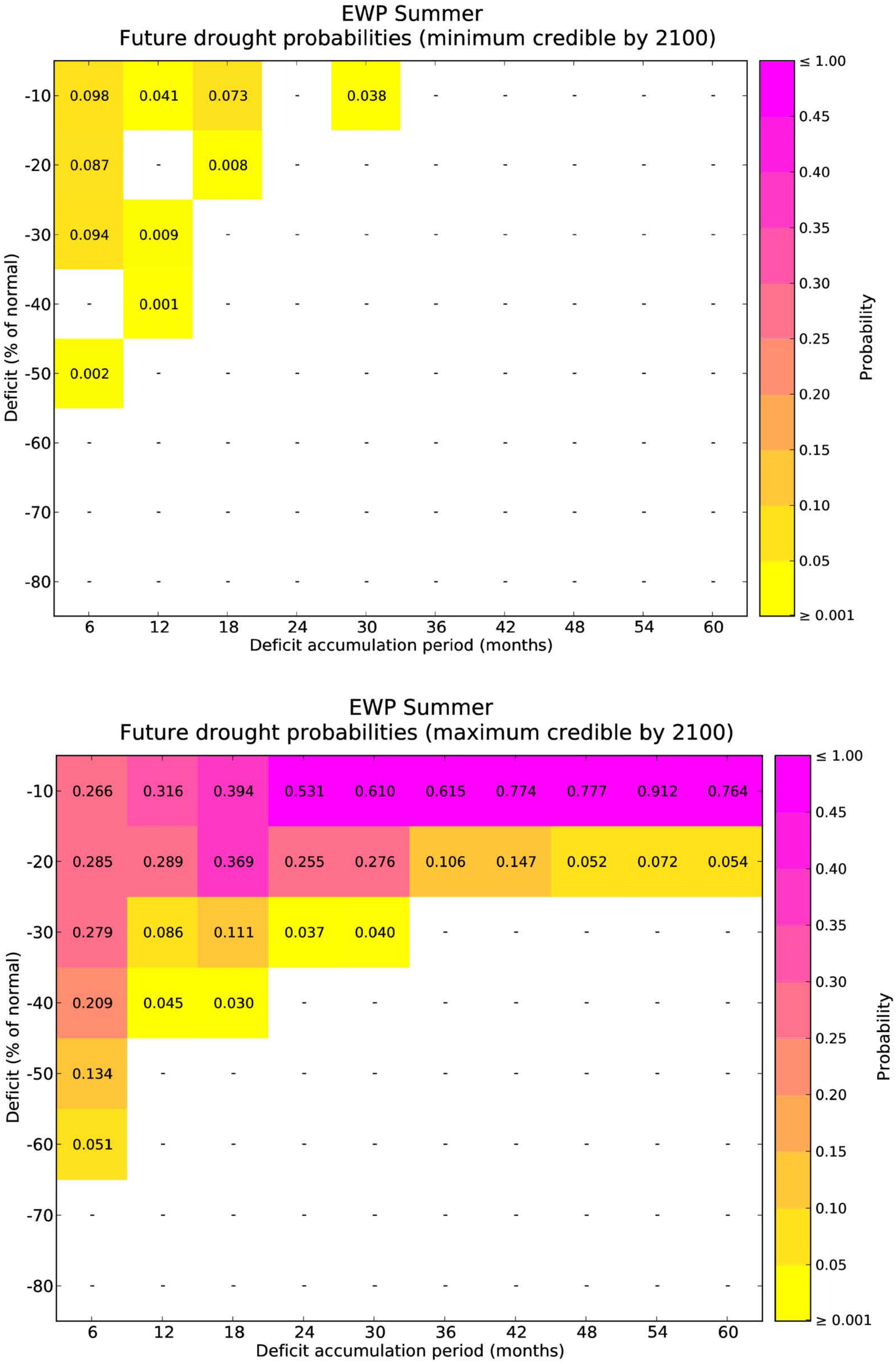


Figure 3.10 Upper (top panel) and lower (bottom panel) estimates of summer drought probability for the England and Wales precipitation region (EWP) credible by 2100.

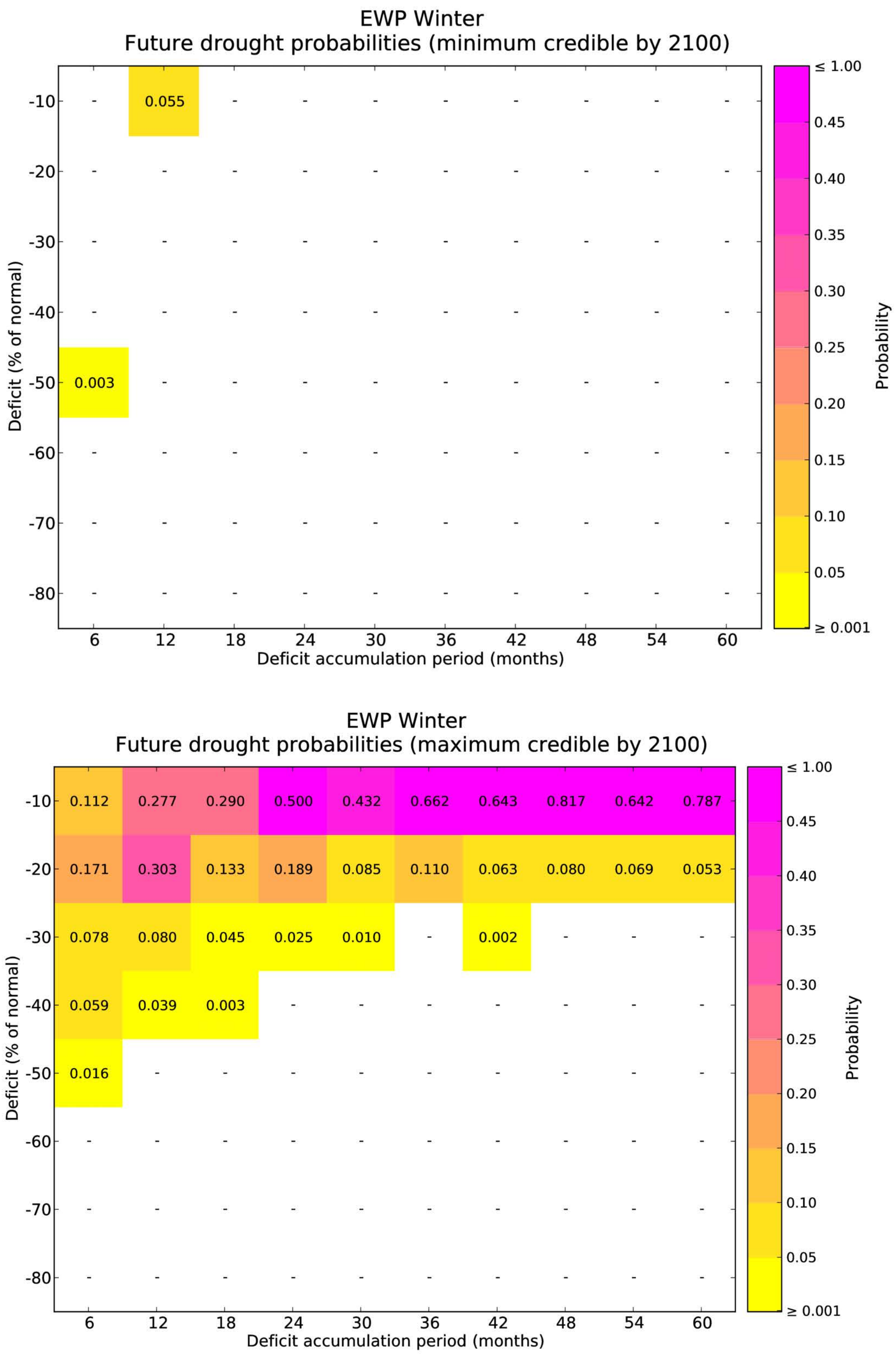


Figure 3.11 Upper (top panel) and lower (bottom panel) estimates of winter drought probability for the England and Wales precipitation region (EWP) credible by 2100.

Appendix CC.1.2

3.5 Physical limits

Thermodynamic arguments favour moister air in a warmer world and increased rainfall intensities (Allan 2011) (Section 5) however for this to be realised the moisture must be delivered and precipitated out. In general for the UK, large scale low pressure (cyclonic) systems deliver new water into the hydrological system which is in turn recycled through local convection. Drought can be initiated either by a reduction in delivery (fewer cyclones) and/or the suppression of precipitation (more anticyclones). Mid latitude cyclones and anticyclones are an inherent feature of our climate system resulting from the rotation of the Earth and its orientation to the sun (Carlson 1991). The path of cyclones across the north Atlantic and hence their incidence over the UK is biased toward a particular path and results in the emergence of what is known as the north Atlantic storm track. Analysis suggests that the position of the storm track is dependent on ocean-atmosphere coupling (Woollings et al. 2012). The dynamics which control the position of the storm track are complicated and poorly understood (Woollings 2010). However, under anthropogenic greenhouse-gas forcing, there is some evidence for the strengthening and eastward extension of the storm track towards Europe which may favour enhanced precipitation (Woollings et al. 2012) and an increased number of cyclones in winter incident upon central Europe (Zappa et al. 2013) (Section 4). This enhancement is counter balanced by the tendency of more warmer conditions to favour the development of larger scale anticyclonic systems (~2% larger for a warming of 4ºC) (James 1951, Holton 2004). There is also evidence that high temperatures, a common feature of anticyclones in summer, can dry the soil which in turn reduces the amount of latent cooling and can thus drive temperatures even higher and soil moisture lower (Fischer et al. 2007). This in turn reduces the moisture available for local recycling. Physical considerations thus reveal competing influences which are consistent with the empirical findings from the climate models analysed.

Spatial coherency

A detailed analysis of the spatial coherency of UK droughts is provided by Rahiz and New (2012). They report a complex picture dependent on drought severity, duration and timing. This is consistent with previous analysis by the UK Environment Agency at the European scale (Hannaford et al. 2009). In general, drought over the UK is associated with blocked atmospheric flow across the North Atlantic Ocean and/or Eurasian land mass. The associated high pressure (anticyclonic) features that tend to suppress rainfall have a typical area that is several times that of the UK. Thus, whilst not all UK droughts are spatially coherent, since the high pressure centre may not be located directly over the UK, the underlying physics suggest that spatial coherency is always a possibility. Thus, in this section we have used the physical limits concept as a sense check of the results and to provide some explanation of the model behaviour.

3.6 Other evidence

Palaeo analogue / evidence

Analysis of European tree-ring data from the last 2500 years (Buntgen et al. 2011) suggest that earlier hydro-climatic changes have at times exceeded recent variations. Particularly alarming is the 200 year long period of reduced precipitation around 500 AD. During this period precipitation was reduced by 15% to 50% of the long-term average (range defined by ±1 standard deviation) for a continuous period of 50 years. This period of time coincided with the demise of the Western Roman Empire and the turmoil of the Migration Period (*ibid*). The severity of this low rainfall period (15%-50% deficits) is similar to what is proposed for a H++ low rainfall (10%-60% over specific time periods) but clearly its longer duration is significant and is a scenario that has not been considered as part of H++. The lack of specific paleo data for the UK precludes any further analysis here but suggests an area for further research.

Industry data

The water industry use information on meteorological droughts for the design of water infrastructure, supply-demand planning and drought planning. In general the industry uses long term records (1920-present day) to understand drought risks and several companies have also considered more severe long duration droughts from the late 19th century. For strategic planning climate change scenarios are used to perturb the historical data making historical droughts in summer more severe but not changing the duration or spatial extent of droughts. For drought planning companies consider the drought situation and plan ahead using historical analogues – “what if the drought develops like 1976”, or simple percentage deficits of rainfall, for example a 20% reduction in rainfall over 12 months. The biggest concerns for UK water companies are related to long multi-season droughts with durations of 18 months to 3 or more years. The water resources impacts of H++ have been considered in a separate ASC project (HR Wallingford, 2015).

3.7 Summary of H++ scenarios

Future summer meteorological droughts in England and Wales could be more or less severe. Under H++ the largest changes suggest the possibility of significant increases in the probabilities of severe 6 month duration summer droughts. The chance of encountering deficits of up to 60% of the expected precipitation (under the current climate) increases from 0% to 5%.

Climate models suggest no significant change in winter droughts; however, the possibility remains of some longer dry periods lasting several years similar to the most severe long droughts on record. Table 3.2 provides a summary of the risk of low rainfall estimated from present day observations, UKCP09, CMIP5 and physical reasoning.

Table 3.2 Summary of H++ risk assessment for rainfall deficits

	Summer	**Winter**	**Multi-year**	**Spatial coherence**
Historic	Maximum deficit 50% of normal is credible	Maximum deficit 50% of normal is credible	**Credible 5 year drought with maximum deficit of 20% below normal**	UK wide droughts are possible
UKCP09	Increased probability	No change	No change	UK wide droughts remain possible. Some indication that the largest reductions in summer rainfall are biased toward central and southern regions
CMIP5**	**Maximum deficit of 60% below normal becomes credible (**probability increases from 0 to 5%)	**No change**	**No change**	**UK wide droughts** remain possible
Palaeo	N/a	N/a	Multi-decadal droughts are possible	Large scale droughts are possible
Physics	Increased probability***	Decreased probability***	No change	UK wide droughts could become more likely

* The current generation of climate models are not capable of synthesising realistic droughts for regions as small as Scotland and Northern Ireland and less credibility is assigned to the change in risk over these regions.
** The results quoted for CMIP5 are considered to be more credible than those for UKCP09 because of the longer baseline and stringent model selection criteria.
*** These entries are highly uncertain because the dynamics which control the position of the storm track are complicated and poorly understood (Woollings 2010).

Chapter 4 Low flows

4.1 Summary of the H++ low flow scenarios

H++ low flow scenarios are defined as changes in Q95 (flow exceeded 95% of the time) associated with rainfall deficits based on CMIP5 outputs from England and Wales for 2080s as described in Chapter 3. Thus, this H++ can be seen as an extension of the rainfall scenarios. The low rainfall scenarios indicated a significant increase in the frequency of 6 month duration summer droughts as well as a potential increase in magnitude from a 50% to 60% deficit over this period. However there was little change in winter as increases in winter rainfall typically returned deficits to normal. Consequently, the most significant H++ low flow scenarios are for the summer period. There are three H++ low flow scenarios for single season (6 months), multi-season (2-3 seasons) and long droughts (2 years or more).

The H++ scenario for summer low flows is a reduction in the Q95 by between 40 and 70 percent in England and Wales and 30 and 60 percent for Scotland and Northern Ireland. The H++ scenario for multi-season (2-3 seasons) droughts with consecutive summers is a 20 to 60 percent reduction in flows in England and Wales and 20 to 50 percent reduction in Scotland and Northern Ireland. For longer droughts (2 years or more) the H++ scenario is for up to 50 percent and 45 percent reductions in flow for England and Wales and Scotland and Northern Ireland respectively[22].

The H++ scenarios were developed by combining the work on low rainfall (Chapter 4) with catchment case studies that make use of set of response surfaces linking changes in precipitation to flow that were developed as part of another Environment Agency project (Ledbetter, Anderton, & Prudhomme, 2015).

The assessment is subject to a number of important caveats, particularly that the H++ results are defined from national rainfall scenarios and it is possible that more severe events could occur at local scale. In addition, rivers in the UK are regulated and influenced by abstractions and discharges, which are managed during drought situations to maintain water resources and protect the environment. This assessment has not considered these effects or new infrastructure that may be

[22] H++ low flow scenarios are given for three durations as impact and management options are likely to differ as drought prolongs: single season; multiple seasons (2-3); and multiple years. To capture uncertainty in projections upper and lower estimates are given.

developed as part of water companies long term plans[23]. A separate research project available alongside this report (Project B – projections of future water availability) has considered the impacts of climate change on UK water resources.

4.2 Historical data and methods

Background

Compared with floods, very little research has been conducted to develop methods and investigate the impact of climate change on droughts and low flows. The main tools available to link H++ scenarios of low rainfall with low flows and subsequently water resources deficits (Project B) are response surfaces generated in an EA research project on investigating the resilience of water supply systems to extreme droughts (SC0120048). These response surfaces present a low flow/drought index based on an ensemble of daily time series river flow simulations in response to synthetic drought scenarios for a number of river basins. An illustrative example of a response surface is shown in Figure 4.1. The key features of the analysis are as follows:

- The response surfaces represent the local sensitivity of river flow to meteorological droughts, defined by their average rainfall deficit (y-axis) and duration of rainfall deficit (x-axis). The colour associated with each combination (duration, deficit) represents the change in the low flow indicator.
- Consistently with current UK practice to quantify low flows (Environment Agency, 2013a, 2013b; Lang Delus et al., 2014), the low flow indicator used is the percentage change in Q95 (calculated over the duration of the drought).
- Drought characteristics of the H++ low rainfall scenarios are quantified as rainfall deficit (departure from the long term average LTA, as % of baseline) and duration (in months). For each duration, the rainfall deficit probabilities in Chapter 4 were used to estimate a 10% and 1% probability of rainfall deficits in the 2080s.
- Then these rainfall deficits were used in combination with local drought response surfaces (for each river basin) to estimate local impacts of H++ low rainfall on low flows at the 10% and 1% probability levels.

[23] Current water resources planning guidelines consider climate change with a focus on the use of UKCP09 Medium Emissions gridded or catchment average data.

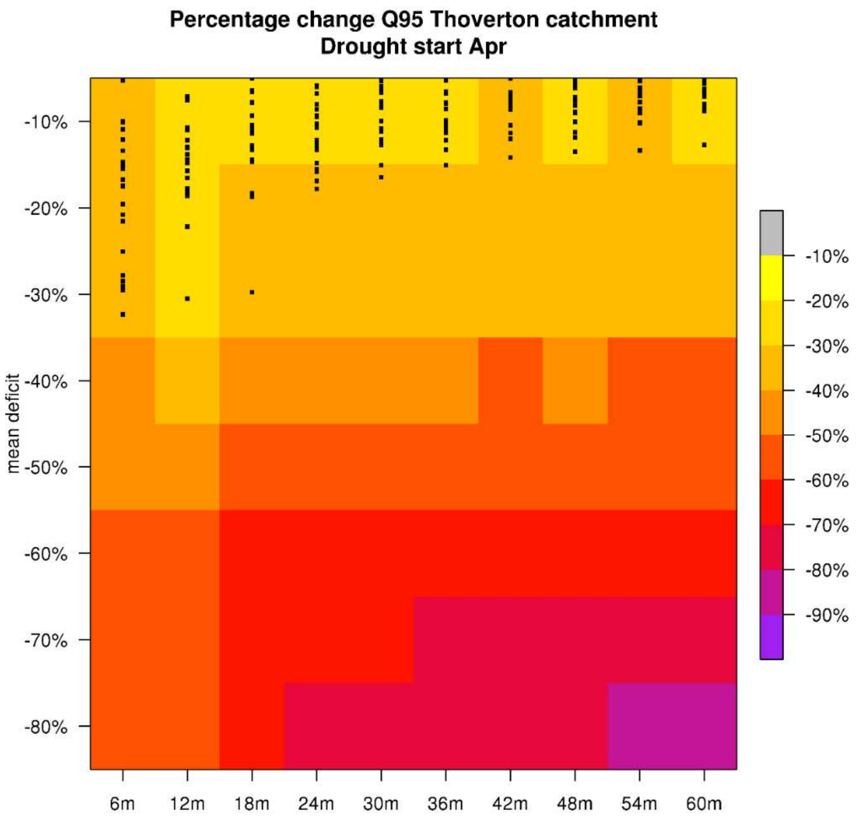


Figure 4.1: An illustrative example of a response surface from EA research project SC0120048. The y axis describes rainfall deficits, x-axis the duration in months and the colours describe impacts on the Q95 flow indicator. The black dots represent historical events.

Data and baseline modelling

Analysis was based on the limited modelling undertaken in the project SC0120048 of six river basins selected according to their location and model performance. The case studies refer to the name of the four water supply systems considered in the original project SC0120048 where the river basins are located. They show a gradient of mean annual rainfall between 624 mm (Ruthamford) to 1980 mm (Barmouth). Due to the budget and time constraints to develop the H++ low flow scenarios, no further modelling could be done and the six river basin results are assumed to be representative of the range of possible hydrological response to meteorological droughts in England and Wales. It can be seen from Figure 4.2 that these basins cover a reasonable range of annual average rainfall conditions but there are more basins in central and southern areas.

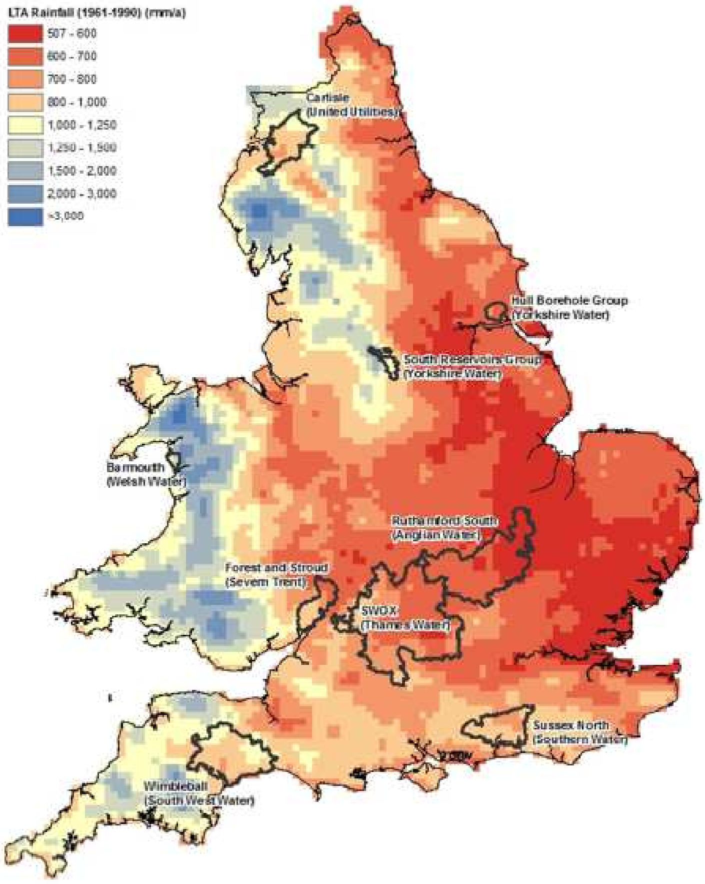


Figure 4.2. Location of case studies considered in project SC0120008. Background shading according to the long term average LTA Rainfall (1961-1990). Source Ledbetter, pers. communication.

Case Study	River basin	NRFA Gauge	Long term average Rainfall (mm)
Barmouth	Llyn Bodlyn	N/A	1980
Carlisle	Eden	Eden at Sheepmount – 76007	1212 (Based on the nearby Gelt basin)
	Gelt	N/A	1212
Ruthamford South	Offord	Ouse at Offord – 33026	624
Wimbleball	Haddeo	Haddeo at Hartford* – 45010	1308
	Thorverton	Exe at Thorverton - 45001	1284

Table 4.1. Case study used for low flow/ droughts analysis. ***River flow discharge was scaled to reflect reservoir inflow prior to modelling***

For the development of the local 'drought response surfaces', catchment average daily rainfall data was calculated from the CEH-GEAR 1-km gridded daily areal rainfall dataset for the period 1961-2012 (Keller et al., 2015; Tanguy, Dixon, Prosdocimi, Morris, & Keller, 2014). Catchment average monthly potential evapotranspiration PET was derived from the Met Office Rainfall and Evaporation Calculation System MORECS (Thompson, Barrie, & Ayles, 1982), and monthly PET distributed evenly throughout the months for the period 1961-2010. Daily gauged river flow time series were obtained from the National River Flow Archive when available and from relevant water companies otherwise. Catchment hydrological models were created and calibrated using HR Wallingford's water resources modelling framework using a PDM (Moore, 2007) type model.

Populating drought response surfaces

The impacts (change in Q95) represented in the drought response surfaces were created using hydrological modelling. Rainfall drought scenarios were defined as a matrix of drought duration (ranging from 6 months to 5 years in 6-month increments) and drought severity (average rainfall deficit of -10% to -90% of LTA). For each drought scenario, synthetic rainfall and PET sequences were created by resampling local historical rainfall and PET daily sequences with monthly rainfall total matching the drought scenario characteristics. The drought sequences, along with preceding and recovery phases of LTA rainfall, were input in the hydrological models and daily river flow sequences generated. Response surfaces were then derived by calculating the low flow index associated with each drought sequence scenario. Details of the methodology can be found in (Ledbetter, Anderton, & Prudhomme, 2015).

Method

The H++ risk assessment for national rainfall deficits (Table 3.2) was applied to the local response surfaces to estimate H++ low flow scenarios based on the same CMIP5 models. This approach is very similar to the use of response functions in the CCRA 2012 Water Sector report, albeit more complex as it is considering multiple drought magnitudes and durations simultaneously. The big assumption in this approach is that the national rainfall deficits for England and Wales translate to the same percent deficits locally. In practice, there will be some variation and local deviations will tend to be much greater in the 'epicentre' of a meteorological drought and much less in distant surrounding areas.

For each river basin, the drought characteristics of the summer and winter 10% and 1% probability levels of the H++ low rainfall scenarios (2080s time horizon) were identified and the associated values in the response surface extracted for each duration. The lower (upper) end of the H++ range are then defined as the corresponding minimum (maximum) absolute change for the 10% (1%) probability level out of the six river basin responses for each duration.

Five H++ low flow scenarios are considered: single season (6 month) summer and winter droughts, corresponding to short intense events; multiple season droughts starting in summer and winter (e.g. with two consecutive dry winters/summers); and long, multi-year droughts (from 24 to 60 month duration). As no local response surface was available outside England and Wales, the H++ low rainfall scenarios of both Scotland and Northern were used along with local responses in England and Wales and combined to provide the Scotland and Northern Ireland H++ low flow scenarios.

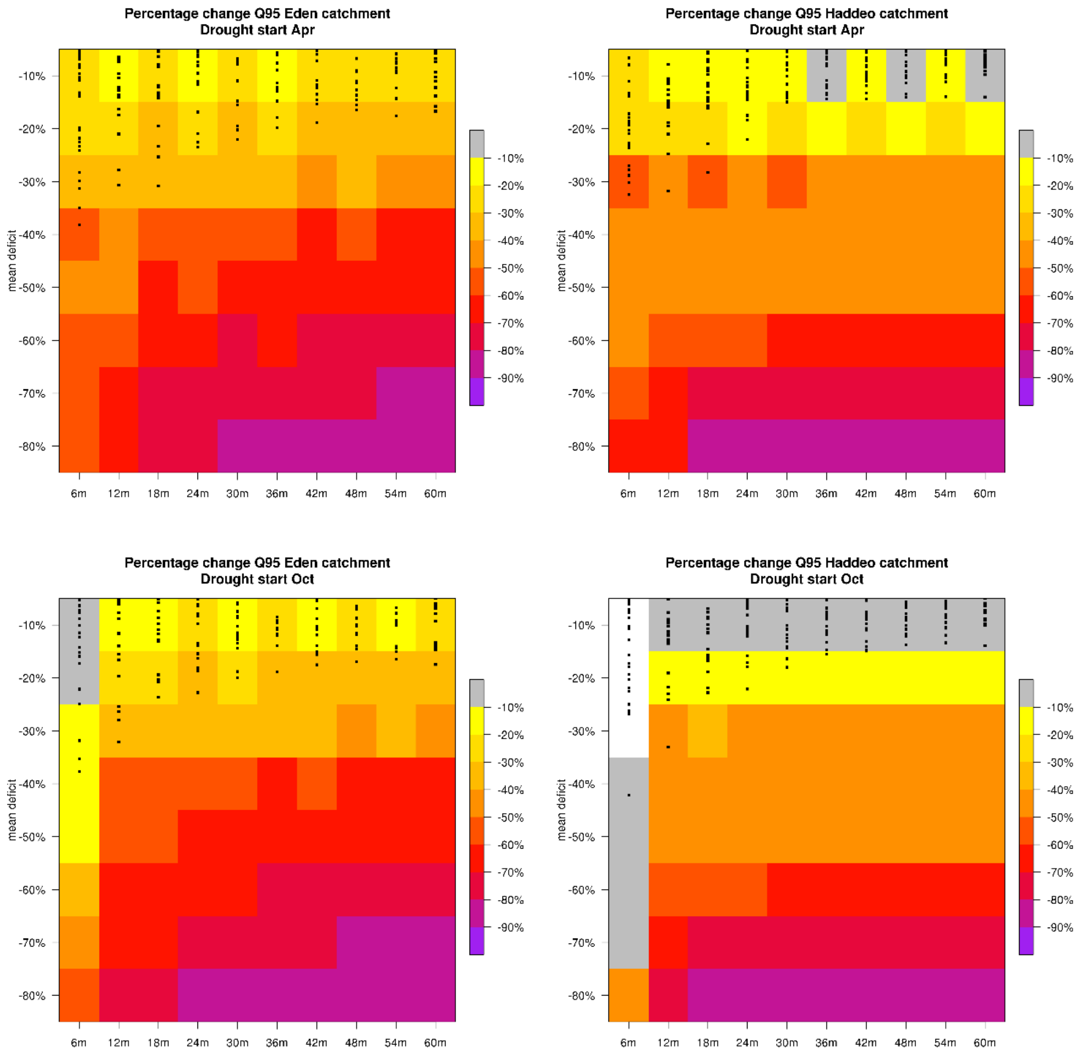


Figure 4.3 Examples of response surface of Q95 anomaly (over drought duration; %) compared to baseline Q95 (annual) for April (top) and October (bottom) drought start

Historical observations

Ways of characterising historic episodes of low flows and hydrological droughts in the UK are currently investigated in several NERC-funded projects specifically ‘DrIVER’ (G8MUREFU3FP-2200-108) and Historic drought (NE/L01016X/1), but projects are still underway and have not yet reported characteristics of the most severe events recorded the UK. For example, an inventory of historic droughts for the UK is expected to be published by the Historic drought project around March 2018.

In a recent review of climate-driven changes in UK river flows, (Hannaford, 2015) noted a general lack of evidence for trends in UK low flows (especially in the 1960s to early 2000s period), despite some recent high-profile drought events with significant societal impacts such as 2004 to 2006 and 2010 to early 2012. Instead, historic droughts have clustered with drought-rich (including multi-year episodes) and drought-poor periods, but there is a general lack of understanding of the causes of this variability (ibid).

The most comprehensive source of information on major historical UK droughts can be found in (Marsh, Cole, & Wilby, 2007), summarised in Table 2. It shows that droughts have manifested themselves over a range of durations. This feature can be seen in the runoff deficit time series associated with reconstructed monthly river flows produced by (Jones & Lister, 1998) shown in Figure 4.4, with both short intense events (e.g. Wharfe in mid 1930s) and long and relative widespread events (e.g. early 1900 in many of the catchments) identifiable. This range of spatio-temporal patterns was also highlighted by (Parry, Lloyd-Hughes, Hannaford, Prudhomme, & Keef, 2011) who examined the spatio-temporal footprints of five major European droughts over the period 1961-2005. This suggests that H++ low flow scenarios should be defined over a range of durations.

Year	Duration	Comments
1854–1860	Long drought	**Major long duration drought**. Sequence of dry winters in both the lowlands (seven in succession at Oxford) and northern England. Major and sustained groundwater impact.
1887/88	Late winter 1887 to summer 1888	**Major drought**. High-ranking rainfall deficiencies across a range of timeframes. Very widespread (across most of British Isles). Extremely dry 5-month sequence in 1887. Primarily a surface water drought – severe in western Britain (including northwest).
1890–1909	Long drought	**Major drought – long duration** (with some very wet interludes, 1903 especially). Initiated by a sequence of notably dry winters. Latter half of the period features a cluster of dry winters. Major and sustained groundwater impact, with significant water supply problems. Most severe phases: 1893, 1899, 1902, 1905. Merits separate investigation.
1921–22	Autumn 1920 to early 1922	**Major drought**. Second lowest 6-month and third lowest 12-month rainfall totals for England and Wales. Very severe across much of England and Wales (including Anglia and southeast; parts of Kent reported <50% rainfall for the year); episodic in northwest England.
1933/34	Autumn 1932 to autumn 1934	**Major drought**. Intense across southern Britain. Severe surface water impacts in 1933 followed by severe groundwater impacts in 1934, when southern England heavily stressed (less severe in the more northerly, less responsive, chalk outcrops).
1959	Feb to Nov	**Major drought**. Intense 3-season drought – most severe in eastern, central and northeastern England. Significant spatial variation in intensity. Modest groundwater impact.
1976	May 1975 to Aug 1976	**Major drought**. Lowest 16-month rainfall in E&W series (from 1766). Extreme in summer 1976. Benchmark drought across much of England and Wales – particularly the lowlands; lowest flows on record for the majority of British rivers. Severe impact on surface water and groundwater resources
1990–92	Spring 1990 to summer 1992	**Major drought**. Widespread and protracted rainfall deficiencies – reflected in exceptionally low groundwater levels (in summer 1992, overall groundwater resources for England and Wales probably at their lowest for at least 90 years). Intense phase in the summer of 1990 in southern and eastern England. Exceptionally low winter flows in 1991/1992.
1995–97	Spring 1995 to summer 1997	**Major drought**. Third lowest 18-month rainfall total for England and Wales (1800–2002). Long-duration drought with intense episodes (affecting eastern Britain in hot summer of 1995). Initial surface water stress, then very depressed groundwater levels and much diminished lowland stream network.

Table 4.2 Major droughts in England and Wales, 1800–2007 (from (Hannaford, 2015) and (Marsh et al., 2007)).

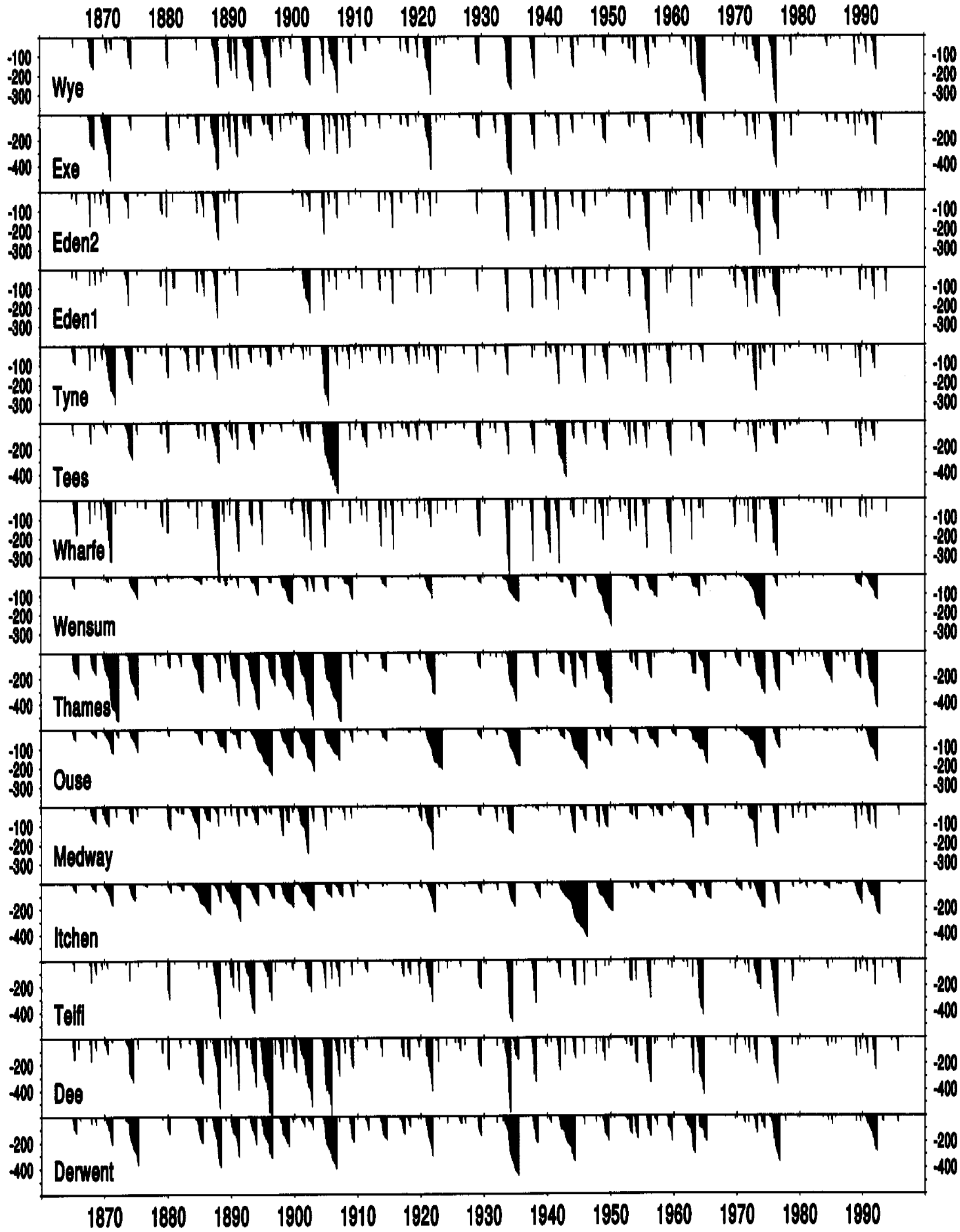


Figure 4.4 Runoff deficit index (mm) for 15 catchments based on reconstructed monthly river flow. Note difference in scale between some catchments. From (Jones & Lister, 1998)

Appendix CC.1.2

4.3 UKCP09

UKCP09 does not include projections of future river flow, although all UK water companies have made use of the projections to estimate the impacts on water resources systems. In 2012, the CCRA used UKCP09 and the results of water company studies in 2009, to estimate potential impacts on low flows at a regional scale. For example in Anglian Region for the 2050s Medium emissions scenario, it estimated changes in Q95 between -14 and -50% and for the 2080s High emissions scenario, changes from -38% to -70% (Wade et al., 2012). A more comprehensive approach adopted for CCRA2 suggests marginally smaller reductions in low flows (Section 4.5).

4.4 Physical limits

Physical limits have not been considered in detail as part of the H++ low flow assessment. However, it is important to recognise that changes in low flows are very sensitive to both catchment characteristics and artificial influences. Groundwater dominated streams are a special case with some headwater streams drying out naturally under drought conditions, whereas others are impacted by groundwater abstraction. Many rivers are sustained by groundwater, even in very dry summers and a significant reduction in groundwater levels would be required to reduce flows. Other rivers are maintained by discharges (effluent and storm water discharges). Detailed catchment studies are required to understand the potential impacts of H++ low rainfall scenarios on specific catchments.

4.5. Other evidence

To complement the limited number of case studies where the H++ low rainfall scenarios could be applied, the modelling results of the CCRA2-B project (HR Wallingford, 2015) were considered and summarised in Table 4.3. Modelling was undertaken for all Future Flows catchments (Prudhomme et al., 2013) with available PDM model (Moore, 2007; Christel Prudhomme et al., 2012). Future climate time series input in PDM (rainfall and PET) were generated using the change factor method (Hay, Wilby, & Leavesley, 2000) based on gridded UKCP09 probabilistic change factors under the High emission scenarios for the 2080s time slice (Murphy et al., 2009). For each 10,000 resulting river flow time series, Q95 (annual) was calculated and compared with that derived from simulations driven by observed climate time series. Regional changes were then derived as an average of catchment changes (weighted by basin area) and the lowest 10% probability level was estimated. UKCP09 upper end (lower end) scenarios for

England, Wales and Scotland correspond to their maximum (minimum) absolute 10% probability level of change found in the region. Note the different number of catchments/ information used to derive regional and national estimates.

By construction the UKCP09 climate scenarios do not include any information on change probability in drought duration or intensity of extreme events but instead give an estimate of how the whole flow regime might shift. While some regional variations are seen, there is a noticeable homogeneity in the UKCP09 upper end changes of a decrease of -50% in Q95.

England		**Wales**		**Scotland**	
UKCP09 upper end	-45	UKCP09 upper end	-50	UKCP09 upper end	-45
UKCP09 lower end	-30	UKCP09 lower end	-50	UKCP09 lower end	-10
Anglian	-40	Dee	-50	Argyll	-45
Humber	-30	Severn	-50	Clyde	-45
Northumbria	-30	Western Wales	-50	Forth	-30
Northwest England	-45			Northeast Scotland	-15
southeast England	-35			north Highland	-25
southeast England	-45			Solway	-45
Thames	-30			Tay	-30
				Tweed	-40
				west highland	-10

Table 4.3 UKCP09 low flow scenarios for the 2080s expressed as changes in annual Q95 based on 10% probability level of changes in simulated river flows driven by the 10,000 probabilistic UKCP09 change factor applied to baseline climate as described in (Christel Prudhomme et al., 2012). [Note that all values are rounded to the nearest 5%.]

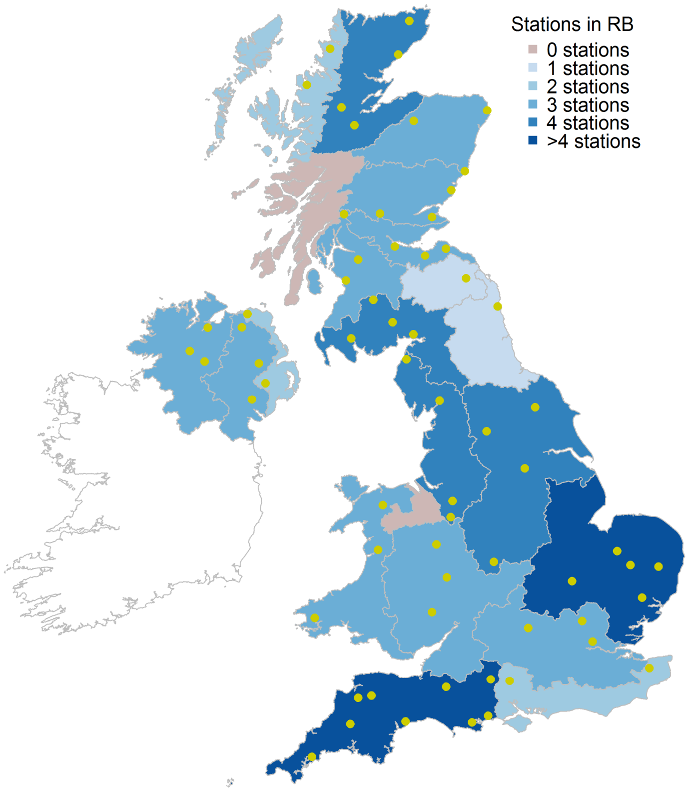


Figure 5.5 Location of FFH stations within each River Basin region in the UK. The river basin regions are coloured according to the number of stations found in each region.

4.6 H++ scenarios

Based on the analysis described in Section 3.1, several H++ low flow scenarios were developed and are summarised in Table 4.4.

The H++ scenario for summer low flows is a reduction in the Q95 by between 40 and 70 percent in England and Wales and 30 and 60 percent for Scotland and Northern Ireland by the 2080s The H++ scenario for multi-season droughts with consecutive summers is a 20 to 60 percent reduction in flows in England and Wales and 20 to 50 percent reduction in Scotland and Northern Ireland. For longer droughts the H++ scenario is for up to 50 percent and 45 percent reductions in flow for England and Wales and Scotland and Northern Ireland respectively[24].

Single season summer droughts are the most severe of the H++ low flow scenarios as the naturally occurring low flows (defined by the Q95 statistic) are further reduced by

[24] H++ low flow scenarios are given for three durations as impact and management options are likely to differ as drought prolongs: single season; multiple seasons (2-3); and multiple years. To capture uncertainty in projections upper and lower estimates are given.

40% to 70%. This is a very similar range as presented for Anglian Region for 2080s High emissions in the CCRA 2012 but here it applies to the whole of England and Wales not just the driest UKCP09 region in England.

Winter droughts are still possible with Q95 deficits of 0 to 40%. When droughts prolong to 2 or 3 seasons the impact of the seasonality reduces, while their probability is reduced due to the projected wetter winters. Multi-year droughts events may still occur in the future and these could be associated with a reduction in low flows of 0- 50% (Q95) over up to 5-year period.

	Summer	**Winter**	**2-3 season (1 or 2 consecutive summers)**	**2-3 season (1 or 2 consecutive winters)**	**Long (>= 2 years)**
	Increased probability	*No change/ decrease*	*Increased probability*	*No change*	*No change*
England and Wales					
H++ upper end	-70	-40	-60	-60	-50
H++ lower end	-40	0	-20	-10	0
Scotland and Northern Ireland					
H++ upper end	-60	-25	-50	-45	-45
H++ lower end	-30	0	-20	-10	-5

Table 4.4 H++ low flow scenarios for England and Wales for the 2080s time horizon, expressed as percentage changes in Q95. [Note that all values are rounded to the nearest 5%.] Probability of occurrence based on evidence given in Section 3.

Caveats

The methodology used to define the H++ low flow scenarios is attached with a number of assumptions that must be considered when using the scenarios. They are summarised below:

- The H++ low rainfall scenarios on which the method is based are national-scale projections; locally it is likely that more extreme low rainfall (and by extension, low flow) scenarios could occur;
- The H++ low flow scenarios are based on response surfaces of six river basins from four case studies. It is possible more extreme response could be found if a wider range of test catchments were considered;
- No simulation was available outside England and Wales so the response surfaces obtained for the case study catchments were used as proxy for Scotland and Northern Ireland. Further work needs to be done to refine the H++ scenarios outside England and Wales.

Chapter 5 High rainfall

5.1 Summary of the High ++ high rainfall scenarios

There are two scenarios for high rainfall, the first is for increases in average winter rainfall (Dec-Jan-Feb), which is important for fluvial and groundwater flood risk, as demonstrated by the flooding in winter 2013/14 that affected large areas of England and Wales, including the Somerset Levels. The second is for heavy daily and sub-daily rainfall in winter or summer, which is important for river flooding, flash flooding and urban drainage, such as the rainfall events in Cumbria in 2009 and Boscastle in 2004 that caused severe flooding. Both scenarios relate to 30 year average conditions.

The H++ scenario for average winter rainfall is an increase of 70% to 100% on the 1961-1990 baseline by the 2080s, which overlaps but is marginally higher than the UKCP09 2080s High emissions scenarios. The H++ for heavy daily and sub-daily rainfall for the same period is a 60% to 80% increase in rainfall depth for summer or winter events based on a consideration of new high resolution modelling and physical processes. This is within the UKCP09 distribution tails for the 2080s High emissions "wettest day of the winter" variable but higher than uplifts previously considered for summer.

For winter rainfall the final High ++ scenario is based primarily on UKCP09, CMIP5 modelling results and expert opinion[25] and is presented as a range of percentage uplifts on average winter rainfall. For daily and sub-daily rainfall the results are based on high resolution modelling and expert opinion which considers the physical limits to rainfall depths and is presented as a percentage increase in rainfall event depths and a range of increases in frequency of heavy rainfall events[26].

Information on H++ scenarios is already included in the Environment Agency FCERM guidance on *"Adapting to Climate Change*", which will be updated again in 2015 (EA, 2015). This explains how H++ scenarios can be used in flood risk management. In addition, the same high resolution modelling results have been considered in new

[25] Expert opinion has been used to weigh up the evidence and decide on the final H++ ranges presented at the end of the section. This is based on opinion of the authors rather than a formal expert elicitation exercise.

research for urban drainage design as part of the UKWIR report "Rainfall Intensity for Sewer Design" (UKWIR, 2015).

5.2 Historical observations

High winter rainfall

Considering the UK as a whole and based on data from 1910, four of the five wettest calendar years have been since 1999 (2000, 2012, 1954, 2014, 2008) and the wettest winters (Dec-Jan-Feb) were 2013/14, 1994/95, 1989/90, 1914/15, 2006/07[27].

The winter of 2013/14 was an exceptional period of winter rainfall affecting a large area of the UK (Figure 5.1). The clustering and persistence of the storms was highly unusual, making December and January exceptionally wet months with an total rainfall of 372 mm over the two months for the south east and central southern England. The monthly totals were greater than 175% and 200% of 1981-2010 average rainfalls, for December and January (Figure 5.1). It was the wettest any 2-month period in the series from 1910. If a large area of England and Wales is considered this is likely to have been the wettest winter in at least 248 years (Met Office and CEH, 2014). Huntingford *et al* (2014) described the driving meteorological factors that influenced the 2013/14 flooding (see Chapter 7).

Figure 5.2 shows a time series of winter precipitation for the south east and south west of England (lines) and deviations from the 1961-1990 average winter precipitation (bars); the winter 2013/14 was the wettest in both regions but there were also notably wet winters in 1929/30 and 1936/37.

Trends in winter rainfall

Any analysis of rainfall trends is hampered by limitations of observing systems, the high natural variability of rainfall and sensitivity to start and end dates. According to the UKCP09 trends report observed increases in winter rainfall (Dec-Feb) from 1961 have been greatest in Scotland and Wales (Jenkins et al., 2008). There is some evidence for and increasing trend in the amounts of precipitation over northern Europe between 1900 and 2005 and increases in heavy rainfall over the UK (Osborn et al., 2000). Kendon (2014) took a novel approach and explored trends in record breaking weather using data from the National Climate Information Centre (NCIC), which highlighted a period of

[27] UK Rainfall areal series starting from 1910. Allowances have been made for topographic, coastal and urban effects where relationships are found to exist. Data are provisional from September 2014 & Autumn 2014. Last updated 02/03/2015

record breaking heavy rainfall in the second decade of the 20th century (1910s) and a large number of notable events since 2000.

Attribution to climate change

Several authors have linked periods of heavy rainfall to climate change. For example, Pall et al. suggested that climate change had already increased the chance of the rainfall that caused the 2000 floods more than two-fold (Pall et al., 2011). A more comprehensive hydrological analysis using similar climate change model data confirmed that the risk of flooding in autumn (September to November) is likely to have increased due to climate change, but suggested a lower increase in the frequency of events (Kay et al., 2011). Similar research on the winter 2013/14 flooding is in progress and will shortly be published. However, this type of attribution activity is still an active area of scientific research and whilst the results are consistent with our understanding of basic atmospheric thermodynamics there is still significant uncertainty in the size of these effects. Furthermore, we should not assume that all recent extreme rainfall events can be attributed to human drivers.

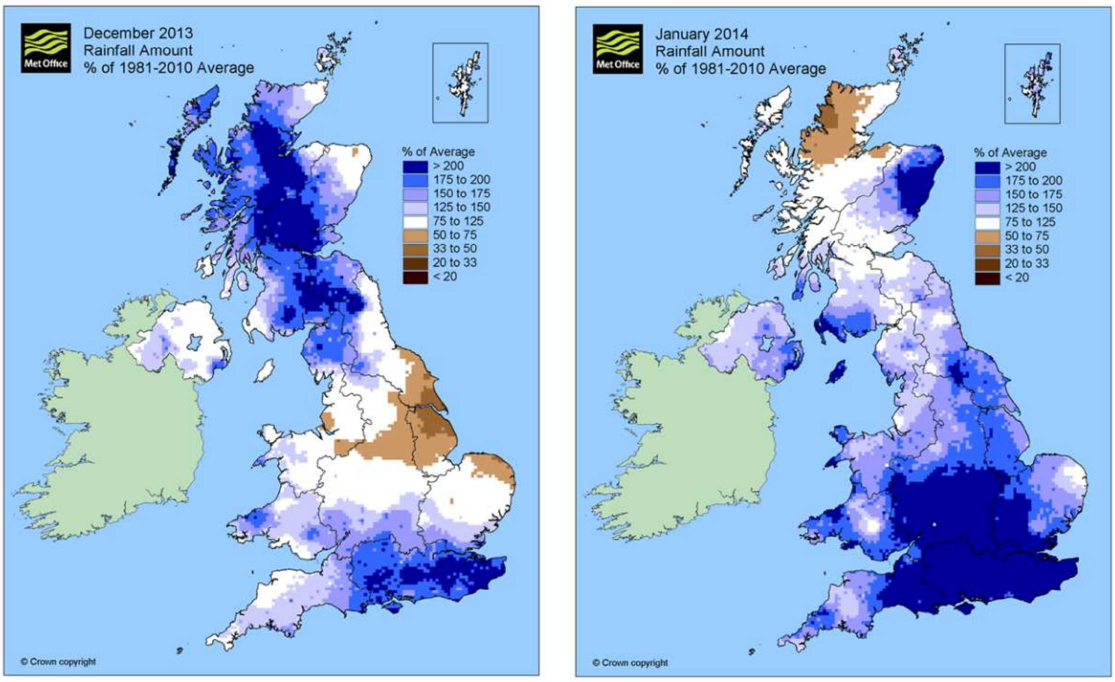
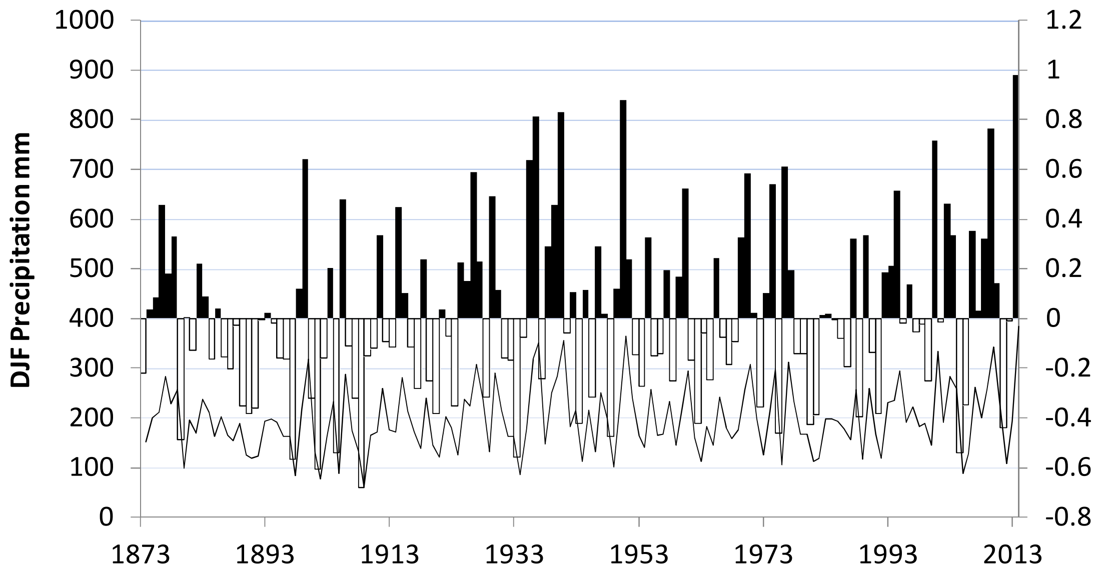


Figure 5.1. Rainfall for December 2013 and January 2014 from the observational network, showing the distribution of rainfall anomalies as a % of the long-term average from 1981-2010.



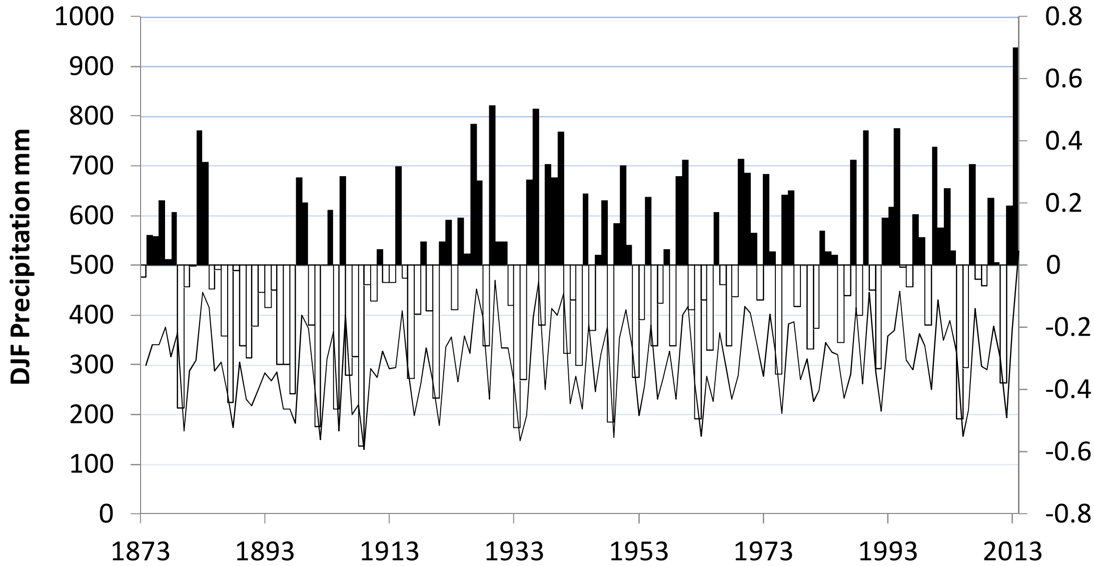


Figure 5.2. South East of England (top) and South West and South Wales precipitation (bottom) for December, January and February (line) and deviation from the 1961-1990 average (bars) from the Met Office regional precipitation time series
Source: *http://www.metoffice.gov.uk/hadobs/hadukp/*

Rainfall events

Hand et al (2004) investigated extreme rainfall events in the United Kingdom from 1900 to 2000 with durations of up 60 hours. They found suitable conditions for extreme rainfall in different meteorological situations related to orographic, frontal and convective systems. Convective conditions caused the heaviest rainfall at short durations and orographic and frontal conditions caused heavier rainfall at durations greater than five hours (Figure 5.3). Particularly notable events have occurred in the summer (June, July or August) for example :

- Castleton (Yorkshire) with 250 mm in 60 hours (frontal)
- Lynmouth in 1952 with 228 mm in 12 hours, which caused devastating floods
- Martinstown (Dorset) in 1955 with 280 mm in 15 hours (both classified as frontal with a significant convective component)
- Hindolvesten (Norfolk) in 1959 with 93 mm in around 20 minutes (convective).

More recently heavy rainfall events that caused severe flooding have occurred at Boscastle in Cornwall (2004) and in Cumbria (2009). The Boscastle floods, 16th August 2004, were caused by a sequence of convective storms that channelled along the North Cornish coast. One station at Lesnewth indicated accumulations of 82mm, 148mm and 183mm over 1, 3 and 5 hours and a peak instantaneous rain rate of nearly 300 mm hr^{-1} (Fenn et al., 2005). Otterham, near Boscastle, recorded 200 mm in 5 hours (Stewart et al., 2013). The Cumbria floods in 2009 were triggered by an exceptional longer duration rainstorm with 316.4 mm recorded at Seathwaite Farm, Borrowdale (Stewart et al., 2012). This is a UK record for rainfall over any 24 hour period and was an exceptional event with an annual probability of approximately 0.1% or 1 in 1000 years.

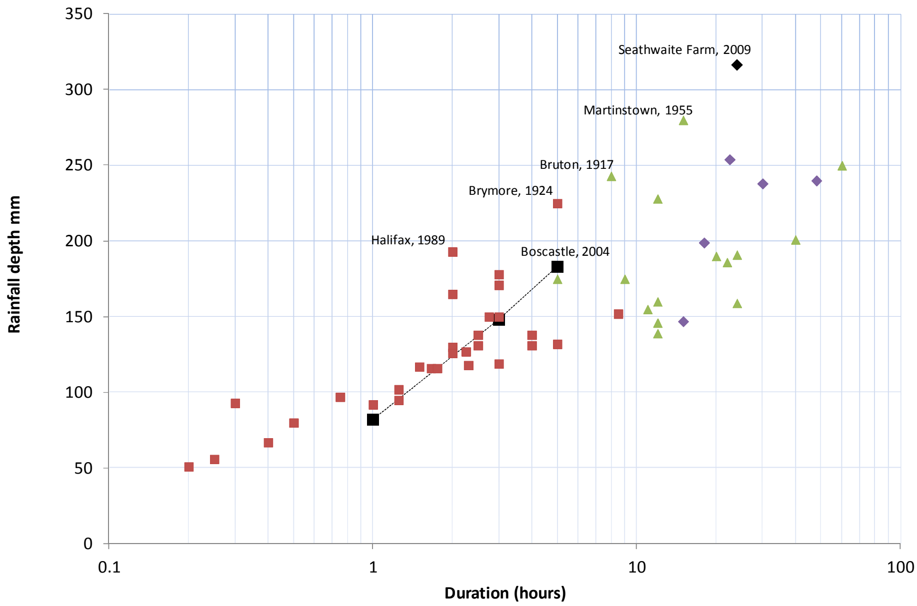


Figure 5.3. Plot of point rainfall amount (mm) versus duration (h) (on a logarithmic scale) for different event categories, square – convective, triangle – frontal and diamond – orographic (adapted from Hand, 2004).

Appendix CC.1.2

Trends

Jones et al. (2013) reported increases in spring and autumn extreme rainfall events in the UK, with longer duration winter events increasing in intensity and becoming more frequent. They also indicate more frequent heavy rainfall events in Scotland and Southwest England. Overall these findings are consistent with the changes projected in UKCP09, based on indicators such as "the wettest day of the winter" and outputs of the UKCP09 weather generator. Over the same period they found that short-duration summer rainfall events had declined in intensity

Attribution

There has been less work on attribution of daily and sub-daily rainfall, primarily due to the inadequate spatial resolution and low skill of climate models at reproducing heavy rainfall events in summer months. In response to the July 2007 floods, Otto et al. (2014) concluded that 5-day rainfall events in July were likely to be heavier and more frequent in comparison to the 1960s.

Estimation of design rainfall

Flood risk, drainage and reservoir engineers use estimates of rainfall depths for the design of flood risk management schemes, urban drainage systems and reservoir spillways. Design estimates are normally based on an agreed national method using either observed data from a single site or, more appropriately, a larger number of sites as in the Flood Studies Report (FSR) or Flood Estimation Handbook (FEH).

A new statistical model of point rainfall depth-duration-frequency (DDF) (FEH13) is under development at CEH and replaces the previous model (FEH99). The supporting research considered historical extremes, Probable Maximum Precipitation (PMP) and different statistical models for estimation of low probability or long return period rainfall events (Stewart et al., 2013). The heaviest events[28] generated in England by the new DDF model are of the order of 500 mm in 24 hours (e.g. Honister Pass, Cumbria, SAAR 3193 mm yr^{-1}, Fig. 9-20 in Stewart et al 2013) and of the order of 220 mm in London (Kew, SAAR 605 mm yr^{-1}, Fig. 9-26 in Stewart et al 2013). For the locations and events included in Figure 4.3, many of the largest observed events, such as Martinstown in 1955 and Halifax in 1989, are close to or even greater than estimates of PMP.

[28] These are estimated to have a return period of 1 in 100,000 years

In general terms both rainfall models (FEH13 and FEH99) produce similar design rainfall depths up to return periods of around 1 in 50 years (probability 2%). The new rainfall model (FEH13) generally produces lower rainfall depths for lower probability events as illustrated in Figures 5.4 to 5.7. The differences between the rainfall models can be large, which highlights the sensitivity of these estimates to different periods of rainfall data as well as methods of analysis. Comparison of these statistical models to historic events (Figures 5.5 to 5.7) indicates that more extreme events are always possible and also that theoretical Probable Maximum Precipitation (PMP) estimates can be exceeded.

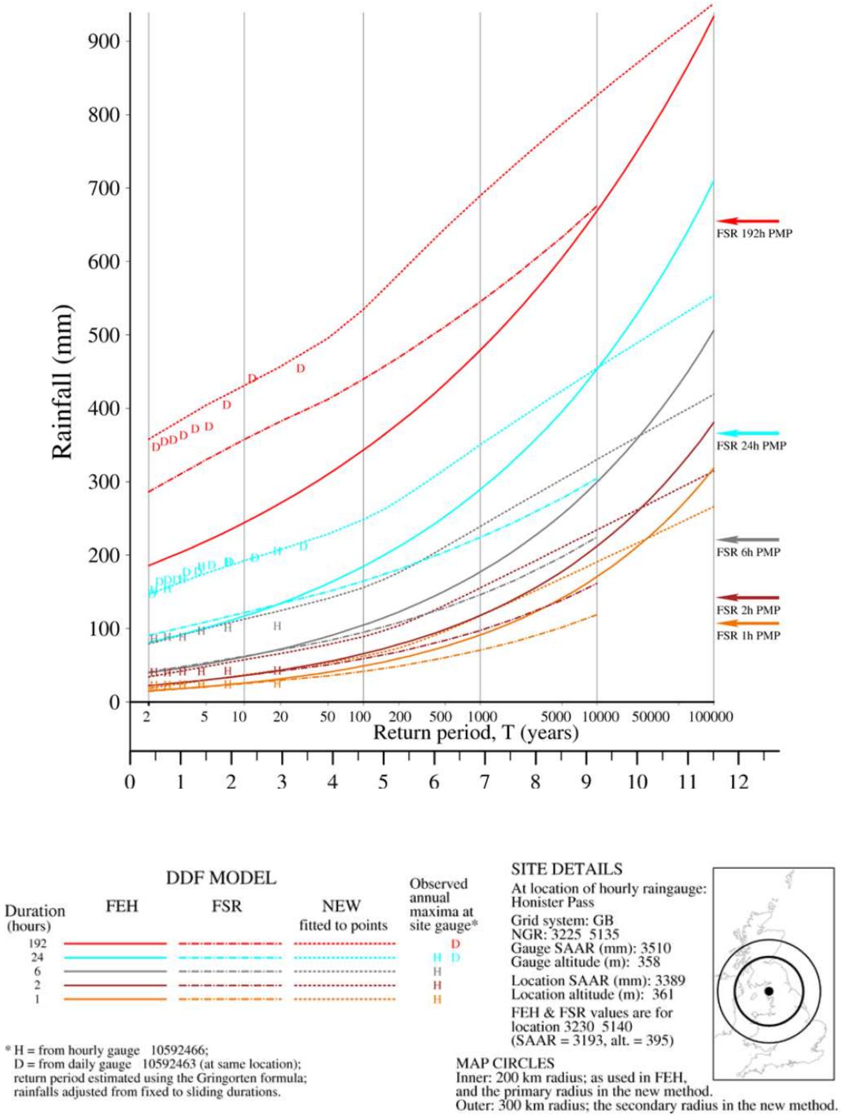
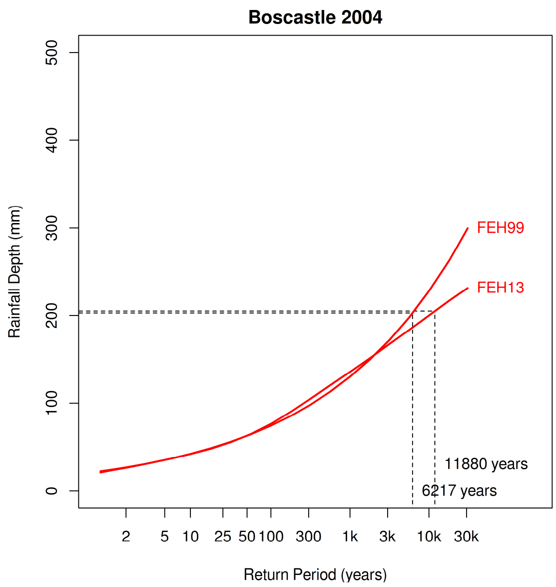


Figure 5.4. Examples of models of extreme precipitation fitted to Honister Pass, Cumbria with 24 hour precipitation shown in blue and previous Flood Studies Report (FSR) Probable Maximum Precipitations as arrows (SAAR 3193 mm yr-1, Fig. 9-20 in Stewart et al 2013). The lower x-axis shows the reduced variate.

Boscastle

Notes:

200 mm in 5 hours were recorded at Otterham (near Boscastle)



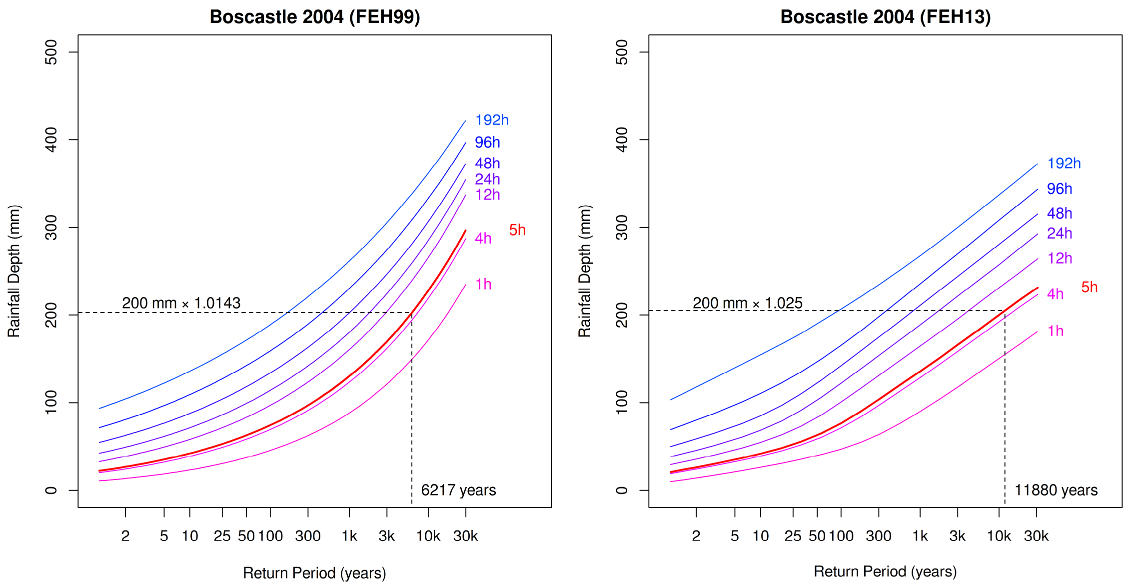


Figure 5.5 Estimate of extreme rainfall at Boscastle according to the FEH99 and FEH13 rainfall models.

Appendix CC.1.2

Seathwaite Farm

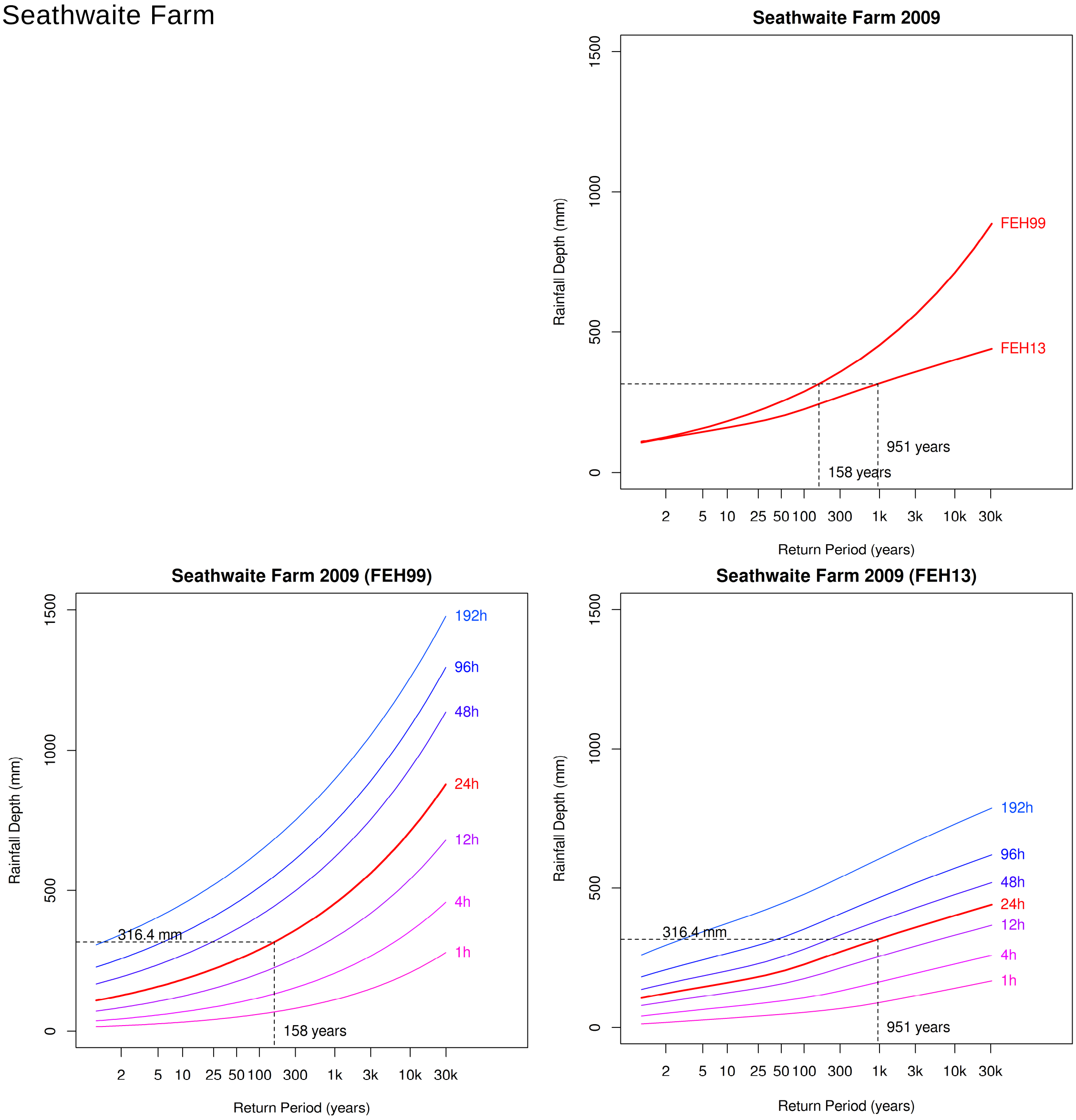


Figure 5.6. Estimate of extreme rainfall at Seathwaite Farm in Cumbria according to the FEH99 and FEH13 rainfall models.

Appendix CC.1.2

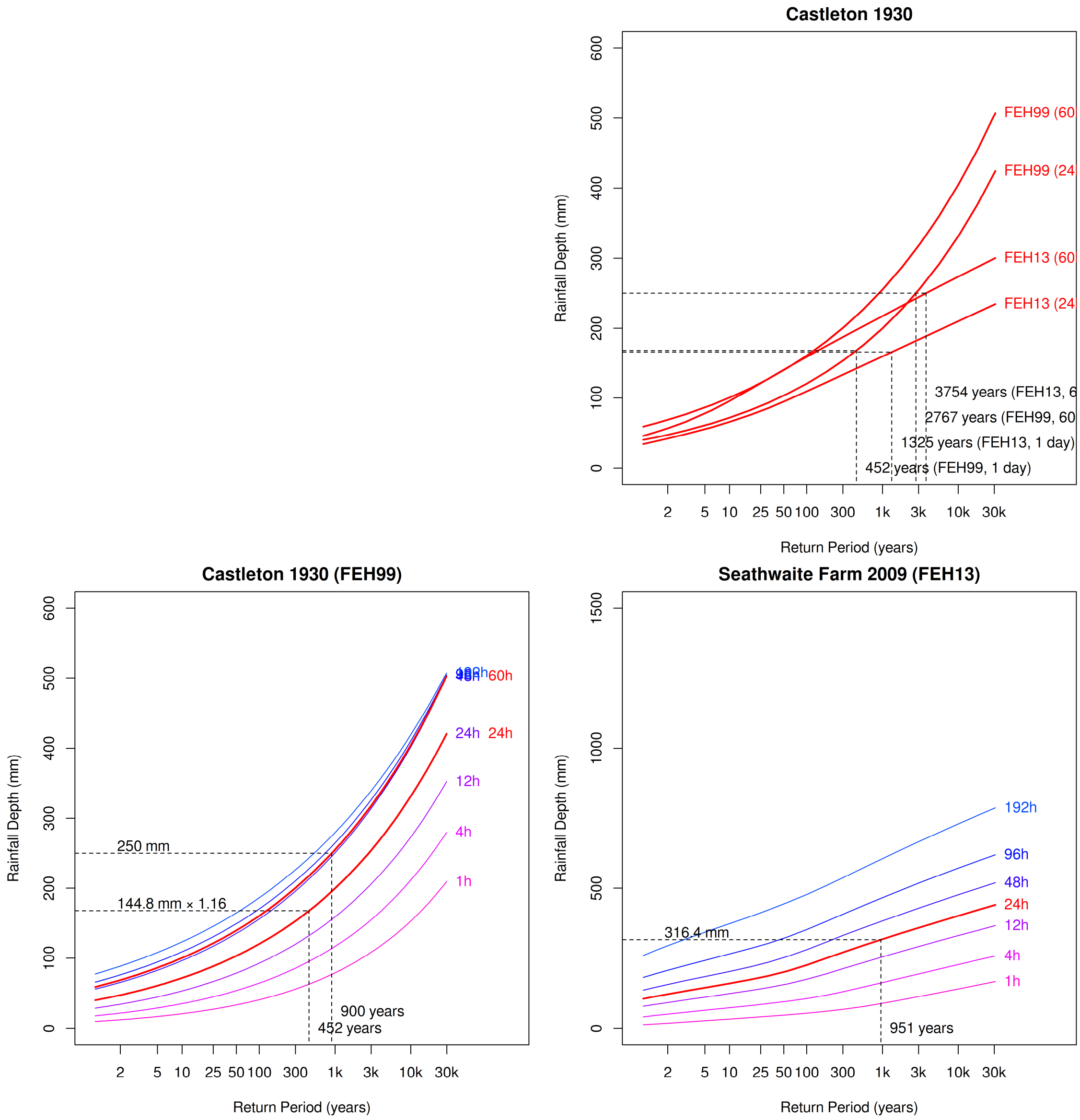


Figure 5.7. Estimate of extreme rainfall at Seathwaite Farm in Cumbria according to the FEH99 and FEH13 rainfall models.

5.3 UKCP09

Winter rainfall

The UKCP09 projections provide information on future changes in the average annual rainfall, seasonal rainfall and "wettest day of the year/season" (Murphy et al., 2009). Figure 5.8 provides maps of projected changes in 30-year average winter precipitation and wettest day of the year[29] (winter) for the High Emissions 2080s and the 50th and 90th

[29] This is calculated as the 99th percentile, so for the annual figure it may be exceeded 3 or 4 days a year but at a seasonal scale it is equivalent to wettest day and measures such as the mean of annual maxima or R_{med}.

percentiles of the UKCP09 sampled data. Both indicate the possibility of changes of around 70 percent (or greater); within individual grid squares projected changes in the wettest day of the winter and average winter precipitation reach 80 and 90 percent respectively (Figures 4.9 and 4.10). The projections provide robust estimates of future changes in winter rainfall (mostly frontal in nature) but are less appropriate for considering heavy summer rainfall (see the following section). Changes of 70-90% are very unlikely under the High Emissions scenario but the tails of the distribution indicate that a winter precipitation like 2013/14 could be an average winter by the 2080s.

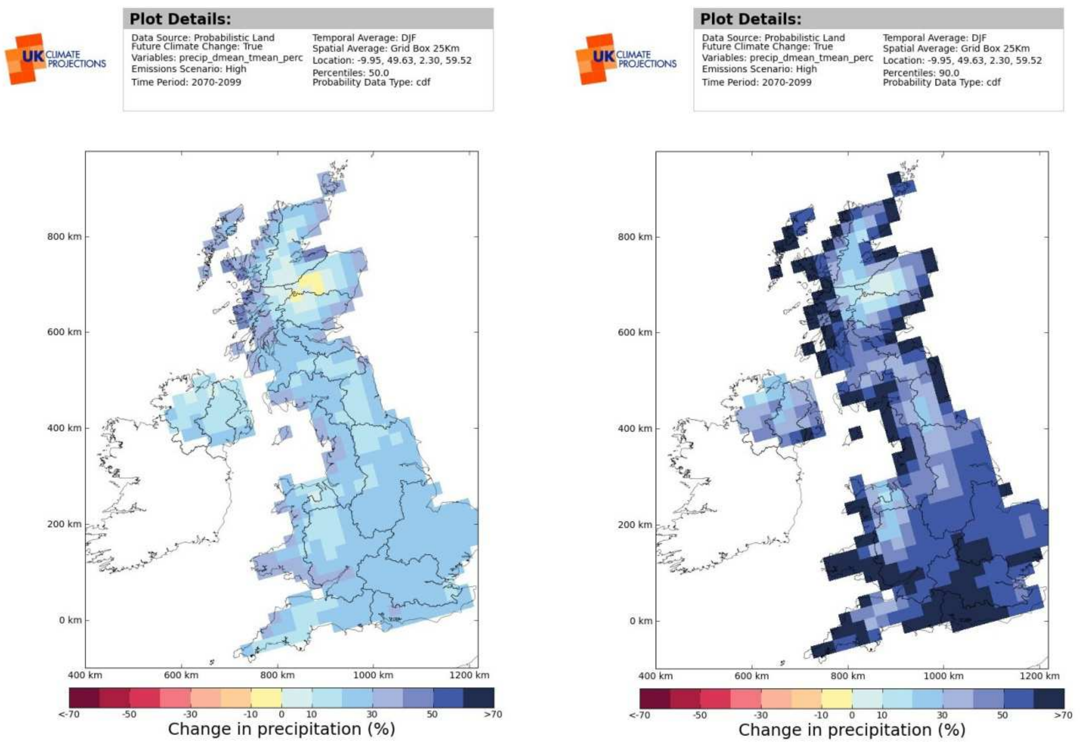


Figure 5.8. Change in precipitation in winter (DJF) for the 2080s High Emissions scenario and 50th and 90th percentiles

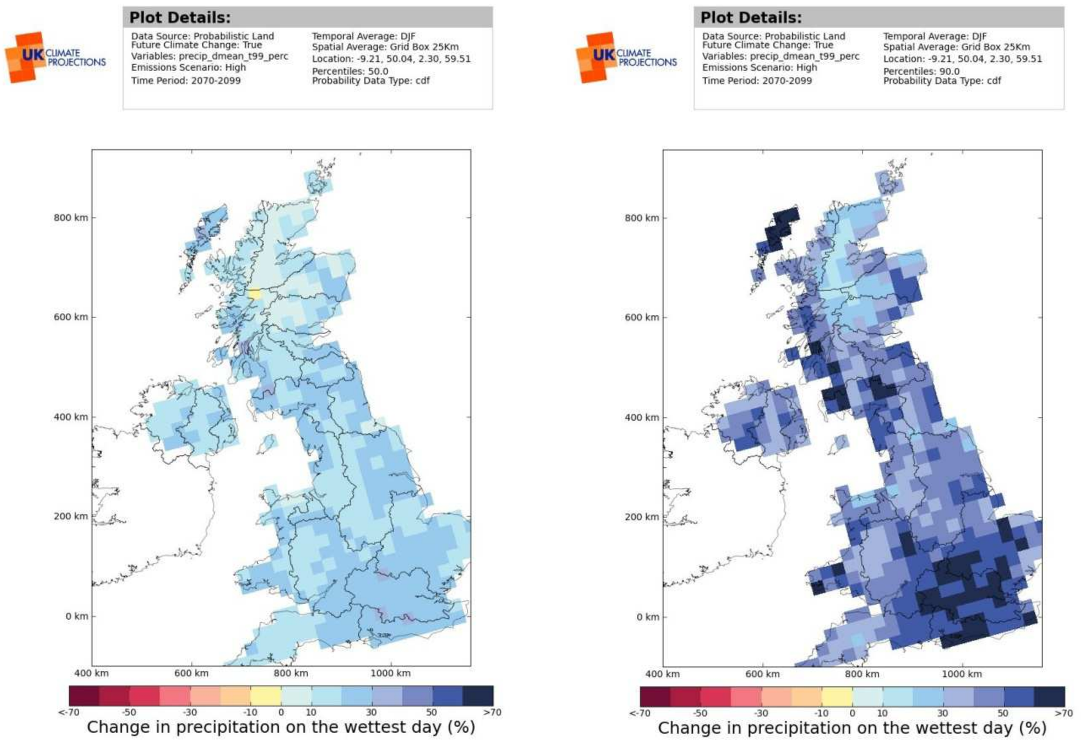


Figure 5.9. Change in precipitation on the "wettest day" of the winter (DJF) for the 2080s High Emissions scenario and 50th and 90th percentiles

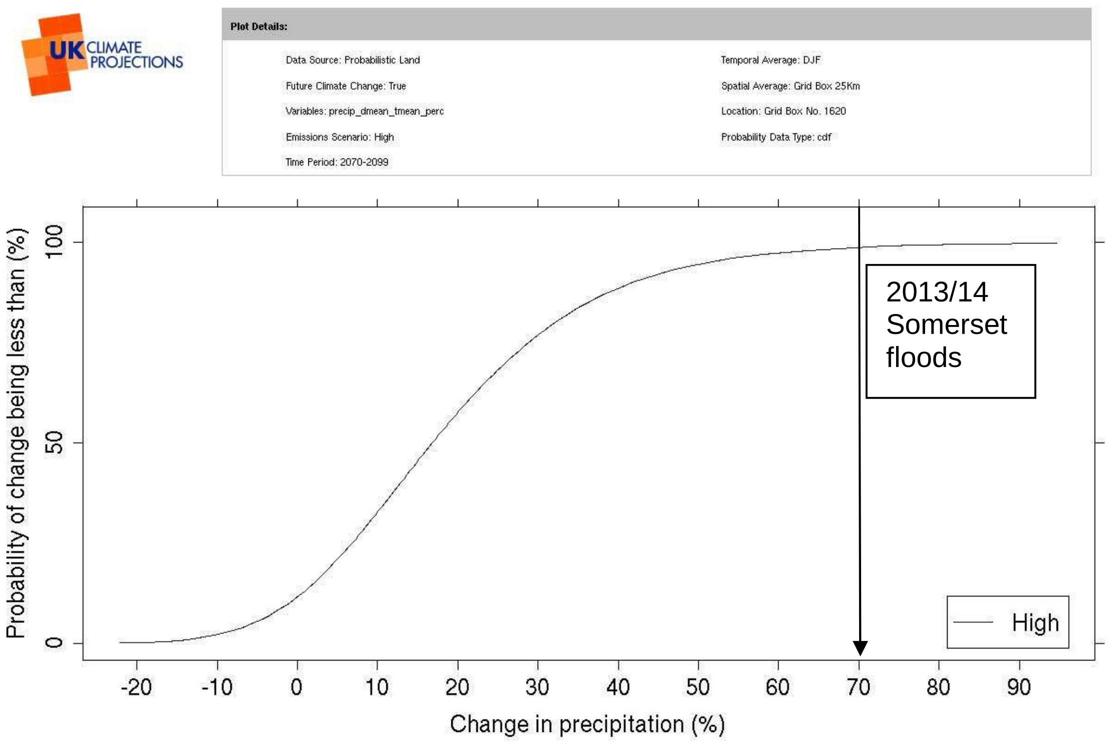


Figure 5.10. Change in 30 year average winter precipitation on the Somerset Levels in winter (DJF) for the 2080s High Emissions scenario shown with the single year of 2013/14 for illustration purposes

Appendix CC.1.2

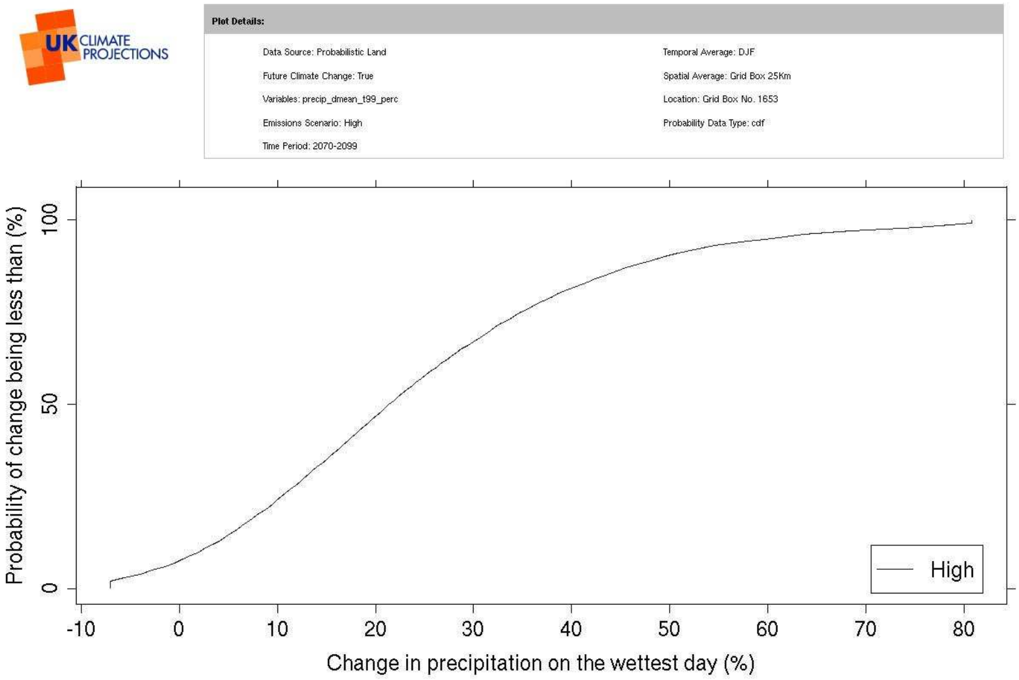


Figure 5.11. Change in average precipitation on the North Cornwall coast on the "wettest day" of the winter (DJF) for the 2080s High Emissions scenario

Daily rainfall

The UKCP09 weather generator (Jones et al., 2009), which has been widely used to estimate uplifts in daily rainfall, produced increases in median annual maximum daily rainfall (R_{med}) of around 12 to 23 percent for the Medium Emissions scenario (P50) and these were used in the CCRA (Wade et al., 2012)[30]. The weather generator was updated in 2011[31]. All locations exhibited a wider uncertainty range both in the baseline and the future with increases in the 90th percentile values and decreases in the 10th percentile values in the future projections compared to the original version. (The uplifts were similar in percentage terms). Using a very different approach based on non-stationary Extreme Value Analysis, data from Regional Climate Models and a 2050s Medium emissions scenario (A1B), Brown et al estimated changes in extreme summer daily rainfall between -16% and +24% and an increase in 5 day autumn rainfall of between 1% and 24% compared to a 1961-1990 baseline (Brown et al., 2014).

[30] The largest uplift reported was 38% (2080s Medium Emissions p90/Control p90)
[31] http://ukclimateprojections.metoffice.gov.uk/22585

5.4 Evidence from CMIP5 and other climate models

A recent Met Office review compared the outputs of CMIP5 models to UKCP09. The ranges of future change in average climatological conditions across CMIP5 models were generally found to be consistent with the probabilistic projections from UKCP09. However, the study did find some significant differences for projections of UK summer rainfall. While UKCP09 and CMIP5 agree that average summer rainfall is more likely to reduce rather than increase in the future, CMIP5 suggests smaller reductions than UKCP09 and a somewhat larger chance that UK summer rainfall could remain similar or become wetter than it is today (Sexton et al., 2013).

The CMIP5 models indicate an increase in heavy rainfall globally, with the greatest changes in the tropics. Lau et al. (2013), from analyses of projections of 14 CMIP5 models, found a robust canonical global response in rainfall characteristics to a warming climate. Under a scenario of 1% increase per year of CO_2 emission, the model ensemble projects globally more heavy precipitation[32] (+7 ± 2.4% K^{-1}), less moderate precipitation (2.5 ± 0.6% K^{-1}), more light precipitation (+1.8 ± 1.3% K^{-1}), and increased length of dry (no-rain) periods (+4.7 ± 2.1% K^{-1}). The sensitivity of rainfall to temperature varies geographically as well over land and oceans, for example Lui et al, (2012) indicated a scaling of 2-4 percent increase in precipitation per degC over land and of the order of 4-15 percent per degC in the tropics.

Lavers et al., (2013) showed that 'Atmospheric Rivers' (ARs), which can be linked to winter flooding in the UK, are likely to approximately double in frequency by the end of the century. ARs are key synoptic features which deliver the majority of poleward water vapour transport that are associated with episodes of heavy and prolonged rainfall. The analysis was based on five global climate models (GCMs) in the fifth Climate Model Intercomparison Project (CMIP5). It suggests that the projected change in ARs is predominantly a thermodynamic response to warming resulting from anthropogenic radiative forcing.

HadRCM

As part of a review for the water regulator Ofwat, Sanderson (2010) estimated the magnitudes of daily rainfall events in 40 cities for events with return periods of 1 in 5, 10, 20, 30, 50 and 100 years from observed and Hadley Centre regional climate model data

[32] Defined as events above the 98.5th percentile

for the 2040s, 2060s and 2080s. The RCM was based on a Medium Emissions scenario and does not span the full uncertainty range in UKCP09. All winter rainfall events are projected to become more frequent. During winter, the biggest increases in frequency of 5 and 10 year events were projected to occur over Essex, Sussex and Kent. For the 20, 30, 50 and 100 year events, the biggest increases occur over Suffolk with a two- to three-fold increase in heavy rainfall events by the end of the century (Figure 4.12). Changes in summer rainfall were more uncertain and summer rainfall events could become much less frequent or more frequent according to this assessment.

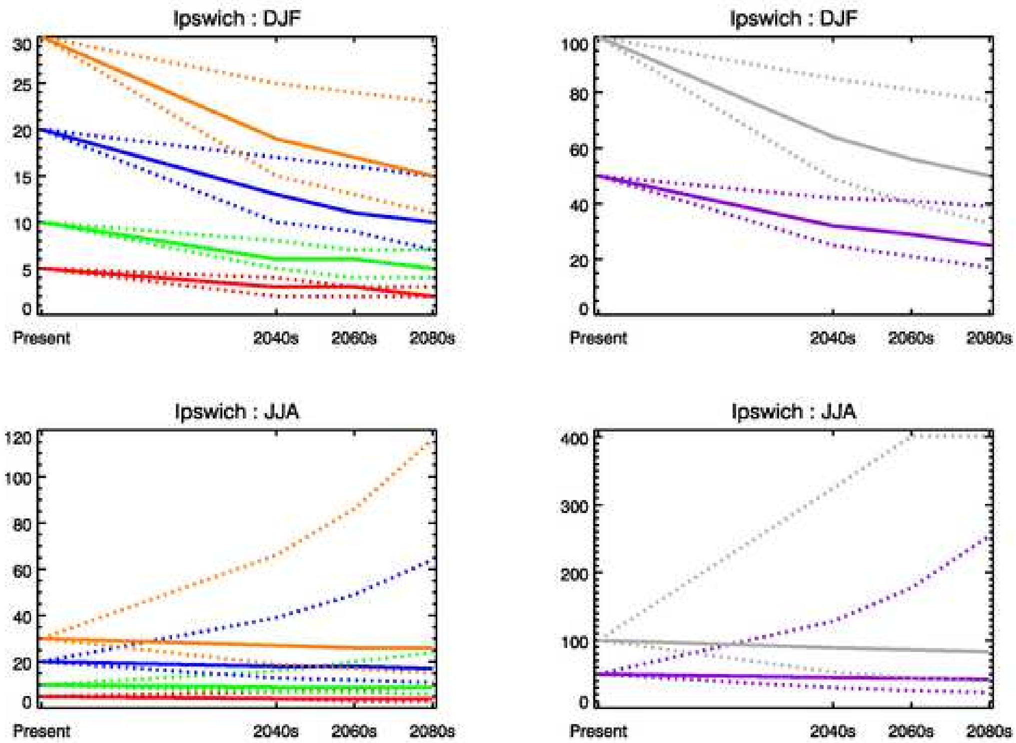


Figure 5.12. Change in return period for rainfall events with present-day return periods of 1 in 5 years (red), 1 in 10 years (green), 1 in 20 years (blue), 1 in 30 years (orange) [left-hand panels] and 1 in 50 years (purple) and 1 in 100 years (grey) [right-hand panels].

Notes: The return periods are shown on the y-axis. The central estimate (50th percentile) is indicated by a solid line, and the 10th and 90th percentiles, calculated using the full range of probabilistic projections from UKCP09, illustrate the possible range of return periods and are shown by dotted lines. The present-day return periods are positioned at 1980 on the x-axis (marked as 'Present'). Changes for winter (DJF, top row) and summer (JJA, bottom row) have been calculated separately. Note that the scale of the y-axis is different for each panel.

The CONVEX project

As part of the recently completed CONVEX project (**CONV**ective **Ex**tremes), the Met Office carried out the first climate change simulations at a very high resolution of 1.5km. This allowed convection to be modelled explicitly, providing an improved assessment of the impacts of climate change on heavy rainfall events in summer (Kendon et al., 2014). The model was based on a high emissions scenario (RCP 8.5) and compared heavy sub-daily rainfall for a thirteen year period at the end of the century to a baseline period of the same length. It was the first assessment to use such a high resolution model and provides key evidence about possible changes in summer rainfall. However, it only provides a single run, and therefore does not quantify the uncertainties around estimates of the changing frequency of events. Multiple model runs at these high resolutions are required to assess these uncertainties and to infer an “upper end/range” of potential increases in the frequency of heavy summer precipitation. There is currently effort underway as part of the ERC-funded INTENSE project to link up results from kilometre-scale models run at different climate research centres, to examine the extent to which the CONVEX results are robust across different regions and models. In addition, for UKCPnext there are plans to carry out high resolution regional downscaling which could include an ensemble of runs at kilometre-scales across the UK.

The CONVEX results suggest that extreme summer rainfall may become more frequent in the UK. Although summers are expected to become drier overall by 2100, intense rainfall indicative of serious flash flooding could become several times more frequent. For example, the 1.5km model suggests intense rainfall associated with flash flooding (more than 30mm in an hour) could become almost five times more frequent by 2100 compared to a recent baseline of 1996 to 2009 (Kendon et al, 2014). This is just one possible plausible realisation. However, it should be noted that an increase in heavy summer rainfall is consistent with the theory of an intensification of convective events in a warmer moister environment.

In terms of heavy winter rainfall, the 1.5km model showed very similar changes compared to a coarser 12km model (Kendon et al 2014). In particular, Chan et al 2014 found very similar changes in hourly rainfall extremes, although there was some suggestion that the better representation of orography may lead to greater increases in multi-hourly rainfall extremes over mountains in winter in the 1.5km model. In general, however, these results suggest that coarser resolution RCMs are likely to be sufficient for projecting changes in heavy rainfall in winter.

5.5 Physical limits

There are a number of factors that may constrain changes in heavy precipitation, including the amount of moisture in the atmosphere, atmospheric stability, the ability of the troposphere to radiate away latent heat released by precipitation (Allen and Ingram, 2002) and changes to circulation patterns. Different driving factors may work together to enhance heavy rainfall or counter each-other to reduce the impacts of increased temperatures on rainfall intensities.

The link between temperature and the atmospheric moisture holding capacity is described by the thermodynamic Clausius-Clapeyron relationship, which suggests a 6-7% increase in atmospheric moisture for 1 degC rise in temperature assuming relative humidity stays constant. This sets a scale for change in precipitation extremes. The results from recent climate models (CMIP5) appear to reinforce this relationship at a global scale (Lau et al., 2013), although this was not the case in earlier climate models (CMIP2) that had a lower gradient of change in precipitation over change in temperature (Allen and Ingram, 2002).

There is some evidence that hourly rainfall intensities may exceed the Clausius-Clapeyron relationship (Lenderink and Van Meijgaard 2008). This seems to be a property of convective rainfall (Berg et al 2013), with one possible explanation being through the dynamic amplification of rain-bearing systems, where the induced circulation drives greater convergence of moisture into the system and hence heavier rainfall (Met Office and CEH, 2014). Figure 5.13 plots heavy rainfall intensities observed in the Netherlands against the Clausius-Clapeyron relationship. This shows that intense rainfall in the Netherlands can follow a steeper CC relationship (2x) as shown by the dotted red lines compared to the 99.9 and 99 percentile rainfall intensities.

The CONVEX project also found that extreme summer hourly precipitation intensities over the southern UK were linked to temperature and that this relationship also followed Clausius-Clapeyron. This provides a good physical basis for estimating H++ sub-daily intensities based on degrees warming. Importantly, however, results from the 1.5km model suggest that this relationship cannot simply be extrapolated into the future due to more complex changes in atmospheric circulation conditions. The CONVEX project concluded that although changes to intense precipitation are dominated by local changes in temperature and associated increases in atmospheric moisture, changes in large scale circulation can have important regional effects, and may serve to suppress precipitation intensities in the future. As such, although they are important, regional surface temperatures may not provide an adequate predictor of changes in precipitation intensity.

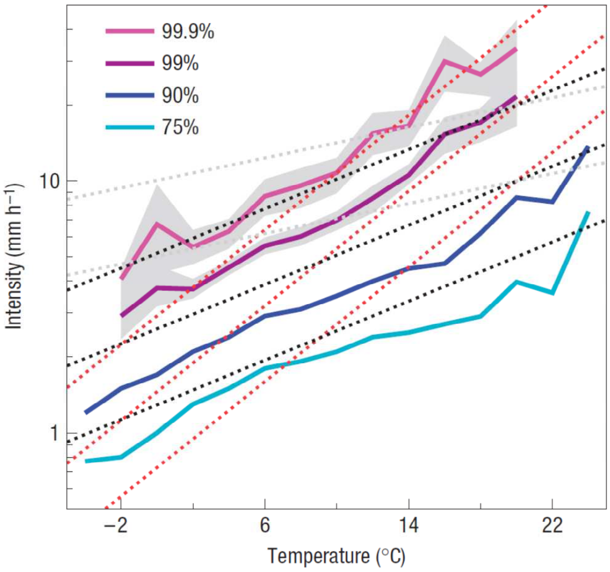


Figure 5.13. Percentiles of observed maximum 1 hour rainfall intensity (mm/hour) on a logarithmic scale as a function of temperature for a 99-year record from De Bilt, The Netherlands.

Notes: Solid colour lines are the different percentiles. Grey bands, plotted only for the 99 and 99.9th percentile, are 90% confidence intervals. Dotted lines are the exponential relations given by 0.5 (light grey), 1 (black) and 2 (dark red) times the Clausius–Clapeyron relation. From Lenderink and Van Meigaard 2008.

5.6 Other evidence

Palaeo analogue / evidence

Palaeo analogue evidence was not considered for rainfall as evidence of erosion and sedimentation (for example from lake sediment cores) is highly sensitive to land use change as well as the precipitation signal. Spatial analogues have been considered in both the research literature and industry studies (see following sections).

Spatial analogues

The use of spatial analogues can be useful for communicating potential changes in climate but need to be used with care and are associated with considerable uncertainties. As we know from the CONVEX results, temperature is an important driver of changes in rainfall extremes, but changes in circulation patterns can have important regional effects. In an ongoing UKWIR project on extreme rainfall for sewer design, temperature is used to identify spatial analogues for future conditions in the UK[33]. Preliminary results from this work suggested potential uplifts of 70 to 90 percent on 6 hourly rainfall totals in the south east of England (Dale, *pers comm.)*.

Industry data

The use of precipitation 'uplifts' on seasonal or extreme daily rainfall

UKCP09 monthly and seasonal change factors have been used directly in studies related to river flooding, groundwater flooding and water resources (see Section 5). Environment Agency guidance for flood risk management suggests using UKCP09 change factors for high probability events (p > 20%) and a 40 percent uplift on extreme rainfall events (p < 20%) for the 2080s; it did not propose a H++ rainfall scenario (Environment Agency, 2011). Forthcoming UKWIR guidance for drainage engineers will propose the use of higher rainfall uplifts for the 2080s based on a mixture of evidence from the CONVEX project and use of spatial analogues (Dale, *pers. comm*.).

5.7 H++ scenarios

A number of quantitative indicators for increases seasonal and daily precipitation are summarised in Figure 5.14. For daily rainfall the H++ range is a 60 to 80 % increase in rainfall event depths and for the winter season (DJF) it is a 70 to 100% increase in 30 yr average winter rainfall. The rationale for these ranges is described below and in both cases they are subject to caveats related to the relative skill of global, regional and higher resolution models of resolving important physical processes.

Winter rainfall

- The wettest winters (Dec-Jan-Feb) in the historical record were 2013/14, 1994/95, 1989/90, 1914/15, 2006/07. The recent winter of 2013/14 is a useful benchmark with a 70% increase in seasonal rainfall (nationally, noting the increases were far greater in some regions).
- The UKCP09 2080s high emissions scenario project changes of around 70% for 30-year average annual winter rainfall (at the 90 % probability level) and changes of up to 90%for individual grid squares compared to the 1961-90 average. **A high end scenario of 70-100% more winter precipitation on average across the UK by the 2080s suggests that winters similar to 2013/14, would be**

[33] The future circulation regime is not used in the selection – so it is likely that the circulation conditions for the spatial analogue may not match those over the UK in future. For reliable future projections, ensembles of high resolution climate models are needed that physically represent the key processes driving future changes.

exceeded in most years in the 2080s. *This is based on expert opinion/interpretation of the data available and is subject to a number of caveats. In particular the unusual meteorological conditions experienced in 2013/14 (Met Office and CEH, 2014; Huntingford et al., 2014) are not well represented in climate models, which form the main source of evidence for this part of the assessment.*

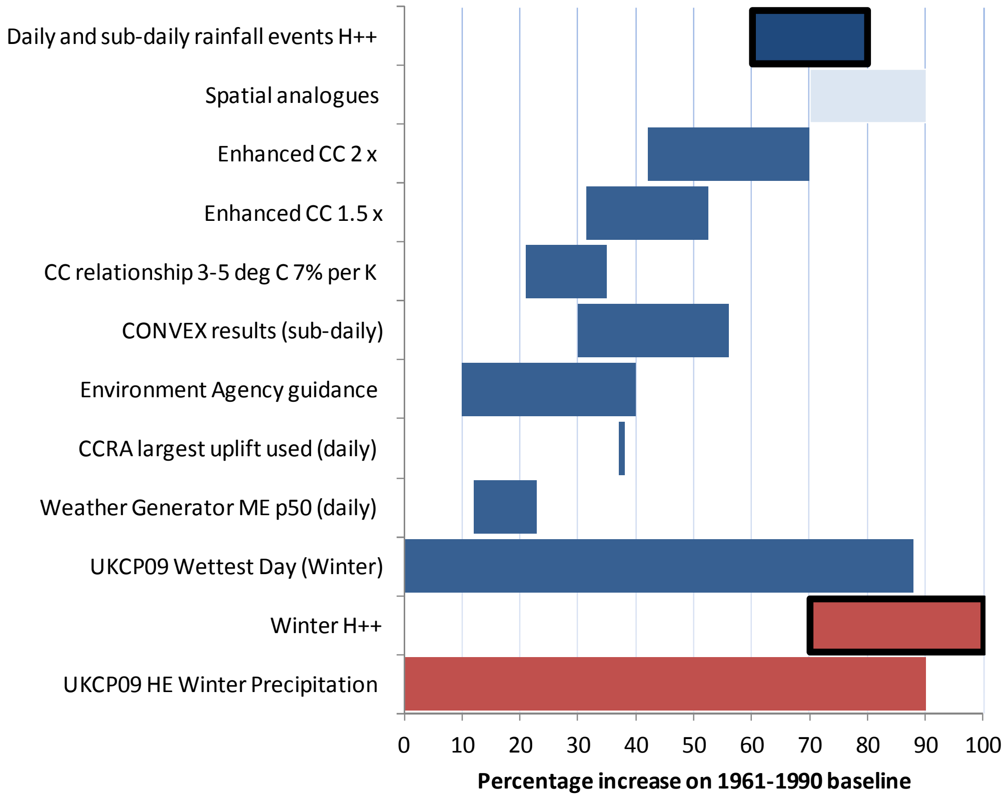


Figure 5.14. A summary of "high-end" ranges of precipitation uplifts presented in UKCP09 and other literature as well as H++ ranges (bold) for daily and sub-daily rainfall (any season) in blue and winter rainfall (Dec-Jan-Feb) in red (Grey bars indicate lower confidence).

Daily and sub-daily rainfall

- The highest recorded 24 hour rainfall in the UK was 316 mm at Seathwaite Farm in Cumbria in 2009. Around 200 mm in 5 hours was recorded at Otterham, near Boscastle in August 2004 and there are several historical events with similar or greater rainfall intensities recorded in the 20th century.
- Evidence from Regional Climate Models suggests a two to threefold increase in extreme daily rainfall. The CONVEX project, which used a high resolution climate

model, suggests a two to five-fold increase in the frequency of heavy sub-daily rainfall in summer and a two to eleven-fold increase in winter but greater increases in frequency can't be ruled out. Large increases in precipitation over the UK may be limited by physical constraints as well as changes in circulation.

- Environment Agency guidance suggests that UKCP09 uplifts (which reach 70 to 80% in the tails of the UKCP09 high emissions scenario) are appropriate for rainfall events with probabilities less than 20 % (or 1 in 5 years) and thereafter plus 40% is an appropriate H++ scenario for flood and coastal erosion risk. There is some evidence from CONVEX and spatial analogues (UKWIR, 2015) that uplifts could be greater than 40% for these rare events; **therefore a H++ range of 60-80% is proposed for daily rainfall in winter or summer.** *Similar to the H++ winter rainfall this sits at the upper end of what is indicated by the evidence and is subject to caveats such as warming of at least four degrees and an enhanced 2x Clausius-Clayperon relationship.*

Chapter 6 High flows

6.1 Summary of the High ++ 'high flow' scenarios

The H++ 'high flow' or flood scenarios are for increases in peak river flow and are presented as a range of percentage increases in peak flow for different regions of the UK. The approach for high flows deviates from the standard H++ methodology because substantive NERC, Defra and Environment Agency research projects have already been completed on the impacts of climate change on river flows, including the development of H++ scenarios. However, this section still covers most of the H++ steps including the use of UKCP09, consideration of other climate models and physical factors that influence flooding.

The High ++ high river flow scenarios are presented on a regional basis at the end of this chapter. The 'lower end' of the 2080s H++ scenarios for regions in England and Wales range from a 60% to 120% increase in peak flows compared to a 1961-1990 baseline. The lower end of the H++ scenarios for regions in Scotland and Northern Ireland range from 55% to 125%. The upper limit is 290% for all cases.

6.2 Background

In 2011 the EA released guidance to flood managers (Environment Agency 2011), which provided information on the range of flood changes under climate change that might be expected in an average catchment in each of 12 river-basin regions across England. This included 'H++ river flow scenarios' for each region (Table 3 of the EA guidance; see Table 6.1 for an example). The guidance was based on research by CEH, funded by Defra/EA (projects FD2020 and FD2648; Reynard et al. 2009 and Kay et al. 2011a), which used the UKCP09 sampled data for river basins, along with a sensitivity-based approach to estimating flood changes from climatic changes. The H++ scenarios provided in the EA guidance represent a high-end estimate of change in a type of catchment that is particularly sensitive to changes in climatic inputs ('Enhanced-High'). Such catchments are more likely to occur in some river basin regions than others (Figure 2 of the EA guidance), but they cannot currently be completely ruled out anywhere.

	Total potential change anticipated for the 2020s	Total potential change anticipated for the 2050s	Total potential change anticipated for the 2080s
Upper end estimate	25%	30%	**50%**
Change factor	10%	15%	**20%**
Lower end estimate	0%	0%	**5%**
H++	**35%**	**45%**	**75%**

Table 6.1: Potential changes in peak river flows for the Northumbria river basin region (Environment Agency 2011).

Note that the H++ high flow scenarios in the EA guidance, and those derived for this project, are presented as percentage changes in flows (from a baseline period of approximately 1961-2001) rather than absolute values of flows. The latter are not appropriate for high flows as, even under the current climate, there is always a chance of a flood event occurring that is larger than any previously experienced at a particular location on a river. Also, the uniqueness of every river catchment, in terms of area, soils, geology, land cover, topography and orientation as well as climatology, means that generic absolute scenarios are impossible. When applying the H++ high flow scenarios, it is thus important that a reliable baseline flood frequency curve is developed, to which the percentage changes can be applied. This would usually be done via one of the Flood Estimation Handbook (FEH) methods, which are discussed briefly later in this chapter.

6.3 Approach

The derivation of the H++ high flow scenarios for the EA 2011 guidance for river basin regions in England was re-assessed, to decide how best to provide H++ high flow scenarios for CCRA2 which are as consistent as possible both with the H++ scenarios for other variables within CCRA2 and with the original EA guidance. In particular, an H++ range was preferred, rather than a single number as in the EA guidance. It was decided that a method similar to that used for the original EA guidance should be applied to derive the ‘H++ lower end’ numbers, thus providing regionally varying values for three time-slices (2020s, 2050s and 2080s), but that the ‘H++ upper end’ should go further into the tails of the UKCP09 distributions and be taken as the maximum across all regions of the UK (for the 2080s under the high emissions scenario). The H++ high flow scenarios thus derived are then discussed in the context of a review of other, more recent, sources of evidence (e.g. from CMIP5).

The final method had to be applied to derive values for all river basin regions across the UK, not just those in England; the Adaptation Sub-Committee (ASC) requested UK-wide consistency wherever possible. This was straightforward for the West Wales river basin region, which was covered in project FD2648, and for river basin regions across Scotland, which were covered in similar research by CEH funded by SEPA (project *R10023PUR*; Kay et al. 2011b), so directly equivalent numbers could be derived for these regions. For river basin regions in Northern Ireland though, there has been no equivalent research using UKCP09 scenarios and the sensitivity-based modelling approach, and such an approach could not be fully developed within the time and budget constraints of this project. However, it was considered reasonable to assume that the range of response types in Northern Ireland is the same as that derived from modelling catchments in England, Wales and Scotland, and that the same FD2020 (average and standard deviation) response surfaces for each response type are applicable in Northern Ireland. The UKCP09 sampled data for the three river basin regions in Northern Ireland have thus been downloaded and overlaid on the 'Enhanced-High' response surfaces, allowing derivation of H++ high flows scenarios for Northern Ireland using region-specific UKCP09 projections, as for the rest of the UK.

What is not known is the chance of any catchment in Northern Ireland being of the 'Enhanced-High' type. Looking at the decision trees for England and Wales (Kay et al. 2011a) and Scotland (Kay et al. 2011b), it is likely that the best estimate of the response type of most gauged catchments in Northern Ireland would be Neutral, due to their high annual rainfall and relatively small catchment area. This is consistent with the pattern across the rest of the UK, where the best estimate of the response type for many catchments in western England, Wales and Scotland is 'Neutral', whereas catchments further to the east are more variable in type. Thus the H++ high flow scenarios have a lower (but currently unquantifiable) chance of occurring for any individual catchment in Northern Ireland, compared to the chance for a catchment in the Anglian, Northumbria, Thames or South-East England regions for example.

Further research is required to better identify catchment-by-catchment differences in response to climatic changes, and thus provide more catchment-specific information on the potential impacts of climate change on flood peaks. A new project to address precisely this issue is just being initiated by EA via FCERM.

6.4 Physical limits

The concept of a probable maximum flood (PMF) for river flooding has always been controversial but the Flood Studies Report (FSR; NERC, 1975) introduced a procedure for estimating PMF based on an extension to the design hydrograph method. PMF can be defined as the flood of near-zero exceedance probability and it is assumed to be caused by the most extreme combination of antecedent catchment wetness, rainfall and runoff response possible. The concept is still used by UK reservoir engineers when assessing flood safety at dam sites (Institution of Civil Engineers, 1996). The recommended procedure relies on a statistical estimate of probable maximum precipitation (PMP) deriving from the FSR which is routed via the unit hydrograph and losses model. The unit hydrograph time-to-peak is reduced to represent the more rapid and intensive response that may occur in exceptional conditions, and optional changes to the percentage runoff allow for higher than normal runoff from frozen ground. The estimation of PMF is gradually being superseded by the use of probabilistic risk assessment within the reservoir industry, reflecting a general feeling that the concept of an upper limit and, more importantly, the methods in current use are outdated.

6.5 Review of other evidence

A recent review of historical changes in UK river flows (Hannaford 2015) describes several recent major flood events and includes a review of changes in high flows and flood indicators. Significant trends are seen in many UK Benchmark catchments (Fig. 3 of Hannaford 2015), and such changes are considered relatively consistent with future projections of changes in flows.

To our knowledge no other study published to date has applied the UKCP09 Sampled Data to look at changes in fluvial flood peaks, but Charlton and Arnell (2014) used them to look at changes in the high flow measure Q5 (the flow exceeded 5% of the time), as well as median flow Q50 and low flow measure Q95, for six catchments in England. They found that the range of changes for Q5 was large but mostly positive, and varied significantly between catchments. Of particular interest here is that some catchments had significantly larger increases than others at higher percentiles (up to approximately a 50% increase at about the 95^{th} percentile, for the 2080s under medium emissions). Although changes in Q5 cannot be directly translated into changes in flood peaks, the fact that both the median and range of changes in Q5 for each catchment are larger than for Q50 (which are larger than for Q95), is suggestive of even greater changes in flood peaks (in terms of median and range), and greater sensitivity of some catchments than others. This is consistent with the results of Kay et al. (2014a) for flood peaks.

Several studies have used time-series from the UKCP09 11-member Regional Climate Model (RCM) ensemble to look at impacts on floods in specific catchments in Britain. Bell et al. (2012) used data from the UKCP09 RCM ensemble to drive a distributed hydrological model (Grid-to-Grid) for the Thames Basin, and looked at changes in (5- and 20-year return period) flood peaks throughout the basin for the 2080s (A1B emissions). They found significant spatial variation in impacts, and significant variation between ensemble members. In some locations, increases in the 20-year return period fluvial flood peak of over 150% were simulated by a member of the RCM ensemble (but this was not always the same member). As the UKCP09 RCM ensemble only has 11 members, the range of impacts from it would be expected to be smaller than that from a much larger ensemble like the UKCP09 Sampled Data, but the amount of difference is likely to vary between catchments. This is confirmed by Kay and Jones (2012), who compare use of the various UKCP09 products, including RCM time-series, for modelling impacts on 20-year return period flood peaks in nine catchments in Britain. For the Enhanced-High catchment modelled by Kay and Jones (2012), the maximum modelled change in flood peaks from direct use of RCM time-series was ~50%, whereas the maximum from modelling using Sampled Data delta changes was significantly higher, at over 250%. This compares to a maximum of over 135% from modelling using time-series produced by the UKCP09 weather generator (although this was only from a 100-member ensemble). The fact that the RCM ensemble is only available for A1B (medium) emissions also reduces the impacts compared to the H++ high flows scenarios presented here, which are for A1F1 (high) emissions for the 2080s.

Cloke et al. (2013) used a range of methods, including both direct forcing of a hydrological model with UKCP09 RCM data and use of response surfaces, to investigate changes in the annual frequency of exceeding a given flood warning level for the Severn at Montford. They found a wide range of uncertainty from the UKCP09 RCM ensemble, as well as from two alternative climate model ensembles, but it is difficult to translate these results into changes in flood peaks. While the ‘Future Flows’ project produced flow time-series for a large number of catchments across Britain using UKCP09 RCM data for 1951-2098 (Prudhomme et al. 2013), no studies have so far published results on changes in fluvial flood peaks using these flow time-series data.

More recent work, using high resolution RCM data (from the CONVEX project) to drive a gridded hydrological model over southern Britain, suggests that use of very high resolution (1.5km) RCM data tends to project larger increases in flood peaks (for all seasons except summer) than use of data from the 12km RCM in which the 1.5km RCM is nested (Kay et al. 2015). However, the availability of only one set of high resolution RCM runs, covering a relatively short period (~13 years), together with increased baseline biases from use of the 1.5km RCM data compared to the 12km RCM data, means that the suitability of this data set for flood risk research remains unclear. It is also possible that smaller, faster responding catchments may show different results to those covered by the gridded modelling above (where mapped river points had a drainage area threshold of $50km^2$).

A global-scale study using CMIP5 data (Dankers et al. 2014) showed increases in flood hazard (measured as 5-day mean peak flows with a 30-year return period) for more than half of the global land grid points in most of the 45 model experiments (5 CMIP5 GCMs x 9 global hydrology/land surface models), for the period 2070-2099 under RCP8.5. It is difficult to distinguish the results for the UK from the global maps presented, particularly in terms of the percentage change in the 30-year return period peak flow, but it looks like the mean impact is an increase of perhaps 10-20% and that a lot of the models agree on an increase, compared with high agreement on decreases in much of the rest of Europe. Another global study, using 11 CMIP5 GCMs, showed similar results for the change in flood frequency over Europe, with the 100-year return period flood peak occurring more frequently in future in Britain but less frequently over much of the rest of Europe (Hirabayashi et al. 2013). But the presented changes in flood return period cannot be readily translated into changes in flood peaks, for comparison with other studies. The apparently opposite potential impacts in Britain, compared to much of the rest of Europe, shown by the latter two global studies may be related to the influence of atmospheric rivers (synoptic features that transport water vapour polewards) on the climate of western Europe, and the fact that these are projected to increase in both magnitude and frequency in future (Lavers et al. 2013).

FEH methods for deriving baseline flood frequency curves

As the H++ high flow scenarios are provided as percentage changes in flood peaks, a brief outline is provided below of the Flood Estimation Handbook (FEH) methods that would usually be used to estimate baseline flood frequency for a catchment of interest in the UK.

The national standard methods for UK flood frequency estimation are presented in the FEH (Institute of Hydrology, 1999) and its subsequent updates (Kjeldsen, 2007; Environment Agency, 2008). Flood frequency curves for any site on the UK river network, gauged or ungauged, can be derived from the improved FEH statistical method, which combines flood peak data from hydrologically similar sites to form a pooling-group using the analysis of L-moments (Hosking and Wallis, 1997). Thus the approach to regionalisation is flexible and not based on the prior definition of geographical regions. A key feature of the FEH statistical approach is the importance of hydrological judgement in the refinement of the estimation procedure for each subject site. While the method has been successfully automated to provide spatial consistency over a wide area, for use in flood risk mapping for example (Morris, 2003), flood estimation on a site-by-site basis is still recommended.

The improved FEH statistical method is flexible and a number of different variants exist depending on the extent of the data available. The method requires the estimation of the index flood (the median annual flood at the site of interest, termed QMED) and a flood growth curve that relates QMED to floods of longer return period. QMED can be estimated from at-site data or, for ungauged or poorly gauged sites, using catchment descriptors together with adjustment from suitable donor catchments. Pooling-groups are constructed using data from the site of interest (if available) and other hydrologically similar sites to derive the flood growth curve. FEH flood growth curves are catchment specific rather than being regionally averaged. Various further adjustments can be applied if the site of interest lies within a permeable catchment or is urbanised. The method makes use of instantaneous flow peaks for about 1000 gauging stations from the NRFA Peak Flow data set, which can be accessed on-line and is regularly updated (http://www.ceh.ac.uk/data/nrfa/peakflow_overview.html). The original FEH statistical method was extended to allow the use of historical data pre-dating the installation of river flow gauging structures (Bayliss and Reed, 2001) and further research on this subject is ongoing.

The FEH analysis included examination of possible trend but found little evidence of non-stationarity in the peak flow series (Robson and Reed, 1999). Thus the methods assume that the underlying data series are stationary, although it is recognised that the UK climate is highly variable and ‘flood rich’ and ‘flood poor’ periods have been identified (Robson *et al.*, 1998; Hannaford and Marsh, 2008). There is a high degree of uncertainty associated with statistical flood frequency estimates (Kjeldsen, 2014) and this is the subject of ongoing research.

6.6. H++ scenarios

The H++ high flow scenarios derived for the UK are given in Table 6.2, as percentage changes in fluvial flood peaks. The scenarios are based on using the UKCP09 Sampled Data for UK river-basin regions, combined with a sensitivity-based approach to estimating flood changes from climatic changes (Kay et al. 2011a). They represent high-end estimates of change in a type of catchment that was identified as being particularly sensitive to changes in climatic inputs: 'Enhanced-High' (Reynard et al. 2009; Prudhomme et al. 2013). Such catchments are more common in some regions than others (Kay et al. 2011a, b). The scenarios are provided as a range, with the lower end of the range given for each of 23 river-basin regions and for three 30-year time-slices (2020s, 2050s and 2080s). The upper end of the range is given for the UK as a whole and only for the 2080s time-slice.

The use of the UKCP09 Sampled Data — which provides climate projections as sets of 10,000 change factors for each river-basin region, for a set of overlapping 30-year time-slices and for three emissions scenarios (Murphy et al. 2009) — enables probabilistic impact ranges to be estimated. Thus the lower end of the H++ range has been taken as the 90th percentile from the 'Enhanced-High' impact curves for 50-year return period flood peaks, using high (A1F1) emissions for the 2080s but medium (A1B) emissions for the 2020s and 2050s. The upper end of the H++ range is taken as the maximum, over all of the river-basin regions, of the 100th percentile from the 'Enhanced-High' impact curves for 50-year return period flood peaks, using high (A1F1) emissions for the 2080s.

The upper end value, 290%, comes from the South-East England river-basin region, but the 100th percentile impact values for the 2080s under high emissions are also high for the Argyll and West Highland river-basin regions (225% and 250% respectively). These three regions also have the highest H++ lower end values (Table 6.2). This regional pattern, with higher impacts in regions to the far south east and far north west of the UK and lower impacts for regions in between, is shown in Kay et al. (2014a,b). The differences are due to regional differences in the UKCP09 climate change projections (see Fig. 3 in Kay et al. 2014a, b).

River-basin region	2020s (2010-2039)	2050s (2040-2069)	2080s (2070-2099)
H++ (lower end):			
Northumbria	20	35	65
Humber	20	35	65
Anglian	25	40	80
Thames	25	40	80
South East England	30	60	120
South West England	25	50	105
Severn	25	45	90
Dee	20	30	60
North West England	25	45	95
West Wales	25	50	100
Orkney and Shetland	30	55	110
North Highland	25	40	80
North East Scotland	15	25	55
Tay	20	35	75
Forth	25	45	90
Tweed	20	35	75
Solway	25	45	95
Clyde	25	50	100
Argyll	30	65	125
West Highland	30	65	125
North East Ireland	20	40	80
Neagh Bann	15	30	70
North West Ireland	20	35	75
H++ (upper end):			
max over all regions			290

Table 6.2: H++ high flow scenarios for the UK, expressed as percentage changes in fluvial flood peaks (50-year return period) compared to 1961-1990. The lower end of the H++ range is given for each of 23 river-basin regions and three 30-year time-slices. The upper end of the H++ range is given for the UK as a whole and only for the 2080s time-slice. [Note that all values are rounded to the nearest 5%.]

All of the values in Table 6.2 are based on an average 'Enhanced-High' catchment, represented by an average 'response surface' for the Enhanced-High type (Reynard et al. 2009). But any individual 'Enhanced-High' catchment could have a response in a range around that average. This range is illustrated by a standard deviation (sd) surface (Reynard et al. 2009), which can be used alongside the average response surface. If 1*sd is applied when calculating the H++ upper end value, to allow for an Enhanced-High catchment potentially being more extreme than the average, then the upper end value increases from 290% to 325%. A more extreme example of an Enhanced-High catchment would likely have an even higher 100th percentile increase in flood peaks. Furthermore, while the overall method accounts for possible bias in the median impact estimated from response surfaces compared to direct hydrological modelling of the catchment (Kay et al. 2014c), the possibility of a wider impact range from direct hydrological modelling is not incorporated. This could further increase the derived H++ scenarios.

Appendix CC.1.2

Chapter 7 Windstorms

7.1 Summary of the H++ windstorm scenario

Windstorms are intense extratropical cyclones that bring strong winds that can damage property and lead to loss of life. Examples of windstorms that have affected the UK include the Great October Storm of 1987, which inflicted 6.3Bn USD of damage (indexed to 2012 values) and 22 lives lost (Roberts *et al.* 2014).

The H++ scenario for windstorm is based on an analysis of the CMIP5 model projections. **The CMIP5 climate model projection suggest a plausible H++ scenario for a 50-80% increase in the days of strong winds over the UK by 2070-2100 compared to the period 1975-2005.** The caveats are that the scenario is based on the CMIP5 climate model simulations, which contain biases in the position of North Atlantic storm track and systematically under-represent the number of intense cyclones.

The data sources for windstorm analysis are summarised in Annex 2.

7.2 Historical data

Paleoclimate data

Paleoclimatology considers aggregate measures of storminess through proxies such as salt marsh inundation and coastal erosion (e.g. May et al. 2012). However, it was considered that these aggregate measures are too coarse to be able to construct a H++ scenario for windstorm.

Historical Windstorms in the UK and NW Europe

Historical records of windstorms before instrumental records exist primarily through their impacts on coastal areas. Lamb (1991) collated records of such windstorms, including major events such as the "Grote Mandrenke" (Great Drowning of Men) in 1362. Strong south-westerly gales lead to extensive coastal flooding and estimated deaths of 11,000 to 30,000 in Northern Germany. The strong winds over England led to the toppling of the bell towers in London, Bury St. Edmunds and Norwich.

Other notable windstorms occurred in November 1570, January 1607 and October 1634. Strong south-westerly gales in early November 1570 led to the "All Saints Flood". Extensive coastal flooding occurred along the North Sea coastline from France to

Denmark, which led to the loss of 100,000 lives. Strong gales in January 1607 are thought to have led to flooding in the Bristol Channel and the loss of 2,000 lives (Horsburgh and Morrit, 2006). A windstorm and associated coastal flooding in October 1634 led to an estimated 6,000 deaths in Northern Germany.

The Great Storm of 1703 is often regarded as most severe windstorm of which we have good written records. The windstorm occurred on the 7-8 December 1703 (current calendar) and left a path of destruction across Wales and Southern England, the Netherlands, Denmark and Northern Germany. The impacts of the windstorm were recorded in a number of written accounts, including Daniel Defoe's book "The Storm". The Great Storm of 1703 led to destruction of buildings across Wales and Southern England, including the collapse of the first Eddystone lighthouse. The Royal Navy was particularly affected with the loss of thirteen ships. Estimates of loss of life from the windstorm range from 1,500 to 10,000 deaths. Lamb (1991) was able to construct rudimentary weather maps from the small number of surface pressure measurements made at that time, which suggested the 1703 storm developed at the end of a period of enhanced storminess during the start of December 1703. Surface winds may have reached an average velocity of over 100 mph, with wind gusts potentially reaching higher values.

Other notable events include a windstorm in December 1717 which led to extensive flooding and storm damage along the North Sea coastline. 11,000 deaths are report to have occurred, mostly in Northwest Germany.

Windstorms in the instrumental record

The introduction of instrumental networks across the UK and Europe during the 19th Century enabled a more quantitative analysis of windstorms. Notable windstorms include:

1839, 6-7 January, Night of the Big Winds (Irish: Oíche Na Gaiothe Móire): 400 deaths and substantial property damage across Ireland and Great Britain. The central pressure of windstorm was measured at 918hPa and gusts were estimated to have been over 100 mph.

1953, 31 January: Strong gales in the North Sea led to extensive coastal flooding along the eastern coastline of the UK, the Netherlands and Northern Germany. The flooding led to 2000 deaths, including 350 deaths in the UK.

1962, 16-17 February: South-easterly gales in the North Sea lead to coastal flooding and 340 deaths in the region around Hamburg.

1976, 2-3 January, Capella Storm: A mobile windstorm developed to the west of Northern Ireland, moved across Britain and into Denmark. 60 lives were lost and there was extensive damage to property across Ireland, the UK, the Netherlands and Northern Germany. The insurance loss in the UK alone was estimated to be £126M at 1976 prices.

1987, 16 October, Great October Storm of 1987: The windstorm developed rapidly and crossed over Southern England and into the North Sea. There was extensive damage to property and 22 were lives lost. Wind gusts measured 115mph on the Sussex coast. Total insurance losses reached 6.3Bn USD (indexed to 2012 values).

1990, 25 January 1990, Daria, Vivian and Wiebke: The months of January and February 1990 were particularly stormy. Daria developed on 25 January and moved across the UK and Northern Germany inflicting total insurance losses of 8.2Bn USD (indexed to 2012 values). Cyclones Vivian and Wiebke developed during 26 and 28 February 1990 inflicting further insurance losses of 7.0Bn USD (indexed to 2012 values).

1993, 8 January, Braer storm: Passed to the northwest of Scotland and so caused little damage on land (apart for the sinking of the eponymous MV Braer). Notable as the central pressure of the storm reached 914hPa, the lowest pressure recorded in a Northern Hemisphere extratropical cyclone.

1999, 26 and 27 December, Cyclone Lothar and Cyclone Martin: Two very intense windstorms passed over Northern France within a period of a few days in December 1999. Total insurance losses from the two storms reached 11.3Bn USD (indexed to 2012 values).

2007, 18 January, Cyclone Kyrill: Kyrill developed in the North Atlantic and rapidly crossed the UK, the Netherlands and Northern Germany. Kyrill lead to 47 deaths and total insurance losses reached 8.2Bn USD (indexed to 2012 values).

In recent years, windstorms have continued to affect the UK. Windstorms include Friedhelm (8 December 2011) and Ulli (3 January 2012) which affected Central

Scotland, Christian (the St Jude's Day storm; 28 October 2013) and the series of windstorms in January and February 2014 that led to coastal flooding in the UK and extensive damage to the railway infrastructure at Dawlish (Kendon and McCarthy, 2014).

Observed trends of European Storminess

One key question is whether there are long terms trends of storminess over the UK and Europe in the instrumental record. Feser et al (2014) provide a comprehensive review of studies of long term storminess from observations, which include long-term records of wind speed, mean sea level pressure and sea level height. Analysis of long term winds records in the UK and Ireland (Hammond, 1990; Sweeney, 2000; Hickey, 2003, Ciavola et al. 2011) have found large decadal variations in storminess, but no significant long term trends. In contrast, Esteves et al. (2011) found a significant decrease in storminess over the period 1929-2002 at Bidston Observatory.

Studies of long term changes in European storminess have also been performed using estimates of geostrophic winds from weather stations, gridded mean sea level pressure datasets and atmospheric reanalysis. Using pressure differences to estimate geostrophic winds between weather stations was pioneered by the WASA Group (1998). Alexandersson et al. (1998, 2000) found large decadal variability in storminess as measured by geostrophic winds, with a maxima in activity in the late 19th century, a comparative lull during the 1960s and an increase in activity in the 1990s. These results were confirmed by later analysis using different measures of storminess (Matulla et al. 2007; Hanna et al. (2008), Wang et al. 2009, 2011). Cornes and Jones (2012) studied changes in storminess using the EMULATE gridded mean sea level pressure dataset, and also found similar results.

Until recently, atmospheric reanalysis have only been constructed after the middle of the 20th Century. However, the 20th Century Reanalysis (Compo et al. 2011) assimilates long term records of mean sea level pressure from 1871 onwards, enabling long term analyses to be performed. Significant increases in storminess have been found in the 20th Century Reanalysis in the Baltic (Donat et al. 2011) and the high latitude North Atlantic and Northern Europe (Wang et al. 2013). However, the consistency of the 20th Century reanalysis is a subject of current debate (Kruger et al. 2013, 2014; Wang et al. 2014; Dangendorf et al. 2014). In particular, Krueger et al. (2013) suggested that long term changes in storminess may be influenced by changes in the density of weather stations over time, and so caution should be exercised in interpreting the 20^{th} Century Reanalysis. In summary, the historical evidence is important for suggesting that long term trends in storminess over the instrumental records are relatively small (and generally statistically insignificant) compared to the large decadal variability.

7.3 UKCP09

Changes in windstorms (i.e. extreme winds) were not explicitly considered in UKCP09, so it is not possible to construct a H++ windstorm scenario from the UKCP09 projections. However, changes in the North Atlantic storm tracks (as measured by mean sea level pressure variance) in the HadCM3 ensemble and the CMIP3 climate model were considered in a supplementary report (Murphy et al. 2009). The analysis found large inter-model spread in the responses of the North Atlantic storm track around the UK, with some CMIP3 models moving the North Atlantic storm track to the north and some models moving the storm tracks to the south. This was in contrast to the HadCM3 climate model ensemble used in the UKCP09 projections, where the North Atlantic storm track tended to move southwards under anthropogenic forcing. This analysis has been updated for CMIP5 climate models and the results are discussed below.

7.4 Evidence from CMIP5 models

Since UKCP09, the CMIP5 inter-model comparison project has provided a major advance in the assessment of future windstorm risk. For the first time in the CMIP process model output has been archived at sub-daily frequencies, allowing a systematic assessment of extra-tropical cyclones and their associated wind extremes. Assessing how the location, severity and number of extratropical cyclones might respond to climate change is essential for understanding how risks from damaging winds might change over the UK. Such an assessment has been performed by a number of groups worldwide, and their results are discussed later in this chapter. Despite the improvement in the resolution of the state-of-the-art climate models used in CMIP5 there are still numerous processes that are known to be not well represented in these models, such as mesoscale circulations embedded within extra-tropical cyclones. Recent evidence relating to these processes is discussed in Section on *Other Evidence.*

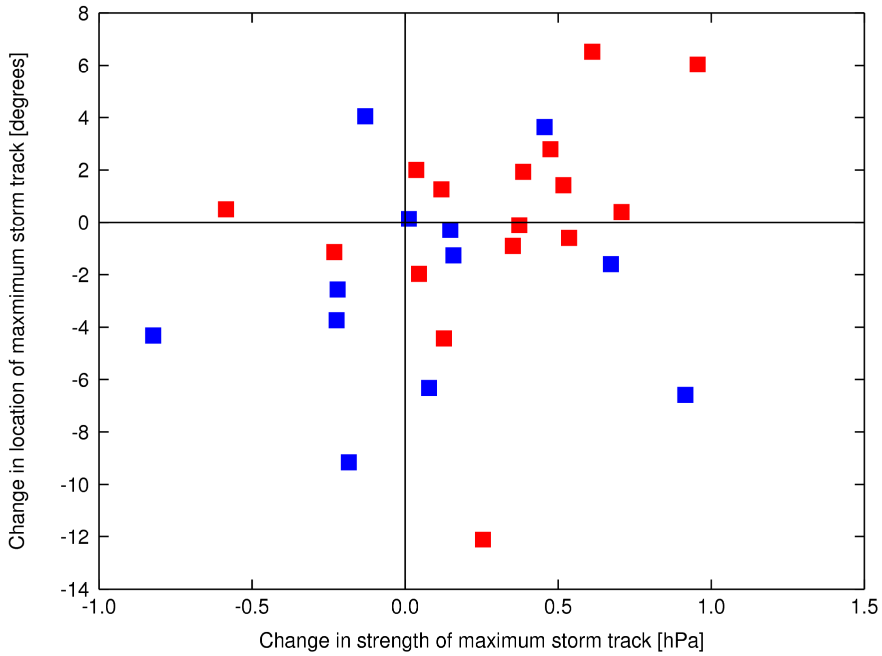


Figure 7.1: Climate change responses of the latitude and strength of the DJF storm track at 0E. Blue and red squares represent CMIP5 (RCP8.5) and CMIP3 (SRESA1B) models respectively and the climate change response is defined as the difference between late 21st century and late 20th century values. The measure of the storm track is the 2-6 day bandpass-filtered mean sea level pressure.

CMIP5 models

The ability of the CMIP5 models to simulate North Atlantic cyclones in present-day conditions was assessed by Zappa et al. (2013a). They find that many of the CMIP5 models show an improvement over the CMIP3 models in their representation of the North Atlantic storm track. However, there is still a systematic deficit in the number of intense cyclones in the CMIP5 Historical simulations. Furthermore, the North Atlantic storm track in the CMIP5 Historical simulations also tends to be located southwards of the observed North Atlantic storm track. The biases in the historical simulations reduce confidence in the CMIP5 climate projections of the North Atlantic storm track.

The CMIP5 future projections of North Atlantic cyclones for the end of the 21st century have been assessed by numerous authors (Harvey et al., 2012; Mizuta, 2012; Chang et al., 2013; Zappa et al., 2013b). These studies utilise both traditional grid-point based statistics (such as the variance of bandpass-filtered sea level pressure) and cyclone tracking algorithms to characterise properties of the storm tracks. Cyclone tracking algorithms, which require the use of the sub-daily data available in CMIP5, provide detailed information on both the number and intensity of cyclones and therefore provide a means of evaluating changes in intense windstorms. The traditional grid-point based statistics are less useful for this purpose as they combine information from all cyclones without distinguishing between their intensity. Two key questions are generally considered in these studies: how do the storm track responses compare between CMIP3 and CMIP5, as measured by the grid-point based statistics, and what extra information do the cyclone tracking algorithms reveal about changes in intense windstorms in CMIP5?

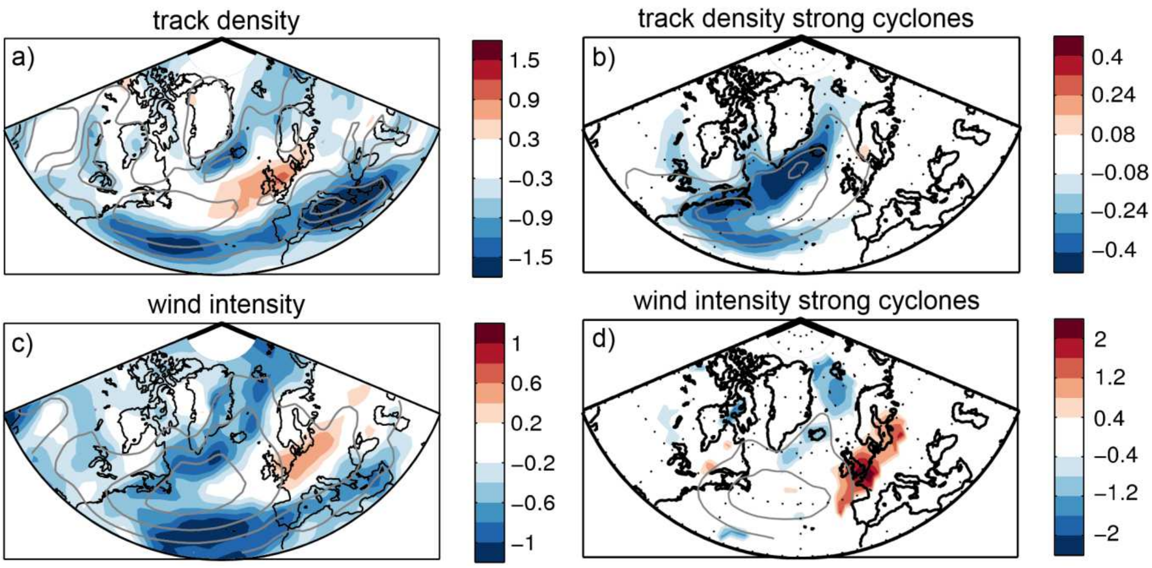


Figure 7.2:
CMIP5 multi-model mean DJF RCP8.5 responses of cyclone track density from (a) all cyclones and (b) the subset of strong cyclones only. The same but for cyclone intensity measured by wind speeds in the lower troposphere (at a height of 850hPa) from (c) all cyclones and (d) the subset of strong cyclones only. Units in (a) and (b) are cyclones per month per unit area with a contour interval of 4 and 1 cyclones per month respectively. The units in (c) and (d) are ms^{-1} with a contour interval of 4 ms^{-1} in (c) and the two contours in (d) indicating 30 ms^{-1} and 35 ms^{-1}. Strong cyclones are defined as those with intensities greater than the 90th percentile in the Historical simulations of each CMIP5 model. Figure kindly provided by Giuseppe Zappa; the corresponding plots for RCP4.5 are published in Zappa et al. (2013b).

The studies of Harvey et al. (2012); Zappa et al. (2013b) and Chang et al. (2013) compare the CMIP3 and CMIP5 storm track responses using the traditional grid-point based diagnostics. There is in general a good agreement in the responses in CMIP3 and CMIP5. In each case the multi-model mean response consists of a tri-polar pattern over the eastern Atlantic, with an increase in storminess over the UK and decreases to the north and south. Relative to the present-day storm track this represents an increase of its southern flank together with a decrease in the subtropics, which may result in an increase of storm activity over the UK. Figure 7.1 shows the responses of the latitude and strength of one measure of the storm track at 0E for both the CMIP3 and CMIP5 models. As noted in the UKCP09 (Murphy et al. 2009) the CMIP3 models show little consistency as to the sign of the shift; the responses in the CMIP5 models however are more consistent with 10 of the 13 models exhibiting a southward shift.

The studies of Zappa et al. (2013b); Chang et al. (2013) and Mizuta (2012) analyse the CMIP5 storm track responses using cyclone tracking algorithms. Regarding the full set of all North Atlantic cyclones, Zappa et al. (2013b) find that both the frequency of cyclones and their mean intensity respond with a qualitatively similar pattern to the grid-point based statistics: there is a tri-polar pattern over the eastern Atlantic with increases over the UK and decreases to the north and south. They present detailed results only for RCP4.5, Figures 2a and c show the corresponding results for RCP8.5. Therefore the tri-polar pattern of storm track response obtained from the grid-point based statistics, can be due to a combination of both increased frequency and increased intensity of cyclones. Chang et al. (2013) provide less detail on the geographical distribution of changes, but consistent with the results of Zappa et al. (2013b) find a slight southward shift in the mean latitude of cyclones in the East Atlantic in the RCP4.5 scenario.

Regarding only those cyclones associated with strong winds, Zappa et al. (2013b) subset their cyclone database based on the maximum 850 hPa wind speed associated with each cyclone. Those cyclones where the maximum wind speed is greater than the value of the 90th percentile from the Historical simulation of that model are classed as strong cyclones. In this way the impact of model biases present in both the present-day and future simulations are avoided. Figures 7.2b and 7.2d show the corresponding RCP8.5 multi-model mean changes in track density and mean wind intensity for the strong cyclones. Over the UK there is little change in the track density of strong cyclones but an approximately 5% increase in the mean intensity of the strong cyclones of the present-day mean.

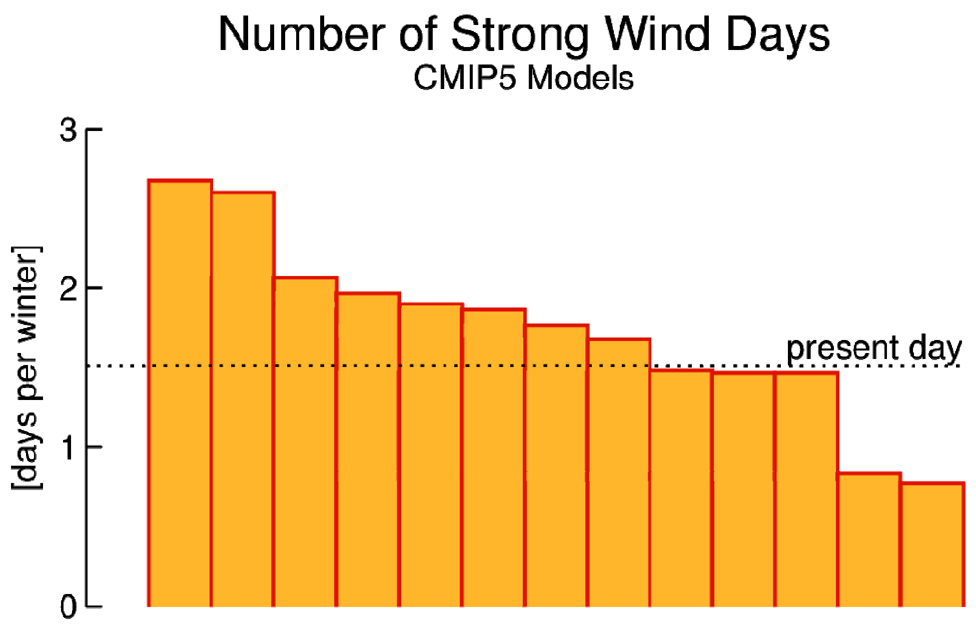


Figure 7.3: The number of strong wind days per extended winter for the late 21st century (2069-2099, RCP8.5) for 13 CMIP5 models. A strong wind day is defined as one where the daily mean wind speed in the lower troposphere (i.e. at 850 hPa) and averaged over the UK (8W-2E, 50N-60N) is greater than the 99th percentile of the HIST (1975-2005) simulations (this corresponds to 1.51 strong wind days per extended winter). An extended winter is defined as October to February.

These published studies focus on the multi-model mean storm track responses. An H++ scenario should consider the range of model spread around the multi-model mean in order to estimate possible values in the tails of the distribution. The analysis here focuses on the 13 CMIP5 models identified by Zappa et al. (2013a) as having a reasonable representation of the present-day North Atlantic storm track. Figure 7.3 shows the change in the number of strong wind days over the UK for the 13 CMIP5 RCP8.5 simulations. A strong wind day in this analysis is defined as one where the daily mean wind speed at 850 hPa is greater than the 99th percentile from the corresponding historical simulations. The wind speed at 850 hPa is used as it provides an estimate of likely maximum surface wind gusts. According to the CMIP5 models considered, the frequency of windstorms and strong wind days over the UK could increase or decrease by the end of the 21st century. **The largest changes in the CMIP5 climate models suggest that the frequency of strong winds over the UK might increase by 50-80%.** The sensitivity of the results to the choice of region was tested by repeating the analysis with a larger Northwest European box. A very similar spread in projections was found, which suggests the conclusions are largely insensitive to small variations in the choice of region.

Other evidence

Haarsma et al. (2013) present a novel mechanism by which the occurrence of strong windstorms over the UK during early Autumn may increase in future. Their very high resolution (25km) global climate model simulations suggest that changes in tropical Atlantic SSTs may yield more frequent and intense tropical cyclones positioned so as to recurve and hit Europe after extra-tropical transition. This mechanism will not be captured by the CMIP5 models which have insufficient resolution to resolve tropical cyclones. However, this work is in its infancy; it has only been identified in one model to date, and further work is needed to quantify this risk.

An additional question to consider is whether the clustering of windstorms might change in response to climate change. Windstorms tend to cluster in time (Mailier et al. 2006) and clustered windstorms have greater socioeconomic impacts (e.g. Lothar and Martin in Northern France, December 1999) through the failure of already weakened or damaged infrastructure and processes such as demand surge. The impacts of climate change on clustering were studied in the ECHAM5 climate model by Pinto et al. (2013), who found a decrease in clustering in Western Europe in response to climate change. These results are, however, only from one climate model. It is not yet clear how well climate models represent clustering, or how robust climate projections are, hence it is presently difficult to incorporate changes in clustering into a H++ scenario.

One other issue concerns the relatively low resolution of climate models. Climate models typically have horizontal resolutions of the order of 100km and relatively low resolution in the vertical. This means that current climate models fail to capture key smaller scale processes, such as sting jets (Browning and Field, 2004) which are important for generating damaging surface winds. Furthermore, low resolution climate models may not adequately capture the representation of latent heat release in windstorms (Willison *et al.,* 2013). An additional area of uncertainty is that damage from windstorms is often caused by the wind-gusts rather than by the sustained winds. However, modelled wind-gusts are not routinely output from climate model simulations. These are areas of current research, and the H++ scenario presented here might be revised with the advent of higher resolution climate models (Shaffrey et al. 2009, Mizielinski et al. 2014).

7.5 Physical limits

It is difficult to construct quantitative physical arguments for how intense an extratropical cyclone might become over the UK in response to climate change. Extratropical cyclones primarily derive their energy from (i) the available potential energy in the equator-to-pole temperature gradient and (ii) from the release of latent energy from moist processes (e.g. the formation of rainfall). However, it is difficult to use these ideas to provide constraints on intensity of individual extratropical cyclones, which will largely depend on the efficiency of the extratropical cyclone to convert these potential energies into kinetic energy.

An alternative approach was adopted by Economou et al (2014), who performed an extreme value analysis on the central pressures of extreme extratropical cyclones over the North Atlantic. This approach suggested that a most likely lower bound on central pressures in Southern England would be 942hPa. There is a relationship between central pressure and the winds generated by an extratropical cyclone. However, this relationship is not straightforward, making it difficult to infer what an upper bound on surface winds might be.

7.6 Summary on Windstorms

- The UK has experienced many extreme windstorms in the past, which have had substantial socioeconomic impacts. In the historical record these impacts have mostly been through the large loss of life from coastal flooding and shipwreck. Extreme windstorms since the 1960s have mostly had their greatest impact in terms of damage to property, where insurance losses can amount to many billions of pounds and they can still lead to loss of life.

- Analysis of the instrumental records suggest that long term trends in storminess over the UK and NW Europe are small, and generally statistically insignificant, relative to the decadal variability.

- CMIP5 climate model projections suggest that the number of strong wind days (i.e. greater than the 99% percentile) might increase or decrease by the 2070-2100. Some climate model projections suggest that the number of strong wind days might increase. **A plausible H++ windstorm scenario is thus a 50-80% increase in the number of windstorms over the UK by 2070-2100 compared to 1975-2005**. The caveats are that the scenario is based on the CMIP5 climate model simulations, which contain biases in the position of North Atlantic storm track and systematically under-represent the number of intense cyclones.

Appendix CC.1.2

Chapter 8 Cold snaps

This chapter deals with cold winters and presents ranges of temperature changes for the coldest days of winter, along with seasonal mean temperature changes. The data sets used are similar with those used for heat waves in Chapter 3 and are described in detail in Annex 2. We refer to the cold snap scenarios as L-- to emphasise that they are at the opposite end of the scale to the extreme warm summer temperatures in H++.

8.1 Summary of L-- cold snap and cold winter scenarios

The L-- cold winter scenarios span a range of time scales (1 day to a season) and encompass the entire UK. The time scales of the L-- scenarios are relevant for a variety of purposes. Periods of prolonged cold weather can lead to frozen water pipes which can then burst, and disrupt transport due to ice and snow. There is also a link to health impacts, with winter mortality at its greatest during cold winters.

Under long-term future warming conditions, future cold winters and cold days in the UK are likely to be less severe, occur less frequently and last for a shorter period of time than present day events. In UKCP09 winter temperatures increase under all scenarios (Section 8.4) thereby providing no evidence for more severe cold conditions in the UK. So, the L-- scenario considers two mechanisms that, were they to occur, would lead to a cooling of UK winter temperatures. These are a slowdown or collapse of the Atlantic Meridional Ocean Circulation (AMOC) and reductions in solar output (Section 8.5).

Under the L-- scenario for the 2020s, UK average winter temperature (for December, January and February) would be 0.3°C. UK average temperature on the coldest day would be around -7°C.

The temperatures for the 2080s are colder than those of 1962/63 and are similar to the coldest winters at the end of the Little Ice Age. This assessment is subject to a number caveats. First, the AMOC slowdown is highly unlikely during the 21st century and the evidence has 'low confidence' associated with it. Secondly, the estimates were derived by adding several different climate effects together and onto to a baseline based on the 1962/63 winter. The validity of this assumption, and in particular whether these events could occur together and the effects linearly combined, should be explored in future work. Finally the effect of volcanic activity, which can exacerbate cooling on timescales of several years, is not considered. Large volcanic eruptions have played a significant role in past climate but are complex to include. Their effects are usually temporary and/or short-lived (Section 8.6).

8.2 Historical data

There are several different data sources which can be studied to examine how periods of cold weather have changed in the past and provide guidance on suitable L--scenarios (Table 8.1). Northern hemisphere annual average temperatures have been estimated using a wide range of proxy data, such as tree ring widths, composition of lake sediments and pollen samples. Some of these proxy records cover the past 2000 years (Masson-Delmotte et al., 2013).

Table 8.1 Summary of evidence and data sources used to identify cold winters and create L-- cold scenarios.

Evidence	Description and Confidence	Confidence
Palaeo	Proxy data; northern hemisphere annual mean temperatures	Medium
Central England Temperature series	Instrument based. Monthly data from 1659, daily min/max from 1878	High
National Climate Information Centre	UK-wide gridded temperatures from 1910	High
Weather Stations	Longest record is at Oxford (about 160 years)	High
Solar output	Climate model simulations	Medium
Atlantic Meridional Overturning Circulation slowdown	Climate model simulations	Low
UK climate projections, UKCP09	Climate model simulations	Medium

The Central England Temperature record (CET; Parker et al., 1992) dates back to 1659, and is the longest instrumental series of this kind in the world. Monthly mean temperatures are available over the entire series. Gridded temperatures based on weather station records are available from 1910. Briefly, for this study data from the UK weather and climate station network were gridded by regression and interpolation to a 5 km × 5 km grid, taking into account factors such as latitude, longitude, coastal proximity and local topography (Perry and Hollis, 2005; Perry et al., 2009). These data have been aggregated to the 25 km × 25 km grid used by the UKCP09 climate projections by simply averaging all 5 km data within each 25 km grid box. Monthly data are available from 1910 and daily data from 1960.

Before these data sources are analysed and changes in winter temperatures are discussed, the next section briefly describes the North Atlantic Oscillation (NAO), which exerts a strong control on UK climate, especially during winter.

The North Atlantic Oscillation

The North Atlantic Oscillation (NAO) is a major driver of north European climate during winter. There is a semi-permanent area of high pressure over the Azores and an area of low pressure over Iceland which modulates the strength and direction of winds across the Atlantic into Europe. The exact positions and strengths of these two pressure systems vary both within and between years, and are known as the North Atlantic Oscillation (NAO). The NAO exists all year, but has the largest influence on European climate during the winter months (November to February).

The NAO is represented by the NAO index, which is based on the sea level pressure difference between the subtropical high and polar low (Osborn, 2011). Pressure is measured at Iceland and the Azores. A positive value of the NAO index corresponds to higher pressure in the Azores and lower pressure near the poles. A negative value represents the reverse. The positive phase of the NAO is associated with a stronger storm track, so winters in the UK tend to be mild and wet. A negative phase of the NAO implies mid-latitude cyclones take a more southerly storm track allowing Arctic air to reach northern Europe, resulting in colder, drier winters. Some studies have examined possible links between the NAO and other large scale modes of atmospheric variability, such as the El Niño-Southern Oscillation (ENSO). For example, the seasonal cycle of the NAO appears to be enhanced during ENSO events, but weaker when the ENSO is decaying toward a neutral phase (Polonsky et al., 2004).

Climate models run for long periods reproduce the broad scale features of the NAO, but there are substantial differences between individual models. Models do not reproduce observed changes in the NAO index, such as the positive trend between 1960 and 2000 (Christensen et al., 2013). Currently, the reasons for interannual and multi-decadal changes in the sign and magnitude of the NAO index are not fully understood. The effect of this is not so problematic here as the model and observations have reasonable agreement with respect to the statistics of warm and cool days.

Reconstructions of past climate

A wide variety of proxy data have been used to reconstruct the Earth's climate over timescales ranging from tens of millions of years to hundreds of years (Masson-Delmotte et al., 2013). In this section, the focus is on temperatures reconstructed for the past 2000 years. Annual mean temperatures for both hemispheres have been reconstructed from a variety of sources, including tree rings, pollen and lake sediments. These reconstructions show that the climate was warm during 950-1250 AD (The Medieval Climate Anomaly, also known as the Medieval Warm Period). The climate was considerably colder between 1450 and 1850 AD, a period known as the Little Ice Age (LIA). During the LIA, annual average temperatures in the northern hemisphere were roughly 1.0 to 1.3°C colder than the present day[34].

The LIA appears to have been caused by several different factors. The Earth's orbital configuration resulted in low summer insolation (the total amount of solar radiation received) across the northern hemisphere. This reduced insolation acted as the trigger for the LIA to start around the end of the thirteenth century (Miller et al., 2012) by allowing Arctic sea ice to expand, leading to an increased albedo effect. The cooling was further reinforced by several large sulphur-rich volcanic eruptions. Changes in solar output are thought to have been unimportant. Another study of decadal and centennial scale variability in northern hemispheric temperatures over the past millennium concluded that volcanic eruptions and changes in greenhouse gas levels were the most important factors, and any changes in solar output had only a small impact (Schurer et al., 2014).

Changes in the coldest and warmest days and months in winter in the Central England Temperature record

As stated above, monthly mean temperatures from the Central England Temperature record (CET) are available from 1659. Monthly mean temperatures for the consecutive months of December, January and February have been averaged to calculate winter

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[34] These approximate temperature changes were estimated from proxy temperature reconstructions shown in Figure 5.7 of the IPCC 5th Assessment Report (Masson-Delmotte et al., 2013).

mean temperatures. The winter mean temperatures are shown as anomalies (i.e. differences) from the 1961-1990 mean in Figure 2.3. The 1961-1990 period was also used as a baseline for the UKCP09 climate projections (Murphy et al., 2009).

The very cold winter of 1962/1963 can be seen clearly, with only two previous winters (1683/1684 and 1739/1740) colder in the CET. The temperature anomaly of the cold winter of 2009/2010 is comparable to winter anomalies 200 years earlier.

From the anomalies shown in Figure 8.1, it can be seen that there has been a slow rise in winter mean temperatures throughout the period (1660-2014). Warm winters have become more frequent and cold winters less frequent, especially after about 1970. Using the Mann-Kendall trend estimator (Sen, 1968), a positive trend of 0.039°C per decade in the winter mean temperatures shown in Figure 8.1 was found. The trend over the period 1660-1900 was smaller, but the uncertainty bounds included zero. The trend for the period 1900-2014 was not significant at the 5% level. Overall, there is some evidence of an upward trend in winter temperatures in the CET, but the value of the trend is very dependent on the time period chosen, and is hard to distinguish from zero.

A closer examination of the temperature anomalies in Figure 8.1 reveals a few interesting features. Temperatures of the warmest winters (those with a positive anomaly of 2°C or more in Figure 8.1) appear to have remained approximately the same throughout the period shown. Temperatures of warm winters (an anomaly larger than 0°C but less than 2°C) have become higher; before 1750, the anomaly was around 0.5°C, but has increased to around 1.5°C in the early 21st century. There is an increased frequency of warm winters from 1970. The winters of 1833/34 and 1868/69 are (at the time of writing) the warmest in the CET.

Changes in the temperatures of the coldest winters in the CET are different to the changes in the warmest winters discussed above. The temperatures of the coldest winters in the twentieth century are generally higher than the coldest winters of the preceding centuries. The frequency of cold winters after 1970 is greatly reduced compared with earlier periods. Using the full CET record of monthly mean temperatures, Christidis and Stott (2012) calculated that the chances of a winter like 2009/10 occurring have reduced by approximately a factor of 2 owing to the human influence on climate. An analysis of the circulation patterns of the 2009/10 winter by Cattiaux et al. (2010)

showed that, in the absence of anthropogenic warming, temperatures would have been comparable to those of the 1962/63 winter.

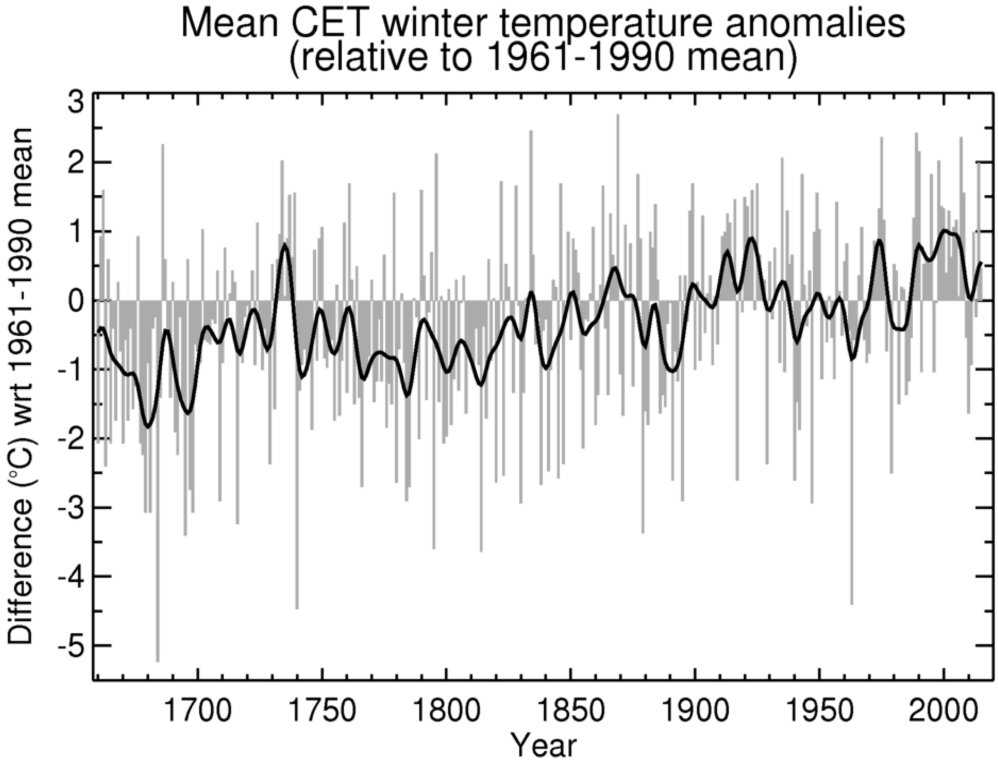

Figure 8.1. Winter mean temperature anomalies in the Central England Temperature record for the years 1660-2015 relative to the 1961-1990 mean. The grey bars show individual anomalies for each year. The black line is a smoothed version created with a 21-term binomial filter (Parker, 2009).

As well as cold winters, changes in shorter cold spells are also of interest. The average minimum temperatures of the coldest 5 and 10 day periods in each year in the Central England Temperature Record are shown in Figure 8.2. These temperatures were calculated using daily minimum temperatures from the CET which are available from 1878. The coldest values are found at the beginning, whereas the warmest values occurred in 2014.

Changes in the highest and lowest temperatures in winter are similar to those seen for winter as a whole (Figure 8.1). There is no significant trend in the highest winter temperatures. Temperatures for recent decades are generally similar to temperatures at the beginning (i.e. 1880-1900). However, the lowest temperatures of the 5 day periods in winter (red crosses) have warmed, from about -11°C in the late 1800s to about -6°C.

Similarly, the lowest temperatures of the 10 day periods (green diamonds) have warmed from -10°C to about -5°C.

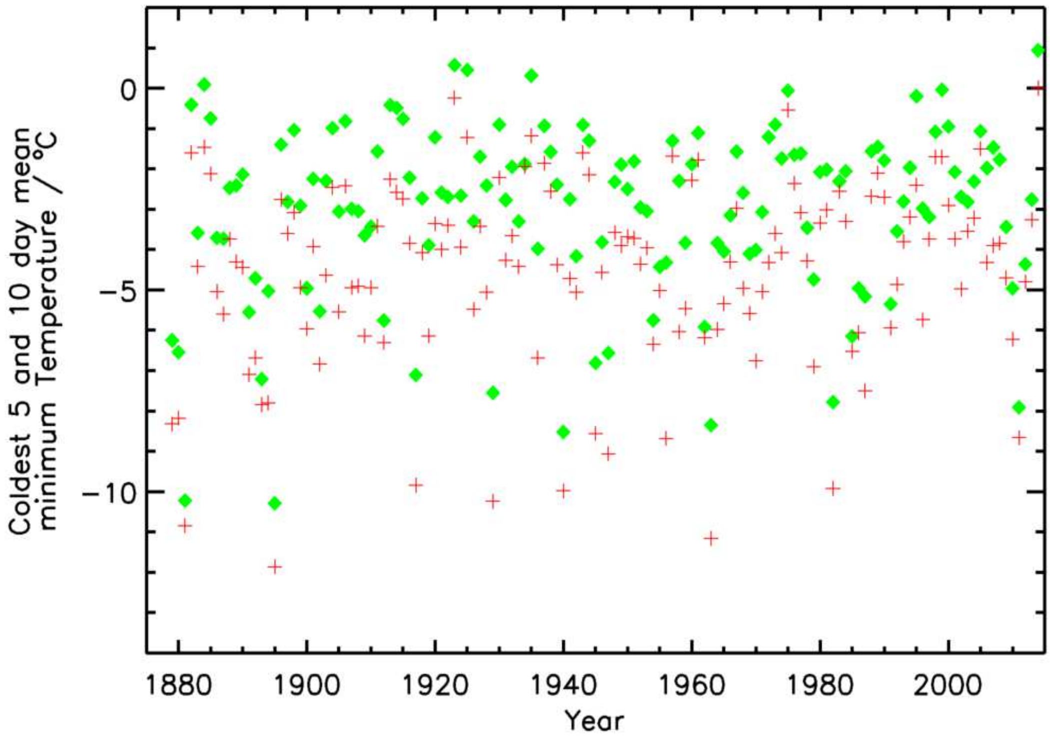

Figure 8.2. Coldest 5 day (red crosses) and 10 day (green diamonds) periods in the Central England Temperature record for the period 1878 – 2014. The mean 5 and 10 day values were calculated from the time series of daily minimum temperatures.

The analysis of seasonal mean and daily minimum temperatures for 5-10 day periods from the Central England temperature record shows that the changes are not a simple linear increase. The highest temperatures in winter have remained approximately constant, despite the observed warming over the whole period. The lowest temperatures have increased, and cold winters have become less frequent, particularly in the last few decades. Despite these trends, December 2010 was one of the coldest in the CET, with a mean monthly temperature of -0.7°C; only December 1890 was colder (-0.8°C). This shows that cold winters are still possible due to natural variability even when there is an underlying warming trend.

Changes in the coldest and warmest days and months in winter for the UK as a whole

In this section, changes in UK-wide winter temperatures inferred from the gridded NCIC data are analysed and discussed. Winter is defined as the consecutive months of December, January and February. Trends in the gridded temperatures for winter have been analysed by Jenkins et al. (2009). Significant upward trends were found for both minimum and maximum temperatures averaged over the winter period between 1961 and 2006. The temperature changes ranged from about 2°C in south-east England to about 1.2°C in Scotland.

The analysis of the CET showed that cold winters had warmed, and cold winters had become less frequent in recent decades. Using the NCIC gridded data, a very cold winter was defined as a winter with a mean daily minimum temperature less than or equal to 0°C. This threshold is arbitrary, but any winter whose mean minimum temperature is below freezing would be considered to be very cold. In such a winter, there would be many impacts such as freezing of water pipes, snowfall, ice on roads and pavements etc. Thresholds for the impact of cold temperatures on health are more uncertain than the impacts from heat (see CCRA1, Wade et al., 2012) and vary regionally; hence, it was decided not to choose a health related threshold for this work.

From the NCIC data, there have been 22 very cold winters since 1910 which are listed in Table 8.2. Very cold winters have occurred throughout the twentieth and early twenty-first centuries. Very cold winters were relatively infrequent between 1910 and the mid-1930s, and between the 1990s and 2000s. During these periods, the NAO had positive values in most years, leading to milder winters (Osborn, 2011). Between about 1940 and 1980, the NAO had mostly negative values, and a number of very cold winters occurred during this period. From 1980 to 2008, the NAO was again mostly positive, and there were a smaller number of very cold winters. The very cold winter of 2009/2010 was associated with a record negative NAO index (Osborn, 2011). The sign and magnitude of the NAO has a strong influence on winter temperatures in the UK, as discussed above.

Table 8.2. Very cold winters, defined as a winter with a mean daily minimum temperature (Tmin) of 0°C or colder in the NCIC record (which begins in 1910). Winter is defined as the consecutive months of December, January and February. The year refers to January and February. Tmin refers to the mean daily minimum temperature from December to February.

Year	T_{min}	Year	T_{min}	Year	T_{min}	Year	T_{min}
1917	-1.08	**1947**	-1.65	**1969**	-0.01	**1986**	-0.23
1929	-1.06	**1951**	-0.45	**1970**	-0.18	**1991**	-0.19
1936	-0.36	**1956**	-0.50	**1977**	-0.29	**2010**	-1.18
1940	-1.40	**1959**	-0.15	**1979**	-1.46	**2011**	-0.46
1941	-0.79	**1963**	-3.07	**1982**	-0.88		
1942	-0.63	**1965**	-0.16	**1985**	-0.46		

The only time three consecutive very cold winters occurred in the NCIC was 1939/1940, 1940/1941 and 1941/1942. Two consecutive very cold winters occurred in 1969 and 1970, 1985 and 1986 and 2010 and 2011 (Table 8.2). The winter of 1962/1963 is by far the coldest in this record (winter mean temperature of -3.07°C).

The mean winter daily minimum temperatures for the years listed in Table 2.2 are plotted in Figure 8.3. There is no significant trend in these temperatures, and the temperatures of the most recent cold winters (2009/2010 and 2010/2011) lie within the range of temperatures of the previous very cold winters. However, very cold winters have occurred less frequently in recent decades than earlier periods.

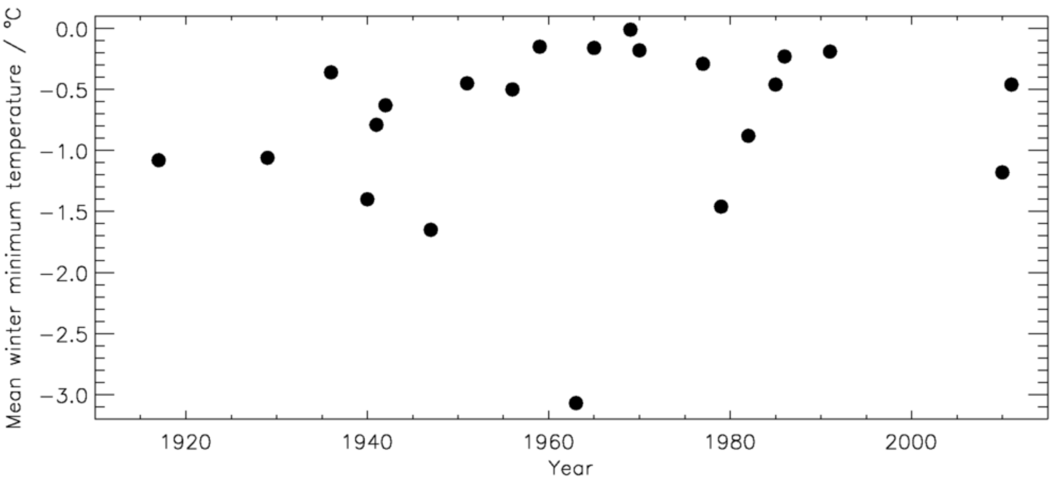

Figure 8.3. UK mean winter daily minimum temperatures from the NCIC records for the period 1910 – 2013. Only very cold winters (where the mean temperature is 0°C or colder) are shown.

UK Cold Climate Extremes

The coldest days and nights in the UK have been identified from weather stations by the NCIC, and the coldest days and nights for each part of the UK are shown in Table 8.3. Most of the record cold temperatures occurred during the cold winters of 1982, 1995 and 2010. Interestingly, none of these records happened during the coldest winters of 1946/47, 1962/1963 or 1978/79.

Table 8.3. UK record cold days and nights using data from individual weather stations.

UK Region	Coldest Daily Minimum / °C	Date	Coldest Daily Maximum / °C	Date
Scotland	-27.2	10.01.1982 11.02.1895 30.12.1995	-15.9	29.12.1995
England	-26.1	10.01.1982	-11.3	23.12.2010
Northern Ireland	-23.3	21.01.1940	-11.3	11.01.1982
Wales	-18.7	24.12.2010	-8.0	12.01.1987

Summary

The NCIC UK mean and CET both show that cold winters have occurred throughout the historical record, and that cold winters are still possible despite the warming of the planet since preindustrial times. The characteristics of cold winters are often very different. For example, 1946/47 was characterised by persistent heavy snowfall between January and early March, whereas 1962/63 had much colder temperatures during a similar period but less snowfall. Using monthly mean temperatures from the CET, the winter of 2010/11 was characterised by one of the coldest Decembers on record, whereas January and February 2011 were relatively mild. In contrast, January and February were very cold during the winter of 1946/1947 and all three winter months during the winter of 1962/1963 were consistently cold.

8.3 UKCP09

Under warming conditions, future cold winters and cold days in the UK are likely to be less severe, occur less frequently and last for a shorter period of time than present day events. In UKCP09, 30-year average mean winter temperatures increase under all scenarios (Murphy et al., 2009). For the medium emissions scenario, the 30-year mean daily minimum temperature increases on average in winter by about 2.1ºC (0.6 to 3.7ºC) to 3.5ºC (1.5 to 5.9ºC) depending on location by the 2080s.

Under the Low emissions scenario at the 10 % probability level and at the regional scale, 30-year average winter (Dec-Jan-Feb) warming is less at 0.2 to 0.5^{o}C in the 2020s and 1.0 to 1.4^{o}C in 2080s[35]. Gridded data for this specific scenario were used for estimation of the L-- cold winter described in Section 8.6.

[35] The range represents different rates in different UKCP09 administrative regions http://ukclimateprojections.metoffice.gov.uk/23672?emission=low

Appendix CC.1.2

8.4 Physical limits

When considering cold extremes, two additional climatic events with low probabilities but potentially high impacts should be considered: a prolonged solar minimum and a slowdown or collapse of the Atlantic Meridional Ocean Circulation (AMOC). Both of these events would cause a cooling of temperatures over the UK. The possible effects of these two events on UK winter mean temperatures are discussed in the following sections. The recent reductions in Arctic sea ice and its potential effect on the probability of cold winters occurring over Europe and the UK are also briefly discussed.

Prolonged solar minimum

Correlations between meteorological variables and solar variability have suggested an influence of solar irradiance on the Earth's climate (Gray et al. (2010) and references therein). For example, Ineson et al. (2011) noted that weaker westerly winds over Europe have been observed in winters when the sun is less active, i.e., at the minimum phase of the 11-year sunspot cycle. These authors suggested that low solar activity increases the chance of cold winters in northern Europe and the United States, and mild winters over southern Europe and Canada, but with little change in global mean temperatures.

A future decline in solar activity would not offset the overall warming caused by anthropogenic greenhouse gas emissions (Ineson et al., 2015). However, variability in ultraviolet (UV) solar irradiance is linked to modulation of the North Atlantic Oscillation (NAO). Ineson et al. (2011) showed that the response of surface pressure patterns at a solar minimum during winter closely resembled the negative phase of the NAO. Temperatures over north-east Europe were also anomalously cold during these periods. Lockwood (2010) calculated an 8% chance of a return to a period of prolonged low solar output by 2060. Given the continuing decline in solar output since about 1990, Ineson et al. (2015) suggested that the 8% estimate is probably too small, and could be between 15 and 20%.

Ineson et al. (2015) have examined the effects of a prolonged solar minimum on European winter temperatures during the twenty-first century. They used the Met Office Hadley Centre general circulation model HadGEM2-CC (Martin et al., 2011) which includes a representation of the carbon cycle. The HadGEM2-CC model has 60 vertical levels and an upper boundary at 84 km, and so can simulate important stratospheric

Appendix CC.1.2

processes and their effects on the troposphere. Future greenhouse gas emissions were taken from the RCP8.5 scenario (a high emissions scenario; van Vuuren et al., 2011; Taylor et al., 2012). Three simulations with no reduction in solar output, and three more with the reduction were completed. Ineson et al. (2015) used two different estimates of future solar output; here, the change in UK winter average temperatures was calculated from simulations with the larger reduction in solar UV fluxes.

Table 8.4. 30-year mean UK winter (Dec-Feb) temperature changes (°C) from the solar minimum simulations. The temperatures are the differences between the control (no change in solar output) run and simulations with reduced solar output. All the changes are negative, showing that reduced solar output results in colder UK 30-year mean winter temperatures. The simulations were run in pairs, so the same initial conditions were used to start simulations with and without the reduced solar UV flux. The decades are 30 year periods indicated by the central decade, so, for example, the 2050s means the period 2040-2069.

	Ensemble Member			**Ensemble Mean**
30-year time period	1	2	3	
2010-2039	-0.35	-0.54	-0.66	-0.52
2020-2049	-0.39	-0.52	-0.47	-0.46
2030-2059	-0.39	-0.32	-0.11	-0.28
2040-2069	-0.49	-0.26	-0.14	-0.30
2050-2079	-0.90	-0.25	-0.40	-0.52
2060-2089	-0.71	-0.49	-0.50	-0.57
2070-2099	-0.70	-0.58	-0.76	-0.68

The reductions in UK winter mean temperatures are relatively modest, and would offset the effects of global warming by at most a decade (Table 8.4). Low solar activity does not guarantee cold conditions in any specific European winter. Solar variability acts only to bias the intrinsic year-to-year variability, which remains substantial for Europe and the UK (Ineson et al., 2015). For example, in the Central England temperature (CET) record (Parker et al., 1992), many cold winters occurred at the beginning of this record (1659 to approximately 1715), which is roughly the end of the Maunder minimum (a period when sunspots became very rare and solar output was reduced). However, the winter of 1685/1686 is one of the warmest in the CET (Figure 8.1). Other studies have shown that changes in solar output have had at most a small effect on climate (Miller et al., 2012; Schurer et al., 2014). Given projected increases in greenhouse gas emissions and the associated warming of the planet, a sustained reduction in solar output would not offset the warming caused by increasing levels of greenhouse gases.

Effects of a slowdown of the Atlantic Meridional Ocean Circulation (AMOC)

An analysis in the most recent IPCC assessment of the AMOC under four emissions scenarios shows that it is very likely that the AMOC will weaken during the 21st century (Collins et al., 2013) and that the weakening tends to increase with higher levels of warming associated with greater greenhouse gas emissions. However, it also finds that the current generations of global climate models suggest that a sudden slowdown or collapse of the AMOC is very unlikely during the 21st century (Weaver et al., 2012; Collins et al., 2013). They consider a collapse due to global warming beyond 2100 to be unlikely. Some caution must be placed on these conclusions because there is some evidence that many of the current generation of climate models might be overly stable with respect to their AMOC response.

Table 8.5. UK winter mean temperatures in simulations of a slowdown of the AMOC. The columns headed Control and Change show the long-term UK mean winter temperatures and the mean change after the AMOC slowdown occurred. The temperature changes are all negative, indicating they are colder in the simulation with a weakened AMOC than the control simulation. The model resolutions are approximate.

Model / Reference	Model Resolution / km (approx.)	CO_2 level / ppm	Temperature / °C	
			Control	Change
HadCM3[(1,2)]	300	286	3.9	-5.2[b]
HadCM3[(2)]	300	500 – 710[a]	7.1	-4.5[b]
HadGEM3[(3)]	150	345	4.6	-4.9[c]
HadGEM3[(3)]	80	345	5.3	-4.1[c]

[a]CO_2 levels from the IS92a scenario between 2050 and 2100. [b]Temperature differences calculated using the first 10 years of the perturbation run only, when the AMOC strength was similar to that in the simulations using HadGEM3. . [c]Temperature differences averaged over 30-60 years; the averaging period was determined by the length of the simulation and the period for which the AMOC was stable following the initial slowdown. References: (1) Vellinga and Wood (2002); (2) Vellinga and Wood (2008); (3) Jackson et al. (2015).

Nevertheless, as a slowdown during the next century cannot be ruled out and because the climatic and economic consequences of a large slowdown of the AMOC are likely to be severe and wide-ranging (Kuhlbrodt et al., 2009; Link and Tol, 2011), so an assessment of the impacts on UK temperatures is expedient. Four simulations of a slowdown of the AMOC were analysed, and the effects on mean winter temperatures in the UK are summarised in Table 8.5. Despite the differing models and initial climatic conditions used in the simulations, the changes in winter mean temperatures are reasonably consistent.

An important caveat is that we have not assessed whether the pattern of temperature change seen in hypothetical AMOC collapse experiments is related to the transient climate response. As we will link these AMOC cooling patterns with models from the lower tail of the UKCP09 ensemble, which tend to have lower transient climate response values, this assumption must be kept in mind.

8.5 Other evidence

The decline of Arctic sea ice has been linked to recent colder winters in Europe and Asia (Mori et al., 2015). The rapid warming of the Arctic has reduced the temperature gradient between mid-latitudes and the Arctic. It has been argued that a reduction in this temperature gradient leads to reduced westerly wind speeds and a slower movement of the jet stream (Francis and Vavrus, 2012), as well as an increased amplitude (or "waviness") of the jet stream (Francis and Vavrus, 2014). However, another study found no evidence of an influence of a warm Arctic on cold European winters (Woolings et al., 2014).

A slower jet stream would lead to increased persistence of weather patterns over the UK, including cold winters (as well as warm winters). A reduction in the speed of the jet stream has not been detected (Barnes, 2013), but it could still change in the future. It is now recognised that large amplitude slow-moving waves in the jet stream can be associated with extreme weather (Screen and Simmonds, 2014). However, it is still not clear whether the jet stream has slowed, how it may change under a warming climate, and whether reductions in Arctic sea ice are linked to any changes in the jet stream (Woolings et al., 2014).

An analysis of 22 CMIP5 global climate model simulations by Mori et al. (2015) showed that projected warming of the climate will overcome any possible effects of reductions in Arctic sea ice on European and Asian winter temperatures, should these effects even exist.

8.6 L-- cold scenarios

The analyses of the NCIC data and the CET show that the mean temperatures of very cold winters have increased over the historical period owing to warming since preindustrial times (approximately 1850). Cold winters have occurred less frequently in the last few decades, whereas warm winters have become common (Figure 8.1). An analysis of monthly mean temperatures from the CET shows that the characteristics of the coldest winters are often very different. Some had mild Decembers but January and February were very cold (for example, 1946/47, 1978/79) whereas others had a very cold December but milder temperatures during January and February (2010/11). December, January and February were all unusually cold during the winter of 1962/63.

An important decision is how to represent an L-- winter. The three coldest winters in the CET record are 1683/84, 1739/40 and 1962/63 (Figure 8.3). The winter of 1683/84 is the coldest in the series, but occurred toward the end of the Little Ice Age, when temperatures were generally lower, by about 1.1°C compared to the 1961-1990 average. The anomalies for the winters of 1739/40 and 1962/63 are similar, at -4.5°C and -4.4°C respectively. The winter of 1962/63 and coldest day (12th January 1987) are used to represent an L-- winter, as gridded temperature data from the NCIC are available for these two periods and they are suitable anomalies to apply to the standard 1961-1990 baseline.

An L-- winter and an L-- coldest day for the 2020s (2010-2039) and 2080s (2070-2099) have been constructed using the data summarised in Table 8.6. These L-- scenarios are expressed using mean temperatures, because minimum and maximum temperatures were not archived from some of the climate model simulations. First, a baseline winter was defined as the average winter temperatures for the period 1961-1990, which is the same period used in the UKCP09 climate projections. This calculation used the gridded temperatures created by Perry et al. (2009). Next, the baseline winter temperatures were subtracted from the actual winter mean temperatures (again using the gridded data created by Perry et al. (2009)) for 1962/63. The winter temperatures for 1962/63 are now expressed as anomalies relative to this baseline.

From the gridded temperature data, the coldest day for the UK as a whole (identified by calculating UK average temperatures from daily mean values in the NCIC record) was 12th January 1987. On this day, record daily minimum temperatures were recorded in Wales (Table 8.3). The baseline winter temperatures were subtracted from the actual temperatures for this day, to create a set of anomalies for the coldest day.

The L-- winter scenario for the 2020s was created as follows. Gridded changes in winter average temperatures from the UKCP09 projections under the low emissions scenario for the 2020s at the 10% probability level were added to the baseline. Then, the

1962/63 anomalies were added onto this revised baseline to create the L-- winter scenario. A similar procedure was used to create the L-- coldest day for the 2020s, using the same revised baseline and then adding the anomalies for the 12th January 1987. These scenarios are therefore event based and describe cold conditions over specific time periods.

Table 8.6. Observations and model data used to create two possible L-- winter scenarios for the 2020s and 2080s.

Variable	Description of the effect on winter temperature	Type[a]
Baseline	Observed winter mean temperature for 1962/63	Gridded[b]
Coldest Day	Coldest day (UK-average; 12th January 1987)	Gridded[b]
UKCP09	Low emission scenario, 10th %ile, 2020s and 2080s	Gridded
AMOC	-4.7°C	Single value[c]
Solar	-0.68°C (2080s)	Single value[d]

[a]"Gridded" means observed temperatures on the 25 km grid used by the UKCP09 climate projections.
[b]Created by averaging all values from the 5 km grid within each 25 km grid box.
[c]Winter mean temperature change from the four AMOC slowdown simulations (Table 8.5)
[d]Ensemble average of winter mean values from Table 8.4.

For the 2080s, temperature changes from the hypothetical solar (Table 8.4) and AMOC (Table 8.5) experiments were also included. The average temperature change from the AMOC experiments (Table 8.6) and the ensemble mean temperature change from the solar experiments for the 2020s (Table 8.6) were added to every model grid point in the baseline. Next, the UKCP09 winter mean temperature changes for the 2080s under the low emissions scenario at the 10% probability level were added to the baseline. Finally, the anomalies for the 1962/63 winter and coldest day (12th January 1987) were added.

UK average temperatures for the L--cold scenarios in the 2020s and 2080s are listed in Table 8.7.

Table 8.7. UK average temperatures for winter and a coldest day. All temperatures represent daily averages

	Time Period	
Variable	2020s	2080s
Winter mean	0.3°C	-4°C
Coldest day	-7.0°C	-11°C

In the L-- scenario for the 2020s, UK mean winter temperature is 0.3°C over all land points. For the L--coldest day scenario, temperatures are well below freezing over the entire UK, averaging -7°C.

For the 2080s L-- scenario, average winter temperatures and the temperatures of the coldest day are much lower than those for the 2020s owing to the effects of the reduced solar output and AMOC slowdown. Average winter temperatures are about -4°C, and temperatures of the coldest day are around -11°C over the land area.

Under the L-- scenario for the 2080s, winter temperatures in December, January and February would be -4°C over averaged over the UK and temperatures on the coldest days would be around -11°C.

The effects of volcanic eruptions, whether large and explosive or smaller and sulphur-rich have not been included in the L-- winters. These effects are not simple to include. Large eruptions cause a temporary cooling of global mean temperatures; for example, the eruption of Mt Pinatubo in 1991 was followed by a cooling of global mean temperatures of 0.5°C (Hansen et al, 1992), whereas smaller eruptions have more of a local effect. In the case of the Little Ice Age, the effect of multiple smaller volcanic eruptions appeared to amplify an existing cooling trend (Miller et al., 2012). Any future volcanic emissions would have to be much larger and prolonged to offset the continued warming of the planet resulting from anthropogenic greenhouse gas emissions.

Chapter 9 Other hazards, wildfires and combined events

This chapter provides a brief review of the implications of H++ type scenarios for other hazards, with a short review of wildfires as an example of an important risk that is highlighted in the National Risk Register.

9.1 Other hazards

The UK is exposed to a range of hazards that can be broadly classified as space weather (e.g. geo-magnetic storms), atmospheric (e.g. wind storms, hail storms and lightning), geophysical (e.g. landslides, earthquakes), shallow earth (e.g. subsidence), hydrological (e.g. floods, droughts) or biophysical (e.g. wildfires, bio-hazards) (Gill and Mallamud, 2014). Many hazards are linked, which raises the issue of whether the H++ scenarios presented in this report could occur together, increasing the risks for people, infrastructure and the environment. A full analysis of the correlations between these events was outside the scope of this report and this was agreed at the inception stage (Met Office, 2014). A summary of important hazards linked to climate change is provided in Table 9.1 with comments of the relevance of H++ type scenarios.

9.2 Systemic risks

Most climate risks faced by the UK are due to a combination of climate and socio-economic factors and many may be exacerbated by inter-linkages and interdependencies in systems. These are referred to as systemic risks and are relevant to H++ scenarios because it will often be a combination of extreme weather events and other factors that have the greatest impact. For example, deaths related Pakistan's 2015 heat wave, where temperatures reached 45^{o}C, have been linked to power cuts that have restricted the use of air-conditioning units and fans and abstention from drinking water in the fasting month of Ramadan. Deaths have been greatest amongst the poorest communities with limited access to resources[36]. The second CCRA will consider systemic risks when assessing the potential impacts of heat waves, floods and droughts. The H++ type scenarios may be included in these assessments.

[36] http://www.bbc.co.uk/news/world-asia-33251100

Table 9.1 A summary of selected hazards and their links to H++ scenarios

Hazard Group	Hazard	H++ Relevance	Links (+ strength)
Atmospheric	Storm	Windstorms are often associated with heavy rainfall e.g. storms in 2013/14. (Huntingford, et al. 2014)	Floods (++) (river, coastal and pluvial flooding)
	Snow storm	Cold winters can be associated with heavy snowfall.	Floods (+) (river flooding)
	Meteorological drought	Low rainfall causes meteorological drought and is a key factor in other types of drought.	Low flows (+++)
	Heat waves	Heat waves are associated with land-atmospheric feedbacks due to dry soils. High temperatures are linked to both heat waves and hydrological drought.	Drought (++) Also clearly linked to impacts such as rail buckling.
Hydrological	Flood	High flows. Increases in peak flows caused heavy rainfall and wet antecedent conditions. Both H++ wet winter and heavy rainfall scenarios are relevant.	High rainfall (+++) (wet winters and heavy rainfall events)
	Hydrological drought	Low flows	Low rainfall (+++)
Geophysical	Landslide	High rainfall (Ch 6) can trigger shallow landslides. Both winter rainfall and event H++ scenarios are relevant to landslide risk assessment	High rainfall (++)
	Snow avalanche	Cold winters can be associated with heavy snowfall. Only relevant in Scotland.	Cold winters (+)
Shallow Earth	Regional subsidence	None. Although high rates of subsidence may increase rates of relative sea level rise.	n/a
	Local subsidence	Low rainfall and dry soils are linked to subsidence with impacts of buildings, roads and pipes.	Low rainfall (++) Heat waves (+)
Biophysical	Wildfires	Low rainfall and heat waves contribute to wild fires.	Low rainfall (+) Heat waves (+)

9.3 Wildfires

This section considers wildfires by reviewing the evidence that links climate change to an increase in the frequency of fires. It provides a qualitative assessment to come up with H++ scenario and suggests the types of research required to come up with a more quantitative assessment of future risks.

Under the H++ scenario described in this section, the UK would experience high-risk fire danger conditions coincident in multiple critical locations, particularly in the south-east of England.

Wildfires are a global hazard, receiving increasing attention as a result of large-scale disasters with high-level impacts across the world in recent years. This attention has prompted the development of global climate change risk assessments for wildfires, summarised in the latest IPCC report (Settele et al., 2014). Along with recent studies (for e.g. Betts et al., 2013; Moritz et al., 2012; Gonzalez et al., 2010; Pechony and Shindell, 2010; Flannigan et al., 2005) current conclusions are that significant portions of the globe are likely to see increases in fire danger under climate change, although some regions may see decreases in fire danger, particularly when vegetation interactions and feedbacks are taken into account. It is also clear that there is a considerable degree of uncertainty in projections due to the highly interlinked nature of climate, vegetation, human interaction and wildfire.

The current threat to the UK from wildfire has been highlighted by its inclusion in the National Risk Register in recent years, prompted by high-impact fires such as Swinley Forest in 2011. Of interest to multiple stakeholders in the UK is the potential for increases in fire risk in the future to allow appropriate adaptive and mitigative action to be taken. The aim of this work is to provide an assessment of high-end scenarios of fire risk for the UK by the end of the century in line with other ‘H++’ scenarios provided for the Climate Change Risk Assessment (CCRA). These scenarios should lend insight and context to decision makers considering the longer-term evolution of land and fire management in the UK to guide costly investment, as well as provide further indication of the high-impact changes that could be avoided by limiting climate change.

Research regarding wildfire the UK is less advanced than research on many of the other risks considered in the CCRA. It is highly multi-disciplinary and our knowledge of the relevant systems and how they interact is still limited. In addition projections of wildfire are not sufficiently developed so as to have high confidence in a model-based assessment. However, it is still useful to consider multiple approaches as used in other H++ assessments. Therefore this assessment will consider the following evidence supporting H++ scenarios for wildfire in the UK:

1. Historical events
2. Temporal and spatial analogues
3. Model simulations

As with all high-end scenarios, expert judgement is a key ingredient, and for this reason an initial activity in this assessment was to convene a group of experts representing different stakeholders in UK wildfire research. The following sections address the evidence base for high-end wildfire scenarios in the UK; followed by an outline of the expert discussion mainly with regard to the question 'what does an H++ scenario for wildfire in the UK look like?' A final section recommends further research needed to address this question with greater confidence.

What evidence do historical events give to H++ scenarios of wildfire in the UK?

It is useful to consider historical fire events, the meteorological and climatological conditions that accompanied them, and the impact of the events. These events provide clear demonstration of the current risk and can be useful analogues of future risk. In this instance we consider a series of 3 events: The 2011 Swinley Forest fires have already been discussed and provide a useful case study of potential damage to critical infrastructure; in addition the hot and dry years of 2003 and 1995 demonstrate a clear link of such weather to wildfire incidence and allow us to consider future occurrence of such events.

In the record heat wave year of 2003 fires in the UK were not nearly as damaging as fires in southern Europe; however fire incidence was much greater than is usually expected. For instance, 870 ha were lost in the Pirbright Ranges, Surrey over 4 days. This area is designated as Special Protection Area (SPA), Special Area of Conservation (SAC) and Site of Special Scientific Interest (SSSI) and the event caused significant ecological damage. The fire also closed local roads, and led to the evacuation of military homes and concerns about Farnborough Airport flight path. The fire had regional implications on major infrastructure and reduced Fire and Rescue resources to respond to other emergencies (Rural Development Initiatives, 2012). Similarly devastating fires affected areas of moorland in the north of the UK.

The years of 1995 of 2003 saw the driest springs and warmest summers in recent years and suffered far greater than the average number of wildfires; the number of primary fires recorded by the Fire and Rescue Services during these years disproportionally account for almost 40% of fires in the entire nine year period between 1995 and 2004 (Table 9.2). By 2040 the temperatures experienced in 1995 and 2003 are expected to be around average, and to be considered a cool year by the end of the century (Stott et al., 2004). Consequently it may be expected that based on temperature alone the number of fires in these years will also become the norm or low risk.

Table 9.2: Number of wildfire recorded in the UK 1995-2004

Calendar Year	1995	1996	1997	1998	1999	2000	2001	2002	2003*	2004*
Primary wildfires **	627	511	380	107	197	183	118	169	303	155
Secondary wildfire ***	13,510	7,629	6,060	3,456	5,721	4,081	6,097	5,466	13,100	5,360

*** Excluding incidents not recorded during industrial action Nov 2002 and Jan/Feb 2003**
**** Primary fires include grassland and heathland fires where 5+ fire appliances attended**
***** Secondary fires include grass, straw and stubble fires where >5 fire appliances attended**
Source: Fire Directorate, Communities and Local Government Fire Statistics, HM Government (19 June 2006)

What evidence do temporal and spatial analogues give to H++ scenarios of wildfire in the UK?

In consultation the expert team advised that conducting analogue studies in this context may have limited use and therefore they are not considered in detail here. The incidence of wildfire is heavily dependent on the vegetation present and also on human interaction. Vegetation and human interaction in warmer or drier periods in the UK past would have been significantly different. It may be useful in future to consider how appropriate spatial analogues from the Mediterranean region may be. It is certainly useful to consider the practices that may be adapted from any fire-prone region in the face of increasing fire risk in the UK.

In addition to analogues on such a large scale, it is also useful to consider transporting knowledge and experience within the UK. Considerable work has evaluated the present day and future fire risk to the Peak District National Park (McMorrow and Lindley, 2006). The situation of the Park was considered to make it particularly vulnerable to climate change, and it is also vulnerable to visitor pressure and hence risk of fire ignition. The Park could therefore be seen as a useful analogue for future fire risk in more northerly peatlands as they experience increased drying and visitor pressure.

What evidence do model simulations give to high-end wildfire scenarios in the UK?

The meteorological drivers of wildfire are well understood, and a variety of indices exist for different regions to help predict fire risk based on a meteorological or climate forecast. For instance the McArthur Forest Fire Danger Index (FFDI, Luke and McArthur, 1978) is a weather-based index derived empirically in south-eastern Australia. It indicates the probability of a fire starting, its rate of spread, intensity, and difficulty of suppression. Originally the calculation took the form of a set of cardboard wheels, into which the user dialled the observations. Later, Noble et al. (1980) converted the FFDI into a form suitable for use by computers.

$$FFDI = 2.\exp(0.987\log D – 0.45 + 0.0338T + 0.0234V – 0.0345H)$$

H = relative humidity from 0-100 (%)
T = daily maximum air temperature (°C)
V = daily mean wind-speed 10-metres above the ground (km/hr)
D = drought factor in the range 0-10

The drought factor (D) is calculated as:

$$D = 0.191(I+104)(N+1)^{1.5} / [3.52(N+1)1.5+R-1)$$

N = No. of days since the last rain (days)
R = Total rainfall in the most recent 24h with rain (mm)
I = Amount of rain needed to restore the soil's moisture content to 200mm (mm). A constant of 120mm has been substituted here, as suggested by Sirakoff (1985).

The previous CCRA chapter for the Biodiversity and Ecosystem Services Sector (Brown et al., 2012) concluded that wildfires and forest fires are likely to increase in frequency although it is not possible to be confident about the size of the increase. This conclusion was based on use of the 11-member Regional Climate Model (HadRM3) ensemble associated with UKCP09. The ensemble is made up of model variations each with slightly different parameter perturbations and therefore allows us to consider a degree of uncertainty in modeling. Data from ensemble were used to calculate the McArthur Forest Fire Danger Index (FFDI; Dowdy et al., 2009, Golding and Betts, 2008) across the UK for the present day and the 2080s.

As a first approximation of plausible high-end projections we take the regional climate simulations that showed greatest change in fire danger (FFDI) and project greatest future fire danger (Figure 9.1). The changes are expected to be greatest in the south of England, however some increases in fire risk are expected across the whole of the UK. Of particular importance is the projected changes for locations of strategic and asset vulnerability and the Southeast is shown here to be at greater risk. The absolute changes are small, however it is important to note the percentage increase in fire risk in some locations and the potential for strain on resources.

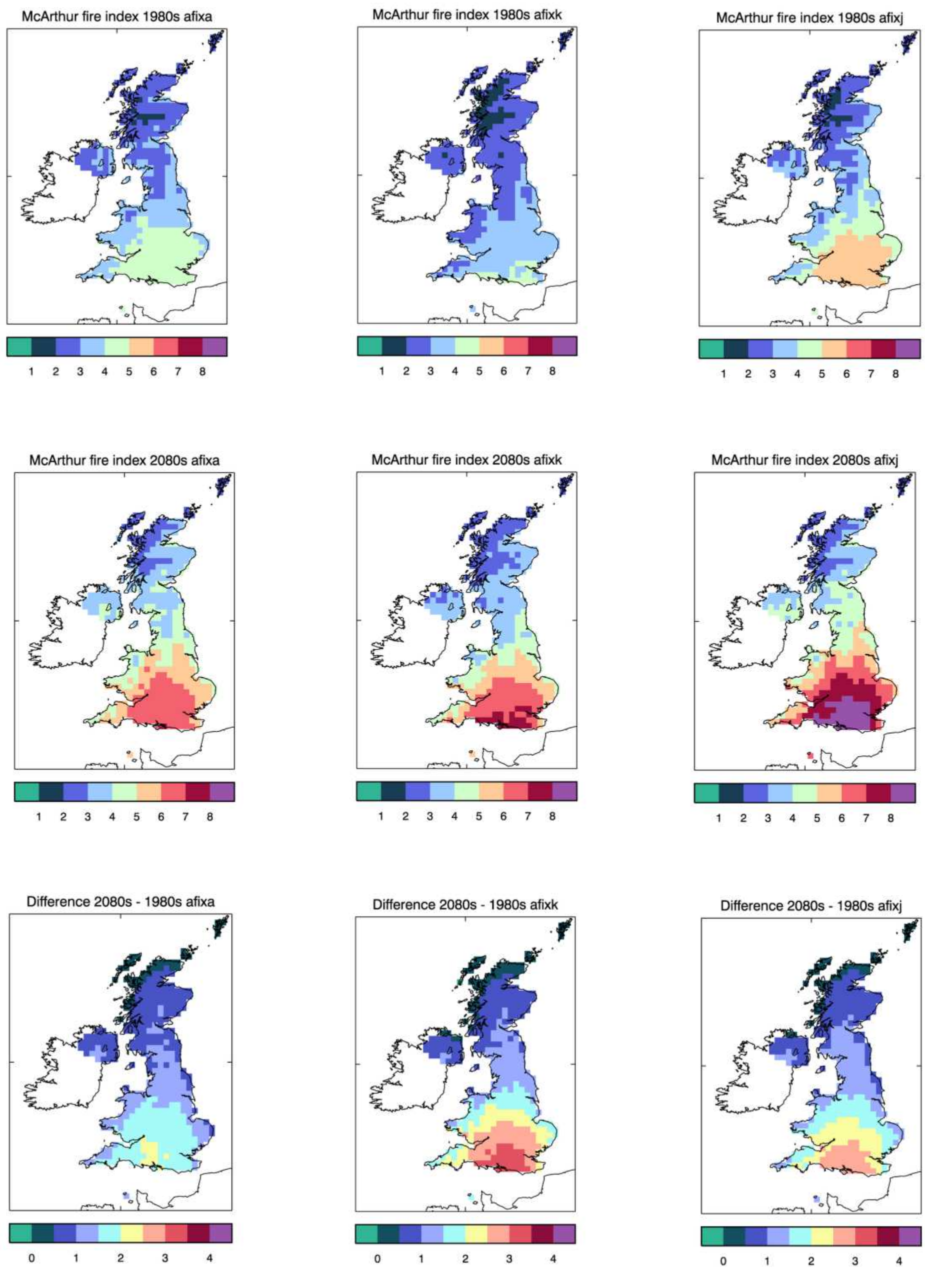

Figure 9.1: Projected future FFDI values (2080s), change in FFDI (1980s-2080s) and % change in FFDI (1980s-2080s) for the 3 ensemble members showing greatest future FFDI values.

It is also important to note that these values are annual average values only and therefore do not provide any quantitative information on future incidence of extreme fire weather or changes in fire risk seasonality. However it is expected that as the annual average FFDI increases the occurrence of extreme FFDI will also increase. Further work using these simulations is necessary to quantify these expected changes.

Finally it is not clear how appropriate the use of the FFDI is as an index for predicting long-term changes in wildfire risk in the UK. The FFDI was developed in Australia, and therefore an index more tuned to the climate, environment and vegetation of the UK might provide a more robust estimate of fire risk and variability. Given the limitations of this index-based approach it is also useful to draw on the conclusions of work presented here on high-end scenarios for heat-waves and drought, those being the major meteorological drivers of wildfire.

The H++ scenario on heatwaves concludes that all measures of extreme heat considered are predicted to increase. Changes in the hottest day of summer also showed that absolute temperatures in excess of 40°C are entirely possible, which, in an index such as the FFDI would increase the maximum fire danger significantly. Of particular importance to wildfires are prolonged periods of sustained high temperature with the night-time temperatures remaining high and therefore allowing no respite to firefighters.

The H++ scenario for meteorological droughts shows a less robust signal, suggested that future summer meteorological droughts in England and Wales could be more or less severe. The largest changes suggest the possibility of a significant increase in 6 month duration summer droughts, and the likelihood is that summer drought will increase, which together with increased incidence and duration of heatwave is significant for wildfire occurrence. Winter droughts are also important for UK wildfire occurrence as they can determine the amount of dead fuel available for burning for spring and early summer fires. The results here suggest no significant change in winter droughts, however, the possibility remains of some longer dry periods lasting several years similar to the most severe long droughts on record.

What does an H++ scenario for wildfire in the UK look like in reality?

It is not possible to separate the question of wildfire in the UK from human interaction. Wildfires are usually caused by human activity, either by accident or on purpose, and therefore wildfires frequently occur in areas containing or close to assets of value to humans, either residential or industrial areas, or natural areas popular for public access. For this reason it is important to note that a high-end scenario for wildfire does not necessarily mean a scenario of greatest fire danger, but a scenario where wildfire has greatest impact.

It was clearly expressed by decision-makers present in this group that the situation already exists in the UK for a ‘worst case’ fire scenario. The right fuels are present in locations that would threaten significant infrastructure and assets, all it requires is the right weather. End of century timescales were considered irrelevant here as it could happen next year.

Moreover it was highlighted that for fire risk the variable of most importance was location of the fire, i.e. close to critical national infrastructure. A Wildfire Threat Analysis scoping study for Swinley Forest demonstrated this point by simulating potential fires at the site of the 2011 damaging fires. They show that if the wind had strengthened, the fire would have been pushed southwest into houses at Crowthorne and to the doorstep of Broadmoor High Security Hospital. A change in wind direction would have allowed the fire to spread northwest into the Transport Research Laboratory or eastwards into Swinley Forest and beyond (McMorrow et al, 2014). Both of these scenarios would have been incredibly costly and are in themselves considered high-risk scenarios. In addition it is the capacity of the fire service that would determine the impact of the fire; should multiple large fire events happen in two critical locations the capacity of the fire service to respond adequately would be challenged. It is therefore of value to consider the changing likelihood of multiple events across the country.

In considering changing fire risk related to climate change it is important to also consider the impacts on fire risk of other events, which may themselves change, for instance impacts on vegetation and soils from drought, pests, flooding. In general the discussions held demonstrated the complex and interactive nature of wildfire in the UK, and hence the value of a more holistic approach to risk assessment than can be achieved here. However, the following evidence provides a basis of current knowledge that will help to inform such an approach.

Conclusions and recommendations for future work on wildfires

This assessment has highlighted the challenges in providing high-end scenarios for wildfire in the UK. The tight linkages between climate, vegetation, human management and interaction require much further study and understanding. However, this assessment has pulled out several key tasks, which would begin to address this:

1. Quantification of changes in projected extreme fire risk is necessary. The annual statistics presented here hide many features of the climate simulations so statistics

based on daily fire risk are needed. In addition further simulations of wildfire risk derived from potential high-end drought and heat climate scenarios would help to identify the more extreme situations that are plausible in the future. This is information is particularly needed to understand where the challenge may fall, i.e. longer fire seasons or fire danger covering greater areas therefore stretching response resources, increased likelihood of multiple locations experiencing high fire danger, or increased likelihood of consecutive years with high fire danger.

2. From an ecological point of view it is necessary to better understand the tolerances of local vegetation to increasing incidence of fire, and to highlight any thresholds relevant to ecology. It would also be useful to consider the adaptive capacity of vegetation to potential new fire regimes.

3. Further research that would aid the development H++ scenarios also includes using a fire-spread model to conduct risk assessments for locations where critical infrastructure has been identified. A similar model for heathland is essential. This research is also necessary to highlight priority areas for adaptation and mitigation.

The opinion that ‘the situation already exists in the UK for a ‘worst case’ fire scenario’ is striking. Indeed, based on the limited evidence presented here, it is likely that climate change will steadily tip the balance in favour of such a scenario occurring. The recommended future work will tell by how much the scales may be tipped, and also help to establish more firmly the locations most vulnerable and most at risk.

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Summary and Chapter 1

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Annex 1 Caveats and guidance

The caveats associated with each H++ scenario are highlighted in each chapter and some initial guidance of H++ use was provided in Chapter 1. This Annex provides a check list of 10 key points for consideration by potential users of H++ scenarios.

1. H++ scenarios provide a high-end range of possible changes in climate suitable for sensitivity testing and long term planning that cannot be ruled out based on current understanding and may occur at some point in the future, without being tied to a specific time frame (e.g. 2080s).
2. They are based on information from different sources including historical observations, global and regional climate models and consideration of limiting physical arguments. Setting the lower and upper limits of the H++ scenarios presented was based mostly on expert opinion of individual authors and may change, subject to further interpretation or expert elicitation based on the available evidence.
3. By their very nature, extremes on time scales of hours, days and seasons are associated with the occurrence of unusual weather or the unusual persistence of a regime of weather. Most H++ scenarios presented relied heavily on climate models, which may not always have sufficient skill in modelling key processes. Users should refer to specific caveats presented in each chapter and recognise that models have limited skill in reproducing the most unusual events.
4. Each H++ scenario presented has specific limitations, for example the cold snap scenarios excluded cooling due to volcanic activity and the heat waves scenarios excluded explicit consideration of the Urban Heat Island effect. Users should refer to specific caveats presented in each chapter.
5. The results are presented in relation to specific spatial scales or with reference to specific catchment types (e.g. “Enhanced-high” catchments, which are particularly sensitive to increases in rainfall). More or less severe scenarios may be possible at local scales and users should refer back to guidance within individual chapters.
6. The H++ scenarios should be used in conjunction with UKCP09 (Murphy et al., 2009) or more recent CMIP5 models. We consider good practice to present them alongside the likely range where this has been quantified.
7. H++ scenarios are not appropriate for some aspects of engineering design or as a replacement to existing statutory methods for including climate change in long term planning. In such cases H++ scenarios could be complimentary and help decision makers consider more extreme or longer term changes.

Appendix CC.1.2

8. There is a history of scenarios that are much more severe (for many events this means much higher) than the mean being misrepresented in the media or elsewhere as disaster predictions. Therefore careful presentation is needed, which will often be tailored for specific audiences.
9. Climate change projections, including more extreme scenarios, represent just one dimension of future risks and users should also consider other dimensions, such as socio-economic change or technological innovation that may reduce or exacerbate future threats and opportunities related to climate change.
10. H++ scenarios should be used in conjunction with appropriate qualitative or quantitative decision making methods such as *minimax*, robust decision making or real options to inform adaptation decisions. More pilot study research is needed on application of H++ to specific problems to understand how they can be used to design flexible adaptation plans or "adaptive pathways" to manage future risks.

Concluding comments on H++ for hazard and risk assessment

H++ scenarios have been developed for cold snaps, heat waves, wind storms, heavy rainfall, floods, low flows and droughts. They are relevant to a wide range of hazards and for incorporation to risk assessments and adaptation plans. The H++ scenarios developed may be considered in the second CCRA. Further research is recommended on (i) H++ landslides and subsidence, (ii) correlation between events and (iii) pilot case studies on the use of H++ in a number of sectors, particularly in estimating the consequences of such scenarios in terms of social, economic and environmental impacts.

It is important to note that this project was an experiment in constructing H++ scenarios. The results were produced by a number of research teams who had flexibility to each interpret the methodology in a manner appropriate to their specialist area. This means that the reliance on any particular element of the methodology varies from scenario to scenario. Compared to earlier work with sea-level rise a greater reliance was placed in the new H++ scenarios on UKCP09 and CMIP5 climate model results. This could be for several reasons, including the greater familiarity of the researchers with these tools, availability of particular datasets and a lack of precision with some paleo data. Observations were used, sometimes in helping to construct the H++ scenario and sometimes in either filtering model results or putting the H++ into context. Limiting physical arguments were more difficult to apply but were sometimes used as a sense check on the model findings.

Annex 2 Data Sources

Heatwaves and cold snaps

A wide range of observed and modelled data have been used in this study, which are described in the following sections.

Historical Observations

NCIC monthly and seasonal UK mean temperatures

The National Climate Information Centre (NCIC) produces UK-wide and regional climatological data. Weather station values, including digitised records historical observations, are interpolated onto a regular grid and then regional and UK-wide values are calculated by taking an average of all the grid points within a given area. Maximum and minimum temperatures are available at monthly and seasonal timescales from 1910 and are constantly updated.

Central England Temperature Record

The Central England Temperature Record (CET) is representative of a roughly triangular area of the United Kingdom enclosed by Lancashire, London and Bristol. Monthly mean temperatures in the CET were first constructed by Manley (1974) and have been further refined and extended by Parker et al. (1992). Monthly mean temperatures are available from 1659. The CET is constantly updated.

Gridded surface temperatures

Gridded data sets of daily maximum, mean and minimum temperatures have been generated from the archive of UK weather observations held at the Met Office. Regression and interpolation techniques were used to generate temperatures on a regular grid from the irregular station network, taking into account factors such as latitude and longitude, altitude and terrain shape, coastal influence, and urban land use. This approach alleviates the impact of station openings and closures on homogeneity, but the impacts of a changing station network cannot be removed entirely, especially in areas of complex topography or sparse station coverage. The methods used to generate the monthly and daily gridded temperatures are described in more detail by Perry and Hollis (2005) and Perry et al. (2009).

Climate Models

Perturbed Physics Ensemble

Seventeen versions of the Hadley Centre's climate model HadCM3 (Gordon et al., 2000) were used to simulate climate for the period 1950-2099. Observed levels of greenhouse gases and aerosols were used up to 1989, and from 1990 emissions were taken from the SRES A1B scenario (Nakicenovic et al., 2000). These different versions of the HadCM3 model were created by perturbing multiple parameters within the model away from their standard values within ranges given by experts. One member of this ensemble is the standard model; i.e., with no parameter perturbations. This ensemble is described in greater detail by Collins et al. (2011), and is referred to as a "perturbed physics ensemble", or PPE.

Eleven members of the HadCM3 ensemble were dynamically downscaled using the regional model HadRM3 for the same period (1950-2099). This model has a horizontal resolution of 25 km, and was forced at the boundary using meteorological data from the global climate model. The same parameter perturbations used in the global model ensemble were also applied to the regional model, so each global model was downscaled using an equivalent regional model. The regional model was executed over Europe, but only results for the UK will be analysed here. Further details of the regional climate model ensemble can be found in Murphy et al. (2009).

CMIP5 Multi-Model Ensemble (also used for low rainfall analysis)

The Coupled Model Intercomparison Project Phase 5 (CMIP5) consisted of a series of both short- and long-term climate simulations which were designed to help answer key scientific questions for the 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2013). Over 30 different models were used to simulate a wide range of scenarios. The studies referenced here analysed projections of future climate using Representative Concentration Pathways (RCPs). There are four scenarios, ranging from aggressive mitigation (RCP2.6) to high emissions (RCP8.5).

Additional data used for low rainfall

HadUKP (Alexander and Jones 2000) is a series of datasets of UK regional precipitation, which incorporates the long-running England & Wales Precipitation (EWP) series beginning in 1766, the longest instrumental series of this kind in the world.

Additional data used high rainfall

The Met Office and the Environment Agency maintain rainfall observation networks including Tipping Bucket Rain (TBR) and collection gauges. While the land observation networks provides a reasonably dense network it is not sufficient to record all localised events and sites at high or inaccessible locations are under-represented. Data from this network has been used to create a number of gridded rainfall data products and models for estimating extreme rainfall, most notably the Depth-Duration-Frequency (DDF) model FORGEX, which is used in the UK's Flood Estimation Handbook[37]. The Met Office Radar network has been operational since 1985 and provides another source of information particularly related to spatial extent of events. Radar rainfall typically underestimates rainfall depth and is normally used in conjunction with ground observations (e.g. Fenn et al., 2005).

The National Climate Information Centre (NCIC) maintains a dataset which contains gridded daily rainfall data at a resolution of 5 km (Perry and Hollis, 2005). In this dataset, rainfall data are available at every land point in the UK, and it is available freely for use with the UKCP09 climate projections. The NCIC gridded data were generated using the irregularly spaced rain gauge data and a regression model which accounts for the many parameters which could influence local rainfall amounts, such as altitude, distance from the coast, local topography, and urbanisation. Gridded daily rainfall data from 1958 to 2007 have been created, and these data have also been aggregated from the 5 km NCIC grid to the same 25 km grid used by the regional climate model.

Some information on baseline and future heavy rainfall is included in UKCP09 (Murphy et al., 2009) based on analysis of the sampled data and use of the UKCP09 weather generator (Jones et al., 2009). These data were incorporated into the CCRA as indicators of potential impacts on pluvial flooding, Combined Sewer Overflow (CSO) spill frequency and rainfall erosivity/soil erosion (Wade et al., 2012). Data from the 11-member RCM ensemble were also released alongside the UKCP09 climate projections. They were generated using a medium emissions scenario (A1B; IPCC, 2000). Daily rainfall data are available from each of the 11 versions of the RCM for the period 1950 –

[37] A new version of FEH, called FEH13 will be released in the summer 2015 (Stewart, pers. comm.)

2099. RCM data have been processed further by CEH to estimate changes in river flooding as part of the Future Flows project (Section 5).

Additional data used for low flows

Catchment average daily rainfall data was calculated from the CEH-GEAR 1-km gridded daily areal rainfall dataset for the period 1961-2012 (Keller et al., 2015; Tanguy et al., 2014). Catchment average monthly potential evapotranspiration PET was derived from the Met Office Rainfall and Evaporation Calculation System MORECS (Thompson et al., 1982), and monthly PET distributed evenly throughout the months for the period 1961-2010. Daily gauged river flow time series were obtained from the National River Flow Archive when available and from relevant water companies otherwise.

Registered number: 10311804

RIVEROAK OPERATIONS LIMITED

UNAUDITED

FINANCIAL STATEMENTS

INFORMATION FOR FILING WITH THE REGISTRAR

FOR THE PERIOD ENDED 31 AUGUST 2017

Appendix F.1.2

RIVEROAK OPERATIONS LIMITED
REGISTERED NUMBER: 10311804

STATEMENT OF FINANCIAL POSITION
AS AT 31 AUGUST 2017

	Note		2017 £
Fixed assets			
Investments			**1,000,000**
			1,000,000
Current assets			
Debtors: amounts falling due within one year	5	**555,169**	
Cash at bank and in hand		**45,251**	
		600,420	
Creditors: amounts falling due within one year		**(912,076)**	
Net current (liabilities)/assets			**(311,656)**
Total assets less current liabilities			**688,344**
Creditors: amounts falling due after more than one year			**(4,458,285)**
Net (liabilities)/assets			**(3,769,941)**
Capital and reserves			
Called up share capital	10		**1**
Profit and loss account	11		**(3,769,942)**
			(3,769,941)

The directors consider that the Company is entitled to exemption from audit under section 477 of the Companies Act 2006 and members have not required the Company to obtain an audit for the period in question in accordance with section 476 of Companies Act 2006.

The directors acknowledge their responsibilities for complying with the requirements of the Companies Act 2006 with respect to accounting records and the preparation of financial statements.

The financial statements have been prepared in accordance with the provisions applicable to companies subject to the small companies regime and in accordance with the provisions of FRS 102 Section 1A - small entities.

The financial statements have been delivered in accordance with the provisions applicable to companies subject to the small companies regime.

The Company has opted not to file the statement of income and retained earnings in accordance with provisions applicable to companies subject to the small companies' regime.

Appendix F.1.2

STATEMENT OF FINANCIAL POSITION (CONTINUED)
AS AT 31 AUGUST 2017

The financial statements were approved and authorised for issue by the board and were signed on its behalf on 4 Ap[redacted]

Anthony Freudmann
Director

The notes on pages 3 to 7 form part of these financial statements.

Appendix F.1.2

1. Accounting policies

1.1 Basis of preparation of financial statements

The financial statements have been prepared under the historical cost convention unless otherwise specified within these accounting policies and in accordance with Section 1A of Financial Reporting Standard 102, the Financial Reporting Standard applicable in the UK and the Republic of Ireland and the Companies Act 2006.

The following principal accounting policies have been applied:

1.2 Valuation of investments

Investments in subsidiaries are measured at cost less accumulated impairment.

Investments in unlisted Company shares, whose market value can be reliably determined, are remeasured to market value at each balance sheet date. Gains and losses on remeasurement are recognised in the Statement of income and retained earnings for the period. Where market value cannot be reliably determined, such investments are stated at historic cost less impairment.

1.3 Debtors

Short term debtors are measured at transaction price, less any impairment. Loans receivable are measured initially at fair value, net of transaction costs, and are measured subsequently at amortised cost using the effective interest method, less any impairment.

1.4 Cash and cash equivalents

Cash is represented by cash in hand and deposits with financial institutions repayable without penalty on notice of not more than 24 hours. Cash equivalents are highly liquid investments that mature in no more than three months from the date of acquisition and that are readily convertible to known amounts of cash with insignificant risk of change in value.

1.5 Financial instruments

The Company only enters into basic financial instrument transactions that result in the recognition of financial assets and liabilities like trade and other debtors and creditors, loans from banks and other third parties, loans to related parties and investments in non-puttable ordinary shares.

Debt instruments (other than those wholly repayable or receivable within one year), including loans and other accounts receivable and payable, are initially measured at present value of the future cash flows and subsequently at amortised cost using the effective interest method. Debt instruments that are payable or receivable within one year, typically trade debtors and creditors, are measured, initially and subsequently, at the undiscounted amount of the cash or other consideration expected to be paid or received. However, if the arrangements of a short-term instrument constitute a financing transaction, like the payment of a trade debt deferred beyond normal business terms or financed at a rate of interest that is not a market rate or in the case of an out-right short-term loan not at market rate, the financial asset or liability is measured, initially, at the present value of the future cash flow discounted at a market rate of interest for a similar debt instrument and subsequently at amortised cost.

Financial assets that are measured at cost and amortised cost are assessed at the end of each reporting period for objective evidence of impairment. If objective evidence of impairment is found, an impairment loss is recognised in the Statement of income and retained earnings.

1. Accounting policies (continued)

1.5 Financial instruments (continued)

For financial assets measured at amortised cost, the impairment loss is measured as the difference between an asset's carrying amount and the present value of estimated cash flows discounted at the asset's original effective interest rate. If a financial asset has a variable interest rate, the discount rate for measuring any impairment loss is the current effective interest rate determined under the contract.

For financial assets measured at cost less impairment, the impairment loss is measured as the difference between an asset's carrying amount and best estimate of the recoverable amount, which is an approximation of the amount that the Company would receive for the asset if it were to be sold at the reporting date.

Financial assets and liabilities are offset and the net amount reported in the Statement of financial position when there is an enforceable right to set off the recognised amounts and there is an intention to settle on a net basis or to realise the asset and settle the liability simultaneously.

1.6 Creditors

Short term creditors are measured at the transaction price. Other financial liabilities, including bank loans, are measured initially at fair value, net of transaction costs, and are measured subsequently at amortised cost using the effective interest method.

1.7 Borrowing costs

All borrowing costs are recognised in the Statement of income and retained earnings in the period in which they are incurred.

2. Judgments in applying accounting policies and key sources of estimation uncertainty

In the application of the company's accounting policies management is required to make judgements, estimates and assumptions about the carrying value of assets and liabilities that are not readily ascertainable from other sources. The estimates and underlying assumptions are based on historical experience and other factors that are considered to be relevant. Actual outcomes may differ from these estimates.

The estimates and underlying assumptions are reviewed on a continuing basis. Revisions to accounting estimates are recognised in the period in which the estimates are revised.

The key areas of estimation uncertainty that have a significant effect on the amounts recognised in the financial statements are described below:

Prepayments & Accrued Expenditure

The company includes a provision for invoices which are yet to be received from and amounts paid in advance to suppliers. These provisions are estimated based upon the expected values of the invoices which are issued and services received following the period end.

3. Employees

The average monthly number of employees, including directors, during the period was 3.

4. Fixed asset investments

	Other fixed asset investments £
Cost or valuation	
Additions	1,000,000
At 31 August 2017	1,000,000
Net book value	
At 31 August 2017	1,000,000

5. Debtors

	2017 £
Amounts owed by group undertakings	45,481
Other debtors	509,688
	555,169

6. Cash and cash equivalents

	2017 £
Cash at bank and in hand	45,251
	45,251

7. Creditors: Amounts falling due within one year

	2017 £
Trade creditors	903,576
Accruals and deferred income	8,500
	912,076

8. Creditors: Amounts falling due after more than one year

	2017 £
Other loans	4,458,285
	4,458,285

9. Loans

Analysis of the maturity of loans is given below:

	2017 £
Amounts falling due 1-2 years	
Bank loans	4,458,285
	4,458,285
	4,458,285

10. Share capital

	2017 £
Allotted, called up and fully paid	
1 Ordinary share of £1	1

1 Ordinary share was issued at par on incorporation.

Appendix F.1.2

11. Reserves

Profit and loss account

The profit and loss reserve is fully distributable.

12. Controlling party

The company's parent undertaking is Riveroak Strategic Partners Limited, which owns 100% of the issued share capital. The ultimate controlling party is MIO Investments Limited, a 90% shareholder in the parent undertaking.

Appendix F.1.5 – Summary business model

(£K)	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11	Y12	Y13	Y14	Y15	Y16	Y17	Y18	Y19	Y20
Freight movements	*-*	*5,252*	*5,804*	*9,700*	*9,936*	*10,144*	*10,872*	*11,184*	*11,392*	*11,600*	*12,064*	*12,547*	*13,048*	*13,570*	*14,113*	*14,678*	*15,265*	*15,875*	*16,510*	*17,170*
Passenger movements	*-*	*-*	*4,932*	*5,024*	*5,064*	*6,702*	*6,754*	*6,754*	*6,754*	*6,754*	*6,966*	*7,186*	*7,416*	*7,654*	*7,902*	*8,160*	*8,428*	*8,707*	*8,997*	*9,298*
WLU (k)	*-*	*966*	*1,748*	*2,351*	*2,424*	*2,780*	*2,905*	*2,982*	*3,143*	*3,099*	*3,235*	*3,394*	*3,535*	*3,698*	*3,876*	*4,053*	*4,226*	*4,431*	*4,605*	*4,815*
REVENUES (£k)																				
Aeronautical	-	16,682	20,124	27,221	28,532	31,215	33,574	34,791	36,854	36,384	37,842	39,341	40,998	42,624	44,596	46,366	48,206	50,298	52,296	54,373
Commercial Net Income	-	-	1,988	2,040	2,060	2,896	2,927	2,927	2,927	2,927	3,035	3,147	3,264	3,385	3,512	3,643	3,780	3,922	4,070	4,223
Other Income	-	9,774	10,391	13,577	19,398	22,168	22,613	22,811	22,891	23,477	23,986	25,050	25,615	26,384	27,317	28,143	29,174	30,082	30,757	32,024
Total Income	**-**	**26,456**	**32,504**	**42,838**	**49,989**	**56,279**	**59,114**	**60,529**	**62,672**	**62,789**	**64,862**	**67,538**	**69,877**	**72,393**	**75,424**	**78,151**	**81,160**	**84,302**	**87,122**	**90,620**
EXPENSES (£k)																				
Direct (Operating)	3,439	13,758	17,752	20,876	21,543	20,838	21,903	22,516	24,116	23,319	24,015	24,656	25,320	26,006	26,928	27,673	28,443	29,368	30,196	31,066
Indirect (Overheads)	6,200	6,200	6,865	7,794	7,824	7,967	8,587	8,614	8,694	8,680	8,725	8,799	8,842	8,917	8,967	9,015	9,086	9,137	9,208	9,257
EBITDA	**(9,639)**	**6,498**	**7,887**	**14,168**	**20,622**	**27,475**	**28,624**	**29,400**	**29,862**	**30,790**	**32,123**	**34,083**	**35,716**	**37,471**	**39,530**	**41,463**	**43,631**	**45,797**	**47,718**	**50,297**

Appendix F.1.6 – Capital Expenditure:

Item Description	PHASE 1 Approximate Quantity	PHASE 1 Unit	PHASE 2 Approximate Quantity	PHASE 2 Unit	PHASE 3 Approximate Quantity	PHASE 3 Unit	PHASE 4 Approximate Quantity	PHASE 4 Unit
CONSTRUCTION								
Demolitions of buildings	-	LumpSum	-					
Runway 10-28	123,660	m³						
Runway Shoulder	41,700	m³						
Redundant Runway Pavement	434,500	m³						
Taxiways	98,800	m³						
Taxiway Shoulder	17,170	m²						
Cargo Apron (Phase 1, 2, 3, 4)	96,533	m²	96,533	m²	27,967	m²	27,967	m²
Passenger Apron (Phase 2)	-	m²	27,600	m²				
Recycling Apron (Phase 2, 3, 4)	-	m²	4,800	m²	4,800	m²	4,800	m²
G.A. Apron (Phase 1, 2, 3)	6,914	m²			2,286	m²		
Peri Tracks	28,800	m	-					
FBO Apron	2,500	m²	-					
New Signal Junction	-	LumpSum						
New Ghost island Junction	-	LumpSum						
Staggered Junction	-	LumpSum						
New Roundabout	-	LumpSum						
New Internal Roads (Phase 1, 2, 3)	9,412	m			688	m		
Parking / Loading / Storage Areas (Phase 1, 2, 3, 4)	57,226	m²	52,725	m²	52,725	m²	52,725	m²
Landscaping	-	LumpSum						
Approvals Process	-	-						
Earthworks - Topsoil Cut	92,500	m³						
Eartworks - General On-Site Cut	475,000	m³						
Earthworks - General On-Site Fill	360,000	m³						
Earthworks - Disposal Off Site of Surplus Topsoil	212,500	m³						
Earthworks - Disposal Off Site of Surplus Cut Material	95,000	m³						
Earthworks - Dispodal Off Site of Contaminated Cut Mat.	90,000	m³						
Earthworks - Extra Over for Imported Fill Material	167,500	m³						
Drainage	6,500	m						
Drainage Items, e.g., interceptors, pumps	-	LumpSum						
Drainage Ponds	26,560	LumpSum						
Noise Mitigation Bunding	-	-						
Pegwell Bay Outfall Pipeline (Remedial Works to Existing)	-	LumpSum						
Airside AGL	-	LumpSum						
Approach Lighting	-	LumpSum						
Apron High Mast Lighting	-	LumpSum						
Navaid Improvements - DME	-	LumpSum						
Navaid Improvements - ILS	-	LumpSum						
Navaid Improvements - IRVR	-	LumpSum						
Navaid Improvements - NDB(L)	-	LumpSum						
Navaid Improvements - VOR	-	LumpSum						
Navaid Improvements - VCCS	-	LumpSum						
Navaid Improvements - Wind Shear Instrument	-	LumpSum						
Airfield Signage	-	LumpSum						
Utility Diversions	-	LumpSum						
Utility/Substation Upgrade Provisions	-	LumpSum						
Relocation of Existing MOD Aerial	-	LumpSum						
Refurb Existing Radar Station	-	LumpSum						
Fixed Ground Power	19	No.						
Control Tower	-	LumpSum						
Fire Station	-	LumpSum						
Fuel Farm	-	LumpSum						
Museum	-	LumpSum						
Business Park - Office Buildings (Phase 1, 2)	6,326	m²	19,949	m²				
Business Park - Warehouse Buildings (Phase 1, 2)	48,775	m²	30,050	m²				
FBO Hanger	2,048	m²	-					
Business Aviation Centre (Phase 1, 2, 3)	1,127	m²						
Recycling Hangar (Phase 2, 3, 4)	-	m²	3,405	m²	3,405	m²	3,405	m²
Cargo Facility (Part Phase 2, 3, 4)	12,038	m²	19,168	m²	19,168	m²	19,168	m²
2 x Business Aviation Hangars (Part Phases 2, 3, 4)	1,066	m²			4,162	m²		
Refurb Existing Terminal Building (Phase 2)	-	LumpSum	-	LumpSum				
New Terminal Building Extension (Phase 4)	-	LumpSum					-	LumpSum
Estimated Cosntruction Costs (£)		**169,026,120**		**62,765,471**		**22,913,171**		**23,430,571**
Contingency (£)	*10%*	**16,902,612**	*10%*	**6,276,547**	*10%*	**2,291,317**	*10%*	**2,343,057**
GRAND BUDGET TOTAL (£)		**185,928,732**		**69,042,018**		**25,204,488**		**25,773,628**

Application by RiverOak Strategic Partners (RiverOak) to upgrade and reopen Manston Airport

This technical note has been produced to summarise the potential harm to heritage assets arising from the construction and operation of the Proposed Development at Manston Airport. It also identifies the public benefits of the Proposed Development and explains how those benefits outweigh the less than substantial harm to heritage assets as required by the Airports National Policy Statement (ANPS) and the NPPF.

1 CONTEXT

1.1 In the questions issued by the Examining Authority (ExA) on the 18 January 2019 relating to the proposals for the reopening of Manston Airport, the ExA has asked a number of questions about the extent of harm to heritage assets. Some of these questions also refer to how the public benefits of the Proposed Development are weighed against any such harm in the planning statement.

1.2 Regulation 3(1) of The Infrastructure Planning (Decisions) Regulations 2010 provides that:

> *"When deciding an application which affects a listed building or its setting, the decision-maker must have regard to the desirability of preserving the listed building or its setting or any features of special architectural or historic interest which it possesses."*

1.3 Paragraph 5.201 of the ANPS states that any harm or loss of heritage assets requires clear and convincing justification.

1.4 Paragraph 5.202 of the ANPS states that substantial harm to or loss of a Grade II Listed Building should be exceptional. Substantial harm to or loss of designated sites including Grade II* Listed Buildings should be wholly exceptional.

1.5 Paragraph 5.203 explains that any harmful impact on the significance of a designated heritage asset should be weighed against the public benefit of development, recognising that the greater harm to the significance of the heritage asset, the greater the justification that will be needed for any loss.

1.6 Paragraph 5.204 states that where the proposed development will lead to substantial harm to or the total loss of significance of a designated heritage asset, the Secretary of State will refuse consent unless it can be demonstrated that the substantial harm or loss of significance is necessary in order to deliver substantial public benefits that outweigh that loss.

Appendix HE.1.2

1.7 Paragraph 5.205 states that where the proposed development will lead to less than substantial harm to the significance of a designated heritage asset, this harm should be weighed against the public benefits of the proposal, including securing its optimum viable use.

1.8 These paragraphs in the ANPS are consistent with the policy contained within Chapter 16 of the NPPF 2018 (Conserving and Enhancing the Historic Environment) and especially paragraphs 193,194,195, 196 and 202 (Considering Potential Impacts).

1.9 In relation to non-designated heritage assets, paragraph 197 of the NPPF requires that the effect of an application on the significance of a non-designated heritage asset should be taken into account in determining the application. In weighing applications that directly or indirectly affect non-designated heritage assets, a balanced judgement will be required, having regard to the scale of any harm or loss and the significance of the heritage asset.

1.10 The ANPS is consistent and states in paragraph 5.192 that the Secretary of State will also consider the impacts on other non-designated heritage assets on the basis of clear evidence that the assets have a significance that merits consideration in that decision, even though those assets are of lesser value than designated heritage assets.

2 PURPOSE OF THIS PAPER

2.1 This paper has been produced to summarise the potential harm to heritage assets arising from the construction and operation of the Proposed Development at Manston Airport. It then sets out the anticipated public benefits of the Proposed Development allowing a robust assessment of the balance of harm to heritage assets against the public benefits, including its optimum viable use, as required by the Airports National Policy Statement (ANPS) in paragraph 5.205.

2.2 A list of each of the heritage (designated and non-designated) assets is provided at Table 3.1 below. This classifies the harm to each heritage asset as “less than substantial.”

2.3 As demonstrated in Section 3 below, in this case it is paragraph 5.205 of the ANPS that is most relevant. Paragraph 5.205 explains that “less than substantial harm” to the significance of the designated heritage assets should be weighed against the public benefits of the proposal, including securing its optimum viable use. Where the public benefits outweigh the less than substantial harm, that heritage harm will be justified in the public interest,

Appendix HE.1.2

3 POTENTIAL EFFECTS ON DESIGNATED HERITAGE ASSETS

3.1 An assessment of potential effects of the Proposed Development was presented in Chapter 9 the Environmental Statement (ES) [APP-033]. The assessment was carried out following receipt of the Scoping Opinion in Appendix 1.2 [APP-057], as agreed with Historic England and Kent County Council (KCC).

3.2 There are no designated heritage assets within the DCO site boundary, and as a result, no adverse effects arising from direct physical disturbance, damage or alteration of designated heritage assets are anticipated. Any adverse effects on designated heritage assets are anticipated to arise as a result of change to setting arising from visibility of the completed development or aviation noise.

3.3 The assessment of effects on heritage assets arising through change to setting was carried out in accordance with Historic England Guidance *GPA3 The Setting of Heritage Assets* (2017) and the *Aviation Noise Metric* (2014). This assessment is set out at Section 9.10 of Chapter 9 of the ES [APP-033]. Designated heritage assets considered in this assessment are identified in Table 3.1 below which also summarises the ES assessment presented at ES Table 9.15 (APP-033) and a statement of whether harm to significance is anticipated to arise.

Table 3.1: Assessment of harm arising through change to setting of designated heritage assets (ANPS 5.201)

Heritage Asset	ES assessment of magnitude of change	Magnitude of Harm (ANPS 5.203-204)
Enclosure and ring ditches sited 180m east-northeast of Minster Laundry (List Entry 1004203)	Heritage significance: High for archaeological interest Magnitude of change: Low – setting makes limited contribution to significance and does not depend on tranquillity. EIA Significance: Not significant	Less than substantial harm
Anglo-Saxon cemetery S of Ozengell Grange (List Entry 1004228)	Heritage significance: High for archaeological interest Magnitude of change: Negligible – setting makes limited contribution to significance and does not depend on tranquillity EIA Significance: Not significant	Less than substantial harm
Chapel House (List Entry 1224336)	Heritage significance: High for architectural and historic interest Magnitude of change: Low – limited increase in noise may affect contribution of rural setting to asset EIA Significance: Not significant	Less than substantial harm

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Heritage Asset	ES assessment of magnitude of change	Magnitude of Harm (ANPS 5.203-204)
Cleve Court and Cleve Lodge (List Entry 1224683)	Heritage significance: High for architectural and historic interest Magnitude of change: Medium – while setting is not dependent on tranquillity, noise levels would present a qualitative change to setting and could detract from historic interest EIA Significance: Significant	Less than substantial harm
Prospect Inn (List Entry: 1224448)	Heritage significance: High for architectural and historic interest Magnitude of change: Low - setting makes limited contribution to significance and does not depend on tranquillity. Existing setting already has relatively high noise levels and the site is associated with aviation. EIA Significance: Not significant	Less than substantial harm
Way House and Wayborough House, and garden wall attached (List Entry 1266887)	Heritage significance: High for architectural and historic interest Magnitude of change: Medium – limited increase in noise would affect contribution of rural setting to asset EIA Significance: Significant	Less than substantial harm
Monastic grange and pre-Conquest nunnery at Minster Abbey (List Entry 1016850)	Heritage significance: High for architectural, archaeological and historic interest Magnitude of change: Low – while tranquillity contributes to setting, anticipated noise levels would present only a limited change. EIA Significance: Not significant	Less than substantial harm
Minster Abbey (List Entry 1223807)	Heritage significance: High for architectural and historic interest Magnitude of change: Low– while tranquillity contributes to setting, anticipated noise levels would present only a limited change. EIA Significance: Not significant	Less than substantial harm
Barn about 30 metres North East of Minster Abbey (List Entry 1223808)	Heritage significance: High for architectural and historic interest Magnitude of change: Low – while tranquillity contributes to setting, anticipated noise levels would present a limited change. EIA Significance: Not significant	Less than substantial harm
Gates and Walls to Minster Abbey (List Entry 1223810)	Heritage significance: High for architectural and historic interest Magnitude of change: Low – while tranquillity contributes to setting,	Less than substantial harm

Heritage Asset	ES assessment of magnitude of change	Magnitude of Harm (ANPS 5.203-204)
	anticipated noise levels would present a limited change. EIA Significance: Not significant	
Wall and Gate Lodge East of Minster Abbey (List Entry 1266990)	Heritage significance: High for architectural and historic interest Magnitude of change: Low – while tranquillity contributes to setting, anticipated noise levels would present a limited change. EIA Significance: Not significant	Less than substantial harm
Laundry about 15 metres West of Minster Abbey (List Entry 1267022)	Heritage significance: High for architectural and historic interest Magnitude of change: Low – while tranquillity contributes to setting, anticipated noise levels would present a limited change. EIA Significance: Not significant	Less than substantial harm
Acol Conservation Area	Heritage significance: High for architectural and historic interest Magnitude of change: Negligible – relatively limited increase in noise would present minimal change to setting. EIA Significance: Not significant	Less than substantial harm
Minster Conservation Area	Heritage significance: High for architectural and historic interest Magnitude of change: Negligible – relatively limited increase in noise would present minimal change to setting. EIA Significance: Not significant	Less than substantial harm
Saxon Shore fort, Roman port and associated remains at Richborough (List Entry: 1014642)	Archaeological significance: High for architectural archaeological and historic interest Magnitude of change: Negligible – minimal increase in noise would present little or no discernible change to setting. EIA Significance: Not significant	Less than substantial harm

3.4 The ANPS distinguishes between harm and substantial harm at sections 5.203 - 5.204 but does not provide specific definitions for either ‘harm’ nor ‘substantial harm’.

3.5 The National Planning Practice Guidance (NPPG) includes a section titled *“How to assess if there is substantial harm”,* which restates the policy provision that it is the degree of harm to the significance of a heritage asset that is the primary consideration (017 Reference ID: 18a-017-20140306) “Substantial harm” should be regarded as loss of significance equivalent to something approaching demolition or the total loss or draining of significance (Bedford BC v SSCLG [2013] EWHC 2847 (Admin)).

3.6 The ES concludes that the impact of the proposed development on the significance of designated heritage assets would be of a relatively limited magnitude. The archaeological interest of all of the assets considered would remain entirely unchanged. A viewer would, in all cases, be able to fully appreciate the architectural and historic interest as expressed through composition, design and specific features of architectural interest of all of these assets. Any loss of significance would be restricted to potential changes to historic interest arising from a sense of noise either being intrusive to a perceived rural context or, in the case of Minster Abbey, to a perceived spiritual or contemplative place. Consequently, it has been assessed that substantial harm would not arise in any case.

4 POTENTIAL HARM TO NON-DESIGNATED HERITAGE ASSETS

Built Heritage Assets

Table 4.2: Assessment of effects on non-designated built heritage assets

Heritage Asset		Significance	Potential Effect
TR 36 NW 881	T2 Hangar	Rebuilt during the 1980's around the original steel frame Represents an isolated and partial survival of a WWII structure. This is a much-altered example of a relatively common structure of which many much better-preserved examples survive. Asset is of low significance for historic and architectural interest.	Asset would be demolished. Loss can be appropriately mitigated by recording of the structure therefore residual harm would be less than substantial.
TR 36 NW 882	Civil Control Tower	Built in 1999 following the end of military aviation operations. Relates to recent use of the airport and is of little historic significance. Asset is of low significance at most.	Asset would be demolished. Loss can be appropriately mitigated by recording of the structure therefore residual harm would be less than substantial.
TR 36 NW 883	Crash Fire Station	Built in 1957 and relates to the USAF use of the site. Has been much altered following the departure of the USAF from Manston and in in poor condition. Asset is of low significance for historic interest.	Asset may be retained in part where reasonably practicable. Partial or total loss can be appropriately mitigated by recording of the structure therefore residual harm would be less than substantial.
TR 36 NW 884	Mechanical Transport Hangar	Relates to civilian use of the airport after 1969 and is of limited historic significance. Asset is of low significance at most.	Asset would be demolished. Loss can be appropriately mitigated by recording of the structure therefore residual harm would be less than substantial.
TR 36 NW 885	Aircraft Dispersal Bay	Relates to the WWII use of the site and is of significance for historic interest, although it comprises an isolated survival of a much larger scheme that has been otherwise lost and modern construction has divorced it from any 'contemporary' setting beyond its	Asset would be demolished. Loss can be appropriately mitigated by recording of the structure therefore residual harm would be less than substantial.

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		association with the wider aviation use of the site. Asset is potentially of medium significance for historic interest.	
TR 36 NW 886	RAF Manston Control Tower	Relates to WWII use of the airfield. Is of a standardised design and has been significantly altered during the subsequent military and civilian use of the airfield. Of significance for historic interest but diminished by extensive structural and cosmetic changes since WWII. Asset is potentially of medium significance for historic interest, although any archaeological interest has been diminished by post-WWII alterations.	Asset is located within safeguarded museums area
TR 36 NW 887	Office Building	Built after 1980 and relates to recent use of the airport. Is consequently of little historic significance. Asset is of low significance at most.	Asset would be demolished. Loss can be appropriately mitigated by recording of the structure therefore residual harm would be less than substantial.
TR 36 NW 888	RAF Battle HQ	Relates to WWII use of the site and is of historic significance. Relates well to the WWII control tower and is a relatively well-preserved example of a well-known type of structure. Related defensive structures are no longer extant, and while views across the site arguably contribute to this asset's significance, these views would relate to early-WWII reconfiguration of Manston which has subsequently been much altered by change within the airport boundary over successive phases of reconfiguration for military and civilian use. Asset is potentially of medium or high significance for historic and architectural interest.	Asset is located within safeguarded museums area.
TR 36 NW 889	Civil Terminal	The original civilian terminal was rebuilt in 1989. The current structure relates to recent use of the airport and is of low significance at most.	Asset would be demolished. Loss can be appropriately mitigated by recording of the structure therefore residual harm would be less than substantial.
TR 36 NW 894	Royal Observer Corps Listening Post	Relates to the USAF use of the site and is of significance for historic interest and has thematic, if not functional, links with TR36 NW883. Represents a well-preserved example of common and well-understood feature. Asset is likely of medium significance for historic interest.	Asset would be retained within active airfield.
TR 36 NW 892	Runway	Runway relates to the late WWII airfield, replacing the earlier main runway. It was one of three emergency diversion runways on the East Coast with historical associations to the later WWII use of Manston as a base for tactical offensive operations against Axis ground forces in Europe and the strategic bomber offensive. Runway has been resurfaced but follows original plan form. Presently none of these runways are in regular aviation use. Asset is of low or medium significance for historic interest, but its layout defines the surviving	Asset would be refurbished and retained for active aviation use.

		historic layout of the airfield and is a key contributor to historic character.	

4.1 As noted in Table 4.1 above, there are few non-designated assets of significance that would be affected as a result of the redevelopment of the airport site. Where significant assets or remains thereof do exist, these are retained, either within the airfield layout or within the safeguarded museums area. Where assets of lesser significance are affected, following implementation of appropriate mitigation (recording) any harm would be less than substantial.

4.2 It is considered that archaeological buildings recording would constitute an appropriate response to the potential loss of structures which hold some limited significance, primarily for historic interest.

4.3 The draft Written Scheme of Investigation (WSI) which is to be submitted at Deadline 4 sets out proposals for archaeological buildings recording.

Archaeological Heritage Assets

4.4 The revised draft Development Consent Order (dDCO) submitted at Deadline 3 contains amendments to Requirement 16 that any archaeological heritage assets of demonstrably equivalent significance to a scheduled monument identified during pre-construction archaeological works or during construction would be preserved in situ. This DCO Requirement represents a clear commitment on the part of RiverOak to meet the policy requirements set out at ANPS 5.191 and 5.202.

4.5 At present, previous archaeological investigation, including the Stone Hill Park geophysical survey and evaluation has identified there are areas of particular archaeological significance at Telegraph Hill, to the north-west of the west end of the runway where remains of potential prehistoric funerary activity and Roman military features have been identified. These remains are potentially of equivalent significance to scheduled monuments, although further work would be required to establish this definitively. In other areas of the site which have been investigated, archaeological remains represent remains of past settlement and agricultural activity, which while of interest, are of lower significance.

4.6 The Northern Grass has not been investigated and the archaeological potential of this area is uncertain. The presence of highly significant remains in the area around the site and in Thanet more generally, suggests that there is a potential for more significant remains to be present in this area.

4.7 The draft WSI, which is to be submitted at Deadline 4, sets out proposals for further pre-commencement archaeological investigation that affords the opportunity to identify and understand the significance of archaeological remains within the site and to inform the process of developing an appropriate response.

4.8 Development within the key area of concern at the west end of the runway is largely limited to installation of services associated with the Approach Indicator Light system and is unlikely to present the level of disturbance that would give rise to discernible harm to significance.

4.9 Development of the Northern Grass is shown on the illustrative masterplan as a maximum extent of development within the parameters set out in the Project Description at Chapter 3 of the Environmental Statement. This approach provides sufficient flexibility to either reconfigure development or to reduce the overall quantum of development in this area where particularly significant archaeological remains are identified.

4.10 At this stage, the uncertainty as to whether such archaeological remains are present, and if present where they may be located or how extensive they may be, is such, that providing any detailed modelling of how such remains might be avoided is neither helpful nor possible but can be appropriately resolved through the processes outlined above and within the WSI.

4.11 The draft WSI provides a clear approach to the identification and assessment of archaeological remains within the development area, and the revised dDCO Requirement 16 provides a robust mechanism by which substantial harm to heritage assets of the highest significance can be avoided.

5 THE PUBLIC BENEFITS OF THE SCHEME

5.1 The public benefits of the Proposed Development are summarised below under topic headings with reference to the Planning Statement [APP-080]; the Environmental Statement [APP-032 to 074]; the Statement of Reasons [APP-012] and the Register of Environment Actions and Commitments [APP-010].

5.2 In summary, the Proposed Development will deliver environmental, social and economic benefits at national, regional and local levels as per the expectations set out in paragraph 4.5 of the ANPS.

Beneficial effects on heritage assets

Heritage assets within the site boundary

5.3 While the historic character of Manston airfield is limited, as noted at Section 9.9.5 of the ES, the Proposed Development has sought to retain historic character in line with Historic England guidance (2016) on 'Historic Military Aviation Sites: Conservation Guidance'. This guidance places significant emphasis, amongst other concerns, on the retention of:

- aviation sites in active aviation use;
- key elements of the layout of airfields, including runways; and
- single ownership of airfield sites.

5.4 The Proposed Development would retain aviation uses using the existing runway, which is a defining factor in establishing the historic character of Manston. The existing runway was originally one of three emergency diversion landing sites for Bomber Command, designed to allow damaged aircraft to land at first landfall (the other two runways were at Carnaby, East Yorkshire and Woodbridge, Suffolk). The scale of the runway suited the airfield for subsequent military and civilian use. The runway will be retained in regular aviation use as part of the operation of the Proposed Development. The runway at Carnaby has been developed for business uses and the Woodbridge runway is in Ministry of Defence (MoD) ownership and is no longer in routine aviation use.

5.5 The Proposed Development retains the basic functional layout of the airfield. The former technical and accommodation areas which are outside the Proposed Development boundary would not be affected, and the Proposed Development will occupy the former operational area of the airfield. Broadly speaking, the proposed terminal, aprons and taxiways would reflect the historic plan form.

5.6 The former RAF Manston Air Traffic Control (ATC) tower would be safeguarded as part of the Museums area, along with the existing museums and Memorial Garden. This area would remain a readily accessible focus for engagement, interpretation and commemoration of the airfield's past use, and would be firmly set into an active aviation context.

Wider Public Benefits

General Aviation Benefits

5.7 The ANPS (Section 2) explains that aviation is very important to the UK and identifies the considerable benefits from aviation – all of which will be realised through the Proposed Development:

1. international connectivity, underpinned by strong airports and airlines, is important to the success of the UK economy;
2. it is essential to allow domestic and foreign companies to access existing and new markets, and to help deliver trade and investment, linking us to valuable international markets and ensuring that the UK is open for business;
3. international connectivity facilitates trade in goods and services, enables the movement of workers and tourists, and drives business innovation and investment, being particularly important for many of the fastest growing sectors of the economy;

4. international connectivity attracts businesses to cluster round airports, and helps to improve the productivity of the wider UK economy;
5. large and small UK businesses rely on air travel, while our airports are the primary gateway for vital time-sensitive freight services;
6. air travel also allows us ever greater freedom to travel and visit family and friends across the globe, and brings millions of people to the UK to do business or enjoy the best the country has to offer;
7. businesses from across the UK utilise our aviation network to access markets worldwide. The UK's strong services sector, which provides significant export earnings for the country, is particularly reliant on aviation;
8. air freight is also important to the UK economy. It is particularly important for supporting export-led growth in sectors where goods are of high value or time critical. In the future, UK manufacturing competitiveness and a successful and diverse UK economy will drive the need for quicker air freight;
9. aviation also brings many wider benefits to society and individuals, including travel for leisure and visiting family and friends. This drives further economic activity; and
10. the importance of aviation to the UK economy, and in particular the UK's hub status, has only increased following the country's decision to leave the European Union. As the UK develops its new trading relationships with the rest of the world, it will be essential that increased airport capacity is delivered, in particular to support development of long-haul routes to and from the UK, especially to emerging and developing economies.

Addressing the Need for Airport Capacity

11. The Proposed Development will make better use of an existing, redundant runway which is wholly supported by the ANPS (paragraph 1.39) and the Government's emerging Aviation Strategy to 2050 (paragraph 1.21)
12. The Proposed Development will provide air services (passenger and freight) to the Kent region that reduces the pressure on the main SE airports with the potential for the airport to develop as an airport of regional importance (paragraph 6.13(1) of the Planning Statement APP-080)
13. The South East is in urgent need of increased airport capacity, even with the third runway at Heathrow Airport, and Manston Airport offers significant scope to provide that capacity

certainly until any new runway is constructed at Heathrow, and thereafter especially in terms of air freight (paragraph 9.0.6 of Volume 1 of the Azimuth Report – APP085)

14. Providing air freight services will respond specifically to the London Mayor's request that air freight should be an important consideration when taking forward plans for airport development in the SE of England (paragraph 8.23 of the Planning Statement APP-080)

15. Providing dedicated freighter capacity will play an important role in supporting industry in London, Kent and the UK

16. The Proposed Development will provide resilience within the UK airports system (paragraphs 4.5.1, 4.5.14 and Section 8.3.1 of Volume 1 of the Azimuth Report – APP085)

17. Manston Airport will present significant opportunities to address known industry constraints including the lack of available slots at South East airports; bumping of freight from passenger aircraft (this means air freight that has been booked onto a passenger flight is denied loading. It is understood that this may happen numerous times before the goods are loaded into the bellyhold of a passenger flight); security issues particularly with outsized cargo and speed of turnaround and bottlenecks for air freight (paragraphs 2.2.4 and 6.1.2 of Volume 1 of the Azimuth Report – APP085)

18. The potential restrictions and delays at the nearby Channel crossings that could result from short and medium-term Brexit impacts will be a cause of concern for those freight shippers reliant on this form of transport. With Manston Airport reopened, there may be a change away from trucking to Europe and using aircraft instead (paragraph 6.0.1 of Volume 1 of the Azimuth Report – APP085)

Transport

19. The Proposed Development will help to ensure that the UK's air links continue to make it one on the best-connected countries in the world and increase links to emerging markets so that the UK can compete successfully for economic growth (paragraph 2.1.12 of Volume 1 of the Azimuth Report – APP085)

20. Reopening Manston Airport will offer another 'port of entry' into the UK which is especially important in light of Britain's decision to exit the European Union. It will also be an important gateway to the rest of the world (paragraph 8.13 of the Planning Statement APP-080)

21. Direct passenger flights from Manston Airport to major airport hubs will offer global connections (paragraph 8.15 of the Planning Statement APP-080)

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22. The airport will provide a key contribution to supporting the connectivity of London (paragraph 8.17 of the Planning Statement APP-080)

23. Investing in East Kent transport infrastructure will bring national benefits, with the effect that the potential return on investing in East Kent's traffic infrastructure will be higher than elsewhere in the UK due to the sub-region's strategic location between mainland Europe, London and the rest of the UK (paragraph 8.59 of the Planning Statement APP-080)

24. The Proposed Development will deliver improvements to the 'traffic challenge' at the B2050/B2190 Spitfire Junction which is a very important local route which together with the A299, is one of the primary arterial routes serving Thanet. The improvements will address existing capacity and safety concerns at this junction (paragraph 8.86 of the Planning Statement APP-080)

25. The availability of air services locally will reduce the need for air passengers and freight to travel long distances to reach larger UK airports. This will relieve road congestion and reduce carbon emissions (paragraph 6.13(1) of the Planning Statement APP-080)

26. The Proposed Development will improve access generally on and around the airport and highways safety by delivering surface access infrastructure including the widening of Spitfire Way between Columbus Avenue and Manston Road and new pedestrian footways on part of the south side of the carriageways on the B2190 Spitfire Way and B2050 Manston Road (paragraph 8.112 of the Planning Statement APP-080)

27. Enhancements to bus services (including a shuttle from Ramsgate railway station) are proposed, and measures to encourage and provide connections for commuting by cycling have been recommended along with improvements for pedestrians. These will benefit locals generally and not just airport users (paragraph 9.230 of the Planning Statement APP-080)

Employment

28. By improving connectivity, the local and regional areas will become more attractive as an employment destination, especially with the improved road and rail connections (paragraphs 6.9 and 8.14 of the Planning Statement APP-080)

29. Jobs will be created for the unemployed in Thanet and further afield in an area where there are some of the highest rates of unemployment in England (paragraph 8.28 of the Planning Statement APP-080)

30. Out-commuting could be reduced by approximately 5% and Manston Airport will give people the opportunity to change jobs (paragraph 3.28 of the RPS Employment and Housing Land Technical Report – Appendix 6 to the Planning Statement APP-080)

31. By 2039, it is predicted that 15,110 people from the local area (including approximately 2,950 recruited from the unemployed) could be recruited to work in jobs associated with the reopening of Manston Airport. On this basis, the airport will not need to rely on in-migrant workers thereby meaning that no additional households would need to be created and there would be no requirement for the provision of new housing directly related to the airport (paragraph 3.18 and Table 3.4 of the RPS Employment and Housing Land Technical Report – Appendix 6 to the Planning Statement APP-080)

32. Measures will be secured to optimise local recruitment during the construction and operation processes, including possible measures to ensure linkages to local training initiatives and/or voluntary agreements relating to local recruitment (Table 13.19 of Chapter 13 of the Environmental Statement APP-034)

Economic

33. The total Gross Domestic Product (GDP) from direct, indirect/induced and catalytic jobs is forecast to be between £1.2 and £1.3 billion (paragraph 8.1.6 of Volume 4 of the Azimuth Report – APP085)

34. By Year 20, the Proposed Development will create approximately 3,400 direct jobs, approximately 6,100 indirect/induced jobs and approximately 13,650 catalytic jobs. The total figure for jobs created by Manston Airport is forecast to be around 23,235. Between 600 and 700 construction jobs are forecast with additional jobs created for off-site work by local construction companies (Table 4 and paragraph 5.4.3 of Volume IV of the Azimuth Report – APP085)

35. The Proposed Development will free-up congestion at other SE airports thereby reducing delays, unreliability and disruption which affect airlines, passengers and the wider community and increase the scope for competition and lower fares (Section 2 of the ANPS)

36. Manston Airport will support and help to grow tourism in the area and would increase demand for visitor accommodation (and related jobs) which is a regional growth objective (paragraph 6.13 of the Planning Statement APP-080)

37. Intervistas research in 2015 (Intervistas, 2015 – “*Economic Impact of European Airports: A critical catalyst to economic growth”*) shows that a 10% increase in connectivity in air transport

is associated with an increase in GDP per capita of 0.5%. The Proposed Development would achieve this economic benefit (paragraph 3.2.3 of Volume 4 of the Azimuth Report – APP085)

Regeneration and Growth

38. Manston Airport will be an essential catalyst in regenerating the local and regional areas which is recognised widely as being much-needed. Thanet suffers from deprivation and ranks as the most deprived area of Kent and one of its wards (Cliftonville West) is ranked 4th out of 32,844 LSOAs in England. Thanet performs consistently behind the rest of Kent with lower wages, lower productivity, higher unemployment and low participation in higher education (Executive Summary Volume 4 of the Azimuth Report – APP085)

39. Manston Airport will help to deliver the vision in the Economic Growth Strategy for Thanet (November 2016) to grow the Thanet economy quickly specifically through supporting local business; improving workforce skills and supporting the visitor economy but also to address the many challenges including strengthening the skills profile; growing jobs and diversifying the business base so that it is not so reliant upon 'public sector roles.' The Strategy identifies Manston Airport as a serious potential opportunity site for Thanet's economy going forward (paragraphs 8.91 and 8.113 of the Planning Statement APP-080)

40. Reopening Manston Airport will contribute to achieving regional and local economic growth and regeneration objectives including those in Thanet Council's Corporate Plan 2016-2020 (2016) to grow the local economy so that Thanet can thrive and to promote inward investment and job creation and achieve greater economic prosperity (paragraph 8.82 of the Planning Statement APP-080)

41. Manston Airport has significant potential to develop into a regional airport and become one of the largest single generators of economic activity in the Kent County (from the Local Transport Plan for Kent (2011) – see paragraph 8.11 of the Planning Statement APP-080)

42. Manston Airport will provide a key contribution to support the London economy (paragraph 8.24 of the Planning Statement APP-080)

43. The proposed air services, which are within easy reach of London, will be critical to the international competitive position of London in a global economy and will help to meet London's passenger and freight needs (Draft Policy T8 in the draft new London Plan 2017 – see paragraph 8.20 of the Planning Statement APP-080)

44. The Proposed Development will provide infrastructure necessary to boost business and jobs thereby creating conditions for economic growth and boosting productivity of business in line

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with the objectives of the South East Local Economic Partnership (SELEP) Strategic Economic Plan (March 2014) and the Kent Forum's Vision for Kent 2012-2022 (2012) (paragraphs 8.26 to 8.30 and 8.61 of the Planning Statement APP-080)

45. Manston Airport will present significant opportunities to rebalance the SELEP economy by supporting priority sectors for the SELEP economy that have been identified for high growth potential, e.g. advanced manufacturing; transport and logistics and the visitor economy (paragraph 8.28 of the Planning Statement APP-080)

46. Manston Airport will help the SELEP achieve its emerging objective to encourage trade and inward investment, in particular, more international trade for the benefit of the SELEP economy including through improving connectivity to enable more businesses to trade overseas and encourage foreign companies to locate in the UK (paragraph 8.32 of the Planning Statement APP-080)

47. Manston Airport will attract much-needed inward investment to the local and regional area (paragraphs 8.32, 8.57 and 8.82 of the Planning Statement APP-080)

48. Brexit may offer opportunities for East Kent such as growth in sectors associated with freight clearance and supply chain growth and Manston Airport would provide critical transport infrastructure to enable this (paragraph 8.38 of the Planning Statement APP-080)

49. Kent (and Medway) is facing increased congestion on both road and rail infrastructure (Kent and Medway Growth and Infrastructure Framework 2018 Update). Manston Airport, together with the nearby Thanet Parkway Rail Station, will offer possible solutions to this problem especially in relation to goods transfer (paragraphs 8.41 to 8.43 of the Planning Statement APP-080)

50. The Kent and Medway Growth and Infrastructure Framework 2018 Update identifies the Manston Airport site as an employment site and a strategic project for economic growth in East Kent. Reopening the airport will help to fulfil this strategic objective (paragraphs 8.41 to 8.43 of the Planning Statement APP-080)

51. Manston Airport will represent important transport infrastructure to support the vision and delivery plan set out in the Thames Estuary 2050 Growth Commission – 2050 Vision Report (June 2018) which includes the areas of north Kent, south Essex and East London. In particular, it will encourage productivity, connectivity and a thriving place capable of adapting including within the North Kent Foreshore area which includes the Thanet area where significant opportunities for growth and development are recognised (paragraphs 8.44 to 8.55 of the Planning Statement APP-080)

52. The Proposed Development supports Business and General Aviation through providing dedicated facilities (paragraphs 6.70, 7.54 and 7.55 of the Planning Statement APP-080)

Education and Training

53. The Thames Estuary 2050 Growth Commission – 2050 Vision Report (June 2018) which covers Thanet and north Kent, specifically states that the Commission wants to implement a more targeted skills strategy with employers and educational institutions that provides clear pathways to employment to address generational skills shortfalls and unemployment. This is working with Kent CC, local authorities, SELEP, employers and educational institutions. The applicant is extremely keen to be part of this strategy and through providing work and training opportunities at the airport to address their employment needs (paragraphs 8.44 to 8.55 of the Planning Statement APP-080)
54. East Kent is in desperate need of high-quality training and employment. The employment and training opportunities presented by Manston Airport will help to raise the career aspirations of Kent's residents (paragraph 2.1.5 of Volume 4 of the Azimuth Report – APP085)
55. Manston Airport will invest in workforce skills (paragraph 8.91 of the Planning Statement APP-080)
56. The applicant is keen to establish an aviation training and education facility in partnership with higher education and further education providers (paragraph 6.6.5 of Volume 4 of the Azimuth Report – APP085)
57. Working with East Kent College (or another party such as Canterbury Christ Church), an aviation college will be located on or close to the Proposed Development site (paragraph 6.6.4 of Volume 4 of the Azimuth Report – APP085)
58. Practical support will be provided to the long-term unemployed such as informal 'meet the employer' events; interview preparation; help with CVs; careers guidance etc. (paragraph 6.6.4 of Volume 4 of the Azimuth Report – APP085)
59. Working with local councils and third sector organisations, job opportunities will be promoted to local people, particularly to the long-term unemployed (paragraph 6.6.4 of Volume 4 of the Azimuth Report – APP085)
60. Working with Further Education (FE) and Higher Education (HE) apprenticeships will be promoted at all levels (paragraph 6.6.4 of Volume 4 of the Azimuth Report – APP085)

61. Working with FE/HE, courses will be developed (where not currently available) relevant to the job opportunities created by the operation of the Proposed Development (paragraph 6.6.4 of Volume 4 of the Azimuth Report – APP085)

62. Working with other employers to provide 'hands on' training opportunities (paragraph 6.6.4 of Volume 4 of the Azimuth Report – APP085)

Leisure and Tourism

63. The existing facilities for the RAF Manston Museum and the Spitfire and Hurricane Memorial Museum will be safeguarded with a natural setting created around the balancing ponds and the memorial gardens which are also being retained (paragraphs 2.20 and 3.76 of the Planning Statement APP-080)

64. The historic association with the airport will be retained d by retaining aviation uses at the site but also through reusing and/or relocating heritage structures where feasible in discussion with museum operators (Table 9.16 of Chapter 9 of the Environmental Statement AP P-033)

65. During operation the additional influx of people, in conjunction with the increased incomes of the local population will likely lead to greater spending in the locality and an increased demand for tourism facilities including from airline crew. This could result in improvements to the volume of trade for business and tourism outlets (Table 13.19 of Chapter 13 of the Environmental Statement APP-034)

Social/Community

66. The Proposed Development removes the uncertainty surrounding the future of the Manston Airport site, which is recognised as a threat and weakness to Thanet's Economic Growth Strategy (2016) (paragraphs 8.95 and 8.114 of the Planning Statement APP-080)

67. Place-making and shaping - the benefits that the airport will bring will help to improve the perception of people's ideas of East Kent and will help to make it a location of first choice that retains and attracts young people, families and entrepreneurs (paragraph 8.37 of the Planning Statement APP-080)

68. The Proposed Development has been designed to ensure that there is no net loss of community facilities (paragraph 7.18 of the Planning Statement APP-080)

69. The reopening of Manston Airport will raise the aspirations of young people by stimulating the desire to continue in education and training, encouraging young people to improve their life chances and realise their full potential (paragraph 9.52 of the Planning Statement APP-080)

Appendix HE.1.2

70. It is likely that the local economy in Thanet will benefit from construction work associated with the Proposed Development, as there are established firms and the proportion of businesses in Thanet providing construction services and accommodation and food services is higher than the national average (paragraph 13.8.60 of Chapter 13 of the Environmental Statement APP-034)

Environmental Improvement

71. Reusing a redundant 'brownfield' site and the infrastructure that already exists, within the existing airport boundary, is a highly sustainable form of development which protects the countryside and ensures that there is no undue development pressure on surrounding land (Section 4 of the Planning Statement APP-080)

72. The character and quality of the area will be improved through a high-quality development design approach

73. 36 ha of off-site habitat to be created for all species that could potentially be found on site which would be accessible to the public (Table 7.7 in Chapter 7 of the Environmental Statement APP-033). This will only be provided in the event that it is necessary for ecological mitigation.

74. Remediation of potential residual contaminants at the Jentex tank farm will be undertaken and beneath the existing runway, subject to risk-based assessment (Table 10.9 in Chapter 10 of the Environmental Statement APP-033)

75. Tree planting and landscaping enhancing the existing environment wherever possible

76. Typically, 45 m wide planted buffers along the perimeter of the business park where it adjoins residential property (Paragraph 3.3.102 of Chapter 3 of the Environmental Statement APP-033)

Health and Wellbeing

77. Improvements to tranquil areas in the interests of recreational and amenity values

78. Thanet District Council (TDC) will benefit from funds to reinstate an air quality continuous monitor at the Thanet Airport location which will monitor Nitrogen Dioxide (NO_2) at hourly intervals in real time (Table 6.2 and paragraph 6.3.4 of Chapter 6 of the Environmental Statement APP-033)

79. Generating employment opportunities within Thanet has potential socio-economic benefits to health (paragraph 15.3.6 of Chapter 15 of the Environmental Statement APP-034)

80. Passenger services will potentially offer quality of life and wellbeing benefits affecting a large number of leisure travellers (paragraph 15.8.37 of Chapter 15 of the Environmental Statement APP-034)

6 CONCLUSION

6.1 There are no designated heritage assets within the site boundary, and as a result, no adverse effects arising from direct physical disturbance, damage or alteration of designated heritage assets are anticipated.

6.2 Any adverse effects on designated heritage assts are anticipated to arise as a result of change to setting arising from visibility of the completed development or aviation noise. However, any loss of significance would be restricted to potential changes to historic interest arising from a sense of noise either being intrusive to a perceived rural context or, in the case of Minster Abbey, to a perceived spiritual or contemplative place. Consequently, it has been assessed that substantial harm would not arise in any case.

6.3 In this case there are no examples where a heritage asset will be subjected to substantial harm as a result of the construction or operation of the proposed development. As such Paragraph 5.205 of the ANPS applies.

6.4 In accordance with paragraph 5.205 of the ANPS and paragraph 196 of the NPPF, the "less than substantial harm" to the significance of the designated heritage assets reported in the environmental statement should be weighed against the public benefits of the proposal, including securing its optimum viable use.

6.5 Similarly, the scale of harm or loss to non-designated heritage assets is expected to be less than substantial and should therefore also be balanced against the substantial public benefit of the proposed development.

6.6 The public benefits of the proposed development (scheme) are summarised above. In light of the fact that the viable uses of the heritage assets are not significantly affected and considering the considerable public benefits of the scheme, these factors are considered to outweigh the harm to the significance of the designated (and non-designated) heritage assets and to justify the less than substantial harm to heritage assets.

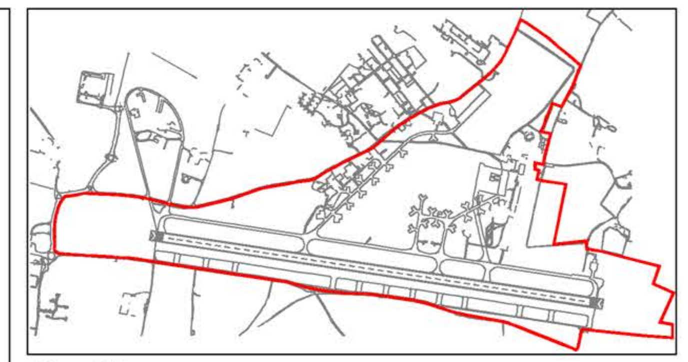
Appendix HE.1.2

6.7 For this reason, the Proposed Development meets the tests outlined in Paragraphs 5.192 and 5.205 of the ANPS and the harm to heritage assets described above is therefore fully justified in the public interest.

Appendix HE.1.2

MANSTON AIRPORT DEVELOPMENT CONSENT ORDER
LANDSCAPE STRATEGY
REGULATION 5 (2) (o)
THANET DISTRICT COUNCIL

RSP



Key Plan

Scale: NTS

KEY

EXISTING

- Site boundary
- Trees to be retained

PROPOSED
SOFT LANDSCAPE

- Trees; Semi mature formal street tree
- Trees; Extra heavy standard tree
- Planting; Native mixed screen planting
- Planting; formal single species hedgerow maintained at 1m high
- Planting; mixed native screen planting maintained at 1.5m high
- Planting; ornamental amenity planting
- Grass; General amenity grass seed short mown
- Mounds; local earthworks to form landscape mounds
- Attenuation pond; deep ponds for surface water storage

HARD LANDSCAPE

- Airfield infrastructure circulation
- Airfield infrastructure lay down
- Vehicular and pedestrian hardstanding; concrete asphalt
- Safeguarding area

Notes

1. OS Data obtained from emapsite™ May 2017:

Rev	Description	By	Ckd	Apr	Date
P01		-	-	-	

Project MANSTON AIRPORT DEVELOPMENT CONSENT ORDER

Title LANDSCAPE STRATEGY

REGULATION (5)(2)(o)
THANET DISTRICT COUNCIL

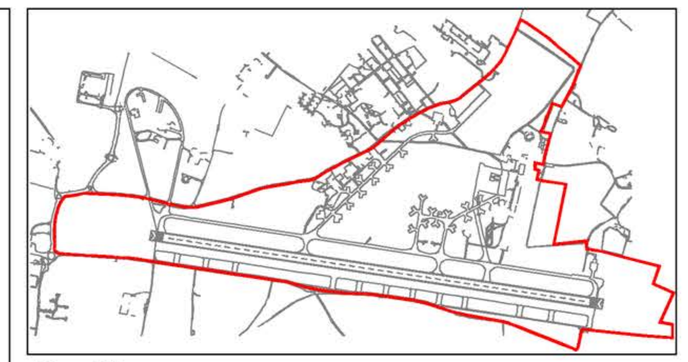
Document Number	Revision
NK018417 - RPS-MSE-XX-DR-C-2051	-
Project Number / Originator - Zone - Level- Type - Role - Drawing Number	

Application Number - TR02002

Scale	Sheet Size	Sheet No	Status
1:7500	A1	1 of 1	S. 56

MANSTON AIRPORT DEVELOPMENT CONSENT ORDER
LANDSCAPE STRATEGY DETAILED PLAN 1 OF 4
REGULATION 5 (2) (o)
THANET DISTRICT COUNCIL

RSP



Key Plan
Scale: NTS

KEY

EXISTING

- Site boundary
- Trees to be retained

PROPOSED
SOFT LANDSCAPE

- Trees; Semi mature formal street tree
- Trees; Extra heavy standard tree
- Planting; Native mixed screen planting
- Planting; formal single species hedgerow maintained at 1m high
- Planting; mixed native screen planting maintained at 1.5m high
- Planting; ornamental amenity planting
- Grass; General amenity grass seed short mown
- Mounds; local earthworks to form landscape mounds
- Attenuation pond; deep ponds for surface water storage

HARD LANDSCAPE

- Airfield infrastructure circulation
- Airfield infrastructure lay down
- Vehicular and pedestrian hardstanding; concrete asphalt
- Safeguarding area

Notes

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Ordnance Survey 0100031673

Rev	Description	By	Ckd	Apr	Date
P01		-	-	-	

Project MANSTON AIRPORT DEVELOPMENT CONSENT ORDER

Title LANDSCAPE STRATEGY DETAILED PLAN 1 OF 4

REGULATION (5)(2)(o)
THANET DISTRICT COUNCIL

Document Number: NK018417 - RPS-MSE-XX-DR-C-2052
Revision: -
Project Number | Originator - Zone - Level Type - Role - Drawing Number

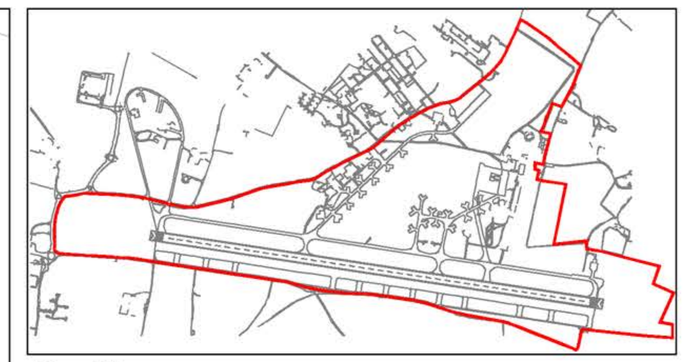
Application Number - TR02002

Scale	Sheet Size	Sheet No	Status
1:2500	A1	1 of 4	S. 56

Appendix LV.1.2

MANSTON AIRPORT DEVELOPMENT CONSENT ORDER
LANDSCAPE STRATEGY DETAILED PLAN 2 OF 4
REGULATION 5 (2) (o)
THANET DISTRICT COUNCIL

RSP



Key Plan
Scale: NTS

KEY

EXISTING
- Site boundary
- Trees to be retained

PROPOSED
SOFT LANDSCAPE
- Trees; Semi mature formal street tree
- Trees; Extra heavy standard tree
- Planting; Native mixed screen planting
- Planting; formal single species hedgerow maintained at 1m high
- Planting; mixed native screen planting maintained at 1.5m high
- Planting; ornamental amenity planting
- Grass; General amenity grass seed short mown
- Mounds; local earthworks to form landscape mounds
- Attenuation pond; deep ponds for surface water storage

HARD LANDSCAPE
- Airfield infrastructure circulation
- Airfield infrastructure lay down
- Vehicular and pedestrian hardstanding; concrete asphalt
- Safeguarding area

Notes

1. OS Data obtained from emapsite™ May 2017:
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Ordnance Survey 0100031673

Rev	Description	By	Ckd	Apr	Date
P01		-	-	-	

Project MANSTON AIRPORT
DEVELOPMENT CONSENT ORDER

Title LANDSCAPE STRATEGY
DETAILED PLAN 2 OF 4

REGULATION (5)(2)(o)
THANET DISTRICT COUNCIL

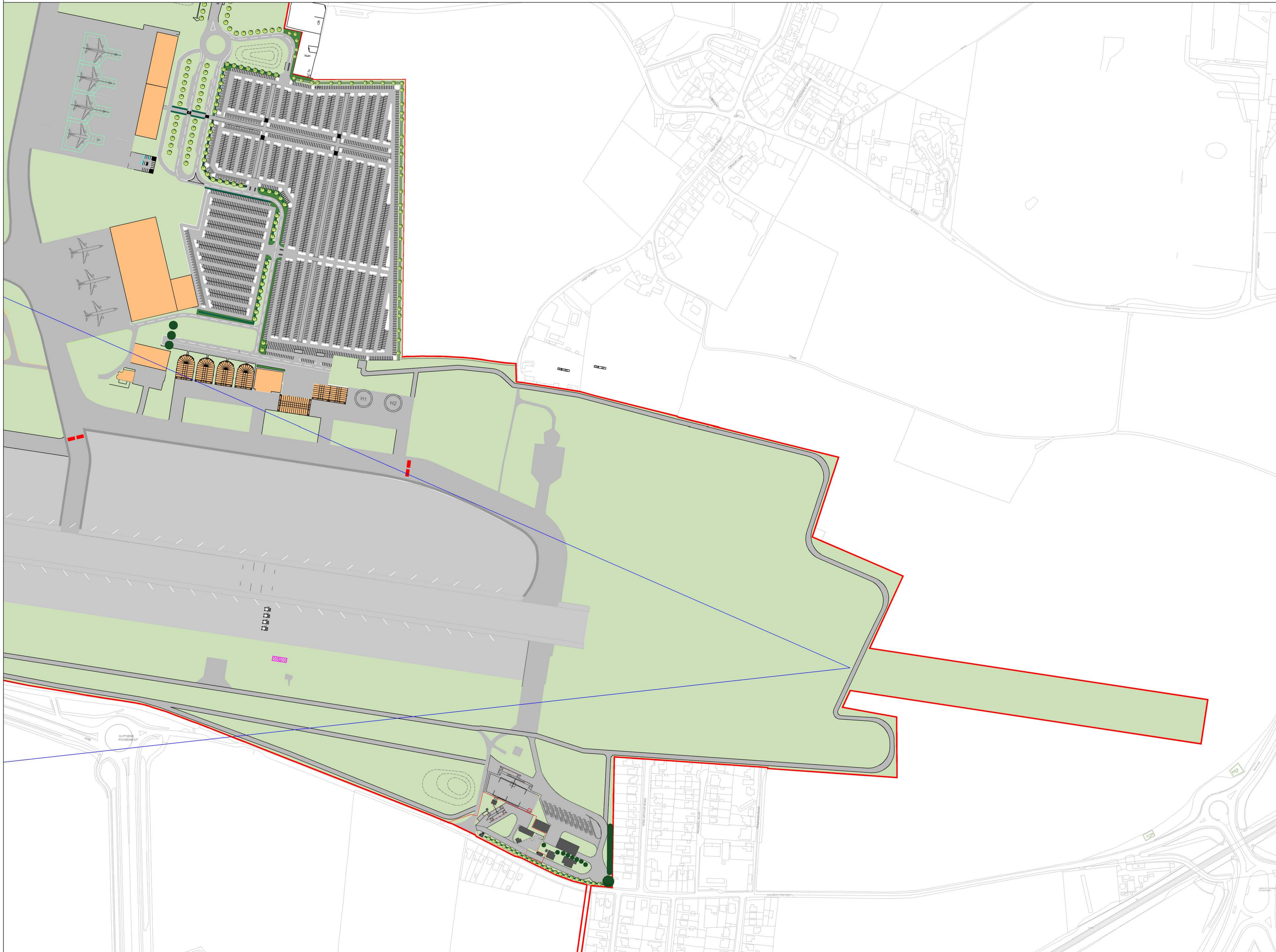
Document Number	Revision
NK018417 - RPS-MSE-XX-DR-C-2053	-
Project Number / Originator - Zone - Level Type - Role - Drawing Number	

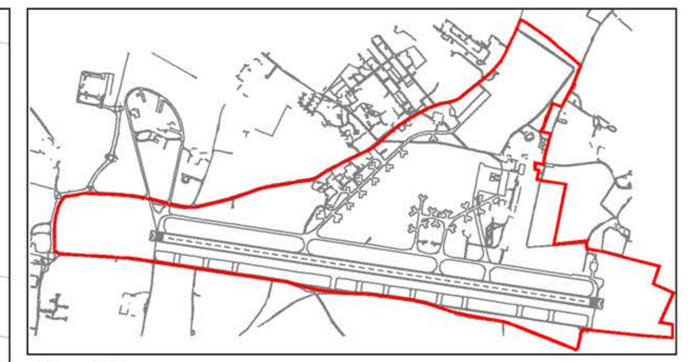
Application Number - TR020002

Scale	Sheet Size	Sheet No	Status
1:2500	A1	2 of 4	S. 56

MANSTON AIRPORT DEVELOPMENT CONSENT ORDER
LANDSCAPE STRATEGY DETAILED PLAN 3 OF 4
REGULATION 5 (2) (o)
THANET DISTRICT COUNCIL

RSP





Key Plan
Scale: NTS

KEY

EXISTING

- Site boundary
- Trees to be retained

PROPOSED
SOFT LANDSCAPE

- Trees; Semi mature formal street tree
- Trees; Extra heavy standard tree
- Planting; Native mixed screen planting
- Planting; formal single species hedgerow maintained at 1m high
- Planting; mixed native screen planting maintained at 1.5m high
- Planting; ornamental amenity planting
- Grass; General amenity grass seed short mown
- Mounds; local earthworks to form landscape mounds
- Attenuation pond; deep ponds for surface water storage

HARD LANDSCAPE

- Airfield infrastructure circulation
- Airfield infrastructure lay down
- Vehicular and pedestrian hardstanding; concrete asphalt
- Safeguarding area

Notes

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Rev	Description	By	Ckd	Apr	Date
P01		-	-	-	

Project MANSTON AIRPORT DEVELOPMENT CONSENT ORDER

Title LANDSCAPE STRATEGY DETAILED PLAN 3 OF 4

REGULATION (5)(2)(o)
THANET DISTRICT COUNCIL

Document Number	Revision
NK018417 - RPS-MSE-XX-DR-C-2054	-

Project Number | Originator - Zone - Level Type - Role - Drawing Number

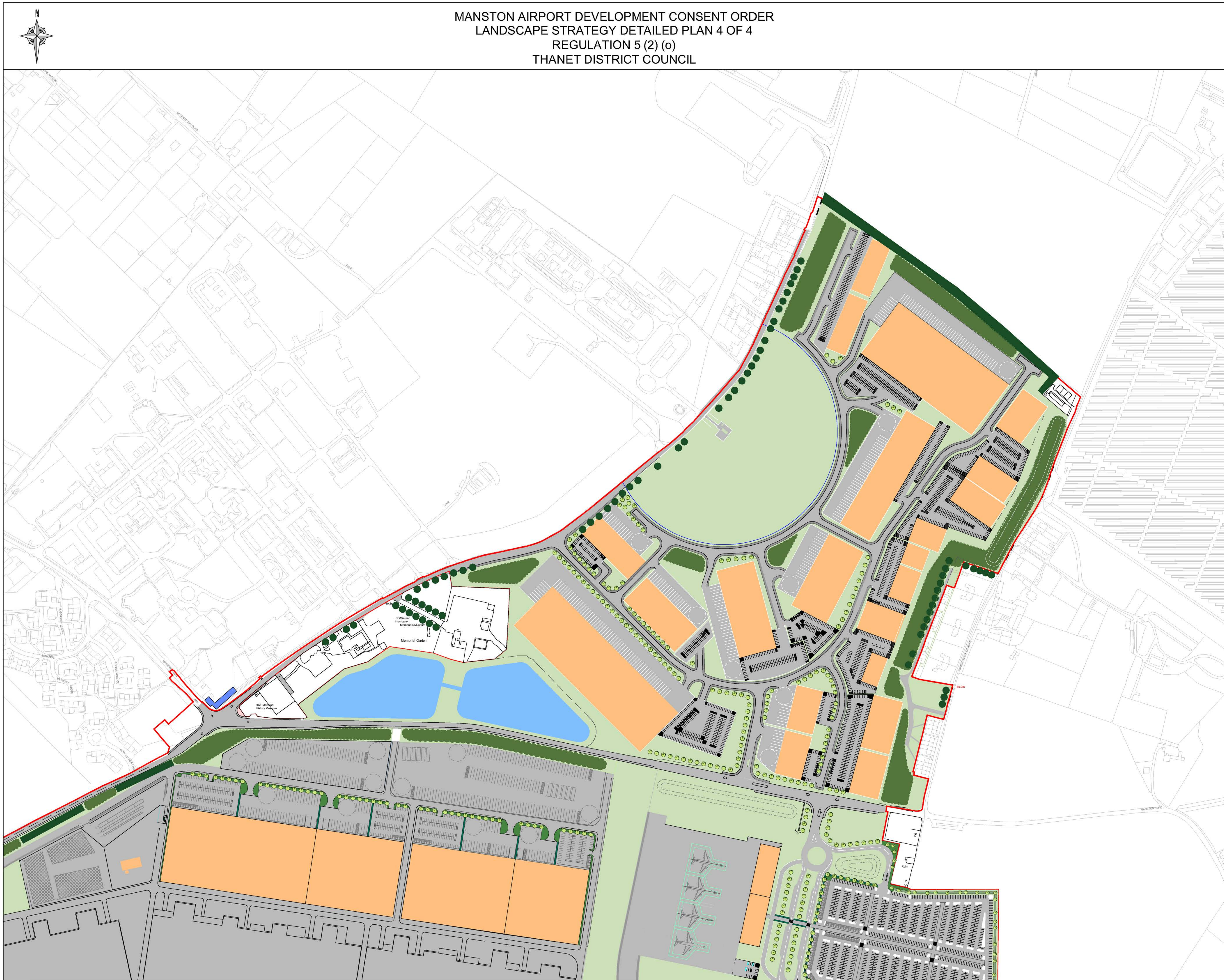
Application Number - TR02002

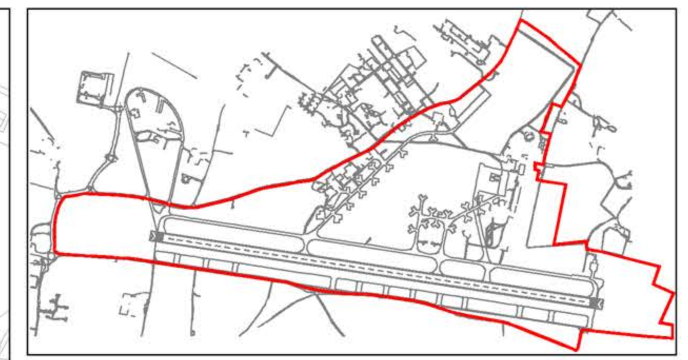
Scale	Sheet Size	Sheet No	Status
1:2500	A1	3 of 4	S. 56

Appendix LV.1.2

MANSTON AIRPORT DEVELOPMENT CONSENT ORDER
LANDSCAPE STRATEGY DETAILED PLAN 4 OF 4
REGULATION 5 (2) (o)
THANET DISTRICT COUNCIL

RSP





Key Plan
Scale: NTS

KEY

EXISTING

- Site boundary
- Trees to be retained

PROPOSED
SOFT LANDSCAPE

- Trees; Semi mature formal street tree
- Trees; Extra heavy standard tree
- Planting; Native mixed screen planting
- Planting; formal single species hedgerow maintained at 1m high
- Planting; mixed native screen planting maintained at 1.5m high
- Planting; ornamental amenity planting
- Grass; General amenity grass seed short mown
- Mounds; local earthworks to form landscape mounds
- Attenuation pond; deep ponds for surface water storage

HARD LANDSCAPE

- Airfield infrastructure circulation
- Airfield infrastructure lay down
- Vehicular and pedestrian hardstanding; concrete asphalt
- Safeguarding area

Notes

1. OS Data obtained from emapsite™ May 2017:
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Ordnance Survey 0100031673

P01		-	-	-	
Rev	Description	By	Ckd	Apr	Date

Project MANSTON AIRPORT DEVELOPMENT CONSENT ORDER

Title LANDSCAPE STRATEGY DETAILED PLAN 4 OF 4

REGULATION (5)(2)(o)
THANET DISTRICT COUNCIL

Document Number	Revision
NK018417 - RPS-MSE-XX-DR-C-2055	-

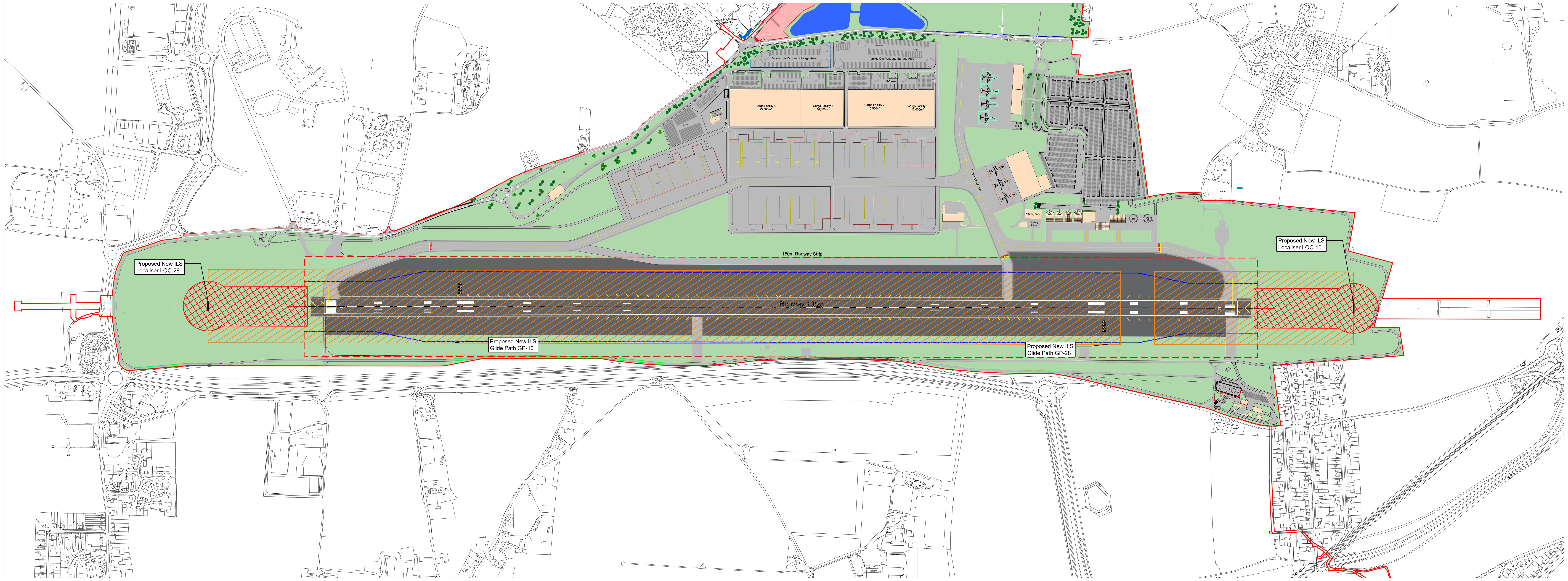
Project Number | Originator - Zone - Level Type - Role - Drawing Number

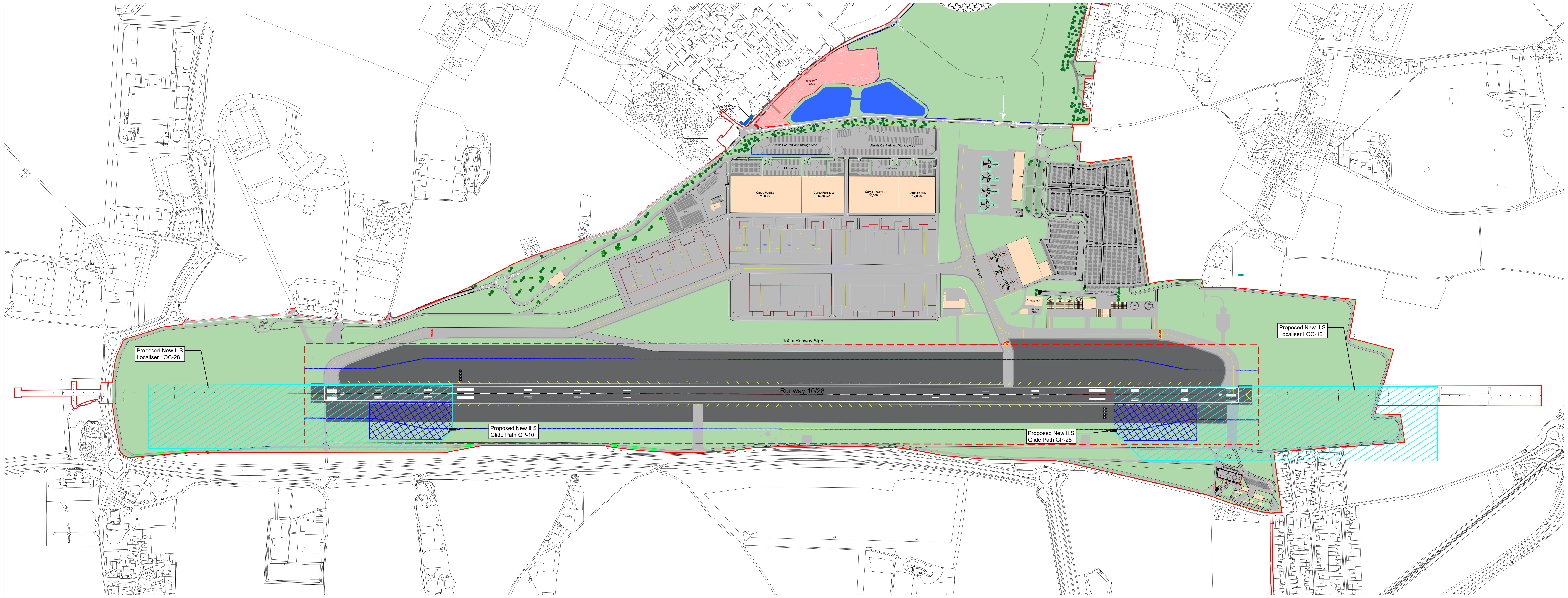
Application Number - TR02002

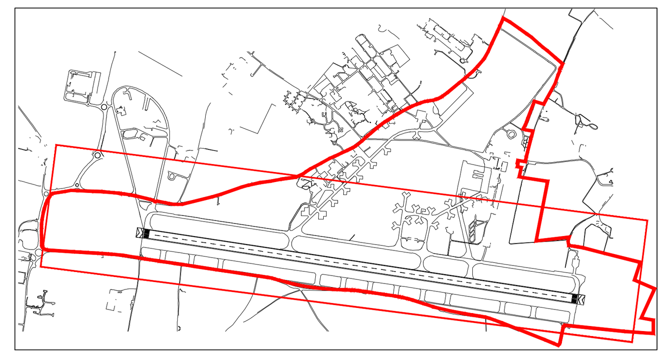
Scale	Sheet Size	Sheet No	Status
1:2500	A1	4 of 4	S. 56

MANSTON AIRPORT MASTERPLAN
ILS CRITICAL AND SENSITIVE AREAS LOCATION PLAN
REGULATION 5(2)(o)
THANET DISTRICT COUNCIL

RSP







Key Plan
Scale: NTS

Key

- Localizer Sensitive Areas
- Localizer Critical Areas
- Glide Path Sensitive Areas
- Glide Path Critical Areas
- Airport boundary

Technical Specifications

- **ILS RWY10**

Developed according to ICAO Annex 10, with the following performance:

Category I Operation - precision instrument approach and landing with:

a. a decision height not lower than 60m (200ft); and
b. with either a visibility not less than 800m or a runway visual range not less than 550m.

The selected Localizer is a Typically 16m (15ft) Semi-Directional, 8 element antenna, placed on a concrete foundation. The selection of a Typically 27m (90ft) Directional Dual frequency, 14 element antenna can reduce the width of the sensitive area from the actual 110m to 60m. The pavement of the foundation is at the same level of the ground, the antenna height is 3,50m from the pavement foundation.

The Glide Path antenna is placed on a concrete foundation. The position of the antenna can move 10m backward and forward from the point on the drawing, along a line parallel to the RWY, in relation to the true level of installation. The antenna pylon height is 14m from the ground level. The earth surface in front of the antenna has to be flat and horizontal for 80m.

- **ILS RWY28**

Developed according to ICAO Annex 10, with the following performance:

Category IIIB Operation - precision instrument approach and landing with:

a. a decision height lower than 15m (50ft) or no decision height; and
b. a runway visual range less than 175m but not less than 50m.

The selected Localizer is a Typically 16m (15ft) Semi-Directional, 8 element antenna, placed on a concrete foundation. The selection of a Typically 27m (90ft) Directional Dual frequency, 14 element antenna can reduce the width of the sensitive area from the actual 210m to 90m. The pavement of the foundation is at the same level of the ground, the antenna height is 3,50m from the pavement foundation.

The Glide Path antenna is placed on a concrete foundation. The position of the antenna can move 10m backward and forward from the point on the drawing, along a line parallel to the RWY, in relation to the true level of installation. The antenna pylon height is 14m from the ground level. The earth surface in front of the antenna has to be flat and horizontal for 80m.

Notes

1. The Critical and Sensitive Areas and the position of the antenna must be reviewed by the developer of the equipment once they are decided
2. This drawing has been prepared in accordance with the scope of RPS's appointment with its client and is subject to the terms and conditions of that appointment. RPS accepts no liability for any use of this document other than by its client and only for the purposes for which it was prepared and provided.
3. If received electronically it is the recipients responsibility to print to correct scale. Only written dimensions should be used.
4. This drawing should be read in conjunction with all other relevant drawings and specifications.
5. OS Data obtained from emapsiteTM May 2017: Crown copyright and database rights 2017 Ordnance Survey 0100031673

10m SCALE 1:1000

Rev	Description	By	Ckd	Apr	Date
P01	First Issue	KA	CJ	CJ	23.02.18

Project MANSTON AIRPORT DEVELOPMENT CONSENT ORDER

Title ILS CRITICAL AND SENSITIVE AREAS LOCATION PLAN REGULATION 5 (2)(o) THANET DISTRICT COUNCIL

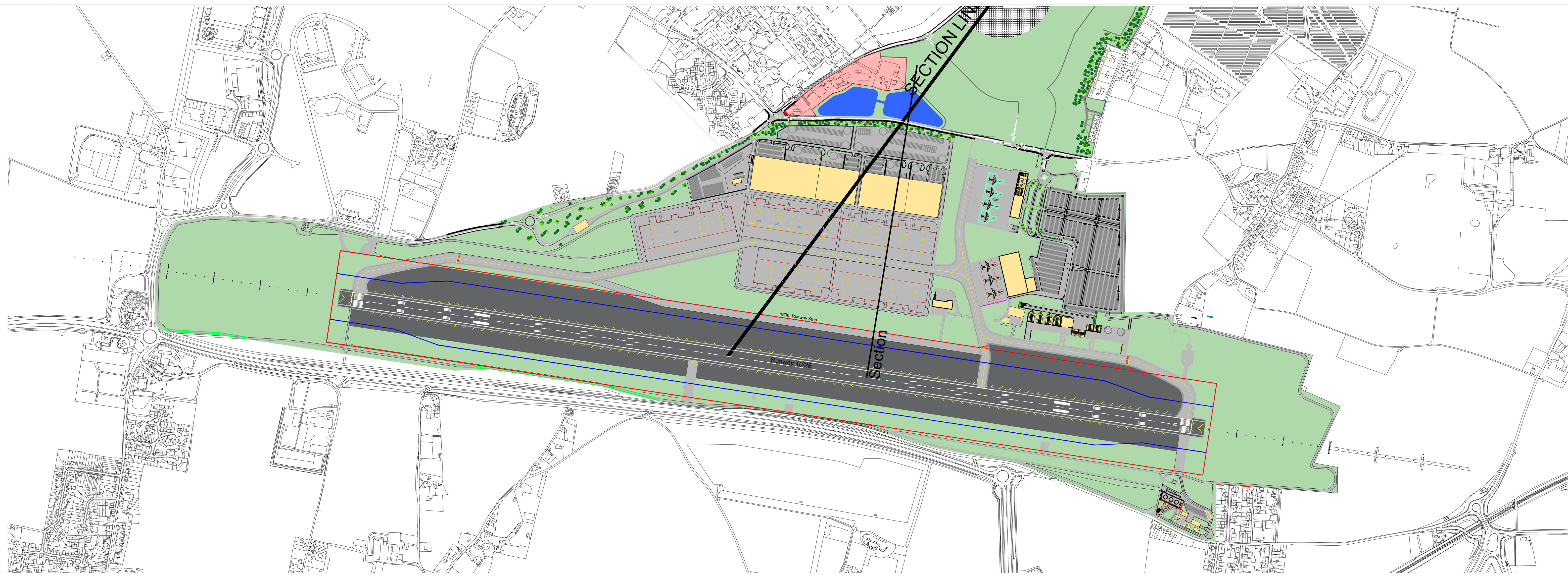
Document Number: NK018417-NK018417-RPS-MSE-X-DR-C-2071
Revision: P01
Project Number - Originator - Zone - Level - Type - Role - Drawing Number

Application Number - TR02002

Scale	Sheet Size	Sheet No	Status
1:1000	A1	1 of 1	S.56

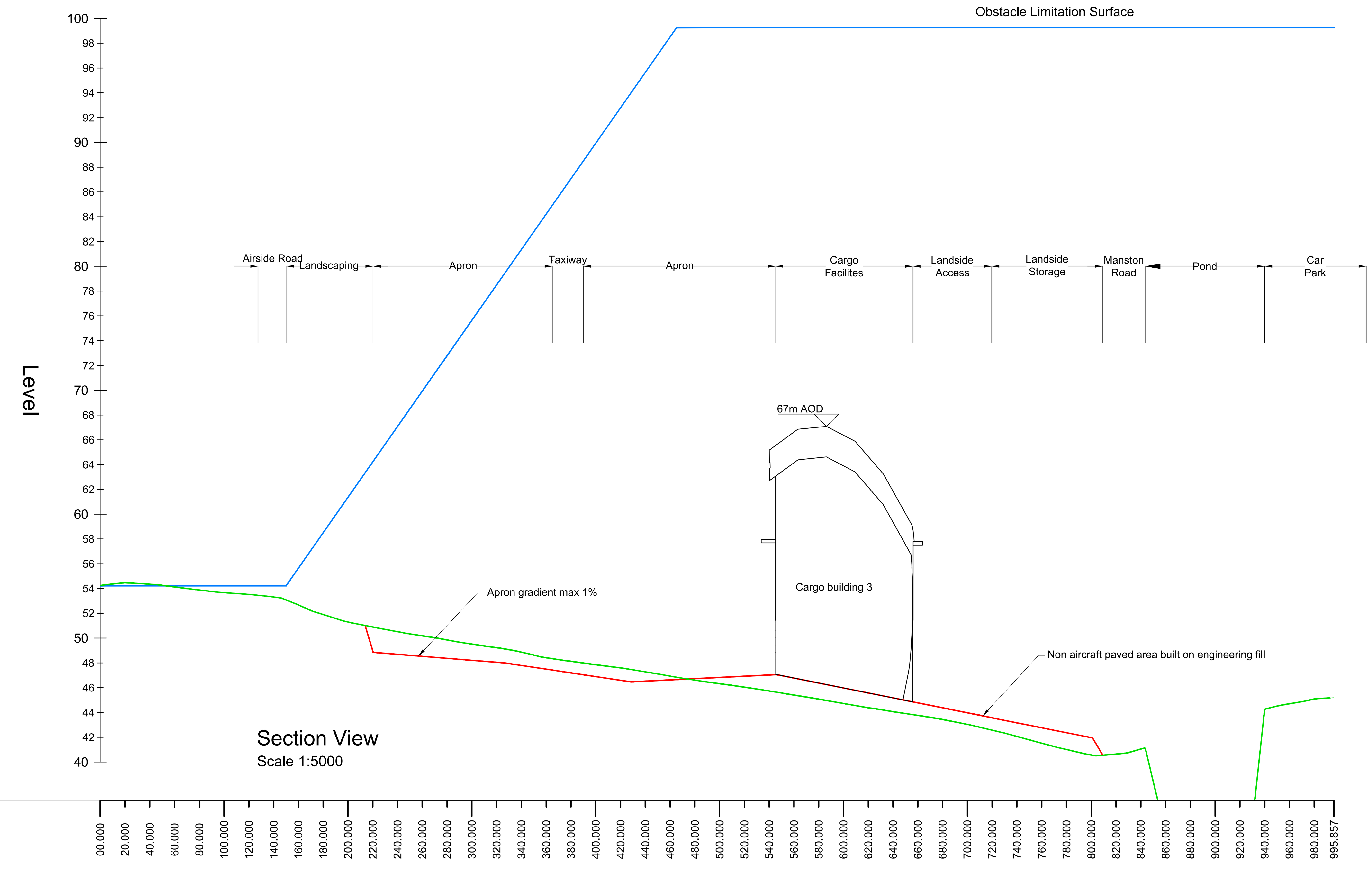
MANSTON AIRPORT DEVELOPMENT CONSENT ORDER
TYPICAL SITE SECTION
REGULATION 5(2)(o)
THANET DISTRICT COUNCIL

RSP



Plan View
Scale 1:1000

SECTION FOR BUILDING HEIGHTS - LONGSECTION (1)
SCALE: H 1:2500,V 1:250. DATUM: 40.000



Section View
Scale 1:5000

Key

Existing Ground

Proposed Ground

Obstacle Limitation Surface

Notes

1. OS Data obtained from emapsite™ May 2017:
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Ordnance Survey 0100031673

100m SCALE 1:5000

100m SCALE 1:10 000

Rev	Description	By	Ckd	Apr	Date
P02	Notes Added To Section View	TAW	CJ	GD	22.02.18
P01	First Issue.	AAG	CJ	GDD	27.10.17

Project MANSTON AIRPORT DEVELOPMENT CONSENT ORDER

Title TYPICAL SITE SECTION REGULATION 5(2)(o) THANET DISTRICT COUNCIL

Document Number: NK018417 - RPS-MES-XX-DR-C-2068 — Revision: P02

Project Number | Originator - Zone - Level - Type - Role - Drawing Number

Application Number - TR02002

Scale	Sheet Size	Sheet No	Status
As Shown	A1	1 of 1	S.56

Appendix LV.1.31

MANSTON AIRPORT DEVELOPMENT CONSENT ORDER
ENGINEERING DRAWINGS AND SECTIONS - EXISTING LAYOUT IN THE CONTEXT OF EASA REQUIREMENTS
REGULATION 5(2)(o)
THANET DISTRICT COUNCIL

RSP

Notes

1. OS Data obtained from emapsite™ May 2017:
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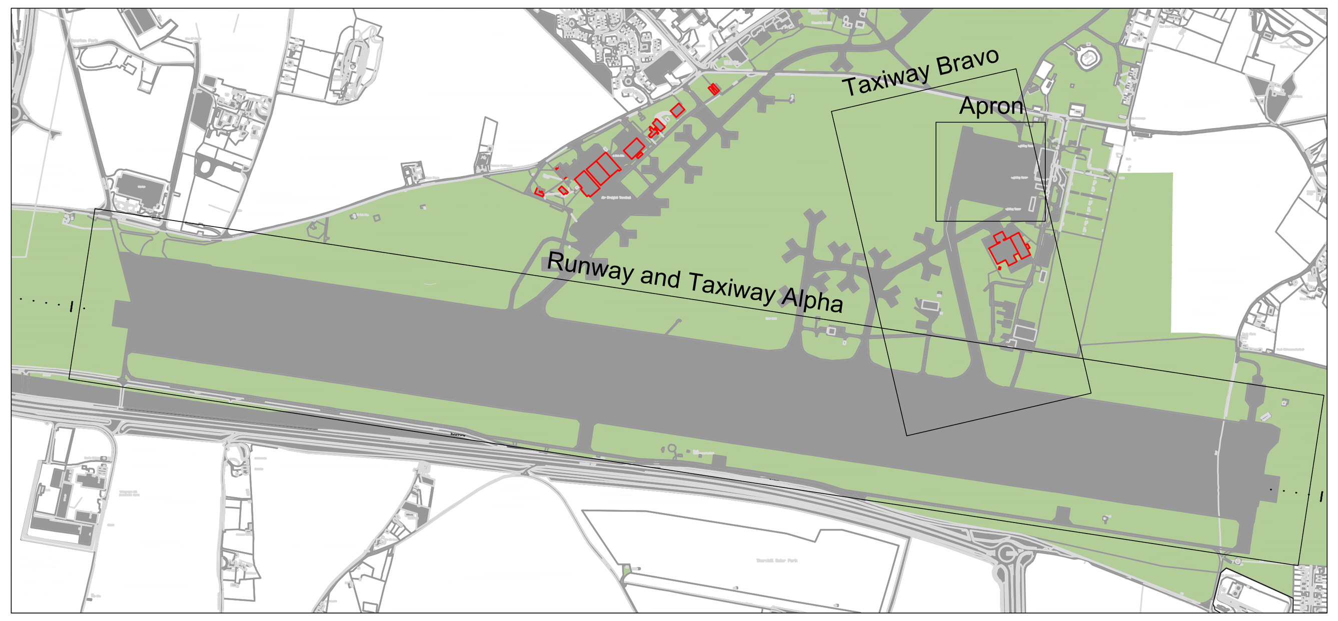
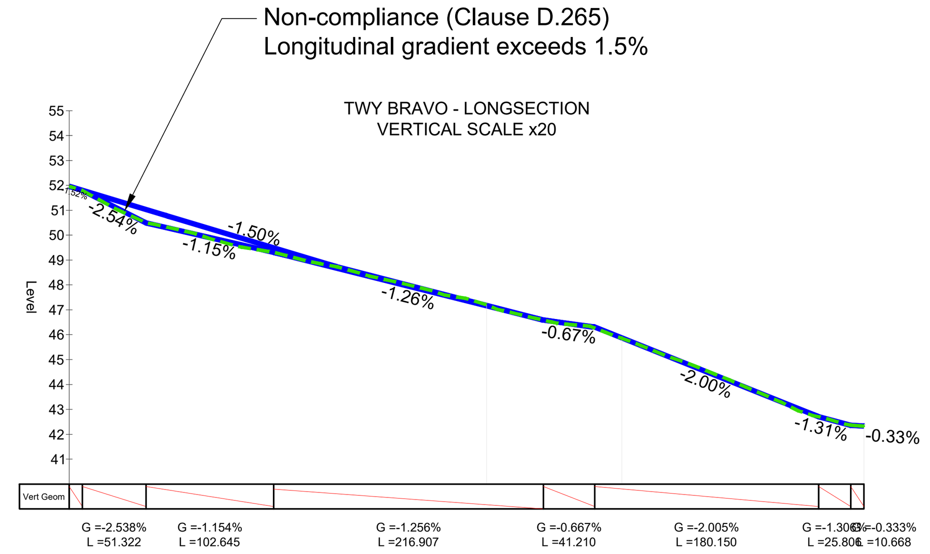
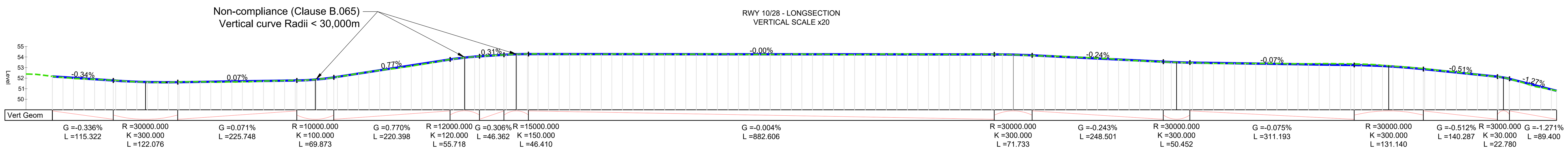
Passenger Terminal Apron - Non-compliance (clause E-360)
On an aircraft stand, the maximum slope should not exceed 1% in any direction
Scale 1:1000

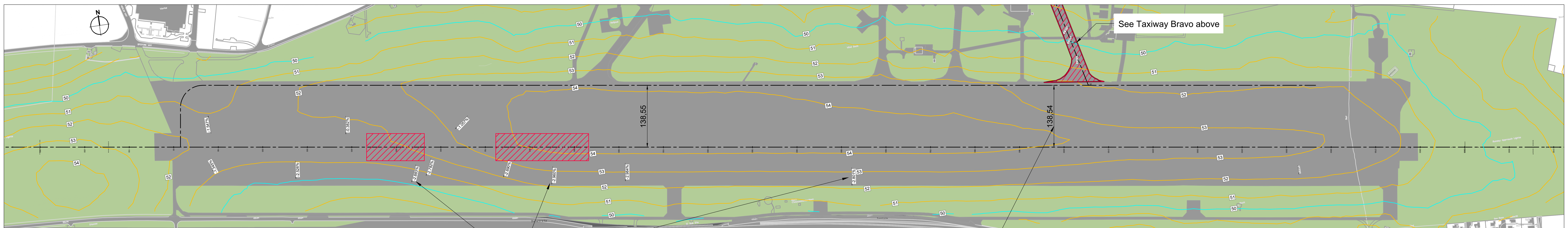


Key Plan
NTS



Taxiway Bravo
Scale 1:5000





Runway 10/28 and Taxiway Alpha
Scale 1:5000

Non compliant clause B185
Transverse slope within the
graded strip should not exceed 2.5%

Non-compliance (Clause D.260)
separation between runway and
taxiway smaller than 182.5m

EASA Document CS-ADR-DSN: Issue 4 December 2017

The precision of the survey dose not allow an exhaustive check of EASA compliance. However, some aspects can be highlighted.

The clauses of the Document CS-ADR-DSN checked are the following:

Runway 10/28 (Code Letter E)

CS-ADR-DSN.B.060 Longitudinal slopes of runways:
Not to exceed gradient 1.25% (0.80% in first and last quarter).

CS-ADR-DSN.B.065 Longitudinal slopes changes on runways:
Minimum radius of curvature 30,000m.

CS-ADR-DSN.B.185 Transverse slopes on runway strip:
Not to exceed 2.50% on the strip portion to be graded.

Taxiway Alpha (Code Letter E)

CS-ADR-DSN.D.260 Taxiway minimum separation distance:
Between taxiway and runway centerline: 172.5m
Updated issue 4 EASA

Taxiway Bravo (Code Letter E)

CS-ADR-DSN.D.265 Longitudinal slope on taxiways:
Not to exceed gradient 1.50%

Passenger Terminal Apron (Code Letter E)

CS-ADR-DSN.E.360 Slopes on aprons:
On an aircraft stand the maximum slope should not exceed 1% in any direction.

Rev	Description	By	Ckd	Apr	Date
P03	Application Number Added	KA	CJ	CJ	23.03.18
P02	Note, document number and scale amended	SO	CJ	GDD	20.03.18
P01	First issue	TC	CJ	CJ	12.02.18

Project MANSTON AIRPORT DEVELOPMENT CONSENT ORDER

Title ENGINEERING DRAWINGS AND SECTIONS - EXISTING LAYOUT IN THE CONTEXT OF EASA REQUIREMENTS REGULATION 5(2)(o) THANET DISTRICT COUNCIL

10m SCALE 1:1000

100m SCALE 1:5000

Document Number: NK018417 - RPS-MSE-XX-DR-C-2004
Revision: P03
Project Number | Originator - Zone - Level - Type - Role - Drawing Number

Application Number - TR020002

Scale	Sheet Size	Sheet No	Status
AS SHOWN	A1	1 of 1	S. 56

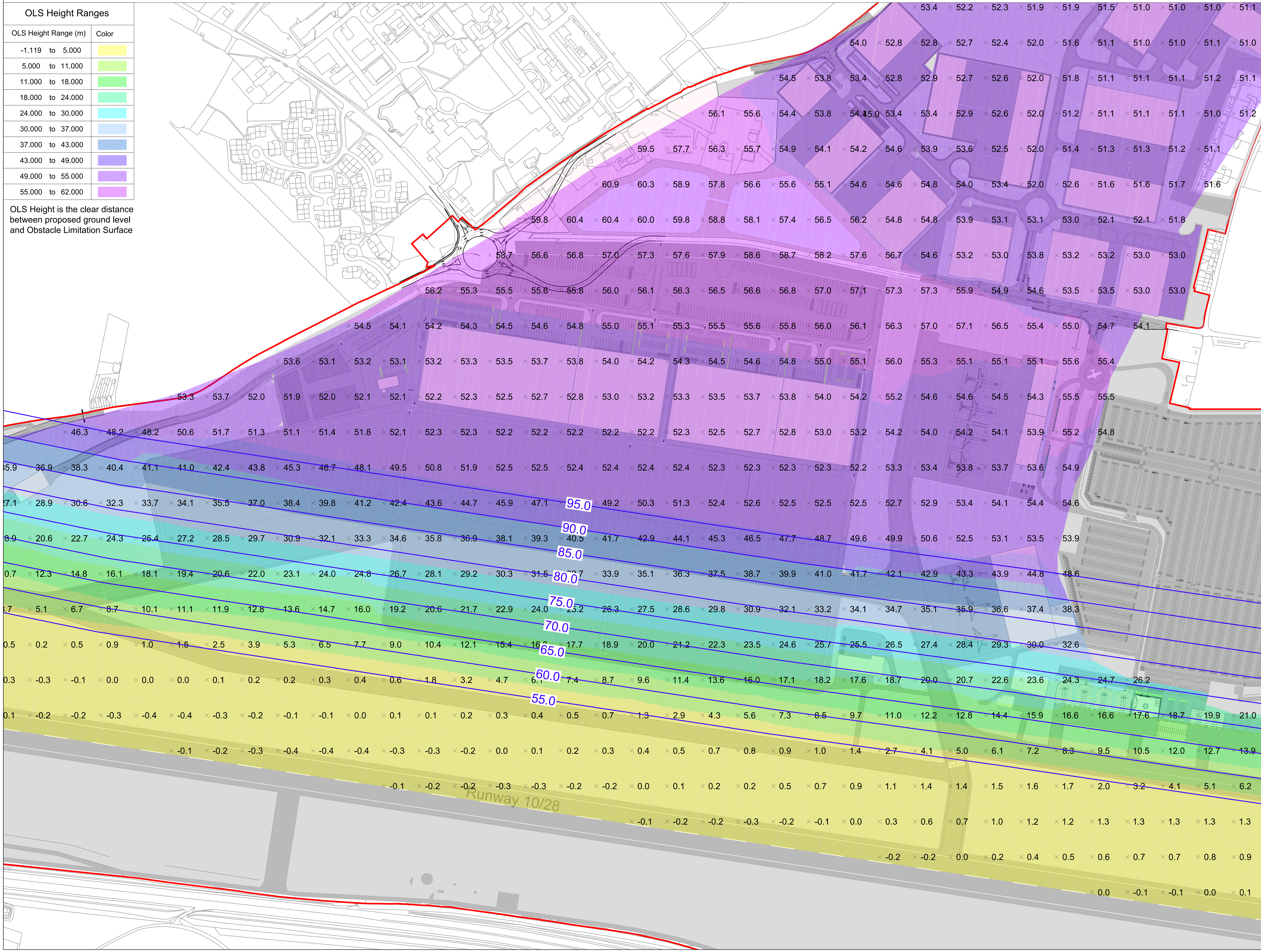
MANSTON AIRPORT DEVELOPMENT CONSENT ORDER
OLS HEIGHTS AVAILABLE

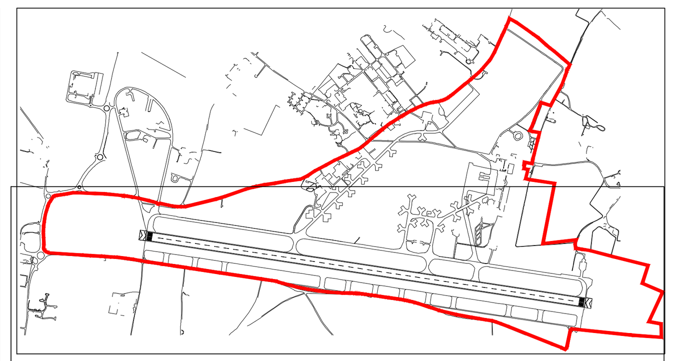
RSP

OLS Height Ranges

OLS Height Range (m)	Color
-1.119 to 5.000	
5.000 to 11.000	
11.000 to 18.000	
18.000 to 24.000	
24.000 to 30.000	
30.000 to 37.000	
37.000 to 43.000	
43.000 to 49.000	
49.000 to 55.000	
55.000 to 62.000	

OLS Height is the clear distance between proposed ground level and Obstacle Limitation Surface





Key Plan
Scale: NTS

Note:

Shading and spot heights illustrate the difference between the proposed levels and the Transitional Obstacle Limitation Surface (OLS).

Therefore the values represent the height available for any facilities (OLS safeguarding).

Key:

DCO boundary

80.0 OLS Surface contours

× 33.9 Clear distance between proposed ground level and Obstacle Limitation Surface

Notes

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50m SCALE 1:2500

Rev	Description	By	Ckd	Apr	Date
P02	Levels Model updated	SW	JLE	CJ	25.10.17
P01	First Issue	KA	JLE	CJ	29.09.17

Project MANSTON AIRPORT DEVELOPMENT CONSENT ORDER

Title OLS HEIGHTS AVAILABLE

Document Number NK018417-RPS-MSE-XX-DR-C-2067 Revision P02

Project Number - Originator - Zone - Level - Type - Role - Drawing Number

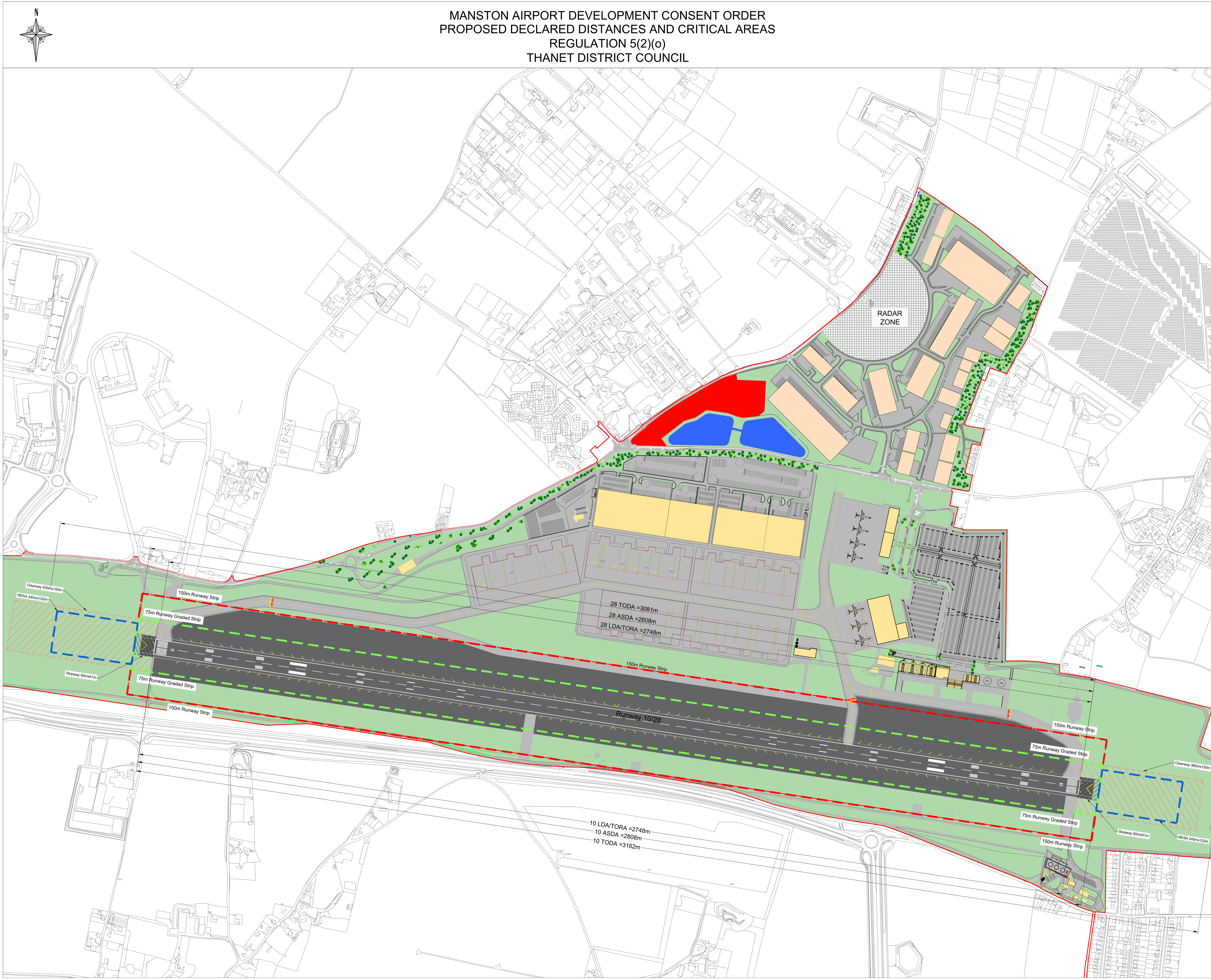
Application Number - TR02002

Scale	Sheet Size	Sheet No	Status
1:2500	A1	1 of 1	Preliminary

Appendix LV.1.31

MANSTON AIRPORT DEVELOPMENT CONSENT ORDER
PROPOSED DECLARED DISTANCES AND CRITICAL AREAS
REGULATION 5(2)(o)
THANET DISTRICT COUNCIL

RSP



Key

- Buildings / Structures
- Grassed Area
- Landscaped Area
- Drainage Pond
- 75m Graded Clearance
- 150m Graded Clearance
- Runway End Safety Area (RESA)
- Clearway
- Stopway

Declared Distances				
Runway Designator	TORA (m)	TODA (m)	ASDA (m)	LDA (m)
10	2748	3162	2808	2748
28	2748	3081	2808	2748

Notes

1. OS Data obtained from emapsite™ May 2017:
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Ordnance Survey 0100031673

Rev	Description	By	Ckd	Apr	Date
P01	First Issue	TC	CJ	GDD	19.02.18

Project MANSTON AIRPORT DEVELOPMENT CONSENT ORDER

Title PROPOSED DECLARED DISTANCES AND CRITICAL AREAS REGULATION 5(2)(o) THANET DISTRICT COUNCIL

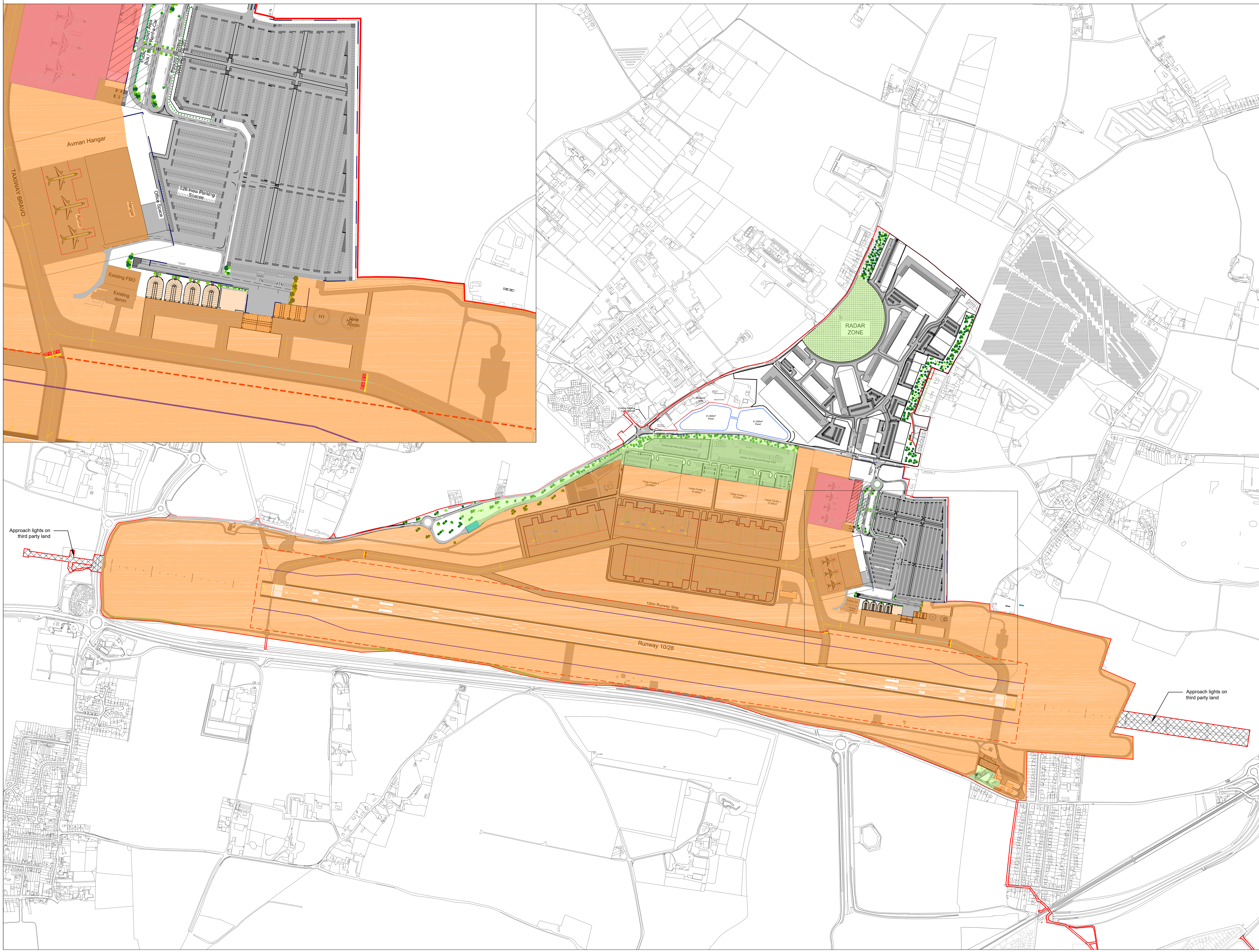
Document Number: NK018417 - RPS-MSE-XX-DR-C-2070 — Revision: P01

Project Number — Originator - Zone - Level - Type - Role - Drawing Number

Application Number - TR02002

Scale	Sheet Size	Sheet No	Status
1:5000	A1	1 of 1	S.56

MANSTON AIRPORT DEVELOPMENT CONSENT ORDER
SECURITY ZONING PLAN
REGULATION 5(2)(o)
THANET DISTRICT COUNCIL



Notes

1. OS Data obtained from emapsite™ May 2017:
© Crown copyright and database rights 2017
Ordnance Survey 0100031673
2. Security requirements for zones to be determined by others.
3. security zone required to be developed in accordance with all relevant standards and CAA requirements.

Key

Security Zone (landside)
- Private land with gated or controlled access.
- No public access.
- Limited security, no free access to airside or critical areas.

Security Zone (airside)
- Operational airfield area
- No access without relevant airside clearance
- Controlled movement and zoning.
- X-ray and standard airfield security screening required to enter area.

Security Zone (critical area)
- area used for embarkation of passenger aircraft.
- Area can not be entered without security checks.

Area protected against vehicle access as part of counter terrorism measures

Third Party Land

Rev	Description	By	Ckd	Apr	Date
P03	Security zones updeted	GS	CJ	GDD	28.02.18
P02	Security zones updeted	GS	CJ	GDD	23.02.18
P01	Security zones updeted	RS	CJ	GDD	01.12.17

Project MANSTON AIRPORT DEVELOPMENT CONSENT ORDER

Title Proposed Fire Station
REGULATION 5(2)(o)
THANET DISTRICT COUNCIL

Document Number: NK018417-RPS-MSE-XX-DR-C-2072
Revision: P03
Project Number | Originator - Zone - Level - Type - Role - Drawing Number

Application Number - TR02002

Scale	Sheet Size	Sheet No	Status
NTS	A1	1 of 1	S. 56

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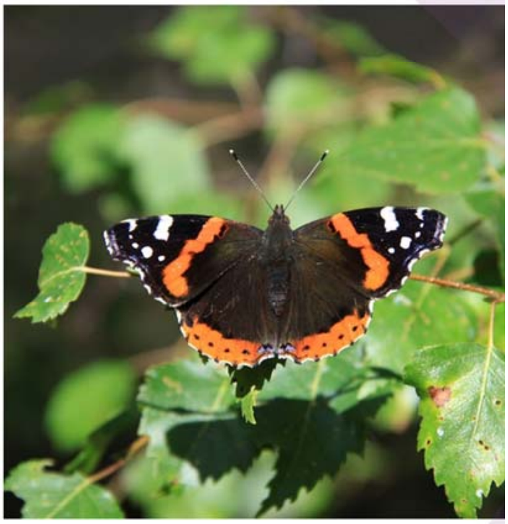
RiverOak Strategic Partners

Manston Airport Development Consent Order

Landscape and Visual Impact Assessment Addendum



Wood Environment & Infrastructure Solutions UK Limited – February 2019

Appendix LV.1.36

wood.

Report for

Main contributors

Kate Ward

Issued by

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Approved by

....

Wood

Canon Court
Abbey Lawn
Abbey Foregate
Shrewsbury SY2 5DE
United Kingdom
Tel +44 (0) 1743 342 000

Doc Ref. 40820RR004i1

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Document revisions

No.	Details	Date
i1	Draft	05/02/19

Appendix LV.1.36

wood.

Contents

Appendix LV.1.36

1. Introduction

1.1 Purpose of this report

1.1.1 This report has been prepared as an addendum to the Landscape and Visual Impact Assessment (LVIA) which formed Chapter 11 of the Environmental Statement (ES) for Manston Airport submitted in July 2018. It has been prepared to address Written Questions made by the Examining Authority during the initial stages of the Examination process.

1.1.2 This addendum provides an assessment of the visual impact of the airport on night-time views. It should be noted that night-time visualisations have not been included as they cannot accurately reproduce the likely appearance of night-time lighting in relation to the existing baseline view and would not therefore enhance the understanding of the impacts for the informed decision maker.

1.1.3 The assessment has been carried out with an understanding of:

- the positions of the lighting elements within the development derived from the plans contained within the *External Lighting Strategy* (which forms Appendix A of this addendum);
- the likely visibility of the lighting elements in the views from each viewpoint derived from the wirelines contained within Appendix 11.1 of the ES; and
- an understanding of the existing night-time baseline derived from the night-time photography provided in Figures 11.22 to 11.29 of the ES.

1.2 It is this information that has allowed the assessors to employ their professional judgement regarding the likely level of effect associated with night-time lighting visible from each viewpoint. Planning policy

Adopted Thanet Local Plan 2006

1.2.1 Policy EP9 of the Adopted *Thanet Local Plan* 2006[1] relates to light pollution and states that "*Development that includes the provision of new outdoor lighting should be designed to minimise light glare, light trespass, spillage and sky glow so as to preserve residential amenity, the character of the surroundings and prevent disturbance to identified wildlife areas*".

1.2.2 Paragraph 13.65 of the *Thanet Local Plan* defines relevant areas of the district identified by Thanet District Council to which the standards included in the (then) Institution of Lighting Engineers (ILE) *Guidance Notes for the Reduction of Light Pollution* apply as follows:

- Zone E1 comprises the Pegwell Bay Special Landscape Area and the former Wantsum Channel;
- Zone E2 comprises the rest of the rural areas outside built confines except Kent International Airport;
- Zone E3 comprises the urban areas and rural settlements within built confines and Kent International Airport; and

[1] Thanet District Council. (2006). *Thanet Local Plan*. [online]. Available at https://www.thanet.gov.uk/wp-content/uploads/2018/06/LocalplanOct06v3_2-2-1.pdf

- Zone E4 comprises the amusement area at Margate Seafront.

Draft Thanet Local Plan to 2031

1.2.3 The *Draft Thanet Local Plan to 2031*[2] includes Policy SE08 – Light Pollution. The supporting text refers to the Institution of Lighting Professionals (ILP) *Guidance Notes for the Reduction of Obtrusive Light* and defines areas of Thanet which correspond to the Environmental Zones identified in this guidance in Table 15 as follows:

Table 1.1 Environmental Zones and corresponding areas within Thanet

Zone	Surrounding	Lighting Environment	ILP examples	Corresponding areas in Thanet
E0	Protected	Dark	UNESCO starlight reserves, IDA dark sky parks	None
E1	Natural	Intrinsically dark	National Parks, Areas of Outstanding Natural Beauty etc	Landscape Character Areas associated with Pegwell Bay and former Wantsum Channel, and European Marine Sites
E2	Rural	Low district brightness	Village or relatively dark outer suburban locations	Rural areas outside of the built confines Includes Green Wedges
E3	Suburban	Medium district brightness	Small town centres or suburban locations	Urban areas and villages
E4	Urban	High district brightness	Town/city centres with high levels of night time activity	Amusement are at Margate Seafront

1.2.4 Policy SE08 – Light Pollution states that development proposals that require specific lighting in connection with the operation of the proposed development will be permitted if it can be demonstrated that:

1) It has been designed to minimise light glare, light trespass, light spillage and sky glow through using the best available technology to minimise light pollution and conserve energy;

2) There is no adverse impact on residential amenity and the character of the surroundings;

3) There is no adverse impact on sites of nature conservation interest and/or protected and other vulnerable species and heritage assets;

4) There is no adverse impact on landscapes character areas, the wider countryside or those areas where dark skies are an important part of the nocturnal landscape;

5) It does not have an adverse impact on long distance views or from vantage points; and

6) Where appropriate, mitigation measures are proposed.

1.2.5 The policy continues "*In addition a lighting strategy may be required for large developments or for those developments with specific lighting requirements*" and that "*A Landscape and visual Impact Assessment with be required for proposed developments that fall in to the E1 category.*"

[2] Thanet District Council. (2018). *Draft Local Plan to 2031. Pre-submission version, regulation 19.* [online]. Available at https://www.thanet.gov.uk/wp-content/uploads/2018/11/CD1.1-Draft-Thanet-Local-Plan-Reg-19.pdf

1.3 Structure of this report

1.3.1 The structure of this report is as follows:

- **Section 2 Methodology**. This includes a schedule of viewpoints considered in the assessment of visual impact on night-time views and confirmation of the assessment methodology;
- **Section 3 Assessment of visual impact on night-time views**. This includes a description of the baseline view at night-time from the twelve viewpoints considered in the assessment and an assessment of the visual effects at night.
- **Section 4 Conclusions.**

1.3.2 The addendum is accompanied by two appendices as follows:

- Appendix A: External Lighting Strategy (prepared by RPS, 2019); and
- Appendix B: Manston Airport Lighting Impact Assessment – Baseline Survey Report (prepared by Services Design Solution Ltd, 2018).

2. Methodology

2.1 Viewpoints used in the addendum

2.1.1 The viewpoints considered in this addendum are those for which night-time photography was obtained in September and October 2017. These viewpoints were selected either due to their proximity to the proposed development or as a result of requests from consultees for their inclusion. The location of these viewpoints is shown on Figures 11.7 and 11.8 of Volume 4 of the ES whilst baseline night-time photographs are presented in Figures 11.22 to 11.29.

2.1.2 The schedule of twelve viewpoints is included in Table 2.1.

Table 2.1 Night-time viewpoint locations

Viewpoint Reference	Viewpoint name	Approximate grid reference	Reason for selection	ES figure reference
Vpt 1	RAF Manston Museum car park	633315, 166524	Included due to its close proximity to the proposed development	Figure 11.22a and 11.22b
Vpt 2	Manston Road	634032, 167145	Included due to its close proximity to the proposed development	Figure 11.23
Vpt 3	Canterbury Road West Public Right of Way (PRoW)	634366, 165089	Included due to its close proximity to the proposed development	Figure 11.24
Vpt 5	A256 Haine Road	635205, 165114	Included due to its close proximity to the proposed development	Figure 11.24
Vpt 6	B2050 western edge of Manston	634619, 166204	Included in the 2017 PEIR	Figure 11.25
Vpt 7	Vincent Road near Flete Farm	634481, 167555	Request for viewpoint to be assessed at night-time made by Thanet District Council	Figure 11.26
Vpt 9	Minster Road, Acol	630872, 166840	Included in the 2017 PEIR	Figure 11.26
Vpt 11	Viking Coastal Trail, Cottingham Road	633107, 164479	Request for viewpoint to be assessed at night-time made by Thanet District Council	Figure 11.27
Vpt 12	A256, Cottington Road Bridge	633790, 164232	Request for viewpoint to be assessed at night-time made by Thanet District Council	Figure 11.27
Vpt 14	Junction of High Street & Shottendane Road, southern Garlinge	633511, 168850	Request for viewpoint to be assessed at night-time made by Thanet District Council	Figure 11.28
Vpt 15	PRoW, Shottendane Road	632531, 168633	Request for viewpoint to be assessed at night-time made by Thanet District Council	Figure 11.28
Vpt 20	North side of bridge at Plucks Gutter	626980, 163458	Included in the 2017 PEIR	Figure 11.29

2.2 Assessment Methodology

2.2.1 The *Guidelines for Landscape and Visual Impact Assessment Third Edition*[3] (hereafter referred to as GLVIA 3) set out considerations for determining the sensitivity of visual receptors which were included in the methodology used for the LVIA as set out in Section 11.7 of the ES. GLVIA 3 does not distinguish between the sensitivity of visual receptors during day-light hours and during the night-time.

2.2.2 In the absence of guidance in GLVIA 3 with regard to the sensitivity of visual receptors at night, a review of the visual sensitivities assigned in Appendix 11.3 of the ES for day-light hours has focused on consideration of:

- Susceptibility to visual change (as set out in Paragraph 6.32 of GLVIA 3) during the hours of darkness as follows:
  - Whether the receptor group at that viewpoint is the same for both day-time and night-time views; and
  - If the receptor group remains the same, whether the activity undertaken is different during the hours of darkness (i.e. residents are primarily resting with their curtains drawn) and whether that affects the extent to which their attention or interest is focussed on the views they experience.
- The value attached to the views experienced (Paragraph 6.37 of GLVIA 3) during the hours of darkness as follows:
  - Whether there is likely to be a change to the value of the view. An appreciation of the landscape and views available is unlikely to be a reason for people using recreational and transport routes at night and is unlikely to be a contributing factor to the quality of the experience of such users. The only exception to this would be if the user was specifically using the route to experience a dark landscape. A review of the viewpoint locations, the Environmental Zones assigned to the viewpoint locations in Table 5.4 of the *Manston Airport Lighting Impact Assessment – Baseline Survey Report* (Appendix B) and the Campaign for Protect Rural England's *Night Blight Mapping* shown in Figure 11.39 of the ES demonstrates that this exception does not apply to the viewpoint locations set out in Table 2.1.

2.2.3 In light of these considerations, in some instances visual receptors will have a lower sensitivity to changes to night-time views than to changes in daytime views.

2.3 Sources of information

2.3.1 This addendum has been informed by the following sources of information:

- The wirelines included in Appendix 11.1 of the ES; and
- Drawings prepared by Abacus and included in the *External Lighting Strategy*[4] which forms Appendix A of this LVIA Addendum.

2.3.2 Reference has also been made to the *Manston Airport Lighting Impact Assessment – Baseline Survey Report*[5] which forms Appendix B of this report. The *Baseline Survey Report* provides a description of

[3] Landscape Institute and Institute of Environmental Management & Assessment (LI and IEMA). (2013). *Guidelines for Landscape and Visual Impact Assessment.* 3rd Ed. Routledge, London and New York.
[4] RPS. (2019). *Manston Airport Development Consent Order External Lighting Strategy*.
[5] Services Design Solution Ltd. (2018). *Manston Airport Lighting Impact Assessment – Baseline Survey Report*

the light sources present at each of the viewpoints set out in Table 2.1 and levels of horizontal and vertical illuminance at each. The report also provides a summary of the Environmental Zone assigned to each viewpoint location.

2.3.3 The conclusion of the *Manston Airport Lighting Impact Assessment – Baseline Survey Report* is that the site is located within an Environmental Zone E3, with the immediate surrounding areas being classified as Environmental Zone E2 (as defined in Table 1.1 above).

2.4 Limitations

2.4.1 Given the outline status of the proposed airport related business development within the 'Northern Grass' area, the lighting design for this area has been based on an indicative layout as illustrated in Annex B of the RPS *External Lighting Strategy*. This layout in based on the maximum design parameters with regard to height and gross floor area of built form and proximity to adjacent sensitive visual receptors. The assessment is based on an indicative lighting design for the airport related business development which is compliant with the thresholds for ILP Environmental Zone E2. This should be considered the maximum parameter for lighting within this area and will be reflected in the design guide to be submitted to the Examiner at deadline 4. Details of ILP Environmental Zones thresholds and means of compliance with such thresholds is provided in the *External Lighting Strategy* in Appendix A.

3. Assessment of visual impact on night-time views

3.1 Assessment of the visual effects of lighting on aircraft

3.1.1 Consideration has been given to the potential effects of lighting on aircraft (including navigational lights, take-off and landing lights and anti-collision beacon lights) landing at and taking off from Manston Airport during the hours of darkness. At Year 10 there would be the equivalent of two flights an hour increasing to approximately four flights an hour by Year 20 between 0700 and 2300. Given the seasonal differences in day light hours it is anticipated that aircraft lighting would be visible in a dark environment for approximately two hours in the summer months (between approximately 2100 and 2300) increasing to a maximum of approximately 8.5 hours during the winter months (between approximately 1530-2300 and 0700-0800).

3.1.2 The intermittent frequency of aircraft landing at or taking off from the airport and the brevity of the period during which aircraft would be visible in receptors views before moving out of the view results in there being no potential for significant visual effects to occur.

3.2 Viewpoint 1 Manston Road close to RAF Manston Museum

Baseline

3.2.1 The baseline night-time view is shown in Figures 11.22a and 11.22b of the ES (Volume 4). This illustrates existing light sources associated with and surrounding the passenger terminal within the existing non-operational airport. There are isolated points of light from a small number of the windows at the properties site along Manston Court Road.

3.2.2 The *Manston Airport Lighting Impact Assessment – Baseline Survey Report* considered this viewpoint as being within Environmental Zone E3.

Assessment

Visual receptor sensitivity

3.2.3 Visual receptor groups at or close to this viewpoint during the day-time are recreational receptors visiting the museum. The visual receptor sensitivity was therefore assessed as Medium during day-light hours (Appendix 11.3 of the ES).

3.2.4 Reference to the website for the RAF Manston History Museum[6] and the Spitfire and Hurricane Memorial Museum[7] indicates that the museums close at 4pm throughout the year. Consequently, visual receptors at Viewpoint 1 during the hours of darkness are likely to be people at their place of work.

3.2.5 Paragraph 6.34 of GLVIA3 notes that visual receptors likely to be less susceptible to change include "*people at their place of work, whose attention may be focussed on their work or activity, not on their*

[6] http://www.rafmanston.co.uk/
[7] https://www.spitfiremuseum.org.uk/visiting

surroundings". They are also likely to place limited value on the views available. As such, the visual sensitivity of receptor groups at or close to this viewpoint during the night-time is assessed as Low.

Description of changes to night-time views

3.2.6 Reference to the wireline included in Appendix 11.1 of the ES and the drawings included in the *External Lighting Strategy* (Appendix A of this report) indicates that lighting on 15m and 10m high masts around Lorry Parks I and J (also referred to in the masterplan as the Airside Car Park and Storage Area) and wall mounted lighting on the northern facades of the Cargo Facilities would be visible beyond the unlit attenuation ponds and Manston Road. Lighting on 25m high masts to the west of the terminal building would also be visible to the south of any lighting introduced along the southern edge of the proposed airport-related business development. These light sources would coalesce to illuminate the middle ground of the view and the structures and components of the airport proposed within it beyond a foreground which would remain dark. The proximity of this viewpoint to the site and the extent of the night-time view in which changes would take place will inevitably give rise to a High magnitude of visual change. When combined with the Low sensitivity of the limited number of visual receptors who may experience this change, the level of visual effect would be Not Significant.

3.3 Viewpoint 2 Manston Road

Baseline

3.3.1 The night-time baseline shown in Figure 11.23 shows that the principal concentration of light is at and around the passenger terminal building and includes several lighting columns with associated localised sky glow. Other sources of light are window illumination at some of the properties sited alongside Manston Court Road in the middle distance and some low-level lighting at the base of the radar tower.

3.3.2 The *Manston Airport Lighting Impact Assessment – Baseline Survey Report* considered this viewpoint as being within Environmental Zone E2.

Assessment

Visual receptor sensitivity

3.3.3 Visual receptor groups close to this viewpoint are residential receptors in properties on the western side of Manston Road. The visual receptor sensitivity assigned in Appendix 11.3 Viewpoint Assessment of the ES was High for day-time views.

3.3.4 When considering the sensitivity to changes to their night-time views for this receptor group, the activity of receptors in their home at night is likely to alter from the day-time (i.e. resting with their curtains drawn) and the extent to which residents' attention is likely to be focussed on their views at night is likely to be lower than in day-light hours. As a consequence, the sensitivity of receptors at or close to this viewpoint at night is assessed as Medium.

Description of changes to night-time views

3.3.5 The indicative lighting layout for the proposed airport-related business development indicates the potential for lighting on 8m high masts to be located on land to the east of the buffer zone which itself would contain a low mound with shrub and tree planting. There is potential for light sources on these elevated masts to be occasionally visible above the intervening landscaped mound to the immediate east of this viewpoint depending on their final siting and height within this part of the site. It is also likely that there would be an increase in sky glow from across the site above a retained dark foreground. The magnitude of visual change to night-time views is likely to be Low which, when combined with Medium sensitivity receptors would result in an effect that it Not Significant

3.4 Viewpoint 3 Canterbury Road West PRoW

Baseline

3.4.1 The baseline night-time view is shown in Figure 11.24. This shows a dark foreground with the highway lighting from the lighting column adjacent to the properties and illuminating highway signage the only sources of light in the view. There are no views of light sources within the current non-operational airport or any sky glow in a northerly direction. The current Jentex site on the northern site of Canterbury Road West is lit with various type of lighting and light sources.

3.4.2 The *Manston Airport Lighting Impact Assessment – Baseline Survey Report* considered this viewpoint as being within Environmental Zone E2.

Assessment

Visual receptor sensitivity

3.4.3 Visual receptor groups at or close to this viewpoint include northbound users of the footpath, residents in properties along the southern side of Canterbury Road West and vehicular receptors travelling along Canterbury Road West. The visual receptor sensitivity (as assigned in Appendix 11.3 Viewpoint Assessment of the ES) was High for users of the PRoW and residents and Medium for vehicular receptors during day-light hours.

3.4.4 When considering the sensitivity to changes to their night-time views for these receptor groups, the activity of receptors in their home at night is likely to alter from the day-time (i.e. resting with their curtains drawn) and the extent to which residents' attention is likely to be focussed on their views at night is likely to be lower than in day-light hours. As a consequence, the sensitivity of receptors at or close to this viewpoint at night is assessed as Medium.

3.4.5 For vehicular and recreational receptors, their activity is likely to remain unchanged from the day-time although the PRoW is unlikely to be heavily frequented during the hours of darkness. The value walkers and motorists place on their night-time view is likely to be lower than in the day-time with appreciation of the landscape unlikely to be a motive for using the route at night with users attention focused on their immediate surroundings. As a consequence, the sensitivity these receptor groups at night would be lower than in day-light hours (i.e. Medium for the limited number of users of the PRoW and Low for vehicular receptors).

Description of changes to night-time views

3.4.6 Reference to the wireline for Viewpoint 3 in Appendix 11.1 of the ES indicates that all built structures proposed within the site would be sited below the intervening landform formed by the bund along the northern side of Canterbury Road. This has the consequence that the proposed lighting within the site would also not be visible from this viewpoint. The exception is any additional lighting required within the fuel store which occupies the current Jentex site although this is likely to be incremental to that which is already present as part of the baseline.

3.4.7 The proposed lighting across the site would contribute to a low level of sky glow above the dark horizon. A Low magnitude of change is predicted for vehicular receptors travelling eastbound or westbound along Canterbury Road West and residents in properties along the southern side of the road as a result of additional lighting within the Jentex site whilst a Negligible magnitude of change is predicted for users of the PRoW as a consequence of the presence of sky glow to the north. For all receptors at or close to this viewpoint, visual effects at night-time would be Not Significant.

3.5 Viewpoint 5 A256 Haine Road

Baseline

3.5.1 The existing night-time view is shown in Figure 11.24. This shows a foreground lit by highway lighting along Canterbury Road West with a dark middle ground in the direction of the site. Domestic lights associated with housing in the northern part of Cliffs End and on the southern edge of Manston are visible to the west.

3.5.2 The *Manston Airport Lighting Impact Assessment – Baseline Survey Report* considered this viewpoint as being within Environmental Zone E2

Assessment

Visual receptor sensitivity

3.5.3 Visual receptor groups experiencing views at or close to this viewpoint are westbound vehicular receptors travelling along Canterbury Road West. The visual receptor sensitivity (as assigned in Appendix 11.3 Viewpoint Assessment of the ES) was assessed as Medium during day-light hours.

3.5.4 A review of the likely receptor group and activity of those receptors at or close to this viewpoint during the hours of darkness has identified that these are likely to remain the same as during day-light hours. However, the value motorists place on their views at night is likely to be lower with the appreciation of the landscape not the primary concern. As a consequence, the sensitivity of vehicular receptors to changes to their night-time views is assessed as Low.

Description of changes to night-time views

3.5.5 All proposed structures within the site would be screened by intervening landform as illustrated in the wireline for Viewpoint 5 in Appendix 11.1 of the ES. As such all lighting proposed within the airport would also be screened by the landform with the CAT III approach lights which are the closest form of lighting to this viewpoint set into the ground. The increase in sky glow beyond a lit foreground would lead to a Negligible magnitude of visual change. Visual effects on night-time views would be Not Significant.

3.6 Viewpoint 6 B2050 western edge of Manston

Baseline

3.6.1 The baseline night-time view is presented in Figure 11.25. This shows a cluster of light sources close to the existing passenger terminal within the non-operational site located in the middle-ground. Other light sources are associated with the residential properties on Manston Court Road and on top of the telecommunications tower west of Manston Road.

3.6.2 The *Manston Airport Lighting Impact Assessment – Baseline Survey Report* considered this viewpoint as being within Environmental Zone E2.

Assessment

Visual receptor sensitivity

3.6.3 Visual receptor groups located at or close to this viewpoint include residential receptors in four properties (Jubilee Cottages) on the western edge of Manston. The visual receptor sensitivity (as assigned in Appendix 11.3 Viewpoint Assessment of the ES) was High during day-light hours.

3.6.4 At night-time, the activity of residents in their home would alter from the day-time (i.e. primarily resting with their curtains drawn) and the extent to which residents' attention is likely to be focussed on their views at night is likely to be lower than in day-light hours. As a consequence, the sensitivity of receptors at or close to this viewpoint at night is assessed as Medium.

Description of changes to night-time views

3.6.5 Visual effects on night-time views would be incremental with regularly spaced lighting within the passenger car park extending to the fore of existing light sources which are the existing focus of the view. These would extend southwards in front of the proposed business aviation hangers beyond a retained dark foreground. The design of luminaries would direct light downwards with the consequence that whilst the lower facades of structures beyond the passenger car park may be visible, the apparent massing and scale of the proposed built form is likely to be lower than in day-light hours. Light sources at aprons to the south of the cargo facilities may be partially visible between or above proposed mid-ground structures. This incremental change to the middle-ground of views would give rise to a Medium magnitude of change to the night-time views of a limited number of resident (at the four properties which comprise Jubilee Cottages) which would be Not Significant.

3.6.6 The magnitude of visual would be lower for the remaining residents at Manston as a result of properties either being oriented away from the site or having sufficient foreground screening to limit views towards the site.

3.7 Viewpoint 7 Vincent Road near Flete Farm

Baseline

3.7.1 The baseline night-time view is shown in Figure 11.26. This shows a dark fore, middle and background to the central part of the view with light sources present to the southwest clustered along Manston Road. The most notable of these is the radar tower within the application site with its red warning light on the top.

3.7.2 The *Manston Airport Lighting Impact Assessment – Baseline Survey Report* considered this viewpoint as being within Environmental Zone E2.

Assessment

Visual receptor sensitivity

3.7.3 Visual receptor groups located at or close to this viewpoint are vehicular receptors using Vincent Road. The visual receptor sensitivity (as assigned in Appendix 11.3 Viewpoint Assessment of the ES) was Medium during day-light hours.

3.7.4 A review of the likely receptor group and activity of those receptors at or close to this viewpoint during the hours of darkness has identified that this is likely to remain the same as during day-light hours. However, the value motorists place on their views at night is likely to be lower with the appreciation of the landscape not the primary concern. As a consequence, the sensitivity of vehicular receptors to changes to their night-time views is assessed as Low.

Description of changes to night-time views

3.7.5 The wireline for Viewpoint 7 included in Appendix 11.1 shows that built form associated with the proposed airport related business development within the 'Northern Grass' area would be visible and would screen views of structures proposed within the airport to the south. Any lighting introduced along the northern edge of the 'Northern Grass' area would be visible as would any lighting proposed further to the south which may be framed between buildings along the northern edge, the exact layout of which is not known as a consequence of the outline status of the application for this area. These light sources would be visible above a currently dark horizon leading to an increase in lighting in the night-time view. The foreground of the view would continue to be dark and the magnitude of visual change is predicted to be Medium. Combined with the Low sensitivity of receptors at night, this would give rise to visual effects which would be Not Significant.

3.8 Viewpoint 9 Minster Road, Acol

Baseline

3.8.1 The baseline night-time view is presented in Figure 11.26. Highway lighting along the western side of Minster Road provides a lit foreground and a well-lit middle-ground beyond a dark agricultural field. Numerous light sources along the western boundary of the Cummings Power Generation complex and wall mounted light sources on the façade contribute to this well-lit middle-ground alongside additional light sources associated with other industrial units within Manston Business Park to the south. There are no views of light sources within the current non-operational airport.

3.8.2 The *Manston Airport Lighting Impact Assessment – Baseline Survey Report* considered this viewpoint as being within Environmental Zone E3.

Assessment

Visual receptor sensitivity

3.8.3 Visual receptor groups located at or close to this viewpoint are residential properties located in Acol. The visual receptor sensitivity (as assigned in Appendix 11.3 Viewpoint Assessment of the ES) was assessed as High during day-light hours.

3.8.4 At night-time, the activity of residents in their home would alter from the day-time (i.e. primarily resting with their curtains drawn) and therefore the extent to which residents' attention is likely to be focussed on their views at night is likely to be lower than in day-light hours. The sensitivity of receptors at or close to this viewpoint at night is assessed as Medium.

Description of changes to night-time views

3.8.5 The existing industrial units within the Manston Business Park screen all views of the proposed structures within the Manston Airport site as illustrated in the wireline for this viewpoint included in Appendix 11.1. Consequently, no proposed light sources would be visible in night-time views with the proposed development contributing to a slight increase to the existing levels of sky glow already generated by lighting within the Manston Business Park. This incremental change would be Negligible and visual effects at night would be Not Significant.

3.9 Viewpoint 11 Viking Coastal Trail, Cottingham Road

Baseline

3.9.1 The baseline night-time photograph in Figure 11.27 shows a dark foreground and horizon with very few light sources visible. The exceptions are a small cluster of lights at Red Cottages. There are no views of light sources within the current non-operational airport

3.9.2 The *Manston Airport Lighting Impact Assessment – Baseline Survey Report* considered this viewpoint as being within Environmental Zone E2.

Assessment

Visual receptor sensitivity

3.9.3 Visual receptor groups located at or close to this viewpoint include residents at Dyas farm and receptors traveling along the minor road which forms part of the Regional Cycle Route (RCR) 15 (Viking Coastal Trail). The visual receptor sensitivity was assessed as High for day-light hours.

3.9.4 A review of the likely receptor group and activity of those receptors at or close to this viewpoint during the hours of darkness has identified that this is likely to remain the same as during day-light hours albeit the route is unlikely to be heavily frequented at night. Cyclists are likely to place greater emphasis on their immediate surroundings in the direction of travel at night and the value cyclists place on their night-time view is likely to be lower than in the day-time with appreciation of the landscape unlikely to be a motive for using the route at night. The sensitivity of receptors would be Medium.

Description of changes to night-time views

3.9.5 The wireline for Viewpoint 11 included in Appendix 11.1 of the ES indicates that there would be no views of any of the built elements proposed within the site due to the topography of the rising southern face of the plateau allied with the woodland in around Throne Farm. There would consequently be no views of any light sources within the site. The only change to the night-time view would be an increase in sky glow above a section of the horizon leading to a Negligible magnitude of visual change. Visual effects on night-time views would therefore be Not Significant.

3.10 Viewpoint 12 A256 Cottington Road Bridge

Baseline

3.10.1 The night-time baseline photograph is shown in Figure 11.27. This shows high levels of light sources along the main 'A' roads and junctions within the view, with highways lighting columns visible both below and above the horizon. Elsewhere there are limited sources of light visible, with lighting at Thorne Farm a single light source to the west. There are no views of light sources within the current non-operational airport.

3.10.2 The *Manston Airport Lighting Impact Assessment – Baseline Survey Report* considered this viewpoint as being within Environmental Zone E2.

Assessment

Visual receptor sensitivity

3.10.3 Visual receptor groups at or close to this viewpoint are vehicular receptors (drivers and their passengers) travelling northbound on the A256. The visual receptor sensitivity (as assigned in Appendix 11.3 Viewpoint Assessment of the ES) was assessed as Low during day-light hours.

3.10.4 A review of the likely receptor group and activity of those receptors at or close to this viewpoint during the hours of darkness has identified that these are likely to remain the same as during day-light hours. However, the value motorists place on their views at night is likely to be lower with the appreciation of the landscape not the primary concern. Consequently, the sensitivity continues to be Low.

Description of changes to night-time views

3.10.5 The wireline in Appendix 11.1 of the ES indicates that lighting on 25m high columns to the south of the 20m high cargo facilities would be visible as a series of regularly spaced light sources just above a dark section of the horizon to the west of the Cliffsend Roundabout. A cluster of lights around the Aircraft Recycling Hangars may also be evident in night-time views. Other lighting within the site would either be screened by vegetation around Thorne Farm, by built form proposed within the site or would be lower in height (10-15m) and therefore susceptible to screening by the edge of the plateau.

3.10.6 Given the baseline view in the road network in the middle-ground is well-lit, the magnitude of change is assessed as Low and visual effects would be Not Significant.

3.11 Viewpoint 14 Junction of High Street & Shottendane Road, southern Garlinge

Baseline

3.11.1 The night-time baseline view is presented in Figure 11.28 of the ES which shows isolated sources of light above or close to the horizon beyond a dark foreground. The telecommunications mast west of Manston Road has light sources with a red warning on the top whilst light from the tall lighting columns within the Defence Fire Training and Development Centre site are visible either side of the mast. Further to the left of the view, occasional light sources associated with individual properties and farmsteads are visible.

3.11.2 The *Manston Airport Lighting Impact Assessment – Baseline Survey Report* considered this viewpoint as being within Environmental Zone E2.

Assessment

Visual receptor sensitivity

3.11.3 This viewpoint is representative of residential receptors on the southern edge of Margate. The visual receptor sensitivity (as assigned in Appendix 11.3 Viewpoint Assessment of the ES) was assessed as High for day-time views.

3.11.4 At night-time, the activity of residents in their home would alter from the day-time (i.e. primarily resting with their curtains drawn) and therefore the extent to which residents' attention is likely to be focussed on their views at night is likely to be lower than in day-light hours. The sensitivity of receptors at or close to this viewpoint at night is assessed as Medium.

Description of changes to night-time views

3.11.5 Indicative lighting designs for the 'Northern Grass' area indicate that lighting introduced within this area, particularly along the eastern and northern perimeters, would be visible in the night-time views from this viewpoint. Whilst the dark foreground of the baseline view would be maintained, the level of individual light sources close to or above the horizon would be increased beyond those associated with individual properties and farmsteads which are present in the view to the north of the telecommunications mast and lighting columns within the Defence Fire Training and Development Centre site.

3.11.6 Lighting on 25m high columns at aprons to the south and west of the air traffic control tower may also be visible as a small cluster of lights just above the horizon in the same section of view as the lighting columns within the closer Defence Fire Training and Development Centre site.

3.11.7 All other proposed light sources within the Manston Airport site such as those to the north and south of the cargo facilities are highly likely to be screened by either the proposed built form within the site or as a consequence of the height of the proposed columns north of the cargo facilities (10-15m) which makes them susceptible to screening by the intervening landform as indicated by the wireline in Appendix 11.1.

3.11.8 Given the baseline view in which distant light sources are already visible and that the dark foreground would be maintained, the magnitude of change is assessed as Low and visual effects would be Not Significant.

3.12 Viewpoint 15 PRoW, Shottendane Road

Baseline

3.12.1 The night-time baseline view presented in Figure 11.28 of the ES shows relatively few sources of light above or close to the horizon beyond a dark foreground. Woodchurch Farm buildings and yard are lit features in the middle-distance whilst beyond the farm, a red warning light and upper lit section of the lattice tower of the telecommunications mast to the west of Manston Road is visible. Further east, individual light sources associated with isolated farmsteads and properties located to the north of Manston Airport are discernible in the view.

3.12.2 The *Manston Airport Lighting Impact Assessment – Baseline Survey Report* considered this viewpoint as being within Environmental Zone E2.

Assessment

Visual receptor sensitivity

3.12.3 This view is representative of views from PRoW TM39 which is unlikely to be heavily frequented during the hours of darkness. The visual receptor sensitivity (as assigned in Appendix 11.3 Viewpoint Assessment of the ES) was High for day-time views.

3.12.4 A review of the likely receptor group and activity of those receptors at or close to this viewpoint during the hours of darkness has identified that these are likely to remain the same as during day-light hours albeit the footpath is unlikely to be heavily frequented at night. Walkers are likely to place greater emphasis on their immediate surroundings in the direction of travel at night and the value they place on their night-time view is likely to be lower than in the day-time with appreciation of the landscape unlikely to be a motive for using the route at night. The sensitivity of receptors would be Medium.

Description of changes to night-time views

3.12.5 The wireline for this viewpoint included in Appendix 11.1 of the ES indicates that all proposed built structures within Manston Airport would be screened by a combination of topography and middle-ground built form and vegetation. Even the most elevated light sources on 25m high masts would be screened by the middle-ground elements when compared against the wireline using the 20m high cargo facilities, air traffic control tower and the aircraft recycling hangars as a proxy. There may be some sky glow above a section of the horizon. The magnitude of visual change to night-time views is assessed as Negligible and effects would be Not Significant.

3.13 Viewpoint 20 North side of bridge at Plucks Gutter

Baseline

3.13.1 The baseline night-time view is shown in Figure 11.29 of the ES. This shows a dark fore and middle-ground with the line of regularly spaced highway lighting columns along the A299 between the Monkton Roundabout and Minster Roundabout to the west of Manston Airport visible in the distance. Some sky glow is also evident in the direction of the coastal conurbations. Light sources within Cliffs End are discernible towards the east (right-hand side) of the view.

3.13.2 The *Manston Airport Lighting Impact Assessment – Baseline Survey Report* considered this viewpoint as being within Environmental Zone E2.

Assessment

Visual receptor sensitivity

3.13.3 Visual receptor groups at or close to the viewpoint include residential receptors at Plucks Gutter and receptors travelling north along Gore Street. The visual receptor sensitivity (as assigned in Appendix 11.3 Viewpoint Assessment of the ES) is High (residents) and Medium (vehicular receptors) for day-time views.

3.13.4 At night-time, the activity of residents in their home would alter from the day-time (i.e. primarily resting with their curtains drawn) and therefore the extent to which residents' attention is likely to be focussed on their views at night is likely to be lower than in day-light hours. The sensitivity of residential receptors at or close to this viewpoint at night is therefore assessed as Medium.

3.13.5 For vehicular receptors, their activity remains unchanged during the hours of darkness although the value motorists place on their views at night is likely to be lower with the appreciation of the landscape not the primary concern. As a consequence, the sensitivity of vehicular receptors to changes to their night-time views is assessed as Low.

Description of changes to night-time views

3.13.6 Reference to the wirelines contained within Appendix 11.1of the ES indicates that in night-time views, proposed light sources on 15m and 25m high masts close to the aprons to the south of the cargo facilities and aircraft recycling hangars (Aprons 1 to 6) would be visible above the crest of the plateau which forms the horizon of the view. This would increase the horizontal field of view in which individual light sources are present to the east of the regularly spaced highway lighting along the A299 and into stretches of existing dark horizon. There may also be an increase in sky glow above the horizon. Given the baseline view in which there is already the presence of lighting above the horizon and sky glow from the coastal conurbations, this increase would give rise to a Low magnitude of change to the night-time view and effects would be Not Significant.

4. Conclusions

4.1.1 A summary of the assessment of the visual impact of the airport on night-time views is provided in Table 4.1.

Table 4.1 Summary of night-time visual effects

Viewpoint reference	Viewpoint name	Visual receptor sensitivity to changes to night-time views	Magnitude of visual change to night-time views	Significance
Vpt 1	RAF Manston Museum car park	Low	High	Not Significant
Vpt 2	Manston Road	Medium	Low	Not Significant
Vpt 3	Canterbury Road West Public Right of Way (PRoW)	Medium (residents and users of PRoW) Low (vehicular receptors)	Low (residents and vehicular receptors) Negligible (users of PRoW)	Not Significant
Vpt 5	A256 Haine Road	Low	Negligible	Not Significant
Vpt 6	B2050 western edge of Manston	Medium	Medium	Not Significant
Vpt 7	Vincent Road near Flete Farm	Low	Medium	Not Significant
Vpt 9	Minster Road, Acol	Medium	Negligible	Not Significant
Vpt 11	Viking Coastal Trail, Cottingham Road	Medium	Negligible	Not Significant
Vpt 12	A256, Cottington Road Bridge	Low	Low	Not Significant
Vpt 14	Junction of High Street & Shottendane Road, southern Garlinge	Medium	Low	Not Significant
Vpt 15	PRoW, Shottendane Road	Medium	Negligible	Not Significant
Vpt 20	North side of bridge at Plucks Gutter	Medium (residents) and Low (vehicular receptors)	Low	Not Significant

4.1.2 The assessment of visual effects on night-time views indicates that the impact of the Proposed Development on views from all twelve locations would be not significant. A number of factors contribute to these conclusions as follows:

- Whilst a high magnitude of change is predicted for Viewpoint 1 (the RAF Manston Museum car park), the sensitivity of receptors at this viewpoint at night (i.e. workers) is assessed as low.
- For a number of the viewpoints (5, 9, 11 and 15) there are no direct views of light sources proposed within the Manston Airport site. From these viewpoints changes to views would be associated with an increase in sky glow above the horizon. The magnitude of change is assessed to be negligible from these viewpoints
- For the remaining viewpoints, it is considered likely that there would be direct views of lighting sources proposed within the site. However, in these scenarios, the lighting would either be too distant (as in the case of Viewpoint 20 at Plucks Gutter), have a more limited presence being

Appendix LV.1.36

partially screened (such as at Viewpoint 2, 7 and 14) or would be introduced into a view which already contains various levels of lighting with the consequence that effects would be incremental (as shown at viewpoints 3, 6 and 12).

- The lighting scheme has been designed to achieve compliance with the International Commission on Illumination (CIE) Guide *CIE 150:2003 Guide on the limitation of the effects of obtrusive light from outdoor lighting installations* for Environmental Zone E2. As noted in Section 2.3, the conclusion of the *Manston Airport Lighting Impact Assessment – Baseline Survey Report* is that the site is located within an Environmental Zone E3, with the immediate surrounding areas being classified as Environmental Zone E2.

4.1.3 The lighting strategy contained within Appendix A sets out the methods that will be used to achieve compliance with the thresholds defined for Environmental Zones E2. Appendices A and B of the *External Lighting Strategy* provide details of indicative lighting designs for the airport and business park respectively. In addition, the appendices to the lighting strategy also provide calculations which demonstrate the performance of the lighting deigns in relation to the thresholds for Environmental Zone E2. These calculations indicate that the lighting design for the business park is fully compliant with the criteria for Environmental Zone E2 whilst the lighting design for the airport complies with all criteria except for that relating post-curfew luminaire intensity. The residential properties that could potentially be affected by this non-compliance are identified in the lighting strategy which also contains proposals for the mitigation of these effects through additional landscaping measures. As such, the lighting strategy and its appendices demonstrate that lighting designs for both the airport and the business park are compliant with the requirements of Environmental Zone E2.

4.1.4 To conclude, this LVIA Addendum provides an assessment of the visual impact of the airport on night-time views from twelve viewpoints within the LVIA study area. No significant effects are predicted.

wood.

Appendix A
External Lighting Strategy (RPS, 2019)

Appendix B
Manston Airport Lighting Impact Assessment – Baseline Survey Report (SDS Ltd, 2018)

Appendix LV.1.36

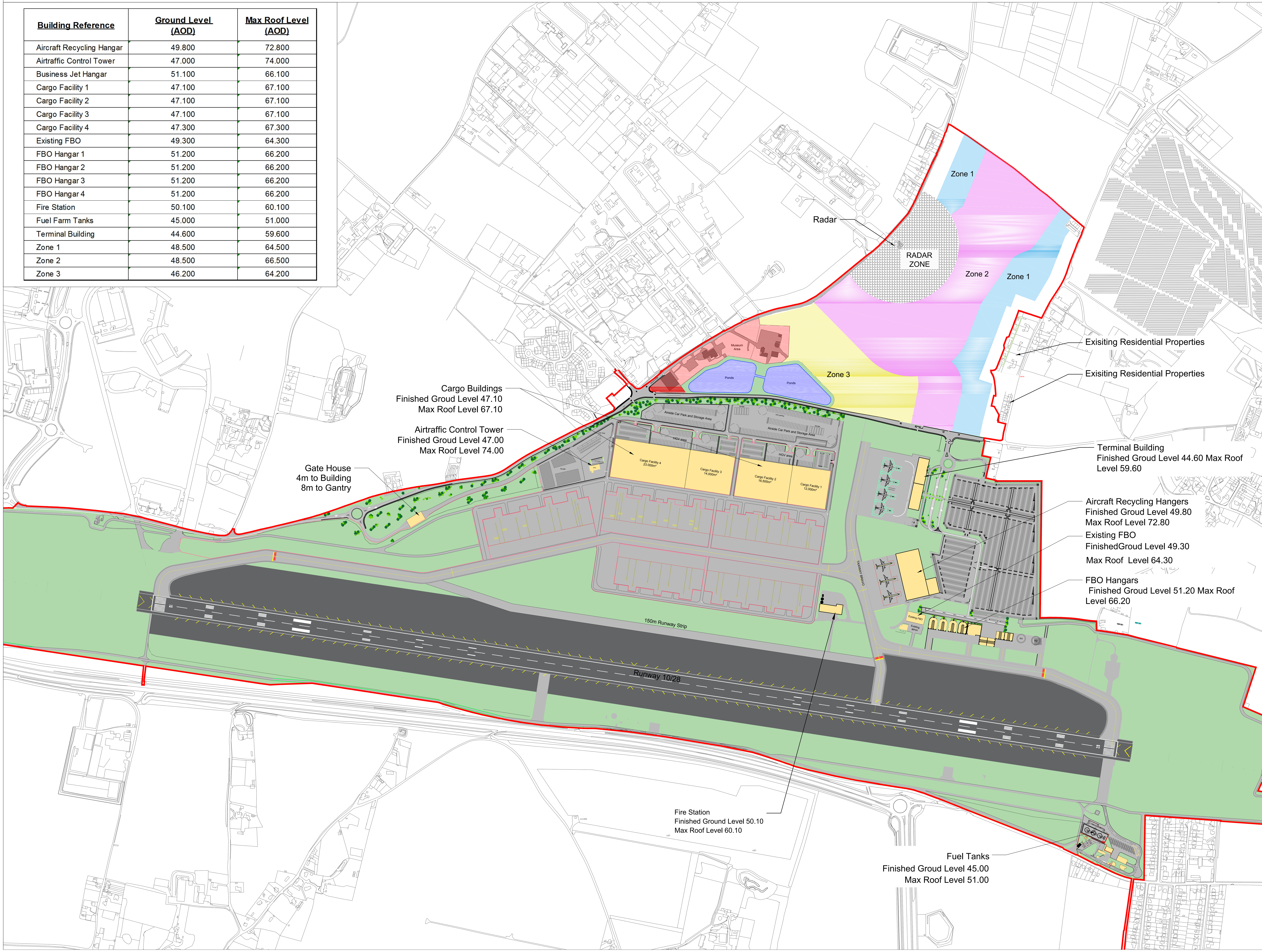
February 2019
Doc Ref. 40820RR004i1

Appendix LV.1.36

MANSTON AIRPORT DEVELOPMENT CONSENT ORDER
ENGINEERING DRAWINGS AND SECTIONS - BUILDING HEIGHT
REGULATION 5(2)(o)
THANET DISTRICT COUNCIL

RSP

Building Reference	Ground Level (AOD)	Max Roof Level (AOD)
Aircraft Recycling Hangar	49.800	72.800
Airtraffic Control Tower	47.000	74.000
Business Jet Hangar	51.100	66.100
Cargo Facility 1	47.100	67.100
Cargo Facility 2	47.100	67.100
Cargo Facility 3	47.100	67.100
Cargo Facility 4	47.300	67.300
Existing FBO	49.300	64.300
FBO Hangar 1	51.200	66.200
FBO Hangar 2	51.200	66.200
FBO Hangar 3	51.200	66.200
FBO Hangar 4	51.200	66.200
Fire Station	50.100	60.100
Fuel Farm Tanks	45.000	51.000
Terminal Building	44.600	59.600
Zone 1	48.500	64.500
Zone 2	48.500	66.500
Zone 3	46.200	64.200



Key

- Order Limits
- Buildings / Structures
- Grassed Area
- Landscaped Area
- Drainage Pond
- Buffer Zone: 45m clearance to first building from site boundary in sensitive areas
- Zone 1: Area of most sensitivity
  - Building height limited to ≤16m above finished ground level height
  - Building use limited to offices
  - Σ Building GFA - ≤30,000m² of B1 development
- Zone 2: Area of moderate sensitivity
  - Buildings limited to ≤18m above finished ground level height
  - Σ Building GFA - ≤60,000m² of B1/B8 development
- Zone 3: Area of minimal sensitivity
  - Building limited to ≤18m above finished ground level height
  - Σ Building GFA - ≤26,000m² of B8 development

Notes

1. OS Data obtained from emapsite™ May 2017:

100m SCALE 1:5000

Rev	Description.	By	Ckd	Apr	Date
P07	ATC ground level correct and key updated	TAW	CJ	GDD	05.02.19
P06	Table and key updated	SO	CJ	GDD	27.03.18
P05	Application Number Added	KA	CJ	CJ	23.03.18
P04	DCO Boundary Updated.	AAG	CJ	GDD	21.03.18
P03	Northern area zones added.	KA	CJ	CJ	23.02.18
P02	Tables of heights added.	SW	CJ	CJ	18.10.17
P01	First Issue.	RS	CJ	GDD	26.09.17

Project MANSTON AIRPORT DEVELOPMENT CONSENT ORDER

Title ENGINEERING DRAWINGS AND SECTIONS - BUILDING HEIGHT REGULATION 5(2)(o) THANET DISTRICT COUNCIL

Document Number: NK018417 - RPS-MSE-XX-DR-C-2060 — Revision: P07

Project Number | Originator - Zone - Level - Type - Role - Drawing Number

Application Number - TR020002

Scale	Sheet Size	Sheet No	Status
1:5000	A1	1 of 1	Preliminary

Implications for the Air Freight Sector of Different Airport Capacity Options

Prepared for the Freight Transport Association
and Transport for London

Final Report

January 2015

York Aviation

Appendix ND.1.7

Contents

The York Aviation contacts associated with this report are:

James Brass
Principal Consultant
Tel: +44 (0)7767 455614
james.brass@yorkaviation.co.uk

Louise Congdon
Managing Partner
Tel: +44 (0)1625 614051
louise.congdon@yorkaviation.co.uk

The Freight Transport Association contact associated with this report is:

Chris Welsh
Director Global and European Policy
Tel: +44 (0)1892 552308
cwelsh@fta.co.uk

Key Points

York Aviation

Appendix ND.1.7

Key Points (1)

- So far, the work undertaken by the Airports Commission has focussed strongly on the needs and requirements of the passenger market at London's airports. Issues around the freight market have largely been underestimated and there are also concerns in the freight industry that the Commission has little understanding of how the air freight market operates or its importance in supporting the UK economy.
- Air freight accounts for about 40% of UK imports and exports by value. It is an essential enabler for a wide range of industry sectors, handling high value goods, which require rapid, secure and reliable transport to destinations all over the globe.
- The UK air freight market is dominated by London and more specifically by Heathrow. In 2013, the main London airports handled around 1.8 million tonnes of freight, with Heathrow accounting for around 1.4 million tonnes.
- Air freight tonnage at the London airports has grown over the last 20 years. However, this disguises a worrying trend. The market grew rapidly until 2000, but since that time it has largely stagnated. This stagnation has coincided with growing capacity constraints at Heathrow and the inability of the London hub to grow in terms of Air Transport Movements (ATMs). The air freight market in London is already being constrained by the capacity issues at Heathrow. It is also seems clear that to a significant degree other airports cannot step in to provide relief as they do not have the long haul networks to support bellyhold capacity. Only Stansted, with its significant spare runway capacity, has emerged as an alternative for pure freighter airlines.
- Air freight is a significant driver for the UK economy. Damaging its ability to function effectively in the longer term through the failure to deliver capacity improvements or the development of the wrong options could have serious implications for the UK economy.
- In 2010, Steer Davies Gleave (SDG), as part of their work for Department for Transport on Air Freight in the UK, estimated the total economic footprint of the sector (direct, indirect and induced effects) to be around £7.3 billion in Gross Value Added (GVA) and 135,300 jobs. The impact of the sector on the wider economy is difficult to quantify effectively. However, SDG estimated that the total value of air freight services including wider impacts to the UK economy was around £14.3 billion and 282,400 jobs.
- By 2050, the London system airports will be full if either no capacity is added or a third runway is added at Heathrow or a second runway is built at Gatwick. Only a 4 Runway Hub would provide some spare capacity at 2050. This has significant implications for the ability to service air freight demand from London. We would expect significant volumes to have to be trucked elsewhere by 2050 in constrained scenarios:
  - No Expansion – 2.1 million tonnes of freight or around half of total freight demand in 2050;
  - Heathrow Runway 3 – 1.2 million tonnes of freight or around 85% of the freight throughput of Heathrow now;
  - 2nd Runway at Gatwick – 1.7 million tonnes of freight.
- This will ultimately have significant negative impacts on the UK economy.
- If no additional capacity is provided in London (No Expansion), the additional trucking costs are estimated to be around £41.6 million per annum in 2050. With a 2nd Runway at Gatwick, these costs reduce to a total of around £36.1 million per annum. Heathrow Runway 3 results in additional costs of around £23.5 million per annum. These costs are likely to be passed through to users of freight services.

Key Points (2)

- There are also potentially significant impacts on freight users time costs from increased transit times. No Expansion of capacity will result in a loss of user time costs of around £378 million per annum. The addition of a second runway at Gatwick improves the situation but the costs are still ultimately significant at around £321 million per annum. Heathrow Runway 3 results in a loss of around £213 million per annum.
- The consequent impacts on long term GVA in the wider economy are again significant. No Expansion results in lost GVA of around £978 million per annum by 2050. Heathrow Runway 3 results in a GVA loss of around £551 million per annum by 2050. 2nd Runway at Gatwick results in a GVA loss of around £836 million per annum by 2050.
- In addition, the impact on the sector's economic footprint (direct, indirect and induced impacts) in 2050 could be :
  - No Expansion – around £637 million in GVA and 6,800 jobs;
  - Heathrow Runway 3 - £359 million in GVA and 3,800 jobs;
  - 2nd Runway at Gatwick - £544 million in GVA and around 5,800 jobs.
- Ultimately, our analysis demonstrates clearly the importance of the provision of sufficient concentrated airport hub capacity in London by 2050. Without this capacity the air freight industry will suffer, as, ultimately, will the end users in the UK economy.

Introduction

York Aviation

Appendix ND.1.7

Introduction

- In August 2014, York Aviation was commissioned by the Freight Transport Association and Transport for London, to consider the potential long term effects on the UK economy from changes in the air freight industry in the UK resulting from different potential development scenarios for runway capacity in London.
- So far, the work undertaken by the Airports Commission has focussed strongly on the needs and requirements of the passenger market at London's airports. The Commission has identified the need for one more runway in London by 2030 and has chosen to focus its work on considering where this additional runway should be located and is currently appraising options at Heathrow and Gatwick and up until September, it was considering the Mayor of London's proposal for a four runway hub in the inner Thames estuary. The Commission has recognised that further runway capacity, beyond the initial additional runway, is likely to be needed soon after 2030 and that certainly by 2050 as, even with one more runway in London, the London airports will be full.
- Clearly, the debate around the location of further runway capacity and, ultimately the amount of further capacity, will not just affect passengers and passenger airlines. There are significant potential implications for air freight operations, with knock-on implications for the broader freight industry and ultimately for freight users. However, to date, issues around the freight market have largely been underestimated in the Commission's publications and there are also concerns in the freight industry that the Commission has limited understanding of how the air freight market operates or its importance in supporting the UK economy.
- This short report seeks to address some of these issues, building on previous work undertaken by York Aviation and on a range of other publicly available information:
  - focussing on potential impacts in the longer term at 2050;
  - examining the implications for air freight capacity in London;
  - considering how the freight industry might react in different scenarios to service demand;
  - identifying and where possible quantifying the potential impacts on freight users.
- The analysis undertaken here necessarily adopts a range of simplifying assumptions given the timescales for the study, the limited availability of information on air freight operations and demand compared to the passenger market and the lack of information on air freight in the forecasting work undertaken by the Department for Transport in its 2013 UK Aviation Forecasts and latterly by the Airports Commission.
- This report is structured as follows:
  - in **Section 2** we set out some basic information on the air freight market in London and across the UK;
  - in **Section 3** we provide some background on the importance of air freight to the economy;
  - in **Section 4** we present our estimates of the impact on air freight capacity in London of the runway development scenarios;
  - in **Section 5** we discuss how the industry might react to these scenarios and present our estimates of the impact on the UK economy;
  - in **Section 6** we outline our conclusions.
- In addition, given the options now being considered by the Airports Commission, we have included an Appendix that specifically considers the relative merits of expansion at Heathrow and Gatwick using the evidence developed during this study.

The Air Freight Market in the UK

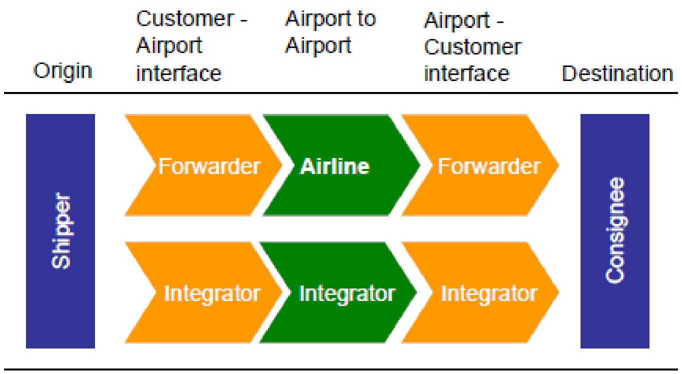
York Aviation

Appendix ND.1.7

Air Freight in the UK

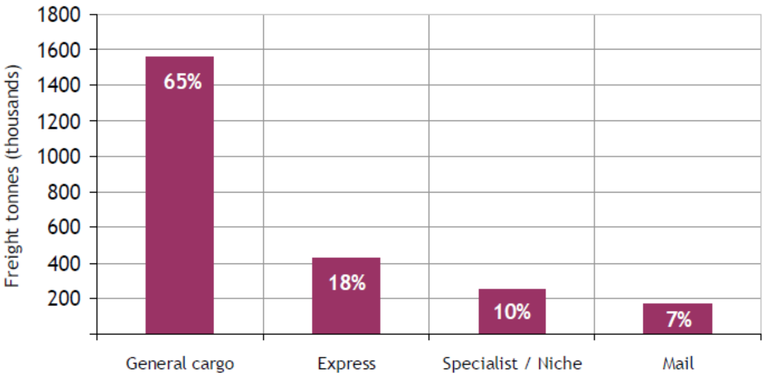
- Air freight accounts for about 40% of UK imports and exports by value. It is an essential enabler for a wide range of industry sectors, handling high value goods, which require rapid, secure and reliable transport to destinations all over the globe. Key users include high end manufacturing, engineering, pharmaceuticals, retailing, financial and business services and the automotive sector.
- Steer Davies Gleave (SDG), in its work for the Department of Transport on UK Air Freight in 2010, identified two broad business models operating in the UK:
  - General Cargo transported by passenger and freight airlines with collection and delivery organised by freight forwarders; and
  - The Integrator model, which tends to focus on smaller consignments, where collection and delivery, and often the air component of the journey are all managed by a single organisation.
- The integrator model, as operated by companies such as DHL, UPS, TNT and Federal Express, has been of growing in importance in the last two decades. This model focussed originally on express courier services but has broadened out substantially. As a consequence, the two models increasingly crossover.
- Broadly, SDG split the air freight market in to four product types. General air cargo, express freight, specialist / niche freight and mail (see figure opposite). Express freight is the fastest growing segment of the market and, while speed is a feature of all air freight, it is within this segment that time critical activities are most extreme.

FIGURE 1.4 SIMPLE DOOR TO DOOR AIR FREIGHT VALUE CHAIN



Source: SDG.

FIGURE 5.1 TOTAL FLOWN UK AIR FREIGHT BY MARKET TYPE 2008 (INBOUND AND OUTBOUND)



Source: SDG analysis of CAA and other sources.

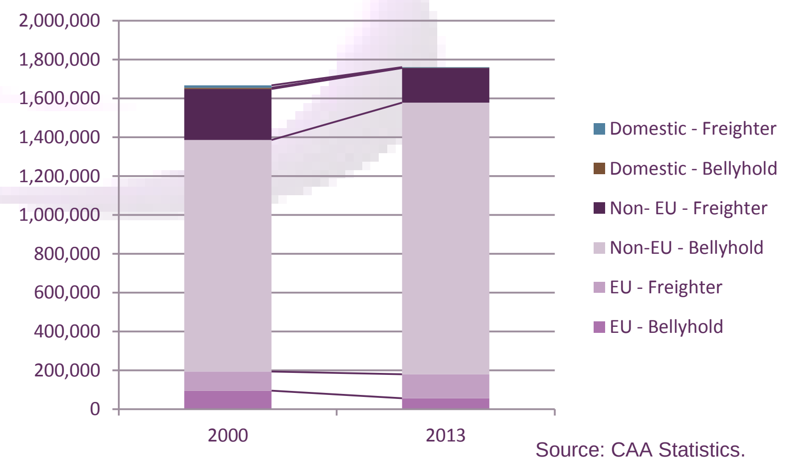
Air Freight Market in London (1)

- The UK air freight market is dominated by London and more specifically by Heathrow. In 2013, the main London airports handled around 1.8 million tonnes of freight, with Heathrow accounting for around 1.4 million tonnes. The only other significant player in the London market was Stansted, which handled around 0.2 million tonnes, with Gatwick handling around 0.1 million tonnes. The market has been largely constant over the last 10 years following rapid growth in the 1990s.
- The air freight market is predominantly long haul and had become increasingly so over time. For domestic and short haul destinations in Europe, it is often cheaper, faster and more flexible to truck freight to its destination. It is difficult to precisely define where the tipping point lies between trucking and air freight in terms of distance. However, for overnight parcels it is believed to around 500km but, for less urgent freight, it could be substantially further.
- Air freight is carried in both the bellyhold of passenger aircraft and in dedicated freighter aircraft. The existence of the former method helps to explain the dominance of Heathrow in the market in London. Heathrow, as a global hub airport, offers by far the largest range of long haul destinations of the London airports and by far the most aircraft capacity. Almost all of the 1.4 million tonnes of freight handled at Heathrow in 2013 was carried in the bellyhold of passenger aircraft. Increasingly, pure freighter operations have moved out of Heathrow as higher yielding passenger services have taken over their slots. The same is true of air freight operations at Gatwick
- Conversely, at Stansted Airport, the only other major player in the London market, the focus is on pure freighter aircraft, operated by a range of freight airlines. The Airport's passenger airlines focus on short haul travel using narrow body aircraft. Their business models do not fit well with carrying freight, particularly the low fares airlines.

Freight Tonnage at London Airports

Source: CAA Statistics.

Freight Tonnage at London Airports by Destination and Configuration

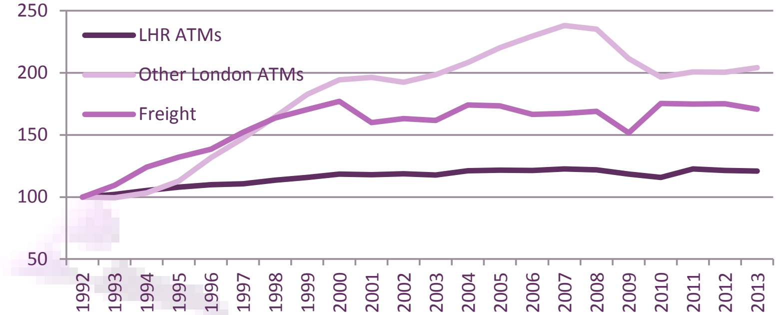


Source: CAA Statistics.

Air Freight Market in London (2)

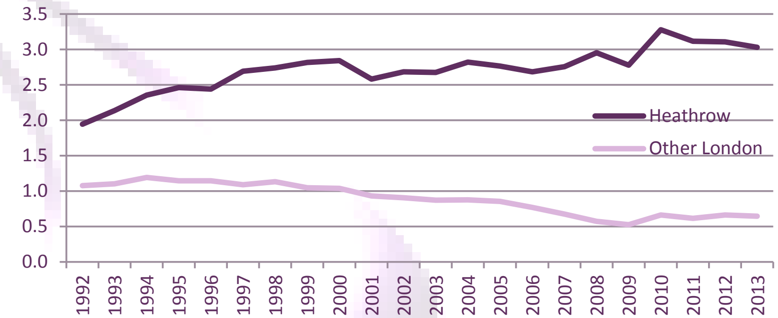
- Air freight tonnage at the London airports has grown over the last 20 years. However, this disguises a worrying trend. The market grew rapidly until 2000, but since that time it has largely stagnated. This stagnation has coincided with growing capacity constraints at Heathrow and the inability of the London hub to grow in terms of Air Transport Movements (ATMs).
- This is demonstrated in the chart opposite which shows freight tonnage tracking ATM growth at Heathrow. The growth in ATMs across the London system as a whole appears to have had no influence at all on air freight growth. This re-emphasises the importance of Heathrow in the air freight market as the primary provider of air freight capacity. The other airports, without Heathrow's long haul connections, simply do not provide an alternative. Only Stansted, with its significant spare runway capacity, has emerged as alternative for pure freighter airlines, albeit the range of destinations served by these aircraft is substantially smaller than is available using bellyhold capacity in passenger aircraft.
- The impact of constraint at Heathrow can also be seen in terms of the increasing freight loads per movement at the airport. Since 1992, the average amount of freight per movement has grown from around two tonnes to around three tonnes. At the same time, the average load at the other London airports has nearly halved, with airlines at the other London airports increasingly focussing on low cost, short haul travel.
- It is also interesting to compare Heathrow's performance to the other major European hub airports. In the last 10 years, both Paris and Frankfurt have outperformed Heathrow. Amsterdam was performing well prior to the global recession but experienced a more significant drop in freight throughput than the others and has still not recovered.
- Overall, it seems to reasonable to suggest that the air freight market in London is already being constrained by the capacity issues at Heathrow. It is also seems clear that to a significant degree other airports cannot step in to provide relief as they do not have the long haul networks to support bellyhold capacity.

Freight Tonnage vs ATM Growth (Index: 1992 = 100)



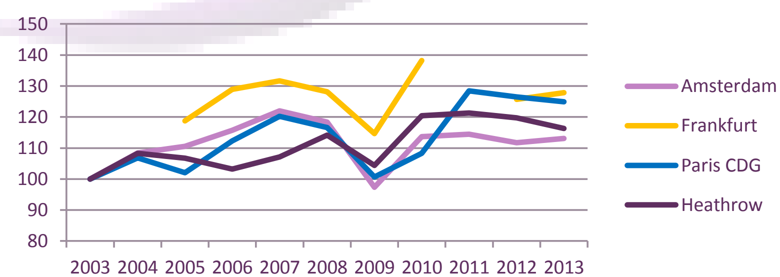
Source: CAA Statistics.

Freight Tonnes per Movement



Source: CAA Statistics.

Freight Tonnes at Europe's Hub Airports (Index: 2003 = 100)



Source: Eurostat.

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Air Freight in the Rest of the UK

- Outside of London and the South East, there are only a limited number of UK airports with a significant air freight presence (the main London airports account for 77% of the market).
- East Midlands is by some margin the most significant freight airport outside London, with nearly 0.3 million tonned. It focuses on pure freighter operations and is the main UK base for DHL and a significant base for UPS and TNT.
- Manchester Airport is the largest bellyhold freight airport outside of London. The airport is also the largest long haul passenger gateway outside London, so this is not surprising. Birmingham Airport also has some bellyhold freight traffic, supported by the airport's long haul services, but is substantially smaller than Manchester.
- Manston Airport in Kent did, until recently, provide some additional freighter capacity for London. However, the airport closed in May 2014 following financial difficulties.
- Overall, this suggests that there is no 'ready made' solution to air freight capacity constraints in London immediately obvious in the UK regions.
- East Midlands clearly has the potential and capacity to be significant freighter only location but does not have a long haul passenger offer to support a bellyhold capability.
- Manchester has some potential to offer an alternative for bellyhold freight but is obviously a considerable distance from London and alternatives on the continent, such as Paris CDG or Amsterdam, offer a significantly greater long haul networks if freight needs to be trucked some distance.
- Birmingham may offer some options for bellyhold capacity but again will struggle to compete with the broader long haul networks at the continental hubs.

Air Freight Tonnes at UK Airports

	Tonnes	%
London - Bellyhold	1,455,725	64%
London - Freighter	304,965	13%
East Midlands - Bellyhold	16	0%
East Midlands - Freighter	266,952	12%
Manchester - Bellyhold	81,927	4%
Manchester - Freighter	14,446	1%
Manston - Bellyhold	9	0%
Manston - Freighter	29,297	1%
Belfast - Bellyhold	106	0%
Belfast - Freighter	29,181	1%
Birmingham - Bellyhold	15,269	1%
Birmingham - Freighter	5,797	0%
Other UK - Bellyhold	21,763	1%
Other UK - Freighter	42,356	2%
Total	**2,267,811**	**100%**

Source: CAA Statistics.

Current Economic Importance of Air Freight in the UK

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Appendix ND.1.7

The Economic Impact of Air Freight

GVA and Employment Impact of Air Freight on the UK Economy

Source: SDG.

- The importance of air freight to the UK economy can be demonstrated by its economic impact. It is not only important as an economic activity in its own right, providing jobs and supporting Gross Value Added (GVA), but, as we have described above, it also supports significant employment and Gross Value Added in the wider economy through the provision of its services to a range of industries in the UK economy.
- In 2010, SDG, as part of their work for Department for Transport on Air Freight in the UK, considered the economic impacts of the sector on the UK economy. It estimated that air freight services directly supported around £2 billion in GVA and around 39,100 jobs. In addition, through its supply chain (indirect effects) and through the expenditure of incomes earned in the direct and supply chain activities (induced effects), it supported significant GVA and employment. SDG estimated the total economic footprint of the sector (direct, indirect and induced effects) to be around £7.3 billion in GVA and 135,300 jobs.
- The impact of the sector on the wider economy is difficult to quantify effectively. However, using a multiplier analysis based on the UK input-output tables, SDG developed an estimate of what it termed forward linkage effects in the economy. Taking these impacts into account, SDG estimated that the total value of air freight services to the UK economy was around £14.3 billion and 282,400 jobs.
- Given the dominance of London in the air freight market in the UK, it is reasonable to assume that a significant proportion of these benefits accrue in the greater South East region and relate to activity at the London airports.
- This analysis also begins to demonstrate what is at stake in terms of the potential impact of different airport capacity development scenarios in London. Air freight is a significant driver for the UK economy. Damaging its ability to function effectively in the longer term through the failure to deliver capacity improvements or the development of the wrong options could have serious implications for the UK economy.

Economic Value of Air Freight to Users

- The value of air freight to users and, hence, ultimately its impact on the wider UK economy is driven by what it offers in terms of advantages over freight transport modes. SDG identified four key features and rated their importance to different users based on surveys and consultations.
- It shows that speed is important for all but, for some, it is a key feature of the service. This is potentially important in considering the potential impacts of different capacity scenarios for London, as, if demand cannot be met within the London system, freight will need to be trucked elsewhere, resulting in longer transit times or earlier final pick-up times for shipments. For some parts of the market, this could represent a critical loss of utility with significant impacts on their operations.
- The other key features are subordinate to speed but for some sectors they are valuable features, notably security for jewellery and art, and reach for aircraft parts.
- A number of quotes from the Freight Transport Association's Sky-High Value report, show the real world importance of air freight to example users. FTA members clearly demonstrate the importance of the existing Heathrow hub to their operations.

> Ford's air freight needs can vary considerably, from a handful of parts to significant volumes. These can be sent by air in response to scheduling or engineering changes and Ford can also air-freight prototype parts, urgent replacement parts for customer vehicles, and occasionally complete vehicles for auto shows or short-notice testing under different conditions.
> **Ford**

Air Freight Drivers by Importance to Key User Groups

	Security	Speed	Information	Reach
Machinery Parts	●	●●●	●●	●●
Electrical Components	●●	●	●	●
Aircraft Parts	●	●●●	●●	●●●
Jewellery	●●●	●	●●	●
Art	●●●	●	●●	●
High Street Fashion		●		
Pharmaceuticals	●●	●		●
Perishables		●●●		

Key: ● = Important ●● = Very Important ●●● = Key Feature

Source: SDG.

> "It is no coincidence that suppliers to the music industry, as with other sectors such as motor sport, are clustered in the West London area. Heathrow's multiple daily departures for a huge number of international destinations are crucial to the company meeting the ever tightening time pressure on tour schedules."
> **Sound Moves, International Logistics for Bands and Artists**

> "Our products are used in scanning for, and treating, serious health conditions. However, our products decay continually, so it is essential that we can make and ship the product on the same day a clinician orders it, so that they receive a useable amount"
> **Pharmaceutical Manufacturer**

Estimates of Air Freight Demand and Capacity in 2050

York Aviation

Appendix ND.1.7

Potential Runway Capacity Development Scenarios

Forecast Movements and Movement Capacity in the London System in 2050 (000s)

	No Expansion	4 Runway Hub	Heathrow Runway 3	2nd Runway at Gatwick
Forecast Movements				
Heathrow / Hub	480,000	903,000	740,000	480,000
Gatwick	280,000	280,000	280,000	540,000
Other London	592,000	592,000	592,000	592,000
Movement Capacity				
Heathrow / Hub	480,000	1,080,000	740,000	480,000
Gatwick	280,000	280,000	280,000	540,000
Other London	592,000	592,000	592,000	592,000
% ATM Capacity Used	*100%*	*91%*	*100%*	*100%*

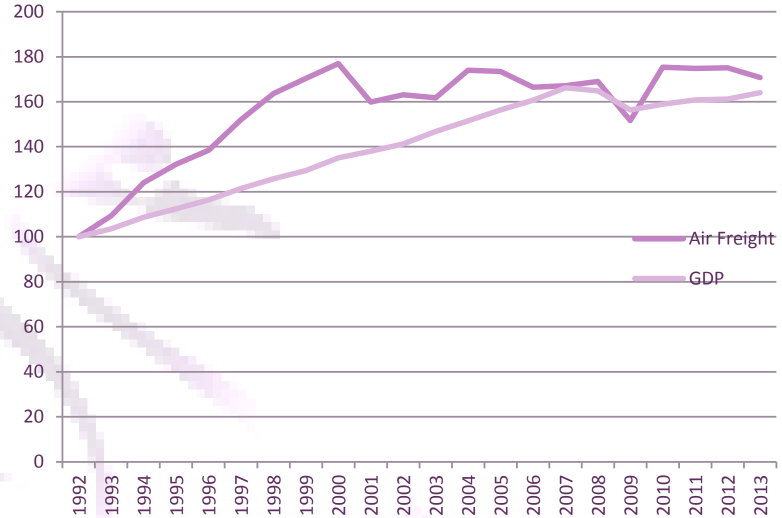
Source: York Aviation analysis of Airports Commission Interim Report, Heathrow and Gatwick submissions.

- In our analysis, we have considered four potential scenarios for runway capacity development in the London system by 2050:
  - No Expansion – no additional runway capacity is built in London before 2050. Movements and movement capacity are as assumed in the Airports Commission Interim Report;
  - 4 Runway Hub – a non-location specific four runway hub airport is developed. This is the only scenario in which there is any spare capacity in the London system. Movements at the hub are assumed to be at a similar level to an unconstrained Heathrow from the Airports Commission Interim Report. Other airports are full and capacities are assumed to be as per the Airports Commission Interim Report. This is included to demonstrate the importance of developing adequate hub capacity in London beyond the 2030 scope of the Airports Commission's current deliberations;
  - Heathrow Runway 3 – a third runway is built at Heathrow, in line with Heathrow Airport Limited's plans as set out on its website. This runway is full before 2050. All other airports are also full and capacities are taken from the Airport's Commission Interim Report;
  - 2nd Runway at Gatwick – a second runway is built at Gatwick in line with Gatwick Airport Limited's published plans on its website. This runway is full before 2050. All other airports are also full and capacities are taken from the Airport's Commission Interim Report.
- These movement forecasts and airport capacities form the basis for our assessment of potential freight capacity in the London system and the extent to which this can meet future demand for air freight in London.

Estimates of Unconstrained Freight Demand at the London Airports in 2050

- Unlike for passenger demand, there are no current published forecasts for air freight demand in the UK. Neither the Department for Transport nor the Airports Commission have produced freight forecasts in any of their recent aviation forecasting work.
- Organisations such as Boeing and Airbus to produce global freight forecasts. However, these typically present an optimistic view of the market, which is not specific to the UK. For instance, Boeing's 2012-2013 World Cargo Forecast predicts global growth of around 5.2% per annum for the next 20 years compared to 3.7% per annum recorded growth over the last 10 years.
- We have, therefore, made a conservative assumption that unconstrained air freight demand in the UK will grow broadly in line with UK GDP through to 2050. The forecasts for GDP growth have been taken from the Office for Budgetary Responsibility's latest short and long term forecasts. These see average per annum growth to 2050 of around 2.3%.
- Given the increasing globalisation of the world economy and the fact that UK trade has tended to grow faster than GDP, we believe this is likely to be a conservative methodology.
- Ultimately, this suggests total unconstrained tonnage demand across the London system in 2050 of around 4.2 million tonnes on a conservative basis.

UK GDP vs. Air Freight at London Airports (Index: 1992 = 100)



Source: ONS and CAA.

Potential Air Freight Capacity in the London System in 2050 (1)

Potential Air Freight Capacity in the London System in 2050

	No Expansion	4 Runway Hub	Heathrow Runway 3	2nd Runway at Gatwick
Total Freight Demand in Tonnes	4,221,831	4,221,831	4,221,831	4,221,831
Bellyhold Capacity				
Heathrow / 4 Runway Hub	1,724,544	3,139,644	2,601,497	1,724,544
Gatwick	127,430	124,775	124,775	465,915
Other London	20,134	19,913	19,913	19,692
Excess Tonnes after Bellyhold	2,349,723	937,499	1,475,646	2,011,680
Residual Freighter Capacity in Constrained Scenarios	240,653	n/a	286,932	286,932
Total Excess Tonnes	2,109,070	937,499	1,188,714	1,724,748
Freighter Movements Required	79,712	35,433	44,927	65,186
Available ATM Capacity	0	177,000	0	0
Accommodated within London with Freighters	0	35,433	0	0
Freight Tonnes to be Diverted Elsewhere	**2,109,070**	**0**	**1,188,714**	**1,724,544**

Source: York Aviation.

- Above, we have considered the potential air freight capacity that might exist in London under different the scenarios. In line with the structure of the market now, we have assumed that the majority of capacity will be provided via aircraft bellyhold freight. We have estimated this capacity based on the number of forecast international movements at the relevant airports in the London system multiplied by the expected average tonnage per international movement in 2050 at each airport. The latter has been derived by taking the tonnes per international movement now estimated from CAA Statistics and growing this by 0.5% per annum to 2050 to reflect increasing loads and larger aircraft. In relation to the 2nd Runway at Gatwick scenario, we have made a further adjustment to allow for the fact that we would expect the airport to attract more long haul services in such a scenario. We have assumed that that tonnage per movement in this scenario would increase significantly to be around double that observed at Gatwick in the other scenarios in 2050. This reflects the Gatwick Airport long term demand forecasts from its submissions to the Airports Commission, which suggest a doubling in the proportion of long haul traffic at the airport by 2050.

Potential Air Freight Capacity in the London System in 2050 (2)

- Within the London system, we have assumed that a hierarchy of preference will exist much as it does now. Heathrow or a 4 Runway Hub will be the first choice for the users of bellyhold freight capacity as they will offer the largest concentration of capacity via their long haul networks and this capacity will be used up first. Excess tonnage will then shift to Gatwick and then finally to other airports in the London system, most likely Stansted.
- For the purposes of this analysis, we have assumed that freighter aircraft primarily act as a means to supplement bellyhold capacity where insufficient bellyhold capacity is available. This is simplification as there are items that cannot be transported on passenger aircraft or for which freighter transport is preferable and destinations that are not served by passenger aircraft. Consequently, we have further assumed that a residual number of freighter movements will still be accommodated in London in capacity constrained scenarios at 2050, i.e. all scenarios other than the 4 Runway Hub.
- These freighter flights may use slots that are not suitable for passenger activities or may simply offer more value than some passenger leisure services and, hence, force such services out of the market. The percentage of total ATMs in the London system accounted for by these services is assumed to be equal to the percentage of pure freighter movements at Heathrow now under these constrained scenarios.
- To the extent that there remains excess tonnage that remains after these two elements of freight capacity have been considered, the scope to accommodate additional freighter aircraft movements within the London system will be dependent on the number of movements entailed and the number of available movements remaining at the airports. As stated above, it is only in the 4 Runway Hub scenario that there is any movement capacity left by 2050 and, hence, it is only in this scenario that any of the excess demand can be accommodated in London. In fact, the available ATM capacity is such all freight demand can be handled at the London airports in this scenario.
- In all the other scenarios, this demand must be satisfied elsewhere at other airports either in the UK or on the continent. By scenario, the excess demand to be accommodated elsewhere is as follows:
  - No Expansion – 2.1 million tonnes of freight or around half of total freight demand in 2050;
  - Heathrow Runway 3 – 1.2 million tonnes of freight or around 85% of the freight throughput of Heathrow now;
  - 2nd Runway at Gatwick – 1.7 million tonnes of freight.

Economic Impacts of Air Freight Development Scenarios

York Aviation

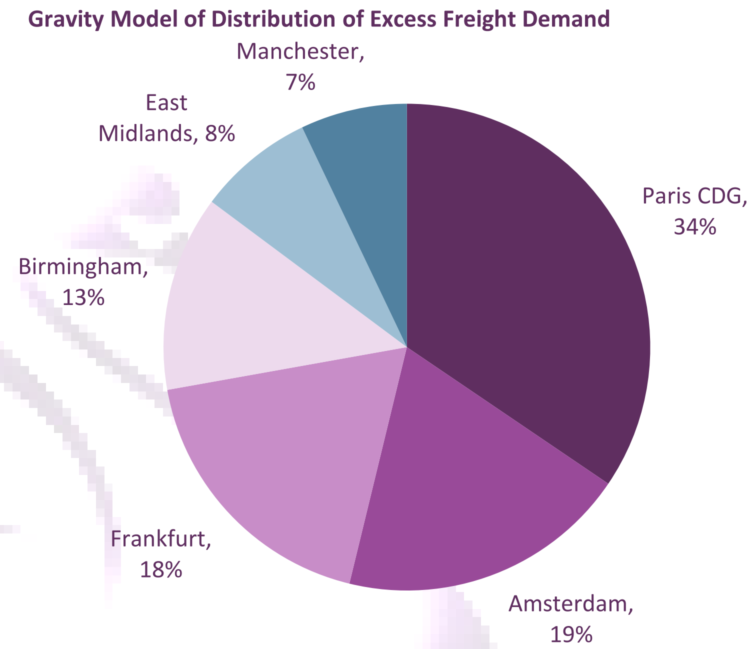
Appendix ND.1.7

How Will the Freight Industry React

- Our analysis of the potential freight demand and capacity within London in 2050 suggests that the air freight industry is likely to face two issues depending on the runway capacity scenario assumed:
  - if a second runway is built at Gatwick and no additional capacity is developed elsewhere, this has the potential to create a second significant geographic node for bellyhold capacity in London. The industry will need to consider how it structures its operations to make best use of this capacity. It should be noted that, while all scenarios involve some use of bellyhold capacity at airports other than Heathrow or a 4 runway hub, it is only in the 2nd Runway at Gatwick scenario that this is likely to represent any more than a business as usual position;
  - where there is significant excess demand that cannot be accommodated within London, the industry will need to examine how it can meet this demand and, in some cases, if it will choose to meet this demand.
- In terms of the first issue, there are potentially three options for companies in the sector:
  - to effectively ignore the shift in the balance of capacity available towards Gatwick and to continue to focus operations on Heathrow, particularly as it is unlikely that Gatwick will offer a significant number of relevant long haul destinations that are not served from Heathrow in any event. This is certainly a possibility for some time. However, we would expect that freight rates at Heathrow would increase to reflect this, with the result that Gatwick would become more attractive for some operators and with the consequence that ultimately bellyhold capacity at both airports would be fully utilised;
  - to split consolidation operations between the two sites. This is perhaps ultimately the most extreme option and it seems unlikely that many would follow this path as it would likely introduce significant inefficiencies in to their operations through duplication of functions. It should, however, be noted that some functions will have to be duplicated for Gatwick to be used at all, for instance transit shed facilities. So, at a less extreme level, there will be an inefficiency cost to the industry. However, within the scope of this work we have not sought to estimate this;
  - The final option is ultimately the most likely. Operators will continue to focus their operations on the main hub but will truck freight to Gatwick to use bellyhold capacity as appropriate. This will impact on the costs faced by the industry, which, in a competitive market, we would ultimately expect to be passed on to freight users. We present estimates of the impact on these costs below. It should also be recognised that transhipment between the two airports increases the chance of service failures and delays, making the option less attractive to operators and impacting ultimately on users. We have not sought to estimate this latter effect in this work and hence impacts may be conservative.
- The options in relation to the excess demand that cannot be satisfied within the London system are subtly different. Again, some companies may simply choose to step back from the London market, either withdrawing or choosing not to seek to expand with demand. This may be particularly true for major global companies with the ability to shift the emphasis of their activity. However, this will ultimately leave unsatisfied demand in and around London and potentially market space for others to step in and seek to serve the market via a different business model. This is most likely to involve trucking freight from London to other airports either in the UK or on the continent that have the necessary capacity and / or long haul passenger networks to support the required levels of demand. This will, however, come at a cost in terms of both additional trucking costs and a loss of utility to users as these avenues will need more time to ship freight, which in an industry where speed is an essential feature is clearly potentially damaging. Again, there is also the potential for increased service failures and delays via this route.
- We consider potential patterns of distribution of this excess demand below.

Gravity Model of Distribution of Excess Demand

- In considering how excess air freight demand from the London system might be served by trucking to other airports in the UK and on the continent, we have developed a basic gravity model to estimate the distribution.
- The model includes three UK airports: the national freight hub at East Midlands and the two primary regional long haul passenger gateways at Manchester and Birmingham. It also includes the three main European hub airports, which all have a significant freight presence now and are likely to grow both bellyhold and freighter capacity in to the future.
- The attraction factor within this model is forecast workload units (a workload unit is one passenger or 100kg of freight) at each airport in 2050 based on the Airports Commission traffic forecasts in its Interim Report. Passenger numbers have been adjusted to reflect the proportion of long haul passengers. Freight is assumed to grow from current levels through to 2050 in line with passenger numbers.
- The distance decay factor within the model is the road haulage cost of transporting a truck load of freight to the relevant airport from London. Freight rates have been derived from data provided by the Freight Transport Association. Distances have been derived from the fastest road route to the destination airport from Google Maps.
- This demonstrates that we would anticipate that a significant proportion of the excess demand will be trucked overseas to the major continental hub airports to take advantage of their extensive long haul networks.
- UK regional airports, despite being substantially closer to London in most cases, cannot match the level of attractiveness offered by the continental hubs and their wider global networks. Consequently, other UK airports are only expected to handle around 28% of any excess demand.



Impacts on the Wider UK Economy

- Drawing on our analysis of the potential capacity implications and operational impacts of the four runway capacity development scenarios set out, we have considered the potential impacts of each scenario on the UK economy.
- We have examined a number of potential streams of impact:
  - the impact on freight costs from additional trucking, either within London in the case of the 2nd Runway at Gatwick scenario or to other UK regional and continental airports where demand has to satisfied away from the London system;
  - the impact on users' utility from increased transit times / earlier cut-off times. As we have discussed, one of the key reasons users choose air freight as a means of transporting goods is speed and, for some parts of the market, speed and time is critical. Therefore, changes in the operating environment that affect speed of delivery or transit times will have an effect on the usefulness or usability (utility) of air freight for some users, which will represent a disbenefit to the economy;
  - the impact on long term productivity in the wider economy from constraints on air freight demand. Ultimately, rising freight costs from additional trucking and the implied rise in costs associated with lost utility to end users will result in reduced demand and impact on productivity in the wider economy, through changes in the ability to trade effectively or decisions around location and investment. This results in lower GVA in the long term;
  - the impact on the sector's economic footprint in the UK from constraints on air freight demand. As we have set out above, air freight services in themselves support significant employment and GVA through their economic footprint (their direct, indirect and induced impact on the economy). Reduced demand for air freight services will ultimately impact on the sector's ability to support this economy activity.

Impact on Freight Costs from Additional Trucking

The Impact on Freight Costs from Additional Trucking in 2050 (2014 Prices)

	No Expansion	4 Runway Hub	Heathrow Runway 3	2nd Runway at Gatwick
Costs of Trucking within London (1)	£0.0	£0.0	£0.0	£2.0
Costs of Trucking to Other UK Airports	£7.5	£0.0	£4.2	£6.2
Costs of Trucking to Overseas Airports	£34.1	£0.0	£19.2	£27.9
Total Additional Costs	£41.6	£0.0	£23.5	£36.1

(1) All scenarios involve some trucking of freight from Heathrow or a new Hub to other airports. However, in most scenarios this is assumed to be 'business as usual', much as it is now. It is only in the second runway at Gatwick scenario that the development of a significant second centre of freight activity is assumed that would result in truly additional trucking costs.

Source: York Aviation.

- Failure to provide sufficient capacity at London's main hub airport or within the London system generally to support the air freight market is likely to result in additional costs to the industry, either from the need to move freight from facilities near to the main hub airport to another airport within London or from London to a range of other airports in the UK or on the continent.
- The costs of trucking in London apply primarily in relation to the scenario whereby a second runway is built at Gatwick and no additional capacity is provided at Heathrow. Using data provided by the Freight Transport Association, we have calculated the number of truck journeys that would be required to move the freight displaced from Heathrow to Gatwick assuming typical loads per truck in the industry and also the likely costs of these journeys based on freight rates. On this basis, we estimate that building a second runway at Gatwick would result in additional costs to the industry of around £2 million per annum from moving freight within London (2014 prices). Much greater costs are, however, incurred by the need to move freight out of the London system to other UK airports or to the continent to meet demand. Again, we have calculated the number of journeys that would be need to accommodate this excess freight tonnage and the associated costs of these journeys.
- If no additional capacity is provided in London (No Expansion) the additional trucking costs are estimated to be around £41.6 million per annum in 2050. With a 2nd Runway at Gatwick, these costs reduce to a total of around £36.1 million per annum. Heathrow Runway 3 results in costs of around £23.5 million. The difference between Heathrow Runway 3 and Second Runway at Gatwick stems primarily from the need to truck freight to Gatwick in the latter scenario.
- A 4 Runway hub provides sufficient capacity such that no additional trucking is required. Hence, there are no additional costs.

Impact on Users Utility from Increased Transit Times / Earlier Cut-off Times

Impact on Users Utility from Increased Transit Times / Earlier Cut Off Times

	No Expansion	4 Runway Hub	Heathrow Runway 3	2nd Runway at Gatwick
Average Increase in Transit Times	158	0	90	136
Time Sensitive Proportion of the Market	30%	30%	30%	30%
Value of Time per Tonne (per hour)	£120.07	£120.07	£120.07	£120.07
Total Impact on Freight User Utility (£m)	**£378**	**£0**	**£213**	**£321**

Source: York Aviation.

- The need to truck freight around London or, more importantly, further afield will impose not only an additional trucking cost but also a utility cost on users that are time sensitive. Users are prepared to pay significant additional amounts for express delivery of air freight and increased transit times or earlier end of day cut off times will impact on these users as the quality of service they experience will be reduced. The value of this time is difficult to calculate and standard values are not available (as they are for passengers). We have, therefore, estimated the extent to which express freight users are willing to pay for an hour's faster delivery for express services using data published in the SDG report for DfT (see assumptions book for additional information). This suggests that value of saving an hour for a tonne of freight for time critical users is around £120.
- For the purposes of this analysis, we have assumed that the time critical portion of the market is approximately represented by the size of the express freight industry. Currently, this is stated by SDG to be around 18% of the market. However, this sector has been growing faster than general air cargo. We estimate that, by 2030 and thereafter, it will account for around 30% of the market.
- The impact on transit times is based on the weighted average of additional time required to truck freight to / from the airport at which it is shipped or received across the market as a whole. This includes freight which continues to travel via its preferred London airport, for which additional trucking time is assumed to be 0. Trucking costs for freight displaced from Heathrow to Gatwick are included.
- The results suggest that there are potentially significant impacts on freight user utility from increased transit times. No Expansion of capacity will result in a loss of user utility of around £378 million per annum. The addition of a second runway at Gatwick improves the situation but the costs are still ultimately significant at around £321 million per annum. Heathrow Runway 3 results in a loss of around £213 million per annum. Only a 4 Runway Hub, which provides sufficient capacity to avoid any additional trucking, does not result in a cost to users.

Impact on Long Term Productivity in the UK Economy (1)

Impact on Wider UK Economy from Lost UK Freight Demand

	No Expansion	4 Runway Hub	Heathrow Runway 3	2nd Runway at Gatwick
Estimated Value of Unconstrained Air Freight Market in 2050 (£m at 2014 prices)	£4,508	£4,508	£4,508	£4,508
Increase in Costs from Trucking and Lost Utility	£419	£0	£236	£358
% Impact on Costs	9.3%	0.0%	5.2%	7.9%
Price Elasticity	-0.5	-0.5	-0.5	-0.5
Lost Tonnage	-196,301	0	-110,639	-167,679
GVA Impact on the Wider Economy (£m at 2014 prices)	**-£978**	**£0**	**-£551**	**-£836**

Source: York Aviation.

- The increase in costs associated with additional trucking and the loss of utility to users will ultimately affect the level of air freight demand in and around London, which will in turn impact on economic activity as productivity will be reduced through channels such as the ability to trade being impaired or companies moving away from the area to a location with the services they need or through lost future investment.
- In previous work for Transport for London Oxford Economics has statistically estimated the link between the level of activity in the economy and a combined index of the level of business air travel and air freight. We have used this relationship to estimate a long term GVA impact of each of the scenarios . The change in the level of demand for air freight is assumed to reflect the percentage increase in total revenues from air freight in the UK caused by increased trucking costs and lost utility to users via a price elasticity relationship. The value of the unconstrained air freight market in 2050 is based on our estimate of air freight demand described above, an analysis of air freight turnover in the UK from the ONS Annual Business Survey and CAA Statistics. This assessment is also consistent with global freight rates as set out in the latest IATA Cargo eChartbook.
- The price elasticity of air freight demand is a poorly researched area. Consequently, we have had to assume an elasticity of around -0.5. This is broadly in line with available data for the price elasticity of business passenger air travel. We believe the figure to be potentially conservative but reasonable in the absence of more specific information.
- The resulting impact on freight tonnage demand in effected scenarios ranges between around 111,000 tonnes (Heathrow Runway 3) and 196,000 tonnes (No Expansion). As before, a 4 Runway Hub has sufficient capacity that the air freight market is not constrained and hence there is no loss.

Impact on Long Term Productivity in the UK Economy (2)

- The consequent impacts on GVA are again significant:
  - No Expansion results in lost GVA of around £978 million per annum by 2050;
  - Heathrow Runway 3 results in a GVA loss of around £551 million per annum by 2050;
  - 2nd Runway at Gatwick results in a GVA loss of around £836 million per annum by 2050.
- In 2013, Oxford Economics in its work for TfL estimated that the GVA loss from constrained business travel would be around £6.9 billion per annum in 2050. Considering the relative sizes of the passenger and freight markets at the London airports, this demonstrates that the impact from the impairment of freight services should be taken at least as seriously as that from passenger markets. The impacts are likely to be proportionately significant.

Impact on Air Freight's Economic 'Footprint'

GVA and Employment Impact on the Air Freight Services Sector Economic Footprint

	No Expansion	4 Runway Hub	Heathrow Runway 3	2nd Runway at Gatwick
Direct Effect				
GVA Lost (£m at 2014 prices)	£174	£0	£98	£149
Employment Lost	2,000	0	1,100	1,700
Total Economic Footprint Effect				
GVA Lost (£m at 2014 prices)	£637	£0	£359	£544
Employment Lost	6,800	0	3,800	5,800

Source: York Aviation analysis of SDG.

- Finally, we have considered the impact of reduced freight demand in the UK on the sector's economic footprint. For the purposes of this analysis, we have assumed that the loss of demand is equal to that described above in relation to the long term impact on GVA in the wider economy. In other words, we have assumed that much of the processing and consolidation of freight will be retained within the UK before freight is ultimately trucked overseas. In this regard, this may mean that the estimates are conservative in terms of the losses demonstrated. However, we believe this to be the most prudent assumption.
- Based on the previous work undertaken by SDG on the economic impact of the sector, we estimate that the impacts of constraint in the London system will be as follows:
  - No Expansion – around £637 million in GVA and 6,800 jobs;
  - 4 Runway Hub – this an unconstrained scenario and hence there are no impacts;
  - Heathrow Runway 3 - £359 million in GVA and 3,800 jobs;
  - 2nd Runway at Gatwick - £544 million in GVA and around 5,800 jobs.

Summary Comparison Between Heathrow & Gatwick Expansion

York Aviation

Appendix ND.1.7

Summary Comparison Between Heathrow & Gatwick Expansion (1)

- Given the Airports Commission's decision to focus on expansion options relating solely to Heathrow or Gatwick, we have in this Appendix provided some additional analysis of the evidence presented in the main body of the report to consider the relative merits of expansion at Heathrow and Gatwick compared to the No Expansion case.
- We have projected that by 2050, all airports servicing London will have reached full capacity even if either the Gatwick or Heathrow expansions go ahead, which will have significant impact on freight efficiency and the economy. Six key comparisons were made between the Gatwick and Heathrow expansion scenarios and 'No expansion', using the analysis above. These comparisons are presented in the Table below.
- Of the three options, the Heathrow expansion provides the most significant economic benefits, in terms of cost reduction, job creation and minimization of extra costs associated with increased freight transit times. For the six key freight comparisons the Heathrow expansion is on average 43% more economically beneficial than 'No expansion' whereas Gatwick is only on average 15% more beneficial than 'No expansion'. We consider this evidence in more detail overleaf.

Comparison of 'No expansion' to London airports with Gatwick 2nd runway and Heathrow 3rd runway

Projections to 2050	No Expansion	Gatwick 2nd runway	Heathrow 3rd runway	Gatwick 2nd runway % difference	Heathrow 3rd runway % difference
Truck elsewhere (m tonnes)*	2.1	1.7	1.2	19.1%	42.9%
Cost of trucking elsewhere (£m)	41.6	36.1	23.5	13.2%	43.5%
Freight user time costs (£m)	378	321	213	15.1%	43.7%
Lost GVA to wider economy (£m)	978	836	551	14.5%	43.7%
Lost GVA to sector's economy (£m)	637	544	359	14.6%	43.6%
Jobs Lost	6,800	5,800	3,800	14.7%	44.1%

Source: York Aviation

Summary Comparison Between Heathrow & Gatwick Expansion (2)

- The freight comparisons for **six key economic measures** are projections for the year 2050 comparing Gatwick and Heathrow expansions with 'No expansion':
  - **Truck elsewhere:** Significant volumes of freight will be trucked elsewhere to cover the shortfall in air freight capacity in the region. The amount diverted is however reduced if either Gatwick or Heathrow undergo expansion (as opposed to 'No expansion'). If Gatwick is expanded then the amount trucked elsewhere is reduced by almost 20%. Under the Heathrow expansion however, this reduction is more than doubled to 43%;
  - **Cost of Trucking elsewhere:** Heathrow expansion is a saving of nearly 44%, or £18.1 million. Gatwick expansion means the cost reduction is only 13%;
  - **Freight User Time Costs:** Trucking elsewhere also incurs extra costs associated with increased transit times for goods. The 'No expansion' scenario equates to an extra time cost of £378 million. The Gatwick expansion would see this cost lowered by 15%and expansion of Heathrow would result in a lowering of nearly 44% which equates to a saving of £165 million;
  - **Knock-on reduction of Economic Gross Value Addition (GVA):** There is an impact to the wider economy measured by a reduction in Gross Value Addition (GVA) arising from supporting goods and services associated with the air freight industry. The loss to the wider economy is estimated to be £978 million which is reduced by nearly 15% if the Gatwick expansion occurs and around 44% if the Heathrow expansion takes place;
  - **Loss of job creation:** Along with a loss of GVA, there is inevitably a reduction in job creation. With 'No expansion', a total of 6,800 extra jobs would not be created. This is reduced by 1,000 with the expansion of Gatwick and by 3,000 with the expansion of Heathrow.
- Of the three options, the Heathrow expansion provides the most significant economic benefits, in terms of cost reduction, job creation and minimization of extra costs associated with increased freight transit times.

References

York Aviation

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- Impacts on the UK Economy through the Provision of International Connectivity – Oxford Economics for Transport for London (2013)
- London Airports Route Networks in 2050 – York Aviation for Transport for London (July 2013)

Assumptions Book

York Aviation

Appendix ND.1.7

Bellyhold Capacity Assumptions

% International Passenger Movements by Scenario

	No Expansion	New 4 Runway Hub	Third Runway at LHR	2nd Runway at LGW
Hub	93%	90%	91%	93%
Gatwick	96%	94%	94%	91%
Other London	91%	90%	90%	89%

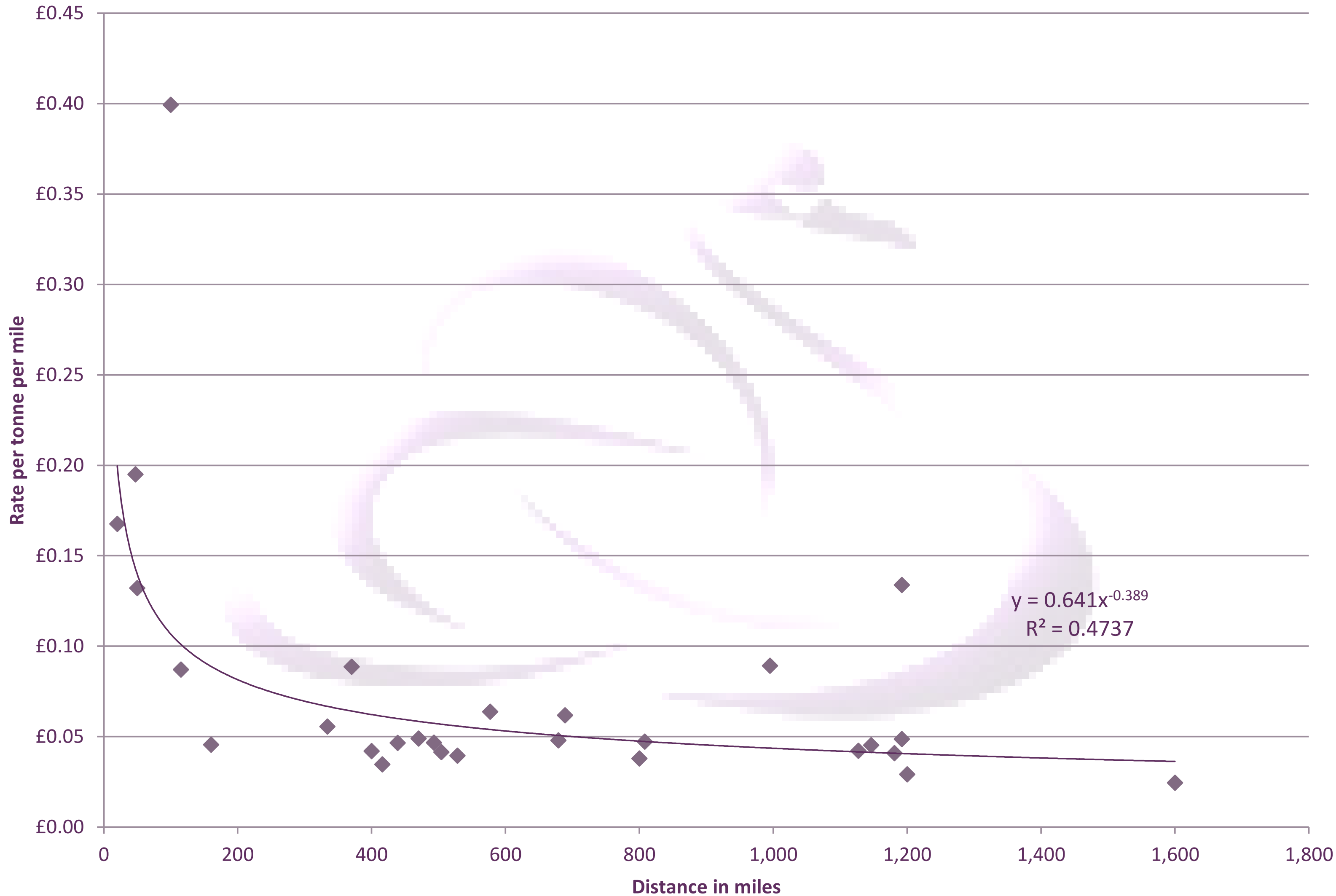
Source: York Aviation London Route Networks 2050 Model.

Freight Tonnes per ATM in 2050

	No Expansion	New 4 Runway Hub	Third Runway at LHR	2nd Runway at LGW
Hub				
Tonnes per Freighter	35.6	35.6	35.6	35.6
Tonnes per Bellyhold Movement	3.9	3.9	3.9	3.9
Gatwick				
Tonnes per Freighter	24.6	24.6	24.6	24.6
Tonnes per Bellyhold Movement	0.5	0.5	0.5	0.9
Other London				
Tonnes per Freighter	24.6	24.6	24.6	24.6
Tonnes per Bellyhold Movement	0.0	0.0	0.0	0.0
London Average				
Tonnes per Freighter	26.5	26.5	26.5	26.5
Tonnes per Bellyhold Movement	2.0	2.0	2.0	2.0

Source: York Aviation analysis of CAA Statistics.

Estimated Road Haulage Rates

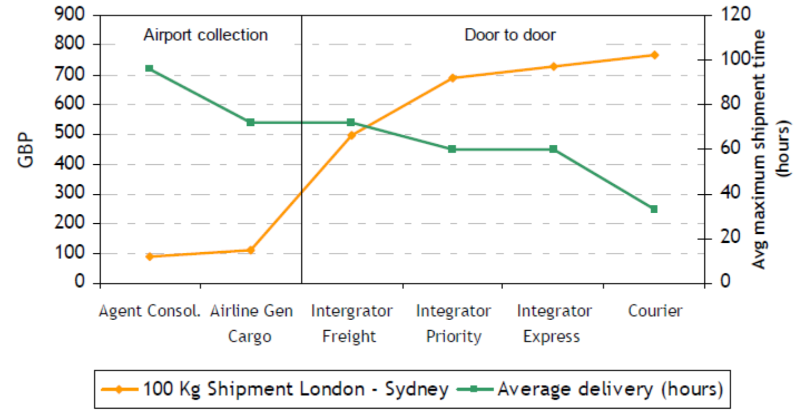


Source: York Aviation analysis of FTA data

Estimate of Value of Time per Hour per Tonne

- A value of time per hour per tonne for time sensitive air freight has been calculated based on the data collected by SDG as part of their work for DfT on Air Freight in 2010.
- The original data has been plotted as an S-curve in the chart below.
- The value of time per hour is assumed to be equal to the average additional amount that would be charged to save an hour on the delivery of a package using an express type service (Integrator Priority, Integrator Express or Courier).
- This has then been converted to a figure for a tonne by multiplying by 10.
- On this basis, the value of time per hour per tonne is around £120.07.

FIGURE 5.3 RELATIONSHIP BETWEEN PRODUCT, SERVICE PROVIDER AND PRICE



Source: Combined tariff from AMI / integrators.

Source: SDG for DfT 2010.

Cost of 100kg Package to Sydney by Delivery Time

Trucking contours - 15 min per hour penalty to demonstrate very heavy traffic:

Manston airport (135mins):

East Midlands (135mins):

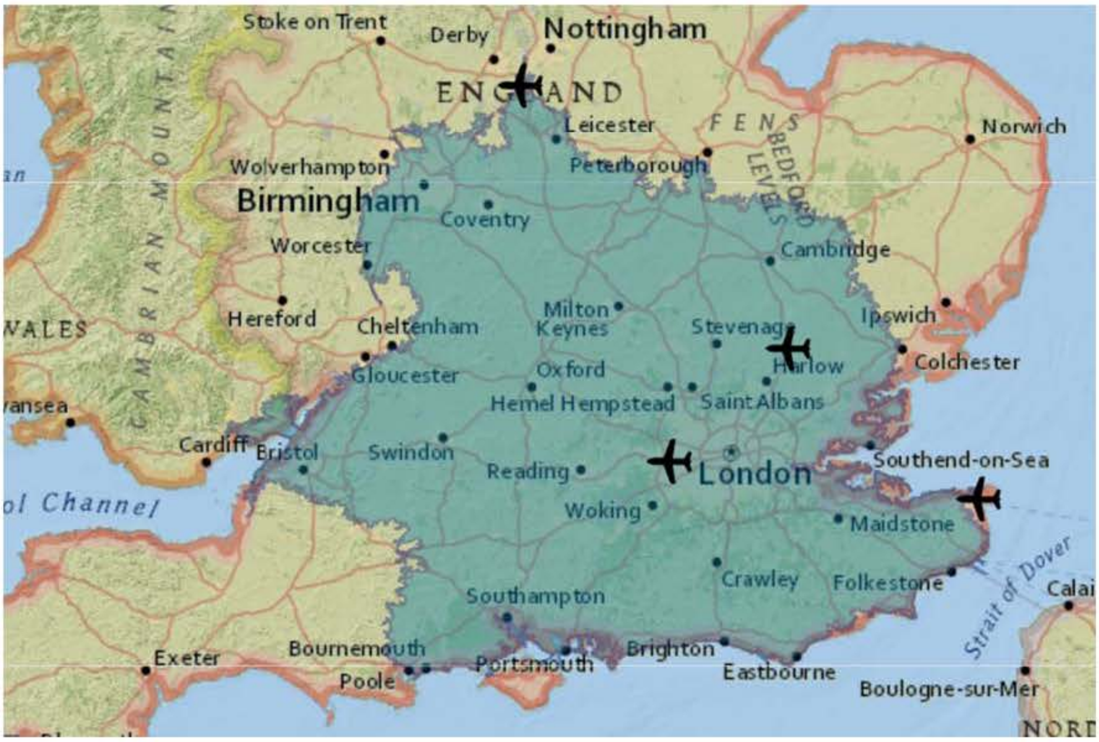
Manston airport vs East Midlands (135mins):

Appendix ND.1.8 (Part A)

East Midlands Airport and MSE at 135 Minute Contours

Appendix ND.1.8 (Part A)

Heathrow airport (135mins):



Appendix ND.1.8 (Part A)

Stansted airport (135mins):

Appendix ND.1.8 (Part A)

Manston and Heathrow (135mins):

Manston vs Stansted (135mins):

Appendix ND.1.8 (Part A)

All 4 combined (135mins):

Appendix ND.1.8 (Part A)

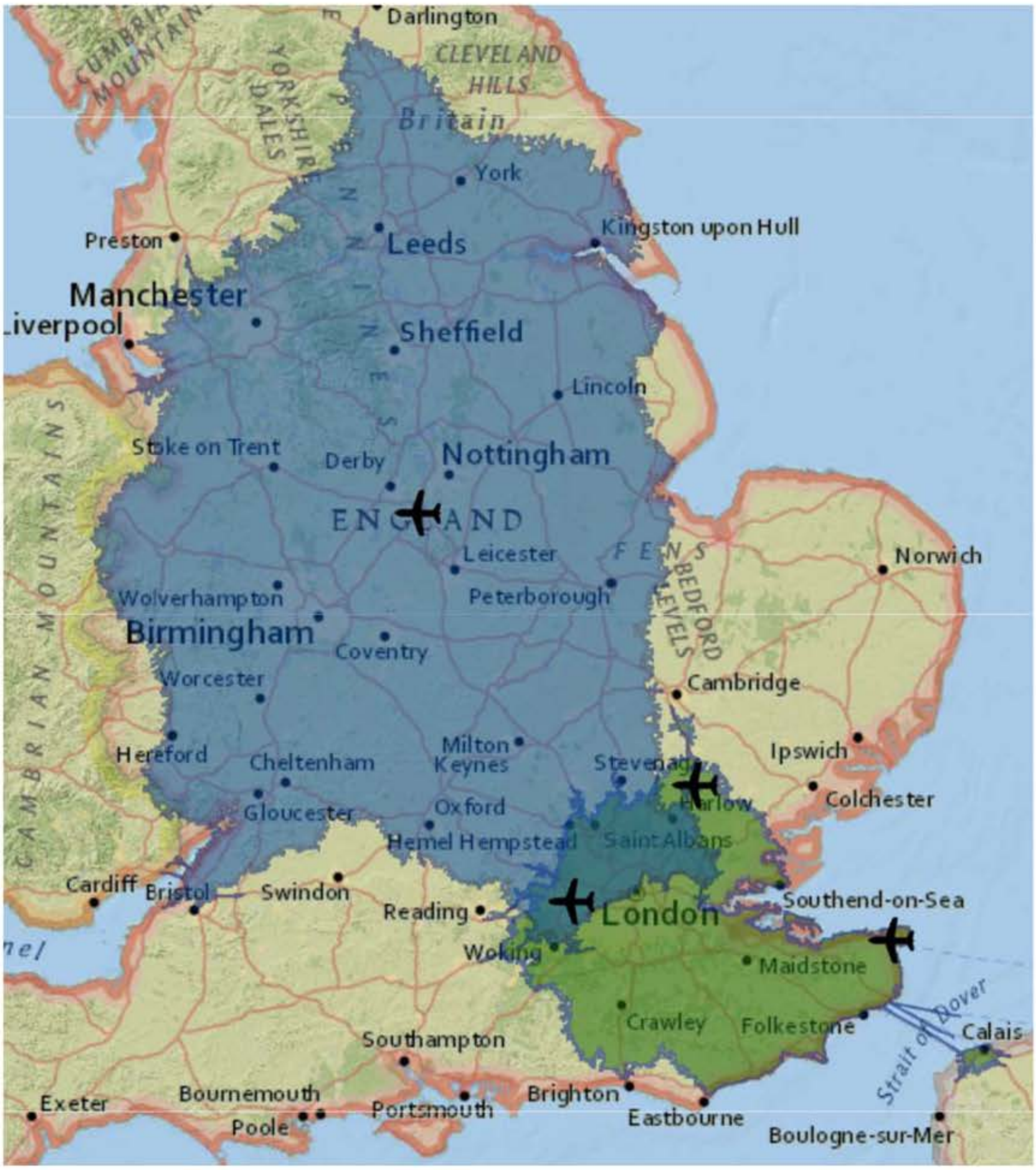
Truck Contours with 10min per hour penalty to Demonstrate Rush Hour

Manston Airport (150mins):

East Midlands (150mins):

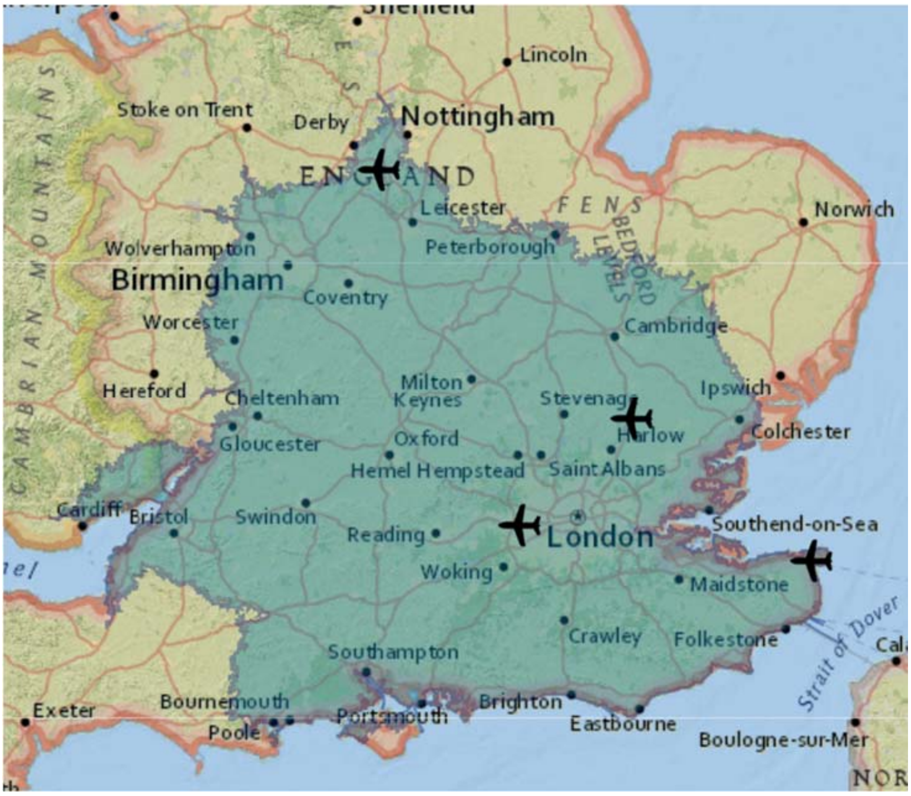
Appendix ND.1.8 (Part B)

Manston airport vs East Midlands (150mins):



Appendix ND.1.8 (Part B)

Heathrow airport (150mins):



Stansted airport (150mins):

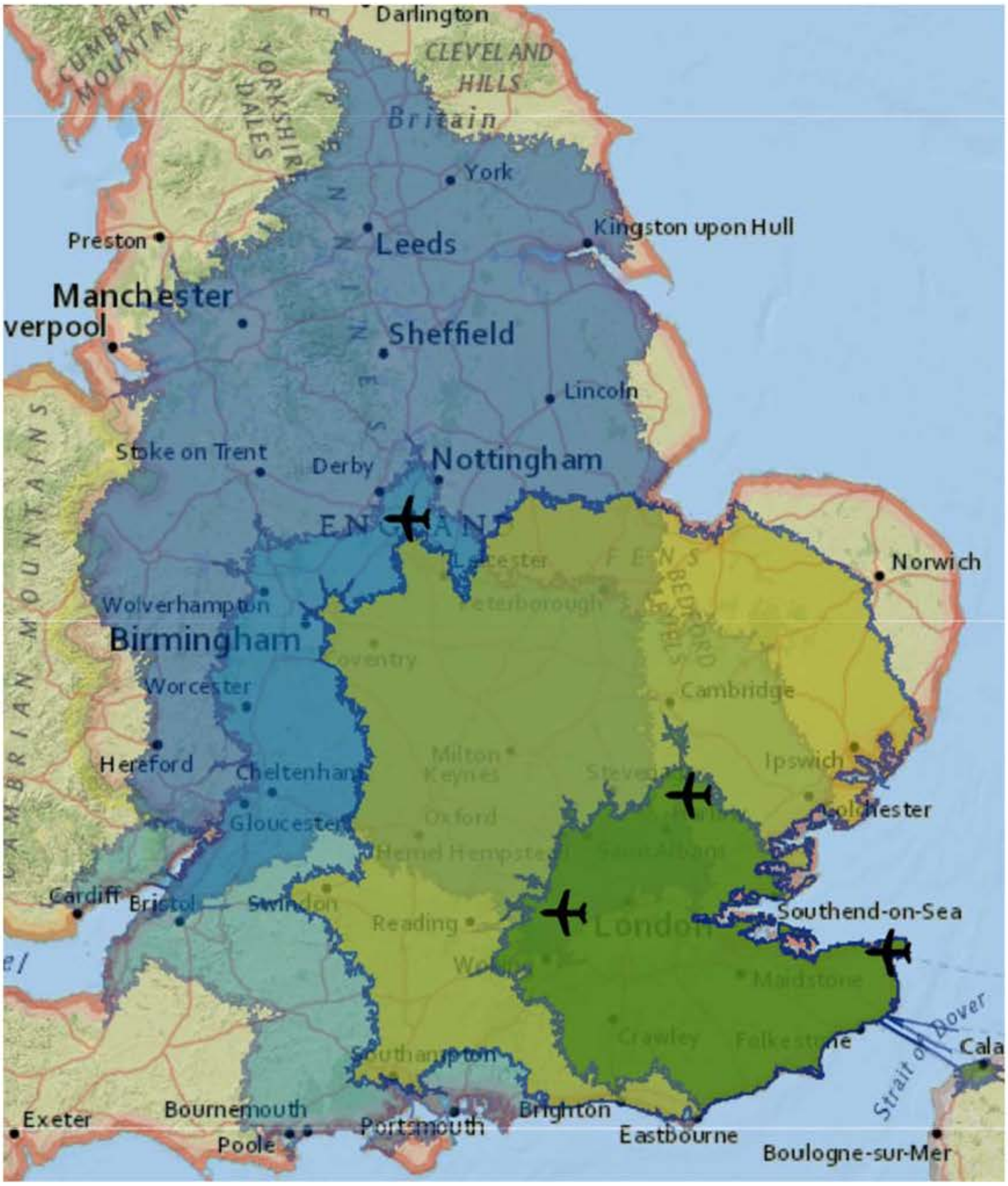
Appendix ND.1.8 (Part B)

Manston airport vs Heathrow (150mins):

Manston vs Stansted airport (150mins):

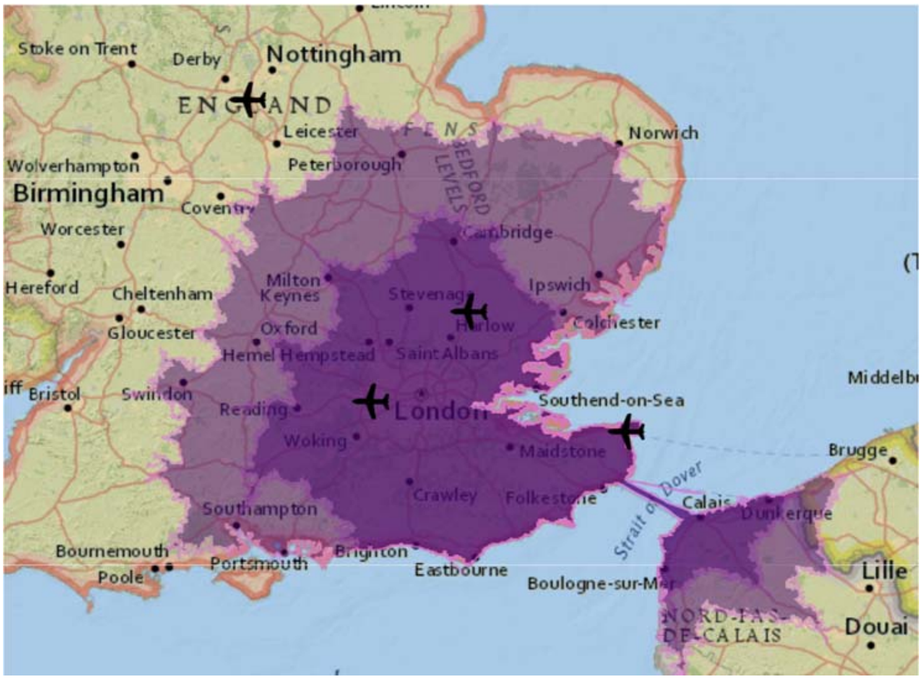
Appendix ND.1.8 (Part B)

All 4 combined (150mins):



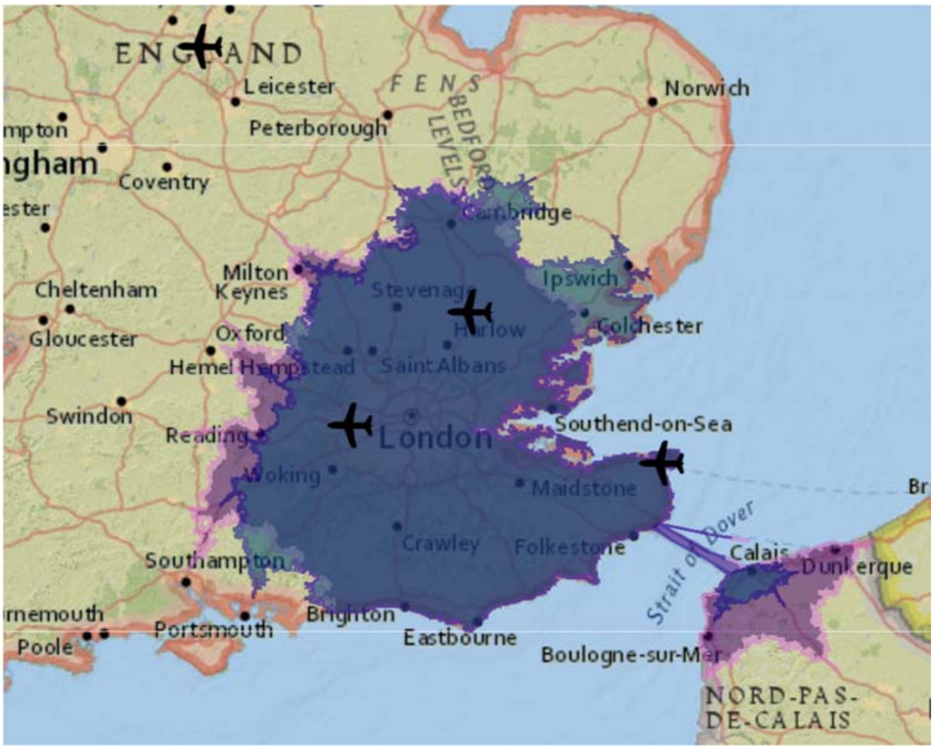
Three Hours Trucking Time from Manston Airport vs Other Cargo Airports

ArcGIS has the option to use car drive time or truck drive time. I compared 180 mins drive time from Manston for a car or truck and there is clear difference:



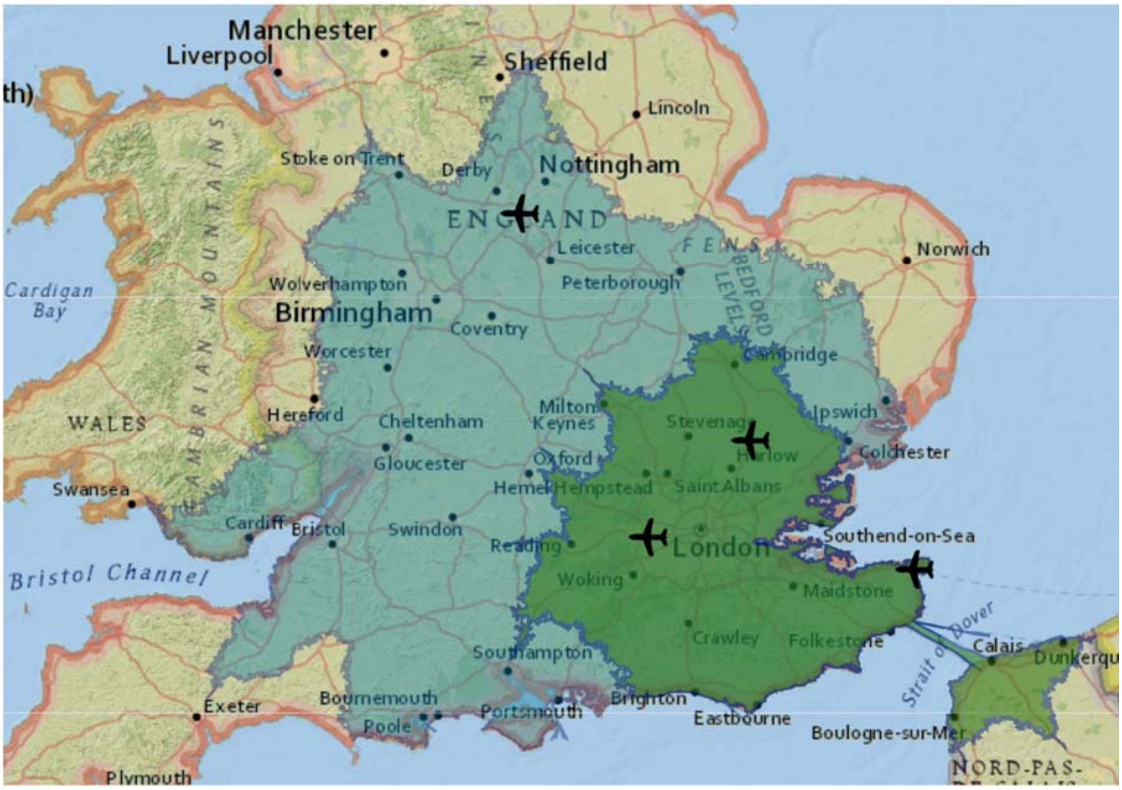
The darker purple is the truck contour and lighter purple car.

Before I found this option, I had worked out that a truck travelling at 55mph for 3 hours would cover roughly the same distance as a car travelling at 70mph for 2 hours 20 mins (140mins). I compared the truck drive time option with the reduced car drive time to see how accurate it was, and it seems pretty good to me:

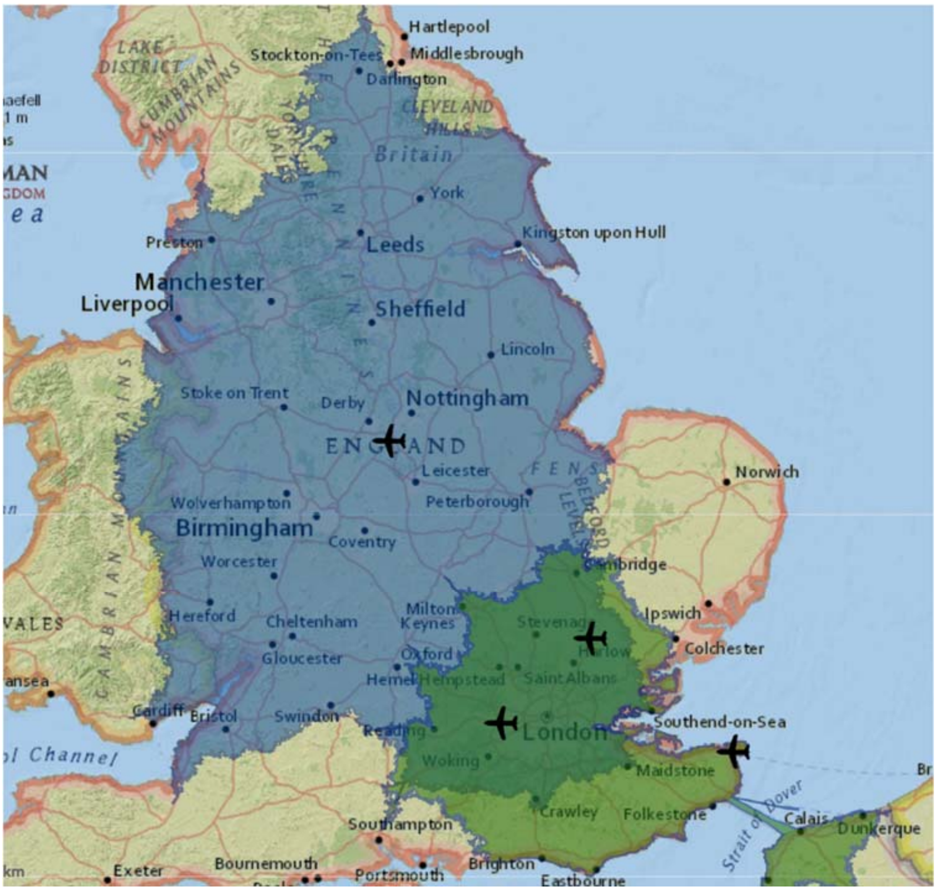


Dark blue is 140 min car drive time from Manston airport and purple is 180 mins truck drive time.

Manston vs Heathrow - 3 hours trucking time catchment from Manston airport in green and Heathrow airport is in light blue.



Manston vs East Midlands – 3-hour catchment from Manston airport in green and from East Midlands in blue.

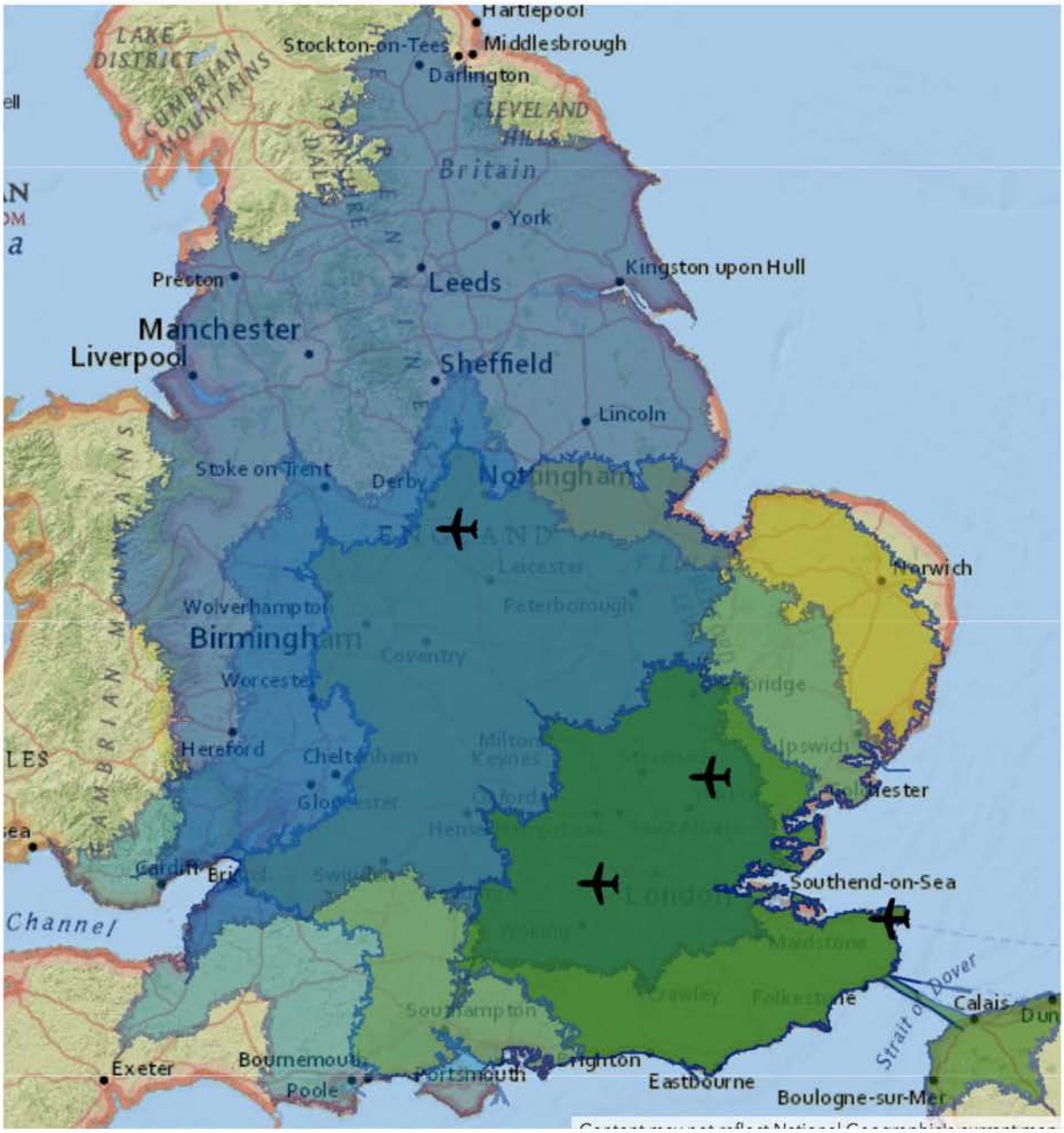


Appendix ND.1.8 (Part C)

Manston vs Stansted – 3 hours trucking time from Manston airport in green and from Stansted airport in yellow

Appendix ND.1.8 (Part C)

All 4 airports together



Appendix ND.1.8 (Part C)

Report
October 2018

Assessment of the value of air freight services to the UK economy

Airlines UK
Our ref: 23348601
Client ref:

Appendix ND.1.13

Appendix ND.1.13

Report
October 2018

Assessment of the value of air freight services to the UK economy

Prepared by:	Prepared for:
Steer	Airlines UK
28-32 Upper Ground	25 Southampton Buildings
London SE1 9PD	London
	WC2A 1AL
+44 20 7910 5000	Client ref:
www.steergroup.com	Our ref: 23348601

steer

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Executive Summary

Background

This study has been produced by Steer for Airlines UK with support from Heathrow Airport Limited, Manchester Airports Group and the Freight Transport Association. It has been undertaken in the context of the UK Government developing its Aviation Strategy, due for publication in Summer 2019, with a Green Paper expected in December 2018. As part of this process, the Government is consulting stakeholders to identify barriers to growth and how to reduce them. While many high value-added industries make significant use of air freight, there remains limited understanding of the role of air freight within the UK economy. The purpose of this study is to assess and quantify the value of the air freight industry to the UK economy, and in particular, its importance to UK regions, international trade and industrial sectors.

Key figures

- Air freight services contribute £7.2 billion to the UK economy and support 151,000 jobs.
- Across all sectors of the economy, £87.3 billion of UK gross value added (GVA) is currently dependent on air freight exports, including a very significant proportion of the GVA of some key industries and their supply chains:
  - Pharmaceuticals - £13.9 billion
  - Computer, electronic & optical - £8.3 billion
  - Creative arts & entertainment - £5.3 billion.
- In 2017 air freight represented 49% of the UK's non-EU exports by value (£91.5 billion) and 35% of non-EU imports (£89.9 billion) - over 40% of total trade by value but under 1% by volume of goods shipped.
- Germany ships just 25% of its non-EU export value by air, and most other major EU economies ship between 20% and 40%. Only Ireland ships a greater share of its non-EU exports by air than the UK.
- 9% of GVA in the North West (worth 14.9bn) is currently dependent on air freight services, compared to less than 2% of London's output. Figures are 8.6% in Wales, 7.6% in the East Midlands and 6.8% in the South West.

Industry structure

The air freight industry is complex and highly fragmented. The four major sub-markets within air freight are General cargo, Express, Specialist and niche products and Mail. Although the industry is complex and business models overlap, two principal business models serve all four markets; the forwarder model and the integrator model.

These business models dominate the UK's major air freight airports: Heathrow, East Midlands, Stansted and Manchester. Heathrow is by far the largest general air freight market using the forwarder business model and the overwhelming majority of cargo is transported in the bellyhold of passenger aircraft, mostly on long-haul routes. East Midlands, by contrast, is dominated by express freight using the integrator business model, with freight carried in freighter aircraft, often overnight on routes to mainland Europe, but also on intercontinental routes. Stansted has a combination of integrators and other freighters, while Manchester is largely bellyhold, although on a much smaller scale than Heathrow.

One notable feature of the UK air freight market is the huge importance of Heathrow and its surrounding freight facilities, with most forwarders having major consolidation centres in the vicinity of the airport. Very significant volumes of air freight are trucked to such facilities near Heathrow, processed and then trucked to another airport, either in the UK or in continental Europe, without ever flying in or out of Heathrow itself.

Night operating restrictions, based on movement limit and noise quota systems, are currently in place at Heathrow, Gatwick and Stansted, while other airports have to produce noise action plans which may set out operating limits for the night period. There is also an additional noise quota limit incentivising the user of quieter aircraft.

The quality of the UK's air freight infrastructure is a major issue, with freight facilities at UK airports often being decades old and having suffered from continued under-investment. While other airports are not as slot congested as Heathrow, they now cater to significantly more widebody freight capacity than the facilities were originally designed for.

Although the terms of the UK's exit from the EU are still being negotiated, withdrawal from the EU has the potential to affect the UK freight industry through changes to customs arrangements and changes to air services agreements (ASAs).

This analysis of the structure of the air freight industry raises a number of issues relevant to the formulation of national aviation policy. These include:

- the positive and negative aspects of the concentration of the air freight industry at and around Heathrow;
- the quality of infrastructure supporting air freight services;
- the balance of the impacts of night and noise restrictions on local residents and air freight services;
- the potential for growth of air freight services at airports outside the South East of England; and
- the management of the potential impacts of Brexit.

Market Analysis

Bellyhold cargo at Heathrow accounted for over 60% of total UK air freight volume in 2017, with forwarders and shippers utilising its extensive intercontinental passenger network. Over 30% of total air freight was shipped on US routes and most of the remainder on Asian routes. Freighter and integrator cargo is concentrated at East Midlands and Stansted, which, in 2017, together accounted for over 20% of all UK freight and the majority of freighter (60%) and integrator (79%) activity. Integrators accounted for over 90% of freight at East Midlands. At Stansted, integrators FedEx and UPS were the largest cargo airlines, although intercontinental freighters such as Qatar Airways, Cargolux and China Southern also accounted for a large share of volume.

In the last 15 years, aside from the decline in 2009 due to the fallout from the financial crisis, total volumes have remained relatively flat, growing with a compound average growth rate (CAGR) of +1.2% over the 15-year period with volumes only surpassing the pre-crisis peak in 2016.

North America was the largest destination market (accounting for 32% of volume), followed by Europe (25%, 18% of which was to the EU) and, South and East Asia (19%). Heathrow, and to a lesser extent Gatwick, handled predominately North American and Asian freight, benefitting from extensive passenger networks. The large European share of volume at East Midlands reflects the airport's role within its integrators' networks. Similarly, at Stansted, much of the freight volume is on European and North American routes.

A relatively large share of many regional airports' volume (including Manchester, Birmingham, Glasgow and Newcastle) is accounted for by Middle Eastern routes, reflecting the importance of the Gulf carriers' networks to these airports' freight operations. Airports in Scotland and Northern Ireland, such as Aberdeen, Belfast and Edinburgh, have a relatively large share of domestic volumes, which is likely to be because trucking to other parts of the UK from these locations is less time-effective.

Although Heathrow is one the largest airports in the EU in terms of freight volumes, due to its slot and operating constraints described above, it has a significantly lower amount of freighter activity compared to other major European hub airports.

As air freight has started to grow again after several years of stagnation, the increasing volumes and longhaul connections at major airports outside the South East of England as well as the prospect of the third runway bringing additional capacity at Heathrow, give rise to a number of policy issues for consideration, including:

- how to make best use of existing infrastructure and unlock more capacity through investment in air freight facilities at UK airports;
- how to manage the air freight implications of the third runway at Heathrow; and
- how to support the air freight sector to grow sustainably.

International Trade

In 2017, non-EU trade classified as being transported by air accounted for over 40% in terms of value but under 1% of total trade in volume terms (with sea accounting for over 98%). Air freight represented 49% by value of non-EU exports (£91.5 billion) and 35% by value of non-EU imports (£89.9 billion).

Many of the products with a high share of UK trade value transported by air, such as aircraft engine parts and power generating machinery, have a high share of both import and export value, likely reflecting the global nature of these industries' supply chains and manufacturing processes. One exception is pharmaceuticals, which account for a significant proportion of export (but not import) value.

It is also interesting to compare the UK's use of air freight for its exports and imports against other European countries. Although Germany is by far the largest EU exporter to non-EU countries, only 25% of its goods by value are transported by air, whereas the UK, which has the second largest total export market, ships a far higher proportion (49% by value) by air. Most of the other major EU economies ship between 20% and 40% of the value of their non-EU exports by air; only Ireland (64%) ships a greater share of its non-EU exports by air than the UK.

On the import side, the UK is the second largest market in the EU and has the highest share of imports transported by air, which makes its imports by air (£90 billion) the most valuable in the EU. Like the UK, most other major European economies ship lower proportion of their non-EU imports (compared to exports) by air, with most importing 10% to 30% by air in value terms.

The importance of air freight to UK international trade, and in particular the UK's higher dependence on air freight than most other countries raises issues for consideration in the development of the UK Government's Aviation Strategy on the appropriate level of Government support for the air freight sector and how its importance should be reflected as part of the strategy for the aviation sector as a whole.

Economic analysis

We have used two different, complementary, approaches to assessing the economic value of air freight:

- the traditional measure of economic impacts on employment, income and GVA of the air freight industry and associated services, generally known as "direct", "indirect" and "induced" impacts (based on the activity in the sector itself and on upstream monetary flows between the air freight industry and other sectors in the economy); and
- the wider economic impacts of air freight, sometimes referred to as "catalytic impacts", which consider how air freight facilitates economic activity in other sectors (based, in this case, on estimating what proportion of GVA in those sectors is currently reliant on air freight services).

Using the traditional approach, we have estimated the "direct", "indirect" and "induced" impacts using a recognised methodology based on the use of Input-Output tables (I-O tables), produced by the Office for National Statistics (ONS). Direct impacts relate to the employment, income and GVA generated by the sector itself, indirect impacts take account of the knock-on effects in the sector's supply chain, while induced impacts also include the impacts of employees' spending in the economy. These can be calculated from the I-O table, by inspection for direct impacts and via standard techniques for the indirect and induced impacts.

Including all of these impacts, we estimate that air freight services support GVA of **£7.2 billion**, **151,000** jobs and associated income of **£4.1 billion** (2014 data and prices).

Note that this result only relates to activities and expenditure either within the air freight and supporting industries, its supply chain and spending by its workforce. It does not include "downstream" effects, i.e. the effect on the industries purchasing air freight services, or the wider, catalytic, impacts on the whole economy. To estimate these, we have used an approach based on the fact that supplying air freight services does not fully represent either the value of what is being flown, or the value of timely delivery. In terms of the value of what is flown, air freight imports and exports, between them, were worth £181 billion (2017 values and prices) , or close to 25 times more than the economic added value (GVA) calculated using the direct, indirect and induced methodology described above.

Each sector of the economy produces outputs for which customers are willing to pay, with primary and secondary sectors producing physical products such as food, machine parts, cars and so on. For these sectors of the economy, their outputs equate to particular commodities so that, for example, farms produce agricultural products while automotive plants produce cars and trucks. Hence, there is a correspondence between each industry and its outputs. By using this correspondence (together with information on exports by air from HMRC, and in comparison with output from ONS), we can establish, for each industry producing physical outputs, what proportion of those outputs is represented by exports transported using air freight services.

It is reasonable to make the assumption that all output contributes equally to the GVA generated by an industry. We have also made the assumption that the proportion of an industry's GVA supported by air freight services is equal to the proportion of its outputs which are exported by air. The final step in this analysis is to recognise that, if a portion of an industry's GVA is dependent on air freight services, then the suppliers who provide inputs to that industry are also dependent on the air freight services.

Using this approach, we have estimated the level of GVA currently dependent on air freight across the economy. Across all sectors of the economy, **£87.3 billion of GVA is currently dependent on air freight exports**. This represents **5% of the total GVA measure of national output** (£1,747 billion in 2016).

While the level of GVA currently dependent on air freight might potentially be reduced through the use of alternative modes of transport, the fact that such alternatives are generally poor substitutes for air freight, which is both much faster and much more expensive than surface freight, indicates that the level of GVA dependent on air freight is likely to remain significant. This indicates that air freight is a very important service supporting a significant fraction of national economic activity.

The analysis of the level of industries' and their supply chains' added value (GVA) which is currently dependent on air freight, enables us to estimate the regional importance of air freight services, by considering the regional distribution of output for each industry.

This analysis demonstrates the importance of the air freight industry in the North West, where £14.9 billion of GVA is currently dependent on air freight, representing 9.0% of the whole economy of the region. Similarly, air freight supports very significant proportions of economic activity in many regions, including 8.6% in Wales, 7.6% in the East Midlands, 6.8% in the South West, 6.0% in the West Midlands and 5.9% in Northern Ireland. The contrast between the very important role of Heathrow in providing air freight services, compared with the high dependence of regions away from the South East economies on air freight, is stark.

Considering both the industry structure and this economic analysis raises particular issues relevant to the formulation of national aviation policy as the UK Government develops an aviation strategy towards 2050:

- how to protect and develop the significant share of the UK economy currently dependent on air freight services; and
- how to support UK regions and nations whose economies are heavily dependent on air freight services, particularly where local airports do not currently benefit from strong air freight services.

1 Introduction

Background

1.1 This study has been produced by Steer for Airlines UK with support from Heathrow Airport Limited, Manchester Airports Group and the Freight Transport Association. It has been undertaken in the context of the UK Government developing its Aviation Strategy, due for publication in Summer 2019, with a Green Paper expected in December 2018. As part of this process, the Government is consulting stakeholders to identify barriers to growth and how to reduce them. While many high value-added industries make significant use of air freight, there remains limited understanding of the role of air freight within the UK economy. The purpose of this study is to assess and quantify the value of the air freight industry to the UK economy, and in particular, its importance to UK regions, international trade and industrial sectors.

Our Approach

1.2 To undertake this assessment, we have undertaken a review of the available literature, with data and information gathered from the following sources:

- The Civil Aviation Authority (CAA);
- The Department for Transport (DfT);
- Her Majesty's Revenue and Customs (HMRC);
- The Office of National Statistics (ONS);
- Eurostat;
- The Official Airline Guide (OAG);
- The United Nations Statistic Division (UNSD); and
- Individual airport traffic statistical releases.

1.3 In addition, we have held interviews and received data from industry stakeholders, including:

- Passenger airlines (UK and foreign);
- Integrators;
- Cargo airlines;
- Airport operators;
- Freight industry trade bodies; and
- UK-based companies using air freight.

This Report

1.4 The remainder of this report is structured as follows:

- Chapter 2 gives an overview of the air freight industry in relation to markets, business models and constraints;
- Chapter 3 describes the UK freight industry in relation to freight volumes;
- Chapter 4 describes air freight's role in international trade; and
- Chapter 5 provides a quantification of the economic contribution of air freight.

1.5 Illustrative case studies have also been provided in the text.

Appendix ND.1.13

2 Industry structure

2.1 In this chapter we provide an overview of the major sub-markets within air freight, the primary business models serving them and the interaction between industry actors. The end of the chapter also provides a description of the current constraints within the UK market, based on information and views provided by stakeholders.

Overview

2.2 The air freight industry is complex and – at some levels – highly fragmented. The organisation which operates the aircraft is often not the same organisation with which the shipper has made a contract – airlines rarely interact directly with the ultimate customer (the shipper). The four major sub-markets within air freight that we have identified are:

- General cargo;
- Express;
- Specialist and niche products; and
- Mail.

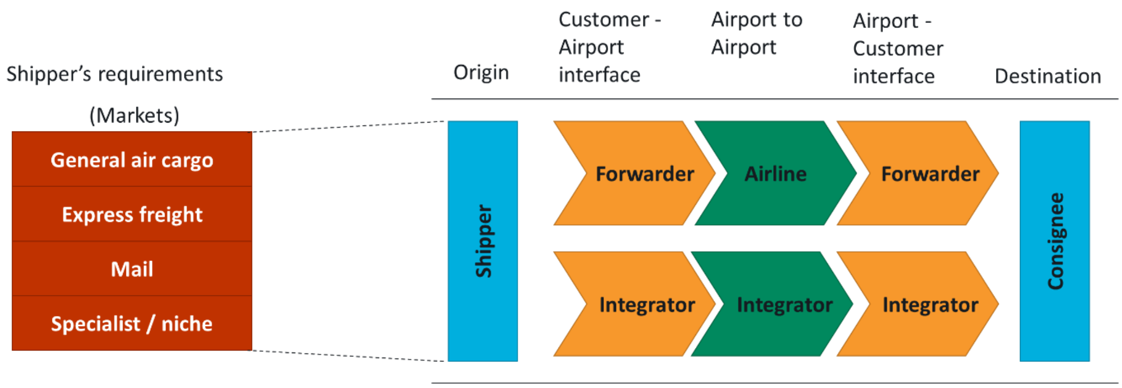
2.3 The products offered within each sub-market are generally driven by customer requirements, which may include (but are not limited to): cost, speed, predictability, storage requirements and shipping regulations.

2.4 Although the industry is complex and business models overlap, two principal business models serve all four markets; the forwarder model and the integrator model. Over the last thirty years, these two types of service providers have significantly increased their product range, coverage and scale of operation, to the point where they now serve almost every market.

2.5 Integrators traditionally offered a worldwide courier product for documents and parcels, but now offer a range of products and geographies which compete at some level with every logistics provider in the supply chain. The forwarders, partly in response and partly in search of higher yields, have expanded their product range to include greater international coverage, door to door products and other logistic services.

2.6 The interaction between the four sub-markets and these two business models is illustrated in Figure 2.1 below.

Figure 2.1: Typical end to end journey: interaction between markets and business models



2.7 In the remainder of this chapter we provide, in turn, a more detailed description of the air freight sub-markets and business models.

Air freight markets

General air cargo

2.8 General air cargo forms the majority of air freight being shipped to and from the UK and is shipped predominately using passenger bellyhold capacity. General cargo is the standard core product offered by most freight-carrying airlines and therefore consists of a broad range of goods. The main carriers of general cargo in the UK are therefore IAG Cargo (British Airways and IAG group airlines), Virgin Atlantic and a number of foreign (predominately American and Asian) passenger airlines flying on long-haul routes, split approximately 40:60 in terms of volumes flown.

2.9 End-customer relationships are generally owned by freight forwarders, who act as intermediaries between shippers and airlines. Freight forwarders will often maintain relationships, possibly on a tendered basis, with a range of shippers, many of whom will have a requirement to send large volumes of freight on a regular basis.

Express freight

2.10 Although air freight is, by its nature, time-critical, express freight services are used when particularly rapid delivery is required and are generally sold on the premise of a guaranteed delivery slot. As well as a guaranteed delivery time, customers are also often able to track a shipment's progress, enabling them to have up-to-date information on geographical position, estimated time of delivery, details of any delays and revised delivery times.

2.11 The international express market is dominated by the four main integrators (DHL, FedEx, TNT (now a subsidiary FedEx)) and UPS), who carry freight on a mixture of their own aircraft and purchased bellyhold capacity. Integrators use their own aircraft within Europe and on high-volume long-haul routes, and purchase bellyhold capacity on lower volume long-haul routes where they do not operate their own aircraft.

2.12 Although business-to-business (B2B) activity still accounts for much of express freight volumes (for example on just in time supply chains), the growth of E-Commerce has increased the demand for business-to-consumer (B2C) services. This has, to some extent, changed the dynamic of express air freight services as a growing share of express demand is now driven by consumer expectation of fast delivery.

Specialist and niche cargo

2.13 In addition to speed, some cargo shipments have requirements that cannot be met by general air cargo due to specific storage, security or regulatory requirements. Some of this cargo, such as perishable foodstuffs or pharmaceuticals, can be shipped as bellyhold freight but will usually require specialist containers and packaging. In some cases, it may also require specially trained staff or additional paperwork.

2.14 Other types of specialist cargo, such as dangerous goods, are not permitted to be carried on passenger aircraft and are therefore transported on dedicated freighters operated either by freight airlines or integrators. In some cases, shippers' requirements will not be met by either bellyhold or dedicated freighter capacity; in such cases, aircraft will need to be specifically chartered to transport goods. Examples of such goods include outsize shipments, goods destined for remote destinations or goods with particular handling requirements – such as live animals.

Mail

2.15 UK air freight capacity is used for mail by the Royal Mail domestically for its faster delivery options and for most of its international deliveries. Nearly all domestic mail is carried by chartered freighters, whereas European and Intercontinental mail is largely carried in the bellyhold of scheduled passenger flights.

2.16 A small number of freight only airlines operate in the UK in support of the major integrators and the Royal Mail; these operators generally supply both aircraft and crew and effectively lease capacity to the integrators and Royal Mail. In 2017, West Atlantic and Titan Airways accounted for over 90% of the domestic mail carried by air in terms of weight.

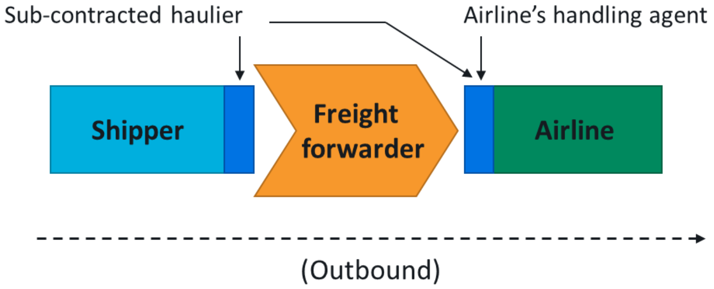
Air freight business models

Forwarder model

2.17 In the forwarder model intermediaries (forwarders) provide the link between those with a requirement for air freight (shippers) and those with the means to provide capacity (airlines), by consolidating consignments from a number of shippers and purchasing capacity from freighter or passenger airlines. This means airlines have little contact with shippers. Many forwarders will ship any type of cargo, but the majority of consignments are general air cargo.

2.18 The forwarder model is illustrated in Figure 2.2. After collecting from the shipper (by subcontracted haulier), the forwarder will often consolidate freight at a regional centre before moving consignments in volume to its warehouses close to an airport, where freight is further consolidated before being sent (by subcontracted haulier) to the airport. At the airport, consignments may be handed directly to the airline, or – more typically – to the airline's appointed handling agent.

Figure 2.2: Typical end to end journey: Freight forwarder



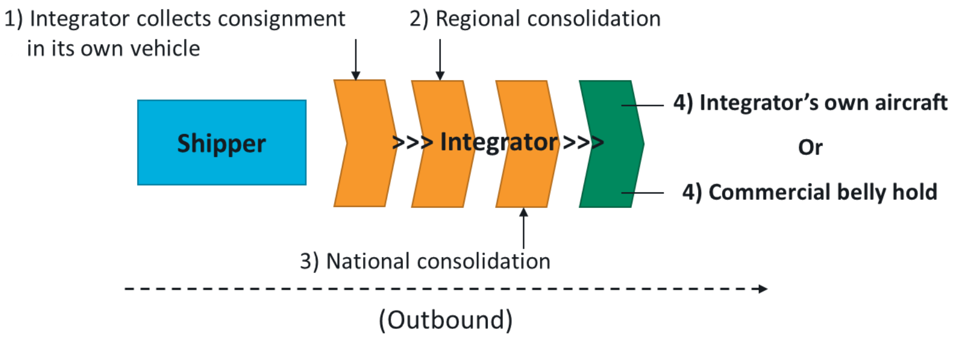
2.19 Freight forwarder activity in the UK is concentrated around Heathrow – Heathrow airport Limited (HAL) stated that approximately 450 freight forwarders are located within five miles of the airport. The concentration of forwarder activity around Heathrow also means that cargo leaving from other UK airports (both around London and further afield) is often consolidated around Heathrow before being trucked to the relevant airport, in some cases not actually being flown to or from Heathrow Airport at all.

Integrator model

2.20 In contrast to the forwarder-airline model, the integrator model has sought to offer customers a logistics solution which combines an extensive surface transport collection and delivery network with an in-house fleet of aircraft, thereby offering an "integrated" product, generally controlling the entire logistics chain from pick up to delivery. While the majority of cargo is express-like products, integrators carry all forms of cargo. On short-haul routes, this is predominately with their own aircraft, while on long-haul routes this is often on purchased bellyhold capacity (with the integrator effectively acting as a forwarder in the latter case).

2.21 A depiction of the integrator model is shown in Figure 2.3. The integrator will collect the goods and deliver them to the final destination, providing all the links in the transport chain, controlling the choice of mode (where appropriate) and offering a comprehensive information flow along with the physical transport of the goods. This is usually using their own road transport, handling, transit warehousing facilities and (for short haul) aircraft.

Figure 2.3: Typical end to end journey: Integrator forwarder



2.22 Integrator air freight activity in the UK is dominated by DHL, FedEx, TNT and UPS concentrated at East Midlands (c.50%) and Stansted (c.25%). Only a small number of dedicated cargo freighter flights operate at Heathrow.

Other models

2.23 Although the forwarder and integrator models are the two principal models handling the majority of UK air freight, several other smaller models exist, including:

- Courier and express services, which use either integrators' services or their own small chartered freighters for especially time-sensitive products such as automotive parts or newspapers.
- Specialist operators, which meet shippers' specific storage or temperature requirements en-route to the airport, in storage before shipping and on board the aircraft for goods such as pharmaceuticals or fresh salmon. Goods may be shipped on specialist freighters or in specialist containers as bellyhold cargo if specified requirements can be met.
- Air cargo brokers, who do not provide vehicles or warehouse space, but who work with freight forwarders, shippers, logistics providers, governments, and relief organisations to offer chartered freighter aircraft on a onetime or long-term basis.
- Mail, which is flown domestically on tendered dedicated freighters and internationally using tendered UK and foreign airline bellyhold capacity.

Trucked freight

2.24 Alongside the business models described above, a significant amount of air freight is transported in customs-bonded trucks between the UK and continental Europe and is classified as air freight with an assigned flight number. Freight is often flown to continental Europe, particularly from Asia, as there is often more available air freight capacity than to UK airports, partly due to lack of available slots for freighter aircraft at Heathrow. The freight is trucked as bonded freight to avoid having to undergo local customs procedures so that importers only need to deal with the UK customs authorities rather than investing in systems to deal with multiple customs authorities. This represents an inefficiency from the perspective of the UK economy as whole. See also the Case Study on consumer electronics imports at the end of this chapter.

2.25 In contrast to goods from Asia, Heathrow stated that goods destined for North America are also often trucked to the UK, in particular Heathrow, from continental Europe in order to take advantage of cheaper rates from the UK on North American routes. As Heathrow is the primary European hub for North American passenger connections, there is a significant level of bellyhold capacity available, which means air freight rates are cheaper compared to other European airports.

Structural constraints

Air freight business models at UK airports

2.26 The business models described above dominate the UK's major air freight airports: Heathrow, East Midlands, Stansted and Manchester (see Figure 3.1 below). Heathrow is by far the largest general air freight market using the forwarder business model and the overwhelming majority of cargo is transported in the bellyhold of passenger aircraft, mostly on long-haul routes. East Midlands, by contrast, is dominated by express freight using the integrator business model, with freight carried in freighter aircraft, often overnight on routes to mainland Europe, but also on intercontinental routes. Stansted has a combination of integrators and other freighters, while Manchester is largely bellyhold, although on a much smaller scale than Heathrow.

2.27 One notable feature of the UK air freight market is the huge importance of Heathrow and its surrounding freight facilities, with most forwarders having major consolidation centres in the vicinity of the airport, as noted in paragraph 2.19 above. Very significant volumes of air freight are trucked to such facilities near Heathrow, processed and then trucked to another airport, either in the UK or in continental Europe, without ever flying in or out of Heathrow itself.

2.28 Another common model is freight arriving from long haul origins (such as China or the US) flown into Heathrow and then being trucked to other airports (e.g. East Midlands) to be flown to continental airports overnight, leading to a symbiotic relationship between the different airports.

2.29 Both of these models mean that the resilience of the road network to and from airports is an important factor in reliability of service. To a large extent, they reflect the constraints on the UK air freight industry, discussed further below.

Operating restrictions

2.30 Night operating restrictions, based on movement limit and noise quota systems, are currently in place at Heathrow, Gatwick and Stansted. The current restrictions to October 2022, are summarised for current and future seasons in Table 2.1. The restrictions apply from 11:30pm to 6am, with less stringent restrictions also applying between 11pm and 11:30 pm, and between 6am and 7am.

Table 2.1: UK airport night-time operating restrictions

Airport	Seasonal Movement Limit	
	Winter (2018/19 –2021/22)	Summer (2019-2022)
Heathrow	2,550	3,250
Gatwick	3,250	11,200
Stansted	5,600	8,100

Source: DfT

2.31 There is also an additional noise quota limit incentivising the user of quieter aircraft.

2.32 Apart from the restrictions at these three London airports, other airports have to produce noise action plans which may set out operating limits for the night period.

2.33 Integrator stakeholders consulted as part of this study stated that the way in which these operating restrictions are applied impacts their ability to operate effectively, as the express business model (described above) is dependent on being able to ship goods during the night to enable maximum productivity for customers who rely on shipments being picked up close to the end of the working day and delivered as early as possible the next.

Capacity

2.34 Several stakeholders have noted that capacity constraints are a significant hinderance to the operation of UK air freight – one stated that it has caused volume growth to fall behind other European countries and another stated it is one of the main reasons why so much freight is flown to mainland Europe and trucked to the UK – in turn causing more road and port congestion.

2.35 While many of the UK's airports are not currently particularly congested, the concentration of air freight activity at Heathrow, which is severely slot constrained and which operates at 98% capacity, means that the congestion there has a disproportionate impact on UK air freight. Slot constraints at Heathrow mean that no additional freighter operations are possible, while the larger passenger aircraft such as the A380 actually have lower freight capacity than the aircraft they are replacing, particularly 747s.

2.36 Historically, much of the UK air freight activity is concentrated around Heathrow due to its significantly more extensive intercontinental passenger network compared to those of other UK airports. Although this remains the case, new intercontinental passenger connections at regional UK airports have increased possibilities for transporting long-haul freight as bellyhold cargo. As discussed in Chapter 3, some other major UK airports have increased their bellyhold volumes significantly with new connections to Asia – one stakeholder noted that Emirates is the "best in class" at utilising regional capacity.

Infrastructure

2.37 Several stakeholders commented that the quality of the UK's air freight infrastructure is a major issue, with freight facilities at UK airports often being decades old and having suffered from continued under-investment. While other airports are not as slot congested as Heathrow, they now cater to significantly more widebody freight capacity than the facilities were originally designed for.

2.38 At Heathrow, the infrastructure has led to severe levels of road congestion, with trucks often queueing for hours at the Cargo Horseshoe (Heathrow's main freight facility), with some operators investing in off-site facilities to mitigate these problems[1]. However, restrictions imposed by the Border Force currently prevents any new such remote-site facilities being developed.

2.39 The Heathrow Cargo Working Group has proposed measures to mitigate these problems, including more flexibility in allowing multiple consignments in bonded truck movements around the airport vicinity.

[1] In particular, some operators have remote "Internal Temporary Storage Facility" (ITSF-R) with customs bond facilities.

Appendix ND.1.13

Potential Brexit impacts

2.40 Although the terms of the UK's exit from the EU are still being negotiated, withdrawal from the EU has the potential to affect the UK freight industry through changes to customs arrangements and changes to air services agreements (ASAs). The purpose of this section is not to speculate on the likely outcome of the negotiations but to describe the impact of any possible changes to current arrangements.

Customs checks

2.41 Under current arrangements, goods traded between the UK and other EU countries are not required to undergo customs checks at ports or airports. However, depending on the terms of the UK's withdrawal agreement, this may cease to be the case. This would mean, firstly, freight traveling by air between the UK and other EU countries may be required to undergo customs checks at airports and, secondly, that freight being trucked in free circulation between the UK and continental Europe may be required to undergo customs checks at ports.

2.42 As has been discussed, much of freight being trucked between the UK and continental Europe travels in customs-bonded trucks and freight traveling on these trucks should not be required to undergo additional customs checks at ports should these be imposed. However, it is likely that trucks carrying bonded freight may still be affected by customs checks at ports, if they were introduced, as additional checks of other trucks are likely to cause delays at ports.

Air service agreements

2.43 The UK is currently part of European Common Aviation Area (ECAA), which includes all EU member states and a number of other European countries. The ECAA entitles an airline with an operating licence from any ECAA country to operate flights anywhere within the ECAA. For example, a UK airline can currently operate a domestic flight in Germany or an international flight between Ireland and France.

2.44 The EU also has a number of bilateral agreements negotiated on behalf of its members with non-ECAA countries, the most important being the 'open skies' agreement with the USA. These agreements are often more liberal for freight services compared to passenger services; the EU-US deal grants 7^{th} freedom rights for cargo services compared to 5^{th} freedom rights for passenger services. 7^{th} freedom rights allow airlines to fly between two foreign countries (for example, a UK airline flying between the USA and Canada), whereas 5^{th} freedom rights only allow airlines to fly between two foreign countries if the journey ends or begins in the airline's own country (for example, a UK airline flying between the UK and Mexico via the USA).

2.45 Leaving the ECAA without an agreement in place would mean UK airlines would no longer have the right to fly to and from EU Member States under existing arrangements, or to fly to third countries, such as the US, under the terms of the EU's open skies agreements. This means the UK would be required to fall back on bilateral agreements with both third countries (such as the USA) and ECAA members.

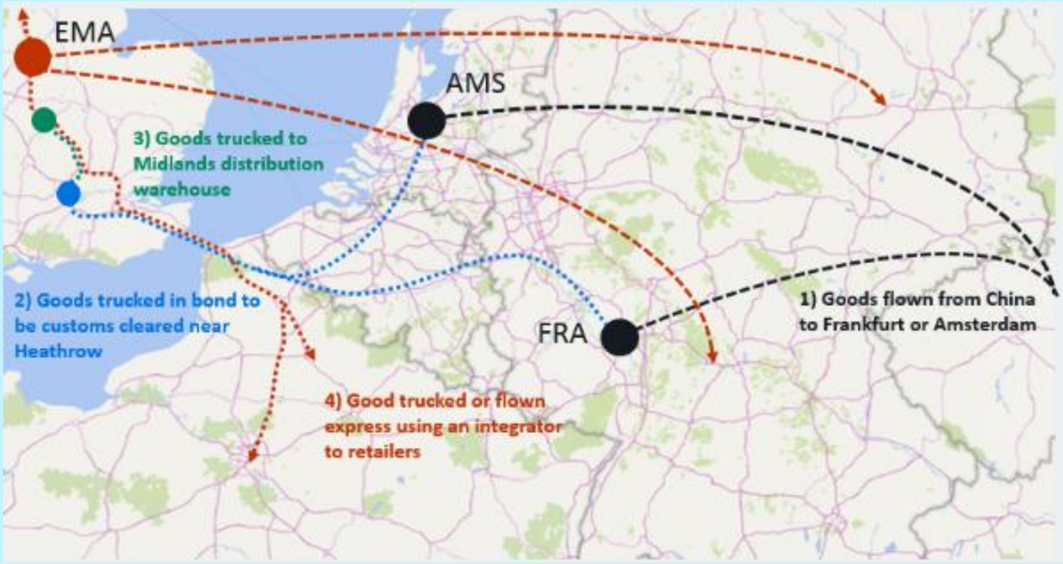
2.46 Many bilateral agreements are more restrictive than the ECAA and, for example, the EU-US open skies agreement. This may lead to more restrictions on how freight is flown between different countries, leading to slower transit times and/or higher costs, unless similarly liberal agreements can be negotiated by the UK with the EU and with other key countries such as the US.

Case Study – Consumer electronics imports

In 2017, the UK imported £10.6 billion's worth of consumer electronics accessories, equivalent to just under 90,000 tonnes of goods. These imports, which are comprised of items such as iPhone cables, car hand-free kits and other similar accessories, are imported primarily from China and other East Asian countries. In 2017, 64% of the total import value was transported by air.

A consumer electronics importer consulted as part of this study, which imports its goods from 20 different locations in China, stated that it imports approximately two thirds of its goods (in value terms) by air, with the remaining third transported by sea. More bulky goods, such as laptop bags and wireless routers tend to be transported by sea, with smaller, lighter items, such as cables, transported by air. Although using air freight is approximately four times more expensive then transporting goods by sea, air freight is often more cost effective as goods can be transported much faster.

Typical journey for imported consumer electronics goods



Since 2008, large retailers selling consumer electronics have been ordering smaller quantities of goods more frequently, which means suppliers need to be able to respond to orders more quickly. As a consequence, volumes shipped by sea have fallen in recent years as, from China to its main distribution warehouse in the Midlands, goods typically take one week by air compared to five to six weeks by sea. This also means warehouse usage has been halved through better management of inventory.

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However, despite the need to import goods by air, the importer stated that it only flies around 20% of its total imports directly to the UK, with the remaining 80% being flown to mainland Europe (usually to Frankfurt or Amsterdam) and trucked in bond to the UK via a ferry or the Channel Tunnel. Imports are usually customs cleared at facilities near Heathrow, before being trucked to its Midlands distribution centre.

The importer stated the reason such a high proportion of its goods are flown to the UK via Europe, is because the UK's air freight capacity is not sufficient to service the required import volumes. Goods are trucked as bonded freight to avoid having to undergo Dutch or German customs procedures, as the importer incurs fewer administration costs as it is only required to deal with UK customs.

The importer stated that, as most of its imports are flown in freighter aircraft, one of the reasons why it often cannot fly its goods into the UK, is because not enough UK airlines operate these types of aircraft. Many airlines that in the past operated long-haul freighter services, for example IAG Cargo at Stansted, no longer do; therefore, there are fewer long-haul freighter options available. However, the main problem the importer cited with UK air freight capacity was the quality of the infrastructure.

The importer stated that it avoids using UK airports because they are too congested and therefore not efficient; air freight infrastructure has not been upgraded in line with increased traffic, which causes delays that can be avoided at continental European airports. The importer stated that there should be better utilisation of regional airport capacity at, for example, Manchester, which was cited as a relatively good operation with not enough freight capacity.

Policy considerations

2.48 The analysis in this chapter raises a number of issues relevant to the formulation of national aviation policy. These include:

- the positive and negative aspects of the concentration of the air freight industry at and around Heathrow;
- the quality of infrastructure supporting air freight services;
- the balance of the impacts of night and noise restrictions on local residents and air freight services;
- the potential for growth of air freight services at airports outside the South East of England; and
- the management of the potential impacts of Brexit.

3 Market Analysis

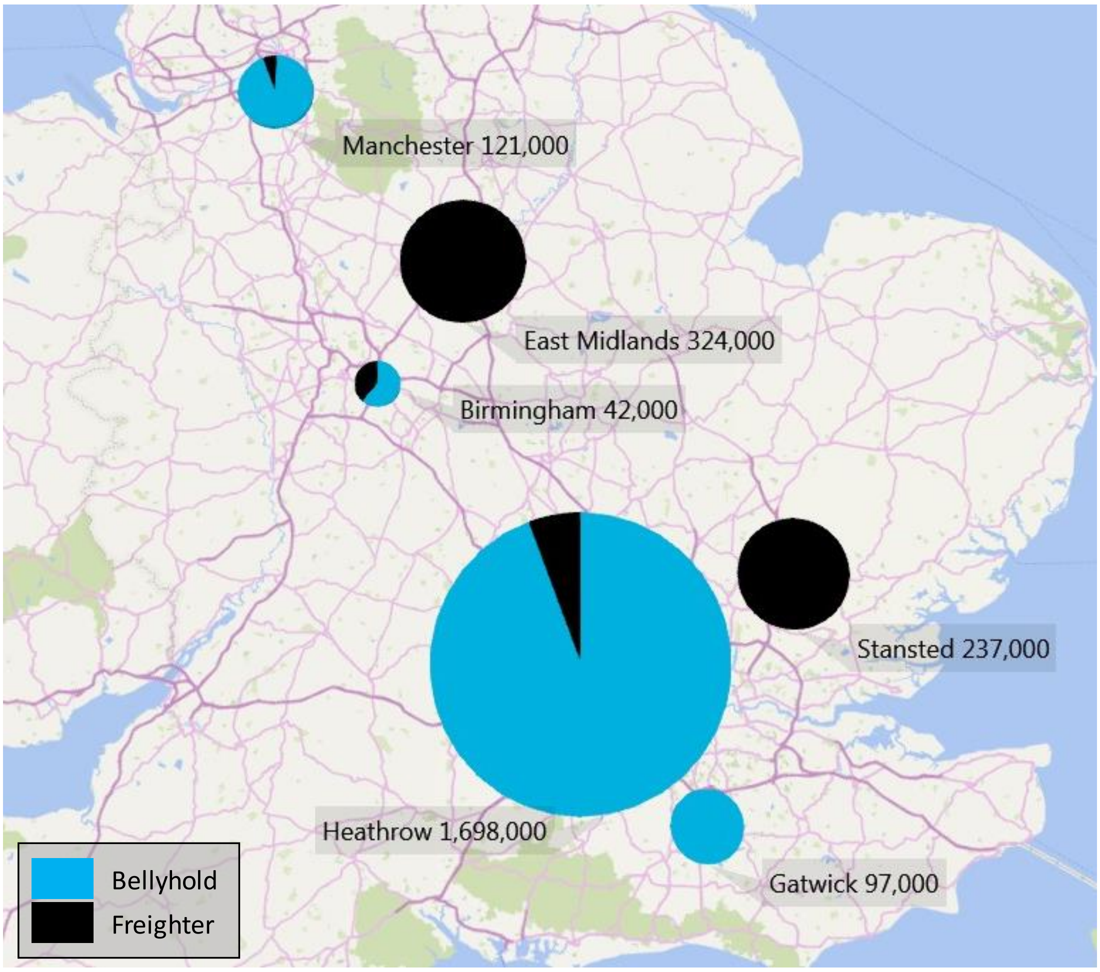
3.1 This chapter describes UK air freight volumes flown from key airports as well as recent growth trends, freight destinations, freight activity at other major UK airports and international comparisons. The analysis of UK freight volumes is based on data provided by the CAA and international comparisons based on Eurostat data.

Overview of air freight volumes

Key airports

3.2 Figure 3.1 shows the volume (tonnage) and type of freight handled at the six largest UK freight airports – the remaining airports not shown each represent less than 1% of the market in terms of volume.

Figure 3.1: Freight volumes at six largest UK airports, tonnes (2017)



Source: CAA

Appendix ND.1.13

3.3 Bellyhold cargo at Heathrow accounted for over 60% of total UK air freight volume in 2017, with forwarders and shippers utilising its extensive intercontinental passenger network. Over 30% of total air freight was shipped on US routes and most of the remainder on Asian routes. The number of freighters at Heathrow are flown by a mixture of cargo-only airlines and passenger airliners with some freighter aircraft.

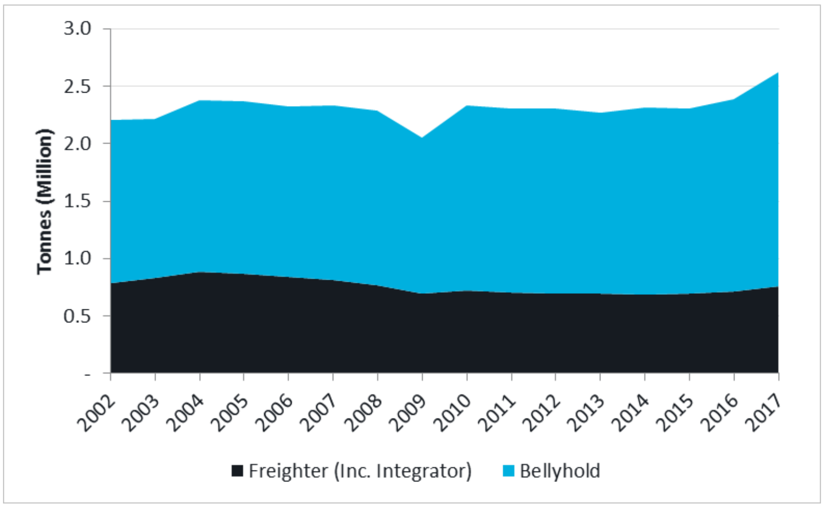
3.4 Freighter and integrator cargo is concentrated at East Midlands and Stansted, which, in 2017, together accounted for over 20% of all UK freight and the majority of freighter (60%) and integrator (79%) activity. Integrators accounted for over 90% of freight at East Midlands, with much of freight being shipped to Europe, particularly Germany, where DHL and UPS both have major hubs, as well as on intercontinental routes. At Stansted, integrators FedEx and UPS were the largest airlines, although intercontinental freighters such as Qatar Airways, Cargolux and China Southern also accounted for a large share of volume.

3.5 Almost all freight at Gatwick and Manchester was carried as bellyhold cargo in 2017, predominately to the UAE and the USA. Although both airports had relatively large freighter operations prior to the financial crisis, these operations have ceased completely at Gatwick and almost completely ceased at Manchester. Prior to 2016, freight handled at Birmingham was almost all bellyhold, and although most of Birmingham's freight volume was carried as bellyhold cargo to Asia in 2017, about a third of its volume was freighter and integrator cargo.

Volume growth

3.6 Figure 3.2 shows the development of total UK freight volumes in the last 15 years. Aside from the decline in 2009 due to the fallout from the financial crisis, total volumes have remained relatively flat, growing with a compound average growth rate (CAGR) of +1.2% over the 15-year period with volumes only surpassing the pre-crisis peak in 2016.

Figure 3.2: UK freight volumes, Million Tonnes (2002-2017)



Source: CAA

Appendix ND.1.13

3.7 The relatively modest CAGR of +1.2% for total volumes is due to a combination of growing bellyhold volumes, which over the 15-year period grew with a CAGR of +1.8%, and stagnating freighter volumes, which declined with a CAGR of -0.2%.

3.8 The share of total volumes carried by freighter aircraft has fallen from over 35% in 2002 to under 30% in 2017 and has fallen away significantly at some airports. The market for dedicated freighter services has struggled globally since the financial crisis due to falling sea-freight rates and the continued rise of air passenger demand (and associated bellyhold capacity), which have driven down freighter yields. Although some UK airports have retained important integrator, and to lesser extent, freight operations, freighter activity has remained relatively flat in recent years and is currently lower than pre-crisis levels.

3.9 Although bellyhold cargo volumes have grown more strongly and are now above pre-crisis levels, their growth has been somewhat inhibited by capacity constraints at Heathrow and limited intercontinental networks at many other UK airports. However, combined bellyhold and freighter volumes grew by 10% in 2017, which suggests the slow growth of the previous few years may have ended.

3.10 The +1.2% CAGR for total UK volumes to some extent masks the mixed performance of different UK airports. Heathrow, East Midlands and Stansted have grown relatively steadily over the last few years, whereas smaller airports have seen more significant increases or decreases in volumes (discussed further later in this chapter). The net result has been a consolidation of freight operations at the largest airports. Between 2002 and 2017, Heathrow's share of total volumes increased from 56% to 65%, while the combined share of East Midlands, Stansted and Manchester increased from 23% to 26%.

Destinations

3.11 Figure 3.3 shows the origin/destination of freight handled at UK airports in 2017[2]. Across all airports, North America was the largest market (accounting for 32% of volume), followed by Europe (25%, 18% of which was to the EU) and, South and East Asia (19%). Heathrow, and to a lesser extent Gatwick, handled predominately North American and Asian freight, benefitting from extensive passenger networks.

3.12 The large European share of volume at East Midlands reflects the airport's role within its integrators' networks, as DHL and UPS have major hubs in Leipzig and Cologne respectively. Similarly, at Stansted, much of the freight volume is on European and North American routes – FedEx has a major hub in Memphis and Stansted is used by FedEx and other

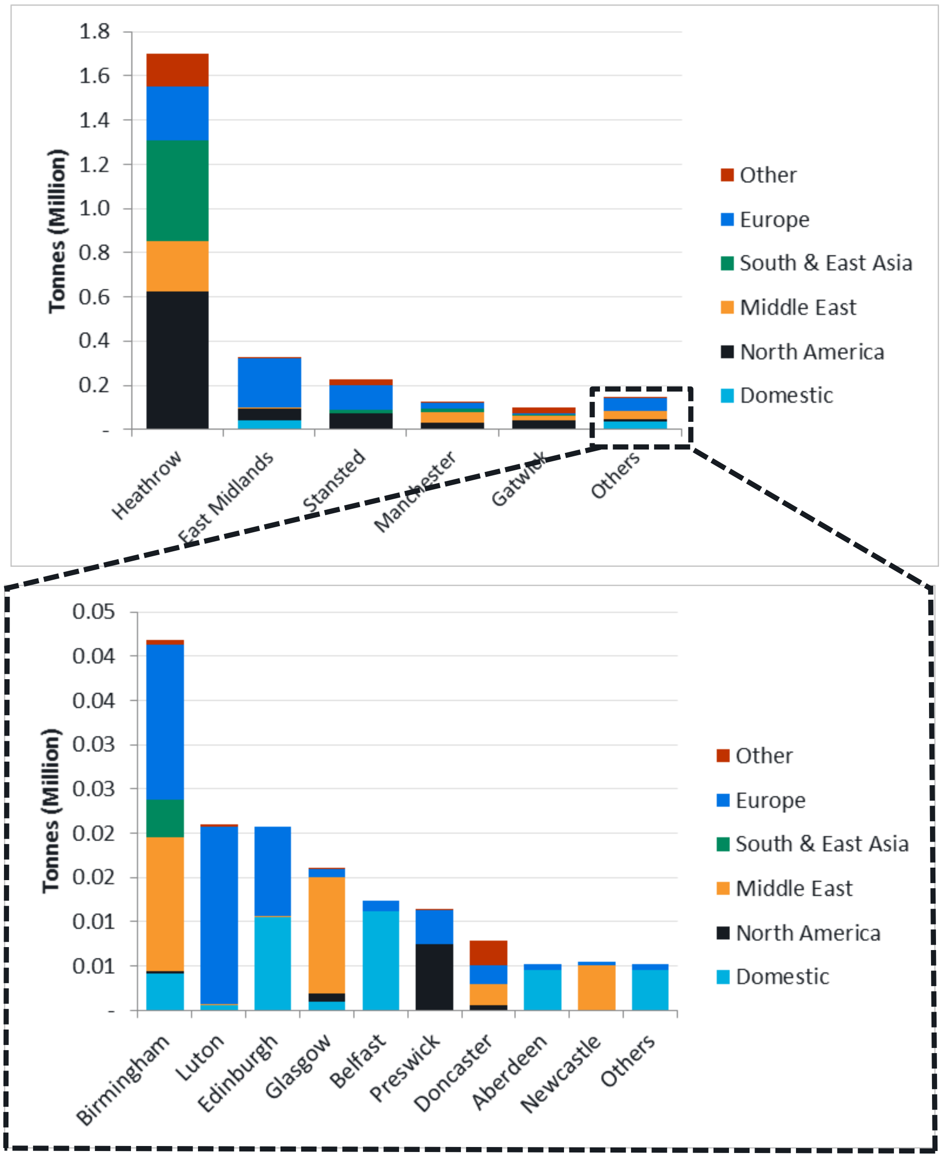
[2] Note that this is based on the origin/destination of the flight to/from the UK, which is not necessarily the same as the true origin or final destination of the cargo itself.

operators for distribution throughout Europe.

3.13 A relatively large share of many regional airports' (including Manchester, Birmingham, Glasgow and Newcastle) volume is accounted for by Middle Eastern routes, reflecting the importance of the Gulf carriers' networks to these airports' freight operations. As commented above, stakeholders noted Emirates is one of the best airlines at utilising regional airport capacity.

3.14 Airports in Scotland and Northern Ireland, such as Aberdeen, Belfast and Edinburgh, have a relatively large share of domestic volumes, which is likely to be because trucking to other parts of the UK from these locations is less time-effective.

Figure 3.3: Destination[3] of UK freight volumes, Million Tonnes (2017)



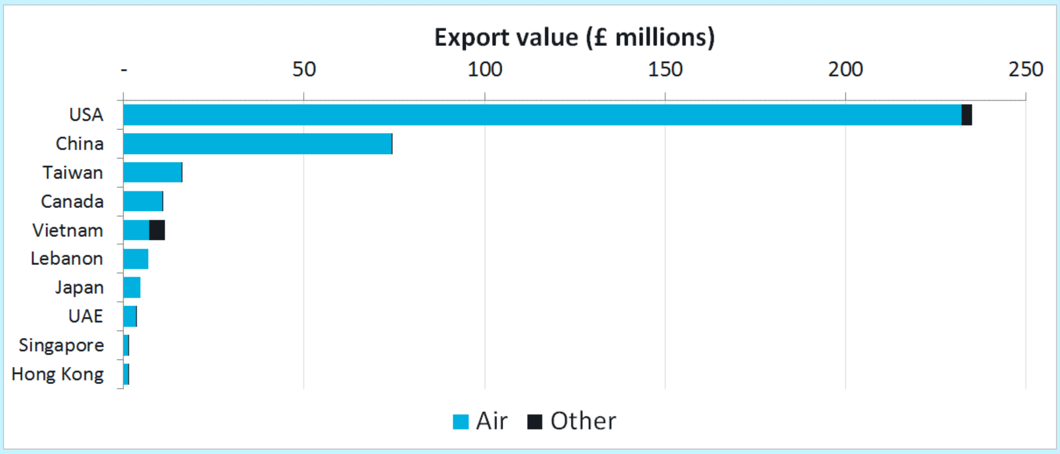
Source: CAA

[3] The "destination" as defined in CAA data is the destination of the flight departing the UK (or origin of arriving flight). It is not necessarily the final destination (true origin) of the freight consignments themselves, as they may be transhipped onto subsequent flights to onward destinations.

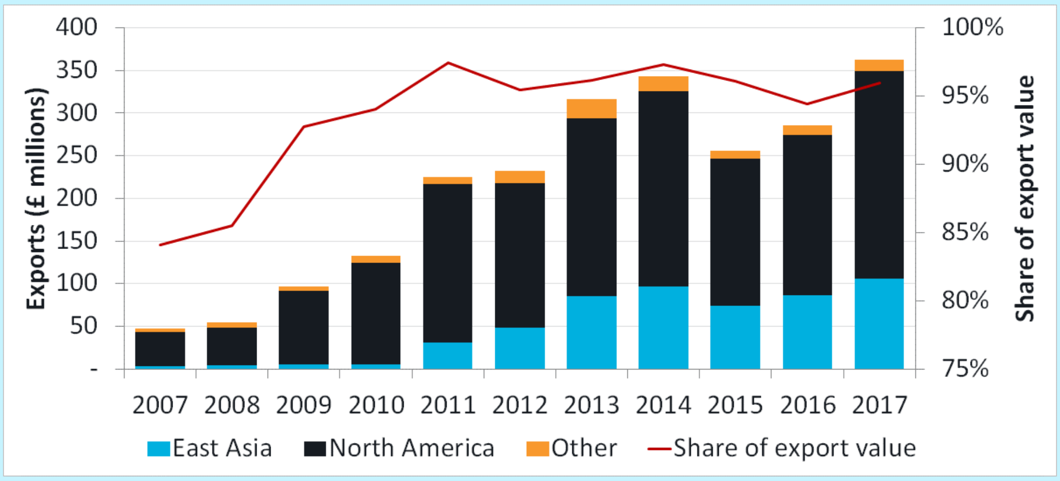
Case Study – Heathrow and the Scottish salmon industry

Scottish salmon exports were worth £600 million in 2017, up 35% on the previous year. In recent years, salmon has become one of the UK's most valuable food exports. Compared to other salmon sold worldwide, the Scottish industry has positioned itself as providing a higher quality product. Air freight is important for getting produce to market quickly to be sold as fresh as possible. Although the USA and France have remained the two largest markets, demand from East Asia has increased significantly in recent years. The share of salmon carried by air has increased with growing intercontinental demand.

2017 10 largest non-EU markets for salmon exports



2007-2017 value of salmon exports to non-EU countries

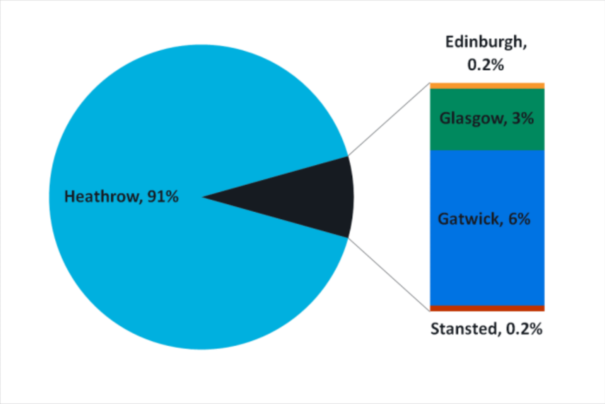


Source: HMRC

The vast majority (91%) of UK salmon is shipped internationally from Heathrow – produce is transported within the UK either by road or by air. While in transit, salmon is stored in temperature-controlled containers and may be stored at specifically designed facilities at Heathrow before being shipped. Outbound capacity must be pre-booked in advance and packing typically takes place 2-3 days before shipping.

While Heathrow is still by far the largest airport supporting the industry (see chart below), increased international connectivity at Scottish airports has given exporters other options – this year salmon was exported on the first direct flight between Scotland and China (from Edinburgh to Beijing).

2017 share of UK salmon exports by airport

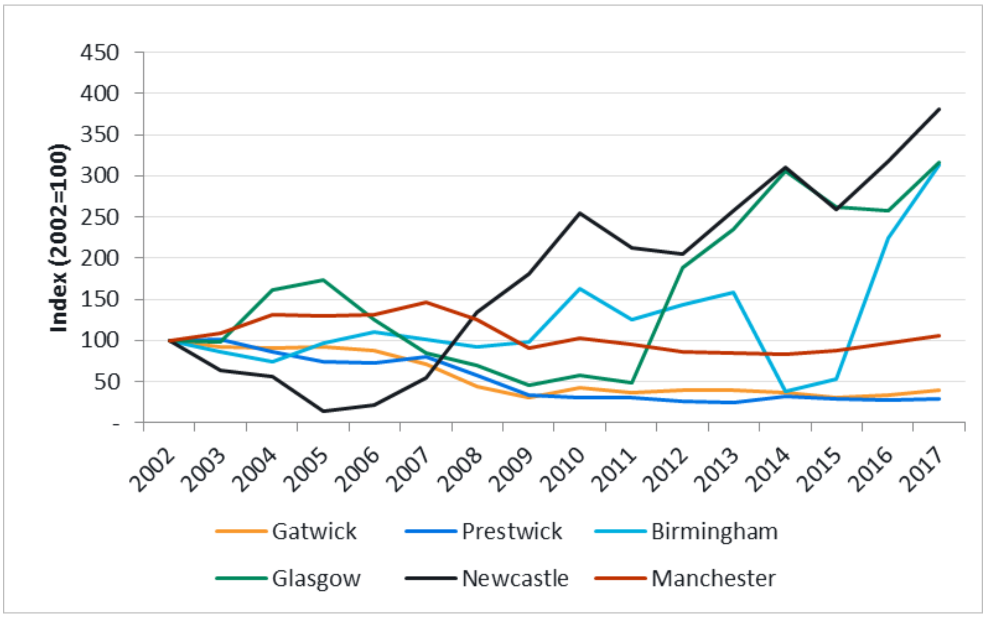


Source: HMRC

Volumes at regional airports

3.15 As discussed above, the +1.2% CAGR for total UK volumes between 2002 and 2017, shown in Figure 3.2, to some extent reflects the mixed performance of different UK airports. Figure 3.4 shows the development of total freight volumes at selected UK airports (not including the largest three freight airports: Heathrow, East Midlands and Stansted).

Figure 3.4: Indexed growth of freight volumes at selected UK airports, 2002=100 (2002-2017)



Source: CAA

3.16 Relatively significant freight operations at Gatwick and Prestwick (which in 2002 were respectively the second and sixth largest UK freight airports) have fallen to less than half of their pre-crisis levels. On the other hand, smaller operations at regional airports, such as Birmingham, Glasgow and Newcastle have increased significantly in recent years, as a result of new or increased frequencies on intercontinental passenger routes. Manchester has experienced a mix of these effects; driven by a reduction of freighter activity, total volumes decreased significantly since the financial crisis, but have grown in recent years as a result of new passenger bellyhold connections.

3.17 The figures below show, for selected regional airports, the number of departing frequencies to intercontinental destinations (represented by the stacked bars) and the total bellyhold freight volumes (represented by the red line). Charter and low-cost carrier frequencies have been excluded as these do not contribute materially to total freight volumes.

Figure 3.5: Glasgow: Departing frequencies and bellyhold freight volumes (2002-2017)

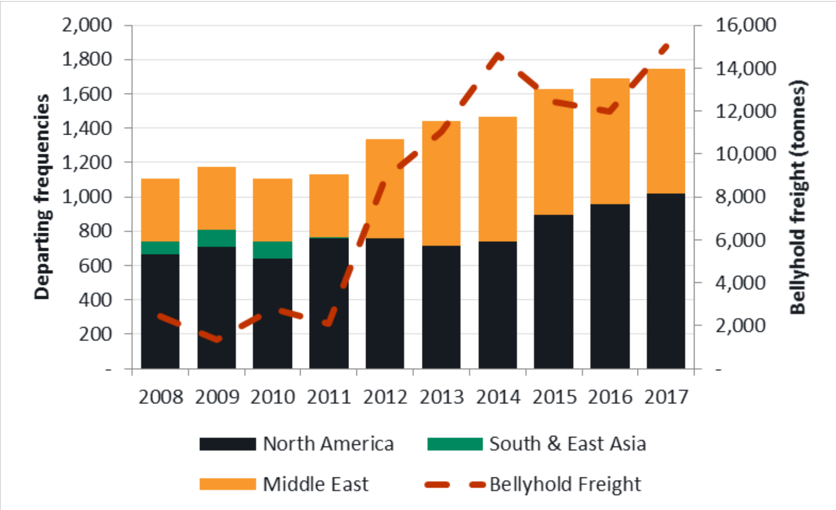


Figure 3.6: Birmingham: Departing frequencies and bellyhold freight volumes (2002-2017)

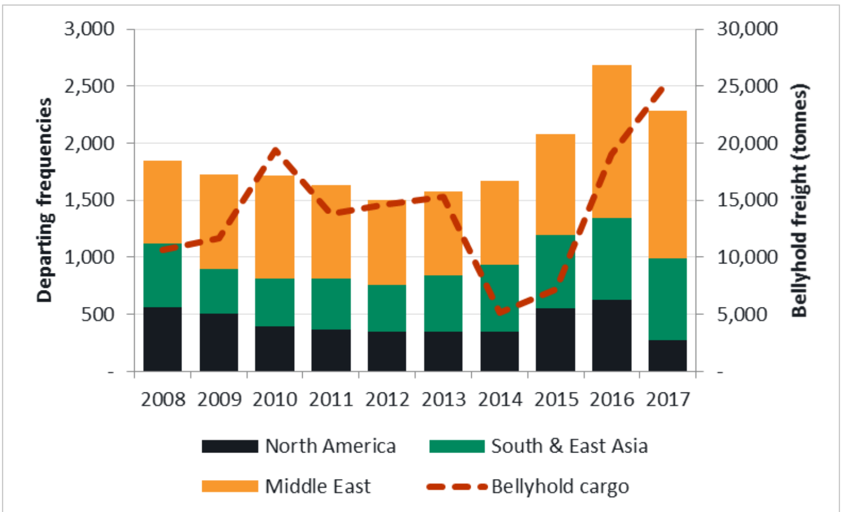
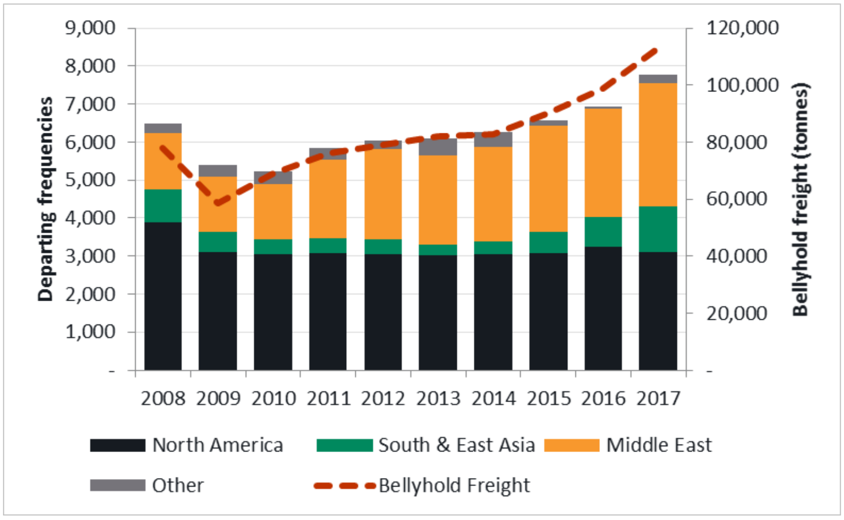


Figure 3.7: Manchester: Departing frequencies and bellyhold freight volumes (2002-2017)



Source: OAG, CAA

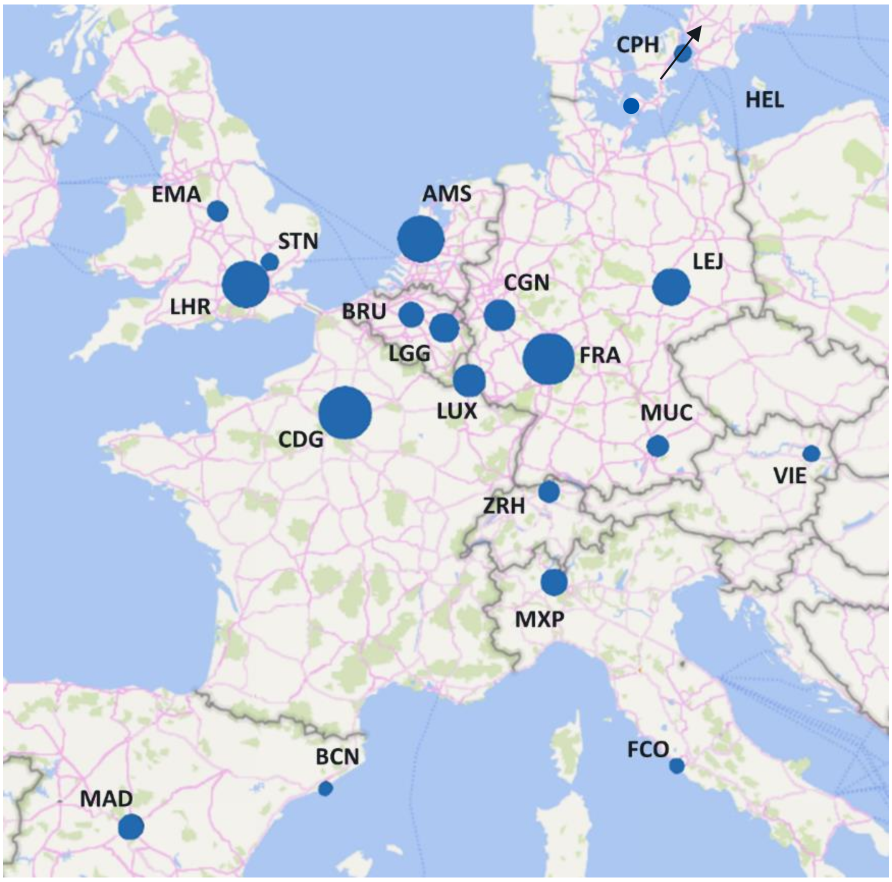
3.18 At the three airports shown in the figures above, increasing frequencies to the Middle East and Asia have significantly increased total bellyhold freight volumes. Although all three airports have had a sustained level of passenger connections to North America, as Figure 3.3 demonstrates, North America does not account for material amount of freight volumes at these airports. This is likely to be because of the large amount of North American bellyhold capacity available at Heathrow, which means shippers and forwarders have little incentive to utilise regional capacity on North American routes.

3.19 On the other hand, Heathrow has relatively less bellyhold capacity available on Asian and Middle Eastern routes, which means airlines have a greater incentive to utilise regional airports on these routes (although five new Chinese routes have started operations from Heathrow in 2018). Other airports' freight volumes have also benefited from their own new connections to East Asia. Direct passenger connections have recently started at Manchester (2016) and Edinburgh (2018) and, given the capacity constraints at Heathrow, it is likely that other airports' freight volumes will continue to benefit from the rapidly growing Asian economies.

International comparisons

3.20 Figure 3.8 shows 20 largest EU airports in 2017 based on total freight volumes.

Figure 3.8: Relative freight volumes at 20 largest EU airports (2017)



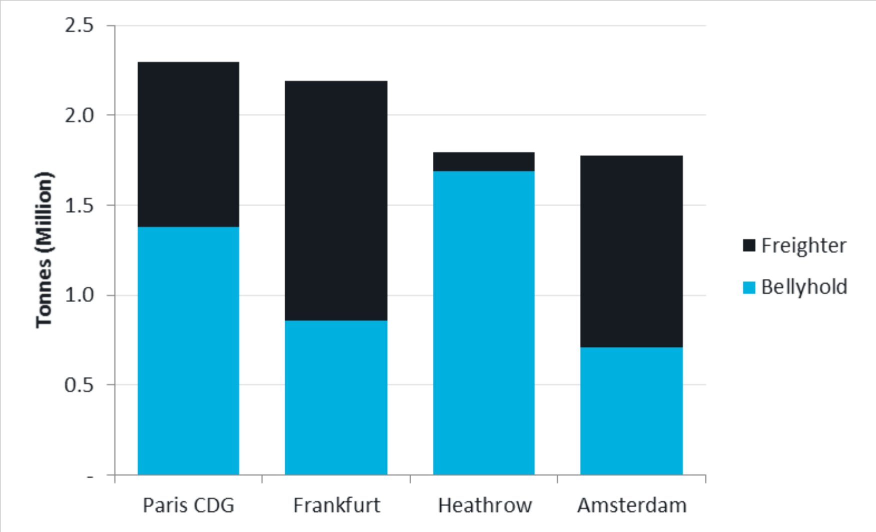
Source: Eurostat

3.21 Many of the largest freight airports in the EU are concentrated in North-West Europe, which is relatively well off and densely populated (therefore generates demand for imports), and is the home of a lot of European industry (therefore produces a large amount of goods for export). The close proximity of many large freight airports to the UK may also to some extent explain why so much air freight is flown to continental Europe and trucked to the UK, as there is much greater capacity available to continental North-West Europe than to the UK.

3.22 In terms of total freight volumes, Heathrow is the third largest airport in the EU (based on Eurostat data) and handles a similar magnitude of freight to that handled by Europe's other three major hub airports (Amsterdam, Frankfurt, Paris). Although East Midlands and Stansted are two of the twenty largest freight airports in the EU, they are significantly smaller than many of the freighter-orientated airports in Europe (including Cologne, Luxembourg, Liège and Leipzig).

3.23 Although Heathrow is one the largest airports in the EU in terms of freight volumes, due to its slot and operating constraints described above, it has a significantly lower amount of freighter activity compared to many major European airports. Figure 3.9 shows the share of total freight volumes carried by freighter and bellyhold capacity at the four major European hub airports.

Figure 3.9: Freighter and bellyhold volumes at four largest European airports, Million Tonnes (2017)

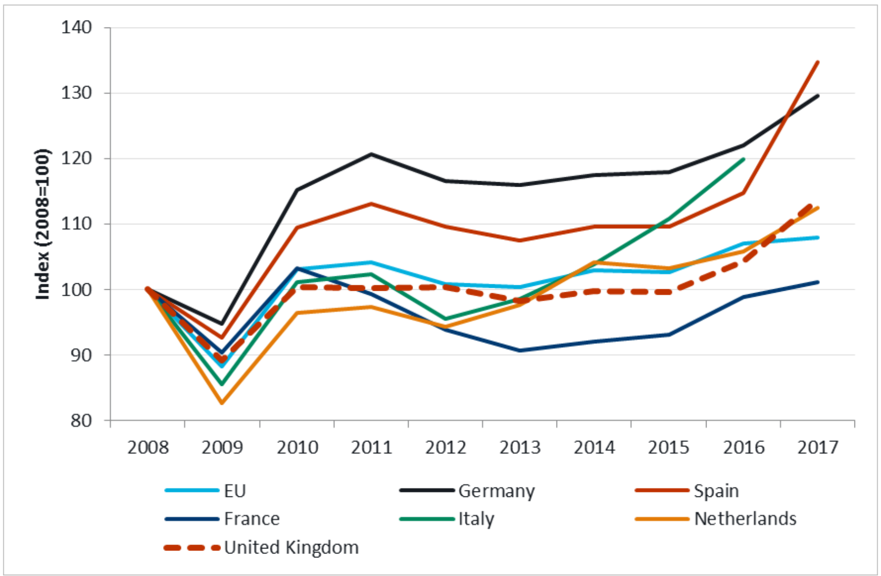


Source: Eurostat, CAA, individual airport traffic statistics (Paris CDG shares based on 2016/17)

3.24 At Heathrow in 2017, 6% of total freight volumes were carried by freighter aircraft compared to between 40% and 60% at Amsterdam, Frankfurt and Paris. Although Heathrow and Amsterdam carried very similar levels of freight in 2017, there were around 3,000[4] freighter air traffic movements at Heathrow compared to just under 17,800 at Amsterdam.

3.25 Figure 3.10 shows the indexed growth of total air freight volumes in the UK against comparable EU countries, as well as the EU as a whole, from 2008 to 2017 (and 2016 for Italy).

Figure 3.10: Indexed growth of selected EU countries freight volumes, 2008=100 (2008-2017)



Source: Eurostat. Note: France's growth prior to 2014 has been adjusted with ADP statistics to account for a change in measurement at CDG

[4] 2,971 non-passenger movements (source: CAA)

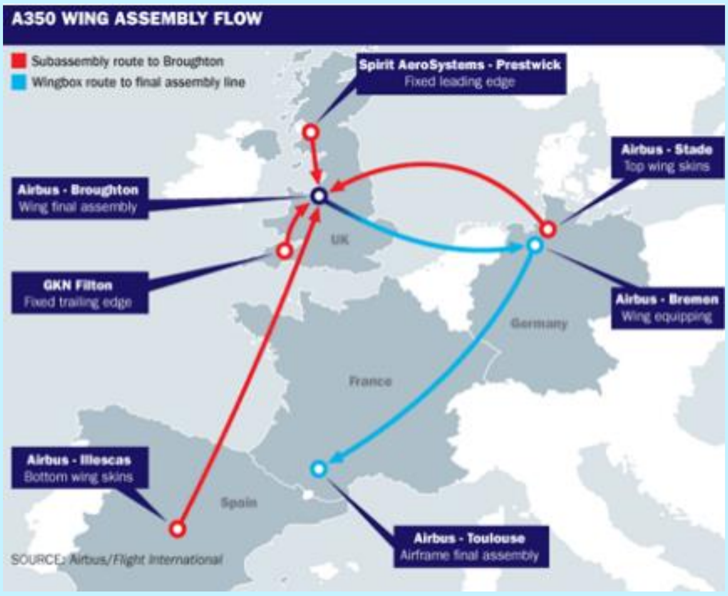
3.26 Although, like many of the countries shown, the level of growth in the UK appears to have picked up in the last couple of years, over the period shown, growth in the UK air freight volumes appears to have been lower than the growth in many other major European economies (with the exception of France).

Case study - Aerospace

The UK aerospace sector is one of the largest in the world which, according to ADS (a UK Aerospace trade organisation), had a total turnover of £45 billion in 2017 and supported 123,000 direct jobs. ADS also states that nearly 90% of final demand for UK aerospace products comes from exports. However, a large volume of goods are also imported, as aerospace supply chains are often located in several different countries, and as much of the UK's aerospace industry focuses on manufacturing aircraft parts, large quantities of components need to be regularly transported in and out of the UK.

In 2017, non-EU trade in aircraft and associated equipment[5] was worth £17.2 billion, equivalent to a little over 48,000 tonnes of equipment. In addition, trade in engines[6] (a large proportion of which are aircraft engines) was worth £28.4 billion, equivalent to a little over 32,000 tonnes of equipment. Air transport accounted for 76% of trade value in aircraft and associated equipment and 89% of trade value in engines. For both these product types, the value of imported and exported goods flown by air was very similar, reflecting the international nature of the production process and the flow of goods between countries. Some the world's most important aerospace firms are UK-based (BAE, Rolls Royce) and many of the world's largest aerospace manufacturing firms (Airbus, Boeing, Bombardier) have significant operations in the UK. For example, UK manufacturing sites are an integral part of the production process for the wings of Airbus aircraft (see map below).

Airbus wing assembly production flow



Source: HM Treasury (via Airbus/Flight International)

[5] SITC code 792
[6] SITC code 714

Appendix ND.1.13

Airbus's assembly line for its A350 wings demonstrates air freight's role in these international production processes. Composite front spars are produced in the USA by Spirit and flown to its facility in Prestwick for assembly; these are then trucked to Airbus's facility in Broughton and are combined with other parts trucked from Filton (UK), flown from Stade (Germany) and from form Illescas (Spain). Completed wings are then flown to Bremen (Germany) for equipping, before being flown to Toulouse for final assembly.

As well as aircraft manufacturing, air freight is also important for facilitating aircraft maintenance and repair operations (MRO).
The figure below shows, on a £/kg basis, the top five UK airports with the most valuable cargo. With the exception of London City (which handles large amount of jewellery and diamonds), all are airports used as a base for aircraft manufacturing plants (Bombardier at Belfast City and BAE at Warton) or MRO (IAG at Cardiff and Marshall at Cambridge). Compared to other imports and exports, this demonstrates the high value of goods and components transported by air within the aerospace sector.

Value of airport cargo - £/kg basis (2017)

Policy considerations

3.27 The analysis in this chapter shows that air freight has started to grow again after several years of stagnation. The increasing volumes and longhaul connections at major airports outside the South East of England as well as the prospect of the third runway bringing additional capacity at Heathrow, give rise to a number of policy issues for consideration, including:

- how to make best use of existing infrastructure and unlock more capacity through investment in air freight facilities at UK airports;
- how to manage the air freight implications of the third runway at Heathrow; and
- how to support the air freight sector to grow sustainably.

4 International Trade

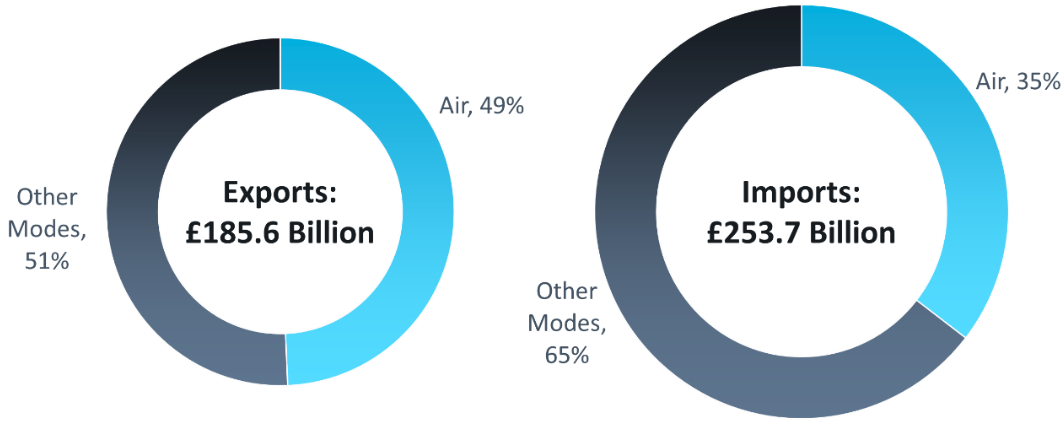
4.1 This chapter examines the breakdown of air freight flows in terms of the commodities flown and their value. We firstly compare the value of imports and exports by air in comparison with the total by all modes, then go on to examine the key product and geographic markets. We also provide a comparison of UK trade with that of other major European markets.

4.2 The analysis of UK trade presented in this section is based on import and export data within HMRC's data downloads, and therefore relates only to trade with non-EU countries. Although HMRC does provide estimates of arrivals and dispatches to and from EU countries, the level of detail provided is insufficient to undertake the analysis presented in this section for non-EU trade.

Role of air freight in UK trade

4.3 In 2017, non-EU trade classified as being transported by air accounted for over 40% in terms of value but under 1% of total trade in volume terms (with sea accounting for over 98%). Air as a proportion of total exports and imports in 2017, in value terms, is shown in Figure 4.1.

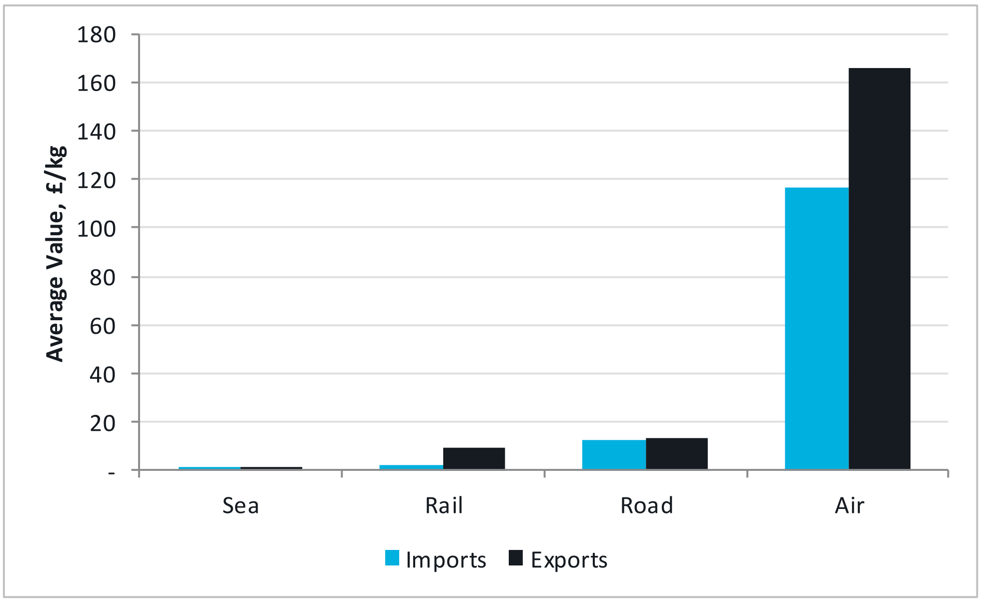
Figure 4.1: Air transport's share of total export and import value, £ Billion (2017)



Source: HMRC

4.4 Figure 4.2 shows the average value per kilogram, of exports and imports, for goods transported by sea, rail, road and air. Goods transported by air, on average, are significantly more valuable than those transported by other modes.

Figure 4.2: Average value of goods transported by each mode, £/kg (2017)

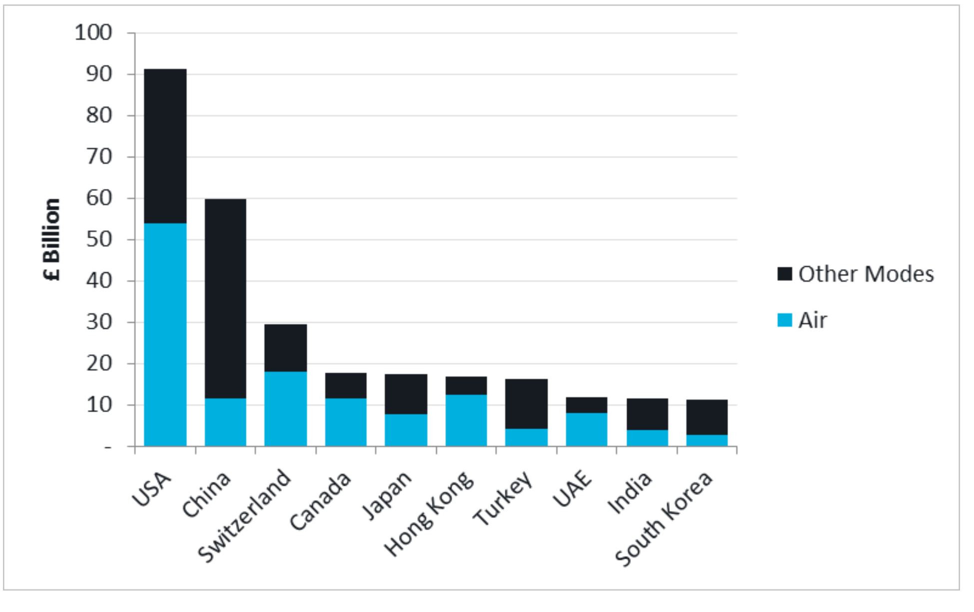


Source: HMRC

4.5 Similarly, for the UK's top ten non-EU trading partners, in volume terms, air accounted for under 1% of trade in most cases (but 1.3% with the US and 1.5% with India). Only with the USA (1.3%) and India (1.5%) did air account for over 1% of trade in volume terms. However, air accounted for a much higher proportion of trade with the UK's top ten trading partners in value terms.

4.6 Figure 4.3 shows the proportion of trade by value transported by air with the UK's top ten non-EU trading partners. Air generally accounts for a higher proportion of trade value with other service and high-end manufacturing-orientated economies (such as the USA and Switzerland), and has lower share with Asian mass manufacturing-based economies (such China and India).

Figure 4.3: Air transport's share of trade value with largest non-EU trading partners, £ Billion (2017)



Source: HMRC

Geographical markets

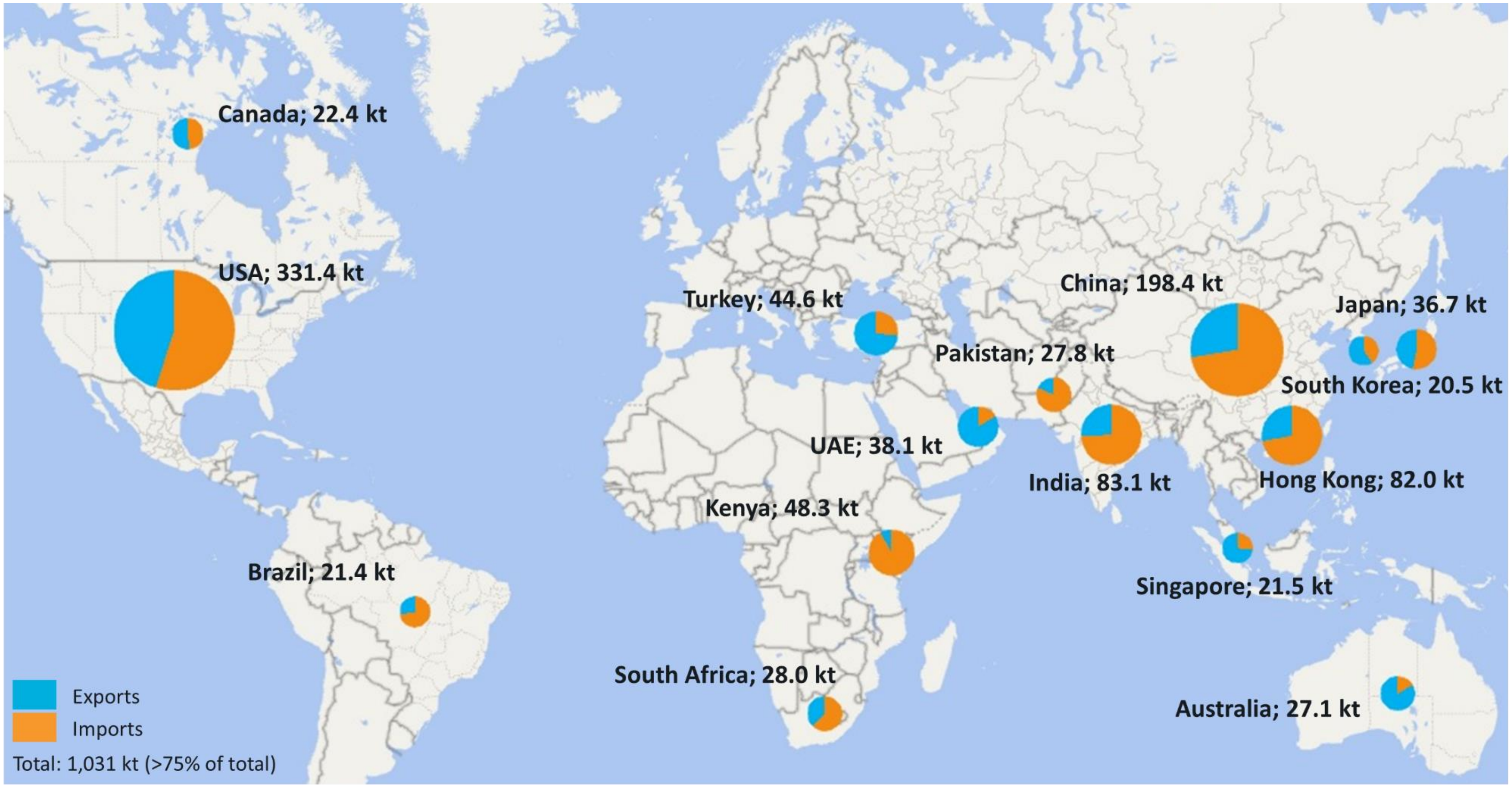
4.7 The size of the import and export markets with the UK's top 15 non-EU trading partners, separately in volume and value terms are shown in Figure 4.4 and Figure 4.5, respectively. Note that although many countries feature within the UK's top 15 non-EU trading partners, in both volume and value terms, the two figures do not show the same 15 countries.

4.8 With its major trading partners, in volume terms, the UK's imports are characterised by a mixture of mass manufactured goods (such as clothing) from Asian countries including China, India and Pakistan, and more high-value manufactured products (such as electronics and machinery) from countries including Japan and South Korea. The UK also imports a significant amount of food and raw materials from countries including Brazil, Kenya and South Africa. On the export side, UK volumes are characterised by high-end manufactured goods (such as transport or scientific equipment) and food, in particular salmon, to higher income countries.

4.9 In terms of value, many of the UK's major trading partners in Asia and North America are also major trading partners in volume terms; however, in value terms UK exports account for a higher share of trade. As with volumes, much of the import and export value is accounted for by high-end manufactured goods (such as industrial machinery) as these goods are high value as well as high volume. Much of the trade with the UK's major partners, in value terms, is accounted for by precious metals and minerals (such as gold), which is high-value but low-volume. This includes imports from countries where these materials are mined, including South Africa, Australia and Canada, as well as Switzerland, which has a large gold refining industry.

Appendix ND.1.13

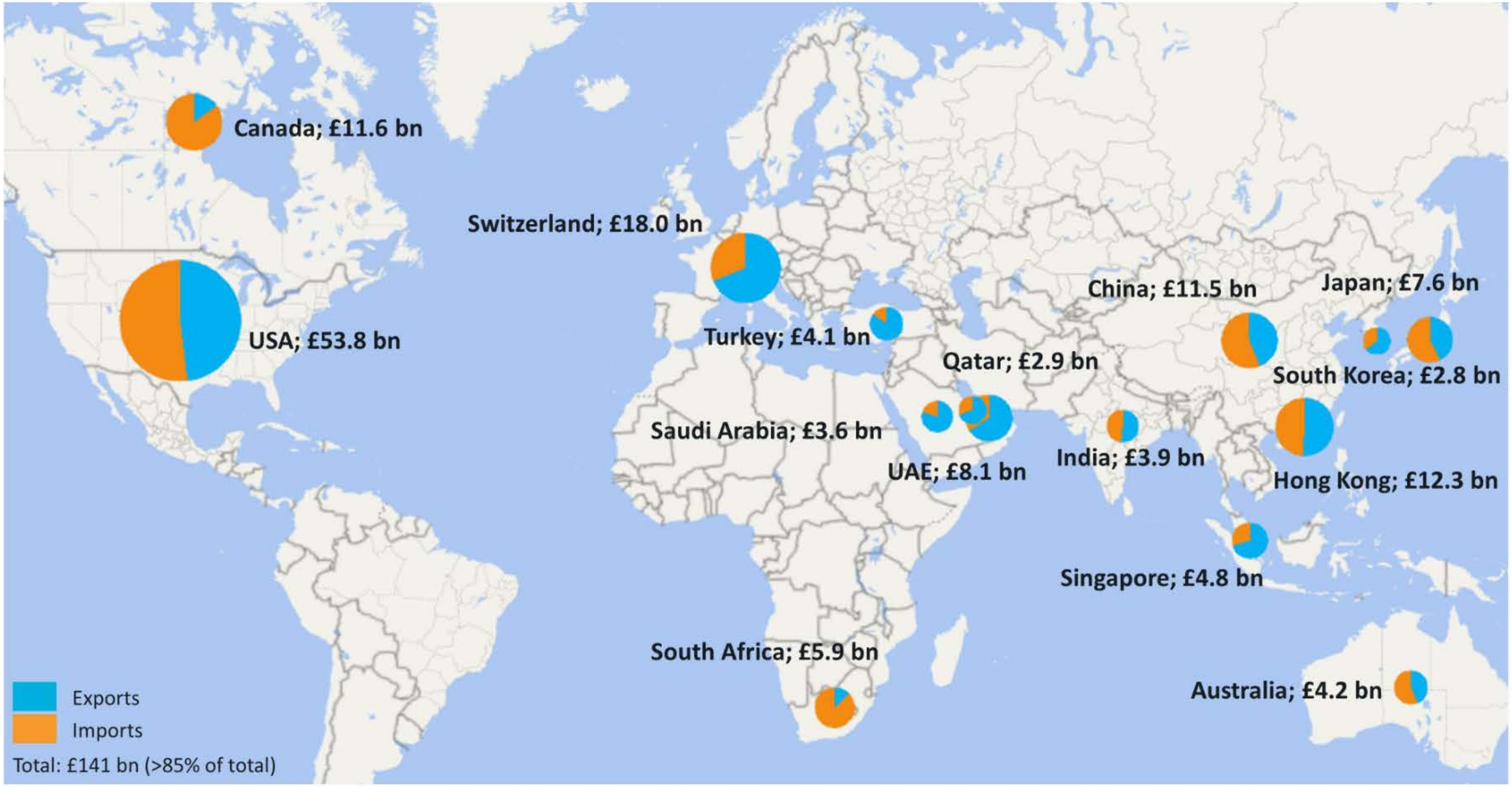
Figure 4.4: Volume of air exports and imports with top 15 non-EU trading partners, 1,000 tonnes (kt) 2017)



Source: HMRC

Appendix ND.1.13

Figure 4.5: Value of air exports and imports with top 15 non-EU trading partners, £ Billion (2017)



Source: HMRC

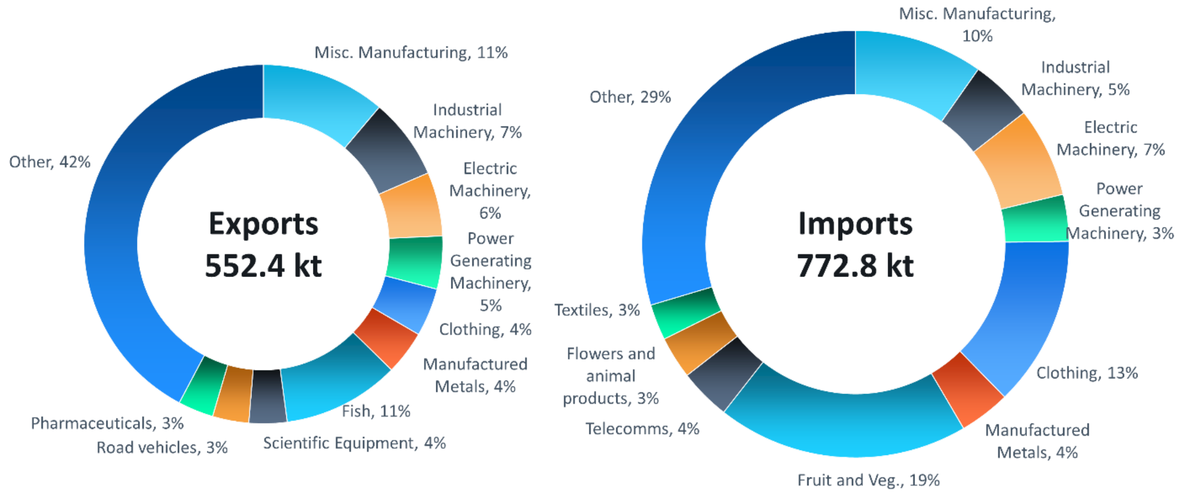
Appendix ND.1.13

Product markets

Products shipped by air

4.10 The UK's exports and imports to all non-EU countries at a 2-digit Standard International Trade Classification (SITC) code level, in volume terms, are shown in Figure 4.6.

Figure 4.6: UK non-EU exports and imports at a 2-digit SITC code level, 1,000 tonnes (kt) (2017)



Source: HMRC

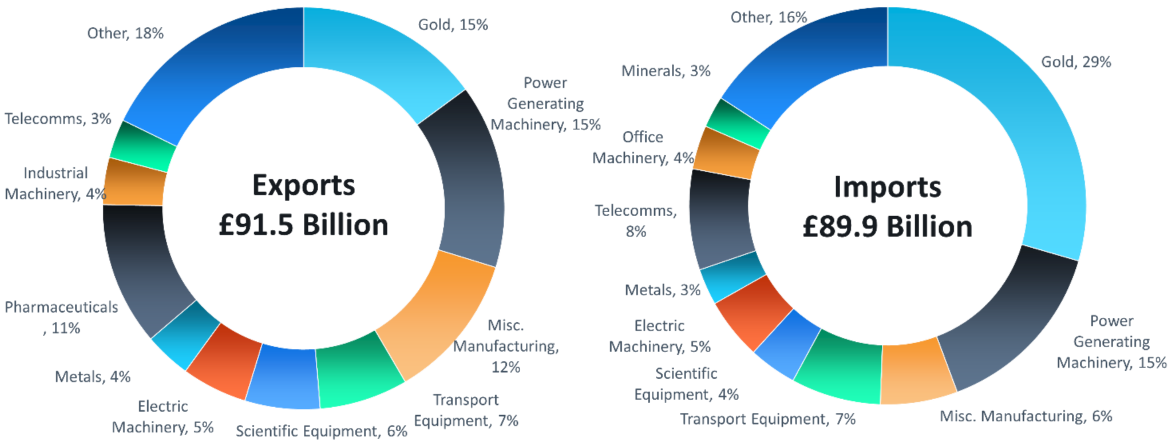
4.11 Clothing and fruit / vegetables are the two largest 2-digit SITC product groups imported by air. Fruit and vegetables are perishable and therefore need to be delivered quickly, while clothing is often shipped by air to enable retailers (particularly online retailers) to meet shifting demand of the latest fashion trends.

4.12 Other high-volume imports include business products including industrial goods, such as electric components and industrial machinery, and consumer goods including mobile phones, flowers and a range of manufactured products.

4.13 On the export side, most products with a high share of total volume are high-end manufactured goods, such as pharmaceuticals, cars, books and plane engines, or creative and knowledge industry-based goods such as books and high-end fashion. The notable exception to this is fish, in particular Scottish salmon, which accounted for over 10% of export volumes.

4.14 Figure 4.7 shows the UK's exports and imports to all non-EU countries at a 2-digit Standard International Trade Classification (SITC) code level in value terms.

Figure 4.7: UK non-EU exports and imports at a 2-digit SITC code level, £ Billion (2017)



Source: HMRC

4.15 Gold accounts for a significant proportion of import and export value, although it should be noted this is largely driven by the existence of the London Bullion Market, which, accounts for over 80%[7] of the global gold trade. This has a distorting effect on both the value of total imports and exports, as well as the value of trade with certain countries (such as Switzerland with its large gold refining industry).

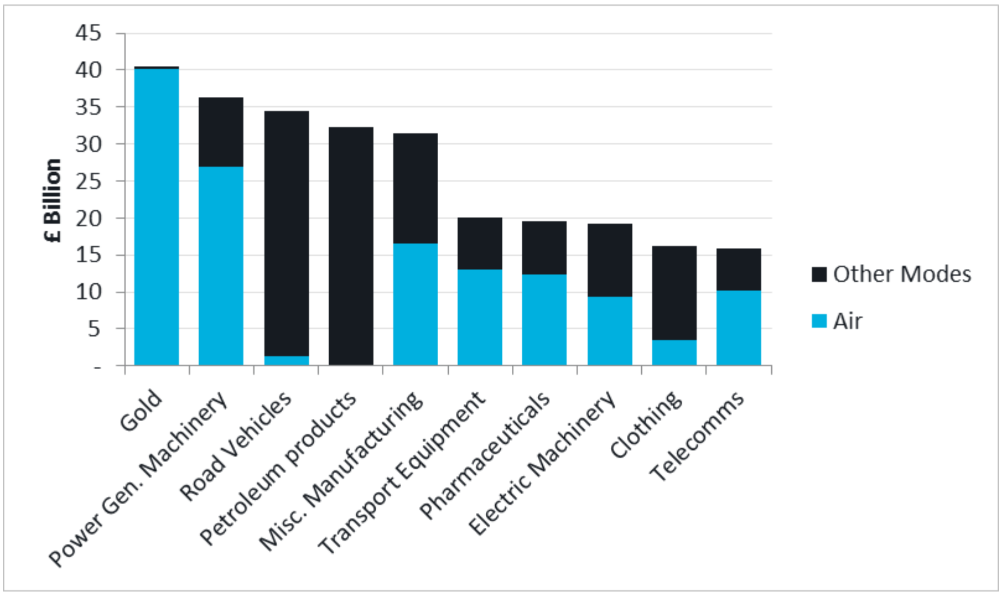
4.16 Many of the other products with a high share of UK trade value, such as aircraft engine parts and power generating machinery, have a high share of both import and export value, likely reflecting the global nature of these industries' supply chains and manufacturing processes. One exception is pharmaceuticals, which account for a significant proportion of export (but not import) value.

Products most dependent on air freight

4.17 Figure 4.8 shows, at a 2-digit SITC code level, the largest traded product groups by value and the proportion transported by air.

[7] Financial Times

Figure 4.8: Largest traded product groups at a 2-digit SITC code level, £ Billion (2017)



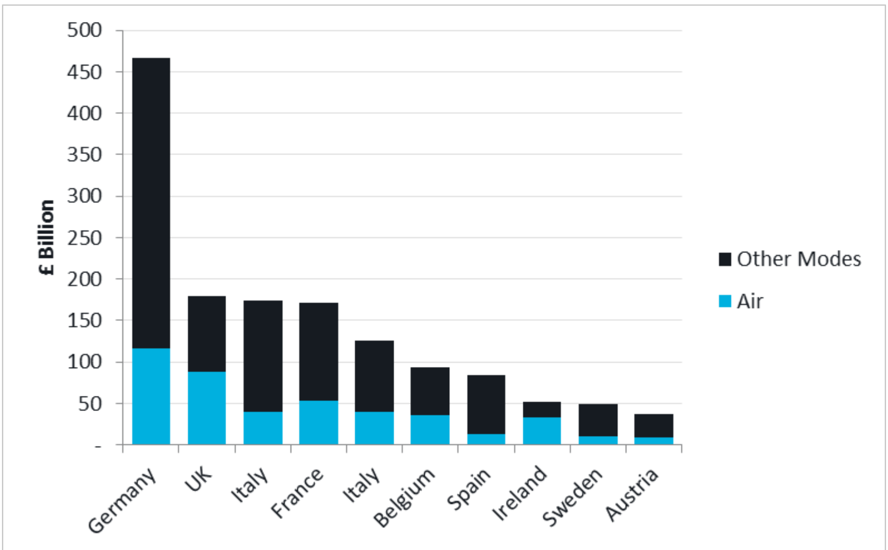
Source: HMRC

4.18 In all but three cases (petroleum products (oil), road vehicles and clothing), air accounted for over half of the value of each 2-digit product group. For some product groups, including miscellaneous manufactures, clothing and telecoms, air also accounted for a significantly higher proportion of exports (in value terms) than of imports.

International comparisons

4.19 The size of the largest EU import and export markets to non-EU countries in value terms, and the shares transported by air, in 2017 are shown in Figure 4.9 and Figure 4.10 respectively.

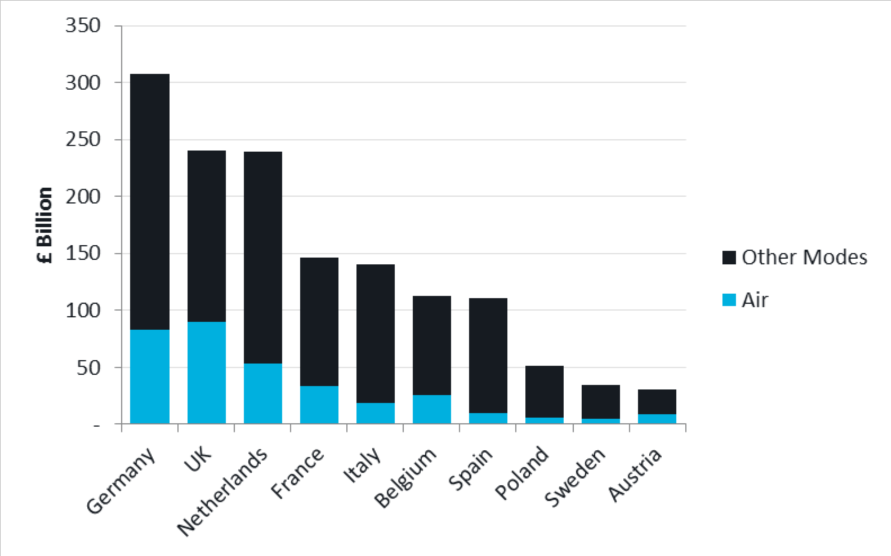
Figure 4.9: Air transport's share of export value in top 10 EU export markets, £ Billion (2017)



Source: Eurostat – figures have been converted from Euros using an average 2017 exchange rate of €1: £0.88

Appendix ND.1.13

Figure 4.10: Air transport's share of import value in top 10 EU import markets, £ Billion (2017)



Source: Eurostat– figures have been converted from Euros using an average 2017 exchange rate of €1: £0.88

4.20 Although Germany is by far the largest exporter to non-EU countries, only 25% of its goods by value are transported by air, whereas the UK, which is second largest total export market, ships a far higher proportion (49% by value) by air. Most of the other major EU economies ship between 20% and 40% of the value of their non- EU exports by air; only Ireland (64%) ships a greater share of its non-EU exports by air than the UK.

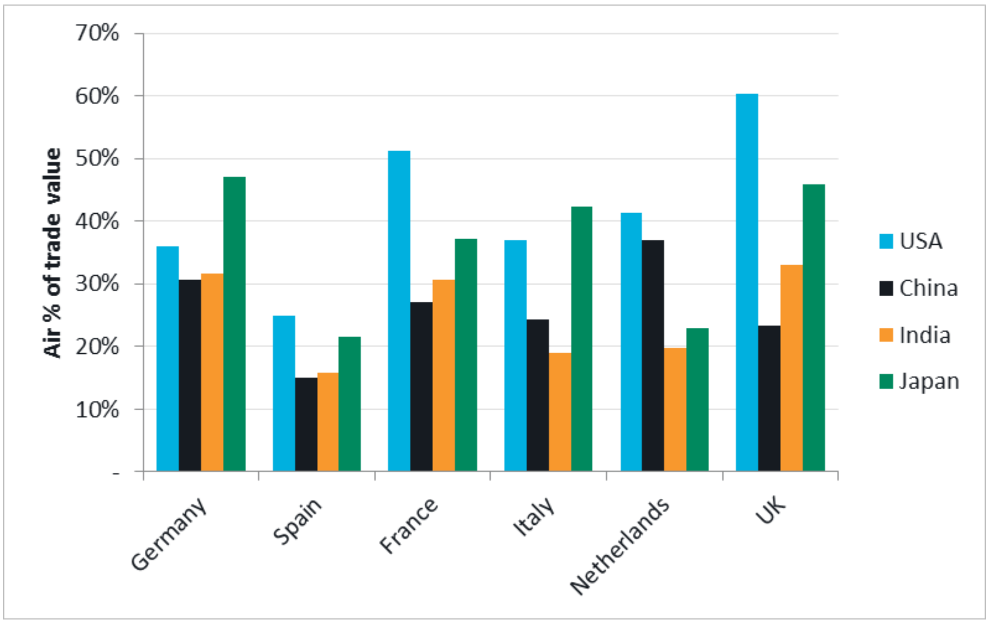
4.21 On the import side, the UK is second largest market in the EU and has the highest share (37%[8]) of imports transported by air, which makes its imports by air (£90 billion) the most valuable in the EU. Like the UK, most other major European economies ship lower proportion of their non-EU imports (compared to exports) by air, with most importing 10% to 30% by air in value terms.

4.22 The high share of air in non-EU trade for the UK (and Ireland) compared to other EU countries, is likely to be explained to some extent by the fact many countries on continental Europe can ship to some non-EU markets (such as Switzerland, Russia or Turkey) much more easily than UK without using air transport.

4.23 Figure 4.11 shows the proportion of trade value transported by air between some of the largest EU and non-EU economies in 2017.

[8] Difference from 35% shown in Figure 4.1 is likely due to slight difference between sources

Figure 4.11: Proportion of trade value transported by air between selected EU and non-EU countries (2017)



Source: Eurostat

4.24 The share of the UK's trade transported by air with India, Japan and the USA is either the highest (or close to the highest) compared to other major EU economies. In 2017, 60% of the UK's trade value with the USA was transported by air, compared to 51% for France and 36% for Germany. To a large extent, the proportion of trade value between two countries transported by air will be driven by the products the two countries trade, import demand preferences and the strength of each country's export markets.

4.25 However, it is likely that, to some extent, the proportion of trade value that is flown by air is linked to the level of air connectivity between the two countries. The UK has significantly more freight capacity to the USA than any other EU country, but has less capacity to China than Germany or the Netherlands. This may partly explain the low relative share of air in UK- China trade value; of the six EU economies shown, only Spain has a lower share of trade value with China that is transported by air.

Case Study – Pharmaceutical exports

In 2017, the UK exported £13.4 billion's worth of medical and pharmaceutical products[9], equivalent to just under 90,000 tonnes of goods. In 2017, 79% of the value these products were carried by air, which, as shown in Figure 4.7, represented over 10% of total air export value. Pharmaceutical products are key strategic knowledge-intensive industry for the UK, that benefits internationally from a reputation for high quality standards.

One company that has taken advantage of this reputation is Loughborough-based Morningside Pharmaceutical[10], which exports supplies to the developing world, to customers including NGOS, ministries of health and private sector clients including hospitals

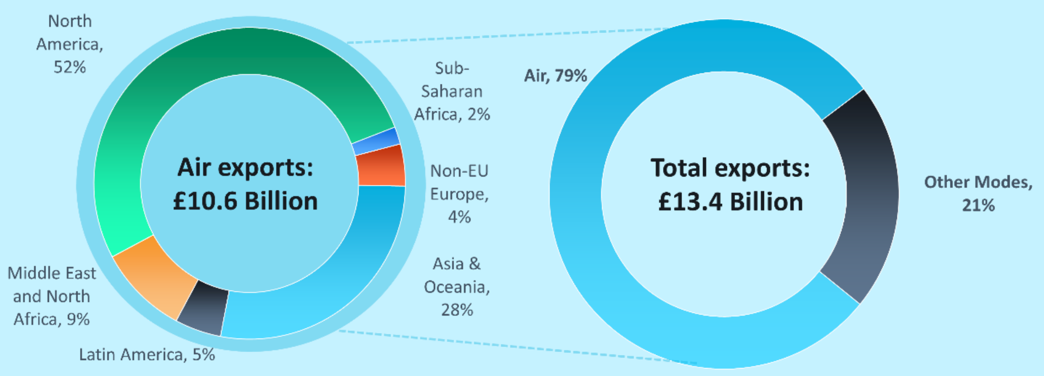
[9] SITC code 54

[10] Credit: East Midlands International Trade Association

and retailers. Shipping by air is more expensive than by sea, however, it enables supplies to delivered faster; shipments can be delivered to in-land locations in the developing world, such as Harare, within two to three days, compared to 45 to 50 days by sea and road. Many shipments are able to leave from East Midlands airport – 20 minutes away from Morningside's facility in Loughborough. Faster delivery is beneficial for Morningside as it facilitates faster payment.

Although companies like Morningside do most of their business in developing markets in Africa, the majority of UK pharmaceutical exports are to more developed economies, as shown in the figure below. In 2017, over half of air export value was shipped to the USA, while Australia, China and Japan were also important markets.

Medical and pharmaceutical supplies (SITC 54): Total and by air, £ Billion (2017)



Source: HMRC

Although it is beneficial for the drugs produced by Morningside to be delivered quickly, other pharmaceutical products are even more time critical. One pharmaceuticals manufacturer of diagnostic and therapeutic medical products, based in South-East England, supplies drugs from their facility, via Heathrow, to hospitals and medical facilities across the world. The drugs have a short life span and are therefore time critical; they must be shipped using express services before they start to degrade.

On the import side, the UK is also a world leader in clinical trials testing, therefore patient urine and blood samples from across the world are sent to the UK in order to develop world class drugs to treat illnesses. The global connectivity provided by Heathrow is therefore important for also facilitating this industry, as samples need to be delivered within 48 hours from collection so as not to compromise the sample integrity. Biological samples are imported (often on dry ice) from countries such as South Africa or Kuwait on direct commercial flights into Heathrow.

Policy considerations

This chapter demonstrates the importance of air freight to UK international trade, and in particular that the UK has a higher dependence on air freight than most other countries. This raises issues for consideration in the development of the UK Government's Aviation Strategy on the appropriate level of Government support for the air freight sector and how its importance should be reflected as part of the strategy for the aviation sector as a whole.

5 Economic analysis

Introduction

5.1 This chapter builds on the analysis earlier in the report to estimate the economic value of air freight to the UK economy. Economic value can be measured in different ways, but typically considers the impacts of an economic sector (or of a proposed project or intervention) on:

- employment (number of employees associated with the sector or intervention);
- income received as salaries by employees; and
- gross value added (GVA).

5.2 GVA is an important indicator which measures the revenues generated by an industry, after netting off the costs of its inputs, in particular its expenditure on the outputs of other economic sectors or on imports, hence the concept of "value added". GVA can be measured for both economic sectors and for geographical regions within a country, allowing for comparisons between each of these. When totalled to cover the whole economy at national level, GVA broadly equates to gross domestic product (GDP), the standard measure for national economic output (the difference is an adjustment for taxes and subsidies on products).

5.3 The analysis in previous chapters demonstrates the importance of air freight to the UK economy. As noted in paragraph 4.3 above, air freight is the transport mode used in UK external trade (to non-EU countries) for:

- 49% of exports by value;
- 35% of imports by value; and
- 41% of combined exports and imports by value.

5.4 However, while clearly demonstrating the significance of air freight, these figures do not automatically translate into the measures typically used by economists to estimate the economic value of the sector (employment, income and GVA), which are discussed below.

5.5 In this chapter, we consider two different, complementary, approaches to assessing economic value:

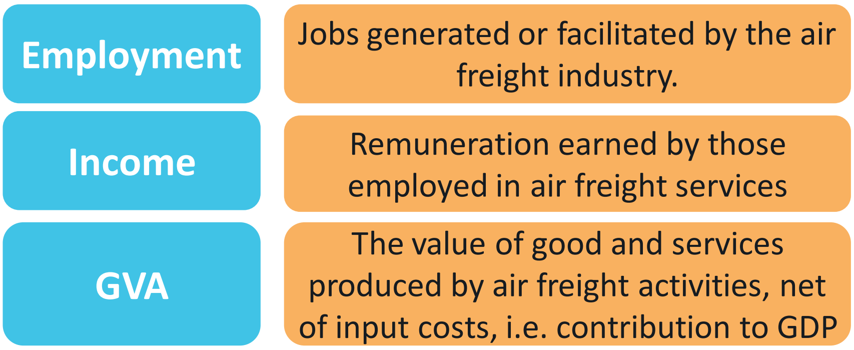
- the traditional measure of economic impacts on employment, income and GVA of the air freight industry and associated services, generally known as "direct", "indirect" and "induced" impacts (based on the activity in the sector itself and on upstream monetary flows between the air freight industry and other sectors in the economy); and
- the wider economic impacts of air freight, sometimes referred to as "catalytic impacts", which consider how air freight facilitates economic activity in other sectors (based, in this case, on estimating what proportion of GVA in those sectors is currently reliant on air freight services).

5.6 Our approach to the wider economic impacts of air freight also allows us to disaggregate these impacts both by economic sector (to illustrate which industries are most dependent on air freight) and by the UK regions and constituent countries. This gives important insights into where the economic benefits of air freight are generated, as distinct from the localities from where or to which it is flown (concentrated at Heathrow and three other airports). These approaches are described in the sections below.

Direct, indirect and induced impacts

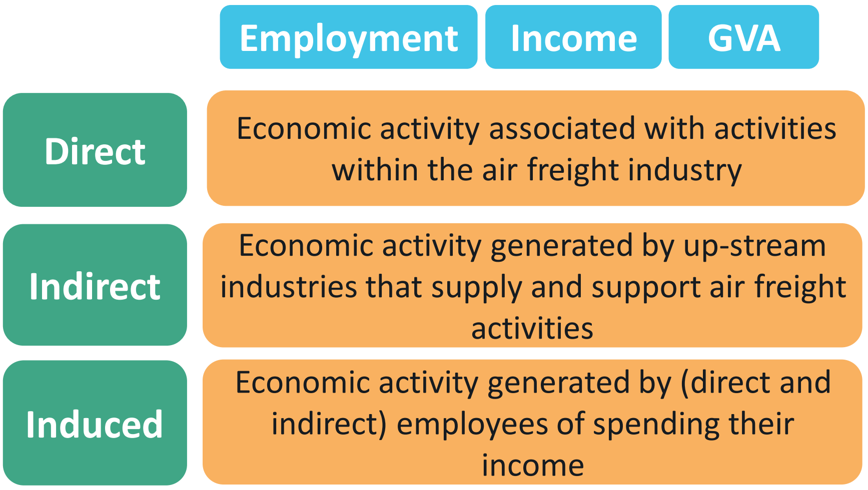
5.7 As noted above, the traditional approach to quantifying the economic impacts of an economic sector is to consider how its activity affects levels of employment, income and GVA, as shown in the diagram below.

Figure 5.1: Measures of economic impact



5.8 For each of these measures, it is possible to compute the "direct", "indirect" and "induced" impacts using a recognised methodology. In addition, wider, catalytic, impacts can also be estimated (see section below), although the approach for this is less standard. In this section, we focus on the direct, indirect and induced impacts, as shown in the diagram below.

Figure 5.2: Direct, indirect and induced economic impacts



Methodology

5.9 The calculation of direct, indirect and induced economic impacts is based on the use of Input-Output tables (I-O tables), produced by the Office for National Statistics (ONS), the latest available version being from 2014. I-O tables cross-tabulate what each industrial sector purchases from each other industrial sector (intermediate demand), and in addition include data on household and government expenditure, employees' income and company profit, as well as taxes, capital investment, exports and imports.

5.10 However, I-O tables are only available at a high level of industrial aggregation. In order to isolate the air freight sector, it has therefore been necessary to break down the existing categories into their constituent parts, and then reconstruct the table so that it provides the best representation of the range of air freight-related activities taking place in the economy.

5.11 In order to capture the economic value of air freight, it is important to include all the economic activities relevant to the delivery of air freight services. However, the Standard Industry Classification (SIC) used by ONS classifies as "air freight" (SIC code 51.2) only the activities related to the scheduled and non-scheduled transport of goods by air, but does not include essential supporting activities such as ground service activities, cargo handling, warehousing and storage. We have therefore developed a wider definition of supporting air freight services, which also includes the following sub-sectors:

- Warehousing and storage facilities (SIC 52.10/2)
- Service activities incidental to air transport (SIC 52.23)
- Cargo handling for air transport act. (SIC 52.24/2)
- Other transport support activities (SIC 52.29).

5.12 Clearly, not all warehousing and storage, or other transport support activities relate to air freight (forwarding, brokerage, etc.), but we have made the assumption that such activities within a given distance of airports will be largely focused on such activities[11]. Based on this assumption and levels of employment in each of the above sub-sectors in wards within these airport "catchments", as compared with overall employment in the sub-sector, we have allocated a proportion of the economic activity in each sub-sector to air freight services. Although this will not capture all aviation-related activity (clearly there will be non-aviation related warehousing near airports, as well as aviation-related warehousing further away), on balance we consider that this approach is reasonable.

5.13 For "service activities incidental to air transport", which includes airport terminals and air traffic control, we have taken a proportion based on air freight's share of overall air transport GVA[12]. Cargo handling for air transport can reasonably be included in its entirety.

5.14 The table below shows the key components of the economic activity for air freight and its supporting services (these correspond to the "direct" impacts).

[11] Within 10km of Heathrow, within 5km of each of Gatwick, Stansted, Manchester, Birmingham and Glasgow, and within 3km of other airports

[12] 2.6%

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Table 5.1: Air freight and supporting services

	Gross Value Added (£m)	Employment (000 jobs)	GVA per worker (£k)	Income generated (£m)	Income per worker (£)
Air Freight (SIC 51.2)	222	3	86	101	38,914
Supporting Air Freight Services	1,261	44	29	1,000	22,838
Total Air Freight Services	**1,483**	**46**	**32**	**1,101**	**23,739**

Source: ONS data, Steer analysis. 2014 data and prices.

5.15 With these adjustments to the ONS 2014 I-O table, we are able to create the underlying data to calculate the direct, indirect and induced economic impacts of air freight and its supporting services. As indicated in Figure 5.2, direct impacts relate to the employment, income and GVA generated by the sector itself, indirect impacts take account of the knock-on effects in the sector's supply chain, while induced impacts also include the impacts of employees' spending in the economy. These can be calculated from the I-O table, by inspection for for direct impacts and via standard techniques for the indirect and induced impacts[13].

Results

5.16 Undertaking the analysis described above allows "multiplier effects" to be calculated. These capture the extent to which changes to air freight services impact the supply chain (indirect impacts) and how the employee income generated by such changes generates knock-on economic activity as this is spent in the wider economy (induced impacts). Multiplier effects are initially calculated for an industry's output, and can then be converted into the corresponding effects on GVA, employment and income. The table below shows the relevant multipliers for (total) air freight services. Note that the multipliers are shown, as is customary, as the overall impact compared to the direct economic impacts (as shown in Table 5.1 above), hence can be considered to be cumulative. The multiplier for direct effects is, by definition, equal to 1.

Table 5.2: Air freight multiplier effects

Multipliers	GVA	Employment	Income
Indirect	2.21	1.81	1.97
Induced (including indirect)	4.88	3.25	3.69

Source: ONS, Steer analysis

5.17 Applying these multipliers to the direct impacts leads to the economic impacts shown in the table below.

Table 5.3: Economic impact of air freight services

Impacts	GVA (£m)	Employment ('000s)	Income (£m)
Direct	1,483	46	1,101
Indirect	1,800	38	1,067
Induced	3,949	66	1,891
Total	**7,232**	**151**	**4,059**

Source: ONS, Steer analysis. 2014 data and prices.

[13] Using Leontief I (indirect) and Leontief II (induced) matrix inversions

5.18 Overall, air freight services support GVA of **£7.2 billion**, **151,000** jobs and associated income of **£4.1 billion** (2014 data and prices) in the UK economy. Note that this result only relates to activities and expenditure either within the air freight and supporting industries, its supply chain and spending by its workforce. It does not include "downstream" effects, i.e. the effect on the industries purchasing air freight services, or the wider, catalytic, impacts on the whole economy. These are discussed in the next section.

Wider economic impacts

5.19 Traditional economic impact assessments are based on the monetary interactions between each sector of the economy with other sectors, as well as with its workforce (salaries), the government (taxation), owners (dividends) and interactions with suppliers and purchasers outside the country (imports and exports).

5.20 However, air freight is a low margin business where the actual revenues earned from supplying air freight services (whether the actual flying or support activities such as ground handling and warehousing) do not fully represent either the value of what is being flown, or the value of timely delivery. In terms of the value of what is flown, air freight imports and exports, between them, were worth £181 billion (2017 values and prices)[14], or close to 25 times more than the economic added value (GVA) calculated using the direct, indirect and induced methodology of the previous section.

5.21 Additionally, beyond the value of the goods transported by air, some products are worth considerably more to the shippers/consignees of the goods than the value of the item itself. This explains why so much machinery and equipment, as well as contractual and legal documents, are delivered using air freight. The items themselves may not be particularly valuable, but a key component may allow a production line to continue to operate rather than being shut down while the component is delivered by surface transport. Similarly, key original signed documents may allow deals worth billions of pounds to go ahead.

5.22 While the value of goods flown (exports and imports) cannot be directly compared with an economic value measure such as GVA, because their worth is not "added value" in the same sense that the activities of an industry add value, the two concepts are linked. We have therefore developed an approach to identify how much value added across the economy is associated with the value of products moved by air.

Methodology

5.23 Each sector of the economy produces outputs for which customers are willing to pay. While service industries produce largely intangible outputs, primary and secondary sectors produce physical products such as food, machine parts, cars and so on. For these sectors of the economy, their outputs equate to particular commodities so that, for example, farms produce agricultural products while automotive plants produce cars and trucks. Hence, there is a correspondence between each industry and its outputs[15].

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[14] See Figure 4.7 above

[15] This correspondence is formally available using tables provided by Eurostat RAMON relating Standard International Trade Classification (SITC) commodity codes and Standard Industry Classification (SIC) codes, together with mappings between different versions of each set of codes provided by ONS and UNSD.

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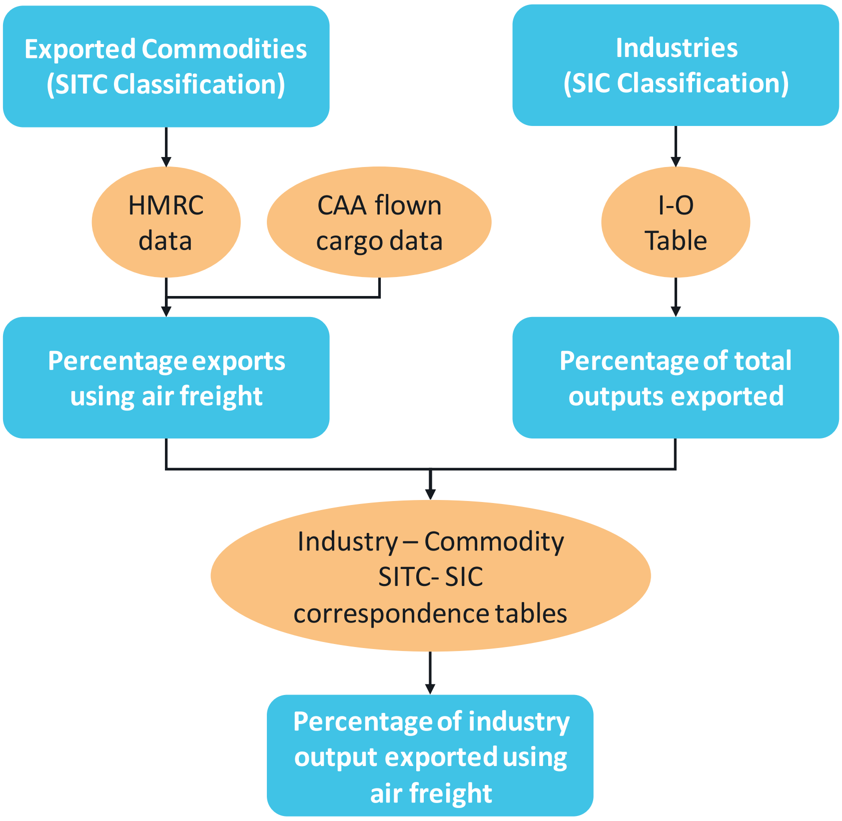
5.24 As identified in Chapter 4 and illustrated in Figure 4.8 above, for a number of commodities air freight plays a significant role in delivering exports of the product (the majority for pharmaceuticals and power generating equipment, for example), as identified by HMRC data on transport mode used for trade. Using the HMRC data, we can therefore identify what proportion of such industries' exports are transported by air. Furthermore, for each industry, the I-O table developed by ONS and described from paragraph 5.9 above, identifies the value of exports produced by each industry in relation to the total value of its output. Bringing these together by using the correspondence between industries and the commodities those industries produce, we can therefore establish, for each industry which produces physical outputs, what proportion of those outputs is represented by exports transported using air freight services. The approach is illustrated in the figure below.

Figure 5.3: Estimation of industry output exported using air freight



Source: HMRC data downloads, ONS weighted correlation tables, Eurostat RAMON, UNSD SITC Rev. 4, CAA airport data, Steer analysis

5.25 Note that because HMRC data covers only non-EU exports, an adjustment needs to be made to account for EU exports by air. In volume terms (tonnage), air freight flown to the EU represents 18.3% of total air freight from the UK, based on CAA flown volumes data[16], so total

[16] CAA 2017 airport data (Table 14)

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air freight export values can be estimated from non-EU exports by uplifting the value of non-EU exports by 22.3%[17].

5.26 An industry's output represents the value of the goods (or services) that it sells, while its value added (measured by GVA), broadly represents the value of outputs net of the cost of inputs[18]. For this reason, GVA, summed across the whole economy, with an adjustment for product taxes and subsidies, represents the whole national economic output (whereas adding all industries' outputs together would double-count the portions of output sold from one industry to another).

5.27 It is reasonable to make the assumption that all output contributes equally to the GVA generated by an industry. For example, based on the 2014 I-O Table, SIC 26, the "Manufacture of computer, electronic and optical products" generated £20.6 billion in output (sales) and its GVA was £7.9 billion. We therefore assume that each £1 million of output from these industries generate a GVA of £383,000.

5.28 We have also made the assumption that, since its exports represent a component of an industry's output and also contribute directly to the value added (GVA) of that industry, that:

- The proportion of an industry's GVA supported by air freight services is equal to the proportion of its outputs which are exported by air.

5.29 In the case of computer, electronic and optical products, using the analysis based on the approach in Figure 5.3, 54.2% of the value of the relevant industries outputs are exported, and of these, 49.5% are exported by air (EU and non-EU combined). Therefore 27.3% of the industries' outputs, or £5.5 billion's worth of sales, are exported by air. Using the assumption that each unit of output generates the same level of GVA, we can therefore deduce that 27.3% of the GVA generated by the industries producing computer, electronic and optical products is, currently, dependent on the use of air freight services. This equates to 27.3% of the industries' combined GVA of £7.9 billion, or £2.1 billion. Note that this represents the "direct" GVA of the industries themselves, and not any knock-on effects on their supply chains. This direct GVA to output relationship is illustrated in the figure below.

---

[17] The 22% uplift is calculated from [1 / (100% - 18.3%)] - 1, and by making the assumption that the commodity value per kg of EU exports using air freight is similar to the value per kg of non-EU air freight.

[18] Some adjustments are made for consistency across industries which sell different proportions of outputs to other industries rather than to consumers or the public sector, so GVA for an industry is actually calculated as the sum of employees' compensation, taxes on production and its gross operating surplus. At a national level, the two approaches are equivalent.

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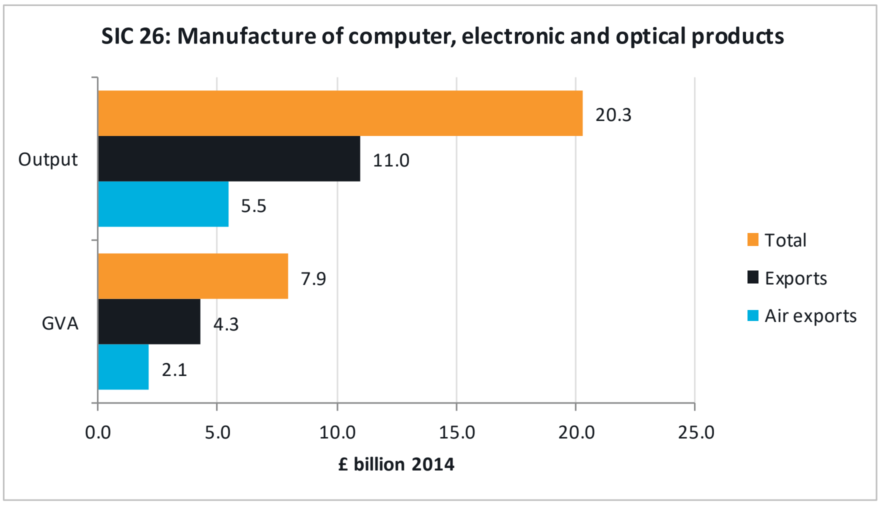
Figure 5.4: Illustration of relationship of industry output and GVA related to exports by air, £ Billions



Source: ONS, HMRC, Eurostat, CAA, Steer analysis

5.30 The final step in this analysis is to recognise that, if a portion of an industry's GVA is dependent on air freight services, then the suppliers who provide inputs to that industry are also dependent on the air freight services. This is the same "knock-on effect" described in paragraph 5.15 above. Following this logic, it is reasonable to apply the industry multipliers for indirect and induced impacts generated from analysis of the ONS I-O table. While Table 5.2 above shows the relevant multipliers for the air freight sector, each different industry sector has its own multiplier[19]. The multipliers are shown, for each sector with air exports, at the single-character industry section level, in the table below.

Table 5.4: Industry sector induced effects multipliers

Code	Industry sector	Induced multiplier
A	Agriculture, Forestry and Fishing	3.3
B	Mining and Quarrying	2.4
C	Manufacturing	3.9
E	Water Supply; Sewerage, Waste Management and Remediation Activities	3.0
H	Transportation and Storage	4.0
J	Information and Communication	3.0
M	Professional, Scientific and Technical Activities	3.0
R	Arts, Entertainment and Recreation	2.8

Source: ONS, Steer analysis

5.31 In the example of the industries manufacturing computer, electronic and optical products, the application of the multiplier for manufacturing (code C), which is 3.9, increases the estimate of GVA dependent on air freight exports from £2.1 billion to £8.3 billion.

[19] These are estimated by the same Leontief matrix inversion approach on the I-O table used to find the air freight multipliers

5.32 This approach leads to analysis that implies that a very significant proportion of some industries' GVA is dependent on air freight. While this is factually true at the current time, it is also necessary to consider the possibility that the exports currently transported by air could be transported by other modes (i.e. land or sea), and hence that this dependency is purely contingent, because substitute transport options exist. In the absence of air freight, some products might be transported via other modes and could not, therefore, be considered "dependent" in the strictest sense.

5.33 However, while it is true that all products which are currently transported by air could, in principle, be transported by surface modes, air transport is qualitatively very different in its characteristics, because:

- transit times are very much faster (e.g. one week for bulk air freight from the Far East, vs. six weeks by sea); and
- prices are very much higher (in a range of four to six times more expensive for bulk air freight, and higher still for express freight).

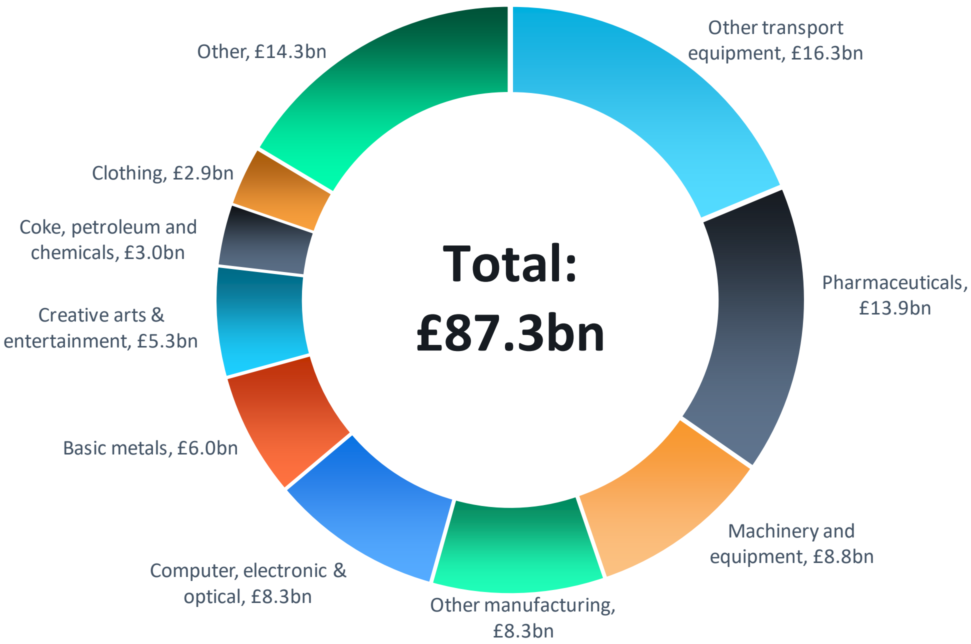
5.34 Therefore, surface modes would appear to be poor substitutes for air freight. Clearly, if air freight became less available and/or more expensive, some users would switch to surface transport. However, it is likely that they would become less competitive by doing so as, if not, they would already have made the switch. Therefore, in the longer run, such industries would tend to migrate away from the UK to other locations where air freight was more readily available and/or cheaper. For example, manufacturing plants which depend on air freight for their supply chains, and particularly to ensure continuous operation when parts fail, would be less efficient if surface transport had to be used, and hence corporations would be less likely to invest in such plants located in the UK.

5.35 For this reason, while the proportion of GVA dependent on air freight estimated using this approach may be reduced through the substitution of other modes, we consider that much of the GVA currently dependent on air freight is likely to remain so in future. Hence, any factors making air freight less convenient, less available or more expensive, are likely to have a negative impact on the industries generating this portion of GVA.

Results

5.36 Using the approach above, we have estimated the level of GVA currently dependent on air freight across the economy. Figure 5.5 below shows the industry sectors with the highest level of GVA currently dependent on air freight exports (including the contribution of their supply chains). The GVA figures are based on ONS' latest release (2016) of figures disaggregated at an industrial and regional level.

Figure 5.5: GVA currently dependent on air freight by industry, £ Billion



Source: ONS, HMRC, Eurostat, CAA, Steer analysis, 2016 values and prices

5.37 The chart shows that £16.3 billion of the GVA generated by the industries producing "Other transport equipment" (SIC 30) is currently dependent on air freight exports (including the contribution of their supply chains). Similarly, £13.9 billion of the GVA of the pharmaceutical industry (and its supply chain) is currently dependent on air freight exports. Across all sectors of the economy, **£87.3 billion of GVA is currently dependent on air freight exports**. This represents **5% of the total GVA measure of national output** (£1,747 billion in 2016).

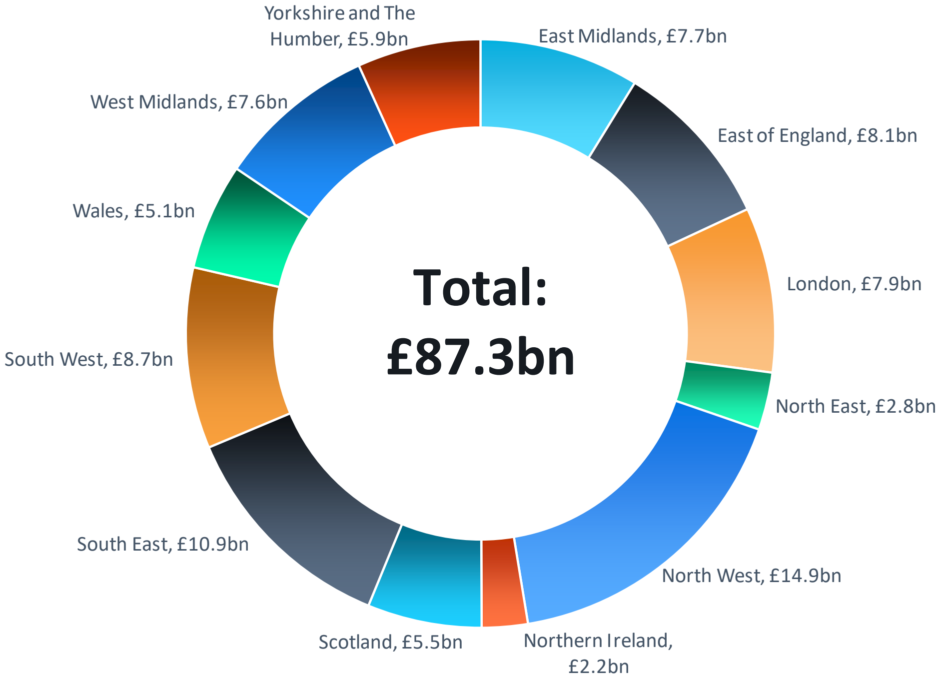
5.38 While the level of GVA currently dependent on air freight might potentially be reduced through the use of alternative modes of transport, the fact that such alternatives are generally poor substitutes for air freight indicates that the level of GVA dependent on air freight is likely to remain significant. This indicates that air freight is a very important service supporting a significant fraction of national economic activity.

Regional economic impacts

5.39 The analysis of the level of industries' and their supply chains' added value (GVA) which is currently dependent on air freight, enables us to estimate the regional importance of air freight services, by considering the regional distribution of output for each industry (and making the reasonable assumption that the proportion of air freight exports, compared with outputs, is the same for each industry across the different regions).

5.40 Figure 5.6 below shows the distribution of the £87.3 billion of GVA currently dependent on air freight exports across the UK's regions. Note that, unlike flown cargo data statistics, this data represents the origin of the air freight (i.e. where it is manufactured) rather than the region of the airport from which it is flown.

Figure 5.6: GVA currently dependent on air freight by region, £ Billion

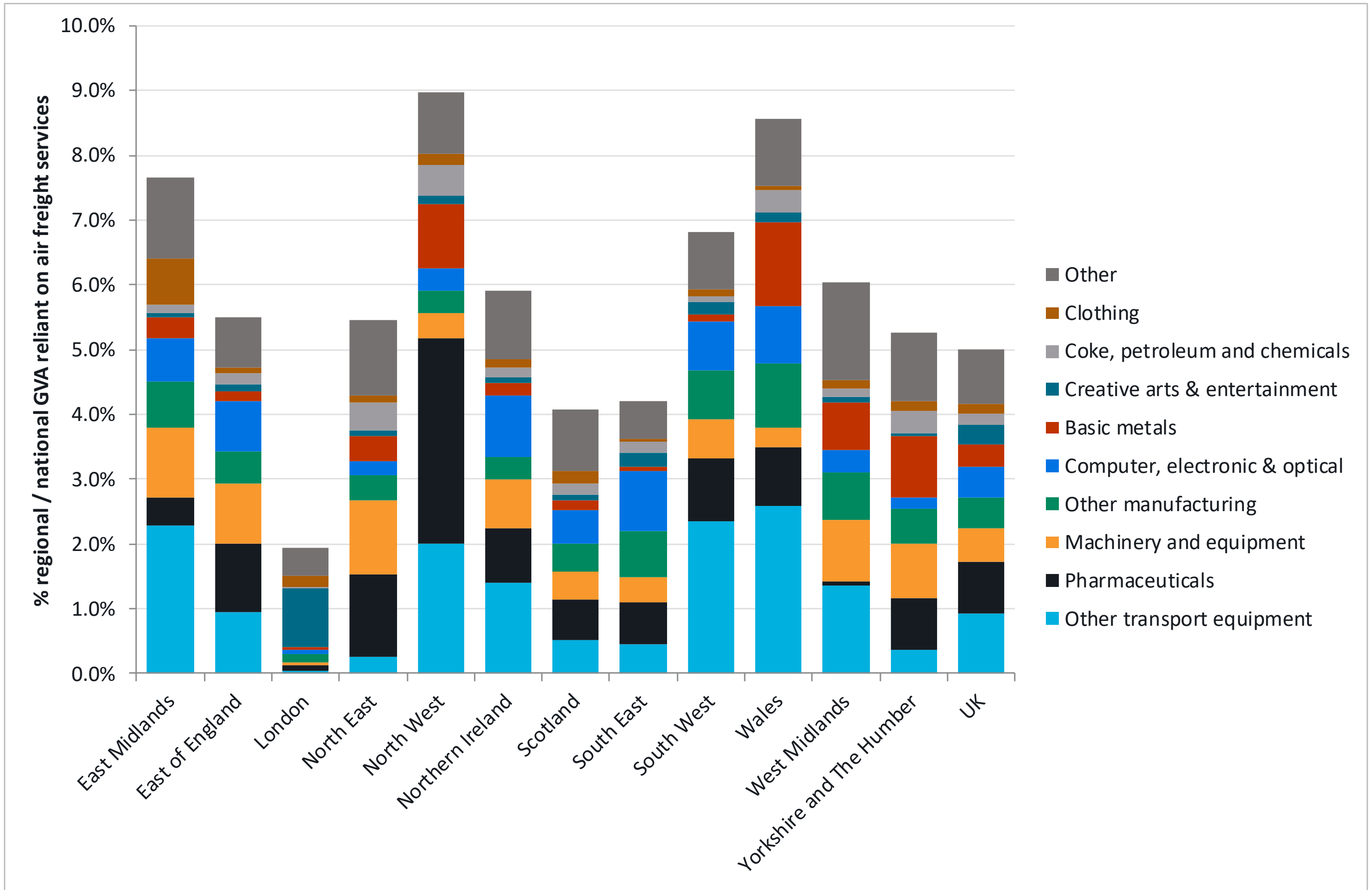


Source: ONS, HMRC, Eurostat, CAA, Steer analysis, 2016 values and prices

5.41 Figure 5.6 demonstrates the importance of the air freight industry in the North West, where £14.9 billion GVA is currently dependent on air freight, representing 9.0% of the whole economy of the region. Similarly, air freight supports very significant proportions of economic activity in many UK regions and nations, including 8.6% in Wales, 7.6% in the East Midlands, 6.8% in the South West, 6.0% in the West Midlands and 5.9% in Northern Ireland. Note that some of these regions have insignificant levels of actual air freight volumes flying from their airports, despite the importance of air freight to their economies, implying a reliance on surface transport to reach airports located elsewhere in the country.

5.42 Taking a combined view of both regions and the industries within them whose GVA is currently dependent on air freight provides some interesting insights, as illustrated in Figure 5.7 below.

Figure 5.7: Proportion of GVA currently dependent on air freight by region and industry



Source: ONS, HMRC, Eurostat, CAA, Steer analysis, 2016 values and prices

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5.43 Figure 5.7 highlights the importance of air freight to transport equipment producing industries in the East Midlands, the North West, the South West and Wales, while pharmaceutical manufacturing in the North West makes very significant use of air freight as well as (to a lesser extent) in other regions. Machinery, equipment and other manufacturing in many regions are supported by air freight, while basic metal industries in Wales, the North West, West Midlands and Yorkshire are also dependent on it.

5.44 Air freight does not support much of the production of the London region, which is unsurprising since it is in general not a manufacturing region, but London's large creative arts sector is seen to be strongly dependent on air freight services.

5.45 The contrast between the importance of London and the South East in terms of providing air freight services (focused on Heathrow), compared with the relatively low dependence of their economies on the sector in comparison to regions such as the North West, Wales, the East Midlands and the South West, is stark.

Case study – Connectivity at Manchester Airport

Several stakeholders consulted as part of this study have stated that, due to the concentration of air freight activity at Heathrow, UK air freight would benefit from greater utilisation of regional capacity. The recent growth in freight volumes at Manchester, enabled by increased intercontinental connectivity, have demonstrated how utilisation on regional capacity can benefit UK air freight and regional exports.

Prior to the financial crisis, freighters accounted for a significant amount of volume at Manchester. Although freighter volumes have fallen away since the financial crisis, increased intercontinental frequencies on passenger aircraft have driven a significant increase in bellyhold freight volumes since 2009. Bellyhold volumes at Manchester have increased with a CAGR of +8.5% between 2009 and 2017.

Bellyhold freight volumes have grown in line with the number of annual departing frequencies to the UAE and Qatar, which have more than doubled since 2009. In more recent years, bellyhold volumes have also been boosted by new direct connections to Hong Kong (2014), Saudi Arabia (2014), Singapore (2016), China (2016) and Oman (2017).

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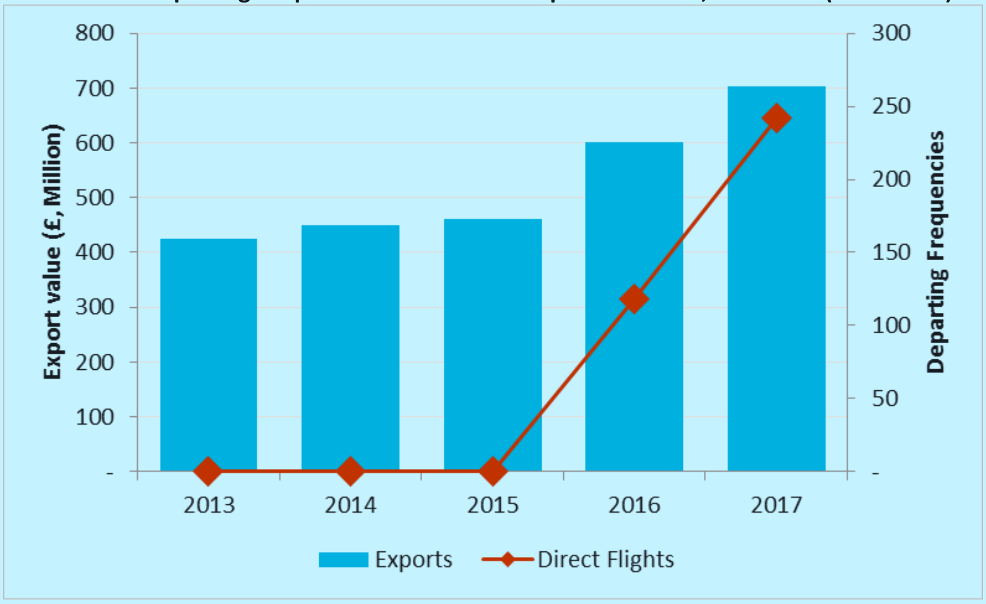
Connections on these new routes accounted for over 15% of freight volumes in 2017. The wider benefits of the China connection were explored in a recent report[20].

As well increasing freight volumes, these new connections have also facilitated exports flown from Manchester Airport. Although some of the routes are to global freight hubs, such as Hong Kong and Singapore, and have therefore not materially affected exports to these countries, other routes have significantly increased the value of exports shipped from the airport. The figure below shows the value of exports to China flown from Manchester Airport as well as the number of annual departing frequencies. The value of exports flown to China from Manchester Airport increased by close to £300 million in the two years since direct frequencies to Beijing were introduced. The exports to other countries have also increased; the value of exports to Oman increased 5-fold by over £40 million the year direct frequencies were introduced.

Manchester: Departing frequencies and value of exports to China, £ Millions (2013-2017)



Source: OAG, HMRC

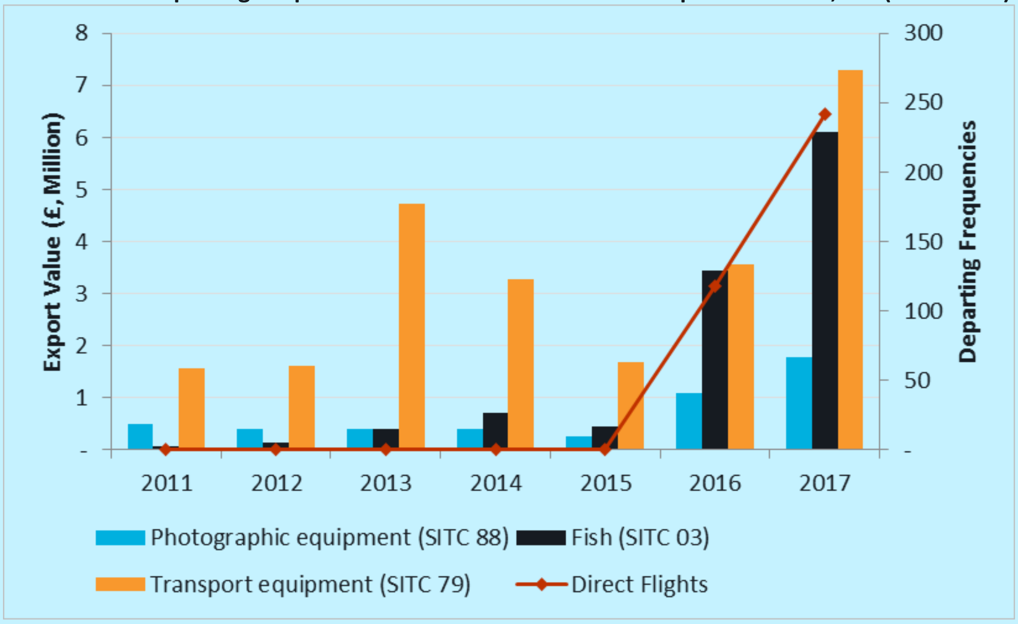
The direct connection to Beijing in some cases also appears to have aided exporters in North-West England. Although total exports to China from the UK grew strongly in 2016 and 2017 (recovering from a slump in Chinese trade in 2015), the value of some products exported to China have grown especially strongly since 2015. HMRC's Regional Trade Statistics (RTS) do not disaggregate exports by transport mode; but there has been strong growth in the value of some exports from the North West, in some products that are transported predominately by air.

The figure below shows the growth in export value from the North-West region to China, for selected product groups that have over a 70% share of air exports nationally, and the number of departing direct flights from Manchester Airport to China. The value of exports

[20] *The China Dividend: Two Years In,* Steer Economic Development, at: https://mediacentre.manchesterairport.co.uk/new-report-shows-manchester---beijing-service-is-a-major-catalyst-for-the-northern-economy/

to China from the North West, in these product groups, have increased significantly in the years since the direct flight to Beijing was introduced.

Manchester: Departing frequencies and value of North West exports to China, £m (2011-2017)



Source: OAG, HMRC

Direct connections to other countries also appear to have benefited local exports; after a new direct connection to Muscat in 2017, the value of exports flown from Manchester Airport to Oman increased 5-fold by over £40 million with export values of flown products from the North West also increased significantly.

The increased freight volumes and export values flown from Manchester demonstrate that long-haul connections served by non-UK carriers, can be a catalyst for the utilisation of regional airport capacity, can help mitigate the decline in freighter activity and can boost exports from regional airports. Given the capacity constraints at Heathrow and that, as of 2017 compared to other major European countries, the UK has relatively few connections with China and the Far East, these markets represent significant opportunity to grow freight capacity.

Policy considerations

5.56 This chapter demonstrates the importance of air freight to the UK economy as a whole, as well as to particular economic sectors and to certain UK regions and nations. Taking account of the analysis of the industry in previous chapters, this raises particular issues relevant to the formulation of national aviation policy as the UK Government develops an aviation strategy towards 2050, including:

- how to protect and develop the significant share of the UK economy currently dependent on air freight services; and
- how to support UK regions and nations whose economies are heavily dependent on air freight services, particularly where local airports do not currently benefit from strong air freight services.

Control Information

Prepared by

Steer
28-32 Upper Ground
London SE1 9PD
+44 20 7910 5000
www.steergroup.com

Prepared for

Airlines UK
25 Southampton Buildings
London
WC2A 1AL

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Author/originator

Mark Scott

Reviewer/approver

Peter Wiener

Other contributors

Cameron Ades, Daniyal Labib, Jake Cartmell

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Attention: Mr. G. Latham,

geoff.latham@dft.gsi.gov.uk

CC: Mr. J. Richardson

Jason.richardson@dft.gsi.gov.uk

8 February 2018

Dear Geoff,

UK airfreight forecasting

Thank you for meeting with us on the 25th January 2018. As requested, I am writing to you to outline our issues with the forecast for dedicated freights in the DfT's document "UK Aviation Forecasts 2017: Moving Britain Ahead".

Our concerns are over the way airfreight is understood and how future demand is predicted and planned in the UK and particularly in the South East. The focus of attention from both Government and the airport sector continues to be on the passenger market. The relative inattention to airfreight is leading to considerable and increasing issues for business. Figures compiled by the Centre for Economics and Business Research[1] show that the UK is missing out on at least £9.5bn in potential trade per year due to airport capacity issues.

The key issues, as we see them, are as follows:

1. The DfT forecast does not match data and intelligence from the airfreight industry or other agencies

The UK Aviation Forecasts 2017 document states that:

> "*Freight is not modelled in detail . . . At the airport level the number of freighter movements has been volatile with some evidence of overall national decline in recent decades. In the absence of clear trends for individual airports, the modelling now assumes that the number of movements will remain unchanged from 2016 levels at airport level across the system*." (DfT, 2017, section 2.56)

The decision to forecast zero growth in the dedicated freighter market is in stark contrast to figures from market sources. For example, IATA 2017 figures show airfreight growth of 11.8% year-on-year in Europe when measured in freight

[1]http://londonfirst.co.uk/wp-content/uploads/2016/09/Importance-of-air-freight-to-UK-exports-PDF-FINAL.pdf

Sally Dixon
MBA PhD MRAeS
01227 772 086
07973 523 898
sally@azimuthassociates.co.uk
www.azimuthassociates.co.uk
17 Island Wall Whitstable Kent CT5 1EP

tonne kilometres[2]. In contrast, capacity (available freight tonne kilometres) grew by only 5.9%, accounting for only half the increase.

Growth in airfreight volume is set to continue into 2018, with prices predicted to rise a further 4% in addition to the 5% rise in 2017. In the UK, the market seems strong with an increase in both imports and exports (October 2017 figures) and manufacturing orders from overseas customers high[3]. AirBridgeCargo has increased its freighters into Heathrow, Etihad has commenced freighter services at Stansted and East Midlands, and Manchester Airport saw 15% growth to China with the addition of Hainan Airline's Beijing service.

2. Dedicated freighter use compared to bellyhold freight carried in passenger aircraft.

Around 56% of global revenue freight tonne kilometres is flown on dedicated freighter aircraft while the remaining 44% is transported in the holds of passenger flights or on aircraft operated by passenger-cargo combination carriers[4]. However, DfT figures[5] show that, in the UK, somewhere between 70% and 78% of freight is carried on passenger aircraft, leaving only between 22% and 30% on dedicated freighters. The relevant citations from the DfT 2017 publication are:

> *3.32 70% (by weight) of freight carried is in the bellyhold of passenger aircraft.*
>
> *4.4 In 2011 (77%) and 2016 (78%) most freight by tonnage is carried in the holds of passenger aircraft.*

This disparity between global and UK-specific figures indicates a problem in the UK system. The most likely explanation is that a lack of capacity (in terms of not only slots but handling capacity at airports including warehousing) forces shippers to either use bellyhold space where available or truck to and from airports outside the UK system. My research for RiverOak shows that shippers can be 'gazumped' from bellyhold space by a competitor prepared to pay higher rates. This bumping from flights may occur numerous times before, sometimes, the shipper gives up attempting to find space to/from the UK and trucks to a northern European airport.

3. Experiences at other European airports

Frankfurt Main Airport is an interesting example of a successful European freight operation. Frankfurt has restricted operating hours and does not permit night flights. Even so the airport handles more than two million tonnes of cargo per

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[2] http://www.iata.org/publications/economics/Reports/freight-monthly-analysis/freight-analysis-dec-2017.pdf

[3] https://theloadstar.co.uk/brexit-effect-seems-positive-comes-uk-air-freight-market/

[4] Budd, L. and Ison, S. (2017) *The Role of Freighter Aircraft in the Provision of Global Airfreight Services*, Journal of Air Transport Management, vol. 61, pages 34-40

[5] UK Aviation Forecasts 2017: Moving Britain Ahead

Sally Dixon
MBA PhD MRAeS
01227 772 086
07973 523 898
sally@azimuthassociates.co.uk
www.azimuthassociates.co.uk
17 Island Wall Whitstable Kent CT5 1EP

year – second in the EU behind Paris Charles de Gaulle. Frankfurt has little integrator traffic with the exception of FedEx and handles a large number of freighters.

Data from Frankfurt highlights the difference between a true market, where capacity is available to attract any number of freighter flights, and a constrained market such as that in London. Figures based on the constrained London markets do not provide an accurate picture of the potential in the South East. Data from Frankfurt Airport also shows that cargo-only airlines are prepared to operate during the day if suitable slots are available and off load and turnaround times are expedient.

Capacity constraints at Amsterdam's Schiphol Airport are particularly impacting freighter operations, which could be reduced by 10.5% (1,900 ATMs) in 2018. Annual quota restrictions on aircraft movements mean that passenger services, with more predictable schedules than freighters, are less likely to be de-allocated their slots. This preference for passenger aircraft makes clear the position in any constrained market and has particular lessons for the South East of the UK.

4. Security issues and potential restrictions

Increasing security, particularly for shipments from high-risk countries, continues to impact transit times and add to costs. Passenger flights carrying airfreight may be particularly affected and the additional time needed for security clearing cargo could cause delays to flights. This may reduce capacity[6] in bellyhold cargo, increasing the need for dedicated freighters. Flights from the Middle East are the latest to be affected[7].

5. Constraints and impact on the UK airfreight market

Cranfield University's research for ACI Europe[8] shows that airport congestion increases passenger ticket prices, with passengers in Europe paying €2.1 billion per year in additional airfares when travelling from congested airports. It seems these increases to the cost of travel from congested airports also apply to airfreight. Over the Christmas 2017 period, airfreight in Europe reached capacity[9]. Shippers with bookings were 'bumped' or 'gazumped' by the highest bidder and rates were "sky high" – up to US$13 per kilogram for a trans-Atlantic route.

6. Forecasting airfreight in the UK

Whilst passenger forecasting is relatively well developed, the UK lacks data sets for the airfreight market. This is a particular problem in a constrained market,

[6] https://theloadstar.co.uk/eu-ramps-air-freight-security-nations-labelled-high-risk/
[7] https://www.reuters.com/article/us-usa-airports-security/u-s-requires-tougher-cargo-screening-from-middle-east-airports-idUSKBN1FB25F
[8] https://www.aci-europe.org/component/downloads/downloads/4883.html
[9] https://aircargoworld.com/allposts/freightos-warns-of-airfreight-rate-jump-as-europe-reaches-capacity/?goal=0_1711f92e66-42df020a11-39626945

where past operations are an unreliable and incomplete indicator of future demand. For some years, the UK has seen an unknown but significant proportion of its airfreight trucked to and from northern European airports for onward air transport. Government forecasts currently do not measure or take account of this slippage from UK airports. This omission will clearly impact the validity and utility of any resultant forecast.

Conclusion

A zero percentage growth forecast for dedicated freighter aircraft to and from the UK is unrealistic. It may be that Government forecasters have modelled very limited freighter access to UK airports whilst the market continues to be constrained and this pragmatism accounts for the zero growth forecast. However, this figure is misleading for those planning future capacity needs. A full picture of the demand for dedicated freighter movements is required urgently so that airlines, airports and other agencies can make appropriate decisions for the economic wellbeing of the UK.

With preparations for the UK's exit from the EU underway, the need for detailed forecasts that take account of the full range of impacts on the airfreight sector is overdue. I hope this information will be useful to your department and look forward to hearing from you.

Yours sincerely,

[redacted]

Consultant to RiverOak Strategic Partners Ltd.

Sally Dixon
MBA PhD MRAeS
01227 772 086
07973 523 898
sally@azimuthassociates.co.uk
www.azimuthassociates.co.uk
17 Island Wall Whitstable Kent CT5 1EP

Department for Transport

Jason Richardson
Regional Airports, Aviation Policy
Department for Transport
Zone 1/25
Great Minster House
33 Horseferry Road
London
SW1P 4DR
Direct Line:

Web Site: https://www.gov.uk/government/organisations/department-for-transport

Our Ref:

01 June 2018

Ms Sally Dixon
Consultant to RiverOak Strategic Partners Ltd.
Azimuth Associates

By Email: sally@azimuthassociates.co.uk

Dear Ms Dixon

Thank you for your correspondence of 8 February on the forecasting of UK air freight.

As you point out, as a Department we do not claim to model freight in detail and therefore have labelled it as an assumption. The Department is currently revaluating air freight policy as part of the developing Aviation Strategy, and you may have seen last July's Call for Evidence and the recent (April 2018) Next Steps response documents which set out some initial options: https://www.gov.uk/government/consultations/a-new-aviation-strategy-for-the-uk-call-for-evidence

We take your suggestion of conducting more detailed modelling of air freight on board and will consider it along with the other suggestions we have received as part of the strategy.

Yours sincerely

[redacted]

Jason Richardson

Appendix ND.1.14

Appendix NS. 1.3

This technical note has been produced in response to Question Ns.1.3 of the First Written Questions issued by the Examining Authority (ExA) on the 18 January 2019.

The ExA requests that the applicant to make a copy of Basner et al 2006 available.

Appendix Ns.1.3

Aircraft noise effects on sleep: Application of the results of a large polysomnographic field study

Mathias Basner, Alexander Samel, and Ullrich Isermann

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Appendix Ns.1.3

Aircraft noise effects on sleep: Application of the results of a large polysomnographic field study[a)]

Mathias Basner[b)] and Alexander Samel
German Aerospace Center (DLR), Institute of Aerospace Medicine, 51170 Cologne, Germany

Ullrich Isermann
German Aerospace Center (DLR), Institute of Aerodynamics and Flow Technology, Bunsenstr. 10, 37073 Goettingen, Germany

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The Institute of Aerospace Medicine at the German Aerospace Center (DLR) investigated the influence of nocturnal aircraft noise on sleep in polysomnographic laboratory and field studies between 1999 and 2004. The results of the field studies were used by the Regional Council of Leipzig (Germany) for the establishment of a noise protection plan in the official approval process for the expansion of Leipzig/Halle airport. Methods and results of the DLR field study are described in detail. Special attention is given to the dose-response relationship between the maximum sound pressure level of an aircraft noise event and the probability to wake up, which was used to establish noise protection zones directly related to the effects of noise on sleep. These protection zones differ qualitatively and quantitatively from zones that are solely based on acoustical criteria. The noise protection plan for Leipzig/Halle airport is presented and substantiated: (1) on average, there should be less than one additional awakening induced by aircraft noise, (2) awakenings recalled in the morning should be avoided as much as possible, and (3) aircraft noise should interfere as little as possible with the process of falling asleep again. Issues concerned with the representativeness of the study sample are discussed. © *2006 Acoustical Society of America.* [DOI: 10.1121/1.2184247]

PACS number(s): 43.50.Qp, 43.50.Sr, 43.50.Rq, 43.50.Lj [BSF] Pages: 2772–2784

I. INTRODUCTION

Between 1999 and 2004, the DLR–Institute of Aerospace Medicine (IAM) in Cologne, Germany, performed extensive laboratory and field studies on the effects of aircraft noise on sleep, mood, and performance in the DLR/HGF project "Quiet Air Traffic."[2–4] The Regional Council of Leipzig (RCL) asked the IAM to propose a concept for the protection of airport residents against the adverse effects of nocturnal aircraft noise on sleep based on the findings of these studies.

Leipzig/Halle airport is planned to be extended to an international freight hub with air traffic predominantly occurring during the night. In order to be able to handle the prognosticated traffic volumes, the southern runway will be turned and extended to a length of 3600 m. Together with the northern runway, this independent parallel runway system will allow for simultaneous takeoffs and landings on both runways. The traffic volume is predicted with 81 000 aircraft movements during the six busiest months in the year 2015.[1] Of these, 45 600 will take place during the day between 6:00 and 22:00 and 35 400 will occur during the night between 22:00 and 6:00. Thus, a large part of the aircraft movements will take place during the night. This situation distinguishes Leipzig/Halle airport from most other airports worldwide.

After an extensive course of consideration the RCL decided to develop a plan for the protection of airport residents against the adverse effects of nocturnal aircraft noise primarily based on the results of the DLR field study,[2] and therefore on the newest available scientific data. On 4 November 2004 the noise protection plan was presented for approval.[1] A few days later, DHL decided to move its international cargo hub from Brussels to Leipzig.

In this publication, methodological aspects of the DLR field study will be reported. The most important findings on the effects of nocturnal aircraft noise on sleep in general and on the probability of noise-induced awakenings in particular will be presented. Based on these results, it will be shown that noise protection plans based on number above threshold (NAT) and/or L_{eq} criteria are not suitable for an adequate description of the effects of nocturnal aircraft noise on sleep. Finally, a noise protection plan based on the findings of the DLR field study will be presented and substantiated.

II. METHODS

The DLR–Institute of Aerospace Medicine investigated the influence of nocturnal aircraft noise on human sleep, mood, and performance in a laboratory and a field study. The concepts of the noise protection plan for Leipzig/Halle airport are mainly based on the results of the field study. Therefore, study design and methods used in the field study will be briefly described. For a detailed description the reader is

[a)]Portions of this work were published in M. Basner, U. Isermann, and A. Samel, "Die Ergebnisse der DLR-Studie und ihre Umsetzung in einer lärmmedizinischen Beurteilung für ein Nachtschutzkonzept (The application of the DLR-study for a medical evaluation of a protective concept on adverse effects of nocturnal aircraft noise)," Z. Lärmbekämpfung **52**, 109–123 (2005).

[b)]Electronic mail: mathias.basner@dlr.de

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asked to refer to the executive summary of the study.[2] The field study was conducted between September 2001 and November 2002 with 64 residents of Cologne-Bonn airport, which is one of the German airports with the highest nighttime traffic densities and mainly used for freight traffic during the night. Subjects were investigated for nine consecutive nights, starting on Mondays.

Participants

Participants, selected in a multi-level process, were between 19 and 61 years old (average: 38 years). Fifty-six percent of the participants were female. Subjects had to be free of intrinsic sleep disorders and had to have normal hearing thresholds according to age. A detailed description of the selection process can be found in the report DLR-FB 2004/7E.[2] Consequences of the selection process for the representativeness of the sample are discussed in detail in Sec. V F. The study protocol was approved by the ethics committee of the Medical Board of the district North Rhine. Subjects were instructed according to the Helsinki declaration, participated voluntarily, and were free to discontinue their participation at any time without explanation.

The electroencephalogram (brain current diagram, EEG), the electrooculogram (eye movements, EOG), the electromyogram (muscle tension, EMG), the electrocardiogram (ECG), respiratory movements, finger pulse amplitude, position in bed, and actigraphy were sampled continuously during the night. With the EEG, EOG, and EMG signals (also called polysomnography), sleep can be classified into different sleep stages.[5]

Wake is differentiated from sleep. Sleep itself is classified in REM sleep, with its typical rapid eye movements, and nonREM sleep. NonREM sleep can be further divided in the four sleep stages S1, S2, S3, and S4. Because of high arousal thresholds,[6] stages S3 and S4 are also called "deep sleep." Deep sleep as well as REM sleep are known to be very important for the restorative power of sleep.[7] Wake and stage S1, on the other hand, do not seem to contribute to recuperation, or only very little.[8]

Historically, each night is usually divided into 30-s epochs. A trained scorer then assigns one of the sleep stages or "awake" to each of the epochs. Since reliable procedures for an automatic sleep stage analysis do not yet exist, sampling and analysis of polysomnographic data are sumptuous, and therefore have only been applied in studies with relatively small sample sizes (see Sec. V F). However, only polysomnography allows the assessment of structural aspects of sleep. Studies using actigraphy try to draw conclusions on sleep quality and quantity based on movements of the wrist of one arm, and are therefore obviously inferior to polysomnography according to the informational value. With 64 subjects and 576 subject nights, the DLR study is the largest polysomnographic field study on the effects of nocturnal aircraft noise so far.

In the field study, sound pressure levels (SPL) and the actual sounds were recorded inside the bedroom (at the sleeper's ear) and outside (2 m in front of the window) with class-1 sound level meters. All events (e.g., aircraft noise, road traffic noise, snoring, etc.) were identified by a human scorer. The beginning and the end of each event were marked. The simultaneous recording of acoustical and electrophysiological signals allowed for an event-correlated analysis with a maximum resolution of 125 ms.

Aircraft noise is intermittent noise. An event-correlated analysis establishes a direct temporal association between the occurrence of an aircraft noise event (ANE) and the reaction of the investigated subject to the ANE. This is only possible because of the synchronous sampling of electrophysiological and acoustical signals. Variables like the nocturnal secretion rate of stress hormones, the annoyance of study subjects asked for in the morning by questionnaires, or the amounts of the different sleep stages are represented in a single datum, which summarizes the effects of all nocturnal ANEs. These integrative measures are unsuitable for an event-correlated analysis, because the connection to single noise events cannot be made.

The reactions of sleeping humans to aircraft noise are nonspecific, since they may also be observed during natural sleep otherwise undisturbed by external stimuli. Hence, reactions observed during an ANE cannot be differentiated from spontaneous reactions according to electrophysiological criteria. Therefore, it is necessary to use an event-correlated analysis to distinguish spontaneous reactions from reactions observed during an ANE. Furthermore, spontaneous reactions occur irregularly. Therefore, if there is a reaction during an ANE, it is important to ask how often this reaction would have taken place spontaneously anyway, i.e., without the influence of aircraft noise. In epidemiology the term *attributable risk* is often used in this context. The probability of a reaction induced by aircraft noise is calculated as

$$P_{\text{induced}} = P_{\text{ANE}} - P_{\text{spontaneous}}. \quad (1)$$

As the physiological reactions may not immediately start after the beginning of an ANE, a certain time interval is screened for reactions of the sleeper. This time interval is called a "noise window." With a size of three epochs (90 s) after the beginning of an ANE, the length of the noise window was chosen to maximize the probability of reactions induced by aircraft noise [P_{induced} in Eq. (1)].

Several potential indicators for noise-induced sleep disturbances have been identified and proposed in the past. Brief EEG and EMG activations are called **arousals**.[9] Because of their short duration they are not classified as stage "awake" according to the rules of Rechtschaffen and Kales.[5] **Awakenings** are longer arousals, defined as EEG and EMG activations that last for at least 15 s and therefore lead to a classification of the sleep stage as "awake." **Sleep stage changes** are defined as transitions from one sleep stage to a different sleep stage. In the context of noise effects research, commonly only those sleep stage changes leading to a lighter sleep are considered, e.g., changes from deep sleep stage S4 to the light sleep stage S2.

Polysomnographic studies conducted in the past predominantly used awakenings as the primary indicator of sleep disturbances induced by environmental noise.[10,11] Because of the following reasons awakenings are appropriate indicators for sleep disturbances induced by environmental noise:

(i) The awakening is the **strongest form of activation**

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of the sleeping organism. The consequences for the restorative functions of sleep are accordingly severe.

(ii) Awakenings are relatively **specific**, i.e., the frequency of spontaneous awakenings is relatively low compared to other indicators. In the 112 baseline nights of the experimental group in the laboratory study, on average about 24 spontaneous awakenings were observed.[4,2] Spontaneous sleep stage changes were seen more than twice as often (on average about 52 changes per night). Mathur and Douglas[12] investigated the spontaneous onset of EEG arousals according to ASDA criteria.[9] They found on average about 21 arousals per hour of sleep. If the mean sleep period time (SPT) of 411.5 min of the noise-free baseline nights of the laboratory study is taken as a basis, this value corresponds to about 144 spontaneous EEG arousals per night.

(iii) In contrast to arousal, awakenings are usually accompanied by prolonged and unimodal increases in heart frequency.[13] We observed in our own investigations that the amplitude and/or the frequency of heart frequency accelerations are relatively low if there is no simultaneous awakening. But especially the regular occurrence of these nocturnal **vegetative reactions** seems to be a possible cause for the development of high blood pressure and the associated diseases of the cardiovascular system (myocardial infarction, stroke).[14] The degree of vegetative reactions accompanied by sleep stage changes or short arousals alone is low compared to reactions associated with awakenings.

(iv) The majority of awakenings last for exactly one epoch (15 to 45 s) and, therefore, are too short to be remembered on the next day. On the other hand, single awakenings may last longer and, therefore, be associated with the occurrence of waking consciousness. As a consequence, these longer awakenings may be recalled on the next day. In this case, they will also dominate the subjective assessment of sleep quality and quantity on the next day. Sleep stage changes and arousals will not be remembered on the next day as they do not lead to the occurrence of waking consciousness.

Sleep stage S1 does not contribute or only little contributes to the recuperative value of sleep. On the contrary, increased fractions of sleep stage S1 were identified as typical effects of sleep fragmentation in the past.[8] Hence, in this analysis not only changes to stage awake were regarded as relevant sleep stage changes, but also changes to sleep stage S1. This preventive measure increased the fraction of reactions associated with ANEs without significantly lowering the specifity of the proposed indicator, which is also called the sleep fragmentation index (SFI). Other authors also prefer to use this indicator in noise effects research.[15] The SFI was shown to correlate highly with the arousal index following ASDA criteria.[16,14] Therefore, in this publication the term "awakenings" implicitly means transitions from sleep stages REM, S4, S3, or S2 to the sleep stages S1 or awake.

Awakening probability does not solely depend on the maximum SPL of the ANE. On the one hand, other acoustical characteristics of the noise event (spectral content, duration, etc.) play an important role. On the other hand, situative and individual factors moderate the reactions to aircraft noise.[2] Therefore, in order to assess the influence of the maximum SPL, the other moderating factors have to be controlled for, which is called adjustment. Since an awakening represents a dichotomous dependent variable (yes/no), logistic regression was used for the analyses. As every subject was exposed to multiple ANEs, the observed reactions within one subject were not independent. Hence, random effects logistic regression was used, which is able to handle clustered data.[17]

Environmental conditions are less controlled in field studies compared to laboratory studies. The emergence of an ANE from the background noise level was identified as an important factor for the incidence of noise-induced awakenings. Therefore, in the field the background noise level was estimated for the minute preceding each ANE. The $L_{AS,eq}$ varied between 16.4 und 58.3 dB with a median of 27.1 dB.

Other noises originating from inside or outside the bedroom may occur during an ANE or between two ANEs. They were identified in the field study. An ANE contributed only to the final analysis if the following conditions were met: (1) In the minute before or during the ANE currently analyzed, only noises that were caused by the subject (except snoring) or by another ANE were allowed. Here, eliminating data with other ANEs in the minute before the start of the ANE currently analyzed could have led to a systematic underestimation of awakening probabilities in times of high air traffic. (2) Noises produced by the subject during the ANE currently analyzed were explicitly not discarded from the analysis, as they could have been caused by a reaction to the ANE. For each ANE, every of the other investigated nights was checked for ANEs in the same period according to the elapsed time after sleep onset. If there was no ANE, this period was used for the estimation of spontaneous awakening probability.

III. RESULTS

In total, 61 of 64 subjects contributed to the final analysis with 483 subject nights, in which 15 556 ANEs were recorded. The data of three subjects had to be discarded because of constant snoring (two subjects) or an intrinsic sleep disorder (one subject). The first night was not analyzed because of the so-called first-night effect.[18] In total, 10 658 ANEs met the inclusion criteria (see above) and contributed to the regression analyses.

Table I summarizes the results of a multivariable random effects logistic regression model (software Egret, Version 2.0.31, Cytel Corp.). The model contains the maximum A-weighted SPL ($L_{AS,max}$) and the background noise level in the minute preceding the ANE ($L_{eq\_}1min$) as well as their interaction term $L_{AS,max} \times L_{eq\_}1min$ as statistically significant variables. Additionally, the sleep stage prior to the occur-

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TABLE I. Results of a random effects logistic regression based on 61 subjects, 483 subject nights, and 10 658 ANEs. $-2 \log L = 6659.8$ with 10 650 degrees of freedom.

	Coefficient	Standard error	p
Intercept	−7.0734	0.8816	<0.001
$L_{AS,max}$	0.0946	0.0185	<0.001
$L_{eq\_}1min$	0.1319	0.0327	<0.001
$L_{AS,max} \times L_{eq\_}1min$	−0.0027	0.0007	<0.001
Elapsed sleep time	0.0006	0.0002	<0.001
Prior stage S3 and stage S4	−0.3205	0.1161	0.0058
Prior REM	0.4195	0.0733	<0.001
Random subject effect	0.3395	0.0540	

rence of an ANE (indicator variables prior stage S3 and stage S4 and prior REM) as well as elapsed sleep time are incorporated as statistically significant moderators in the model.

Awakening probability increases with maximum SPL $L_{AS,max}$ of the ANE, with background noise level $L_{eq\_}1min$ as well as with elapsed sleep time (positive coefficients). Awakening probability is lower from deep sleep (stages S3 and S4) and higher from REM sleep compared to stage S2. Nevertheless, stage S2 constitutes the most vulnerable sleep stage according to noise-induced awakenings, as the probability of spontaneous awakenings was much higher from REM sleep than from stage S2 sleep [see Eq. (1)]. The statistically significant interaction of maximum SPL $L_{AS,max}$ and background noise level $L_{eq\_}1min$ corroborates the importance of the emergence of an ANE from the background noise level.

Figure 1 illustrates the relationship between the maximum SPL of an ANE and the percentage awakened based on results of the regression model presented in Table I (black line). The background noise level was assumed constant with 27.1 dB (median). For preventive reasons, the sleep stage prior to the ANE was assumed to be stage S2 in all cases, i.e., the most sensitive sleep stage. Likewise, elapsed sleep time was set to the middle of the more sensitive second half of the night (epoch 601, about 5 h after sleep onset in the field study).

The highest SPL measured in the field inside the bedroom was 73.2 dB. Spontaneous changes to awake or stage S1 occurred with a probability of 8.6% (dashed line). A threshold value of about 33 dB was found in the field study, i.e., awakening probability increased only for ANEs with maximum SPL above 33 dB compared to spontaneous awakening probability (see Fig. 1). This threshold was only 6 dB above the background noise level, which seems physiologically plausible: First noise-induced awakenings should be observed once the human auditory system is able to differentiate the ANE from the background noise. Nevertheless, it must be pointed out that the awakening probability just above the threshold is accordingly very low. Only 2 of 1000 people exposed to an ANE with a maximum SPL of 34 dB will show a noise-induced awakening. Due to the large number of subjects and ANEs, the precision of the point estimate is very high, i.e., the width of the 95% confidence interval is very low (3.1% at 39 dB and 10.5% at 73.2 dB).

As already mentioned, awakenings are not specific for aircraft noise, as they also occur spontaneously. The probability of noise-induced awakenings is calculated by sub-

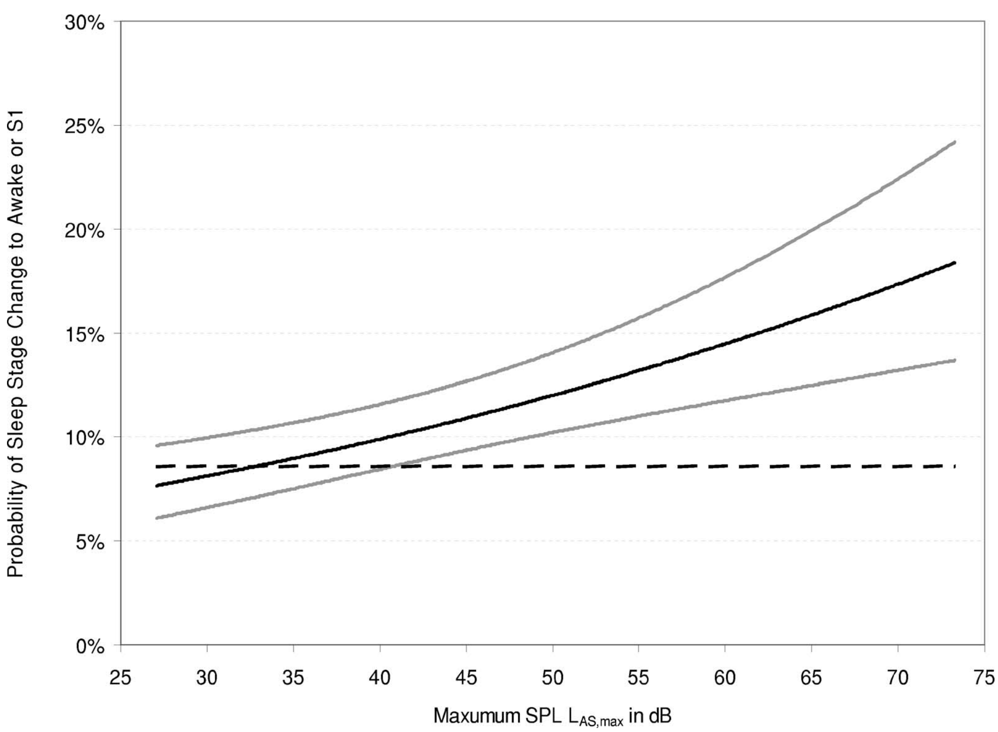

FIG. 1. Probability of sleep stage change to stage S1 or awake depending on maximum SPL $L_{AS,max}$ based on the regression results from Table I. Assumptions: Background noise level $L_{eq\_}1min = 27.1$ dB constant (median), prior sleep stage = stage 2, elapsed sleep time = 601 epochs (middle of second half of the night). Point estimates (black line), 95% confidence limits (gray lines), and spontaneous reaction probabilities (dashed line) are shown.

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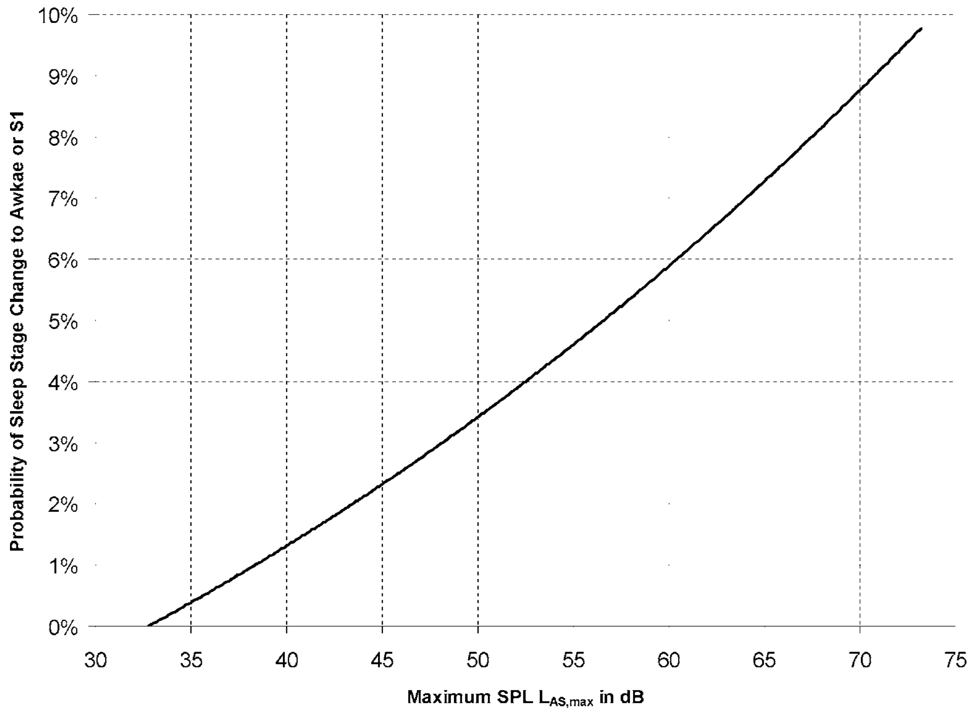

FIG. 2. Probability of aircraft-noise-induced awakenings depending on maximum SPL of ANEs. First reactions occur above maximum SPLs of 32.7 dB. This threshold exceeds the assumed background noise level of 27.1 dB only by 5.6 dB.

tracting spontaneous awakening probability (dashed line in Fig. 1) from awakening probability observed under the influence of aircraft noise (black line in Fig. 1) as indicated in Eq. (1). Aircraft-noise-induced awakening probability depending on the maximum SPL of an ANE is shown in Fig. 2.

The regression line can be approximated with a second-degree polynomial between 32.7 and 73.2 dB. Awakening probability in % is calculated as

$$P_{\mathrm{AWR}} = 1.894 \times 10^{-3} L_{\mathrm{AS,max}}^2 + 4.008 \times 10^{-2} L_{\mathrm{AS,max}} - 3.3243. \quad (2)$$

The awakening probabilities calculated by the polynomial deviate less than 0.1% from the original regression line within the specified interval.

Both the number and the duration of aircraft-noise-induced awakenings play an important role for the evaluation of the effects of aircraft noise on sleep, because the probability of a recalled awakening in the morning increases with the awakening duration. Thus, the results of the DLR laboratory study showed that awakening duration increased with the maximum SPL of an ANE (see Fig. 3).

Awakenings induced by ANEs with maximum SPLs of 65 dB or lower were relatively short. After 1.5 min, descriptively no difference in the percentage of subjects having fallen asleep again compared to spontaneous awakenings was observed. In contrast to that, awakenings induced by ANEs with maximum SPLs of 70 dB or higher were markedly longer than spontaneous awakenings.

IV. DISCUSSION OF NOISE PROTECTION STRATEGIES

In Germany, the most recent proposal for the protection against aircraft noise effects on sleep is based on a combination of *number above threshold* (NAT) and equivalent continuous sound level (L_{eq}) criteria ("Beschluss zur Novelle des Fluglärmgesetzes" from 25 May 2005). Pros and cons of NAT and L_{eq} criteria will be briefly discussed here based on the findings of the DLR field study. Both criteria are calculated from acoustical parameters (maximum SPL, time integrated SPL, or noise duration).

A. Number above threshold (NAT) criteria

NAT criteria are based on the assumption that below a defined threshold value no or only negligible effects of aircraft noise on sleep can be found. It was shown in Sec. III that first noise-induced awakenings can be expected if the maximum SPL exceeds 33 dB. Current proposals recommend limit values for NAT criteria between 52 and 55 dB, i.e., markedly above the threshold found in the DLR field study. Awakenings induced by ANEs with maximum SPLs between 33 dB and the proposed limit value are therefore not taken into account by the corresponding NAT criterion. Theoretically, an arbitrary number of ANEs with maximum SPLs below the NAT limit value are permitted without violating the NAT criterion, but simultaneously inducing relevant sleep disturbances.

NAT criteria also limit the number of ANEs above the threshold value, but without a definition of how much this threshold value may be exceeded by single ANEs. For example, a NAT criterion of 4×52 dB states that a maximum

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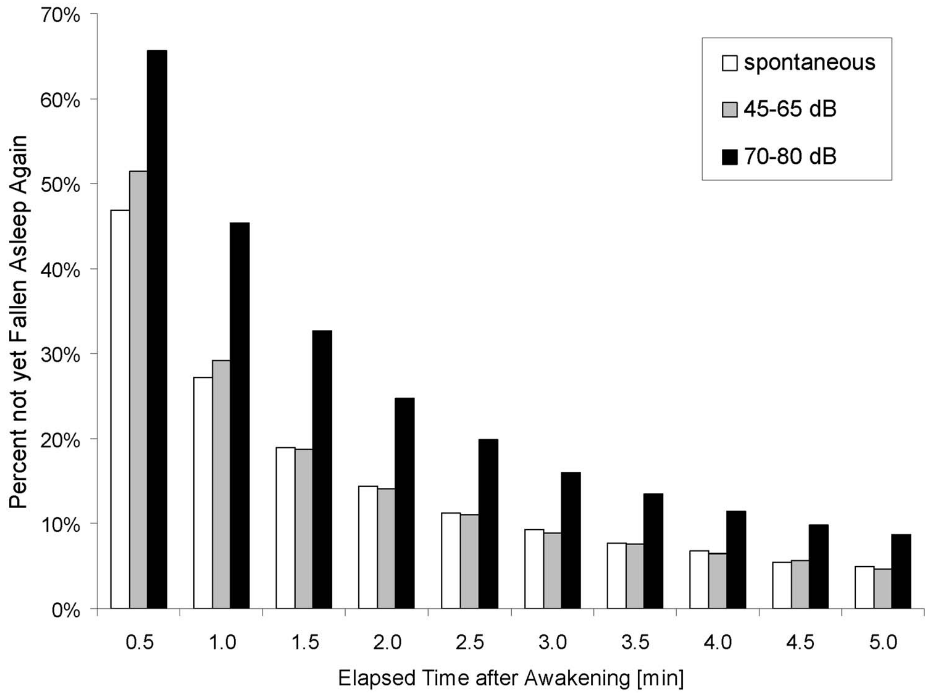

FIG. 3. Duration of noise-induced awakenings compared to spontaneous awakenings. Parameter is maximum SPL.

SPL of 52 dB may be exceeded no more than four times. Therefore, the criterion is neither violated by four ANEs with maximum SPLs of 53 dB nor by four ANEs with maximum SPLs of 73 dB. Calculations based on the dose-response relationship established in the DLR field study expect that 16 of 100 airport residents will be woken up by four events with 53 dB, whereas 39 of 100 residents, i.e., more than twice as many, will be woken up by four events with 73 dB (see Fig. 2).

B. L_{Aeq} criteria

Reducing the number of ANEs by 50% without changing the aircraft types means that the energy equivalent continuous sound level L_{Aeq} will decrease by 3 dB. Criteria solely depending on L_{Aeq} therefore implicitly assume that the effects of aircraft noise on sleep are simultaneously diminished by 50%, e.g., that the number of awakenings induced by aircraft noise is halved. Figure 4 demonstrates that this is not true. Following the epidemiologic concept of *numbers needed to harm*, it shows, depending on the maximum SPL of single ANEs, how many ANEs are needed to induce one additional awakening on average, where independent events were assumed.

If the maximum SPL of single ANEs is reduced by 3 dB from 72 to 69 dB, the permitted number of ANEs inducing one additional awakening may not be doubled but only in-

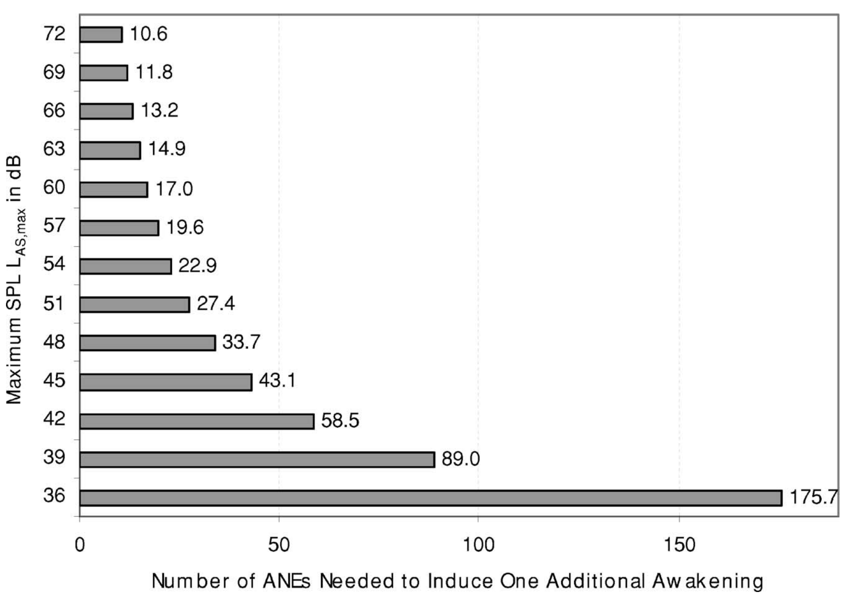

FIG. 4. Number of ANEs needed to induce one additional awakening on average and depending on the maximum SPL. Results are based on the dose-response relationship found in the field study (see Table I).

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creased by 11% from 10.6 to 11.8 movements. The allowable change in the number of ANEs following reductions in maximum SPL of 3 dB increases continuously from 11% (decrease from 72 to 69 dB) to 97% (decrease from 39 to 36 dB), i.e., the number of ANEs may be nearly doubled only very close to the threshold value of 33 dB.

C. Combinations of NAT and L_{Aeq} criteria

Potentially, there are two main advantages of combining NAT and L_{Aeq} criteria:

(i) The L_{Aeq} is mainly influenced by events with high SPLs. If ANEs are much louder than the limit value of the NAT criterion, the L_{Aeq} criterion will be violated quickly.

(ii) The number of ANEs with maximum SPLs between the physiological threshold (33 dB) and the limit value of the NAT criterion cannot be increased at will without violating the L_{Aeq} criterion. Especially in the case of high traffic volumes, the L_{Aeq} criterion will dominate the combined criterion, although there is a strong dependence on the actual limit values for both criteria.

Nevertheless, the problems associated with each of the criteria are not completely solved by the combination of both criteria. There are several constellations concerning the number and the maximum SPL of ANEs with maximum SPLs between the physiological threshold and the limit value of the NAT criterion that violate neither the L_{Aeq} criterion nor the NAT criterion, but lead to a relevant number of noise-induced awakenings nevertheless. A publication of the Health Council of the Netherlands states that, given a certain L_{night}, the least favorable situation regarding a direct biological effect occurs if maximum SPLs of single ANEs are about 5 dB higher than the physiological effect threshold.[19] Of course, this noise pattern constitutes an unrealistic *worst case scenario*.

D. A physiological noise effects criterion

As mentioned above, combinations of the acoustical NAT and L_{Aeq} criteria dominate current proposals of concepts for the protection of sleep against adverse effects of aircraft noise. Practically, noise protection zones around airports are represented by noise contours, i.e., curves on which a certain noise descriptor has a constant value. Such contours are usually estimated by calculations rather than by measurements. They are derived from the maximum SPL as well as the duration and number of ANEs, which again are based upon the airport's traffic description. This description, which can be a forecast, specifies the number and types of aircraft operating at the airport during a well defined time period. Until now, noise contours around German airports were solely based on acoustical criteria, i.e., areas where a certain L_{Aeq} is exceeded (e.g., 50 dB outside) or a certain maximum SPL is exceeded too often (e.g., 6×75 dB outside). By establishing these purely acoustical contours, it was implicitly assumed that aircraft-noise-induced sleep disturbances are acceptable outside the contours without additional sound insulation measures.

The dose-response relationship established in the DLR field study (see Fig. 2) can be combined with the estimation of immission values in order to explicitly specify the effects of aircraft noise on sleep around airports. The average number of aircraft-noise-induced awakenings at a certain location in the airport environment is calculated from the distribution of A-weighted maximum SPLs $n(L_{AS,max})$ at this location:

$$N_{AWR} = \int_{-\infty}^{\infty} f_{AWR}(L_{AS,max})\, n(L_{AS,max})\, dL. \tag{3a}$$

The function f_{AWR} follows from Eq. (2) as

$$f_{AWR}(L_{AS,max}) = \max(1.894 \times 10^{-5} L_{AS,max}^2 + 4.008 \times 10^{-4} L_{AS,max} - 3.3243 \times 10^{-2}; 0). \tag{4}$$

The max-function assures that there are no negative contributions of maximum SPLs below the threshold of 33 dB. The assumption that the function f_{AWR} is still valid above the range of 73 dB is arbitrary. In practice, there are no problems associated with this assumption, as maximum SPLs of this magnitude inside the bedroom only occur in highly exposed areas close to the airport.

These equations can easily be implemented in any calculation procedure capable of providing distributions of maximum SPLs (e.g., the German AzB procedure, which was used for the calculations in this publication). In practice level distributions are realized by SPL classes of a certain width rather than by a distribution function $n(L_{As,max})$. In that case, Eq. (3a) migrates to the following equation:

$$N_{AWR} = \sum_i f_{AWR}(L_{AS,max,i})\, n(L_{AS,max,i}). \tag{3b}$$

The summation has to be performed over all level classes denoted by the index i. It is likely that there will be an influence of the class width. In order to minimize this effect, the calculations performed for this investigation were carried out with a class width of 0.2 dB. Additionally, normally distributed maximum SPLs with a standard deviation of 3 dB were assumed instead of the discrete maximum SPL values provided by the AzB algorithm for the particular aircraft categories. This is currently also a common approach for the calculation of NAT contours. There is some potential to improve the implementation of the N_{AWR}-calculation scheme into existing aircraft noise calculation tools. Such optimizations are currently the subject of further investigations.

With the method described above, the number of aircraft-noise-induced awakenings can be predicted for each location around the airport. Hence, the need for protective measures against the adverse effects of aircraft noise can be quantified explicitly and precisely. This is illustrated in Fig. 5 for Frankfurt airport. Two areas based on L_{Aeq} criteria are compared with three areas outside of which less than one, two, or three additional noise-induced awakenings are expected.

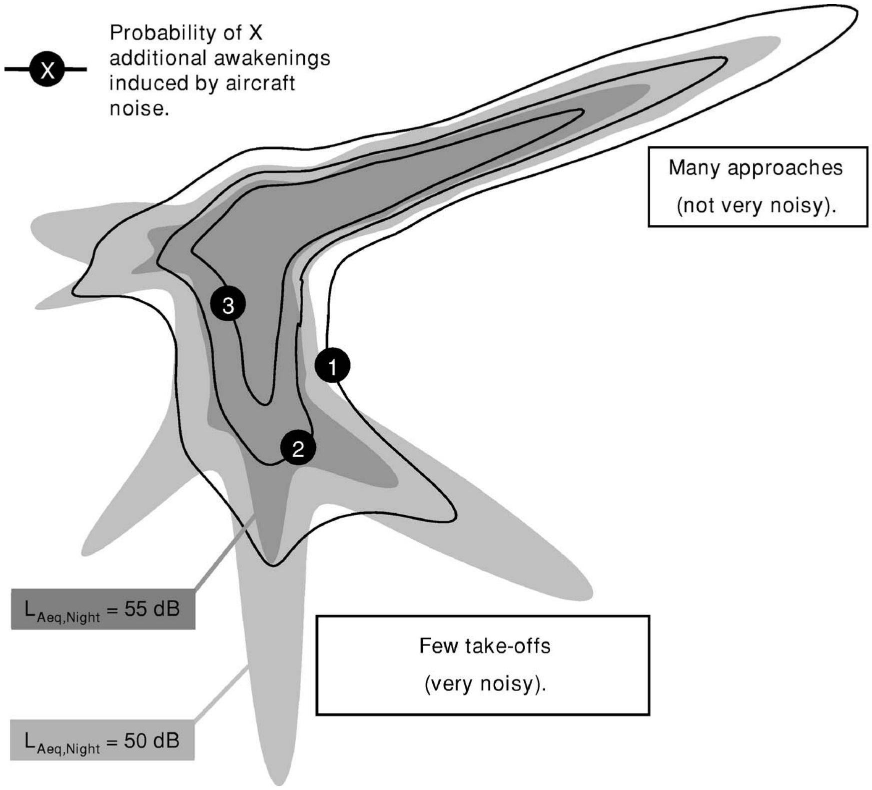

FIG. 5. Prognosis of noise effects for Frankfurt airport: on average one, two, or three additional awakenings induced by aircraft noise (black lines), L_{Aeq}=55 dB (dark gray), and L_{Aeq} =50 dB (light gray). Calculations are based on 25 000 nocturnal aircraft movements in the busiest six months of the year.

Apparently, there are qualitative differences: On the one hand, the contours for additional awakenings extend into areas with many but relatively quiet fly-overs (approaching aircrafts). On the other hand, in areas with few but relatively loud fly-overs (departures) they are not as pronounced as the L_{Aeq} contours. This illustrates the fact that L_{Aeq} criteria are not suitable for an adequate description of the effects of nocturnal aircraft noise on sleep.

The introduction of a physiological measure for sleep disturbances (i.e., the probability of awakenings) reflects a more medical- and health-related position than acoustical dimensions can do. The combination of a physiological reaction and an acoustical event, represented in a dose-response curve, and the calculation of acoustical immissions at a given location in the vicinity of airports provides a powerful tool for the protection of the affected population. Therefore, an easily applicable concept for the protection against adverse effects of nocturnal aircraft noise on sleep has been developed.

V. CONCEPT FOR THE PROTECTION AGAINST ADVERSE EFFECTS OF NOCTURNAL AIRCRAFT NOISE

The DLR concept for the protection against adverse effects of nocturnal aircraft noise on sleep will be presented and substantiated. Potential restrictions of the concept will also be discussed.

A. Objectives of the concept

The adequate protection of people affected by nocturnal aircraft noise has to be the main objective of a protective concept in order to prevent negative health consequences. Changes in sleep structure that may lead to a nonrestorative sleep are the primary effects of nocturnal aircraft noise. Sleepiness and impaired mental capacities are two of the possible immediate consequences. Furthermore, annoyance may be induced by consciously perceived noise events during the night. It is also being discussed whether repeatedly (over years) occurring noise-induced sleep disturbances may lead to other health impairments, such as an increased risk for high blood pressure or myocardial infarction.[20–22] If established, these noise impacts on health would be of major societal importance. However, in practice it is very difficult to substantiate a causal link between noise and long-term health effects, as many different and well-proven risk factors lead to the same diseases and induction periods are usually very long. Until now, there is no study corroborating this causal link for nocturnal aircraft noise.[19]

In order to overcome this dilemma, the DLR concept is based on two assumptions:

(1) Because of biological plausibility, it is hypothesized that a causal link between noise-induced sleep disturbances and long-term health effects exists. Vice versa, long-term health effects can be prevented with a high probability if noise-induced sleep disturbances are minimized.
(2) It is assumed that humans—like any organism—represent an adaptive system, which is able to compensate for certain strains without negative effects for the organism. Hence, it is not necessary to eliminate strains completely. It is simultaneously assumed that there are very sensitive subjects, who fail to compen-

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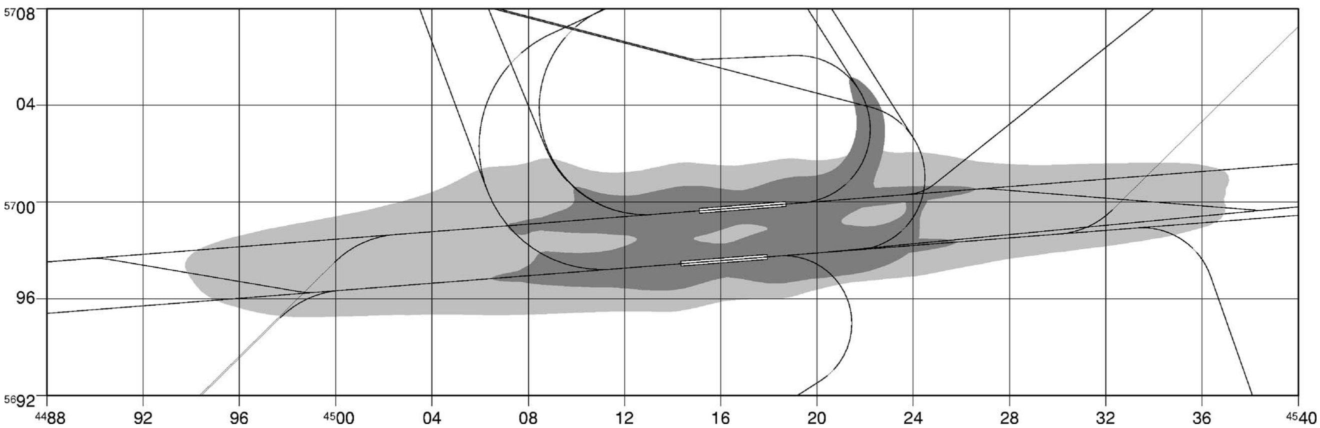

FIG. 6. Noise protection zone for Leipzig/Halle airport (traffic prognosis for 2015) consisting of the combination of two areas: (1) area outside of which less than one additional awakening induced by aircraft noise is expected on average (light gray) and (2) area outside of which maximum SPLs of 80 dB or higher (measured outside) occur less than once (dark gray, envelope of two contours calculated separately for 100% flight movements in each direction).

sate for small strains, as well as there are very robust subjects, who endure strong strains without negative consequences.

From a medical point of view, sound insulation should only be used if all other measures fail. Methods for the reduction of noise emissions are an active research field (e.g., silent engines, noise reduced takeoff and landing procedures, etc.). They should be consequently and quickly applied in practice.

B. Description of the concept

The DLR concept is based on three objectives, which reflect three highly correlated dimensions of sleep:

(1) On average, there should be less than one additional awakening induced by aircraft noise. Here, awakenings are defined as an electrophysiological phenomenon classified according to the rules of Rechtschaffen *et al.*[5]
(2) Awakenings recalled in the morning should be prevented as much as possible.
(3) There should be no relevant impairment of the process of falling asleep again.

Figure 6 illustrates the proposed noise protection zone for Leipzig/Halle airport for the night (22:00 until 06:00), based on a traffic prognosis for 2015. Two contours are combined: Outside of the light gray area on average less than one additional awakening induced by aircraft noise is expected. This contour is based on the expected, average distribution of flight movements on the two operation directions. Outside of the dark gray area, maximum SPLs of 80 dB or higher (measured outside) occur less than once. This contour is the envelope of two contours estimated for a 100% distribution of flight movements in both operating directions. This leads to an overestimation of effects, which was intended as awakenings recalled in the morning are regarded as especially severe sleep disturbances. The three columns of the DLR concept will be discussed in detail in Secs. V C to V E.

C. Less than one additional awakening induced by aircraft noise on average (first criterion)

Self-evidently, humans either wake up or they do not, i.e., on the individual level and within one night noninteger values for the number of additional awakenings do not make sense. However, they do if one refers to more than one night or to more than one subject (i.e., to averages). The criterion “on average less than one awakening per night” would be violated if a subject is woken up by aircraft noise 365 times in one year. However, it would just not be violated if the subject is woken up by aircraft noise 364 times in one year. When interpreting these numbers it has to be kept in mind that about 24 spontaneous awakenings can be expected per night on average and therefore about 8760 spontaneous awakenings can be expected per year.[2]

If and how often a subject is actually woken up by aircraft noise depends on the amount of air traffic in the special night, other situative and individual factors, as well as on chance. Therefore, in single nights it is possible that a subject is woken up more than once, e.g., two times. If the criterion should not be violated it has to be guaranteed that the subject is not woken up by aircraft noise in one other night, thus compensating for the two awakenings. The same is true for an even higher number of noise-induced awakenings: If a subject is woken up four times by aircraft noise in one night, this has to be compensated for by three nights with no additional awakenings, otherwise the criterion would be violated in the long run.

A Monte Carlo Markov chain (MCMC) simulation was used to calculate how the numbers of noise-induced awakenings per night are distributed over the 365 nights of one year: Maximum SPLs were randomly drawn from the maximum SPL distribution found in the DLR field study. For each SPL, awakening probabilities were calculated according to the dose-response relationship shown in Fig. 2. With a random number generator and based on the derived awakening probability it was determined whether the simulated human subject woke up or did not wake up induced by aircraft noise. This procedure was repeated and awakening probabilities were summed until the criterion of one additional aircraft-

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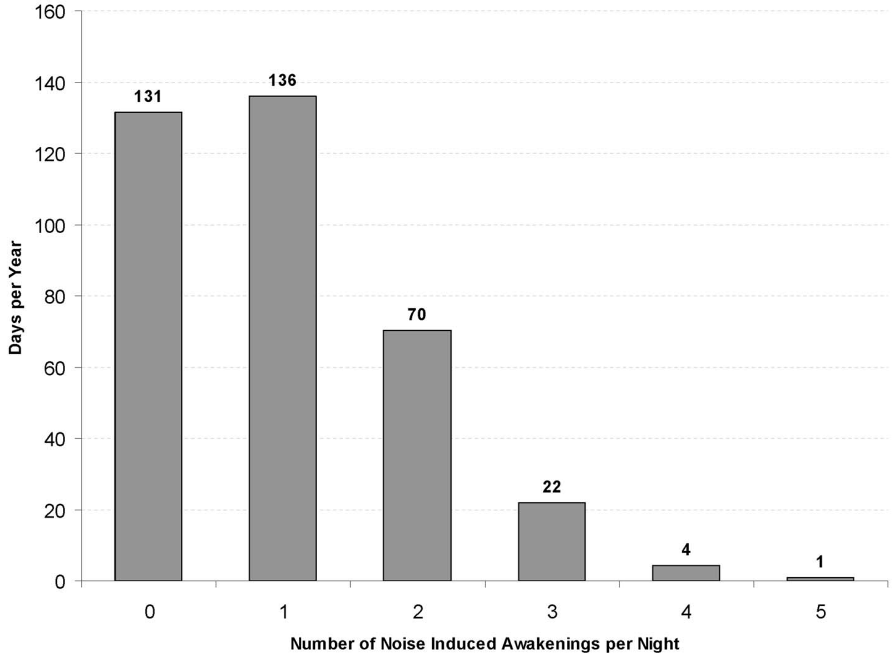

FIG. 7. Distribution of aircraft-noise-induced awakenings over the 365 days of one year if the criterion "on average less than one noise-induced awakening" is just not violated.

noise-induced awakening was just violated. This noise event was the last event counted, unless the sum of awakening probabilities up to the previous noise event, that just did not violate the criterion, was closer to the limit value in absolute terms. In that case, the previous noise event was the last event counted. With this method, 1 000 000 noise nights were simulated.

The expected distribution of aircraft noise-induced awakenings over the 365 days of one year is shown in Fig. 7.

In 131 nights there is no, in 136 nights there is one, in 70 nights there are two, and in 22 nights there are three additional awakenings. Four or five noise-induced awakenings per night occur extremely seldomly, and six or more awakenings practically do not occur.

These reactions are electrophysiological awakenings based on the definition by Rechtschaffen and Kales.[5] They are usually too short to be remembered on the next day (see above). From a preventive point of view, however, the number of electrophysiological awakenings induced by aircraft noise should be restricted as much as possible,[23] although the impact of electrophysiological awakenings on health, quality of life, and psychological outcomes remains a matter of scientific debate and therefore uncertain.[24] As electrophysiological awakenings go along with vegetative arousal reactions (e.g., increases in heart frequency and blood pressure), it is at least biologically plausible that repeatedly occurring noise-induced awakenings over years may impact health.[13] It is currently not known how many noise-induced awakenings are tolerable without leading to middle- or long-term impairments of well-being and health. With the high number of spontaneous awakenings and the high variability in several nights of the same person in mind, it is not deemed necessary from a medical point of view to completely avoid additional awakenings induced by aircraft noise. It is rather assumed that impacts of aircraft noise on health can be excluded in areas where less than one additional awakening is expected to be induced by aircraft noise on average.

D. Recalled awakening (second criterion)

The risk of recalled awakening increases with the duration of the awakening. Recalled awakenings are correlated with the subjective evaluation of sleep quality and sleep quantity: The higher the number of recalled awakenings, the worse is the evaluation of sleep quality (field study: $r_{\text{Spearman}} = -0.316$) and sleep quantity (field study: $r_{\text{Spearman}} = -0.269$). Additionally, ANEs occurring in the sleep period influence the assessment of annoyance only when they are perceived consciously by airport residents, and longer awakenings are a prerequisite for regaining consciousness.[19]

Recalled awakenings not only fragment sleep: They go along with psychological disadvantages as well and therefore constitute a major sleep disturbance. Psychosomatic disorders cannot be excluded if recalled awakenings are induced over longer time periods. Therefore, special attention has to be drawn to recalled awakenings in the process of evaluating the impacts of aircraft noise on sleep. From a medical point of view, recalled awakenings induced by aircraft noise should be prevented as much as possible.

The first criterion limits the number of noise-induced awakenings irrespective of the duration of the awakenings. Therefore, the number of recalled awakenings is limited as well. Most of the spontaneous awakenings are too short to be remembered on the next day. Analyses of the laboratory study showed that the duration of noise-induced awakenings increases with the maximum SPL of ANEs. Relevant differences compared to spontaneous awakenings were observed for maximum SPLs of more than 65 dB (see Fig. 3).

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For this reason, maximum SPLs of more than 65 dB should be avoided in the bedroom. For a partly opened window with an assumed difference in SPLs of 15 dB between inside and outside, the $1 \times 80\ \mathrm{dB}_{\mathrm{outside}}$ contour of Fig. 6 (dark gray) assures that outside this area maximum SPLs of 65 dB are exceeded less than once inside the bedroom on average. As recalled awakenings should be avoided as much as possible, this contour is based on a 100% flight movement in one direction estimation, i.e., a worst case.

TABLE II. Relevant polysomnographic field studies on the effects of aircraft noise on sleep. In the study of Hume *et al.*[15] SPLs were measured outside the bedroom only.

Study	No. of subjects	No. of subject nights	Age range (years)
Basner *et al.*[2] (2004)	64	576	19–61
Hume *et al.*[15] (2003)	46	178	20–70
Flindell *et al.*[11] (2000)	18	90	30–40
Ehrenstein *et al.*[26] (1982)	3	30–45	8–10
Vallet *et al.*[25] (1980)	40	160	20–55

E. Falling asleep again (third criterion)

The problem of falling asleep again is practically not considered in the literature of noise effects on sleep, disregarding the fact that about 7% of the sleep period is spent awake.[13] ANEs can prevent the sleeper from falling asleep again in these situations, and therefore have a negative impact on sleep structure.[2]

The traffic prognosis for Leipzig/Halle airport in 2015 forecasts two very busy periods during the night caused by freight handling. Between 0:00 and 1:30 up to 60 approaches per hour and between 4:00 and 5:30 up to 50 starts per hour are expected. The short time period of 1 to 1.5 min between two noise events in these peak hours leads to an increased risk of preventing the affected population from falling asleep again. If a subject already regained consciousness, annoyance reactions may result from consciously perceived noise events. Indeed, many airport residents complain about ANEs in early morning hours. At this time of the night, sleep pressure and awakening thresholds are low: Falling asleep again is difficult anyhow and aggravated by aircraft noise events.

Extensive analyses based on the data of the DLR field study were performed to assess the impact of aircraft noise on falling asleep again. The analyses are complicated by the fact that people who are prevented from falling asleep again stay awake and may be repeatedly prevented from falling asleep again by additional ANEs. In statistical terms, probabilities are no longer independent, but they are conditional on what happened in the past.

The results of these analyses will be presented elsewhere. They are based on a Markov state transition model which differentiates between two states only: awake and sleep. In the model, transitions between these two states depend on maximum SPL $L_{\mathrm{AS,max}}$ of the ANE, elapsed sleep time, the current state (awake/sleep), and the elapsed time spent in the same sleep stage and estimated with autoregressive logistic regression based on the data of the field study. The Markov model was used to predict the number of awakenings, the duration of wake periods, the number of awakenings recalled in the morning, and the percentage of highly annoyed subjects. The results indicated that maximum SPLs of ANEs in the second half of the night should receive a malus of 1.4 dB, i.e., they should be artificially elevated by 1.4 dB, in order to assure an undisturbed process of falling asleep again similarly in all regions around Leipzig/Halle airport.

F. Transferring study results to the population level

Polysomnography is the only method that allows us to draw conclusions on structural aspects of sleep. At the same time, data acquisition and analysis are cumbersome, time consuming, and therefore expensive. Hence, polysomnographic studies on the impact of aircraft noise on sleep are scarce and were usually based upon small samples. These studies differed considerably in study design and the methods applied, thus complicating comparisons or meta-analyses between them. As there is considerable intersubject variability in noise sensitivity, small studies may per chance investigate only very sensitive or only very insensitive subjects according to aircraft-noise-induced changes in sleep structure. Hence, transferring the results of small studies to the population level is not possible or limited.

The sample size of the DLR field study is compared to other relevant field studies using polysomnography in Table II.

Vallet[25] investigated the effects of aircraft noise on sleep in the field on 40 subjects aged 20 to 55 years (160 subject nights). Flindell *et al.*[11] examined 18 subjects aged 30 to 40 years on five consecutive nights (90 subject nights). The authors call their study a pilot study for a potential extension of the Ollerhead *et al.* study.[10] Ehrenstein[26] investigated three children aged 8 to 10 years in the vicinity of Munich airport. As there was no air traffic after 21:30, only ANEs between 20:00 and 21:30 could be analyzed. Ollerhead *et al.*[10] performed an actigraphic study in the vicinity of several British airports. Polysomnography was additionally performed on 46 of the 178 subjects. The results of the polysomnographic data were published by Hume *et al.*[15] in 2003. In this study, the SPL was measured only outside of the dwellings, restricting the validity of the results. None of the studies investigated nonhealthy subjects.

In the DLR field study, 64 subjects were studied for 576 subject nights, resulting in the largest polysomnographic study with identical methodological approach so far. Nevertheless, the study does not claim representativeness for the whole population. It is impossible to be representative for a whole population in a study with huge methodological expenses for a single subject like the DLR study. Additionally, some inclusion criteria had to be met in order to be eligible for study participation, leading to a higher internal validity of the results. This is a prerequisite for external validation, but also it restricts it to some extent.[2]

Therefore, the results of the field study were not trans-

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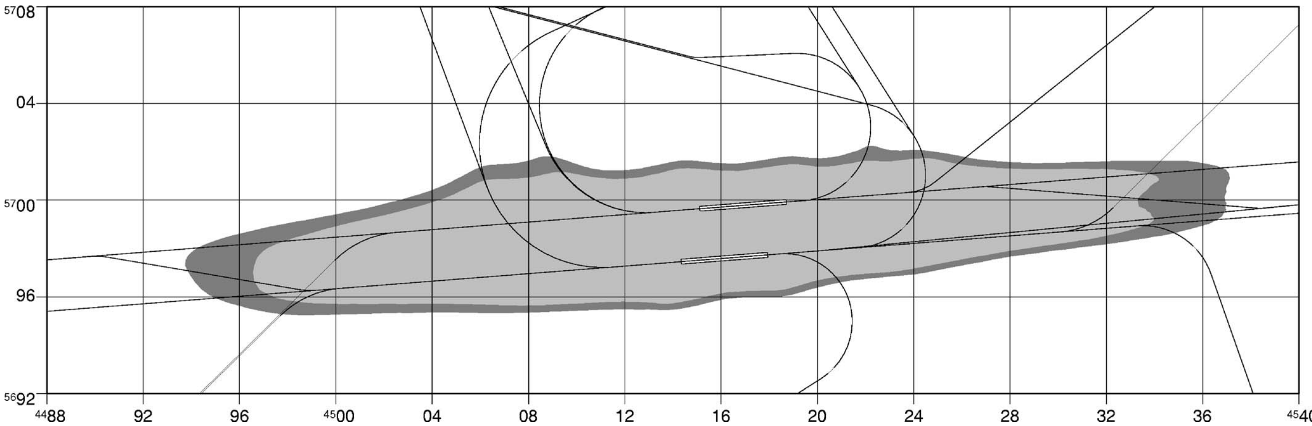

FIG. 8. Areas outside of which less than one awakening is additionally induced by aircraft noise. Comparison of preventive approach (sleep stage S2, middle of second half of the night, outer dark gray area) with approach based on actual data found in the field study (inner light gray area). By the preventive approach the noise protection zone is increased by 28% (=43 km^2).

ferred 1:1 to the population living in the vicinity of Leipzig/Halle airport. Instead, several preventive measures were taken in order to protect those parts of the population that were not represented in the DLR field study and that are more sensitive to aircraft noise at the same time. Some of these measures shall be briefly summarized:

(i) Subjects assessing themselves as sensitive to and annoyed by aircraft noise were included preferably into the study. Seventy-five percent of study subjects assessed themselves as moderately, strongly, or very strongly annoyed, compared to 15% of a representative German survey.[27]

(ii) Not only awakenings but also sleep stage changes to stage S1 were counted as relevant noise-induced sleep disturbances, increasing the probability of reactions to aircraft noise.

(iii) For the calculation of the dose-response curve based on the regression results it was assumed that the sleeper spent the whole night in the most sensitive sleep stage S2 and in the middle of the more sensitive second half of the night. In reality, an average night contains only about 50% of sleep stage S2. Hence, the dose-response curve is shifted to higher probabilities compared to calculations where the actual sleep stage distribution is used. Because of this measure alone the noise protection zone increases from 156 km^2 by 28% to 199 km^2 (see Fig. 8).

(iv) Subjects with illnesses leading to a lower noise sensitivity (e.g., hypakusis, hypersomnolence) were excluded from study participation.

(v) The calculations for the noise protection zone were based on the six busiest months of the year according to air traffic.

(vi) Sound insulation was increased by 3 dB for sensitive institutions (e.g., hospitals) and individuals with relevant diseases accompanied by a higher noise sensitivity.

(vii) The proposal of allowing only one additional awakening induced by aircraft noise makes sense in terms of preventive medicine. It has to be taken into account that on average 24 spontaneous awakenings can be observed in an otherwise undisturbed night anyway.

VI. CONCLUSIONS

The DLR-Institute of Aerospace Medicine investigated the influence of aircraft noise on sleep, mood, and performance in an extensive polysomnographic field study between 1999 and 2004 as part of the DLR/HGF-project "Quiet Air Traffic." The dose-response relationship developed in this study was used to establish a concept for the protection of subjects against the adverse effects of nocturnal aircraft noise on sleep. Advantages of this new concept compared to conventional NAT criteria, L_{eq} criteria, or combinations of NAT and L_{eq} criteria were discussed.

It is planned to extend Leipzig/Halle airport to a freight hub with an independent parallel runway system. Major parts of air traffic will take place during the night. The Regional Council of Leipzig decided to use the results of the DLR field study for a new noise protection concept at Leipzig/Halle airport. This concept culminates in the three propositions presented and discussed in Sec. V and reflects three correlated dimensions of sleep: There should be on average less than one additional awakening induced by aircraft noise, noise-induced awakenings recalled in the morning should be prevented as much as possible, and no relevant impairments of the process of falling asleep again should occur. These three provisions have been proposed in order to consider the special conditions under which Leipzig/Halle airport will operate: (1) construction of a second independent runway, (2) settlement of a night cargo hub for a big service integrator, (3) heavy air traffic during night including peak hours with up to 60 movements per hour, and (4) practically no nocturnal air traffic in the present. These circumstances necessitate a special concept for the protection of the affected population against the adverse effects of nocturnal aircraft noise on sleep.

With the decision for the implementation of the results of the DLR field study, fresh ground was broken, as noise

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protection zones solely depended on acoustical criteria so far. The noise protection zone for nocturnal air traffic proposed by DLR exceeds the one of the current law amendment under discussion, which should come in force in 2011, by 60 km^2, and will be correspondingly accompanied by additional financial burdens for the airport resulting from the installation of sound insulation.

Shortly after the publication of the official documents of the approval process for the extension of Leipzig/Halle airport in November 2004, the integrator DHL decided to move its European freight hub from Brussels to Leipzig/Halle. In the long run, this could lead to several thousands of new jobs in this region. Despite the very conservative approach taken in constructing the noise protection zones, some residents living in the vicinity of Leipzig/Halle airport were still not satisfied with the concept: They sued in order to prevent the start of construction at the airport. The Federal Administrative Court rebutted this legal action in May 2005 in the first instance, and the construction measures started without delay in August 2005.

ACKNOWLEDGMENTS

We would like to thank all subjects who agreed to participate in our studies as well as the investigators from the DLR flight physiology department for their extraordinary effort in sampling and analyzing the data.

[1]Regierungspräsidium Leipzig (Leipzig Regional Council), "Planfeststellungsbeschluss für das Vorhaben Ausbau des Verkehrsflughafens Leipzig/Halle Start-/Landebahn Süd mit Vorfeld" (official documents for the approval process of Leipzig/Halle airport, available on the internet http://www.rpl.sachsen.de/de/internet/service/planung/flughafen/startseite.htm last visited 11/03/2005), Leipzig, Germany, Az.: 14-0513.20-10/14 (2004).

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Appendix Ns.1.3

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Review

WHO Environmental Noise Guidelines for the European Region: A Systematic Review of Transport Noise Interventions and Their Impacts on Health

Alan Lex Brown [1,*] and **Irene van Kamp** [2]

[1] Griffith School of Environment/Cities Research Institute, Griffith University, Brisbane 4075, Australia
[2] Centre for Sustainability, Environment and Health, National Institute for Public Health and the Environment (RIVM), 3720BA Bilthoven, The Netherlands; Irene.van.kamp@rivm.nl
* Correspondence: Lex.Brown@griffith.edu.au; Tel.: +61-418-182-352

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Abstract: This paper describes a systematic review (1980–2014) of evidence on effects of transport noise interventions on human health. The sources are road traffic, railways, and air traffic. Health outcomes include sleep disturbance, annoyance, cognitive impairment of children and cardiovascular diseases. A conceptual framework to classify noise interventions and health effects was developed. Evidence was thinly spread across source types, outcomes, and intervention types. Further, diverse intervention study designs, methods of analyses, exposure levels, and changes in exposure do not allow a meta-analysis of the association between changes in noise level and health outcomes, and risk of bias in most studies was high. However, 43 individual transport noise intervention studies were examined (33 road traffic; 7 air traffic; 3 rail) as to whether the intervention was associated with a change in health outcome. Results showed that many of the interventions were associated with changes in health outcomes irrespective of the source type, the outcome or intervention type (source, path or infrastructure). For road traffic sources and the annoyance outcome, the expected effect-size can be estimated from an appropriate exposure–response function, though the change in annoyance in most studies was larger than could be expected based on noise level change.

Keywords: transport noise; interventions; health effects

1. Introduction

This paper systematically reviews the literature from 1980 to 2014 on evidence of the effects of transport noise interventions on human health. A wide range of noise interventions, noise management, or noise control, actions are included, and the source types considered in this review were road traffic, railways, and air traffic. The intent of both exposure-related, and non-exposure-related, interventions is to change (generally reduce) the adverse health outcomes from noise, and the health outcomes reported here include sleep disturbance, annoyance, cognitive impairment of children, and cardiovascular diseases. Exposure-related actions aim to change the level of noise exposure of people, usually as measured at the external façade of their dwellings. Non-exposure related actions such as communication or education are directed at changing health outcomes but do not include changing people's exposure. The different noise sources, and the different types of interventions possible for each noise source, introduce considerable complexity to this review, and a structure that provides a conceptual framework for considering interventions and health effects is presented in the next section.

2. A Framework for Noise Interventions

A conceptual model by which to consider noise interventions and their health effects was first reported by Brown and van Kamp [1]. The model built on related frameworks from the air

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pollution field that have been utilised to evaluate whether actions taken to improve air quality have resulted in reduced health effects—so-called *air pollution accountability research* [2–5]. These air pollution frameworks have an emphasis on ambient concentrations of the pollutants, but this is not appropriate for environmental noise where exposure of people is always strongly influenced by the length and nature of the propagation paths from sources to receivers, and hence highly dependent on the disposition of receivers relative to the sources. For noise interventions, the propagation path thus needs to figure as a significant component of the system between sources and the human receivers, and this has been incorporated in the basic systems model between environmental noise sources and human health. This framework is generic to all sources of environmental noise.

Another difference is that air pollution accountability research has tended to focus on regulatory interventions directed at reducing emissions; examining whether this type of intervention consequently reduces ambient concentrations over time. While regulatory intervention is also used in managing environmental noise, for example by control of aircraft or road vehicle source levels, this is only one of a range of possible environmental noise interventions [6] (Chapter 5). Environmental noise management, or environmental noise control, often involves technical interventions that include not only reduction of source emissions but also alteration of the transmission path, for example by the positioning of outdoor barriers between source and receivers, and changes in the acoustic properties of building envelopes to reduce levels at receivers. It also includes other source-related changes such as time restrictions on operations of sources, or changes in infrastructure. Examples of the latter include the opening or closure of new roadways and railway lines, bypass roadways, or the opening of new airports/runways and consequent rearrangement of air traffic load on flight paths. Environmental noise management has also utilised interventions that promote change that reduces peoples' exposures or that is directed at mitigating their adverse reactions to exposure. Communicating an authority's intent to make changes, e.g., with respect to flight paths, is an example of the latter.

Based on the available intervention literature, and the experience of many decades of noise management, five broad categories of transport noise intervention were identified and are listed in Table 1. Terminology for two of the technical interventions has been borrowed from the environmental noise control field (*source interventions* and *path interventions*). The third category of intervention is termed *new/closed infrastructure.* The fourth category is termed *other physical interventions*, and the fifth category referred to as *education/communication interventions*. The categories and sub-categories of these intervention types are largely self-explanatory, but they are also illustrated by the examples included in Table 1. Such categorisation of interventions is necessary as compilation of evidence regarding outcomes from interventions may only be appropriate when the evidence comes from studies that belong to the same category. This framework provides a systematic and comprehensive basis for this (and any future) work with respect to the effects of noise interventions.

The framework for considering noise interventions and related health effects is in Figure 1. It shows where different categories of interventions fit along the system pathway between noise sources and human outcomes. It also shows different measurement points along the pathway where changes relevant to human outcomes can be measured. This framework provides a systematic and comprehensive basis for this, and any future work with respect to the effects of interventions in environmental noise of all source types. Note that not all of the interventions types included in the framework are represented in the individual studies identified in the literature search described below.

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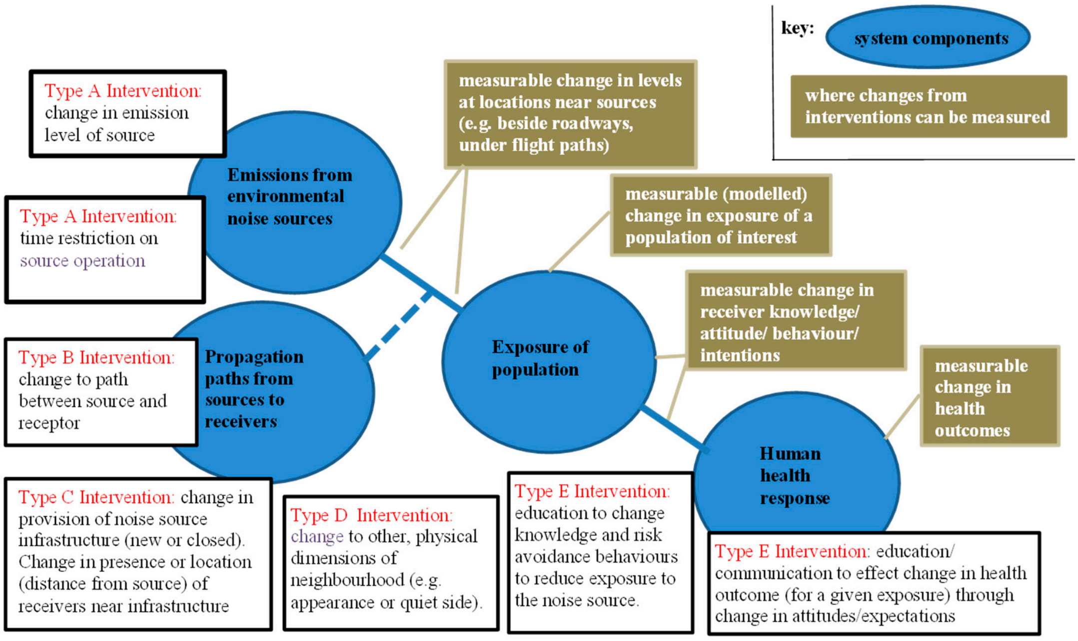

Figure 1. Intervention framework showing: system components of the path between environmental noise and human health, where different types of noise intervention potentially act along that path, and points along the pathway where changes resulting from interventions can be measured.

Table 1. Categorisation of Noise Interventions.

Type	Intervention Category	Intervention Sub-Category	Examples
A	Source interventions	change in emission levels of sources	motor vehicle emission regulation; rail grinding; road surface change; change in traffic flow on existing roadways/railways; change in number of aircraft flights
		time restrictions on source operations	airport curfew, heavy vehicle curfew
B	Path interventions	change in the path between source and receiver	noise barrier
		path control through insulation of receiver's dwelling	insulation of building envelope
C [1]	New/closed infrastructure	opening of a new infrastructure noise source, or closure of an existing one	new flight path; new railway line; new road bypass; or closure of any of these
		planning controls [2] between (new) receivers and sources	urban planning control; 'buffer' requirements [2]
D	Other physical interventions	change in other physical dimensions of dwelling/neighbourhood	availability of a quiet side; appearance of the neighbourhood; availability of green space
E	Education/communication interventions	change in behaviour to reduce exposures; avoidance or duration of exposure	Educating people on how to change their exposure
		community education, communication	Informing people to influence their perceptions regarding sources, or explaining reason for noise changes

[1] Intervention Type C is introduced to categorise situations where noise levels from a source have changed from (say) non-existent to high because of new infrastructure—e.g., from very little road traffic to now being beside a newly opened freeway; or in an area now under a new flight path where previously there had been no overflights. Type C interventions also include the converse: where say road traffic noise drops from a high level because a roadway had been closed, or aircraft noise is eliminated because an airport runway has been shut. Of course, changes in transport infrastructure may produce consequent changes in traffic load on other parts of the network leading to changes (increases or decreases) in source levels, but these are best categorised as Type A Source interventions as they are changes in levels from an existing source. Type C is intended to describe interventions where a (completely) new source is introduced, or an existing one removed—though the distinction will sometimes be blurred [7,8]. [2] With Intervention Type C describing opening a new noise source (say, roadway) near an existing dwelling, we extend this category to also incorporate building a new dwelling near an existing noise source. In an urban planning sense, a noise management 'intervention' that may be used is the requirement of some minimum distance between existing noise source and new residential development. The effect of such an 'intervention' could be measured by comparing human outcomes in newly constructed dwellings at different distances from the same noise source.

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3. Measurement of the Health Outcomes of an Intervention

Noise interventions are presumed to result in changes in various outcomes along the system pathway between noise sources and human health responses.

Evidence of the effect of any noise intervention on human health can best be examined in studies in which the effect of the intervention has been reported directly in terms of a change in health outcomes. The availability of a measured change in health outcomes in an intervention study was the primary basis for inclusion of a study in this review.

However, on the assumption that there is a well-established link between exposure and particular health outcomes, it is not necessary to evaluate interventions only by means of change in measured health outcome. Evaluation by the *intermediate outcome* of change in exposure of a population of interest is also appropriate as change in exposure can be presumed to result in changes in health outcome. Thus, individual studies that reported a change in the exposures of the population of interest were also included.

In addition, certain interventions for environmental noise, directed at changing knowledge or perceptions, may result in change in exposure of a group. They also may result directly in changes in health outcomes—as where a group may report lower annoyance scores from a transport source if authorities have undertaken a program of communication and explanation regarding the noise. Thus, studies where the intervention was designed to educate or change behaviour or perceptions were also considered.

Figure 1 shows, on the intervention framework, where each of the change in *health outcomes*, the intermediate change in *exposure outcomes*, and the *change in knowledge/attitude outcomes* could potentially be measured.

We note, however, that there are many examples in the literature of noise management or noise control where the effect of a noise intervention is reported solely as change in the level of noise at or near the source. For example, the effects of motor vehicle source limit regulations, or of limits on aircraft noise emission resulting from certification requirements, may be reported as changes in noise levels emitted by these sources. Equally, the effect of a path intervention through construction of a noise barrier near a roadway may be reported as the change in level immediately behind the barrier—not as a change in exposure levels for some affected population. Similarly, after an intervention involving modification to airport flight paths, the effect may be reported as changes in noise levels at particular points on the ground—again not as a change in exposure levels of an affected population. These types of outcomes are indicated on Figure 1 as *measurable change in levels at locations near sources*. Studies of this sort that report only change in levels near sources, rather than changes in people's exposure, cannot be utilised to elucidate the relationship between interventions and their health consequences.

4. Methods

4.1. Search Strategy for the Identification of Studies

Five prior narrative reviews on environmental noise interventions were located. These are listed in Supplementary File 1.

To identify individual studies, we performed search runs on the following data sets:

SBAS	Scopus	
ME66	MEDLINE	NLM
EM74	EMBASE	2014 Elsevier B.V.
PI67	PsycINFO	AM. PSYCH. ASSN. 2010
IN73	Social SciSearch	Thomson Reuters
IS74	SciSearch	Thomson Reuters
BA70	BIOSIS Previews	Thomson Reuters

The search string was refined and adapted for the different data bases and is available (Supplementary File 2). The search was restricted to publication years 1980–2014.

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4.2. Inclusion Criteria

Papers were read independently by the two authors, applying the following inclusion criteria. A study was retained for further analysis if the following conditions were met:

1. It dealt with noise sources as defined in the Study Protocol … *rail*, *road*, *aircraft*
2. It reported the nature of an intervention of any Type A through E
3. It specified (for intervention Types A–C), the change in exposure, usually as levels before and after the intervention
4. The intervention (for intervention Types A–C) was not temporary or laboratory-based
5. It reported:
    a. before and after health outcomes OR
    b. before and after exposures of a target population OR
    c. for interventions Type E, before and after knowledge/attitudes/behaviour OR
    d. a comparison of two exposure conditions with variation in some other relevant factor (e.g., quiet side).

A list of the papers that were excluded, with brief explanation of the reasons for exclusion, is available (Supplementary File 3).

4.3. Data Extraction and Synthesis of Findings Across Studies

It will be shown below that, overall, there is a relatively small number of studies available on the health effect of interventions. Further, when individual studies are grouped according to noise source categories, health outcome categories, and intervention categories, the number of studies within most of the categories is very small. Further, even in categories with more than two or three studies, these studies tend to be very different from each other.

Differences between studies include the magnitude of the change in exposure that results from the intervention; the distribution of the magnitude of change in exposure across the study sample (the nature of many of the interventions is such that the change in noise level exposure varies across a study site. For example, people close to the roadway in a barrier intervention experience a large reduction in noise levels, but, further from the barrier, they experience less change, out to eventually a zero change. Several of the studies like this reported only wide bands of noise level magnitude change; others reported the mean magnitude change for (sub) groups of respondents. This allows for relating the observed outcomes only to some averaged change in exposure rather than to actual individual changes in exposure); the exposure levels before the intervention; the study design; and the approach to data analysis. Differences in the latter include reporting response scores for groups/subgroups as measures of central tendency (mean or median)—which cannot then be converted to, say, percentages highly annoyed as is commonly used in other studies. Some studies analyzed and reported outcome responses as logistic regressions of individual responses on exposures, with no reporting of effects at group or subgroup levels. Studies also utilised various noise exposure scales (for example, the traffic noise intervention studies variously reported levels on scales: L_{den}, L_{dn}, $L_{Aeq,24\,h}$, L_{Day}, $L_{10,18\,h}$, $L_{10,12\,h}$, $L_{10,3\,h}$) and outcome response scales (sleep outcomes were reported on several different scales and in one case by wrist actigraphy. Annoyance was variously measured using annoyance, dissatisfaction, or bother, with the number of points on the response scale ranging from 4 to 10. Some studies reported Percentage Annoyed rather than Percentage Highly Annoyed). As Köhler et al. [9] note, specifically with respect to dwelling insulation but relevant to all interventions, '*Although the studies can be evaluated as being of good methodological quality, comparison between them is hard to make, due to difference in research groups, the way confounders are dealt with, sample size, study design … and the fact that information concerning particular characteristics is not always given …* '. Risk of bias in most individual studies was judged as high (see Supplementary File 5).

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Given these differences between studies and the small number of studies within groups, it was not possible to perform a meta-analysis by means of statistical pooling the data to report the strength of association between interventions and the changes in health outcome. While we could transform some results to common scales of exposure and to common scales (and sometimes cut-offs) of response, the other differences between individual studies within each group would remain. Overall, the consequence is that we have had to seek other ways to summarise the available evidence.

We sought instead to use the evidence presented within each of the individual studies to qualitatively answer two questions with respect to the effect of environmental noise interventions. These questions were as follows:

1. Did the study demonstrate that the intervention led to a change in health outcome?
2. For source, path and infrastructure change interventions, if there was a change in health outcome, was the observed change in outcome of a magnitude at least equivalent to that which would be predicted from a relevant exposure–response function (ERF), based on the observed change in exposure?

In examining the first question, we do not assess the magnitude of the change for each individual study (but report it if available), but look instead to any evidence that health outcomes did change in association with the intervention. We include a column in the tables below to record this observation. While this question is a minimal test of the consequence of an intervention, it contributes to an important policy issue: do environmental noise interventions change health outcomes?

The second question refers to a relevant ERF. Effectively, the author(s) of each individual study specified the ERF they believed was relevant to the context of their study: either an ERF derived from before-study responses from the study area, or one that had been reported from elsewhere but was considered appropriate. Given that synthesised ERFs are, by definition, the amalgamation of a wide range of study-specific ERFs, we suggest that the approach we adopt is no less appropriate than comparing each individual study results to some normative, synthesised ERF. Further, where the comparison is with an ERF derived from the before-data of the same study, it has the advantage of controlling for many confounders in that study area. The relevant ERF used in each individual study is reported in the summary tables below. In the individual studies, the relevant ERFs (all for the annoyance outcome, except for sleep disturbance in one study) were as follows:

1. an ERF based on the responses to the before (steady-state) exposure conditions in that particular study (using grouped response data or individual responses), or sometime separate ERFs for both before and after states (5 studies used an ERF of this nature).
2. an ERF reported from similar situations to those in the particular individual study, as determined by the study authors (4 studies used an ERF of this nature).
3. a previous synthesis of ERFs. The particular ERF chosen depended on the date of the study,: namely, Schultz's 1978 synthesis [10] (2 studies); the FICON 1992 synthesis [11] (1 study); Miedema & Vos' 1998 synthesis [12] (2 studies); Miedema & Oudshoorn's 2001 [13] or European Commission's 2002 synthesis [14] (3 studies).

We compared the magnitude of the observed change in health outcome to the magnitude of the change that would be 'predicted' from the same change in exposure on the relevant ERF. If the observed health outcome changed similarly to the ERF-predicted change, the conclusion was that the ERF could have estimated the magnitude of the response to the intervention given the magnitude of the change in exposure. If the observed change was greater, then the study has reported an excess response to the change [15]. We include a column in the tables below recording this observation for each study. Where the magnitude of the observed change is the same as the ERF-estimated change, the slope of the observed change is parallel to the ERF; where it is greater, it is steeper than the ERF. It will be seen that there are no studies in which the slope of the observed change was found to be shallower than the ERF (which would represent an under-response to the intervention). The observations provide

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guidance on another important policy issue: can the magnitude of the effect of an intervention be estimated from a relevant ERF?

4.4. Organisation of the Review

Different source types are each considered separately in Sections 6–8 below. The review initially included hospital noise and noise from personal listening devices/music venues and other recreational sources (See Supplementary File 6), but the present paper reviews transport noise sources only. Within each section, there is an overview of the evidence available for that source type. This is followed by subsections on the different outcomes and, for each type of intervention, a narrative summary of evidence for that outcome for that intervention type, and a table listing and summarising each individual study included in that group.

5. Overall Search Results

Figure 2 illustrates the literature search process. We identified over 500 studies that met our inclusion criteria. Excluding duplicates, this search resulted in 448 articles. A further 36 articles were identified through personal communications with experts and from the additional narrative reviews that had been found. After consideration of all these, we asked our professional librarian for an additional search, resulting in 61 additional articles being identified (including some duplicates).

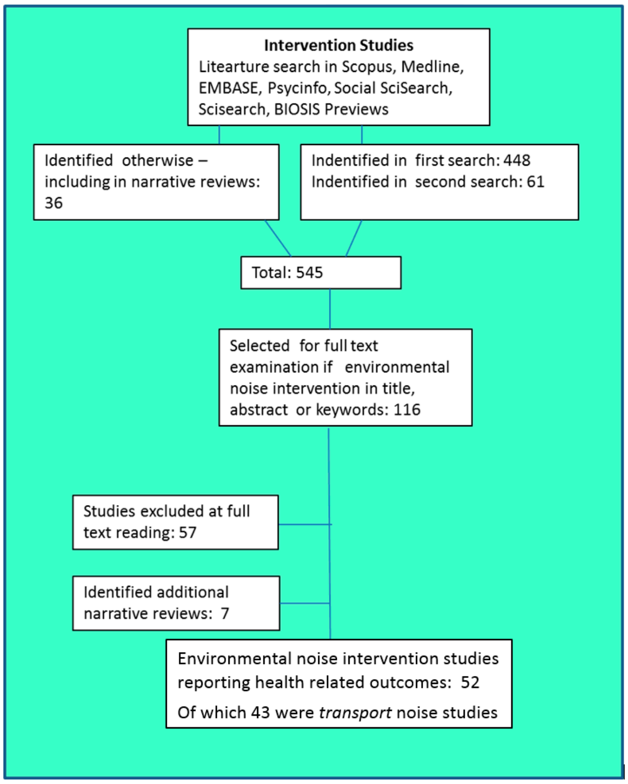

Figure 2. Flow diagram outlining the study selection process.

The resulting 545 titles, keywords and abstracts were examined by each of the authors independently to identify papers that were to be read in full, based on the inclusion criteria described in Section 4.2. The result was agreement to examine the full text of 116 papers. Fifty-seven of these were excluded at full text reading, and 7 were found to be narrative reviews rather than individual studies. Of the remaining 52 noise intervention studies, 43 were transport sources and are reported on in this paper (see Supplementary File 6 for the studies of non-transport sources).

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From this selection process we arrived at a small, but relevant, set of studies for each transport related noise source that linked transport noise interventions to health outcomes. The distribution of the papers, grouped across sources, outcomes, and type of intervention, is shown in Table 2. They are referred to as 'entries' because individual studies that reported more than one outcome are duplicated in relevant sections for each outcome. The majority of entries are for road traffic noise; fewer for aircraft noise and rail traffic noise. Previous reviews of the effects of change in noise exposure [16] have similarly reported the limited number of such studies available, and the difficulty in synthesizing information across them.

Table 2. Number of Individual Studies within each Group (Noise Source × Outcome Measure × Intervention Type).

	Number of Peer Reviewed Papers	Number of Non-Peer Reviewed Papers	Total Papers per Group
ROAD TRAFFIC NOISE SOURCES			
Outcome: Annoyance			
A Source Intervention	7	3	10
B Path Intervention	4	2	6
C New/Closed Infrastructure	1	1	2
D Other Physical	6	1	7
Outcome: Sleep Disturbance			
A Source Intervention	1	-	1
B Path Intervention	1	1	2
C New/Closed Infrastructure	2	-	2
D Other Physical	1	-	1
Outcome: Cardiovascular Effects			
D Other Physical	4	-	4
Outcome: Modelled Change in Exposure/Effect *			
A Source Intervention	1	1	2
AIRCRAFT NOISE SOURCES			
Outcome: Annoyance			
B Path Intervention	1	-	1
C New/Closed Infrastructure	2	1	3
Outcome: Sleep Disturbance			
C New/Closed Infrastructure	1	1	2
Outcome: Cognitive Development in Children			
C New/Closed Infrastructure	1	-	1
Outcome: Modelled Change in Exposure/Effect *			
A Source Intervention	1	-	1
RAIL NOISE SOURCES			
Outcome: Annoyance			
A Source Intervention	-	1	1
C New/Closed Infrastructure	1	-	1
E Education/Communication	-	1	1

* The modelled outcomes are described in Supplementary File 4.

6. Results for Road Traffic Noise

Some 37 papers (35 after removal of duplicate reporting of the same study) describing road traffic noise interventions met the inclusion criteria—with papers counted twice if they reported results on two different outcomes. This is considerably more than the number of intervention papers reporting on each of air and rail traffic interventions (seven and three papers respectively).

For road traffic noise:

- 25 papers examined the effects of an intervention on the annoyance of adults in their dwellings

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- 6 examined the effects of an intervention on sleep on adults in dwellings (several reported the effect of the intervention on both annoyance and sleep disturbance)
- 4 examined cardiovascular effects
- 2 modelled the extent of exposures to different levels of road traffic noise or the prevalence of annoyance arising from hypothetical interventions (studies modelling the effect of hypothetical interventions are considered separately from this review, in Supplementary File 4).

Under half (10) of the road traffic noise studies were source interventions; a smaller number path interventions; new or closed infrastructure; or other physical interventions.

The publication dates of the studies were approximately equally divided over three periods: 2010 to present; 2000–2009; the two decades 1980–1999. This indicates an increasing frequency of reporting of road traffic noise intervention studies, though the total number of such studies is small.

The tables below group together studies of the same health outcome from the same intervention type, summarising each of the individual studies in that group. The tables report the nature of the intervention; the study design, size and method; and the exposure levels before and after the intervention, and what is reported about the distribution of the magnitude of the changes in exposure across the study sample. The tables also show how the outcome measures of annoyance or sleep disturbance/quality changed as a consequence of the intervention, and whether the magnitude of that change was statistically significant. There is also an observation on the relationship of the observed change in response to that estimated from the same change on a relevant ERF.

6.1. Annoyance

6.1.1. Evidence from Source Interventions

Of the source intervention studies:

- Most were where traffic flow rates on the roadway changed (including several multi-site studies). Most were a decrease in traffic flow as a consequence of provision of relief roads, but at several sites there was an increase in traffic flow. Less than half of the studies were single-site studies; the others included results from multiple roadway sites.
- 1 was where there was improved roadway resurfacing.
- 1 was a truck restriction strategy.
- 1 was a complex set of control measures including barriers, road surfaces and other measures.

All studies as presented in Table 3 were before and after designs, including two with three and four 'after' rounds of survey. Three of the studies included control groups. The number of participants varied between 20 and 2870.

Most of the changes experienced were reductions in noise levels, but in one study, and at a small number of sites in three multi-site studies, the change experienced were increases in level. The changes in level ranged from approximately −15 dB to +15.5 dB (various noise scales) but not uniformly across this range, with the majority of changes in the range from −5 to +5 dB. The source interventions were generally where before-conditions were high road traffic noise exposure (e.g., such as greater than $L_{eq,24}$ of 70 dB), but several were where levels were considerably lower (by 10 to 15 dB) than this. In one study, there was very limited change in exposure resulting from reduced traffic flow and no observed change in annoyance outcomes. This study is not considered further below. In another, where there was a restriction in night-time truck traffic flow, there was zero change in energy-based noise indicators but a significant change in annoyance—postulated by the author as a response to the change in the number of noise events in the night-time traffic stream.

Apart from the two 'no-change' studies, the studies all found that the source intervention resulted in change in annoyance outcomes: four reported that the observed changes were statistically significant; three observations were based on data, tables or plots in the original papers, but without statistical tests.

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Table 3. Source Interventions (Type A).

Authors	Intervention & Study		N, Response Rate & Method	Exposure Levels		Change in Levels and Distribution of Change across Participants	Outcome Measure(s) before and after Outcomes	Did Outcome Change with Change in Exposure? Yes/No (Significance Tested?)	Before/after Outcome Change Compared to That Estimated from an ERF	Comments	Confounders Adjusted for in Analyses
	Nature	Design		Before	After						
Brown (2015) [17]	Brisbane, Truck restriction, change in traffic composition Note: the date of this paper was outside the search time period	B/A. Five rounds of after surveys out to 20 months	99 in panel Response rate 84% ~20% of panel drop out each survey round Interviews	65–73 L_{den} 60–68 L_{night} 69–77 $L_{10,18\ h}$ Measured	65–73 L_{den} 60–68 L_{night} 69–77 $L_{10,18\ h}$ Measured	No change in L_{den}, L_{night} or $L_{10,18\ h}$ But see comments All Ps experienced same change—but were exposed to different before levels	%HA based on 7, 8 & 9 of ISO (but with 0–9 scale). B: 58% HA A: 33%, 18%, 18% HA respectively at survey rounds 2, 3 & 4 Mean Annoyance also reported	n.a. as no change in L_{den} exposure (but there was a change in number of noise events) Est. Marg. Mean annoyance scores changed significantly over period of truck restriction (F4,170.4 = 12.18, $p <$ 0.001) (see comments)	ERF cited was Miedema & Oudshoorn (2001) [13] 58% HA in before-study much higher than estimated by ERF (latter is 16 to 30% for L_{den} over the range of Ps' exposures No observation possible on the relationship of change in outcomes with the ERF because L_{den} did not change	Change in response attributed to change in number of noise events	Noise sensitivity; neighborhood quality; respondent association with trucking industry.
Pedersen, Le Ray, Bendtsen & Kragh (2013) [18]	Copenhagen Resurfacing with noise reducing pavement.	B/A study 12 mo. After Not repeated measure	2870 over two areas near roads Response rate 41% Mail surveys	42–74 L_{den} Modelled noise map. Note: wide range of before levels	38–70 L_{den}	Measured 4 dB reduction in source levels Same reduction assumed for all Ps	%HA based on 8, 9 & 10 of ISO (0–10 scale) Mean Annoyance also reported	Yes B&A mean annoyance scores were different (Welch's *t*-test, $p < 0.001$)	Authors reported logistic regression ERFs for each of before and after conditions (n = 2870). The 95% CIs of B & A curves tended to overlap, and authors merged the data to establish the ERF. Hence change in response to −4 dB intervention estimated by the ERF. B & A ERFs curves are overlapping—largely parallel but with ERF (after) slightly lower than ERF (before). Response to change estimated by ERF. Slightly lower ERF(A) indicates excess response. The authors also report '... *a small tendency to a lower %HA in the 50–60 dB range in the after situation* ... '.	Merged ERF was higher than Miedema & Oudshoorn (2001) [13] ERF over 60–74 L_{den}	
Stansfeld, Haines, Berry & Burr (2009) [19]	UK Bypass roads constructed reducing traffic flow in three small towns	B/A study B:1 year A: 6–7 mos	17 5 exposed 184 control Response rate B:70% A: 74% 67 Ps at exposed area follow-up Delivered questionnaire	$L_{10,3\ h}$ (& $L_{eq,3\ h}$) Exposed: 75–78 Control: 55–58 Measured Includes train noise	See next column	Change in $L_{10,3\ h}$ of −2 to −4 dB suggested for most locations No reporting of distribution of these small changes across Ps.	'Standard' noise question for assessing level of annoyance with environmental noise at home. No significant change in mean annoyance score with intervention.	No change in annoyance. Explanation was that the change was too small to be noticed	n.a.	Changes in traffic flow on source roads were small: 24 h flow changed from 26 k to 23 k veh/day, and 24 k to 21 k veh/day	
Baughan & Huddart (1993) [20]	U.K. Decreased traffic flow at 14 sites; increased traffic flow at 6 sites; 2 control sites	B/A study + controls 1–2 mos B&A changes Repeated measure	33–50 per site Response rate and dropout rate not reported Interviews	$L_{10,18\ h}$ Decrease sites: 66–76 Increase sites: 65–78		$L_{10,18\ h}$ 14 sites with changes ranging from −15 to +5 dB	7 point numerical scale of satisfaction with level of road traffic noise with endpoints labelled *Def. Satis*. And *Def. Unsatis* Outcome reported as mean dissatisfaction score	Yes Infer from next column No statistical tests reported	Authors refer to ERF derived from 'TRRL' survey at 35 steady-state sites. Authors conclude: For decreases, both before and after levels (of dissatisfaction) differed significantly from steady state (ERF). B/A transitions steeper than ERF; For increases, after levels differed significantly from steady state. B/A transitions steeper than ERF; No statistical tests reported; Response to change in same direction as estimated by ERF, but much steeper, indicating excess response	Data used in Griffiths & Raw (1989) [21] below also included in analysis in this paper	

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Table 3. *Cont.*

Authors	Intervention & Study		N, Response Rate & Method	Exposure Levels		Change in Levels and Distribution of Change across Participants	Outcome Measure(s) before and after Outcomes	Did Outcome Change with Change in Exposure? Yes/No (Significance Tested?)	Before/after Outcome Change Compared to That Estimated from an ERF	Comments	Confounders Adjusted for in Analyses
	Nature	Design		Before	After						
Griffiths & Raw (1989) [21]	England. Repeated measure of after survey in Langdon & Griffiths (1982) [22] 5 sites	Repeat of After study at 7–9 years. After 48% of Ps repeat interview	430 Interviews	See Langdon & Griffiths (1982) [22]			Four-point verbal bother scale Outcome reported as mean bother score for each of B&A conditions	n.a.(because there was no change in exposure between 7 and 9 years)	See results in Langdon & Griffiths (1982) [22] below. Observed Excess responses show no diminution out to 2 years after change, but is diminished, but still exists, 7–9 years after the change		
Brown (1987) [23]	Brisbane. Increase in traffic flow	B/A study 2 weeks B, 7 & 19 mos A Repeated measure	20 Response rate 83% Interviews	$L_{Aeq,24\,h}$ 60 $L_{10,18\,h}$ 60 L_{dn} 61	$L_{Aeq,24\,h}$ 66/67 $L_{10,18\,h}$ 68/71 L_{dn} 69/71	$L_{Aeq,24\,h}$ + 6/+7 dB $L_{10,18\,h}$ +8/+11 dB L_{dn} +8/+10 dB	7 point semantically labelled annoyance scale. Reported individual responses and %HA based on top two categories.	Yes Distribution of individual annoyance responses changed after intervention (Friedman Two-way Anova, $p < 0.01$). 90% CIs for %HA B & A intervention do not overlap	ERF cited was Schultz (1978) [10] and plotted as band containing 90% of data points used in Schultz synthesis. Before %HA lay within Schultz 90% band, After %HA lay above ERF (though Cis for %HA are wide due to small sample size). Indicates excess response to increase in exposure	Note: No evidence of adaptation. Distribution of annoyance scores not different at 7 and 19 mos after change (*t*-test, $p < 0.05$)	
Griffiths & Raw (1986) [24]	England. Decreased traffic flow at 6 sites; increased traffic flow at 2 sites	B/A study 1–4 mos before change 2–3 mos after change Repeated measure	469 Response rate 74% 17% drop out between surveys (391)	$L_{10,18\,h}$ Decrease sites: 65–81 Increase sites: 54–56 Measured and calculated	$L_{10,18\,h}$ Decrease sites: 66–74 Increase sites: 61–69	Change in $L_{10,18\,h}$ at seven sites were: (1) −14.5 dB (2) −5.7 dB (3) −2.6 dB (4) −3.1 dB (5) −1.3 dB (6) +5 dB (7) +15 dB	7 point numerical scale of satisfaction with level of road traffic noise with endpoints labelled *Def. Satis.* And *Def. Unsatis* Reported site mean dissatisfaction scores	Yes Infer difference between B&A mean dissatisfaction scores from next column	Authors calculated ERF using 'steady-state' before responses. Site mean dissatisfaction scores regressed against before $L_{10,18\,h}$. Mean dissatisfaction scores (After) were compared to those estimated by the ERF. For decreases: decrease in site mean dissatisfaction score was greater than estimated by a conservatively estimated ERF (t = 3.14, df = 4, $p < 0.025$). Similarly, at two increase sites, increase in individual dissatisfaction score was greater than estimated (t = 2.93, df = 81, $p < 0.005$). Response to decrease/increase changes in direction estimated by ERF, but steeper—hence excess response	Note: resurvey of three decrease-sites out to 17–22 mos. After change showed no change in observed excess response. Griffiths & Raw (1989) [21]	
Brown, Hall & Kyle-Little (1985) [25]	Brisbane. Reduction in traffic flow	B/A study with 2 control groups (quasi experimental)	49 Cntrls: 52, 40	$L_{10,12\,h}$ 74.3 Calculated Cntrl. 75.1 Measured	$L_{10,12\,h}$ 64.5 Measured Cntrl. 65.2 Measured	$L_{10,12\,h}$ −9.8 dB	7 point semantically labelled annoyance scale. Reported %HA based on top two categories. Annoyance with before conditions assessed in retrospect.	Yes Note, before %HA based on retrospective assessment No statistical test reported—but see next column	ERF cited was Schultz [10] and plotted as band containing 90% of data points used in Schultz synthesis. After %HA and Control sites %HA lay within 90% band. Before %HA (retrospective) lay outside 90% band. Response to decrease in same direction as estimated by ERF, but steeper, indicating excess response	This study relied on retrospective assessment of annoyance before the change	

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Table 3. *Cont.*

Authors	Intervention & Study		*N*, Response Rate & Method	Exposure Levels		Change in Levels and Distribution of Change across Participants	Outcome Measure(s) before and after Outcomes	Did Outcome Change with Change in Exposure? Yes/No (Significance Tested?)	Before/after Outcome Change Compared to That Estimated from an ERF	Comments	Confounders Adjusted for in Analyses
	Nature	Design		Before	After						
Langdon & Griffiths (1982) [22]	U.K. Reduction in traffic volumes at 6 sites after opening of new relief roads	B/A study 2–3 mos. B to 4–6 mos. A	Number of respondents at each of the six sites not reported	$L_{Aeq,24\,h}$ 72–76.5	$L_{Aeq,24\,h}$ 56.5–73.5	Change in $L_{Aeq,24\,h}$ 6 sites ranging from −5 to −15.5 dB All Ps at a site experienced the same change in exposure	Four-point verbal bother scale Outcome reported as median of bother score for each of B&A conditions at all six change sites	Yes Infer difference between B&A median bother scores from next column	Authors compare change data to ERF from eight sites in London where exposure and response were measured under steady-state condition. For the six change sites: No sig. diff. between median Before bother scores and scores estimated by ERF (*t*-test = 2.13, $p > 0.05$). Sig. diff between median After bother scores and scores estimated by ERF (*t*-test = 8.25, $p < 0.001$) Response to change in same direction as estimated by ERF, but steeper, indicating excess response		
Kastka (1981) [26]	Germany Complex set of noise and traffic control measures in 6 cities Plots 50 data points	B/A study	1800	Measured L_d (range 47–68 B, 50–65 A		Range of sites with changes of −8 to +3 dB (mean −1 dB)	Complex set of measures including assessment of sensory experience and interferences of noise	Yes Infer from next column No statistical tests reported Percentage highly annoyed in line with an extra 6 dB from steady-state scale	Author reports ERFs of both response measures on L_D for both B and A conditions After ERFs much lower, but somewhat parallel to the Before ERFs Shows strong excess response, equivalent to that of a 6 dB (8 dB for the second response measure) change in exposure No statistical test reported	This study has been included under Type A source interventions even though it is not fully clear exactly what intervention(s) were responsible for the change in response	

Abbreviations used in this and all subsequent tables: N: number of participants; B: Before-study; ERF: Exposure response function; n.a.: not applicable or not available; A: After-study; P(s): Participant(s); CI: confidence interval; ISO: ISO annoyance scales (ISO_TS_15666_2003); mos: months; Q: questionnaire; %HA: Percentage Highly Annoyed; s.d.: standard deviation; B/A: Before and After study; SE: standard error.

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With respect to the strength of association between the change in exposure and the change in annoyance responses, all intervention studies demonstrated that the response was of a magnitude, *at least*, as estimated by a steady-state ERF for annoyance. Two provide statistical tests that the change in response was an *excess-response* to the change—both for decreased and for increased exposures. Observations on the other studies of *excess response* were based on data, tables, or plots in the original papers, but without statistical tests.

There is only a little evidence available with respect to long-term effects of the interventions. The studies generally undertook the after-outcome measures 2 to 12 months after the intervention, but two of them also repeated the after-measure, one 12 months after the first, the other 9 years after. The limited findings from these longitudinal studies are that this excess response undergoes some attenuation, but is largely maintained out to several years.

There is only one study in this group [17] in which the exposure–response function, or the test of a change effect, was adjusted for confounding (noise sensitivity, neighbourhood quality, and association with the trucking industry). In most of the other studies the influence of confounders and potential moderators was analysed in a univariate manner or presented in exposure–response curves per subgroup. A list of the confounders variously measured in the included studies were age (2 studies); gender (2); noise sensitivity (3); length of residency (2); deprivation; general opinion of the area; attitudes towards roads, traffic, and the authorities; wish to move because of fear of accidents; type of dwelling; number in dwelling; children in house; windows open; hearing problems; awareness actions were being taken (each, 1 study).

6.1.2. Evidence from Path Interventions

Of the seven path intervention studies that are in Table 4:

- 1 was of dwelling insulation (with a repeated survey two years after the first survey reported separately);
- 3 were barrier construction (one of which was a multi-site study involving 12 sites);
- 1 was a combination of barriers and dwelling insulation;
- 1 was a full-scale building intervention, filling in gaps between existing buildings to create a barrier for dwellings further from the roadway.

All studies were before and after designs, with only the dwelling insulation study having more than one after-survey round. Most before-studies were conducted 6 months to 1–2 years before the intervention. Apart from the dwelling insulation study where the after-study was conducted some six months after insulation was installed (12 months after the before-survey) the time gap between before and after studies was much larger than for the source interventions, presumably related to the required construction time of the barrier or building refurbishments. Apart from one barrier study where the gap was 2 years, the before-after gap varied between 5 and 10 years. Three of the studies included control groups. The number of participants in the studies varied between 75 and 852.

The changes in level achieved by the interventions ranged from −3 to −13 dB (various noise scales). Apart from the dwelling insulation intervention where all participants experienced a uniform reduction in exposure of −7 dB, the variation in the change in levels experienced by respondents within any one study was wide, varying, for example, from −10 to −13 dB close to barriers, small to zero changes distant from the barriers.

All six studies (excluding the repeat after-survey study) found that the path intervention resulted in change in annoyance outcomes; three of the studies demonstrated that the observed difference in outcomes was statistically significant, the other three studies reported no statistical tests on the changes in response, but differences were observed in the data, tables, or plots in the original papers.

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Table 4. Path Interventions (Type B).

Authors	Intervention & Study		*N*, Response Rate & Method	Exposure Levels		Change in Levels and Distribution of Change across Participants	Outcome Measure(s) before and after Outcomes	Did Outcome Change with Change in Exposure? Yes/No (Significance Tested?)	Before/after Outcome Change Compared to That Estimated from an ERF	Comments	Confounders Adjusted for in Analyses
	Nature	Design		Before	After						
Amundsen, Klaeboe & Aasvang (2011) [27]	Norway Façade insulation	Two survey rounds: B&A Target; Control & Supplement groups. B & A surveys approx 6 mos. either side of intervention	Target: B: 168 Response rates 57% A: 161 (65%) Control: B: 469 (57%) A: 254 (65%) Supplement: 112 Mail survey	$L_{Aeq,24\ h}$ 61–78 outside. Calculated Mean 71 (Av inside level before change is 43)	Façade insulation reduces inside levels by 7 dB	–7 dB for indoor noise levels for all Ps in target group	Standard ISO annoyance scale (5 point verbal). %HA calculated using top two points of scale B: 42%HA A: 16%HA Control: B: 24%HA A: 29%HA	Yes Intervention resulted in substantial and significant ($p < 0.001$) reductions in individual annoyance scores	Authors chose not to compare their results with Miedema & Oudshoorn ERF [13]. Fitted a model of individual annoyance responses to outdoor levels for all Ps (target, control and supplementary: n = 738) with *receiving the intervention* as a dummy variable. Estimate of effect size −0.820 ($p < 0.000$) and 95% CI −1.170 to −0.470. Authors claim size of annoyance reductions with intervention is in line with ERF modelled from individual indoor levels. However this appears to be contradicted by the large reduction in the Target Group's %HA (42% before intervention to 16% after). Summarised as 'unclear'	Authors note no explanation why %HA sig. lower in control than target before intervention; and second round higher than first in control	Gender, age, education level, marital status, access to a bedroom on the quiet side of the building, and sensitivity
Amundsen, Klaeboe & Aasvang (2013) [28]	See Amundsen, Klaeboe & Aasvang (2011) [27] above. Same study details but this was a repeat survey 2 year after first post-intervention study. Mailed to all Ps who had completed first post-intervention study. Number of participants now 104 (Response rate 58%) in target; 139 in Control; 63 in supplement						2nd after-study: A: 16%HA	Result the same two years after initial After survey ($p < 0.01$) Additionally, repeated ANOVA was conducted on panel who had answered all three survey rounds (N = 212). Change in annoyance as a result of intervention significant in first ($p < 0.0005$) but not second (p = 0.33) after survey	In this repeated ANOVA, multivariate partial eta square = 0.44		
Bendtsen, Michelsen & Christensen (2011) [29]	Denmark Enlargement of motorway lanes but with dwelling insulation, barriers, & quiet pavement	B/A study 1 year before constr & 1 year after B/A gap 6 year	Q sent to 1200 dwel. In 6 areas out to800 m from motorway Response rates B:71% A: 65% 38% B&A Mail survey	L_{den} 45–65 Calculated. Unclear as to whether calculated levels included traffic sources other than motorway	L_{den} 45–60 Calculated. Not reported is whether some Ps may have experience increased after-levels	Reductions in extent of exposure 60–65 & 55–60 bands but increase in lower two bands. Reported only at population level. No indication of the change experienced by individual Ps	ISO scale (5 point verbal) % top three annoyance categories dropped, other two categories increased Top two categories (%HA—but authors did not use this term) dropped from 37% to 16%	Yes but no data presented of change in exposure of those reporting change in annoyance No statistical tests	n.a.	Classed as path intervention, even though includes quiet pavement as intervention Multiple sources of road traffic exposure—not just motorway	
Gidlöf-Gunnarsson, Öhrström & Kihlman (2010) [30]	Sweden Full-scale filling-in building gaps; barriers & housing improvement	B/A study 5 year apart	B: 160 Response rate: 56% A: 153 (47%) Mail survey	$L_{Aeq,24\ h}$ at façade 48–71 Calculated		–5 to −10 on exposed facades; −4 to −10 courtyards	ISO scale (5 point verbal) %Annoyed cut-off includes top 3 points.(Note: NOT %HA) For Ps highly exposed and with large change: B: 84% Annoyed A: 28% Annoyed For P's with less change: B: 45–55% Annoyed A: 21–22% Annoyed	Yes Large and consistent reductions in %Annoyed associated with reduction in noise exposure (but no statistical tests)	Authors refer to Öhrström [7] who cites ERF of Miedema & Vos [12] For Ps in most exposed part of study, B/A 84/28%Annoyed outcomes both higher than estimated by this ERF, but also show much larger decrease in response than estimated by ERF. Response to change in same direction as estimated by ERF, but steeper, indicating excess response. (But no statistical tests)	This was a reconstruction project that included many other environmental changes—not just change in noise exposure (Ps reported 36% increase in overall satisfaction with area)	

Table 4. *Cont.*

Authors	Intervention & Study		N, Response Rate & Method	Exposure Levels		Change in Levels and Distribution of Change across Participants	Outcome Measure(s) before and after Outcomes	Did Outcome Change with Change in Exposure? Yes/No (Significance Tested?)	Before/after Outcome Change Compared to That Estimated from an ERF	Comments	Confounders Adjusted for in Analyses
	Nature	Design		Before	After						
Kastka, Buchta, Ritterstaedt, Paulsen & Mau (1995) [31]	Germany Noise barriers at 12 sites + 2 control sites	B/A study 1–2 years B, 8–10 years A barriers were built	283 B Response rate 59% 212 A (72%) 97 Ps both B&A	$L_{eq,D}$ B 50–70 Measured	$L_{eq,D}$ A:51–66 Measured	–13 dB close to barriers to 0 dB at 200 m Av. Change −4.1 dB	(1) 5 point verbally labelled disturbance scale (2) %HA calc. as top two responses on scale in (1) (3) factor K1: sensory-perceptional and emotional experience of traffic noise (0–10) (4) factor K2: noise interferences	Yes All response variables show significant reductions, e.g., %HA B: 64%; A:35% (chi^2 = 39.69 $p < 0.005$) Control sites response variables same B&A	Authors calculated an ERF using the steady-state before-responses. For this, mean disturbance scores (and, separately, other outcome variables including %HA) were regressed against before $L_{eq,D}$ Mean (After) disturbance scores were compared to those estimated by this ERF. At 11 of the 12 sites, estimated mean disturbance score was greater than observed. Difference was statistically significant (matched pair *t*-test, df = 11, $p < 0.05$). Response to change in same direction as estimated by ERF, but steeper, indicating excess response following barrier construction	Authors reported extensive additional analyses They suggest no simple causal relation between noise level reduction and annoyance reduction	
Nilsson & Berglund (2006) [32]	Sweden Noise barrier	B/A study + control 9 mos. B; 15 mos. A Repeated measures on 59%, 46% only	Before 304 Response rate 77% (241 control Response rate 66%) (After Response rates: 72%, 69%) Self-administered	L_{den} 70 to <45 Calculated	L_{den} 62.5 to <45 Calculated	–7.5 dB; with reducing change out to 100 m from barrier. Distribtn of change was: –7.5 dB 52 Ps −5 dB 47 Ps −2.5 dB 31 Ps	Visual analogue scale 7-point annoyance scale. Transformed to 0–100 scale. Reports %HA as above cut-off 72	Yes Reductions in %HA were significant ($p < 0.05$, sign-test) for three groups of Ps within 100 m of roadway Control: no diff in B&A %HA	ERF cited was Miedema & Oudshoorn (2001) [13] Reports both B&A %HA agree with prediction by ERF (no statistical test) Response to change same direction and magnitude as estimated by ERF	Outdoor annoyance did not conform to ERF	
Vincent & Champelovier (1993) [33]	France Noise barriers and low noise road surface	B/A study at 2(?) sites.	75 Response rate not reported	$L_{eq,12\,h}$ 65.1 Location of measurement site relative to Ps not reported	$L_{eq,12\,h}$ 56.3 Location not reported	Change in levels was variable with distance from road: −10 to −3 dB between 10 and 100 m.	% highly annoyed (scale and definition of HA not reported). B: 22%HA A: 8%HA	Yes (but no statistical test)	No comparison of change to any ERF	Author notes that response to 'Often disturbs sleep' dropped from 13% to 6%	

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Four of these path intervention studies compared the change in response to that estimated by an ERF. All four showed that the response to the change was in the same direction and *at least* of the same magnitude as estimated by the ERF (statistical test reported in one study). Two of these also showed responses to the change were much steeper than the gradient of the ERF over the same exposure range, thus exhibiting an *excess response* (and another was unclear with respect to the presence of excess response). Only one study provided a statistical test of the presence of excess response.

There was one study in this group in which the exposure–response function, or the test for a change effect, was adjusted for confounding (gender, age, education level, marital status, access to a bedroom on the quiet side of the building, and noise sensitivity). In most of the other studies, the influence of confounders and potential moderators was analysed in a univariate manner. Confounders (moderators) included in this way were as follows: distance to the road (2 studies); visual aspects (2); window opening behaviour (1); other interventions such as playgrounds; access to shopping centre; opinion of residents towards noise source; coping; acceptance; window type; newcomers between surveys; negative experience before the intervention; SES (each 1 study).

6.1.3. Evidence from New/Closed Infrastructure Interventions

Of the two infrastructural intervention studies included in Table 5:

- both studies involved major changes (reductions) in road traffic flows;
- both studies combined the main intervention with other environmental improvements.

Both studies were of new road tunnel infrastructure that resulted in very large reductions in traffic and levels of noise for residents near the previously heavily trafficked surface roadway. They are distinguished from Type A interventions by the magnitude of the change in flows (e.g., traffic flow on nearest road to some participants dropped from 60,000 vehicles/d to zero).

Both studies were before and after designs using repeated measures of annoyance outcomes. Both conducted before- and after-studies approximately one year before and after the tunnel opened. Both included a control. The number of participants experiencing the change was 758 and 50 in the two studies.

Noise levels ($L_{Aeq,24\,h}$) reduced an average of −12 dB in one study (the distribution of the magnitude of the change across the sample of participants was not reported); between −11 dB and −17 dB for just under half of the respondents with the other half experiencing −3 to −5 dB reductions. In the other study, participants experienced a mean −12 dB reduction, with no information of the distribution of the magnitude of change across the sample.

Both studies demonstrated statistically significant lower annoyance responses post intervention (one tested % Annoyed; the other % Highly Annoyed and mean annoyance score) with no change in the controls.

Both studies also compared the change in outcomes to those estimated from an ERF. They reported that the after-scores in the studies matched those estimated by the ERF (though, in fact, one comparison was with an ERF of individual annoyance scores fitted only to the after exposure levels) and suggested on this basis that there was no evidence of excess response. However, both reported, but did not identify as excess response, very large changes in the before-to-after levels resulting from the interventions. This means that the response to change was not only in the same direction as estimated by the ERF, but much steeper (i.e., excess response).

None of the studies in this group adjusted for confounders in their analyses.

Confounders included otherwise were noise sensitivity (2 studies), location of bedroom (2), insulation, and window opening behaviour (each 1 study).

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Table 5. New/Closed Infrastructure (Type C).

Authors	Intervention & Study		N, Response Rate & Method	Exposure Levels		Change in Levels and Distribution of Change across Participants	Outcome Measure(s) before and after Outcomes	Did Outcome Change with Change in Exposure? Yes/No (Significance Tested?)	Before/after Outcome Change Compared to That Estimated from an ERF	Comments	Confounders Adjusted for in Analyses
	Nature	Design		Before	After						
Gidlöf-Gunnarsson, Svensson, & Öhrström (2013) [8]	Stockholm Opening urban road tunnel reduced traffic on road system	B&A Exposure and control groups 1 year B & 1 year A Repeated measures	Exposure group: B:758 Response rate 55% A: 493 (75%) Control: B: 311 A: 165 Analysis based on 658 in both B&A Mail survey	$L_{Aeq,24\,h}$, 48–71 Control: 52–66 Measured/some estimated	See next column	194 Ps: −11 to −17 dB 225 Ps: –3 to −5 dB Control: no change in levels	ISO scale (5 point verbal) %Annoyed (note: not %HA) calculated using top three points of scale Exposure group: B: 60% Annoyed A: 20% Annoyed Control: B: 24% Annoyed A: 29% Annoyed	Yes Intervention resulted in substantial and significant (McNemar-test, $p < 0.001$) reduction in annoyance over the exposure area—but no change in control area	Authors cite Miedema & Oudshoorn (2001) ERF [13]—but refer only to %Annoyed, not %HA (uses $L_{den} = L_{Aeq,24\,h} + 4$) Authors also fitted a model of individual annoyance responses to exposure levels for all Ps, but using the exposure levels AFTER the intervention (n = 437: excluding Ps in one study sub area and control). Authors report that these modelled outcomes fit ERF for %Annoyed in Miedema & Oudshoorn (2001) [13] However, %Annoyed with exposures BEFORE the intervention was very much higher than indicated by ERF. Thus response to change in same direction as estimated by ERF, but steeper, indicating excess response	Authors suggest their modelling of %Annoyed on after-levels indicates no change-effect. They noted, but did not investigate, the excess response in the overall before-to-after change Authors reported 'dramatic' improvement in living environment for Ps with largest noise reduction (note: traffic on nearest road dropped from 60,000 veh/day to zero)	
Öhrström (2004) [7] Öhrström & Skånberg (2000) [34]	Gothenburg Major traffic reduction by construction of tunnel + narrowing of surface roadway	B/A study + control 1 year. B&A tunnel opening. Repeated measure	50 (92 control) Response rate 62% ~15% between surveys Delivered survey forms	67 (range 56–69) Control Av. 45 Calculated Note range of before levels	Av. $L_{Aeq,24\,h}$ 55 (range 44–57) Control Av. 44 Calculated	–12 dB Av $L_{Aeq,24\,h}$ reduction Distribution of magnitude of the change across individual Ps not reported	%HA based on top category of 4 point verbal scale B: 58%HA A: 7%HA Control B&A 1.1%HA to 0%HA Mean Annoyance on ISO also reported (B: 8.9; A: 1.4)	Yes Sig. diff. ($p < 0.001$) in B&A %HA Sig. diff. (paired t-test, $p < 0.001$) in B&A mean annoyance scores	Author refers to ERF of Miedema & Vos (1998) [12]. This ERF indicated %HA should move from approx. 30%HA to approx. 10%HA for the change in exposure experienced in this study. Observed percentages were 58%HA to 7%HA measured in the study group Thus response to change much steeper than ERF indicating large excess response	Note: author claimed no excess response—based on after levels Author speculates large change in response may also be related to air quality, vibration and appearance changes	

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6.1.4. Summary: Information from Other Physical Interventions

The only studies that are available on other physical interventions (Table 6) are not intervention studies per se as they do not provide direct evidence of an intervention. Instead, they provide, by comparing responses from groups with and without the particular physical dimension of interest, indirect evidence on the magnitude of the likely effect of certain interventions (such as the provision of a quiet side to the dwelling). The existence of a 'quiet side' may affect exposure (depending on how a person may use different rooms in his/her house), but also may be related to perceived respite—perhaps similar to the effect resulting from the existence of green areas in the neighbourhood, or the provision of green space in the neighbourhood. Interventions of this sort could be achieved as part of comprehensive housing/roadway redesign activities over some area.

In these studies, the designs were such that participants could be similarly exposed at the most exposed façade of the dwelling but would differ on some other dimension (say the difference between the exposures on the most and least-exposed facades of the dwelling). The other physical dimensions considered in this group of studies, in addition to availability of a quiet side, included: whether bedroom or living room windows faced a quiet street (effectively a variation on the existence of a quiet side to the dwelling), the non-acoustic 'quality' of the space that constituted the quiet side of the dwelling (such as a courtyard); and the existence of nearby green areas. Quiet side was defined differently in the different studies: for example, 10 dB noise/quiet difference in one, $L_{Aeq,24\,h}$ less than 48 dB in another.

All studies found the presence of the particular dimension being investigated had an effect, and all but one demonstrated that this was statistically significant (for example, the difference in the percentage of at least moderately annoyed participants between homes with and without a quiet side was statistically significant). One study reported the Odds Ratio was 3.3 when adjusted for noise sensitivity (95% CI 1.35–8.01) and, when participants actually used a bedroom on the quiet side, the OR = 10.6 (CI 2.0–56). Another study showed that visual quality of the space that provided the quiet side was also relevant, with 9–13% of participants less annoyed, depending on noisy side exposure levels. The Odds Ratio for courtyard quality was 0.59 (95% CI: 0.36–0.96).

In this group, several of the studies adjusted for a large number of different confounders in their analyses (see Table 6) but others only for age, noise sensitivity, or window-closing behaviour.

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Table 6. Other Physical Intervention (Type D).

Authors	Study		*N*, Response Rate & Method	Exposure Levels	Outcome Measure(s)	Did Outcome Change with 'Intervention'? Yes/No Strength of Effect	Comments	Confounders Adjusted for in Analyses
	Nature	Design						
de Kluizenaar et al. (2013) [35]	Questionnaire survey	Cross- sectional Stratified sample on age and district	1967 50% RR	For each dwelling, exposure levels were calculated at the most and least exposed façade (L_{den},most and $L_{den,least}$, respectively). 40–70 dB	Annoyance ISO scale (0–10 point verbal)	Yes Stronger association between noise and annoyance for those: who have relative quiet available (>10 dB difference between most and least exposed façades). Beta = 0.099 SE = 0.012, $p \leq 0.0001$, who have higher noise level at the least exposed façade. Beta = 0.035, SE = 0.016, $p \leq 0.05$) No interaction was confirmed		Age, gender, education, and annoyance from neighbour noise and 'humming' noise
Babisch et al. (2012) [36]	(HYENA) study is a large-scale multi-centered study carried out simultaneously in 6 European countries Prevalence of (designed as a hypertension study with air and road traffic sources) Study examined many modifiers. Here only the result wrt quiet side and living room facing the street are reported	Cross-sectional in stratified random samples around 6 airports (but response to road traffic noise examined here)	4861 (45–70 years old) 30–78% RR	$L_{Aeq24\,h}$ 45–65 road traffic noise	Annoyance ISO scale (0–10 point verbal)	Yes Location of the bedroom resulted in decreased annoyance at night (Beta = 1.25, CI = 1.12–1.38 vs. Beta = 0.81, CI = 0.65–0.97; interaction p < 0.001). per 10 dB Those with location of the living room facing the street were more annoyed during daytime with increasing road traffic noise level (Beta = 1.63, CI = 1.50–1.76) than those whose living room was located on the back side (Beta = 1.44, CI = 1.18–1.69); interaction p = 0.007	Samples based on air traffic noise but models adjusted for this	Full models, both continuous noise levels (Air and Road), type of housing, location of rooms shielding due to obstacles, visibility of the postal street, window opening habits, type of windows length of residence, time spent in the living room on workdays, time spent in the bedroom on workdays noise reducing remedies, building modifications to reduce noise, self reported hearing problems, rooms per occupant
van Renteghem & Botteldooren (2012) [37]	Belgium Effect of presence of a quiet façade on annoyance in high noise exposure dwellings	Comparison: of responses in dwellings with and without a quiet side All dwellings had noisy side: half also had a quiet side	100 Response rate 70% Interviews	L_{den}. 65–75 at most exposed façade—all dwellings. Half of dwellings also had quiet side Both levels sourced from END maps	ISO scale (5 point verbal) Analysis used mid category cut-off 'at least moderately annoyed'	Yes Absence of quiet façade results in increased 'at least moderately annoyed' respondents: Odds ratio 3.3 when adjusted for noise sensitivity (95% CI 1.35–8.01) When people actually used the bedroom at the quiet side OR = 10.6.(95% CI 2.0–56)	Quiet side defined as a front/back façade level difference >10 dB	Noise sensitivity, window closing, bedroom on a quiet side,, front-façade Lden

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Table 6. *Cont.*

Authors	Study		*N*, Response Rate & Method	Exposure Levels	Outcome Measure(s)	Did Outcome Change with 'Intervention'? Yes/No Strength of Effect	Comments	Confounders Adjusted for in Analyses
	Nature	Design						
de Kluizenaar et al. (2011) [38]	Questionnaire survey	Data drawn from a prospective cohort study For a postal questionnaire survey	18 973 (15–74 years) 70% RR	For each dwelling, exposure levels were calculated at the most and least exposed façade ($L_{den,most}$ and $L_{den,least}$, respectively). 40–70 dBA (Estimates available for *N* = 17,650)	Total Annoyance Dichotomous scale	Yes Stronger association between noise and annoyance for those who have relative quiet available (>10 dB difference between most and least exposed façade) for all levels >45 dB Ors range: 1.33–6.54 (all significant) Interaction term significant for two noise categories: OR = 3.177 for Lden interval 57.5–62.5; OR = 5.584 for Lden >60		Age, sex, body mass index, exercise, marital status, work situation, financial difficulties, alcohol use, education
Gidlöf-Gunnarson & Öhrström (2010) [30,39]	Sweden Effect of appearance of quiet side courtyard on annoyance in dwelling with high noise exposure	Comparison: of responses in dwellings with and without an attractive courtyard All dwellings had noisy side and a quiet side	385 Response rate 59% Mail survey	$L_{Aeq,24\,h}$ Calculated levels Noisy façade in two categories: 58–62 dB (*n* = 241) and 63–68 dB (*n* = 144). All had access to a 'quiet side' 239 Ps had low quality courtyard, 146 had high quality courtyard	ISO (5-point verbal) scale Analysis used mid category cut-off *at least moderately annoyed* Percentage of noise annoyed residents was significantly lower across the two sound level categories among those who had high (16% and 29%) than low-quality quiet courtyards (27% and 42%)	Yes Percentage annoyed depended on noisy façade exposure level, but was less when quality of courtyard was high, rather than low Odds Ratio for courtyard quality was 0.59 (95% CI: 0.36–0.96)	Quiet side defined as $L_{Aeq,24\,h}$ < 48 including façade reflection Quality of courtyard was assessed objectively.	Type of housing; Lay out and population characteristics: were comparable in the two study groups
Gidlöf-Gunnarsson, & Öhrström (2007) [40]	Sweden Nearby green area	Green versus non green Quiet site available versus not available All areas above 60 dB Most aspects kept constant at similar noise exposures, road traffic dominating source	500 Response Rate 59% Interviews	>60 dB	ISO scale (0–10)	Yes Significant associations emerged for availability to green areas (p < 0.001) and for access to a quiet side (p = 0.001), However, the effect sizes were low (partial η^2 = 0.029 and 0.023, respectively)	Interaction quiet side and green space not tested	Age

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6.2. Outcome: Sleep Disturbance

6.2.1. Summary: Evidence from Source Interventions

In the one study in Table 7, there was very limited change in exposure resulting from reduced traffic flow and no observed change in sleep outcomes. This study is not considered further.

6.2.2. Summary: Evidence from Path Interventions

The details of the two studies in Table 8 were reported under annoyance outcomes above (Table 4).

The studies found that the path intervention resulted in change in sleep outcomes. The percentage of people with self-reported disturbed sleep (variously measured/defined) was lower (statistically significant in one study, no tests in the other). In one of the studies, a follow-up survey two years after the intervention found that the changes observed in the initial study remained the same.

In one of the two studies in this category, the exposure response function was adjusted for confounding, including gender, age, education level, marital status, access to a bedroom on the quiet side of the building, and noise sensitivity.

6.2.3. Summary: Evidence from New/Closed Infrastructure Interventions

The summary details of the two studies reported in Table 9 (new tunnels removing traffic flow on surface roadways) were also reported under annoyance outcomes above (Table 5). Subjective and objective measures of sleep quality were also assessed before and after the intervention.

Both studies demonstrated statistically significant lower reporting of various sleep disturbance indicators (or improvement in sleep compared to conditions before the intervention), post-intervention.

In one study, a remarkable finding was that the time spent in bed was significantly reduced after the intervention, suggesting increased sleep efficiency according to the authors. The group aged 48 years and over seemed to profit most from the intervention.

None of the studies adjusted for confounding in their analyses, but in one study the participants in the experimental and control groups were matched on relevant characteristics, and in this *way* the risk of confounding was minimised. Other confounders included in the study were noise sensitivity (1 study), insulation (1), quiet side (2), and window opening behaviour (2).

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Table 7. Source Interventions (Type A).

Authors	Intervention & Study		*N*, Response Rate & Method	Exposure Levels		Change in Levels and Distribution of Change across Participants	Outcome Measure(s) before and after outcomes	Did Outcome Change with Change in Exposure? Yes/No (Significance Tested?)	Do before and after Outcomes fit with Relevant ERF	Comments	Confounders Adjusted for in Analyses
	Nature	Design		Before	After						
Stansfeld, Haines, Berry & Burr (2009) [19]	UK Bypass roads constructed reducing traffic flow in three small towns	B/A study B: 1 year A: 6–7 mos	175 exposed 184 control Response rates B: 70% A: 74% 67 Ps at exposed area follow-up Delivered questionnaire	$L_{10,3\,h}$ (& $L_{eq,3\,h}$) Exposed: 75–78 Control: 55–58 Measured some train noise	See next column	Change in $L_{10,3\,h}$ of −2 to −4 dB suggested for most locations No reporting of distribution of these small changes across Ps	Jenkins Sleep Scale No significant change in sleep total score	No change in sleep disturbance Explanation was that the change was too small to be noticed	n.a.	Change in traffic flow on source roadways were small: 24 h flow changed from 26 k to 23 k veh/day, and 24 k to 21 k veh/day	SES

Table 8. Path Interventions (Type B).

Authors	Intervention & Study		*N*, Response Rate & Method	Exposure Levels		Change in Levels and Distribution of Change across Participants	Outcome Measure(s) before and after Outcomes	Did Outcome Change with Change in Exposure? YES/NO (Significance Tested?)	Before/after Outcome Change Compared to that Estimated from an ERF	Comments	Confounders Adjusted for in Analyses
	Nature	Design		Before	After						
Amundsen, Klaeboe & Aasvang (2013) [28]	See Table 4					$L_{Aeq,24\,h}$, –7 dB for indoor noise levels for all Ps in target group	Several sleep questions, but '*sleep disturbed*' based on Yes/No response to either of: '*I am disturbed by traffic noise*' or '*I wake up because of traffic noise*' B: 45% disturbed A: 22% disturbed	YES %Sleep Disturbed dropped after intervention ($p < 0.0005$ McNemar's test) No change in control group Results stayed the same two years after	n.a.	Overall sleep quality also assessed (top two points of 5-point sleep quality scale = '*poor sleep*' Intervention resulted in less '*poor sleep*' similar to change in %Sleep Disturbed	Gender, age, education level, marital status, access to a bedroom on the quiet side of the building, and noise sensitivity
Bendtsen, Michelsen & Christensen (2011) [29]	See Table 4					L_{den} Reductions in extent of exposure 60–65 & 55–60 bands but increase in lower two bands	Unclear. Appears to be based on binary response to two questions: '*difficulties in falling asleep*' & '*wake up at night*'	Yes Ps. Reported sleep disturbance (both questions) dropped B: 14 & A: 7% No statistical tests	n.a.	No data presented of change in exposure of those reporting change in sleep	

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Table 9. New/Closed Infrastructure (Type C).

Authors	Intervention & Study		N, Response Rate & Method	Exposure Levels		Change in Levels and Distribution of Change across Participants	Outcome Measure(s) Before and after Outcomes	Did Outcome Change with Change in Exposure? Yes/No (Significance Tested?)	Before/after Outcome Change Compared to that Estimated from an ERF	Comments	Confounders Adjusted for in Analyses
	Nature	Design		Before	After						
Öhrström (2004) [7] Öhrström & Skånberg (2000) [34]	Gothenburg Major traffic reduction by construction of tunnel + narrowing of surface roadway	B/A study + control 1 year. B&A tunnel opening. Repeated measure	50 (92 control) Response rate 62% ~15% between surveys Delivered survey	Av. $L_{Aeq,24\,h}$ 67 (range 56–69) Control Av. 45 Calculated Note range of before levels	Av. $L_{Aeq,24\,h}$ 55 (range 44–57) Control Av. 44 Calculated	12 dB Av $L_{Aeq,24\,h}$ reduction Distribution of magnitude of the change across individual Ps not reported	15 questions on sleep and sleep environment. Ps asked to compare sleep and sleep behaviour with how it was one year earlier—before intervention	YES Sig. diff. ($p < 0.01$) in % exposed Ps reporting improvement, compared to control, in following: sleep with open windows time for falling asleep wakes up sleep quality tiredness in morning	n.a.		
Öhrström & Skanberg (2004) [41]	See row above: Öhrström (2004) [7] Öhrström& Skånberg (2000) [34] Substudy of above. Exposed area 25–67 m from roadway (11 Ps); control area 125–405 m from roadway (13 Ps) Longitudinal study: B & two A: 5 mos and 17 mos after intervention					$L_{Aeq,24\,h}$ outside Exposed 11 Ps –10 to −13 dB Control 13 Ps Most 0 to −1 (one P each −4 and −5)	Sleep questionnaire & wrist actigraphy After outcome: Questionnaire: reduced difficulty falling asleep & better sleep quality Actigraphy: fewer long wake episodes & shorter sleep times	Yes Questionnaire & actigraphy showed Ps significant reduction of time in bed (increased sleep efficiency) ($p = 0.02$); increase in subjective sleep quality and less time needed to fall asleep	n.a.	Primary purpose was to test if there was a difference between sleep questionnaire and sleep actigraphy	

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6.2.4. Information from Other Physical Interventions

The summary details of the one study in Table 10 (new tunnels removing traffic flow on surface roadways) were reported under annoyance outcomes above (Table 6). As indicated there, this is not an intervention study per se, as it does not provide evidence of the effect of an intervention. However, it does provide indirect information on the magnitude of the likely effect of a particular intervention (such as the provision of a quiet side to the dwelling), which could be undertaken as part of a significant *housing/roadway redesign* intervention.

Subjective assessment of difficulty in falling asleep was assessed before and after the intervention. The difference in the percentage of participants reporting difficulty falling asleep '*at least sometimes*' between homes with and without a quiet side was statistically significant. Absence of quiet façade results in increased reporting of this sleep parameter. The Odds Ratio for falling asleep was 5.5 (95% CI 0.7–44.1).

Confounding was adjusted for in the analyses of the ERFs including noise sensitivity, window closing behaviour, and front-façade L_{den}.

6.3. Outcome: Cardiovascular Effects

Information from Other Physical Interventions

This group are, again, not intervention studies per se as they do not provide direct evidence of an intervention. However, they do provide evidence of the likely effect of a particular action (such as the provision of a quiet side to the dwelling), which could be undertaken as part of a significant housing/roadway redesign intervention. Three of the studies found changes (including in self-reported high blood pressure) with and without a quiet side—two of those were tested to be significant. One study found no change.

Confounders included age, gender, education, body mass index, physical activity at leisure, alcohol intake, family history of hypertension, and occupants per room (listed for each study in Table 11 below).

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Table 10. Other Physical Intervention (Type D).

Authors	Study		*N*, Response Rate & Method	Exposure Levels	Outcome Measure(s)	Did Outcome Change with 'Intervention'? Yes/No	Before/after Outcome Change Compared to that Estimated from an ERF	Comments	Confounders Adjusted for in Analyses
	Nature	Design							
van Renteghem & Botteldooren (2012) [37]	Belgium Effect of presence of a quiet façade on sleep in dwellings with high noise exposure	Comparison: of responses in dwellings with and without a quiet side All dwellings had noisy side: half also had a quiet side	100 Response rate 70% Interviews	L_{den}. 65–75 at most exposed façade All dwellings Half of dwellings also had quiet side Both levels sourced from END maps	I A Na: sleep indicators: difficulties in falling asleep, awakening due to noise and window open (4 point scale: *never, sometimes, a lot, always*)	Yes Absence of quiet façade results in increased *'at least sometimes'* respondents: Odds ratio for falling asleep 5.5 (95% CI 0.7–44.1)	n.a.	Quiet side defined as a front/back façade level difference >10 dB	Noise sensitivity, window closing, bedroom on a quiet side, front-façade L_{den}

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Table 11. Other Physical Intervention (Type D).

Authors	Study: Nature	Study: Design	*N*, Response Rate & Method	Exposure Levels	Outcome Measure(s)	Did outcome Change with 'Intervention'? Yes/No Strength of Effect	Comments	Confounders Adjusted for in Analyses
Babisch, Wölke, Heinrich & Straff (2014) [42,43]	Germany Effect of quiet side and type of road on blood pressure	Major and secondary roads, quiet side available or not	1770 (Major road 753, Side street 1017) Response Rate not reported	L_{den} Major road: mean 67 s.d. 7.2 Side street: mean 49 s.d. 4.7	Self-reported hypertension.	11% increase of the risk of hypertension per increment of 10 dB(A) of the road traffic noise level was found Yes 31% higher risk of hypertension along major roads compared to those who lived in side streets In people that lived on major roads, an odds ratio of OR = 1.736 (95% CI = 1.005–2.997, p = 0.048) was found for the extreme comparison between both rooms on the front or the rear side of the house	Location of living room more important than location of the bedroom (not in line with other studies)	Age, gender, education, body mass index, physical activity at leisure, alcohol intake, family history of hypertension and occupants per room
Babish et al. (2012) [36]	(HYENA) study was a large-scale multi-centered study carried out simultaneously in 6 European countries Prevalence of (designed as a hypertension study with air and road traffic sources). Study examined many modifiers. Here only the result wrt quiet side and living room facing the street are reported	Cross-sectional in stratified random samples around 6 airports	4861 (45–70 years old) 30–78% RR	$L_{Aeq24\,h}$ 45–65 road traffic noise	Hypertension based on blood pressure measurements during home visits (defined as: a systolic BP $\geq$ 140 or a diastolic BP $\geq$ 90)	No Location of the bedroom did not result in significantly increased or decreased hypertension (OR = 1.09, 95% CI = 0.98–1.22 vs. OR = 1.10, 95% CI = 0.94–1.28; interaction p = 0.555) Location of the living room facing the street did not show an increase in the risk of hypertension with increasing road traffic noise level (OR = 1.06, 95% CI = 0.96–1.17)	Samples based on air traffic noise but models adjusted for this	Full models, both continuous noise levels (Air and Road) type of housing location of rooms, shielding due to obstacles, visibility of the postal street, window opening habits, type of windows length of residence, time spent in the living room on workdays, time spent in the bedroom on workdays noise reducing remedies, building modifications to reduce the noise, self-reported hearing problems, rooms per occupant
Lercher et al. (2011) [44]	Oral and telephone interviews by means of a structured questionnaire	Cross sectional	1653 first wave, 252 second wave 35% & 41% RR	L_{den} 30–78. Calculated.	Self-reported hypertension	No Results show that participants with bedrooms facing toward a quiet yard reveal a clear trend, but non-significant, toward a reduction in hypertension diagnoses in the ALPNAP-study (OR = 0.78, 95% CI = 0.59–1.05).		Age, sex, BMI, family history, education, health status, duration of living, age
Bluhm et al. (2007) [45]	Questionnaire survey	Cross-sectional	667 77% RR	Estimated noise levels dB(A)) annual mean $L_{Aeq24\,h}$. Individuals were classified into exposure categories of 5 dBA, from 45 dB(A) to 0.65 dB(A)	Self-reported hypertension	Yes Stronger association between noise and hypertension for those whose bedroom windows was facing the street (OR 1.82; 95% CI 1.22 to 2.70). Also a stronger effect for those who did not have triple glazed windows (OR 1.66; 95% CI 1.17 to 2.34)	Note: The effect of window glazing is 'indirect evidence' for a path effect.	Age, type of residence, occupation, smoking (others included but not significant)

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7. Evidence: Aircraft Noise

In the individual studies concerning aircraft noise that met the inclusion criteria, the health outcomes reported were distributed as follows:

- 4 reported effects of the intervention on the annoyance of people in their dwellings;
- 2 of these also reported effects of the intervention on sleep;
- 1 reported effects of the intervention on cognitive development in children;
- 1 modelled a hypothetical intervention in terms of the effect of the intervention on annoyance and sleep disturbance (the study modelling the effect of hypothetical interventions is considered in Supplementary File 4).

None of the studies were of source interventions; one was a path intervention involving dwelling insulation; four were new or closed infrastructure (new or abandoned or rearranged flight paths from airports).

The publication date of the aircraft studies were generally more recent that the road traffic noise interventions, with all published from 2002, with four of them in the last eight years.

The tables below group together studies of the same health outcome from the same intervention type, summarising each of the individual studies in that group. The tables report the nature of the intervention; the study design, size and method; and the exposure levels before and after the intervention, and what is reported about the distribution of the magnitude of the changes in exposure across the study sample. The tables also show how the outcome measures of annoyance or sleep outcome changed as a consequence of the intervention, and whether the magnitude of that change was statistically significant. There is also a commentary on the relationship of the observed change in response to the slope of a relevant ERF.

7.1. Outcome: Annoyance

7.1.1. Summary: Evidence from Path Interventions

This path intervention study for aircraft noise was around five Spanish airports (Table 12). A noise insulation program (NIP) in Spain retrofitted dwellings near airports with acoustic insulation. The study was primarily interested in the overall effectiveness of this program, namely in residents' satisfaction with the management of the process and the installation activities—but it did also assess whether there had been a change in the annoyance (and sleep disturbance) as a result of the NIP. The study demonstrated a drop in annoyance following the insulation intervention. However, no statistical tests were reported on the change in annoyance, and comparisons with other studies, and with any ERF, are not appropriate as the study used retrospective assessment by participants as the before-intervention baseline against which to compare post-intervention annoyance scores.

This study did not adjust for confounding, but reports in a descriptive manner on the influence of the aesthetics of the installed measures; and the performance of the construction company—explaining respectively 30% and 25% of the variance in satisfaction.

7.1.2. Summary: Evidence from New/Closed Infrastructure Interventions

All three studies in this group were associated with opening of new runways, closure of others, or flight path rearrangements (Table 13). Two were in Europe (Amsterdam and Zurich) and one in Canada (Vancouver). The interventions were, by and large, the introduction, or removal, of overflights, as a step change, over certain areas near the respective airports—as distinct from increases or decreases of air traffic flow along existing flight paths. Two were before and after studies, and one a panel study with four waves of survey.

The changes in exposure over the areas studied were highly variable, with only relatively small numbers of participants experiencing the larger changes in noise level (7, 12, and 14 dB: L_{den} or similar).

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However, for the majority of participants the change was much smaller, perhaps 1 to 2 dB. Changes in two of the studies included increased exposures as well as decreased exposures. It would appear that attempts to carefully design a study associated with changed flights paths to ensure a good distribution of changed exposures is difficult because of differences in what is initially proposed (and used as the basis for intervention study design) and what is actually implemented in terms of flight paths and aircraft numbers. The changes at Zurich were particularly related to changes in number of flights in the shoulder hours: early morning and late evening.

In all three studies, there was evidence that the changes in noise exposure, as a consequence of the flight path changes, resulted in change in annoyance outcomes and that these observed changes were statistically significant.

With respect to the strength of association between the change in exposure and the change in annoyance responses, all intervention studies demonstrated that the response was of a magnitude, *at least* as estimated by a steady-state ERF for annoyance. Both the Zurich and Amsterdam studies estimated a site-specific ERF. The Vancouver study made reference to the FICON [11] synthesis. Further, all provide evidence that the change in response was an *excess-response* to the change—both for decreased and for increased exposures in one study, and for increased exposures in the other two. An interesting development in intervention studies was the incorporation (in both the Amsterdam and the Zurich studies) of both level, and change in level, as exposure variables for participants, for modelling the effects of change. Evidence of excess response was tested statistically in the Amsterdam study and presented graphically in the other two studies.

The Amsterdam study provided evidence on the durability of the excess response – it still being present three years after the intervention—though with one unexplained temporary reduction from the fourth panel survey.

In this group of studies, all three studies either adjusted for confounding, or ruled out confounding by design. Military aircraft noise was accounted for by exclusion. Variables included pertained to year of survey, age, sex, ethnicity, home ownership, degree of urbanisation, time of residence, living satisfaction, noise sensitivity, expectations about the airport and the neighbourhood, coping behaviour, dependency on the airport, fear for aircraft crashes, and a negative attitude towards the airport.

Table 12. Path Interventions (Type B).

Authors	Intervention & Study		*N*, Response Rate & Method	Exposure Levels		Change in Levels	Outcome Measure(s) before and after Outcomes	Did Outcome Change with Change in Exposure? Yes/No (Significance Tested?)	Before/after Outcome Change Compared to That Estimated from an ERF	Comments	Confounders Adjusted for in Analyses
	Nature	Design		Before	After						
Asensio, Recuero, & Pavón (2014) [46]	Spain 5 airports Window insulation as part of NIP (Noise Insulation Program)	After study only—following insulation. Time since intervention not reported Before by retrospective assessment	689 Random selection from buildings that had been insulated Response rate not reported Telephone interviews	$L_{day} > 65$ $L_{night} > 55$ Calculated Actual exposures not reported	Not reported	Not reported	ISO annoyance scale (0–10) Before annoyance asked in retrospect during after-survey, followed immediately by after-annoyance question Annoyance for Day, for Night, & outdoors in neighbourhood were separate questions. Mean annoyance scores for each of these were 8.5, 7.6 and 9.0	Yes Mean Day and Night annoyance scores dropped 3.7 and 3.4 points on annoyance scale. (Note: retrospective Before annoyance) No statistical test reported. There is a difference in the distribution of annoyance reductions across the five airports	n.a.	Primary purpose was assessment of the overall NIP process	

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Table 13. New/Closed Infrastructure (Type C).

Authors	Intervention & Study		*N*, Response Rate & Method	Exposure Levels		Change in Levels and Distribution of Change across Participants	Outcome Measure(s) Before and after Outcomes	Did Outcome Change with Change in Exposure? Yes/No (Significance Tested?)	Before/after Outcome Change Compared to That Estimated from an ERF	Comments	Confounders Adjusted for in Analyses
	Nature	Design		Before	After						
Brink, Wirth, Schierz, Thomann & Bauer (2008) [47]	Zurich Relocation of flights in shoulders (early morning and late evenings)	B&A study Effectively two cross sectional studies from which change sample was located 2 years gap between surveys	394 change respondents (a subgroup of the 1816 Ps who were interviewed twice 1816 Ps in first ERF study/1719 in second (Response rates 54%/36%) mail & tel	L_{den} (and others) over range 30–70 dB Calculated		Change measured in L_{Aeq} over the shoulder periods 6–9 a.m. and 9–12 p.m. Range of intervention change in this indicator was −12 dB to +12 dB, but between −3 dB and +3 dB for ~70% of the 394 Ps who experienced the intervention	ISO 0–10 numerical scale and 5 point verbal scale. HA cutoff was 8	Yes Logistic regression models of prob. High annoyance show change is a significant parameter (Effect 0.16 p = 0.028 for morning change; Effect = 0.16, p < 0.001 for evening change) in addition to L_{Aeq}	ERFs for logistic regression of HA obtained from random sample around Zurich airport averaged across 2001 and 2003 surveys. Excess response ERFs developed that have L_{den} and change in $L_{Aeq,3\,h}$ as independent predictors. The ERF in this model is different to the one developed above, demonstrating an effect of change Demonstrated descriptively that Ps who experienced an increase through the intervention exhibited quite strong excess response	ERF developed in this study is approx. parallel to EU position paper ERF [14], but shifted 5–10 dB to left. Thus %HA around Zurich higher than predicted	Military aircraft noise was accounted for by exclusion; year of survey
Breugelmans et al. (2007) [48]	Amsterdam New runway opening Step-change increase in exposure Focussed on changes in outcomes	Had been 3 cross sectional surveys 1998, 2002 & 2005 2002 used as starting point for panel study Four rounds of panel survey	640 In area with forecast change >3 dB Half surveyed in different seasons 478 completed all 4 waves Mail survey	L_{den} L_{night} Calculated For the three subgroups: 53 61 55 Change in exposure is a noise indicator	57 55 54	Based on after-levels, Ps to three subgroups based on change in L_{den}. >+1.5 range: 1.5 to 13.7 (mean = +2.5) n = 118 <−1.5 range: −2.2 to −1.5 (mean = −1.9) n = 117 Control range: −1.4 to +1.4 (mean = 0.1) n = 405	ISO 0–10 scale. Reports % 'severely' annoyed (=%HA?)	Yes %HA does not change for control group. %HA does change for increase group (%HA changes from <40% to >60% (difference significant based on plotted Cis)	2002 panel survey before-results used to derive ERF Observed %HA control and decrease subgroups are in agreement with outcomes estimated from this ERF Observed %HA increase subgroups exceed outcome estimated from ERF Odds Ratio per 3 dB change = 0.44)—slightly less after control for confounders. Stronger association found with change over past 12 months (OR = 1.73) Excess response present for increase subgroup still present 3 years after intervention (one inconsistent result in fourth panel survey)	Part of Health Impact Assessment Schiphol Airport program Excess response was not explained by non-acoustical factors	Age, sex, ethnicity, home ownership, degree of urbanization, time of residence, living satisfaction, noise sensitivity, expectations about the airport and the neighbourhood, coping behaviour, fear for aircraft crashes, and a negative attitude towards the airport
Fidell, Silvati, and Haboly (2002) [49]	Vancouver Step change with new runway Change in aircraft operations	B/A study Independent samples, not a panel 15 mos B and 21 mos A. 3 year gap	B: 1000 A: 1067 Located in 7 areas Telephone interviews	L_{dn} 44–71 But most areas experienced 44 to 54 Calculated using INM	44–70	Ps in 5 areas experience effectively no change in exposure. One area experienced +7, another +3	Filter question as to whether bothered or annoyed in last year. If yes, then 4 point verbal annoyance scale. HA cutoff at top two points (*very, extremely*) Reported %HA each area B & A Most areas, no change. See next column	Yes +7 dB area: B: 11%; A: 52% (chi^2 59.8, p < 0.007) +3 dB area: B: 0%; A: 18% (chi^2 19.7, p < 0.007)	Author cites FICON ERF [11] For the two sites with major increase, the %HA is higher than predicted by the above ERF—and outside of a one s.d. error of the mean value of the ERF. Author notes excess response in only +7 dB area—but it is also present in the +3 dB area too Response to change in same direction as estimated by ERF, but steeper, indicating excess response	Author comments: *greater-than-predicted increase in the prevalence of annoyance cannot be attributed to change in noise exposure alone*	Attitude; dependency on airport; fear of crashes

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7.2. Outcome: Sleep Disturbance

Summary: Evidence from New/Closed Infrastructure Interventions

See summary of these papers under Section 7.1.2 above.

In both studies (Table 14), there was evidence that the changes in noise exposure as a consequence of the flight path changes resulted in change in sleep disturbance outcomes. In the Amsterdam study, it was also demonstrated that response was in the same direction, and of a magnitude, as estimated by a steady-state ERF for sleep disturbance for Amsterdam derived from before-intervention responses.

Both studies adjusted for confounding including the same variables as described in Table 13 above.

7.3. Outcome: Cognitive Development in Children

Summary: Evidence from New/Closed Infrastructure Interventions

As in the three aircraft noise studies in Table 13, the intervention in this study (Table 15) involved the rearrangements of flight path resulting from the opening of a new airport and closure of another. The study found various cognitive effects on children (for both the reduction in exposure, and the increase in exposure). Effects disappeared when the old airport closed, emerging after the new airport opened.

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Table 14. New/Closed Infrastructure (Type C).

Authors	Intervention & Study		N, Response Rate & Method	Exposure Levels		Change in Levels and Distribution of Change across Participants	Outcome Measure(s) before and after Outcomes	Did Outcome Change with Change in Exposure? Yes/No (Significance Tested?)	Before/after Outcome Change Compared to That Estimated from an ERF	Comments	Confounders Adjusted for in Analyses
	Nature	Design		Before	After						
Breugelmans et al. (2007) [48]	Amsterdam New runway opening Step-change increase in exposure. Focused on changes in outcomes		See study details as reported in Table 13 (annoyance) Calculated L_{night} and change in L_{night} were the exposure measures				Sleep disturbance 0–10 scale	Yes %Highly Sleep Disturbed does change for increase group	2002 panel survey before-results used to derive ERF for sleep disturbance Observed %Highly Sleep Disturbed is consistent with that estimated from above ERF Sleep disturbance response to change as estimated by ERF		Wide range of confounders incorporated into the analysis. See Table 13
Fidell, Silvati, & Haboly (2002) [49]	Vancouver Step change with new runway Change in aircraft operations		See study details as reported in Table 13 (annoyance)				Filter question, then: 'bothered or annoyed in last year' If Yes, Has your sleep been disturbed? Y/N Reported %sleep disturbed each area B & A Most areas, no change. See next column	Yes +7 dB area: B: 16%; A: 43% (chi^2 27.5, $p < 0.007$) +3 dB area: B: 5%; A: 17% (chi^2 8.2, $p < 0.007$)	n.a.		See Table 13

Table 15. New/Closed Infrastructure (Type C).

Authors	Intervention & Study		N, Response Rate & Method	Exposure Levels		Change in Levels and Distribution of Change across Participants	Outcome Measure(s) before and after Outcomes	Did Outcome Change with Change in Exposure? Yes/No (Significance Tested?)	Before/after Outcome Change Compared to That Estimated from an ERF	Comments	Confounders Adjusted for in Analyses
	Nature	Design		Before	After						
Hygge, Evans & Bullinger (2002) [50]	Munich Opening new airport closing old airport	Prospective cohort study +control matched om SES 3 data collection waves B (6 mos) & two A (1&2 year)	326 (mean age 10.4 years) Memory and Reading paper and pencil tests High response rates	Measured $L_{Aeq,24\ h}$ at school only Increase: 53 (n = 111) Decrease: 68 (n = 65) Control: (n = 107)	62 54	+9 new airport –14 old airport	Long and short term memory; reading; attention; speech perception	Yes Effects on reading, memory and speech perception, not attention. Effects disappeared when old airport closed; emerging after the new airport opened Various statistical tests including interactions.	n.a.	Children tested in soundproof caravan Suggest effects may be reversible	Confounds ruled out by design: ethnicity; mother's education; number of family members; occupation; attrition

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8. Evidence: Rail Noise

Three studies (Tables 16–18) reporting rail traffic noise interventions met the inclusion criteria, all reporting annoyance outcomes at people's dwellings. Two were conducted in Germany; one in Hong Kong. Two studies involved rail grinding, which can be considered a source intervention, but as one was also associated with an investigation of the effects of informing the community about the noise intervention, it is included below (Table 18) as an education/communication intervention. All were before and after studies, with two having a further after-survey twelve months after the first.

In two of the studies, the changes in the level of exposure as a result of the intervention were minimal, but in one of these there was, additionally, a communication intervention (Type E).

8.1. Outcome: Annoyance

8.1.1. Summary: Evidence from Source Intervention

In this one study, there was evidence that the approximately −10 dB changes in noise exposure as a consequence of the source level change resulted in change in annoyance outcomes; that this difference was statistically significant; and that it persisted more than 12 months after the intervention. However, this was a small study, with only one estimate of noise level change reported across all participants together with the means of their annoyance scores.

This study did not adjust for confounding factors.

8.1.2. Summary: Evidence from New/Closed Infrastructure Intervention

While this was new rail infrastructure in Hong Kong, noise from road traffic overwhelmed the train noise for effectively all participants. This study is not reported on further.

8.1.3. Summary: Evidence from Education/Communication Intervention

This study provides some evidence that information communicated to participants about a noise source (as part of an intervention to alter its source levels) has the effect of reducing that community's response to the noise.

This study did not adjust for confounding but took age, gender, education and coping into account in a descriptive manner.

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Table 16. Source Interventions (Type A).

Authors	Intervention & Study: Nature	Intervention & Study: Design	*N*, Response Rate & Method	Exposure Levels: Before	Exposure Levels: After	Change in Levels and Distribution of Change across Participants	Outcome Measure(s) before and after Outcomes	Did Outcome Change with Change in Exposure? Yes/No (Significance Tested?)	Before/after Outcome Change Compared to That Estimated from an ERF	Comments	Confounders Adjusted for in Analyses
Möhler et al. (1997) [51]	Germany Rail grinding to reduce railway noise emissions	B and two A. 1 mo. B; 1mo A. 3rd round was 1 year after 2nd round	B. 81 A. 64 A2. 46 questionnaire	L_{dn} 55–75 Calculated, with some measurement	L_{dn} 50–65	−7 to −8 dB Distribution of change across Ps not reported	0–10 total annoyance scale Reported as mean annoyance scores for group Difference in mean reported	Yes Difference between B & A = 0.6 (t = 2.07, df = 63, $p < 0.05$) Difference between B & A2 = 0.8 (t = 2.26, df = 45, $p < 0.05$) No difference between A1 & A2	n.a.		

Table 17. New/Closed Infrastructure (Type C).

Authors	Intervention & Study: Nature	Intervention & Study: Design	*N*, Response Rate & Method	Exposure Levels: Before	Exposure Levels: After	Change in Levels and Distribution of Change across Participants	Outcome Measure(s)	Did Outcome Change with Change in Exposure? Yes/No	Before/after Outcome Change Compared to That Estimated from an ERF	Comments	Confounders Adjusted for in Analyses
Lam & Au (2008) [52]	Hong Kong Opening of new 11 km urban rail line	6 mos B and two A. 2nd round 3 mo after. 3rd round was 1 year after 2nd round.	6000 invitation letters. Response rate not reported Face-to-face interviews B and A1 Telephone interview A2	Estimation of noise + validating measurements Noise mapping, validating measurement		Introduction of railway lead to very small increase in total noise exposure. $L_{Aeq,30\ min}$. 70% Ps experienced <+1 dB change. Others had +2 to +4 dB change		n.a. Results showed that original noise from road traffic overwhelmed the train noise for effectively all Ps	n.a.	There was a parallel survey over same area that experimentally manipulated information supplied to Ps about noise mitigation. This component is not reported here	

Table 18. Education/Communication Intervention (Type E).

Authors	Intervention & Study: Nature	Intervention & Study: Design	*N*, Response Rate & Method	Exposure Levels: Before	Exposure Levels: After	Change in Levels and Distribution of Change across Participants	Outcome Measure(s) before and after Outcomes	Did Outcome Change with Change in Exposure? Yes/No (Significance Tested?)	Before/after Outcome Change Compared to That Estimated from an ERF	Comments	Confounders Adjusted for in Analyses
Schreckenberg et al. (2013) [53]	Germany Rail grinding plus provision of information to Ps	BA. 3 mos B; 1–2 mos A. Part given information about rail grinding, part not given information. Randomly distributed over an information and non-information group	B: 411 A: 340 (163 informed area; 177 uninformed area) Response Rates: 73% & 83%) Repeated interviews	Not reported		Emission levels LAeq (day and night)reduced by only 1–2 dB	5 point verbal annoyance scale and range of disturbances Authors' conclusion based on the above	Rejected that rail disturbances dropped because of noise level drop. Yes However, author suggests disturbances are less where Ps have been given information compared to not given information	n.a.		

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9. Discussion

9.1. Overview of Findings Across All Studies

9.1.1. Change in Health Outcomes

Below we provide an overview, across source types, health outcomes, and intervention types, as to whether the intervention resulted in a change in the health outcome, and observations on the magnitude of that change. Table 19 below is a summary overview of the findings reported for each individual study in the sections above. Studies that reported more than one health outcome are entered under both outcomes.

Table 19 shows that most interventions involved road traffic noise (77%), with fewer aircraft noise (16%), and railway noise (7%). The exposure-related interventions in most of the entries in Table 19 were associated with a decrease in environmental noise exposure. However, in five studies (four road traffic noise studies and one aircraft noise study), some or all of the participants experienced noise exposure increases. Observations below with respect to change in responses refer to both the increases and the decreases.

Nearly all of the entries in Table 19, irrespective of the noise source, health outcome, or intervention type, show that the intervention led to a change in the aggregate health outcome of those who experienced the intervention (asterisk shown in the *YES* column). Excluding those studies for which no observation was appropriate (because there was no change in exposure, or the study was a follow-up survey at some interval after the original) there was only one transport noise study reporting no change in health outcomes. The original authors had provided statistically significant tests of this change in 51% of the entries (red asterisks); in a further 37% of entries this observation was interpreted, by the original authors or as part of the process of this review, from the data, tables, or plots presented in the papers, but without statistical tests (black asterisks).

Table 19 also provides an overview of the observed magnitude of change in health outcome as a result of the interventions. Seventeen studies of source, path, and new/closed infrastructure interventions for road and aircraft noise sources reported that the minimum magnitude of the change in outcomes (16 of the studies were of change in annoyance outcome; one of change in sleep disturbance outcome) could have been predicted from a relevant exposure–response function (ERF)—and all but two of these also found there to be an *excess response*—a *change effect* in addition to the *exposure effect* predicted by an ERF. In other words, the reduction in outcome was greater than would be expected based merely on the reduction in noise levels. Brown and van Kamp [15] reported that, for road traffic studies, and source intervention changes, the excess-response change-effect tends to be greater (often much greater) than the change in annoyance due to the noise level exposure change itself. Table 19 shows that observations of excess response in annoyance were for both road traffic (13 studies) and aircraft noise (3 studies).

In general, interventions at the source, in the pathway and intervention in infrastructure (Types A to C) are effective in reducing annoyance, but the available evidence is too poorly conditioned across different group of studies to be able to test for any differences in change in health outcomes arising from different types of interventions.

There is also no clear evidence with respect to thresholds regarding changes in health outcomes as a result of interventions. Intervention thresholds could have two dimensions: (1) the smallest change in exposure levels that result in a change in outcome, and (2) the minimum before-level. The only observation we can make is that several interventions that reduced noise exposures by −1 to −2 dB (energy-based scales) did not result in any observed change in health outcomes.

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Table 19. Summary of evidence from the individual studies on the effect of the intervention on health outcomes.

	Number of Papers	Evidence [1] That Health Outcome Changed			Observed Magnitude of Change in Health Outcome		
		YES	NO	n.a.	Magnitude *at Least* as Predicted by ERF	Excess [2] Response	n.a.[3]
ROAD TRAFFIC NOISE SOURCES (33)							
Outcome: Annoyance (23)							
A Source Intervention	9	*******		**	*******	*******	**
B Path Intervention	6	******			****	** ?	**
C New/Closed Infrastructure	2	**			**	**	
D Other physical	6	******					
Outcome: Sleep Disturbance (6)							
A Source Intervention	1			*			*
B Path Intervention	2	**					**
C New/Closed Infrastructure	2	**					**
D Other physical	1	*					
Outcome: Cardiovascular Effects (4)							
D Other physical	4	***	*				
AIRCRAFT NOISE SOURCES (7)							
Outcome: Annoyance (4)							
B Path Intervention	1	*					*
C New/Closed Infrastructure	3	***			***	***	
Outcome: Sleep Disturbance (2)							
C New/Closed Infrastructure	2	**			*		*
Outcome: Cognitive Development in Children (1)							
C New/Closed Infrastructure	1	*					*
RAIL NOISE SOURCES (3)							
Outcome: Annoyance (3)							
A Source Intervention	1	*					*
C New/Closed Infrastructure	1			*			*
E Education/Communication	1	*					

* Statistical significance of finding reported in the original study. * Finding interpreted by original, or current, authors based on data/tables/plots in original study. [1] Note that the evidence is indirect for Interventions Type D (Other Physical). [2] Excess response occurs where the total difference between the observed before and after outcomes is greater than the magnitude of the change in response estimated from an ERF, for a given change in exposure. [3] n.a. = not applicable/not available: no change in exposure or not reported. ? = unclear finding.

When interpreting the results, the quality of evidence for various combinations of source, intervention type, and outcome, needs to be considered. The overall quality of evidence within each of the source/intervention type/outcome groups varied, and was judged to range from high to very low across the different groups (see details in Supplementary File 5). It should be noted, however, that for all rows of Table 19 that contain more than two studies, the grouping are assessed as having either high or moderate qualities of evidence (other than sleep disturbance from aircraft noise for new/closed infrastructure which has a moderate quality of evidence).

The influence of contextual, situational, personal factors has to be accounted for. The following factors came forward from the review: noise sensitivity, distance to the road, availability of a quiet side, and window opening behaviour. Additionally, the context around the intervention should be considered, such as attitude towards policy and the party carrying out the measures, expectations about effectiveness of the intervention and satisfaction with the residential area. Only a few studies incorporated these types of factors into their analysis of change in health outcomes.

The studies of 'other physical interventions' (such as the provision of a quiet side to the dwelling, or the provision of green space in the neighbourhood) were not intervention studies per se as they did not provide direct evidence of an intervention. Instead, they provide comparisons of health outcomes from groups with and without the particular physical dimension of interest. These 'other physical interventions' did, in the majority of studies, demonstrate the efficacy of potential interventions of this sort, but it must be noted that this is indirect evidence consisting of comparison of outcomes of different groups under different conditions, rather than before-after comparisons on the same group.

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9.1.2. Sustainability of the Change in Health Outcomes

Nearly all of the entries in Table 19 were before-and-after studies, with the identification of the magnitude of the change in outcome fixed by the timing of the after-survey following the intervention. This was normally one to twelve months after the intervention, but varied considerably. For some of the interventions involving construction, such as barriers or housing reconfiguration, the gap between before and after studies was much longer: five to six years, and eight to ten years, in some studies.

However, a handful of studies continued to assess participant health outcomes longitudinally beyond the initial after-survey. Four road traffic studies, two aircraft studies and two railway studies resurveyed participants after various intervals: five surveys out to 20 months; six surveys out to three years; 12 months; two years, seven to nine years, etc. While the evidence is meagre and scattered, the consistent finding is that the latter after-surveys showed no difference in outcomes to those surveys immediately following the intervention—with no diminution in the magnitude of the effect, including excess response if present. The exception was that the survey seven to nine years after the intervention did show some attenuation in the excess response observed at the first after-survey.

In summary, while there is little evidence regarding longer-term changes in health outcomes subsequent to the initial change following an intervention, none of it suggests adaptation (*adaptation* being defined [54] as movement of the observed excess response, post intervention, towards expected steady-state response levels).

9.2. Implications

9.2.1. Implications for Noise Policy and Management

1. This review has provided a positive answer to an important policy question: *do environmental noise interventions change health outcomes?* This finding is largely consistent across the transport noise interventions. It shows that many current noise management strategies have a beneficial effect on human health. The caveat is that this evidence is not extensive or well distributed over all transport noise sources, intervention types, or health outcomes.
2. Another finding is that relevant ERFs for annoyance can provide an estimate of the *minimum* change in human outcomes that can be expected from a given change in exposure as a result of an intervention. This supports current noise management as ERFs for annoyance can thus provide a first conservative estimate for the health impact assessment of future interventions. The available evidence is more limited for aircraft noise than for road traffic noise. It is also too poorly conditioned across different groups of studies to be able to test for any differences in outcomes arising from different types of interventions. The evidence for ERFs predicting the minimum change in sleep disturbance is restricted to one aircraft noise intervention study only.
3. The review demonstrated that there was *excess response* to the intervention in 14 road traffic noise interventions and three aircraft noise interventions. Excess response occurs where the total difference between the before-outcome and the after-outcomes is greater than the magnitude of the change in response estimated from an ERF for the given change in exposure. A similar result was found for sleep disturbance for one aircraft noise study. The notion of excess response to interventions has been considered in depth by Brown and van Kamp [54] where they examined, and rejected some of, the many explanations that have been proposed for this phenomenon. This study found that: '*The evidence of the magnitude, and the persistence over time, of the change effect . . . and the existence of plausible explanations for it, suggest that it is a real effect and needs to be taken into account in assessing the response of communities in situations where noise levels change. Within the limitations of existing evidence on change, communities that experience an increase in noise exposure are likely to experience greater annoyance than is predicted from existing exposure–response relationships, and communities that experience a decrease in exposure experience greater benefit than predicted. Policy makers need to be informed of these potential* change effects, *particularly as situations in which noise*

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levels increase as a result of infrastructure changes are always likely to be contentious. To do otherwise would be to deny them important information regarding potential community response in these contexts'.

9.2.2. Guidance for Future Studies of Interventions

The following are implications arising from this review for further research into the health effects of interventions:

1. Further studies directly linking environmental noise interventions to health outcomes are required, for all sources of environmental noise, but particularly for aircraft and rail noise sources, and for human health outcomes other than annoyance.
2. Authorities proposing/funding interventions, whether at local, national, or international level, and whether or not the primary purpose of the intervention concerns noise, should be encouraged to include significant funding for the design and implementation of studies to evaluate outcomes from the interventions. At present, many of the evaluations appear to be addendums to, rather than integral components of, the interventions.
3. The effect of the intervention on the exposure of defined populations needs to be assessed, and its effect on the health outcomes of the same populations – not just the changes in noise levels that result from the intervention.
4. Intervention studies should use validated, and where possible, harmonised, measures of exposures and outcomes, as well as of moderators and confounders.
5. We recognize the difficulty in doing so in many intervention studies, but precise specification of the change in exposure for individuals, or subgroups, is desirable. In part to encourage this, we suggest that there are advantages in following the approach used in two of the individual aircraft noise studies [47,48] of reporting both the noise exposure before the intervention, and change in noise exposure as a result of the intervention, of the study participants, and using both in the analysis.
6. Most interventions result in step changes in exposure with expected step changes in human response to this change in exposure. While many intervention studies use a before and after design, there is generally insufficient consideration that the change in human response to a step change in exposure may have a different time course to that of the change in exposure.
7. A protocol is required for the conduct of future intervention studies that provides longitudinal assessment of both exposure and human response, and Brown [17] reported a design that is suitable (included below as Table 20). With a change in noise exposure over the interval between t_0 and t_1, sequential measurements of effect should be made before and after the change, preferably with multiple after measurements (A_{-1}, A_0, A_1, A_2, … A_x). Repeated measurements should also be made of activity interference (Act_x), potential confounders such as noise sensitivity ($Sens_x$), coping strategies (Cop_x), and a range of other attitudinal, retrospective, and prospective assessments. In addition, that model incorporates steady-state controls into the study design. The protocol in Table 20 is specific to studies of the effect of interventions on annoyance, but the principles of longitudinal measurements of exposure, of responses, and of potential confounders, can be adapted readily to studies of other human outcomes.
8. In reporting the evidence for excess response (in annoyance outcomes) above, we noted that an excess response occurs when the magnitude of the observed change in outcomes is greater than that 'predicted' by the ERF, irrespective of whether the observed before and after outcomes themselves lie on the ERF curve. We have noted a tendency, in many studies in which there is evidence of an excess response, for the observed before-outcomes to be much higher than would be indicated by synthesised ERFs. Authors of these individual studies did not explain these higher than anticipated before-responses. We also note the comment by Baughan and Huddart [20] that it is only high noise level situations that receive interventions to reduce noise exposures. In short, intervention studies are biased towards noise situations that are 'hotspots'.

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We leave this as an observation only as we have no evidence from this, or previous, reviews as to any mechanism that would lead to changes in reported outcomes from such hotspots (but see a range of potential explanations for excess response in Brown and van Kamp [54] that may have application to 'hotspots').

9. We note that the noise exposure metrics reported in the individual studies reviewed did not include a metric that dealt specifically with noise events in transport noise time histories. One exception is the study (Table 20) by Brown (2015) [17]. Participants in that study responded to a noise intervention that focused on a change in the number of noise events, even though there was no change in energy-based noise metrics. We flag this as an issue to be considered in future intervention studies for transport noise.

Table 20. Model protocol for intervention studies. After Brown (2015) [17].

Sequential Measurements	Before_{-1}	Before_0	After_1	After_2 ...
Time	t_{-1}	t_0	t_1	t_2 ...
noise exposure	L_{-1}	L_0	L_1	L_2 ...
Effect Measures (or Respondent Attribute Measures)				
annoyance	A_{-1}	A_0	A_1	A_2
activity interference	Act_1	Act_0	Act_1	Act_2
retrospective annoyance			RA_{01} [1]	RA_{02}
noise sensitivity	$Sens_{-1}$	$Sens_0$	$Sens_1$	$Sens_2$
attitudes to authorities etc.	Ats_{-1}	Ats_0	Ats_1	Ats_2
opinion of neighbourhood	$Neigh_{-1}$	$Neigh_0$	$Neigh_1$	$Neigh_2$
coping strategies	Cop_{-1}	Cop_0	Cop_1	Cop_2
prior knowledge	...	X_{10} [2]	...	...
expectations	...	Y_{10} [2]	...	...
Steady-state Controls	Before Control		After Control	

[1] RA_{01} is a respondent's retrospective assessment of annoyance at t_1 of conditions that existed at t_0. [2] X_{10} and Y_{10} are respondent's prior knowledge, and expectations, at t_0, of conditions that will exist at t_1. Other non-acoustic factors may have to be added.

9.3. Systems-Wide Considerations

There is a range of systems-wide matters that additionally should be considered in future evaluations of the health outcomes of transport noise interventions. We note them here, largely without comment, except to indicate that few of these matters were raised within any of the papers examined in the systematic review. However, they are important as they provide, in contrast to existing evidence based on a specific intervention within specific space and time bounds, a systems-wide understanding of transport noise interventions. The latter are likely to be important in comprehensive evaluation of the human health effects of transport noise interventions:

1. Spatial scales of interventions and effects will vary from highly local (e.g., noise barrier on a particular roadway) to regional, national (emission limits for motor vehicles), or international (e.g., emission limits for aircraft).
2. There may be lag times between interventions (e.g., regulations specifying vehicle limits which might take years to implement, or which rely on natural turnover in the vehicle fleet) and measurable effect. There may also be lag times between noise reduction and health consequences, e.g., decreased risk of cardiovascular disease.
3. Some interventions are applied for short periods (e.g., temporary flight path changes) vs. permanent interventions (studies of temporary interventions were excluded from the current review).
4. Interventions may result in unintended displacement outcomes. For example, a traffic restriction intervention that forces traffic into surrounding areas, introduces higher exposures in other areas, even though at the point of application the exposure is reduced. Examples include congestion charging in London [55] and the removal of diesel cars in Rome [56]. In these examples, the reduction in noise levels at one location was accompanied by an increase elsewhere and often in a more deprived area.

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5. A related consideration is that there may be subgroup differences in health outcomes from an area-wide intervention (e.g., effects on different socio-economic subgroups) and interventions that redistribute exposures across different areas need to be cognizant of differential socio-economic status of populations in these different areas.
6. There may be effects on human health responses to noise generated by interventions in other fields (e.g., intervention with respect to traffic congestion, or planning interventions that alter urban density).

9.4. Publication Bias

It is appropriate to note the possibility that publication bias may have influenced the findings of this review. We have no evidence of this, but it is reasonable to suggest that intervention studies that failed to find a change in human-response outcomes may tend to go unreported compared with those that did find a change.

A potential impediment is that some government and private instrumentalities who initiate noise intervention programs may have little interest in undertaking an evaluation of that intervention once a decision to implement it has been taken—avoiding any possible reputational risk that could be associated with a costly intervention later being shown to have little effect on human health.

10. Conclusions

1. An environmental noise intervention framework, showing different types of interventions along the causal path between noise sources and human outcomes, and measurement points along the pathway where changes relevant to human outcomes can be measured, has been used to structure this review. The framework also assists in focussing future studies of the effects of noise intervention strategies.
2. This systematic review of the literature, 1980–2014, found, overall, that there has been a limited number of transport intervention studies published that report observed changes in health outcomes, or observed changes in peoples' exposures, together with quantitative details on the association between change in exposure and change in human health effects.

   The majority of these were for road traffic noise sources; fewer for aircraft noise and rail traffic noise. The principal change in health outcomes assessed was annoyance, with fewer sleep disturbance, cardiovascular effects, and cognitive development in children.
3. We note that there are many studies in the noise management/control literature of interventions, which report a change in noise emissions or in noise levels, but in the absence of reporting of change in health outcomes or of exposures, these do not elucidate the relationship between interventions and health.
4. The consequence is that there is a restricted evidence base on the health effects of transport noise interventions, with studies spread across 16 different groupings (grouped by source type, health outcome, and intervention type). Only two of these groupings source interventions and path interventions for road traffic for the annoyance outcome have more than three studies.
5. A major difficulty for this review was the diversity between studies, even within those categorised in the same group. This was in terms of study designs method of analyses, exposure levels, and changes in exposure experienced as a result of the interventions. In some studies, the changes in noise exposure were variable across participants (sometimes reported in aggregate) and were not always adequately linked to the corresponding change in outcomes.
6. Because of the diversity, a meta-analysis across studies examining the association between changes in level and changes in outcome was not possible. However, the available evidence did show that transport noise interventions changed the health outcomes reported by those who experience the intervention. This is the case irrespective of the source, the outcome or the intervention type.

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7. The *minimum* magnitude of the change in annoyance outcomes because of the interventions can be predicted using a relevant exposure–response function (ERF). Further, in the majority of these studies, the magnitude of the change in response to an intervention exhibited a change effect—an excess response in addition to the level effect predicted using an ERF. This evidence was available for studies of road traffic noise sources (and a small number of aircraft noise studies) and largely only for the annoyance outcome.
8. The available evidence did not allow testing for any differences in change in health outcomes arising from different types of interventions, or for different source types. We also could not make observations regarding thresholds for observable changes in health outcomes, other than that several interventions that reduced noise exposures by −1 to −2 dB did not result in any observed change in health outcomes.
9. While there is little evidence available with respect to the longitudinal path of health outcomes changes following the initial change as a result of an intervention, there is no evidence to suggest the initial change in response is not sustained over at least several years—that is, there is no adaptation.
10. Further studies directly linking transport noise interventions to health outcomes are required, particularly for aircraft and rail noise sources, and for human health outcomes other than annoyance. A protocol has been recommended for the design of future studies.
11. While recognising the difficulty in doing so in many study designs, we suggest that future intervention studies should aim for precise specification of the change in exposure for individuals, or subgroups. There are advantages in following the approach [45,46], of reporting both the noise exposure before the intervention, and change in noise exposure as a result of the intervention, of the study participants, and using both in the analyses.
12. Policy makers need to be informed of the existence of the *change effect* associated with interventions, particularly as situations in which noise levels increase as a result of infrastructure changes are always likely to be contentious. To do otherwise would be to deny them important information regarding potential community response to these changes.
13. The results of the studies available to us regarding other physical interventions were obtained primarily through indirect evidence (comparison of outcomes under different conditions, rather than before-after designs). These have proved useful as a means of estimating the efficacy of such potential interventions, but they need to be supplemented by direct evidence.
14. We note, without evidence, that publication bias may have influenced the findings of this review. We also suggest, again without evidence, that government and private instrumentalities that initiate noise intervention programmes may be inhibited in conducting follow-up evaluations of the intervention through a perception of reputational risk in doing so.
15. The environmental noise intervention studies included in this review focussed on changes at the site of the interventions. We have indicated that there is a range of system-wide factors that also need to be considered in any comprehensive evaluation of the human health effects of any particular environmental noise intervention.

Supplementary Materials: The following are available online at www.mdpi.com/1660-4601/14/8/873/s1, Table S1: Previous narrative review papers on transport noise source interventions and effects, Table S2: Key search terms (in title, abstract and/or keywords), Table S3: Studies excluded based on full-text reading, Tables S4 and S5: Modelled outcomes of hypothetical interventions, Tables S6–S15: GRADE Tables for quality of evidence for various combinations of source, intervention type and outcome, and of individual studies, Tables S16–S29: Assessment of the risk of bias in the individual studies, Tables S30–S39: Hospital Noise and PLD/Music Venues/Other Sources Interventions.

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alone are responsible for the views expressed in this publication and do not necessarily represent the decisions or the stated policy of the World Health Organization.

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Appendix Ns.1.5

Manston Airport:
Consultation with Civil Aviation Authority

This technical note has been produced in response to Question Ns.1.11 of the First Written Questions issued by the Examining Authority (ExA) on the 18 January 2019.

The ExA requests that the applicant point to where in its application documents the Civil Aviation Authority's (CAA's) response to consultation can be found. The CAA did not directly provide a response to the Scoping Report as they were was consulted with on a number of other occasions outside of the formal Environmental Impact Assessment scoping process.

Table 1.1 provides a record of the meetings held with the CAA. There are no formal minutes of the meetings held available but the outcome of these discussions will shape the discussions during the Air Space Change process.

Table **Error! No text of specified style in document.**.1 Details of meetings between the applicant and the CAA

Date	Details
09 March 2016	A meeting was held at CAA House Kingsway with CAA Manager Aerodromes and two Principle Airspace Regulators. The purpose of the meeting was to introduce the re-opening of Manston Airport project to the CAA.
03 November 2016	A meeting was held at the Aviation House Gatwick with CAA Manager Aerodromes. The applicant provided an update on the project and discussed the aerodrome certification requirements with the CAA.
06 March 2017	A meeting was held at Aviation House Gatwick with new CAA Manager Aerodromes to provide an update on the project and discuss the aerodrome certification requirements.
15 May 2017	A meeting was held at the CAA House Kingsway with CAA Manager Airspace, Principle Airspace Regulator and Consultation Lead to provide an update on the project and discuss the airspace requirements
12 June 2017	A Process Workshop was held to run through the CAA/Planning Inspectorate Interaction Doc as part of the initial application. The CAA Manager for Airspace, CAA Principal Airspace Regulator, CAA Consultation Lead and CAA Legal met with representatives from the Planning Inspectorate.
09 October 18	A meeting was held at Aviation House Gatwick with the Head of Airports, Airspace and Aerodromes, Manager Aerodromes and Air Traffic Services, Manager Airspace and CAA Legal to discuss airspace, airport certification and a Statement of Common Ground.

Table Notes: There has also been informal engagement with the CAA, such as discussion via emails, but only formal points of contact with the CAA have been included in this table.

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Appendix NS. 1.22
Revised construction tables

This technical note has been produced in response to Question Ns.1.22 of the First Written Questions issued by the Examining Authority (ExA) on the 18 January 2019.

The ExA requests that the applicant revised construction tables.

Table 12.16 Phase 1 Monthly Construction Noise Predictions for Core Construction Hours (Weekdays 07:00 to 19:00 and Saturdays between 08:00 and 13:00)

Receptor Number	Receptor	Ambient Sound Level (dB $L_{Aeq,12hr}$)	BS 5228 Construction Impact Threshold (dB $L_{Aeq,12hr}$) 'ABC' Category shown in brackets (See Table 12.5)	Noise Levels (dB $L_{Aeq,12hr}$)						
				Cut & Fill	Concreting	Asphalt	Warehouse	Airport Buildings		Highways Improvements
								Demolition	Construction	
1	Bell Davies Drive	51 (LT2)	65 (A)	63	54	48	47	47	45	63
2	Spitfire Way	51 (LT2)	65 (A)	61	53	54	42	53	59	63
3	Smugglers Close	53 (LT6)	65 (A)	58	54	56	33	53	54	43
4	Southall Close	53 (LT6)	65 (A)	52	46	48	33	45	46	42
5	Ivy Cottage Hill	53 (LT6)	65 (A)	55	48	52	38	47	48	46
6	King Arthur Road	52 (LT5)	65 (A)	56[4]	52[4]	54[4]	34[4]	50[4]	57[4]	32[4]
7	High Street	53 (LT3)	65 (A)	59[1]	52[1]	51[3]	42[1]	48[1]	51[1]	47[1]
8	Manston Court Road	53 (LT3)	65 (A)	65	58	46	48	53	59	56
9	Manston Road	51 (LT2)	65 (A)	65	56	43	44	45	50	53

Mitigation assumptions (Paragraph 12.5.3 of the ES and Figures 12.3a & 12.3b)
[1] Includes 5dB reduction for construction noise barriers on the perimeter of site compounds for some or all of works associated with activity
[2] Includes 5dB reduction for construction noise barriers to the south of the internal access road for some or all of works associated with activity
[3] Includes 5dB reduction for construction noise barriers along the perimeter roads used as haul roads for some or all of works associated with activity
[4] Includes 10dB reduction for construction noise barriers along the perimeter roads used as haul roads for some or all of works associated with activity
[5] Includes 10dB reduction for local screening for some or all of works associated with activity

Table 12.17 Phase 2 Monthly Construction Noise Predictions for Core Construction Hours (Weekdays 07:00 to 19:00 and Saturdays between 08:00 and 13:00)

Receptor Number	Description	Ambient Sound Level (dB $L_{Aeq,12hr}$)	BS 5228 Construction Impact Threshold (dB $L_{Aeq,12hr}$) 'ABC' Category shown in brackets (See Table 12.5)	Noise Levels dB $L_{Aeq,12hr}$						
				Cut & Fill	Concreting	Asphalt	Warehouse	Airport Buildings		Highways Improvements
								Demolition	Construction	
1	Bell Davies Drive	51 (LT2)	65 (A)	56	50	-	48	45	47	-
2	Spitfire Way	51 (LT2)	65 (A)	54	51	-	48	49	49	-
3	Smugglers Close	53 (LT6)	65 (A)	57	54	-	51	53	54	-
4	Southall Close	53 (LT6)	65 (A)	49	45	-	42	44	46	-
5	Ivy Cottage Hill	53 (LT6)	65 (A)	51	47	-	44	46	47	-
6	King Arthur Road	52 (LT5)	65 (A)	55[4]	52[4]	-	48[4]	50[4]	52[4]	-
7	High Street	53 (LT3)	65 (A)	52[1]	47[1]	-	40[1]	44[1]	44[1]	-
8	Manston Court Road	53 (LT3)	65 (A)	60[5]	54[5]	-	40[5]	44[5]	54[5]	-
9	Manston Road	51 (LT2)	65 (A)	61[5]	50[5]	-	37[5]	39[5]	59[5]	-

Mitigation assumptions (Paragraph 12.5.3 of the ES and Figures 12.3a & 12.3b)

[1] Includes 5dB reduction for construction noise barriers on the perimeter of site compounds for some or all of works associated with activity

[2] Includes 5dB reduction for construction noise barriers to the south of the internal access road for some or all of works associated with activity

[3] Includes 5dB reduction for construction noise barriers along the perimeter roads used as haul roads for some or all of works associated with activity

[4] Includes 10dB reduction for construction noise barriers along the perimeter roads used as haul roads for some or all of works associated with activity

[5] Includes 10dB reduction for local screening for some or all of works associated with activity

Table 12.18 Phase 3 Monthly Construction Noise Predictions for Core Construction Hours (Weekdays 07:00 to 19:00 and Saturdays between 08:00 and 13:00)

Receptor Number	Receptor	Ambient Sound Level (dB $L_{Aeq,12hr}$)	BS 5228 Construction Impact Threshold (dB $L_{Aeq,12hr}$) 'ABC' Category shown in brackets (See Table 12.5)	Noise Levels (dB $L_{Aeq,12hr}$)						
				Cut & Fill	Concreting	Asphalt	Warehouse	Airport Buildings		Highways Improvements
								Demolition	Construction	
1	Bell Davies Drive	51 (LT2)	65 (A)	62[2]	57[2]	-	51[2]	55[2]	44[2]	-
2	Spitfire Way	51 (LT2)	65 (A)	61[2]	55[2]	-	49[2]	55[2]	47[2]	-
3	Smugglers Close	53 (LT6)	65 (A)	57	54	-	51	53	54	-
4	Southall Close	53 (LT6)	65 (A)	49	45	-	43	45	45	-
5	Ivy Cottage Hill	53 (LT6)	65 (A)	52	47	-	45	48	47	-
6	King Arthur Road	52 (LT5)	65 (A)	55[4]	51[4]	-	48[4]	50[4]	51[4]	-
7	High Street	53 (LT3)	65 (A)	54[1]	51[1]	-	45[1]	46[1]	48[1]	-
8	Manston Court Road	53 (LT3)	65 (A)	50[5]	46[5]	-	38[5]	37[5]	40[5]	-
9	Manston Road	51 (LT2)	65 (A)	45[5]	38[5]	-	37[5]	36[5]	35[5]	-

Mitigation assumptions (Paragraph 12.5.3 of the ES and Figures 12.3a & 12.3b)

[1] Includes 5dB reduction for construction noise barriers on the perimeter of site compounds for some or all of works associated with activity

[2] Includes 5dB reduction for construction noise barriers to the south of the internal access road for some or all of works associated with activity

[3] Includes 5dB reduction for construction noise barriers along the perimeter roads used as haul roads for some or all of works associated with activity

[4] Includes 10dB reduction for construction noise barriers along the perimeter roads used as haul roads for some or all of works associated with activity

[5] Includes 10dB reduction for local screening for some or all of works associated with activity

Table 12.19 Phase 4 Monthly Construction Noise Predictions for Core Construction Hours (Weekdays 07:00 to 19:00 and Saturdays between 08:00 and 13:00)

Receptor Number	Receptor	Ambient Sound Level (dB $L_{Aeq,12hr}$)	BS 5228 Construction Impact Threshold (dB $L_{Aeq,12hr}$) 'ABC' Category shown in brackets (See Table 12.5)	Noise Levels (dB $L_{Aeq,12hr}$)						
				Cut & Fill	Concreting	Asphalt	Warehouse	Airport Buildings		Highways Improvements
								Demolition	Construction	
1	Bell Davies Drive	51 (LT2)	65 (A)	56[2]	57[2]	-	59[2]	-	42[2]	-
2	Spitfire Way	51 (LT2)	65 (A)	65[2]	55[2]	-	49[2]	-	43[2]	-
3	Smugglers Close	53 (LT6)	65 (A)	52	51	-	52	-	51	-
4	Southall Close	53 (LT6)	65 (A)	47	43	-	44	-	43	-
5	Ivy Cottage Hill	53 (LT6)	65 (A)	52	45	-	46	-	44	-
6	King Arthur Road	52 (LT5)	65 (A)	54[4]	49[4]	-	49[4]	-	49[4]	-
7	High Street	53 (LT3)	65 (A)	55[1]	52[1]	-	35[1]	-	47[1]	-
8	Manston Court Road	53 (LT3)	65 (A)	50[5]	37[5]	-	27[5]	-	33[5]	-
9	Manston Road	51 (LT2)	65 (A)	44[5]	27[5]	-	27[5]	-	27[5]	-

Mitigation assumptions (Paragraph 12.5.3 of the ES and Figures 12.3a & 12.3b)
[1] Includes 5dB reduction for construction noise barriers on the perimeter of site compounds for some or all of works associated with activity
[2] Includes 5dB reduction for construction noise barriers to the south of the internal access road for some or all of works associated with activity
[3] Includes 5dB reduction for construction noise barriers along the perimeter roads used as haul roads for some or all of works associated with activity
[4] Includes 10dB reduction for construction noise barriers along the perimeter roads used as haul roads for some or all of works associated with activity
[5] Includes 10dB reduction for local screening for some or all of works associated with activity

Table 12.20 Phase 2 Monthly Construction Noise Predictions for Evening Construction Hours (Weekdays 19:00 to 23:00 and Saturdays 1300-2300)

Receptor Number	Receptor	Ambient Sound Level (dB $L_{Aeq,4hr}$)	BS 5228 Construction Impact Threshold (dB $L_{Aeq,4hr}$) 'ABC' Category shown in brackets (See Table 12.5)	Noise Level (dB $L_{Aeq, 4hr}$)						
				Cut & Fill	Concreting	Asphalt	Warehouse	Airport Buildings		Highways Improvements
								Demolition	Construction	
1	Bell Davies Drive	50 (LT2)	55 (A)	46	47	-	-	-	-	-
2	Spitfire Way	50 (LT2)	55 (A)	46	46	-	-	-	-	-
3	Smugglers Close	54 (LT6)	60 (B)	35	35	-	-	-	-	-
4	Southall Close	54 (LT6)	60 (B)	35	35	-	-	-	-	-
5	Ivy Cottage Hill	54 (LT6)	60 (B)	40	42	-	-	-	-	-
6	King Arthur Road	50 (LT5)	55 (A)	40[4]	38[4]	-	-	-	-	-
7	High Street	48 (LT3)	55 (A)	50[1]	51[1]	-	-	-	-	-
8	Manston Court Road	48 (LT3)	55 (A)	45[5]	44[5]	-	-	-	-	-
9	Manston Road	50 (LT2)	55 (A)	40[5]	39[5]	-	-	-	-	-

Mitigation assumptions (Paragraph 12.5.3 of the ES and Figures 12.3a & 12.3b)

[1] Includes 5dB reduction for construction noise barriers on the perimeter of site compounds for some or all of works associated with activity
[2] Includes 5dB reduction for construction noise barriers to the south of the internal access road for some or all of works associated with activity
[3] Includes 5dB reduction for construction noise barriers along the perimeter roads used as haul roads for some or all of works associated with activity
[4] Includes 10dB reduction for construction noise barriers along the perimeter roads used as haul roads for some or all of works associated with activity
[5] Includes 10dB reduction for local screening for some or all of works associated with activity

wood.

Table 12.21 Phase 3 Monthly Construction Noise Predictions for Evening Construction Hours (Weekdays 19:00 to 23:00 and Saturdays 1300-2300)

Receptor Number	Receptor	Ambient Sound Level (dB $L_{Aeq,4hr}$)	BS 5228 Construction Impact Threshold (dB $L_{Aeq,4hr}$) 'ABC' Category shown in brackets (See Table 12.5)	Noise Level (dB $L_{Aeq,4hr}$)						
				Cut & Fill	Concreting	Asphalt	Warehouse	Airport Buildings		Highways Improvements
								Demolition	Construction	
1	Bell Davies Drive	50 (LT2)	55 (A)	53^{2}	52^{2}	-	-	-	-	-
2	Spitfire Way	50 (LT2)	55 (A)	53^{2}	53^{2}	-	-	-	-	-
3	Smugglers Close	54 (LT6)	60 (B)	39	37	-	-	-	-	-
4	Southall Close	54 (LT6)	60 (B)	39	37	-	-	-	-	-
5	Ivy Cottage Hill	54 (LT6)	60 (B)	46	44	-	-	-	-	-
6	King Arthur Road	50 (LT5)	55 (A)	40^{4}	40^{4}	-	-	-	-	-
7	High Street	48 (LT3)	55 (A)	50^{1}	50^{1}	-	-	-	-	-
8	Manston Court Road	48 (LT3)	55 (A)	43^{5}	42^{5}	-	-	-	-	-
9	Manston Road	50 (LT2)	55 (A)	39^{5}	38^{5}	-	-	-	-	-

Mitigation assumptions (Paragraph 12.5.3 of the ES and Figures 12.3a & 12.3b)

[1] Includes 5dB reduction for construction noise barriers on the perimeter of site compounds for some or all of works associated with activity

[2] Includes 5dB reduction for construction noise barriers to the south of the internal access road for some or all of works associated with activity

[3] Includes 5dB reduction for construction noise barriers along the perimeter roads used as haul roads for some or all of works associated with activity

[4] Includes 10dB reduction for construction noise barriers along the perimeter roads used as haul roads for some or all of works associated with activity

[5] Includes 10dB reduction for local screening for some or all of works associated with activity

Table 12.22 Phase 4 Monthly Construction Noise Predictions for Evening Construction Hours (Weekdays 19:00 to 23:00 and Saturdays 1300-2300)

Receptor Number	Receptor	Ambient Sound Level (dB $L_{Aeq,4hr}$)	BS 5228 Construction Impact Threshold (dB $L_{Aeq,4hr}$) 'ABC' Category shown in brackets (See Table 12.5)	Noise Level (dB $L_{Aeq,4hr}$)						
				Cut & Fill	Concreting	Asphalt	Warehouse	Airport Buildings		Highways Improvements
								Demolition	Construction	
1	Bell Davies Drive	50 (LT2)	55 (A)	50[2]	50[2]	-	-	-	-	-
2	Spitfire Way	50 (LT2)	55 (A)	55[2]	53[2]	-	-	-	-	-
3	Smugglers Close	54 (LT6)	60 (B)	39	37	-	-	-	-	-
4	Southall Close	54 (LT6)	60 (B)	39	37	-	-	-	-	-
5	Ivy Cottage Hill	54 (LT6)	60 (B)	47	45	-	-	-	-	-
6	King Arthur Road	50 (LT5)	55 (A)	47[4]	38[4]	-	-	-	-	-
7	High Street	48 (LT3)	55 (A)	48[1]	50[1]	-	-	-	-	-
8	Manston Court Road	48 (LT3)	55 (A)	43[5]	43[5]	-	-	-	-	-
9	Manston Road	50 (LT2)	55 (A)	40[5]	39[5]	-	-	-	-	-

Mitigation assumptions (Paragraph 12.5.3 of the ES and Figures 12.3a & 12.3b)

[1] Includes 5dB reduction for construction noise barriers on the perimeter of site compounds for some or all of works associated with activity

[2] Includes 5dB reduction for construction noise barriers to the south of the internal access road for some or all of works associated with activity

[3] Includes 5dB reduction for construction noise barriers along the perimeter roads used as haul roads for some or all of works associated with activity

[4] Includes 10dB reduction for construction noise barriers along the perimeter roads used as haul roads for some or all of works associated with activity

[5] Includes 10dB reduction for local screening for some or all of works associated with activity

Table 12.23 Phase 2: Monthly Construction Noise Predictions for Night-time Construction Hours (Weekdays 23:00 to 07:00)

Receptor Number	Receptor	Ambient Sound Level (dB $L_{Aeq,8hr}$)	BS5228 Construction Impact Threshold (dB $L_{Aeq,8hr}$) 'ABC' Category shown in brackets (See Table 12.5)	Noise Level (dB $L_{Aeq,8hr}$)						
				Cut & Fill	Concreting	Asphalt	Warehouse	Airport Buildings		Highways Improvements
								Demolition	Construction	
1	Bell Davies Drive	44 (LT2)	50 (B)	46	47	-	-	-	-	-
2	Spitfire Way	44 (LT2)	50 (B)	46	46	-	-	-	-	-
3	Smugglers Close	48 (LT6)	55 (C)	35	35	-	-	-	-	-
4	Southall Close	48 (LT6)	55 (C)	35	35	-	-	-	-	-
5	Ivy Cottage Hill	48 (LT6)	55 (C)	40	42	-	-	-	-	-
6	King Arthur Road	47 (LT5)	50 (B)	40[4]	38[4]	-	-	-	-	-
7	High Street	46 (LT3)	50 (B)	50[1]	51[1]	-	-	-	-	-
8	Manston Court Road	46 (LT3)	50 (B)	45[5]	44[5]	-	-	-	-	-
9	Manston Road	44 (LT2)	50 (B)	40[5]	39[5]	-	-	-	-	-

Mitigation assumptions (Paragraph 12.5.3 of the ES and Figures 12.3a & 12.3b)

[1] Includes 5dB reduction for construction noise barriers on the perimeter of site compounds for some or all of works associated with activity

[2] Includes 5dB reduction for construction noise barriers to the south of the internal access road for some or all of works associated with activity

[3] Includes 5dB reduction for construction noise barriers along the perimeter roads used as haul roads for some or all of works associated with activity

[4] Includes 10dB reduction for construction noise barriers along the perimeter roads used as haul roads for some or all of works associated with activity

[5] Includes 10dB reduction for local screening for some or all of works associated with activity

Table 12.24 Phase 3: Monthly Construction Noise Predictions for Night-time Construction Hours (Weekdays 23:00 to 07:00)

Receptor Number	Receptor	Ambient Sound Level (dB $L_{Aeq,8hr}$)	BS5228 Construction Impact Threshold (dB $L_{Aeq,8hr}$) 'ABC' Category shown in brackets (See Table 12.5)	Noise Level (dB $L_{Aeq,8hr}$)						
				Cut & Fill	Concreting	Asphalt	Warehouse	Airport Buildings		Highways Improvements
								Demolition	Construction	
1	Bell Davies Drive	44 (LT2)	50 (B)	53[2]	52[2]	-	-	-	-	-
2	Spitfire Way	44 (LT2)	50 (B)	53[2]	53[2]	-	-	-	-	-
3	Smugglers Close	48 (LT6)	55 (C)	39	37	-	-	-	-	-
4	Southall Close	48 (LT6)	55 (C)	39	37	-	-	-	-	-
5	Ivy Cottage Hill	48 (LT6)	55 (C)	46	44	-	-	-	-	-
6	King Arthur Road	47 (LT5)	50 (B)	40[4]	40[4]	-	-	-	-	-
7	High Street	46 (LT3)	50 (B)	50[1]	50[1]	-	-	-	-	-
8	Manston Court Road	46 (LT3)	50 (B)	43[5]	42[5]	-	-	-	-	-
9	Manston Road	44 (LT2)	50 (B)	39[5]	38[5]	-	-	-	-	-

Mitigation assumptions (Paragraph 12.5.3 of the ES and Figures 12.3a & 12.3b)
[1] Includes 5dB reduction for construction noise barriers on the perimeter of site compounds for some or all of works associated with activity
[2] Includes 5dB reduction for construction noise barriers to the south of the internal access road for some or all of works associated with activity
[3] Includes 5dB reduction for construction noise barriers along the perimeter roads used as haul roads for some or all of works associated with activity
[4] Includes 10dB reduction for construction noise barriers along the perimeter roads used as haul roads for some or all of works associated with activity
[5] Includes 10dB reduction for local screening for some or all of works associated with activity

Table 12.25 Phase 4: Monthly Construction Noise Predictions for Night-time Construction Hours (Weekdays 23:00 to 07:00)

Receptor Number	Receptor	Ambient Sound Level (dB $L_{Aeq,8hr}$)	BS5228 Construction Impact Threshold (dB $L_{Aeq,8hr}$) 'ABC' Category shown in brackets (See Table 12.5)	Noise Level (dB $L_{Aeq,8hr}$)						
				Cut & Fill	Concreting	Asphalt	Warehouse	Airport Buildings		Highways Improvements
								Demolition	Construction	
1	Bell Davies Drive	44 (LT2)	50 (B)	50[2]	50[2]	-	-	-	-	-
2	Spitfire Way	44 (LT2)	50 (B)	55[2]	53[2]	-	-	-	-	-
3	Smugglers Close	48 (LT6)	55 (C)	39	37	-	-	-	-	-
4	Southall Close	48 (LT6)	55 (C)	39	37	-	-	-	-	-
5	Ivy Cottage Hill	48 (LT6)	55 (C)	47	45	-	-	-	-	-
6	King Arthur Road	47 (LT5)	50 (B)	47[4]	38[4]	-	-	-	-	-
7	High Street	46 (LT3)	50 (B)	48[1]	50[1]	-	-	-	-	-
8	Manston Court Road	46 (LT3)	50 (B)	43[5]	43[5]	-	-	-	-	-
9	Manston Road	44 (LT2)	50 (B)	40[5]	39[5]	-	-	-	-	-

Mitigation assumptions (Paragraph 12.5.3 of the ES and Figures 12.3a & 12.3b)

[1] Includes 5dB reduction for construction noise barriers on the perimeter of site compounds for some or all of works associated with activity

[2] Includes 5dB reduction for construction noise barriers to the south of the internal access road for some or all of works associated with activity

[3] Includes 5dB reduction for construction noise barriers along the perimeter roads used as haul roads for some or all of works associated with activity

[4] Includes 10dB reduction for construction noise barriers along the perimeter roads used as haul roads for some or all of works associated with activity

[5] Includes 10dB reduction for local screening for some or all of works associated with activity

Appendix NS. 1.25
Airport car parking

This technical note has been produced in response to Question Ns.1.25 of the First Written Questions issued by the Examining Authority (ExA) on the 18 January 2019.

The ExA requests that the applicant confirms how airport car parking noise has been assessed.

1. Overview

Prediction of noise from parking areas in Manston Airport has been performed based on the methodology recommended by the Bavarian State Office for the Environment[1], hereinafter referred to as the Bavarian method. The resulting noise impact has then been assessed using guidance provided in British Standard BS 4142:2014 entitled 'Methods for rating and assessing industrial and commercial sound'.

Figure 1 shows a top-down view of the parking areas for passengers, as well as two indicative receptor points, i.e. the nearest residential property, and Grove house, for which baseline noise details are presented in Appendix 12.4 of the ES for Manston airport. More specifically, Grove House, which is referred to as LT3 in the ES is located approximately 480m east of the eastern site perimeter. The Manston Airport DCO states that the passengers parking area has 1815 spaces. It is divided in two parts, referred to in this report as a large part and a small part, as illustrated in Figure 1. Also showed is a green-shadowed area in the top-right area of the parking area, which is used to assess a hypothetical worst scenario, when all cars are parked as close as possible to receptor areas.

Figure 1 Parking areas and indicative receptor points (1: Nearest residential, 2: Grove House)

[1] 'Parking Area Noise, Recommendations for the Calculation of Sound Emissions of Parking Areas, Motorcar Centers and Bus Stations as well as of Multi-Storey Car Parks and Underground Car Parks, 6th ed., Bayerisches Landesamt für Umwelt, Augsburg, 2007

2. Parking noise assessment

The Sound Power Level (SWL) for the parking areas is calculated through the Bavarian method as follows:

The plane-specific SWL is calculated with:

$$L_W'' = L_{w0} + K_{PA} + K_I + K_D + K_{StrO} + 10\log(B \cdot N) - 10\log(S/1) \qquad dB(A) \qquad [1]$$

The essential input to get the sound power level (SWL) of parking area is the frequency of motion, N, i.e. the vehicle motions per carport and time period. This can either be obtained by published tables that provide indicative values of N for various types of parking areas, or estimated from traffic flows, if available. Noise and Air Quality Transport Flows for Manston Airport are available and hence the latter option is used here. Table 1 outlines traffic flow data, in particular for the B2050 Manston Road east of passenger access, which provides access to the parking areas. Car movements are listed in Table 2 along with the associated frequencies of motion, N for the parking areas at different time periods.

Table 1 Traffic flows data for B2050 Manston Road east of passenger access

Time period	Car movements*	Cars/min
Day 18 Hour (06:00 to 00:00)	4668	4.3
Night Period	1026	2.9
Worst Night Hour (05:00 - 06:00)	361	6.0

** From noise and air quality traffic flows, B2050 Manston Road east of passenger access*

Table 2 Calculated values for motion frequency at the parking areas, for different periods of the day

	Car movements			Motion frequency, N		
	Day	Night	Worst Night Hour	Day	Night	Worst Night Hour
Passengers Parking (large part)	3764	827	291	0.14	0.09	0.20
Passengers Parking (small part)	904	199	70	0.14	0.09	0.20
Worst-case scenario area (worst night only)	-	-	361	-	-	1.00

Table 3 Values of parameters required for SWL calculation according to the Bavarian method

Parameter	Description	Value	Obtained from
L_{w0}	SWL of one motion/h on P + R areas	63 dB(A)	Bav. Method Table 30
K_{PA}	Surcharge for the parking area type	0	Bav. Method Table 34
K_I	Surcharge for the impulse character	4	Bav. Method Table 34
K_D	Level increase due to passaging traffic	8 (large part) 6 (small part)	Bav. Method Eq. (3)
K_{StrO}	Surcharge for different lane surfaces	0	Bav. Method Section 8.2.1
B	Number of the carports	1815 Parking (large part) 842 Parking (small part)	Manston Airport DCO
N	Frequency of motion	See Table	Calculated through traffic flows
S	Total area of the parking area	77269 m^2 (large part) 18566 m^2 (small part)	Calculated from site layout

Assuming that the airport parking area is similar to a P + R area, then the remaining parameters for calculating the plane-specific SWL (through equation [1]) take the values listed in Table 3. The SWL for the complete parking areas are then obtained from equation [2] and listed in Table 4.

$$L_W = L_W'' + 10\log(S/1) \qquad \text{dB(A)} \qquad [2]$$

Table 4 SWL for the different parking areas and for the worst-case scenario

	SWL, Lw, dB(A)		
	Day	**Night**	**Worst Night Hour**
Passengers Parking (large part)	98.1	96.3	99.55
Passengers Parking (small part)	96.5	94.7	97.9
All cars parked close to receptors			98.9

The SWL is assumed to be uniform all over the complete parking area expanse and at a height of 0.5 m above ground. The noise at receptors is calculated according to the guideline DIN ISO 9613-2 that here is implemented through the software Predictor-LimA. The parking areas are defined as area sources consisting of point sources that are 10x10m apart.

3. Results and conclusion

Table 5 lists the noise exposure at the indicative receptor locations, i.e. the nearest residential, as well as the background noise level at LT3 which is presented in Appendix 12.4 of the ES for Manston airport and reproduced in Table 6.

Comparison between Table 5 and Table 6 suggest that car park noise exposure levels at receptor positions are below the existing background noise levels during the day, night and worst night hour. For the worst case when all cars are parked close to receptors, car park noise exposure level at receptor positions is equal to the existing background noise levels. British Standard BS 4142:2014 entitled 'Methods for rating and assessing industrial and commercial sound' states:

- 'The significance of sound of an industrial and/or commercial nature depends upon both the margin by which the rating level of the specific sound source exceeds the background sound level and the context in which the sound occurs', and
- 'The lower the rating level is relative to the measured background sound level, the less likely it is that the specific sound source will have an adverse impact or a significant adverse impact. Where the rating level does not exceed the background sound level, this is an indication of the specific sound source having a low impact, depending on the context'.

It can therefore be concluded that parking noise at Manston airport will have low impact on nearby residents. Hence no significant effects are identified.

Table 5 Noise exposure level ($L_{A,eq}$) for indicative receptor locations

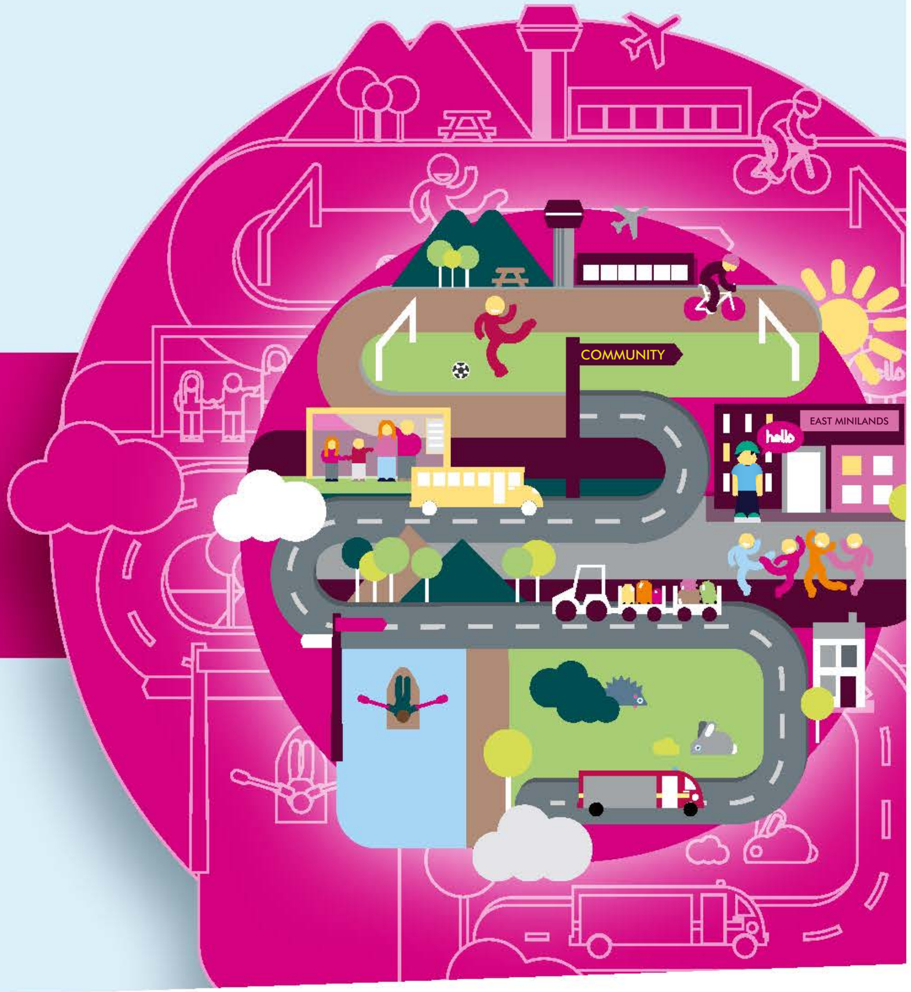
	$L_{A,eq}$ dB(A)			
Receiver ID - name	**Day**	**Night**	**Worst Night Hour**	**Worst Night Hour (all cars close to receptors)**
LT3 - Grove House	33	31	34	34
CL_RES - Nearest Residential	33	31	34	35

Table 6 Background noise level at LT3 – Grove House.

	Day	**Night**
$L_{A90,T}$ dB(A) [mean average]	45	35

SOUND INSULATION GRANT SCHEME

East Midlands Airport
at the heart of your community



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Appendix Ns.1.30

EAST MIDLANDS AIRPORT SOUND INSULATION GRANT SCHEME (SIGS)

CONTACT FOR FURTHER INFORMATION

Wakemans
11-12 Highfield Road, Edgbaston, Birmingham B15 3EB
Telephone **0121 454 4581** or email Mike Greenway at
m.greenway@wakemans.com

WHO IS ELIGIBLE FOR A GRANT?

The scheme covers those in the most heavily impacted areas around the Airport and is based on a noise footprint.

The boundary of the scheme is shown on page 4. All dwellings within the shaded area may be eligible for a grant. The map is for guidance only and if you are unsure of your eligibility please contact our Managing Agent (see details below).

Any building (or part of a building) which is being used as a domestic dwelling may be eligible for a grant provided that:

- It is within the boundary of the scheme (see map on page 4);
- It was built before January 2002.

Not all dwellings are suitable for the installation of acoustic insulation. Dwellings that may be unsuitable include:

- Houses which are not of standard brick construction;
- Individual rooms built into roof space which do not have standard brick walls.

LISTED BUILDINGS

Any installation of acoustic insulation to a 'listed' building is likely to require the prior consent of the District Council. Whilst our Managing Agent will be able to provide contact details for the local planning officer and general advice, the responsibility for obtaining any 'listed' building consent rests with the householder. Our Managing Agent will require evidence that all necessary consents have been obtained before the offer of a grant is made.

NOISE SENSITIVE BUILDINGS

Whilst the Scheme only makes grants available to dwellings within the eligible area, we accept that some noise sensitive buildings, such as local schools, may also benefit from noise insulation. The Airport may make discretionary awards available and we would ask that, in the first instance, you please contact the Managing Agent. All cases will be considered individually.

WHAT ARE THE SCHEME OPTIONS?

The Scheme offers grants towards the cost of installing secondary glazing, high performance double glazing, loft insulation and replacement doors.

SECONDARY GLAZING

Secondary glazing is added to existing windows to create a 'double window'. The two panes work together to reduce the noise entering the room. To ensure maximum noise reduction, the panes are as wide apart as possible and of different thickness.

HIGH PERFORMANCE DOUBLE GLAZING

High performance double glazing is a replacement glazing system using PVCu which has similar acoustic performance to secondary glazing. The system offered by the Scheme has been shown to have excellent performance in noise reduction.

LOFT INSULATION

Acoustic loft insulation has been shown to give significant noise reduction. You may apply for a grant to cover the cost of purchasing insulation for your loft.

DOORS

Where an external door leads from the outside directly into a habitable room, this should also be insulated to achieve maximum noise reduction.

Grant support is offered to insulate or replace a door as necessary. The survey of your property will recommend the appropriate insulation.

VENTILATION

In order to ensure that maximum noise reduction can be achieved with all windows closed, the Airport strongly recommends that mechanical acoustic ventilators are installed. The Scheme's Managing Agent will discuss this with the householder and will be able to provide information about the products that are recommended.

RELOCATION

A one-off payment for relocation provided the property was purchased before December 2003. This offer is limited to those dwellings in Zones C and D.

Appendix Ns.1.30

HOW MUCH WILL I RECEIVE?

The Scheme is designed to offer greatest support to those who experience the greatest noise impact.

The plan on page 4 shows the areas within which grant awards are available. Within these areas the maximum grant award is as follows:

Zone A £3,000 Zone B £5,000 Zone C £10,000

Applications are dealt with in the order that they are received, with the exception of those in **Zones C** and **D**, which will be afforded a greater priority. The Managing Agent will be able to advise you on the progress of your application.

CAN I HAVE ADDITIONAL WORK CARRIED OUT?

You may decide to instruct the Contractor to undertake additional work. You are, of course, free to do so but any additional work will be at your own cost. The Airport does not accept liability for any part of such costs.

Please note the Managing Agent may wish to inspect the work before payment of the grant is made.

All applications must be submitted before work is carried out. Applications will not be considered retrospectively. Tenants of rented accommodation must obtain written agreement from their landlord stating that they have no objection to the works. This written confirmation must be included with your application.

WHO WILL DO THE WORK?

Following a competitive tendering exercise, we have appointed a preferred contractor. By adopting this selection process it has been possible to obtain very competitive rates.

The contractor has been chosen on the basis of cost, quality and design to ensure high standards of installation at an economical price. The performance of the contractor is continually monitored to ensure that a consistently high standard is maintained. However, please note the Airport is not liable for the acts or omission of any of the contractors.

The Airport does offer grant support if you choose not to use the preferred contractor. However, should you choose to do this you will be liable to pay the full cost for the windows and we will reimburse you once the work has been inspected and approved by the Scheme's Managing Agent and a copy of the paid invoice is sent through.

If you wish to use a different contractor please ensure that you obtain the consent of the Managing Agent before any work is undertaken.

Failure to obtain prior consent may mean that a grant payment will not be made available.

IS THE WORK GUARANTEED?

The installation and products used comply with the appropriate British Standards. The installation and products will be guaranteed by the contractor in accordance with recognised codes of practice.

HOW DO I APPLY?

To begin the application process it is advised that you contact the Managing Agent to confirm that you qualify, discuss the process and clear up any queries.

You then need to fill out the appropriate application form available from the managing agent.

FOR ACOUSTIC GLAZING

1. Once the Managing Agent has received your completed form they will then contact you to arrange a survey of your property and a detailed quote from the approved contractors.
2. Once the survey and quotes are complete and approved (by the householder) the Managing Agent will confirm that your application has been accepted and instruct the contractor to begin the work.
3. The Airport will pay the grant funding directly to the contractor (unless the householder chooses not to use an approved contractor – see page 3). If the final bill is in excess of the grant offered, the remaining invoice will be sent to the householder after completion of the works.

FOR LOFT INSULATION

1. Once the Managing Agent has received your completed form they will contact you to confirm the offer of a grant.
2. It is then the responsibility of the householder to purchase the loft insulation and provide a copy of the receipt to the Managing Agent.
3. Once a receipt of purchase has been received, the grant will be sent out.

HEALTH & SAFETY

Every room to be insulated must have ventilators installed at high level, to allow the flow of fresh air. Ventilators will be fitted in accordance with performance standards included in the Buildings Regulations. The amount of ventilation in a room will depend on the number and type of combustion appliances in that room.

- Do not bring a flueless combustion appliance, such as portable oil or gas fire, into a room which has been insulated;
- If you change the combustion appliance in a room which has been insulated, you should make sure that the new appliance can operate safely;
- Keep the permanent ventilators unobstructed and do not block the air flow in any way;
- Once installed, the secondary or replacement windows and ventilators become the responsibility of the property owner. The installer will advise on cleaning and maintenance requirements;
- Where a combustion appliance with a flue (such as a gas fire and/or back boiler) is installed in a room to be glazed, it will be necessary to conduct a gas spillage test before and after the installation of the glazing.

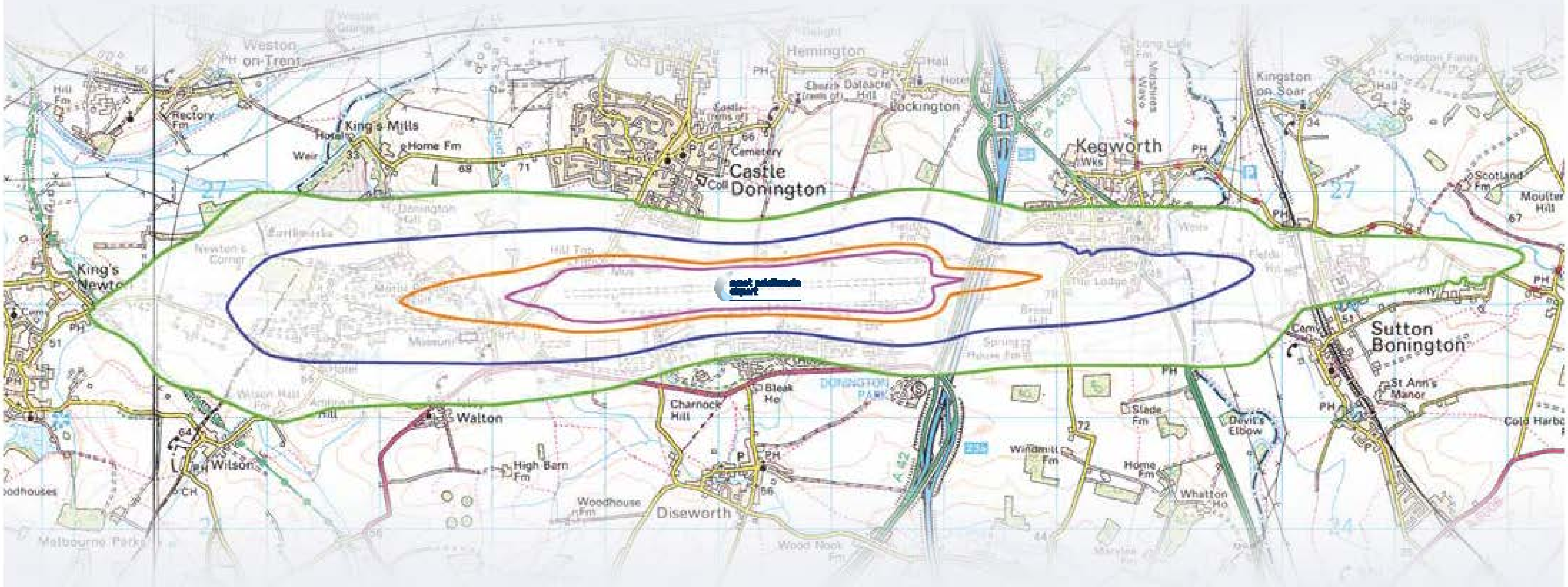
IMPORTANT

Any grants which East Midlands Airport may approve shall be made on the terms contained in the approval notification which shall be deemed to incorporate all the terms contained in this brochure. Applicants shall be deemed to have read and understood the terms contained in this brochure.

- The decision of the Airport's Managing Agent regarding the eligibility (or otherwise) of any application and/or the amount of any grant shall (save in the case of manifest error) be final and binding.
- The information in this brochure is believed to be correct at the time of going to print but the Airport will not be liable for any errors, omissions or inaccuracies.
- The Airport reserves the right to amend any of the terms and conditions of the scheme at its absolute discretion (provided that where any grant has been given final approval and the relevant purchase order has been placed prior to the date of such amendment, the amount of such grant will not be affected by such amendment).
- Grants are provided for the installation of acoustic insulation only as set out in this scheme. Any works of a decorative nature that are necessary following installation remain the sole responsibility of the householder.
- The Airport shall not be liable to the Applicant for the acts of omissions of the Contractor nor for the performance of the Contractor pursuant to any contract between the Contractor and the Applicant for the carrying out of any works (whether covered by the scheme or otherwise). The Airport shall not be liable to the Contractor for the performance of any obligation on the part of the Applicant pursuant to such contract.
- In any event, the Airport's liability in each case shall not exceed the amount of the relevant grant calculated in accordance with this scheme by reference to the relevant contractor's quotation.
- The Airport will not be responsible for obtaining any necessary planning permissions, building regulations consents, building warrants or other consents which may be requested for carrying out the works. These are the responsibility of the Applicant.
- It will be the responsibility of the Applicant to carry out (at his/her own cost) any necessary enabling work identified by the Contractor including lifting and subsequent re-fitting of carpets.
- The Airport reserves the right to withdraw, alter or amend the terms of any offer or the Scheme, at its discretion, at any time.

MAP SHOWING SCHEME AREA

KEY
- Zone A
- Zone B
- Zone C
- Zone D



Scale at A4 : 1:56,400

Appendix Ns.1.30

DEPARTMENT FOR TRANSPORT

DfT Circular 01/2010
Department for Transport
Great Minster House, 76 Marsham Street, London SW1P 4DR

5 March 2010

CONTROL OF DEVELOPMENT IN AIRPORT PUBLIC SAFETY ZONES

1. This Circular updates DfT Circular 1/2002 to take account of the shift of day-to-day administrative responsibilities for implementing Public Safety Zone (PSZ) policy from the Department for Transport to the Civil Aviation Authority (CAA). The PSZ policy itself and the guidance to local planning authorities contained in the Annex to this Circular remain the same.

2. Following an internal DfT review, it has been concluded that the administration of PSZ policy will be carried out by the CAA. The CAA has, therefore, taken over responsibility for the implementation of new PSZs and the review and update of existing PSZs, as instructed by DfT.

3. DfT Circular 1/2002 is hereby withdrawn.

4. Enquiries about this Circular should be addressed to:

   Airports Policy Division
   Department for Transport
   1/24 Great Minster House
   76 Marsham Street
   London SW1P 4DR

   or to psz@dft.gsi.gov.uk.

Appendix OP.1.7

Enquiries regarding existing PSZs, including requests for paper copies of Public Safety Zone maps and, where applicable, the 1 in 10,000 individual risk contours in digital format, should be addressed to:

Aerodrome Standards
Civil Aviation Authority
Aviation House 2W
Gatwick Airport South
West Sussex RH6 0YR

or to psz@caa.co.uk.

John Parkinson, Divisional Manager

Addressed to:

The Chief Planning Officers in England

ANNEX

CONTROL OF DEVELOPMENT IN AIRPORT PUBLIC SAFETY ZONES

THE BASIC POLICY OBJECTIVE

1. Public Safety Zones are areas of land at the ends of the runways at the busiest airports, within which development is restricted in order to control the number of people on the ground at risk of death or injury in the event of an aircraft accident on takeoff or landing. The basic policy objective governing the restriction on development near civil airports is that there should be no increase in the number of people living, working or congregating in Public Safety Zones and that, over time, the number should be reduced as circumstances allow.

INDIVIDUAL RISK CONTOUR MODELLLNG

2. The implementation of Public Safety Zone policy at civil airports is based on modelling work carried out using appropriate aircraft accident data to determine the level of risk to people on the ground around airports. This work determines the extent of individual risk contours, upon which a person remaining in the same location for a period of a year would be subjected to a particular level of risk of being killed as a result of an aircraft accident. Public Safety Zone policy is based predominantly on individual risk, while extending beyond it in relation to particular types of development such as transport infrastructure and to temporary uses. The areas of the Public Safety Zones correspond essentially to the 1 in 100,000 individual risk contours as calculated for each airport, based on forecasts about the numbers and types of aircraft movements fifteen years ahead. The Public Safety Zones represent a simplified form of the risk contours, in order to make the Zones easier to understand and represent on maps, and also in recognition of the necessarily imprecise nature of the forecasting and modelling work. In some cases the resultant shape of the Public Safety Zones is that of an elongated isosceles triangle. In others the triangle is slightly modified to form an elongated five-sided shape. In all cases the Public Safety Zones are based on the landing threshold for each end of the runway and taper away from the runway.

3. The Public Safety Zones are based upon risk contours modelled looking fifteen years ahead, in order to allow a reasonable period of stability after their introduction. The Public Safety Zones should be of sufficient size to allow for possible future growth in the number of aircraft movements, without affecting unnecessarily large areas of land. Third party individual risk contours around airports will be remodelled at intervals of about seven years, based on forecasts about the numbers and types of aircraft movements fifteen years ahead. It is likely that this will lead to the redefinition of the Public Safety Zones, though the changes will not necessarily be significant. In the meantime, the contours will be remodelled in the event that a significant expansion of an airport is approved which has not already been assumed in the modelled risk contours. In addition, the Public Safety Zones will need to be redefined if a runway is extended or if a landing threshold is moved.

RISK APPRAISAL

4. The basis of the policy of restricting new development within Public Safety Zones is constrained cost–benefit analysis. This is a risk appraisal principle under which individual risk is reduced to a tolerable level irrespective of cost, and then further reduced only if the benefits of doing so exceed the costs. Within the Public Safety Zones there are safety benefits from preventing any new or replacement development, or change of use, which would result in an increase in the numbers of people within the Zones. The economic costs of removing existing development throughout the Zones would, however, outweigh the safety benefits of doing so, and the Secretary of State is therefore not proposing that course.

5. Although the boundaries of the Public Safety Zones correspond essentially to the 1 in 100,000 individual risk contours, the level of risk in some areas within the Zones may be much higher. The Secretary of State regards the maximum tolerable level of individual third party risk of being killed as a result of an aircraft accident as 1 in 10,000 per year. At some airports, the 1 in 10,000 individual risk contour extends beyond the airport boundary and includes occupied property. In other cases there is no occupied development within the areas concerned, or the areas concerned are contained wholly within airport boundaries.

PURCHASE OF PROPERTY BY AIRPORT OPERATORS

6. The Secretary of State wishes to see the emptying of all occupied residential properties, and of all commercial and industrial properties occupied as normal all-day workplaces, within the 1 in 10,000 individual risk contour. In cases where any part of a residential property falls within this contour he will expect the operator of an airport for which new Public Safety Zones have already been established to make an offer to purchase the property or, at the option of the owner, such part of its garden as falls within this contour. In addition he will expect such operators to make an offer to purchase, in whole or in part, a commercial or industrial property if that property, or the relevant part of it, is occupied as a normal all-day workplace and falls within this contour. If the part of the property in question is discrete or self-contained, and its loss would not materially affect the business concerned, only that part need be the subject of such an offer. Otherwise the airport operator should offer to purchase the entire property. In the case of airports for which Public Safety Zones are established or redefined after the date of this Circular, the Secretary of State will expect the operators to make such an offer, where applicable, within twelve months of the notification of the Public Safety Zones and the 1 in 10,000 individual risk contours.

7. The Secretary of State will expect all such offers to be kept open indefinitely. If an owner wishes to sell a property, the airport operator should apply the Compensation Code. Airport operators will be expected to demolish any buildings purchased and to clear the land. The Secretary of State will be prepared to consider applications for compulsory purchase orders by airport operators with powers under section 59 of the Airports Act 1986.

Appendix OP.1.7

ESTABLISHMENT OF PUBLIC SAFETY ZONES

8. Public Safety Zones have been established at all the airports for which modelling work produced 1 in 100,000 individual risk contours of a sufficient size to justify doing so. PSZs may from time to time be established at other airports if the modelled level of individual third party risk in their vicinity fifteen years ahead justifies this.

ROLE OF LOCAL PLANNING AUTHORITIES

9. This Circular contains guidance to local planning authorities to enable them to decide planning applications and consider road proposals affecting land within Public Safety Zones. Local planning authorities need not carry out risk assessments in considering individual planning applications for sites within Public Safety Zones: the principle of constrained cost–benefit analysis underlies the specific guidance contained in paragraphs 10 to 12 below. Nor will it normally be necessary for them to consider whether the granting of an individual planning application would lead to an increase in the number of people living, working or congregating in the Public Safety Zone: the specific guidance contained in paragraphs 10 to 12 indicates whether or not particular types of development are acceptable.

GENERAL PRESUMPTION AGAINST DEVELOPMENT WITHIN PUBLIC SAFETY ZONES

10. There should be a general presumption against new or replacement development, or changes of use of existing buildings, within Public Safety Zones. In particular, no new or replacement dwellinghouses, mobile homes, caravan sites or other residential buildings should be permitted. Nor should new or replacement non-residential development be permitted. Exceptions to this general presumption are set out in paragraphs 11 and 12.

DEVELOPMENT PERMISSIBLE WITHIN PUBLIC SAFETY ZONES

11. Two types of exception to the general presumption may be permitted within those parts of Public Safety Zones outside any 1 in 10,000 individual risk contours. First, it is not considered necessary to refuse permission on Public Safety Zone grounds for the following forms of extension or change of use:

(i) an extension or alteration to a dwellinghouse which is for the purpose of enlarging or improving the living accommodation for the benefit of the people living in it, such people forming a single household, or which is for the purpose of a 'granny annex';

(ii) an extension or alteration to a property (not being a single dwellinghouse or other residential building) which could not reasonably be expected to increase the number of people working or congregating in or at the property beyond the current level or, if greater, the number authorised by any extant planning permission; or

(iii) a change of use of a building or of land which could not reasonably be expected to increase the number of people living, working or congregating in or at the property or land beyond the current level or, if greater, the number authorised by any extant planning permission.

Second, certain forms of new or replacement development which involve a low density of people living, working or congregating may be acceptable within a Public Safety Zone. Examples of these might include:

(iv) long stay and employee car parking (where the minimum stay is expected to be in excess of six hours);

(v) open storage and certain types of warehouse development. 'Traditional' warehousing and storage use, in which a very small number of people are likely to be present within a sizeable site, is acceptable. But more intensive uses, such as distribution centres, sorting depots and retail warehouses, which would be likely to entail significant numbers of people being present on a site, should not be permitted. In granting planning permission for a warehouse, a local planning authority should seek to attach conditions which would prevent the future intensification of the use of the site and limit the number of employees present;

(vi) development of a kind likely to introduce very few or no people on to a site on a regular basis. Examples might include unmanned structures, engineering operations, buildings housing plant or machinery, agricultural buildings and operations, buildings and structures in domestic curtilege incidental to dwellinghouse use, and buildings for storage purposes ancillary to existing industrial development;

(vii) public open space, in cases where there is a reasonable expectation of low intensity use. Attractions such as children's playgrounds should not be established in such locations. Nor should playing fields or sports grounds be established within Public Safety Zones, as these are likely to attract significant numbers of people on a regular basis;

(viii) golf courses, but not clubhouses; and

(ix) allotments.

12. Paragraphs 5 to 7 set out the general policy in relation to buildings and land within any 1 in 10,000 individual risk contours. The principal feature of that policy is that people should not be expected to live or have their workplaces within such areas. Consequently very few uses will be acceptable within this risk contour. But certain forms of development which involve a very low density of people coming and going may be acceptable within it. Examples of these might include:

(i) long stay and employee car parking (where the minimum stay is expected to be in excess of six hours);

(ii) built development for the purpose of housing plant or machinery, and which would entail no people on site on a regular basis. Examples might include boiler houses, electricity switching stations or installations associated with the supply or treatment of water; and

(iii) golf courses, but not clubhouses.

REFERENCE TO THE DEPARTMENT

13. A local planning authority may exceptionally receive applications for other forms of development on sites within Public Safety Zones for which it may consider that there is a reasonable expectation of low-density occupation and may therefore be minded to grant planning permission. The authority may wish to refer such applications to Airports Policy Division in the Department for Transport, which may be able to advise on whether the proposed development is consistent with the general thrust of Public Safety Zone policy.

CONDITIONS

14. Local planning authorities should consider the use of suitably-worded conditions in appropriate cases in order to limit the number of people who might be expected to be present on site at any time.

TRANSITIONAL ARRANGEMENTS

15. Planning permissions are valid for five years or for a specified alternative period, and local planning authorities may have granted planning permission in relation to sites which were not within Public Safety Zones at the time when the permissions were granted. Similarly, local planning authorities may have granted outline planning permission in relation to such sites but not yet considered applications for permission for the details. The Secretary of State is not seeking the revocation or modification of an unimplemented planning permission during its lifetime. Nor is he seeking the refusal of planning permission on Public Safety Zone policy grounds when an application for the approval of details comes to be considered, provided that the approval of such an application does not result in a greater number of people on the site than would have been appropriate for the type of use for which the outline permission was granted. On the other hand, if a planning permission has not been implemented by the time it expires, any application for an extension of the permission should be considered in the light of the specific guidance contained in paragraphs 10 to 12 above.

DEVELOPMENT NOT REQUIRING PLANNING PERMISSION

16. Public Safety Zone policy has full effect only when an application for planning permission is made. But local planning authorities should also have regard to Public Safety Zone policy when considering and commenting on proposed development for which they are not the determining authority, such as Crown development, overhead lines, some forms of permitted development and orders made under the Transport and Works Act 1992.

17. Where the exercise of permitted development rights would encourage more people on to land within a Public Safety Zone, the local planning authority should consider whether an Article 4 direction, made under the Town and Country Planning (General Permitted Development) Order 1995 in order to require a planning application, would be appropriate. Relevant circumstances might include the temporary use of land within a Public Safety Zone for the holding of a market or its proposed use as a caravan site.

TRANSPORT INFRASTRUCTURE

18. Although transport infrastructure within Public Safety Zones is typically used by any one person for only a short period at a time, a large number of people can be using a particular facility at any particular time. The density of occupation of a six-lane motorway or a mainline railway, averaged over a day, is similar to that of a housing development. Transport infrastructure is therefore considered for Public Safety Zone policy purposes as if it is residential, commercial or industrial development. As with those forms of development, the Secretary of State does not consider it necessary to remove existing transport infrastructure from within Public Safety Zones. But new transport infrastructure such as railway stations, bus stations and park and ride schemes should not be permitted within Public Safety Zones, as they would result in a concentration of people for long periods of the day. The planning of new transport links requires careful consideration. Although people passing along a transport route are likely to be within the Public Safety Zone for only a very small part of the day, the average density of occupation within the Zone may be significant, and as high as that for fixed development. Individual schemes should therefore be considered on their merits. Proposals for major roads and motorways should be carefully assessed in terms of the average density of people that might be expected to be exposed to risk. Careful attention should also be given to the location of major road junctions and to related features such as traffic lights and roundabouts which may lead to an increase in the number of stationary vehicles within a Zone. Low-intensity transport infrastructure, such as minor or local roads, can be permitted within Public Safety Zones.

OFFICIAL SEARCHES

19. Local planning authorities whose areas include a Public Safety Zone or part of a Zone should ensure that the associated restrictions on development are entered in the Register of Local Land Charges.

PURCHASE NOTICES AND COMPENSATION PAYABLE BY LOCAL PLANNING AUTHORITIES

20. The refusal of planning permission on Public Safety Zone policy grounds does not carry with it an automatic entitlement to compensation. But there may be a right to compensation under a purchase notice if a site or property is incapable of being put to any alternative beneficial use as a result of it being within a Public Safety Zone. Where permission for development is refused, or conditions are imposed, a local planning authority may have to acquire the site under the purchase notice provisions in sections 137–144 of the Town and Country Planning Act 1990, or pay compensation under section 144 (2) of that Act. Similarly, if planning permission is revoked or modified, or if permitted development rights are withdrawn by a direction under Article 4 of the Town and Country (General Permitted Development) Order 1995 and planning permission is refused or granted subject to conditions, a local planning authority may incur expenditure under sections 107, 108 or 279 of the 1990 Act. In these circumstances, if the action which gives rise to a compensation claim has been taken solely on Public Safety Zone policy grounds, the following arrangements apply:

    (a) local authority or privately owned airports subject to Part V of the Airports Act 1986

Any airport in respect of which a permission to levy charges is in force under Part IV of the Airports Act 1986, or in respect of which there is a pending application for such permission (subject to certain exclusions), is subject to Part V of the Act. Section 61 of the 1986 Act provides for the local planning authority to recover from the airport operator compensation which the authority has become liable to pay. This provision applies if the compensation liability results from a planning decision which would not have been taken, or from an order under section 97 of the Town and Country Planning Act 1990 which would not have been made, other than to prevent persons or buildings from being struck by aircraft using the airport. Section 61 of the 1986 Act also provides for the purchase of land by the operators of airports subject to Part V of that Act where a purchase notice is served.

(b) local authority or privately owned airports not subject to Part V of the Airports Act 1986

Where a local authority or privately owned airport is not subject to Part V of the Airports Act 1986, section 61 does not apply. Local planning authorities may wish to seek specific deeds of indemnity from the owners of any such airports against liability under the purchase notice and compensation provisions of the Town and Country Planning Act 1990, so that the airport owners will be the bodies to whom any land acquired under a purchase notice will normally be conveyed.

PUBLIC SAFETY ZONE MAPS

21. Printed copies of maps showing the Public Safety Zones and, where applicable, the 1 in 10,000 individual risk contours, will be sent to the local planning authorities whose areas are affected by them. Additional copies will be available for sale from the CAA. The boundaries of the Public Safety Zones and any 1 in 10,000 individual risk contours are available from the CAA, free of charge, in digital format.

INCORPORATION OF PUBLIC SAFETY ZONES INTO DEVELOPMENT PLANS

22. Regional Spatial Strategies and Local Development Frameworks should include a policy stating that Public Safety Zones have been established for a particular airport and that there is a general presumption against most kinds of new development and against certain changes of use and extensions to existing properties within the Zones, as described in DfT Circular 1/2010. The extent of Public Safety Zones and any 1 in 10,000 individual risk contours should be indicated on proposals maps accompanying regional spatial strategies and local development frameworks.

MILITARY AERODROMES

23. The Ministry of Defence is responsible for Public Safety Zone matters at military aerodromes, although there are no such Zones currently in use at these sites.

Appendix OP.1.7

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Appendix OP.1.7

Thanet District Council

Notification of Grant of Permission to Develop Land
TOWN AND COUNTRY PLANNING ACT 1990
TOWN AND COUNTRY PLANNING (DEVELOPMENT MANAGEMENT PROCEDURE)
(ENGLAND) ORDER 2015

thanet district council

To: Cogent Land LLP
C/O Stratland Management Ltd
33 Margaret Street
London
W1G 0JD

OL/TH/14/0050

TAKE NOTICE that **THANET DISTRICT COUNCIL**, the District Planning Authority under the Town and Country Planning Acts, has **granted permission** for:

PROPOSAL: **Application for outline planning permission including access for the erection of 785 dwellings, highways infrastructure works (including single carriageway link road), primary school, small scale retail unit, community hall, public openspace**

LOCATION: **Land East And West Of, Haine Road, Ramsgate**

In coming to this decision regard has been had to the following policies:
Thanet Local Plan Policies:

CC1	**Development in the Countryside**
CC2	**Landscape Character Areas**
H1	**Residential Development Sites**
H4	**Windfall Sites**
H8	**Size and Type of Housing**
H14	**Affordable Housing Negotiations**
TC1	**New Retail Development**
TR3	**Provision of Transport Infrastructure**
TR15	**Green Travel Plans**
TR16	**Car Parking Provision**
D1	**Design Principles**
D2	**Landscaping**
HE11	**Archaeological Assessment**
HE12	**Archaeological Sites and Preservation**
SR4	**Provision of New Sports Facilities**

Appendix OP.1.10

SR5	**Play Space**
EP5	**Local Air Quality Monitoring**
EP7	**Aircraft Noise**
EP8	**Aircraft Noise and Residential**
EP9	**Light Pollution**
EP13	**Groundwater Protection Zones**
CF1	**Community Facilities**
CF2	**Development Contributions**

The application was processed having regards to the National Planning Policy Framework, which requires that where there are potential solutions to problems arising in relation to dealing with planning applications, the Council will work with applicants in a positive and proactive manner to seek solutions to those problems.

The permission is SUBJECT TO the conditions specified hereunder:

1 Approval of the details of the layout, scale, appearance of any buildings to be erected and the landscaping (hereinafter called 'the reserved matters') for each phase of the development shall be obtained from the Local Planning Authority in writing before the relevant phase of the development is commenced. The phase shall thereafter be developed in accordance with the approved details.

REASON:
As no such details have been submitted in respect of these matters as the application is in outline. In accordance with Section 92 of the Town and Country Planning Act 1990.

2 Any application for approval of the reserved matters for the first phase of the development shall be made in writing (and accompanied by sufficient plans and particulars as specified in condition 4) to the Local Planning Authority before the expiration of 3 years from the date of this permission. Any application for approval of the reserved matters for any remaining phases shall be made to the Local Planning Authority before the expiration of 5 years from the date of this permission.

REASON:
In accordance with Section 92 of the Town and Country Planning Act 1990.

3 Each phase of the development shall be begun within two years of the date of approval of the final reserved matters to be approved for that phase.

REASON:
In accordance with Section 92 of the Town and Country Planning Act 1990 (as amended by Section 51 of the Planning and Compulsory Purchase Act 2004).

4 The reserved matters submitted in accordance with Condition 1 in respect of each phase shall include the following details in respect of that phase to the extent that they are relevant to the reserved matters application in question:-

A. Layout

i. the layout of routes, buildings and spaces;
ii. the block form and organisation of all buildings;
iii. the locations and plan form of non-residential buildings;
iv. the distribution of market and affordable dwellings within that phase including a schedule of dwelling size (by number of bedrooms and floorspace);
v. the location of dwellings designed to seek to meet the Local Planning Authority's Lifetime Homes guidance;
vi. full details of the approach to vehicle parking including the location and layout of visitor parking and parking for people with disabilities for each building type together with details of the design approach for access points into, and the ventilation of, any under croft parking;
vii. full details of the approach to cycle parking including the location, distribution, types of rack, spacing and any secure or non-secure structures associated with the storage of cycles and the location and form of open areas.
viii. the extent and layout of public open spaces and play space within the phase.

B. Scale and Appearance

Scale, form and appearance of the architecture within each phase, including frontage design and public/private realm definition and boundary treatments

C. Landscaping

The landscape design and specification of hard and soft landscape works within each phase, including detailed surveys of all trees, shrubs and hedges in that phase, giving details of all trees having a trunk diameter of 75mm or more to include species type, spread of crown, height, diameter of trunk and condition assessment, details of existing trees, shrubs and hedges to be retained and details of new trees, shrubs, hedges and grassed areas to be planted, together with details of the species and method of planting to be adopted, details of walls, fences, other means of enclosure proposed. Any such details shall be accompanied by the Landscape Management Plan and Open Space Specification for that phase to be approved under conditions 7 and 8.

Each phase of the development shall be constructed and laid out in accordance with those details submitted to and approved in writing by the Local Planning Authority.

REASON:
In the interests of achieving sustainable development, in accordance with Thanet Local Plan Policy D1, and the principles within the National Planning Policy Framework.

5 Any reserved matters applications submitted pursuant to this outline application shall accord within the principles and parameters of the following Parameter Plans received by the Local Planning Authority on 26th May 2015 (including any text set out on those Plans to illustrate the development principles): -

011 - Land Use and Amount
012 - Scale
013 - Landscape
014 - Movement
029 - Staner Hill Junction improvements

REASON:
For the avoidance of doubt, so as to ensure that any development is in accordance with and within the parameters of that assessed by the Local Planning Authority for the

purposes of the Town and Country Planning (Environmental Impact Assessment) Regulations 2011 and in the interests of achieving sustainable development, in accordance with Thanet Local Plan Policy D1, and the principles within the National Planning Policy Framework.

6 The phasing of the development shall not be carried out otherwise than in accordance with the approved phasing plan (drawing number s106-007 Rev T) subject to any revisions to the approved phasing plan submitted and approved in writing by the Local Planning Authority pursuant to this condition. This condition does not prevent the construction periods of any phase running concurrently with other phases.

REASON:
To secure the programming and phasing of, and an orderly pattern to the development in accordance with the phasing arrangements that have been assessed.

7 No phase of the development shall be commenced unless and until an Open Space Specification for the phase has been submitted to and approved in writing by the Local Planning Authority. The Open Space Specification shall:

i. identify the location and extent of the main areas of formal and informal open space to be provided which shall accord with the details submitted under condition 1;
ii. outline the local play space to be provided, the proposed distribution of play areas and a detailed specification for any equipped play areas to be provided. Such play space shall be provided at a rate of at least 0.7 hectares per 1000 population (criteria as stated in Thanet Local Plan 2006 Policy SR5) of which at least 36% shall be equipped play area in accordance with the Local Planning Authority's Supplementary Planning Document "Planning Obligations and Developer Contributions - April 2010";
iii. identify how the relevant areas of public open space and play areas are to be laid out, paved, planted or equipped; and
iv. include the proposed programme for delivery of all landscaped, open space and play space in the phase linked to the occupation of dwellings within the phase. The proposed programme shall ensure that (where applicable in relation to the plans submitted in accordance with condition 1) at least one area of open space and at least one area of local play space/equipped play area within the phase are provided and available for use prior to the occupation of any dwellings in the phase.

The landscaped areas, open space and play space in that phase shall be laid out and implemented in accordance with the agreed timetable and shall be permanently retained thereafter in accordance with the approved Open Space Specification for that phase and used for and made available for public amenity and play space purposes only.

REASON:
In the interests of the visual amenities of the area and to adequately integrate the development into the environment, and provide local play space, in accordance with Policies D1, D2 and SR5 of the Thanet Local Plan, and guidance within the National Planning Policy Framework.

8 No phase of the development shall be commenced unless and until a Landscape Management Plan for the phase in question has first been submitted to and approved in writing by the Local Planning Authority for all landscaped, open space and play areas identified in the Open Space Specification for the phase which shall include long term design objectives, details of who is to have ongoing management responsibilities for the area and how those arrangements will be secured in perpetuity and annual maintenance schedules for all landscaped, open space and play areas within the phase.

The approved Landscape Management Plan for each phase shall be implemented and adhered to as approved subject to any minor revisions thereto as may be approved in writing by the Local Planning Authority. The public open spaces in that phase shall be permanently retained and maintained thereafter in accordance with the approved Landscape Management Plan for that phase and used for and made available as public open space for public amenity purposes only.

REASON:
In the interests of the visual amenities of the area and to adequately integrate the development into the environment, and provide local play space, in accordance with Policies D1, D2 and SR5 of the Thanet Local Plan and guidance within the National Planning Policy Framework.

9 No development shall take place until the applicant, or their agents or successors in title, has submitted to and obtained the approval of the Local Planning Authority to a site wide scheme, specification and programme of archaeological field evaluation works identifying the works associated with each phase of the development.

9b Thereafter, no development shall take place on each phase of the development unless or until the applicant or their agents or successors in title has secured the implementation in accordance with details approved pursuant to 9a above of:

a. any archaeological field evaluation works for the phase in accordance with a specification and written timetable which has first been submitted to and approved in writing by the Local Planning Authority; and

b. following on from the evaluation, and to the extent that the work carried out pursuant to 9b(a) identifies archaeological deposits, any safeguarding measures to ensure preservation in situ of important archaeological remains and/or further archaeological investigation and recording in respect of that phase including arranging for the development archive to be deposited in a suitable museum or similar repository in accordance with a specification and timetable which has been submitted to and approved in writing by the Local Planning Authority.

REASON:
To ensure that due regard is had to the preservation in situ of important archaeological remains in accordance with advice in the National Planning Policy Framework.

10 No development shall take place on each phase of the development until temporary fencing has been erected in a manner to be agreed with the Local Planning Authority, around the archaeologically sensitive zones (if any) within that phase as identified pursuant to the evaluation carried out per 9b above which (if required pursuant to the approved scheme) shall be followed by a long term demarcation of the archaeologically sensitive area in accordance with details and a timetable agreed with the Local Planning Authority. The temporary fencing in a phase shall be retained for the duration of the construction works in that phase. No works shall take place within the area inside the fencing without the consent of the Local Planning Authority.

REASON:
To ensure that due regard is had to the preservation in situ of important archaeological remains in accordance with Thanet Local Plan Policy HE12 and the advice contained within the National Planning Policy Framework.

11 Not to occupy or permit occupation of the first dwelling constructed pursuant to this planning permission unless and until the applicant or their agents or successors in title has submitted and obtained the approval of the Local Planning Authority to a written Heritage

Management Plan containing a programme of heritage enhancement and interpretation measures with and a timetable for their implementation. Thereafter, the programme of heritage enhancement and interpretation measures shall be implemented as approved and in accordance with the timetable approved.

REASON:
To ensure that due regard is had to the preservation of the signficance of designated heritage assets in accordance with the advice contained within the National Planning Policy Framework.

12 No development shall take place on each phase of the development until details of the means of foul and surface water disposal for that phase have been submitted to and agreed in writing by the Local Planning Authority. Details submitted shall include a Surface Water Drainage Strategy (including an assessment of the hydrological and hydro geological context of the phase, and details of the implementation, timetable and management of Sustainable Urban Drainage Systems across the phase). The development within that phase shall not be occupied unless and until the approved scheme and strategy have been implemented. The phase shall be developed and thereafter maintained in accordance with the approved details and strategy.

REASON:
To prevent pollution in accordance with Thanet Local Plan Policy EP13 and guidance contained within the National Planning Policy Framework.

13 No development shall take place on each phase of the development until a surface water drainage scheme for that phase, based on sustainable drainage principles and an assessment of the hydrological and hydro geological context of the phase and including details of how the scheme shall be maintained and managed after completion, which shall integrate with the Surface Water Drainage Strategy approved pursuant to condition 12 above, has been submitted to and agreed in writing by the Local Planning Authority for that phase. The development within that phase shall not be occupied unless and until the approved scheme has been implemented. The phase shall be developed and thereafter maintained in accordance with the approved details.

REASON:
To prevent the increased risk of flooding, in accordance with the National Planning Policy Framework.

14 No development shall take place on each phase of the development until details of the proposed water infrastructure for that phase have been submitted to, and approved in writing by, the Local Planning Authority. The development within that phase shall not be occupied unless and until the approved scheme has been implemented. The phase shall be developed and thereafter maintained in accordance with the approved details.

REASON:
To prevent pollution in accordance with Thanet Local Plan Policy EP13 and guidance contained within the National Planning Policy Framework.

15 Prior to the commencement of development approved by this planning permission (or such other date or stage in the development as may be agreed in writing with the Local Planning Authority) the following components of a scheme to deal with the risks associated with contamination of the site shall each be submitted to and approved in writing by the Local Planning Authority:

a. A preliminary risk assessment which has identified:
All previous uses

Potential contaminants associated with this uses
A conceptual model of the site indicating sources, pathways and receptors
Potentially unacceptable risks arising from the contamination of the site.

b. A site investigation scheme based on (a) to provide information for a detailed assessment of the risks to all receptors that may be affected including those off site.

c. The results of the site investigation and the detailed risk assessment referred to in (b) and based on these an option appraisal and remediation strategy giving full details of the remediation measures required and how they are to be undertaken.

d. A verification plan providing details of the data that will be collected in order to demonstrate that the works set out in the remediation strategy (c) are complete and identifying any requirements for longer term monitoring of pollutant linkages, maintenance and arrangements for contingency action. Any changes to these components require the express written consent of the Local Planning Authority. The scheme shall be implemented as approved.

REASON:
For the protection of controlled waters, the site is located over a principal aquifer and with a groundwater source protection Zones 1 and 2.

16 No occupation of any part of the development shall take place until a verification report demonstrating completion of the works set out in the approved remediation strategy and the effectiveness of the remediation has been submitted to and approved in writing by the Local Planning Authority. The report shall include results of sampling and monitoring carried out in accordance with the approved verification plan to demonstrate that the site remediation criteria have been met. It shall also include a long term monitoring and maintenance plan for longer term monitoring of pollutant linkages and maintenance and arrangements for contingency action, as identified by the verification plan as necessary, and for the reporting of this to the Local Planning Authority. The development shall be carried out in accordance with any long term monitoring and maintenance plan approved by the Local Planning Authority pursuant to this condition.

REASON:
To ensure that the proposed development will not cause harm to human health or pollution of the environment, in accordance with the advice contained within the National Planning Policy Framework.

17 If, during development, significant contamination is suspected or found to be present at the site, then any development of the phase in question shall cease until such time as this contamination has been fully assessed, an appropriate remediation scheme has been agreed with the Local Planning Authority and the approved works have been implemented so as to render harmless the identified contamination given the proposed end use of the site and surrounding environment, including controlled waters.

REASON:
To ensure that the proposed site investigation, remediation and development will not cause harm to human health or pollution of the environment, in accordance with the advice contained within the National Planning Policy Framework.

18 No infiltration of surface water drainage into the ground is permitted other than with the express written consent of the Local Planning Authority, which may be given for those parts of the site where it has been demonstrated that there is no resultant unacceptable risk to controlled waters.

REASON:
To prevent harm to human health and pollution of the environment, in accordance with the advice contained within the National Planning Policy Framework.

19 No piling or foundation designs using penetrative methods is permitted other than with the express written consent of the Local Planning Authority, which may be given for those parts of the site where it has been demonstrated that there is no resultant unacceptable risk to groundwater.

REASON:
To prevent pollution in accordance with the National Planning Policy Framework.

20 There shall be no vehicular access link between Manston Road and Haine Road via phase 1 and phase 2 identified on the phasing plan.

REASON:
In the interest of highway safety.

21 Details pursuant to condition 1, insofar as they relate to each phase of development, shall include details of any proposed roads (and identify which roads are to be offered for adoption), footways, footpaths, verges, junctions, street lighting, sewers, drains, retaining walls, service routes, surface water outfall, vehicle overhang margins, embankments, accesses, carriageway gradients, driveway gradients and street furniture in that phase. The phase shall be laid out and constructed in accordance with those details as submitted to, and approved by, the Local Planning Authority prior to occupation of any part of the development within that phase and thereafter retained.

REASON:
In the interests of highway safety and to ensure the proper development of the site without prejudice to the amenities of the occupants.

22 The details submitted and approved pursuant to condition 21 (above) shall provide that access (other than emergency access) for the occupants of all dwellings to the east of Haine Road and access to the primary school shall be provided from Manston Road and there shall be no vehicular access (other than emergency access in accordance with details approved by the Local Planning Authority) to said dwellings or the school from Haine Road prior to the completion of the link road pursuant to Condition 23 unless otherwise agreed by the Local Planning Authority in consultation with the local highway authority.

REASON:
In the interest of highway safety.

23 The link road as shown on Drawing 11-T019-27 shall be begun prior to the commencement of phase 3. No dwellings in phase 3 of the development shall be occupied until the link road has been completed.

REASON:
In the interest of highway safety.

24 Details pursuant to condition 1, insofar as they relate to each phase of development, shall include details of the areas reserved for vehicle loading and unloading, vehicular parking spaces and/or garages, and manoeuvring and turning facilities in that phase, which shall be provided in accordance with standards to be agreed with the Local Planning Authority. Such facilities as approved shall be constructed and made available for use prior to the occupation of the unit for which they are provided to meet relevant parking and layout standards, and thereafter shall be retained for their approved purpose.

REASON:
In the interests of highway safety and traffic flow, in accordance with Thanet Local Plan Policy TR16.

25 Details pursuant to condition 1, insofar as they relate to each phase of development, shall include the provision of adequate secure covered cycle parking facilities within that phase, in accordance with standards to be agreed with the Local Planning Authority. Such facilities as approved shall be made available for use prior to the occupation of the unit for which they are provided to meet relevant parking and layout standards, and thereafter shall be retained for their approved purpose.

REASON:
In the interests of highway safety and to facilitate the use of alternative means of transport, in accordance with Thanet Local Plan Policy TR12.

26 Details pursuant to condition 1, insofar as they relate to each phase of development, shall include the vehicular and pedestrian sightlines for all new junctions and accesses for that phase in accordance with details and standards to be agreed with the Local Planning Authority. No dwelling or non-residential floorspace forming part of the relevant phase shall be occupied until all relevant junctions and access roads serving that dwelling or floorspace (and linking it to the adopted highway) including the approved sightlines have been provided in accordance with the approved details. They shall thereafter be retained free from obstruction.

REASON:
In the interests of highway safety.

27 Details pursuant to condition 1 above shall include the provision of means and routes of access for pedestrians and cyclists within each phase of the development. No building within that phase shall be occupied until all such routes and means of access within that phase serving that building are constructed and ready for use and thereafter shall be retained for their approved purpose.

REASON:
In the interests of highway safety and to facilitate the use of alternative means of transport, in accordance with Thanet Local Plan Policies TR11 and TR12.

28 No development shall take place on each phase of the development until a Construction Method Statement has been submitted to, and approved in writing by, the Local Planning Authority for that phase. The approved Statement shall be adhered to throughout the construction period of that phase. The Statement shall provide for and include in respect of that phase:

a. the parking of vehicles of site operatives and visitors.

b. construction vehicle loading/unloading, turning facilities and access routes/arrangements.

c. loading and unloading of plant and materials.

d. storage of plant and materials used in constructing the development.

e. the erection and maintenance of security hoarding including decorative displays and facilities for public viewing, where appropriate.

f. wheel washing facilities and their use.

g. measures to control the emission of dust and dirt during construction a scheme for recycling/disposing of waste resulting from construction works.

h. a Construction Environment Management Plan, including details of construction time, enclosures for noise emitting equipment, and siting of stationary noisy or vibrating plant equipment.

REASON:
In the interest of highway safety.

29 No residential dwelling or building intended to take access from any road shall be occupied until the carriageway of that road (and any other estate roads connecting that road to the adopted public highway) has been laid out and constructed up to and including at least road base level.

REASON:
In the interests of highway safety and to ensure the proper development of the site without prejudice to the amenities of the occupants.

30 No more than 90% of the dwellings within each phase shall be occupied until all carriageways, footways, shared surfaces, footpaths and cycleways serving that phase have been completed with final surfacing, unless the road is an identified construction route in which case the final surfacing shall be completed within 1 month following the cessation of use of that road as a construction route.

REASON:
In the interests of highway safety and to ensure the proper development of the site without prejudice to the amenities of the occupants.

31 Within phase 3 of the development there shall be no more than 1no. vehicular access crossing the bridleway shown marked with a dashed red line on "Parameter Plan 4 - Movement" (Drawing 014 Rev O).

REASON:
In the interest of highway safety.

32 All hard and soft landscape works in a phase shall be carried out in accordance with the approved Landscape Management Plan and Open Space Specification for that phase. The works shall be carried out prior to the occupation of any part of the phase of the development to which it relates, or in accordance with the programme of works agreed in writing with the Local Planning Authority pursuant to the approved Open Space Specification and approved Landscape Management Plan for that phase. Any trees or plants within a phase which within a period of 5 years from the completion of development within that phase die, are removed or become seriously damaged or diseased, shall be replaced in the next planting season with others of a similar size and species, unless the Local Planning Authority gives any written consent to any variation.

REASON:
In the interests of the visual amenities of the area and the interests of bio-diversity and ecological potential, and to adequately integrate the development into the environment, in accordance with Policies D1 and D2 of the Thanet Local Plan and the National Planning Policy Framework.

33 No development shall commence unless and until a scheme for the offsetting of bio-diversity impacts, including farmland birds, has been submitted to and agreed in writing by the Local Planning Authority. The offsetting scheme shall include:

a. Details of the offset measures of the development;

b. The provision of arrangements to secure the delivery of the offsetting measures (including a timetable for their delivery); and

c. A management and monitoring plan (to include for the provision and maintenance of the offsetting measures in perpetuity).

The scheme shall be designed to offset site level biodiversity impacts or to contribute to the strategic offsetting approach currently in development through the Local Plan, and shall be implemented and maintained as agreed.

REASON:
In the interests of preserving and enhancing bio-diversity and ecological potential, and to adequately integrate the development into the environment, in accordance with Policies D1 and D2 of the Thanet Local Plan and the National Planning Policy Framework.

34 No phase of the development shall commence until details and samples of the materials to be used in the construction of the external surfaces of the development permitted in that phase have been submitted to, and approved in writing by, the Local Planning Authority. The phase shall be carried out using the approved materials.

REASON:
In the interests of visual amenity in accordance with Policy D1 of the Thanet Local Plan.

35 The construction of phases 1a,1b, 2a, 3a and 3b as detailed on the approved phasing plan shall not commence until a scheme for protecting the development which falls within these phases from aircraft noise has been submitted to, and approved in writing by, the Local Planning Authority.

The scheme shall cover all of the development which has been identified to be impacted based upon the submitted aircraft noise contours 2033 -92 day summer LAeq(16 hour) submitted by the applicant on 2nd July 2015. Unless otherwise agreed in writing by the Local Planning Authority such a scheme must demonstrate that the guideline noise levels from Tables 5 and 6 of BS8233:1999 can be achieved. Any dwelling requiring noise protection shall not be occupied until all works which form part of the approved scheme have been completed in respect of that dwelling. The approved works shall thereafter be retained.

REASON:
In the interests of the amenities of residential dwellings in close proximity to Manston Airport and the A256 Haine Road, in accordance with National Planning Policy Framework paragraph 17.

36 No dwellings shall be constructed within the part of the site that falls within Noise Category C as set out within the Thanet Local Plan 2006.

REASON:
To ensure that the development result in sufficient quality of residential development without resulting in harm to the living conditions which future occupiers would expect to enjoy, in accordance with Thanet Local Plan Policies and paragraph 17 of the National Planning Policy Framework.

37 No less than 70% of the total number of dwellings constructed pursuant to this planning permission shall be dwellings of two or more bedrooms.

REASON:
To ensure the provision of a mix of house sizes and types to meet a range of community needs, in accordance with Policy H8 of the Thanet Local Plan.

38 The development shall provide for not more than 785 dwellings and the gross floor space provision across the development for other purposes shall not exceed that stated below:

Primary School - 2,000sqm
Community Hall - 500sqm
A1 (retail) unit - 200sqm

REASON:
In the interests of certainty as to what is permitted as so as to ensure that the development as constructed falls within the parameters of the application.

39 Each phase of the development approved shall not commence until the identification in that phase of a minimum of 15% of housing to lifetime home and wheelchair standards and the specification of such dwellings has been submitted to and approved in writing by the Local Planning Authority. Each phase shall be developed so that the identified dwellings are provided in accordance with the approved details and specification.

REASON:
To meet the housing needs of the community in accordance with Policy H8 of the Thanet Local Plan 2006.

INFORMATIVES

1 It is the responsibility of the applicant to ensure, prior to the commencement of the development hereby approved, that all necessary highway approvals and consents where required are obtained and that the limits of highway boundary are clearly established in order to avoid any enforcement action being by the Highway Authority. The applicant must also ensure that the details shown on the approved plans agree in every aspect with those approved under such legislation and common law. It is therefore important for the applicant to contact KCC Highway and Transportation to progress this aspect of the works prior to commencement on site

2 A formal application to requisition water infrastructure is required in order to service this development. Please contact Southern Water's Network Development Team (Wastewater) based at Atkins Ltd, Anglo St James House, 39a Southgate Street, Winchester, SO23 9EH (tel 01962 858688) or www.southernwater.co.uk

3 For the avoidance of doubt, any reference to a phase within the planning conditions on this planning permission shall mean a phase shown and defined on the approved phasing plan for the purposes of Condition 6.

Dated: 13 July 2016
Thanet District Council
P.O Box 9
Cecil Street
Margate
Kent CT9 1XZ

Signed [redacted]
Planning Applications Manager

Based on Pt IV of Report 7.4, 3,417 direct jobs are projected to be generated by the DCO proposals by Year 20 of operation; of these 1024 have been categorised as working for the airport operator (sub-divided in to ten categories) as set out below.

Airport Operator Direct Headcount in Year 20

Y20		
211	Passenger	
507	Freight	
25	ATS	
57	RFFS	
38	Operations	
49	Maintenance	
49	MT	
71	Site and Freight Security	
17	Administration	
1,024	TOTAL	

The remaining 2,393 'direct' jobs therefore are projected to be generated by other companies operating on or adjacent to the airfield. These can be broken down as follows:

Non Airport Operator Direct Headcount

Cargo Sheds	1250
MRO Facility	600
Based Airlines	100
FBOs/Heli Base	40
GA Related	50
Surface Access	50
Outsourcing	50
Other Companies located On Northern Grass	203
Total	**2,393**

Based on the masterplan the foregoing principally covers categories such as:

- MRO providers (AvMAn would this type but there maybe others with more scale)
- Aircraft dismantling is an alternative to MRO
- Based airlines - not airport co, but based on site
- Car rental/surface transport (bus/taxi) providers
- Other outsourced services - cleaning, building maintenance, training

- Bus/Av and Helicopter FBO (Polar/Signature/Weston would fall into this category)
- GA operators - flight schools, emergency services, air survey companies)

Other than the above, the biggest employment generator (other than the Northern Grass area) would be the air cargo handling facilities. Based on ratio's found elsewhere, the scale of employment will be in the range of:

2500 jobs in express freight use for 700,000 sq ft and c1000 in distribution centre type use. Assuming a non-freighter style operation is somewhere in-between that implies 1750 jobs. The Airport operator table includes 500 freight jobs associated with airside operations as opposed to those involved in freight handling, transhipment and distribution in the cargo sheds, giving a net additional direct job figure associated with the cargo shed operators of 1,250.

The MRO facility covers 100,000 sq ft and because it generates employment densities similar to light industrial operations than warehousing, then a ratio of 3-4 jobs/1000 sq ft is a good approximation, so conservatively another 300 jobs; but with shift work this would double to say 600 jobs.

The foregoing leaves a further 440 jobs unaccounted for. They include:

- Based airlines/airlines: 100 (15 per based aircraft +10)
- FBOs/Helicopter Base: 40 (Assumes maintenance)
- GA related: 50
- Surface access: 50 (assume this is not in the motor transport category)
- Outsourcing: 50

leaving 150 outstanding and those are assumed to be associated with companies on the Northern Grass operating freight forwarding or car rental type businesses which are completely dependent on the airport’s presence.

Manston Airport Education and Training Meeting
Meeting summary and actions from 9th January 2019

Attended:

Munya Badze (Enterprise Coordinator, The Education People)
Tina Cardy-Jenkins (Director, Jentex)
Sally Dixon (Consultant, Azimuth/RSP)
Tim Ingleton (Head of Inward Investment, Dover District Council)
Anne Nortcliffe (Director of Engineering Curriculum, Canterbury Christ Church University)
Paul Sayers (Executive Director for Strategy and Partnerships, East Kent College)
Jamie Weir (Head of Corporate Communications and PR, East Kent College)
Paul Winter (Chair, Kent and Medway Skills Commission)

Apologies:

George Yerrall (Director, RSP)

Not represented:

Thanet District Council

Summary and actions arising:

It is vital for EKC and CCCU to have data on the demand for aviation-related courses and range required. Without this it will be difficult to assess how viable courses might be and to establish capital, funding and staffing requirements.

There may be funding available through Locate in Kent to conduct an analysis of skills gaps in the South East market. This study would be generic but include the needs of a reopened Manston Airport. Paul Winter informed the group that there is a SELEP skills funding underspend [Paul W – would you let me know if this is correct, please?]. Applications have to prove sustainability and therefore specific research would be useful if a bid were to be made.

Action: Paul Winter to speak to Gavin Cleary at Locate in Kent with regard to Steve Matthews conducting a skills gap analysis and making the introduction to Sally.

Until the analysis has been conducted, any discussion about the need for facilities on the airfield cannot be specific. However, facilities would be likely to need to include:

- An apprenticeship centre
- A few training rooms
- A working (hydraulics, etc.) aircraft
- A multipurpose laboratory area
- Good IT/wifi
- An open plan café area that could be used for groups such as school visits, networking, etc.

The group would like to have information on the scale of employment opportunities that would be created by the operation of the airport (airport operator, airlines, logistics companies, etc.). This would help understand the type of and demand for training required and be fundamental to careers advice given to school pupils.

Action: Sally to look at establishing some outline figures for each job category and supply to the group

Tim talked about the potential development of Lydden Hill race circuit at Wootton, which is looking to provide space for technology start-up businesses. The site is only about 30 minutes from Manston Airport. Tim also talked about Pfizer's potential return to Sandwich, which may include manufacturing. Pharmaceuticals are a key market for air freight.

EKC and CCCU will look at different models for working together and potentially with other providers. There was some discussion about the potential to link with other airports such as Southend, London City, and Gatwick. This would have the benefit of providing more sustainability for aviation-related courses. However, this is generally only possible at higher levels (level 3+) since lower levels/age range are less likely to be able to travel. Paul Winter has contacts at Southend Airport, who have good training and education links.

Action: Paul Sayers to talk to Bromley College about the model for collaboration they use in relation to aviation-related courses associated with Biggin Hill Airport

Anne said that CCCU are refocusing on STEM subjects across all departments.

Paul Winter explained that logistics is not currently one of Kent's priority sectors. He encouraged the group to provide him with a rationale for the inclusion of logistics, as this would help focus attention and funding for skills development. Anne talked about the potential for a degree in logistics.

Action: All to send rationale to Paul, if possible

There was considerable discussion about engaging with schools, including both secondary and primary. Anne talked about the need for a 'drip drip' approach with students from a young age. This has been found to work most effectively at encouraging children to take up STEM subjects. As well as the Education People's Enterprise Advisor network, there is also the STEM Ambassadors programme run in Kent through CCCU and led by Helen Ward.

There is considerable opportunity to link engineering and aviation cross-curricula to subjects such as history (war/spitfire aircraft etc.).

There was a discussion about engaging with hard to reach groups. Children in care/looked after children who have no family network to help them find work were identified as well as offenders. KCC would have to be involved in liaison with these groups.

Sally asked if the group thought the idea of a Local Employment Partnership Board including Thanet District Council, Dover District Council, Canterbury City Council, Swale Borough Council and the Airport Company would be useful. The London City Airport S106 Agreement includes such a Partnership Board. There was general consensus that this was worth exploring.

Action: Paul Winter to speak to Swale BC to ascertain if they would be interested
Sally/RSP to contact TDC
Representatives from Canterbury City Council, Swale Borough Council and Thanet District Council to be invited to the next meeting

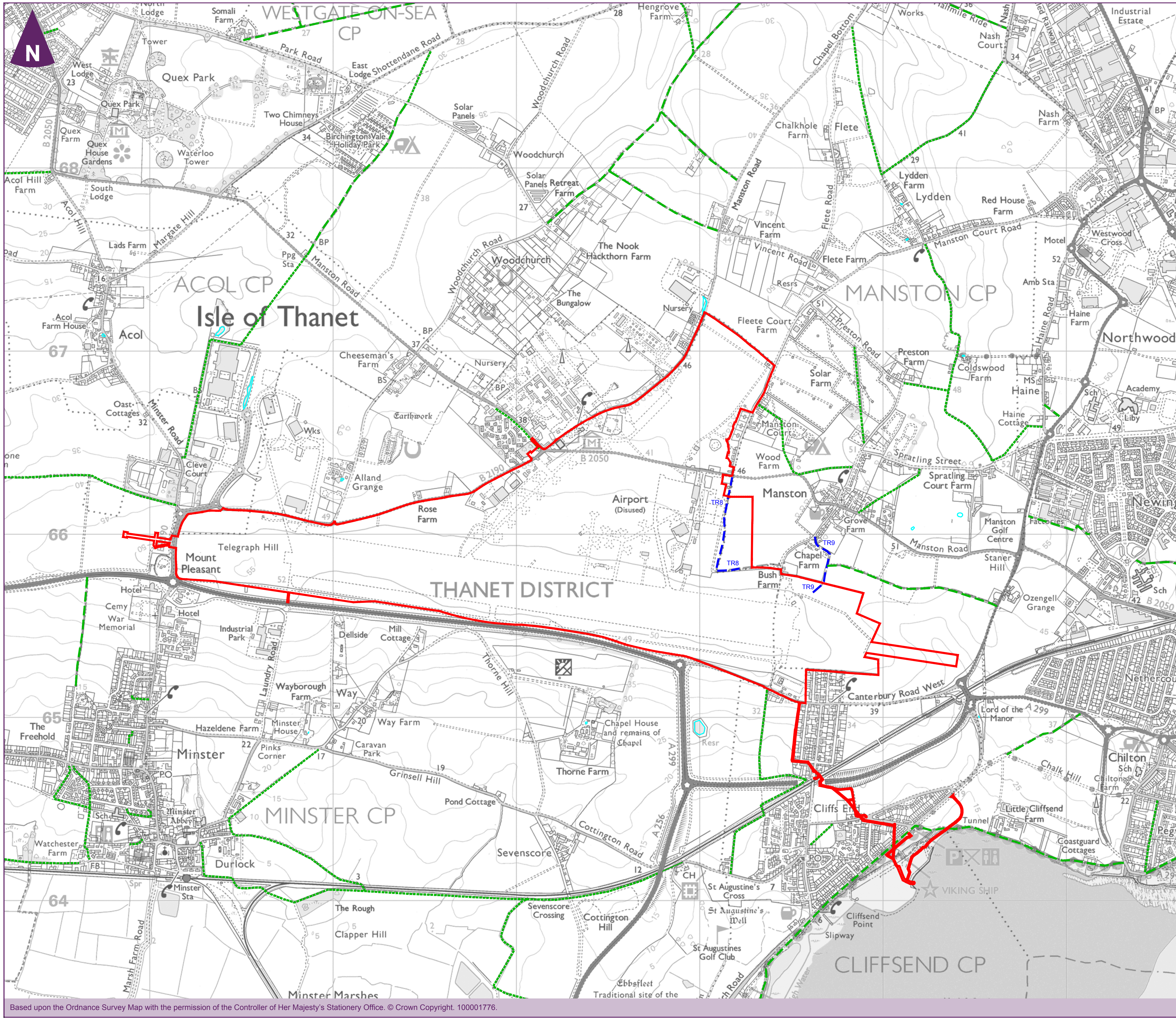
Sally discussed the Section 106 Agreement for Manston Airport and asked that the group consider other items that might be included relating to education and training. Paul Sayers said that EKC would like agreement that opportunities for apprentices, work experience and T levels (if necessary) would be provided by RSP during the airport's construction phases.

Action: Sally to discuss with RSP and report back to Paul
All to send Sally any thoughts on the S106 for education and training

Additional note:

Following the commencement of the Manston Airport DCO process, it has been established that there is some urgency to produce a S106 Agreement, which should include education, training and local recruitment commitments. Whilst we do not yet have a timetable (due 18th January), this issue is likely to be examined by mid June. RSP would like the Section 106 Agreement to include education, training, careers advice, aspiration-raising and local recruitment initiatives. It is therefore vital for relevant organisations, particularly those represented at the meeting on the 9th January, to make their views known. As such, it would be prudent to arrange the next meeting in mid-February 2019, rather sooner than anticipated.

Action: Sally to circulate potential dates for the next meeting



Key

- Application Boundary
- Affected PRoW
- Public Footpath
- Public Bridleway

0 m 1000 m

Scale 1:20,000 @ A3

Client

RSP

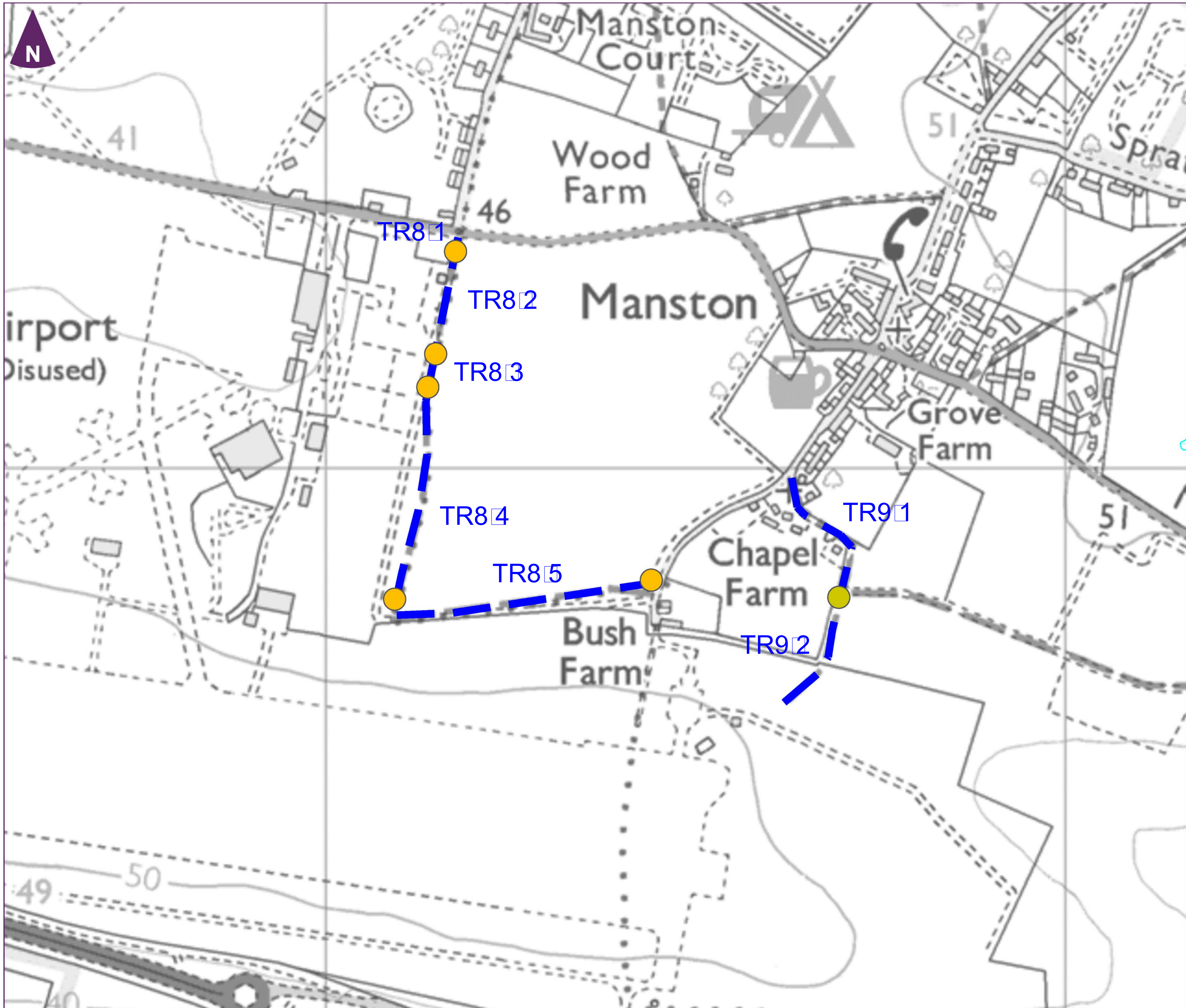
Manston Airport DCO
Environmental Statement
Public Rights of Way
Management Strategy

amec foster wheeler

Figure 2.1
PRoW around Manston Airport

February 2018 38199-Lon312.dwg guya

Appendix TR.1.48



Key

- Affected PRo□
- PRo□ Sections

Client

RSP

Manston Airport DCO
□nvironmental Statement
Pubic Rights of □ ay
Management Strategy

amec foster wheeler

Figure 2.2
Affected PRoW sections

February 2018

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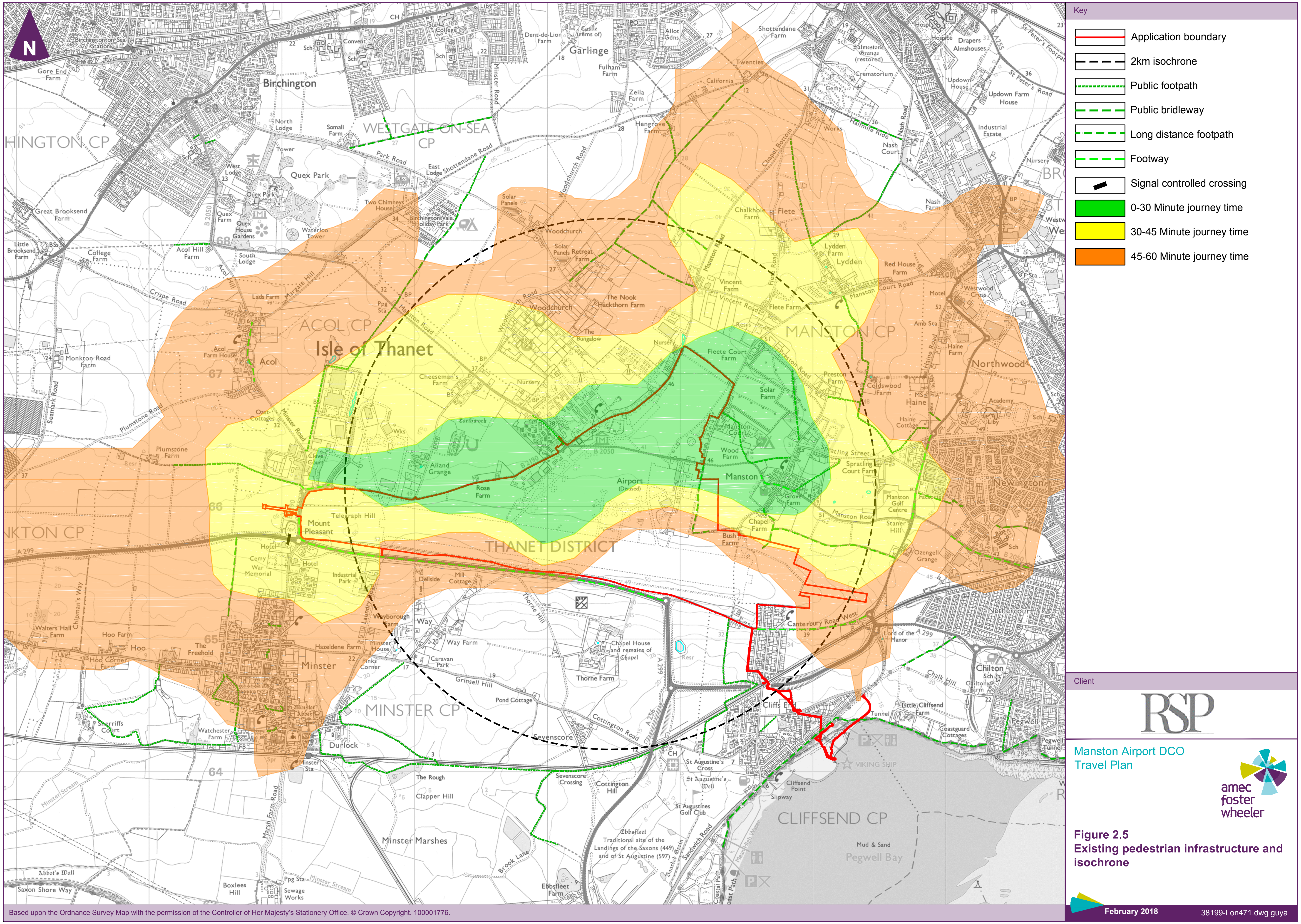
Appendix TR.1.48



Appendix TR.1.49