M5 Junction 10 Improvements Scheme

Environmental Statement

Chapter 14: Climate

TR010063 - APP 6.12

Regulation 5 (2) (a)

Planning Act 2008

Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009

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Gloucestershire
COUNTY COUNCIL

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Infrastructure Planning

Planning Act 2008

The Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009

M5 Junction 10 Improvements Scheme

Development Consent Order 202[x]

6.12 Environmental Statement:

Chapter 14: Climate (Tracked Change Version)

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14. Climate

14.1. General introduction

14.1.1. This chapter presents the environmental assessment of the M5 Junction 10 Improvements Scheme ("the Scheme") for Climate based on the Scheme as it is described in Chapter 2 – The Scheme (Aapplication document TR010063/—APP/-6.2) and detailed in the General Arrangement Plans (Aapplication document TR010063/—APP/-2.9). To do this the chapter sets out the relevant standards and methodologies that have been used, defines the study area, presents baseline conditions and then identifies and assesses: potential impacts, suggested mitigation measures and residual effects. The chapter also considers cumulative effects and sets out how it is policy compliant.

14.1.2. This chapter has been divided into two sub-sections in order to address the climate change requirements outlined in The Infrastructure Planning (Environmental Impact Assessment) Regulations 2017 (SI 2008/301), which state that the assessment should consider both:

- The likely effects of the Scheme on climate, in particular the magnitude of greenhouse gases (GHGs) emissions emitted during both construction and operation.
- The vulnerability of the Scheme to climate change, in particular the impacts of extreme weather (caused by climate change) during operation and construction and adaptation to mitigate the effects of these impacts.

EFFECTS ON CLIMATE

14.2. Introduction

14.2.1. The scope of this section of the Climate chapter (the Effects on Climate) assesses the effects of the Scheme on climate during construction and operation. It identifies the study area, describes the methodology, presents baseline conditions, identified potential impacts on climate and presents suggested mitigation measures during construction and operation. The approach taken aligns with the guidance set out in Design Manual for Roads and Bridges (DMRB) LA 114[1] and DMRB LA 105 Air Quality[2].

14.2.2. The Scheme has the potential to effect the Earth's climate by increasing the emissions of GHGs into the atmosphere, which will occur during construction and throughout its operational life. The earth absorbs energy from the sun and re-emits it as thermal infrared radiation. GHGs in the atmosphere absorb this radiation, preventing it from escaping into space. The higher the concentration of GHGs, the more heat energy is retained, and the higher global temperatures become. Due to human activities the concentration of GHGs in the atmosphere has increase dramatically, leading to global warming. This leads to myriad indirect impacts as the climate responds to the increased atmospheric temperature.

[1] https://www.standardsforhighways.co.uk/dmrb/search/d1ec82f3-834b-4d5f-89c6-d7d7d299dce0
[2] https://www.standardsforhighways.co.uk/prod/attachments/10191621-07df-44a3-892e-c1d5c7a28d90?inline=true

~~14.2.4.~~14.2.3. The UK has made commitments to tackle the root cause of climate change by reducing GHG emissions, as well as to increase the resilience of development and infrastructure to the changing climate. The Climate Change Act 2008 (amended in 2019)[3] sets a target to reduce net GHG emissions by at least 100% from 1990 levels by the year 2050.

~~14.2.5.~~14.2.4. The effective assessment and management of impacts on climate offers the opportunity to reduce the impact of projects on climate by minimizing the magnitude of GHG emissions as far as possible.

~~14.2.6.~~14.2.5. This chapter addresses regulation 5(2)(c) and paragraph 5(f) of Schedule 4 of The Infrastructure Planning (Environmental Impact Assessment) Regulations 2017 (SI 2017/572) (herein referred to as the 'EIA Regulations 2017'), which state that the assessment should consider the potential effects of the Scheme on climate, in particular the magnitude of GHGs emitted during both construction and operation.

14.3. Competent Expert

14.3.1. This section has been written by a competent expert with more than 4 years professional experience and is chartered by Institute of Environmental Management and Assessment, CEnv. They have experience developing climate effects assessments for transport schemes as well as residential, commercial and public developments and for energy and natural resources infrastructure.

14.4. Planning policy and legislative context

14.4.1. Human activities contribute to the emissions of GHGs such as carbon dioxide (CO_2) to the atmosphere, primarily by the combustion of fossil fuels. GHGs trap heat in the atmosphere, with higher concentrations leading to increased global temperatures. Atmospheric CO_2 concentrations now exceed 400 parts per million for the first time in around 3 million years[4], and increased emissions have led to global average surface temperatures of 1°C higher than pre-industrial levels. There is a global consensus that emissions must be reduced dramatically. Relevant international, national and local policies are cited below in Table 14-1.

14.4.2. It should be noted that the details presented in this section are not intended to provide a full consideration of the relevant documents and their application to the Scheme. This information is provided within the Planning Statement and Schedule of Accordance with National Policy Statement (A~~a~~pplication document TR010063/~~ – ~~APP/~~–~~7.1) that accompanies the application for a DCO.

Table 14-1 - Policy review

Scale	Policy document	Policy summary
International	Kyoto Protocol (1997)	The first international agreement to mandate GHG emission reductions. Under the United Nations Framework Convention on Climate Change (UNFCCC) treaty, industrialised nations pledged to cut their annual emissions by 5% on a 1990 baseline by 2012. Although the target was met successfully, it was insufficient to offset the increase in emissions from industrialising countries. Total global emissions continued to grow over the period, by 40% between 1990 and 2009.

[3] https://www.legislation.gov.uk/ukdsi/2019/9780111187654
[4] Atmospheric CO2 concentrations in 2020

Scale	Policy document	Policy summary
	Paris Agreement (2015)	Strengthened negotiations at Conference of the Parties (COP) 21 led to the 2015 Paris Agreement, the aim of which is to maintain the increase in global average temperature at 'well below' 2°*C* and 'pursue efforts' to limit the temperature increase even further to 1.5°*C*. In 2018, the International Panel on Climate Change (IPCC) published a special report in response to the Paris Agreement, to present the impacts of the targeted 1.5°*C* temperature rise. The report highlighted that to achieve this, global emissions must decrease by 45% by 2030 (against a 1990 baseline), and that net zero global emissions (where emissions and removals from the atmosphere are balanced) must be achieved by 2050. This is noted to require rapid and far-reaching transitions of every sector on an unprecedented scale.
National	Climate Change Act (2008)	To support international efforts, the UK Climate Change Act (2008) set a legal reduction target of 80% against 1990 levels by 2050. It also introduced a series of carbon ‘budgets’ for five-year periods, to act as stepping-stones to the overall reduction. There are budgets currently set up to 2037. In response to the ambitions of the Paris Agreement, in 2019 the Climate Change Act was amended to set the overall reduction target by 2050 to at least 100% in net emissions against 1990 levels. The UK has so far outperformed its budgets, but progress is slowing, and the country is not on track to meet its future budgets or the overall reduction target, according to the most recent progress report to Parliament by the Committee on Climate Change (CCC)[5].
	National Policy Statement for National Networks (NPS NN) (2014)	The NPS NN paragraph 5.17 states that ‘it is very unlikely that the impact of a road project will, in isolation, affect the ability of Government to meet its carbon reduction plan targets.’ However, the paragraph goes on to say that Applicants should provide evidence of the carbon impact of the project and an assessment against the Government’s carbon budgets. Paragraph 5.18 states that any increase in carbon emissions is not a reason to refuse development consent, unless the increase in carbon emissions

[5] Climate Change Committee (2022) Progress in reducing emissions 2022 Report to Parliament https://www.theccc.org.uk/wp-content/uploads/2022/06/Progress-in-reducing-emissions-2022-Report-to-Parliament.pdf

Scale	Policy document	Policy summary
		resulting from the Scheme are so significant that it would have a material impact on the ability of Government to meet its carbon reduction targets. Paragraph 5.19 outlines the need for appropriate mitigation measures to be implemented in both design and construction. The effectiveness of such mitigation will be considered by the Secretary of State in order to ensure the carbon footprint is not 'unnecessarily high', with the adequacy of the measures constituting a material factor in the decision-making process.
	National Planning Policy Framework (NPPF) (2021)	Paragraph 152 outlines its support for transitioning to a low carbon future, by way of reducing GHG emissions and supporting renewable and low carbon energy and associated infrastructure. Building on the NPPF, planning practice guidance published in June 2014 advises on how to identify suitable measures in the planning process to mitigate for and adapt to climate change.
	Transport Decarbonisation Plan (TDP)	In response to the UK's Net Zero emission target, the Department for Transport published its Transport Decarbonisation Plan (TDP) in 2021. The TDP outlines a number of commitments by the Government to remove all emissions from road user transport to achieve Net Zero by 2050. Commitments that will have a direct impact on road user emissions from the Scheme include: an end to the sale of new petrol and diesel cars and vans by 2030; all new cars and vans must be 100% zero emission at the tailpipe by 2035; an end to the sale of all non-zero emission road vehicles including HGVs by 2040.
	National Highways Net Zero Highways Plan (2021)	National Highways' Net Zero Plan is aligned with the TDP, and sets out aspirational greenhouse gas reduction targets and a roadmap with targets to cut corporate emissions (100% of corporate emissions to be net zero without purchased offsetting by 2030), maintenance and construction emissions (40-50% reduction in emissions compared to 2020 by 2030, and 100% of schemes net zero by 2040) and road users (100% of the network will be net zero by 2050).
	Construction 2025, HM Government (2013)	Construction 2025 sets out how efficiency improvements will be created in construction covering sustainability

Scale	Policy document	Policy summary
		and carbon and including a target to reduce emissions by 50%. The emissions reduction target of 50% is not scheme specific, and the efficiency improvements are broad. In terms of the Scheme and emissions reduction, the reduction target should be taken into account when developing Scheme specific mitigation measures, where relevant.
	Infrastructure Carbon Review	HM Treasury produced the Infrastructure Carbon Review (2013) to set out carbon reduction actions required by infrastructure organisations. In terms of the Scheme and emissions reduction, the reduction actions should be taken into account when developing Scheme specific mitigation measures, where relevant.
	Net Zero Strategy: Build Back Better, HM Government (2021)	Sets out the UK Government's strategy for continuing the path to Net Zero by setting out clear policies and proposals for keeping the UK on track for the coming carbon budgets, the National Determined Contributions and the government's vision for a decarbonised economy in 2050.
Guidance	Design Manual for Roads and Bridges LA 114: Climate	This document sets out the requirements for assessing and reporting the effects on climate of GHG emissions from construction, operation and maintenance projects for roads.
	Publicly Available Specification 2080:2023 Carbon Management in buildings and infrastructure	Acts as a global standard for managing whole life carbon emissions within the built environment. The framework looks at the whole value chain, aiming to reduce carbon through more intelligent design, construction and use. The principles of PAS 2080:2023 are used to inform the assessment of projects on climate and supplement the guidance provided in LA 114.
Regional and Local	Gloucester, Tewkesbury and Cheltenham Joint Core Strategy (JCS) 2011-2031 (2017)[6]	Policies INF6, SD3 and SD4 are particularly relevant to the Scheme as they makes reference to the need for additional infrastructure and services and the relevance to climate change. SD3 states that *'development proposals will demonstrate how they contribute to the aims of sustainability by… avoiding the unnecessary pollution of air….'* INF6 states that the local authority should *'seek to secure appropriate infrastructure, which is necessary, directly related, and fairly and reasonably*

[6] Adopted Joint Core Strategy — Joint Core Strategy

Scale	Policy document	Policy summary
		related to the scale and kind of the development proposal', including climate change mitigation and adaptation.'
	Gloucestershire County Council Climate Change Strategy and Action Plan	In 2019 GCC committed to deliver a net zero council by 2030 and to work with partners to identify actions needed to deliver an 80% reduction by 2030 from a 2005 base.
	Gloucestershire Local Transport Plan (2020-2041)	The Local Transport Plan sets the strategic transport vision to 2041, and includes 4 key objectives: • Protect and enhance the natural built ~~environment~~environment. • Support sustainable economic ~~growth~~growth. • Enable safe and affordable community ~~connectivity~~connectivity. • Improve community health and wellbeing and promote equality of opportunity. GCC's vision is to improve accessibility across Gloucestershire through low carbon modes. Policy LTP PD 0.1 reducing transport carbon emissions and adapting to climate change notes that GCC will work with its partners to reduce transport carbon emissions by 2045.
	Gloucestershire's Climate Change Strategy 2022 – 2027 Released December 2021	This document provides the updates to the Climate Change Strategy Action Plan for the period 2022-2027. Actions of relevance to transport include the installation of 200 new electric vehicle charging points by 2023, securing funding for new cycling infrastructure and creating high quality public transport networks.
	Cheltenham Borough Council (CBC) Climate Emergency Action Plan (2022)[7]	CBC declared a climate emergency in July 2019 and has committed to becoming a carbon neutral borough and council by 2030. A key part of this plan is to change the way people travel within and through the Borough by prioritising investment in cycling and walking, enabling the shift to electric cars with more charging points and, requiring certain modes of transport to switch to electric or zero—carbon forms of transport (e.g. taxis).
	Tewkesbury Borough Council (TBC) Carbon Management Programme (2020)[8]	TBC declared a climate emergency in October 2019 and committed to becoming a carbon neutral council by 2030. The programme identifies ways in which the council can become carbon neutral, noting that the next steps will be

[7] climate_emergency_action_plan_pathway.pdf
[8] tewkesbury-borough-council-2f98c5b.pdf (climateemergency.uk)

Scale	Policy document	Policy summary
		to then tackle GHG emissions across the borough.

Table 14-2 - UK carbon reduction targets

UK Carbon budget period	UK Carbon budget level
1st carbon budget (2008 to 2012)	3,018 $MtCO_2e$
2nd carbon budget (2013 to 2017)	2,782 $MtCO_2e$
3rd carbon budget (2018 to 2022)	2,544 $MtCO_2e$
4th carbon budget (2023 to 2027)	1,950 $MtCO_2e$
5th carbon budget (2028 to 2032)	1,725 $MtCO_2e$
6th carbon budget (2033 to 2037)	965 $MtCO_2e$

14.5. Methodology

14.5.1. The approach taken aligns with the Design Manual for Roads and Bridges (DMRB) LA 114 Climate[9], DMRB LA 105 Air quality[10] and TAG Unit A3 Environmental Impact Appraisal, Chapter 4 Greenhouse Gases[11]

14.5.2. It is key to note that whilst Effects on Climate is a wide-ranging topic in terms of potential sources, it is simple in terms of its receptors and impacts because:

- There is only one receptor, the atmosphere.
- There is only one direct impact, global warming.
- All units of CO_2e can be considered to have the same impact no matter where they are emitted.

14.5.3. Therefore, assessment of the effects of the Scheme on climate is limited to quantification of the magnitude of emissions, from individual sources and in total, and comparison of these to the baseline. Different GHGs have different global warming potentials, and to account for this they will be reported throughout this assessment as their carbon dioxide equivalent (CO_2e) value.

14.5.4. The goal of the assessment is to calculate the emissions anticipated to be generated by the Scheme to:

- Determine the magnitude of the Scheme's effect on climate, in comparison with the Do-Minimum scenario.
- Assess the significance of the effect on climate by considering it in context with UK carbon reduction targets and carbon budgets.
- Enable identification of emissions hot spots within the 'Do-Something' scenario to inform identification of appropriate mitigation measures.

14.5.5. Emissions calculations are carried out by multiplying activity data by an emission factor associated with the activity being measured. Activity data is a quantitative measure of an activity that results in emissions during a given period of time, (e.g., kilometres driven,

[9] LA 114 - Climate - DMRB (standardsforhighways.co.uk)
[10] https://www.standardsforhighways.co.uk/prod/attachments/10191621-07df-44a3-892e-c1d5c7a28d90?inline=true
[11] TAG UNIT A3 Environmental Impact Appraisal (publishing.service.gov.uk)

kWh electricity consumed, tonnes waste sent to landfill). An emission factor is a measure of the mass of emissions relative to a unit of activity.

14.5.6. The life cycle stages and GHG emissions sources included within the assessment are presented in Table 14-3, in accordance with DMRB LA 114 Section 3.11.1.

Table 14-3 - Sources and lifecycle stages for project GHG emissions

Main stage of project lifecycle	Sub-stage of life cycle	Potential sources of GHG emissions (not exhaustive)	Included within assessment?
Construction Stage	Product stage; including raw material supply, transport and infrastructure	Embodied GHG emissions associated with the required raw materials	Yes
	Construction processes stage; including transport to and from works site and construction processes	Activities for organisations conducting construction work	Yes – Transportation of materials and construction processes and employee commuting to site ~~No – Business and employee travel to the site is unknown at the current stage of design~~
	Land Use Change	GHG emissions mobilised from vegetation or soil loss during construction	Yes
Operation stage	Use of infrastructure by the end-user (road user)	Vehicles using highways infrastructure	Yes
	Operation and maintenance	Energy consumption for infrastructure operation and activities of organisations conducting routine maintenance	Yes – Assumed as 0.29% of road-user emissions as a worst-case scenario
	Land use and forestry	Ongoing land use GHG emissions/sequestration each year	Yes
Opportunities for reduction	GHG emissions potential of recovery including reuse and recycling GHG emissions potential of benefits and loads of additional functions associated with the study system	Avoided GHG emissions through substitution of virgin raw materials with those from recovered sources	Waste and arisings material quantities and recycling / reuse fate

Study area

14.5.7. The study area has been defined according to National Highways DMRB LA 114. For the construction and operational maintenance, the study area comprises the GHG emissions associated with project construction related activities/materials and their associated transport. For operational road user GHG emissions, the study area consists of the road links within the defined traffic reliability area of the project's traffic model. The study area is not limited to the geographic extent of the Scheme itself, as many emissions will result from upstream and off-site activities such as raw material extraction and processing.

14.5.8. The activities for which emissions have been quantified in the assessment include the direct and supply chain activities for the Do-Something scenario of the Scheme's life cycle, for both the construction and operation stages of the Scheme. The specific elements of the Scheme lifecycle included in the assessment boundary are listed in Table 14-3. The 'assessment boundary' defines the source of emissions considered, including direct or supply chain emissions.

Calculating construction emissions

14.5.9. A quantification of construction phase emissions has been calculated using National Highways' Carbon Tool v2.5 (herein after referred to as 'The Carbon Tool'). The Carbon Tool is spreadsheet-based, and provides space to input material and non-material construction information under the following categories:

- Bulk materials
- Earthworks
- Fencing barrier, and road restraint systems
- Drainage
- Road pavements
- Street furniture and electrical equipment
- Civil structures and retaining walls
- Fuel, electricity, and water use
- Business and employee transport
- Waste

14.5.10. The Carbon Tool uses a range of pre-programmed materials data (e.g., mass) and carbon factors to calculate an itemised and overall emissions total. Materials emissions factors are sourced from the Bath Inventory of Carbon and Energy (ICE) database v2 and v3[12]. These factors are in tCO_2e/t. All energy, waste and transportation factors are taken from Government Carbon Factors 2022. Where an input unit is not required as a mass, such as numbers or metres of a product, a conversion factor is applied. This is based upon the mass of a product calculated using suppliers' specifications and technical drawings.

14.5.11. When a product contains multiple materials a weighted average carbon factor has been calculated using multiple factors from the ICE. ICE carbon factors used within the Carbon Tool include the embodied carbon within the raw materials but do not account for the carbon associated with the manufacture or processing of the raw materials into a product prior to their purchase by the reporting contractor[13].

14.5.12. The design and construction information for the assessment was obtained from the design team and specific data request spreadsheet prepared based on the requirements of the Carbon Tool.

14.5.13. Data for as many categories as possible has been collected for this stage. However, only a subset of the data is available for quantification ~~and therefore business and employee transport has been excluded from this stage of the assessment~~. Further, it has been assumed that all excavation and topsoil material will be 100% re-used at this stage.

Transportation of materials

14.5.14. Information relating to where materials will be sourced is not yet available, as this will be determined at a later date by the appointed Principal Designer and Principal Contractor and outlined in Chapter 12 – Materials and Waste (application document TR010063 – APP 6.10). It has been assumed that all materials would be transported an approximate worst-case distance of 50 km by HGV, based on previous experience by specialists of

[12] Embodied Carbon Footprint Database - Circular Ecology
[13] Emissions Factors tab of the Carbon Tool

materials transportation for infrastructure schemes, including highway schemes. Locally sourced materials are often preferentially used to reduce transportation cost and to minimise transport emissions, and many materials will be sourced from a distance of less than 50 km. However, not all required materials are expected to be available locally and will have to be sourced from further afield. Hence, based on professional judgment and consultation with design team to prefer locally sources material as far as possible, 50 km worst case has been considered which draws on the Royal Institution of Chartered Surveyors 'whole life carbon' transport distances of 50 km for locally manufactured materials, but accounts for some scenarios where portions of the necessary materials may have to be transported from further afield. The emission factor used for transportation is based on a heavy goods vehicle having an assumed average load. This factor is integral to the Carbon Tool.

Employee commuting

14.5.15. As the construction phase has not yet commenced, IInformation on the number, method and distance travelled by employees and contractors to the site has been based on discussions with the Principal Contractoris based onand the following assumptions as a worst-case scenario:

- There will be an average 400 staff onsite during the construction phase;
- All staff will travel to site using private vehicles;
- There are 26 working days each month;
- Staff will travel an average of 100km per day commuting.

Calculating operational emissions

14.5.14.14.5.16. Operational emissions are calculated separately from the Carbon Tool, which is focused specifically on construction-phase emissions. Road user carbon emissions have been calculated using the National Highways speed band emissions factors based on DEFRA's Emissions Factors Toolkit (v11). These emission rates were the latest available at the time the emissions modelling was undertaken and include assumptions about future fleet mixes. The calculations used traffic data from the Scheme specific traffic model and considered the full road network included in this traffic model, for the opening year and a further future year (2027 and 2042 respectively), and over the 60-year appraisal period. The operational data is split into 'Direct and Indirect' data. Direct data is associated with the road user carbon of the roads and the vehicles using it, whereas indirect road user is associated with the charging of batteries for the electric fleet.

14.5.15.14.5.17. There is no project-specific data available for direct emissions associated with operating the Scheme, such as for lighting, or for maintenance and refurbishment during the Scheme's operational life. Emissions have been estimated using published data from other highway schemes of a similar scale to this Scheme, based on the assumption that emissions from the operation and maintenance of similar highways is broadly consistent across the UK road network. This is because maintenance of highways follows the Manual of Contract Documents for Highway Works (MCHW) which sets out the standards to be followed when completing works on highways. Published data from three other highway schemes[14] (M4CaN new relief road, A14 improvement scheme, A465 embankment works) shows that proportionately, annual emissions from operational energy use and maintenance works equate to between 0.05 and 0.29% of in-use traffic emissions. As a reasonable worst case therefore, operational and maintenance have been assumed to be 0.29% of the road user emissions in each case, and to cover the same study area as for operational road user emissions, i.e. roads in the wider area affected by traffic changes. These emissions are considered to be conservative, given the need to meet the net zero target by 2050.

[14] Welsh Government (2016). M4 Corridor around Newport, Environmental Statement: Volume 3, Appendix 2.4 Carbon Report

~~14.5.16.~~14.5.18. Operational emissions were compared with emissions from the Do-Minimum scenario for the Opening Year, Future Year and cumulatively over the 60-year operational appraisal period.

~~14.5.17.~~14.5.19. The activities for which emissions have been quantified in the assessment include the direct and supply chain activities for the Do-Something scenario of the Scheme's life cycle, for both the construction and operation stages of the Scheme. The specific elements of the Scheme lifecycle included in the assessment boundary are listed in Table 14-3. The 'assessment boundary' defines the source of emissions considered, including direct or supply chain emissions.

Calculating Land Use and Land-Use Change (LULUC) emissions and removals

~~14.5.18.~~14.5.20. LULUC plays an important role in the balance and transfer of carbon through global carbon cycles. Carbon is stored in and exchanged between the atmosphere and biosphere, which includes plants and soils. When humans alter land-use, they impact the carbon stocks held within the biosphere and the exchange of carbon with the atmosphere. These changes can have adverse climate change impacts, but also provide key mitigation opportunities by removing carbon from the atmosphere and storing it in terrestrial biospheres.

~~14.5.19.~~14.5.21. The construction and operation of the Scheme has the potential to:

- change and disturb land-uses, leading to the release of carbon dioxide (CO_2) into the atmosphere from vegetation and soils.
- create and enhance carbon stocks in vegetation and soils, encouraging increased removals of greenhouse gases from the atmosphere.

~~14.5.20.~~14.5.22. Baseline calculations have been calculated by establishing annual sequestration or emission rates per hectare of each habitat present on site, sourced from literature. These rates were then multiplied by the total area for each habitat, derived from the Phase 1 habitat survey, which provided the area of land-use type which would be lost or disturbed by construction work for each option and variation. The results provided the annual sequestration or emission rate of each habitat, assuming it remains the same in future. The totals for each habitat type were then summed to give the total emissions, and multiplied by 60, to produce the total for the operational appraisal period.

~~14.5.21.~~14.5.23. The same data were used to derive the emissions for the operational assessment as a result of the lost sequestration over the 60-year period. It should be noted that this is a conservative approach, as it assumes that land-uses would continue to sequester carbon in their current state. In reality, once a land-use is established (this takes different lengths of time depending on the land-use and management methods), it is likely to be neutral in terms of its emissions / removals, i.e., the two will balance each other out in any given year. A conservative approach of including projected sequestration for existing land-uses has been taken to prevent an under-estimation of the impact of any of the route options.

~~14.5.22.~~14.5.24. Carbon emissions lost during construction as a result of the removal of habitats have been calculated by estimating the change in carbon stocks held within the different land-use types within the study area for the Scheme, using the information derived from the Phase 1 habitat survey (Appendix 7.1 – A~~a~~pplication document TR010063/~~ – ~~APP/~~ ~~6.15). These areas were multiplied by typical carbon stocks per ha for that land-use type to give a total carbon stock loss (in tonnes of carbon). This loss in carbon was converted into emissions of CO_2 (multiplying tC by (44/12) to give tCO_2).

~~14.5.23.~~14.5.25. A 'value-transfer' approach was taken to ascribing carbon stock data, whereby data from existing studies into similar land-use types were applied to the study area. Based on the habitats present, the data sources used included the following:

- Natural England (2021) Carbon storage and sequestration by habitat: a review of the evidence (second edition), Natural England Research Report NERR094.

IPCC's 2006 National Greenhouse Gas Inventories Comparison to UK carbon budgets

~~14.5.24.~~14.5.26. The UK has in place carbon budgets for five-year periods up to 2037. The proposed construction phase (2025-2027) of the Scheme falls within the fourth budget period (2023 to 2027). The emissions over the total construction period have been split evenly across the four years.

~~14.5.25.~~14.5.27. The first year of the operational phase will fall within the fourth budget period (2027), the next five years within the fifth budget period (2028 to 2032) and the five years after that within the sixth budget period (2033 to 2037). The results of emissions calculations will therefore be presented in terms of their percentage contribution to the fourth, fifth and sixth carbon budget periods. It is assumed that these emissions are evenly distributed across the years.

~~14.5.26.~~14.5.28. The Design Year (2042) falls beyond the sixth budget period, which ends in 2037, and there is currently no budget with which to compare emissions.

Significance assessment

~~14.5.27.~~14.5.29. The emissions calculated for the Do-Something scenario of the Scheme have been compared against the Do-Minimum scenario baseline for the assessment years. The difference between these emissions can be considered to be the impact of the Scheme.

~~14.5.28.~~14.5.30. DMRB LA 114, section 3.20 states that: 'The assessment of projects on climate shall only report significant effects where increases in GHG emissions will have a material impact on the ability of Government to meet its carbon reduction targets'. The table of reporting significance in section 3.18 of DMRB LA 114 has been used to compare the Scheme's carbon emissions with respective carbon budget periods.

~~14.5.29.~~14.5.31. The NPS NN acknowledges that the emissions from the construction and operation of a road scheme are likely to be negligible compared to total UK emissions and are unlikely to materially impact the UK Government's ability to meet its carbon reduction targets: 'it is very unlikely that the impact of a road project will, in isolation, affect the ability of Government to meet its carbon reduction plan targets'.

Limits of deviation

~~14.5.30.~~14.5.32. The assessment has been conducted within the Limits of Deviation (LoD) outlined within Chapter 2 - The Scheme (application document TR010063 – APP 6.2). The vertical and lateral LoD for the Scheme have been reviewed with respect to sensitive receptors identified within this ES chapter, and would not affect the conclusions of the assessment reported in this chapter.

14.6. Consultation

14.6.1. A climate chapter was published as part of the PEIR and consulted on during the statutory consultation. This process is detailed in the Consultation Report (Aapplication document TR010063/—APP/-5.1).

14.6.2. There is a full list of S42 matters raised in Appendix M of the report. Please refer here for responses to the matters raised during consultation.

14.6.3. There is a full list of S47 matters raised in Appendix N of the report. Please refer here for responses to the matters raised during consultation.

14.6.4. Targeted consultation matters raised are in Appendix J of the report. Please refer here for responses to the matters raised during consultation.

14.7. Baseline conditions

14.7.1. Baseline conditions are defined by the:

- Total background emissions from all sources, i.e., all UK emissions, at all scales.
- Predicted total emissions assuming the Scheme is not constructed, i.e., the 'Do-Minimum' scenario, for both the Opening Year (2027) and the Design Year (2042), and over the 60-year appraisal period.

National emissions baseline

14.7.2. The UK's emissions for 2021 (the last reported year) were 426.5 million tonnes of CO_2e[15]. The transport sector was the largest emitting sector of UK GHG emissions in 2021, contributing 26% of emissions. Most sectors saw a rise in emissions from 2020 to 2021, largely due to Covid-19 restrictions easing and more heating use due to colder weather. Transport emissions rose by 10% from 2020 but have fallen overall by 15% from the 1990 base.

14.7.3. Provisional figures have been released for 2022 and total UK emissions were 417.1 million tonnes of CO_2e[16]. This is 2.2% lower than 2021, following warmer weather in 2022 and a large drop in emissions from the residential sector. Transport emissions rose 4% from 2021 to 2022 as a result of all Covid-19 restrictions being eased, but were 8% lower than in 2019. Transport remained the largest emitting sector, responsible for 27%% of emissions.

14.7.4. The UK is currently in the fourth carbon budgetary period (2023-2027), the budget for which is 1,950 $MtCO_2e$. The UK cannot legally emit more GHG than this within the budgetary period. The fifth carbon budget is 1,725 $MtCO_2e$ (2028-32), and the sixth carbon budget is 965 $MtCO_2e$ (2033-37). Whilst budgets are not set beyond this, there is a legal requirement for the UK to reach 'net zero' emissions (0 $MtCO_2e$) by 2050. The construction (2025) and Opening Year (2027) of the Scheme fall within the fourth and fifth carbon budgets respectively.

Scheme baseline

14.7.5. The calculated emissions for the Do-Minimum scenario cover the following life cycle modules, assuming the Scheme is not constructed, for the area covering the road network likely to be affected by traffic changes:

- Road user carbon emissions
- Maintenance and refurbishment
- Operational energy use
- Carbon sequestered for land use type

[15] https://www.gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-to-2021
[16] https://www.gov.uk/government/statistics/provisional-uk-greenhouse-gas-emissions-national-statistics-2022

14.7.6. Only these life cycle modules are included as they are the only stages relevant to an operational highway. There are no construction emissions associated with the Do-Minimum scenario.

Road user carbon

14.7.7. The user carbon emissions for the Do-Minimum scenarios have been calculated in accordance with DMRB LA114 and are detailed in Section 14.5. They are as follows:

2027 Opening Year: 424,208 tCO_2e

2042 Design Year: 321,103 tCO_2e

60-year operational period: 20,091,039 tCO_2e

14.7.8. The data show an expected decrease in emissions between the Opening and Design Years, as cleaner vehicles enter the fleet in future years.

Operational energy use and maintenance

14.7.9. As detailed in Section 14.5, applying 0.29% of road user emissions as a reasonable worst-case value, the Scheme's Do-Minimum scenario emissions for operational energy use and maintenance of the existing roads in the study area can be estimated as:

2027 Opening Year: 1,230 tCO_2e

2042 Design Year: 931 tCO_2e

60-year operational period 58,264 tCO_2e

LULUC

14.7.10. Table 14-4 shows the quantity of carbon in tCO_2e which would be sequestered because of natural habitat, as identified from the land use assessment of the Phase 1 habitat survey, see Chapter 7 – Biodiversity (TR010063 – APP 6.5) for further details. The total for the 60-year appraisal period has been divided by 60 to give the amount in each of the opening and design years, 2027 and 2042 respectively, with the assumption that there is no change over time.

Table 14-4 - Carbon sequestered in a Do-Minimum Scenario

Future Year	Emissions (tCO_2e)
2027	-154
2042	-154
60-year appraisal period	-9245

Rounding may cause totals to not look complete

Scheme Baseline Summary

14.7.11. Table 14-5 provides a summary of the total emissions for the Do-Minimum scenarios.

Table 14-5 - Emissions for Do-Minimum scenario in 2027 and 2042

Year	Emissions (tCO_2e)			
	Road-user carbon	Operational energy use and maintenance	LULUC	Total
2027	424,208	1,230	-154	425,284
2042	321,103	931	-154	321,880
60-year operation	20,091,039	58,264	-9,245	20,140,058

14.8. Potential impacts

14.8.1. The construction stage of the Scheme would have an adverse effect on climate, as it would give rise to emissions. These emissions would arise from the production of materials to be used in construction, their transportation to site, and onsite through construction activities (~~e.g.~~e.g., emissions from diesel-fueled construction plant).

14.8.2. The operational stage of the Scheme would give rise to emissions from road users and operational energy use (for example, street lighting). Impacts may be positive or negative depending on whether this presents an increase or decrease against the Do-Minimum scenario. The results of the assessment are presented in Section 14.10.

14.8.3. The loss of habitats due to the construction of new highway and its elements will result in release of carbon stored in biomass, which will contribute to the net construction emissions.

14.8.4. There may also be a change in carbon sequestration potential as a result of land use change, and this has been calculated over the 60 year appraisal period.

14.9. Mitigation measures

14.9.1. DMRB LA 114 states that: ‘Projects shall seek to minimise carbon emissions in all cases to contribute to the UK’s target for net reduction in carbon emissions’. This requirement applies whether or not the Scheme is anticipated to generate a significant effect on climate.

14.9.2. Emissions are mitigated by applying the carbon reduction hierarchy set out in DMRB LA114: Avoid / Prevent, reduce, Remediate. Items at the top of the hierarchy have a greater potential to reduce emissions and are prioritised.

- Avoid / prevent:
    - Maximise potential for re-using and / or refurbishing existing assets to reduce the extent of new construction required.
    - Explore alternative lower carbon options to deliver the project objectives (i.e., shorter route options with smaller construction footprints).
- Reduce:
    - Apply low carbon solutions (including technologies, materials, and products) to minimise resource consumption during the construction, operation, user’s use of the project, and at end-of-life.
    - It is recommended that as far as possible, materials are locally procured to minimised transportation emissions.

- Construct efficiently, using techniques (e.g., during construction and operation) that reduce resource consumption over the life cycle of the project.

- Remediate:
  - After addressing steps 1 and 2 projects will identify, assess and integrate measures to further reduce carbon through on or off-site offsetting or sequestration.
  - Potential mitigation measures relevant to the construction and operation stages of the Scheme are suggested below.

14.9.3. To fully embed this hierarchy in the project team's ways of working, the Principal Contractor should commit to adhering to the principles of the PAS 2080 – Carbon Management in Infrastructure verification[17]. PAS 2080 is a global standard for managing infrastructure carbon and looks at reducing carbon across the whole value chain through more intelligent design, construction and use. It also ensures that carbon consistently and more transparently quantified at key points during the process, to inform decision-making.

14.9.4. The Principal Contractor will be required to produce a Carbon Management Plan (CMP) as part of their contract. The CMP will set out how GHG emissions will be managed and reduced over the lifetime of the S~~s~~cheme. The Principal Contractor will also set targets for GHG emissions reductions for each stage of the S~~s~~cheme which will be included within the CMP.

Embedded mitigation

14.9.5. Embedded mitigation measures are those which are incorporated into the design to avoid or prevent GHG emissions. DMRB LA 114 notes that 'minimising GHG emissions through design is a core principle of the Government's Infrastructure Carbon Review and the Specification on infrastructure carbon management PAS 2080:2016[18]'. Mitigation measures which have been embedded into the design are shown in Table 14-6.

Table 14-6 - Embedded mitigation measures

Life cycle module	Mitigation measures	DMRB LA 114 Carbon reduction hierarchy action
Construction (product stage)	Optioneering of the design structures through the Preliminary Design process has resulted in the selection of structures (e.g. River Chelt Bridge) with lower carbon than other alternatives.	Reduce
	The Scheme is committed to reuse over 99% of the excavated soil onsite. This would reduce the quantity of materials required to be managed or disposed of off-site. This reuse will be facilitated through the implementation of a Materials Management Plan (MMP) which will be produced under the CL:AIRE Definition of Waste: Code of Practice (DoWCoP). The MMP will be produced in conjunction with the Principal Contractor and a declaration submitted by a Qualified Person registered with CL:AIRE.	Reduce

[17] https://www.bsigroup.com/en-GB/our-services/product-certification/product-certification-schemes/pas-2080-carbon-management-in-infrastructure-verification/
[18] This has now been superseded by PAS 2080:2023

Life cycle module	Mitigation measures	DMRB LA 114 Carbon reduction hierarchy action
	Circular economy considerations would be included in the Detailed Design stage through specifications to use the target amount of recycled material, e.g. 30% recycled content target in construction of the Sscheme. Opportunities for potential re-use and recycling of all material assets and waste will be promoted and material use will be managed in order to maximise the re-use within the Sscheme.	Reduce
Construction (construction process stage)	Optioneering of the design structures through the Preliminary Design process has resulted in the selection of structures (e.g. River Chelt Bridge) with less materials. This has reduced the transport of materials to site, and also the extent of on-site construction/installation processed required.	Avoid/prevent
	Standard and easy-to-source materials have been specified for the Scheme, to increase the likelihood that they can be procured locally and reduce transport emissions.	Reduce
	The Scheme is committed to reuse over 99% of the excavated soil onsite. This would reduce the transportation of materials to site. A full MMP would be implemented to meet the CL:AIRE DoWCoP, to enable maximum use of on-site materials.	Reduce
	Waste treatment / disposal would be carried out in accordance with the mitigation measures outlined in the Materials and Waste chapter (application document TR010063 – APP 6.10). Impacts from material asset use and waste generation will be managed during construction through the implementation of the Environmental Management Plan (first iteration) (application document TR010063 – APP 7.3).	Reduce
Operation	Additional planting within the boundary of the sScheme will lead to increased removal and sequestration of GHGs from the atmosphere of an estimated 5 tCO_2e per year. This is predominantly created by the creation of new woodland and species-rich grassland habitats.	Remediate

14.10. Residual Effects

14.10.1. This assessment presents the emission calculated for the Do-Something scenario, a comparison against the Do-Minimum baseline, and assessment against UK Government carbon budgets.

Construction impacts

14.10.2. The calculated construction phase emissions for the Do-Something scenario, compared with the Do-Minimum, are shown in Table 14-7.

14.10.3. The construction phase of the Scheme will generate 206,14982,217 tCO_2e. The largest emitting categories are Bulk Materials and Earthworks, contributing 55,898 tCO_2e and 99,961 tCO_2e respectively. Emissions from the loss of sequestration potential from land use change will generate 7,971 tCO_2e. As emissions from construction do not occur in the Do-Minimum scenario, it can be considered that the construction stage of the Scheme would have the impact of releasing an additional 206,14982,217 tCO_2e into the atmosphere in the Do-Something scenario.

Table 14-7 - Construction phase emissions

Category	Emissions (tCO_2e)		
	Materials	Transportation	Total
Bulk Materials	18,819	37,079	55,898
Road pavements	278	258	536
Fencing, barriers & road restraints systems	1,060	73	1,133
Drainage	681	81	762
Earthworks	16,356	83,605	99,961
Street furniture and electrical equipment	997	27	1,0243
Civil structures & retaining walls	559	563	1,122
Waste	63	0	63
Construction plant & equipment (fuel consumption)	32,488	1,259	33,747
Employee and Business travel	3,932	-	3,932
Land Use change	-	-	7,971
Total Emissions	**75,2331,299**	**122,9454,206**	**206,14982,217**

Table source: NH Carbon Tool v2.5 output (excluding Land Use change emissions – sourced from Natural England NERR094 output)

Operation impacts

14.10.4. The calculated operation phase emissions for the Do-Something scenario, compared with the Do-Minimum, are shown in Table 14-8.

14.10.5. The Do-Something scenario of the Scheme will generate 5,8076 tCO_2e in the Opening Year, and 14,068 tCO_2e in the Design Year compared with the Do-Minimum. This is an increase in annual operational emissions of 1.4% and 4.4% for the Opening and Design years respectively and corresponds to an increase in vehicle kilometres travelled with the Scheme.

14.10.6. The change in emissions from land use and forestry from the Scheme will result in an additional 5 tCO2e being sequestrated per year. This is primarily due to the planting of additional woodland (11.73ha) and species rich grassland (19.2ha) as part of the Scheme.

Table 14-8 - Operation phase emissions for 2027 and 2041

Life Cycle	Emissions (tCO_2e)								
	2027 Do-Minimum	2027 Do-Something	Difference	2042 Do-Minimum	2042 Do-Something	Difference	Total over 60-year operation* (Do-Minimum)	Total over 60-year operation* (Do-Something)	Difference
Road User Carbon	424,208	430,003	5,795	321,103	335,135	14,032	20,091,039	20,867,060	776,021
Maintenance and Operation	1,230	1,247	17	931	972	41	58,264	60,514	2,250
Land use and forestry	-154	-159	-5	-154	-159	-5	-9,245	-9,557	-312
Total Emissions	425,284	431,091	5,807	321,880	335,948	14,068	20,140,058	20,918,017	777,959

*Cumulative over the period 2027-2087

Comparison to UK Carbon Budgets

14.10.7. The S~~s~~cheme is likely to contribute 300,315~~297,1696,383~~ tCO_2e to the UK Carbon Budget's across the period 2025-2037, compared with the Do-Minimum scenario. The (net) contribution of the Scheme to the fourth Carbon budget period would be 211,955~~08,024~~ tCO_2e (equivalent to 0.011% of that budget), including construction and operational phase emissions. The contribution of the Scheme to the fifth Carbon Budget would be 37,296 tCO_2e (equivalent to 0.002%) of that budget)., from operational emissions. The contribution of the Scheme to the sixth Carbon Budget would be 51,064 tCO_2e (equivalent to 0.005% of that budget). The Scheme is unlikely to cause significant effects on climate, or significantly affect the UK's ability to meet its emissions reduction targets. It is considered that this magnitude of emissions from the Scheme will not materially impact the Government's ability to meet the budget, and therefore will not have a significant effect on climate.

14.10.8. This is in line with the position set out in the National Policy Statement for National Networks (NPS NN), which acknowledges that the emissions from the construction and operation of a road scheme are likely to be negligible compared to total UK emissions, and are unlikely to materially affect the UK Government's ability to meet its carbon reduction targets. The NPS NN specifically states that 'it is very unlikely that the effect of a road project will, in isolation, affect the ability of Government to meet its carbon reduction plan targets'.

14.10.9. The carbon budget associated with the Design Year has not been set and a quantitative assessment of significance for this period therefore cannot be carried out. However, Design Year emissions are of a similar order of magnitude to Opening Year emissions and, in the absence of any information on what the carbon budget for the period might be, it is expected that their contribution would be similarly small.

14.10.10. Table 14-9 shows the proportion of the relevant carbon budgets that the Scheme would contribute, over the 5-year budget period.

Table 14-9 - Comparison of Scheme to UK Government Carbon Budgets

Project stage	Estimated total carbon over carbon budget (tCO_2e) ('Do - Something' scenario)	Net CO_2 project GHG emissions (tCO_2e) (Do-Something – Do-Minimum)	Relevant carbon budget			
			3rd carbon budget (2018-22)	4th carbon budget (2023-27)	5th carbon budget (2028-32)	6th carbon budget (2033-37)
Construction	206,149~~83,475~~	206,149~~82,217~~		206,149~~82,217~~		
Operation	4,393,144	94,166		5,80~~7~~6	37,296	51,064
Total	4,599~~6~~,292~~,147 619~~	300,315~~297,169 6,383~~		211,955~~08,024~~	37,296	51,064
Percentage of carbon budget	-	-	-	0.011%	0.002 %	0.005 %

Source: Adapted from DMRB LA 114, populated with own calculations

14.10.11. Mitigation measures to reduce carbon emissions form an inherent part of the project's design and construction practices. Therefore, the assessment of emissions in this chapter already takes into consideration the mitigation described in the assessment above.

14.10.12. The overall (net) residual effect of the S~~s~~cheme in the fourth carbon budget period is a 0.011% contribution to the budget. The overall net effect on the fifth carbon budget will be 0.002% of the budget. The overall net effect on the sixth carbon budget will be 0.005% of the budget. This will not generate a significant impact on the UK's ability to meet its budgets.

14.10.13. It is very unlikely that the impact of a road project will, in isolation, affect the ability of Government to meet its carbon reduction plan targets.

14.11. Cumulative effects on climate

14.11.1. The effects of the GHG emissions outlined in this assessment are essentially cumulative. This is due to the traffic modelling for the Scheme being undertaken in line with TAG guidance published by the Department for Transport (DfT). The traffic model used for the Scheme has been developed in line with DfT requirements and takes into account data from the following sources:

- The Scheme and adjoining Strategic Road Network (SRN) and local road network.
- Other schemes promoted by National Highways in the near vicinity of the Scheme with a high certainty that they are to be progressed.
- Foreseeable developments promoted by third parties that are likely to be developed in a similar timeline to the Scheme.
- National government regional growth rates which include a representation of likely growth rates (excluding known planning development already included in the traffic model).

14.11.2. For this reason, the impact of the Scheme should be considered in the context of overall emissions from the UK, by comparing against the UK's Carbon Budgets. Given that the operational road user emissions are derived from a strategic traffic model, which considers other developments within the wider regional area, the effects from the Scheme can in any case be considered as inherently cumulative.

14.11.3. On the basis of the above, there are no additional cumulative effects (intra-Scheme or inter-project) from the assessment of the impacts of the Scheme; and the impacts of the Scheme plus RFFPs on climate. This conclusion relates to construction and operation.

14.12. Assumptions and limitations

14.12.1. The data for the assessment has been provided by the design team and is as up to date for this stage of the design as can be reasonably expected. Where assumptions have been made, they have been selected to present the worst-case scenario for that item/factor.

14.12.2. Due to the proposed project development stage being at PCF Stage 3, there are a number of exclusions due to insufficient knowledge and accuracy at this stage for the construction phase and where no general or specific assumption could be applied. The list of exclusions is provided below:

14.12.3. Exclusions from materials and construction:

- Road Markings
- Business and employee transport.

14.12.4. The key limitation of the assessment is the availability and accuracy of design and construction information to enable calculations. This may require assumptions to be made, and some industry standard data to be used as a proxy. The data and associated assumptions considered for the carbon emissions assessment are detailed below.

14.12.5. The following assumptions have been made during the carbon assessment:

- All concrete (other than pre-cast concrete) used in construction is modelled as 'ready-mix concrete'.
- Aggregates are assumed to make up 75% of the total weight of the concrete used in construction.
- All cement and binder are assumed to be Portland Cement.
- All earthwork materials used in construction are assumed to be soil unless mentioned as otherwise in the bill of quantities.
- All signage is assumed to made from aluminium.
- Drainage pipes are rounded up to the closest size available in the Carbon Tool if no exact size is available.
- Assumed Polypropylene geotextile / matting unless stated otherwise.
- All materials are assumed to be nationally manufactured and transported to site from an average distance of 50km (as detailed in the default transport scenarios in RICS[19]).
- Carbon factors are drawn from the Highway England Carbon Tool (v2.5) which are sourced from the Inventory of Carbon and Energy database.
- Road User Carbon is drawn from the Defra's Emissions Factor Toolkit (v11). Within the toolkit, account is not taken for the increase of electric vehicles beyond 2030. It is consistent with the TAG methodology defined by the DfT and assesses emissions over a 60-year period.
- The scenario 'R' has been used in the assessment of Road User Carbon, which includes expected emissions from scheme-enabled developments.
- 400 staff and contractors will be on site during the construction phase.
- Staff and contractors will travel an average of 1020km to site using private vehicles.

[19] whole-life-carbon-assessment-for-the-built-environment-1st-edition-rics.pdf

14.13. Monitoring

14.13.1. It is not possible to directly monitor GHG emissions. However, the Carbon Tool will be populated on a quarterly / monthly return basis through the construction process and during maintenance activities through the life of the Scheme, to provide carbon reporting to GCC. The objective of this activity is to allow tracking of actual construction and maintenance emissions, which can be compared against those forecast in this assessment. The scope and parameters of the reporting are as set out in the construction phase element of this assessment, to include material use and transport, transport of workers, and onsite construction processes. The Carbon Tool will be updated and shared by the Main Contractor with GCC during operation, and by the Area Management Team during maintenance works in the operation phase.

14.13.2. In addition, a comprehensive carbon management plan is being developed for the Scheme, which would be implemented from the Detailed Design stage and through construction. This would follow a data collection and analysis methodology which adheres to the requirements of the PAS 2080 – Carbon Management in Infrastructure verification technical standard (see 14.9.3). This would assess carbon use for the whole lifecycle of the project and promote embodied carbon management ad commit to achieving carbon reductions.

14.14. Chapter summary

14.14.1. In terms of construction phase emissions, the Scheme will generate an additional 206,149~~82,217~~ tCO_2e. This would contribute 0.011% to the UK's fourth carbon budget. In line with the conclusions drawn in the NPS NN, it is not deemed that the construction phase of the Scheme would have a significant effect on climate.

14.14.2. In terms of operation phase emissions, the Do-Something scenario of the Scheme will generate an additional 5,80~~7~~6 tCO_2e in the Opening Year, and 14,068 tCO_2e in the Design Year compared with the Do-Minimum scenario due in large part to an increase in vehicle kilometres travelled, taking into account the added emissions from scheme-enabled developments. Cumulatively over a 60-year period, the net emissions due to the Scheme would be 775,934 tCO_2e.

14.14.3. It should be noted that this assessment is conservative, representing a reasonable worst case.

14.14.4. Due to the status of published and legislated Carbon Budgets, according to the Climate Change Act, not all cumulative emissions can be compared directly to Carbon Budgets which only run to 2037. The emissions due to the Scheme would represent 0.011% of the fourth Carbon Budget (2023-27), 0.002% of the fifth Carbon Budget (2028-33) and 0.005% of the sixth Carbon Budget (2033-37).

14.14.5. In line with the conclusions drawn in the NPS NN, DMRB LA114, it is not deemed that the Scheme would have a significant effect on climate.

VULNERABILITY TO CLIMATE CHANGE

14.15. Introduction

14.15.1. In this environmental assessment, climate vulnerability is taken to be the degree to which receptors in the study area are susceptible to the effects of climate change (beneficial and adverse). These affects include slow onset trends in climate as well as projected changes to extreme weather. An explanation of key climate related terms used in this chapter are included in Appendix 1.1 (application document TR010063 – APP 6.15).

14.15.2. The main objective of the climate vulnerability assessment is to ensure that climate change, and impacts associated with extreme weather, are considered during the planning of the Scheme so that they can be avoided and, if that is not possible, mitigated during its construction and operation. To achieve this objective this chapter presents:

- An examination of the current climate baseline using the Met Offices latest regional dataset of 30-year averages and data from nearby long running meteorological stations.
- A consideration of the projected future climate for the study area in 2071-89.
- An assessment of how the Scheme may be vulnerable to the impacts of climate change during its construction and operation.
- Identification of specific mitigation to adapt the design and operational processes to reduce the Scheme's potential adverse climate vulnerabilities.
- An assessment of the residual climate change vulnerability of the Scheme that considers both adverse and beneficial vulnerability impacts by quantifying their likelihood and consequence of each potential vulnerability.

14.15.3. The adopted assessment approach reviews how climate change could affect the Scheme's assets (Climate Change Risk Assessment), as well as how it could affect the potential environmental impacts identified in the other chapters of this assessment, i.e., how it could impact environmental receptors (In-Combination Climate Impacts [ICCI] assessment). The methodology follows guidance set out in DMRB LA 114[20] and is informed by best practice climate assessment approaches and literature, as well as professional judgement.

14.15.4. This chapter should be read in conjunction with the description of the development presented in Chapter 2 - The Scheme (Aapplication document TR010063/—APP/-6.2). It is also noted that the scope of the climate vulnerability assessment has overlaps with aspects of other chapters in this report, in particular Chapter 8 - Road Drainage and the Water Environment (Aapplication document TR010063/—APP/-6.6) - which includes consideration of the impact of future climate change on the water environment through, for example, increased high intensity short duration rainfall events.

14.15.5. The examination of climate projections has confirmed that the study area's climate (see Section 14.20) is expected to change in the future. The climate vulnerability assessment presented in this chapter finds that without mitigation the Scheme could be vulnerable to impacts linked to these changes in the climate. Mitigation measures that either avoid these impacts, minimises them or reduces their consequences to an acceptable level are therefore built into the design (i.e., embedded mitigation). After consideration of this mitigation no potential climate vulnerability impacts are found to be significant adverse.

14.16. Competent expert

14.16.1. This section has been written by a competent expert with more than 15 years professional experience who is chartered by RGS.C.Geog, MCIWEM, C.WEM, CEnv, CSci. They have experience developing climate vulnerability assessments for transport schemes (national

[20] https://www.standardsforhighways.co.uk/dmrb/search/d1ec82f3-834b-4d5f-89c6-d7d7d299dce0

road schemes, rail and air developments) as well as residential, commercial and public developments and for energy and natural resources infrastructure.

14.17. Planning policy and legislative context

14.17.1. The legislation and policy framework for the Scheme's vulnerability to climate changes is set out in Table 14-10. It should be noted that the details presented in this section are not intended to provide a full consideration of the relevant documents and their application to the Scheme. This information is provided within the Planning Statement and Schedule of Accordance with National Policy Statement (Aapplication document TR010063/—APP/7.1) that accompanies the application for a DCO.

Table 14-10 - Policy review

Scale	Policy document	Key implication for the Scheme
National	Infrastructure Planning - Environmental Impact Assessment Regulations (2017)[21]	The Regulations require: "A description of the likely significant effects of the project on climate (for example the nature and magnitude of GHG emissions) and the vulnerability of the project to climate change."
	National Policy Statement for National Networks (NPS NN) (2014)[22]	The Scheme falls within the definition of a Nationally Significant Infrastructure Project (NSIP), making the NPS NN the primary planning policy against which an application for a Development Consent Order (DCO) for the Scheme would be judged. Paragraph 4.40 states that "new national networks infrastructure will be typically long-term investments which will need to remain operational over many decades, in the face of a changing climate". Therefore, applications "must consider the impacts of climate change when planning location, design, build and operation". Paragraph 4.42 states that "The Aapplicant should take into account the potential impacts of climate change using the latest UK Climate Projections available at the time and ensure any environment statement that is prepared identifies appropriate mitigation or adaptation measures. This should cover the estimated lifetime of the new infrastructure." Paragraph 4.43 states that "The Aapplicant should demonstrate that there are no critical features of the design of new national networks infrastructure which may be seriously affected by more radical changes to the climate beyond that projected in the latest set of UK climate projections." Paragraph 4.44 states that "Any adaptation measures should be based on the latest set of UK Climate Projections, the Government's national Climate Change Risk Assessment and consultation with statutory consultation bodies. Any adaptation measures must themselves also be assessed as part of any environmental impact assessment and included in the environment statement, which should set out how and where such measures are proposed to be secured."
	National Planning Policy Framework (NPPF) (20231)[23]	Given that the Scheme is an NSIP, the NPPF has the status of a material consideration in planning terms. The NPPF develops a planning system that contributes to radical reductions in GHG emissions, minimises vulnerability and improves resilience. The NPPF states that "Plans should take

[21] https://www.legislation.gov.uk/uksi/2017/572/regulation/1/made
[22] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/387222/npsnn-print.pdf
[23] https://www.gov.uk/government/publications/national-planning-policy-framework--2

Scale	Policy document	Key implication for the Scheme
		a proactive approach to mitigating and adapting to climate change, taking into account the long-term implications for flood risk, coastal change, water supply, biodiversity and landscapes, and the risk of overheating from rising temperatures. Policies should support appropriate measures to ensure the future resilience of communities and infrastructure to climate change impacts, such as providing space for physical protection measures, or making provision for the possible future relocation of vulnerable development and infrastructure" (paragraph 153).
	Climate Change Act (2008) [24]	The UK passed legislation that introduced the world's first long term legally binding framework to tackle the risks posed by climate change. The Climate Change Act (2008) created a new approach to managing and responding to climate change in the UK, by: • Setting ambitious, legally binding reduction targets. • Taking powers to help meet those targets. • Strengthening the institutional framework. • Enhancing the UK's ability to adapt to the impacts of climate change. • Establishing clear and regular accountability to the UK Parliament and to the developed legislatures. Key provisions of the Act in respect of climate change adaptation include a requirement for Government to report, at least every five years, on the risks to the UK of climate change, and to publish a programme setting out how these will be addressed. This Act also introduces powers for Government to require public bodies and statutory undertakers to carry out their own risk assessment and make plans to address those risks. The Adaptation Sub-Committee of the CCC will provide advice to, and scrutiny of, the Government's adaptation work.
	UK Climate Change Risk Assessment[25]	This report sets out the UK Governments position on the key climate change risks and opportunities that the UK faces today. In it it is stated that: *"The government accepts that climate hazards will cause increasing threats to our supply chains through our infrastructure and transport routes. Consideration will need to be given to the potential vulnerabilities for the transport system including rail, roads, ports and airports." (Priority risk area 5, page 31)*
	National Highways, Preparing for Climate Change on the Strategic Road Network - third adaptation report under the Climate Change Act (2022)	The report identifies key areas of risk along with associated standards, guidance, monitoring, data, pilot projects and research to address them.[26]
	Highways England Sustainable Development	National Highways recognise that changes in climate may result in more frequent and severe weather events. This document sets out their commitment to ensure resilience to climate change is embedded in the activities of their business

[24] https://www.legislation.gov.uk/ukpga/2008/27/contents
[25] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1047003/climate-change-risk-assessment-2022.pdf
[26] https://nationalhighways.co.uk/media/z1ndodqx/preparing-for-climate-change-on-the-strategic-road-network.pdf

Scale	Policy document	Key implication for the Scheme
	Strategy and Action Plan (2017)[27]	to reduce whole life costs and increase safety. To do this their ambition is to invest for the long-term – "our road network contains components that have a very long design life, such as bridges and tunnels. they will require timely and cost-effective investments to reduce the risk of increased future costs, whilst improving resilience to climate change."
	DMRB LA114	Sets out the requirements to be applied to the assessment, reporting and management of effects of climate on projects.
Regional	Joint Core Strategy (JCS) 2011-2031: Gloucester, Cheltenham and Tewkesbury[28]	The JCS is a partnership between Gloucester City Council, Cheltenham Borough Council and Tewkesbury Borough Council, which sets out a strategic planning framework for the three areas. Policy SD3: Sustainable Design and Construction sets out that "All development will be expected to be adaptable to climate change in respect of its design, layout, siting, orientation and function".
	Gloucestershire Waste Core Strategy (2012)[29]	LTP PD 4.2 – Highway network resilience makes specific reference to the importance of a 'resilient highway network that can withstand unforeseen events including extreme weather events and long-term changes to the climate.' This will be achieved through the identification of the most vulnerable parts of the transport network and developing contingency plans to ensure a functioning network during unplanned events. Importantly, as part of this policy, GCC also pledge to 'continue to deliver highway and flood alleviation schemes which reduce the risk of highway closures on class one and two routes', as well as work with the Environment Agency, National Highways and communities to 'ensure that the highway network and the communities, trade and commerce that it serves are better protected from flood impacts.'
	Gloucestershire Climate Change Strategy (2019)[30]	The report sets out the Councils plan to develop a live 5-year rolling action plan to reduce emissions and improve resilience. The report also sets out the Councils' plan to: - Work with its partners so that all new development sites deliver high quality green infrastructure in line with the 'Building with Nature' standards, developed by Gloucestershire Wildlife Trust - Stress testing public sector assets and services against climate change - Continue to develop and deliver a programme of works to minimise flood risk and its wider impacts, and advise on major development applications to future-proof their climate resilience
	Gloucestershire County Council Climate Change Strategy 2nd Annual Report & Action	This report provides an annual update of progress with the Gloucestershire Climate Change Strategy. The report sets out the Councils ambition to develop a Council-wide adaptation plan, linked to the Council's Business Continuity Management process. A Climate Change & Air Quality Officer and two

27 https://www.gov.uk/government/publications/highways-england-sustainable-development-strategy
28 https://jointcorestrategy-my.sharepoint.com/personal/website_jointcorestrategy_onmicrosoft_com/_layouts/15/onedrive.aspx?id=%2Fpersonal%2Fwebsite%5Fjointcorestrategy%5Fonmicrosoft%5Fcom%2FDocuments%2FJoint%20Core%20Strategy%20%28JCS%29%20website%2FHome%2FJCS%20Plan%20Adopted%20Verison%20%28PDF%2E%2010MB%29%20Formatted%2Epdf&parent=%2Fpersonal%2Fwebsite%5Fjointcorestrategy%5Fonmicrosoft%5Fcom%2FDocuments%2FJoint%20Core%20Strategy%20%28JCS%29%20website%2FHome&ga=1
29 https://www.gloucestershire.gov.uk/planning-and-environment/planning-policy/gloucestershire-waste-core-strategy/
30 https://data.climateemergency.uk/media/data/plans/gloucestershire-county-council-ebcbab2.pdf

Scale	Policy document	Key implication for the Scheme
	Plan 2022/23 – 2026/27 (2021) [31]	Sustainability & Engagement Officers have been appointed to facilitate this.
Local	Cheltenham Borough Council Climate Change Emergency Action Plan (2022)[32]	The report sets out that for the Council to meet their climate obligations also they will need to develop climate resilience, which will include: - Mitigating flood risk - Considering adaptations that reduce vulnerability to climate change impacts - Developing a more tightly-knit community - Planning for more green and natural space for both people and wildlife.
	Tewkesbury Borough Council (TBC) Climate Change Strategy (2020)[33]	TBC commissioned this study to produce a current status baseline and first stage Action Plan relating to the council's own buildings and business-related transport, in response to the climate emergency they previously declared.

14.18. Methodology

14.18.1. Where the climate change impact on project receptors is potentially significant, a risk assessment has been undertaken. The method for this assessment is set out in this section. It follows the standards set out in DMRB LA 114 and is informed by best practice climate assessment approaches and literature, as well as professional judgement.

Study area

14.18.2. In accordance with LA114 (Section 3.25) the study area for the climate vulnerability assessment incorporates the construction footprint of the Scheme (the Order limits including compounds and temporary land take), all potential environmental receptors that could be impacted by the Scheme and the regional transport network around the Scheme that could be affected by cumulative climate vulnerability impacts.

14.18.3. The temporal scope of the study has, in accordance with LA114 (Section 3.31), taken the lifespan of the project to be 60 years.

Assessment methodology overview

14.18.4. There are four stages to the climate vulnerability assessment method:

- Stage 1 - Identify the hazards and receptors.
- Stage 2 - Assess the likelihood of impacts on each receptor.
- Stage 3 - Assess the consequence of impacts for each receptor.
- Stage 4 - Determine the significance of each impact based on a combination of the likelihood of an impact occurring and the consequences of that impact.

Stage 1 - Identification of hazards and receptors

14.18.5. Receptors which may be affected by climate change hazards have been identified with consideration of the characteristics of potential future extreme weather events as well as gradual changes to the climate that could occur in the study area over the Scheme's design life. Identification of these is based on an assessment of climate projections from United Kingdom Climate Projections 2018 (UKCP18[34]). These projections have been developed by the Met Office Hadley Centre Climate Programme which is supported by

[31] https://glostext.gloucestershire.gov.uk/documents/s77480/20221222%20Cabinet%20Glos%20Climate%20Change%20Strategy%20Annual%20Report%20FINAL%20v2.pdf
[32] https://www.cheltenham.gov.uk/download/downloads/id/9650/pathway_to_net_zero.pdf
[33] https://data.climateemergency.uk/media/data/plans/tewkesbury-borough-council-2f98c5b.pdf
[34] https://www.metoffice.gov.uk/research/approach/collaboration/ukcp

the Department of Business, Energy and Industrial Strategy (BEIS) and the DEFRA. They provide the most up-to-date assessment of how the climate of the UK may change over the 21st century.

14.18.6. In accordance with DMRB LA 114 (Section 3.34) the assessment has considered the impacts of climate change on the following receptors:

- Construction process (including workforce, plant, machinery etc.).
- The assets and their operation, maintenance, and refurbishment (including pavements, structures, earthworks and drainage and technology assets such as signals and signs).
- End-users (members of the public, commercial operators, nearby residential properties, road user safety and experience).

14.18.7. Where it is not already covered in the relevant topic chapters, consequential loss or damage to environmental receptors as a result of the Scheme's vulnerability to climate change is discussed in the cumulative effects section of the chapter.

Stage 2 - Assess the likelihood of impacts

14.18.8. In accordance with DMRB LA 114, the likelihood of potential climate changes and events occurring are determined using available data (such as the known recurrence interval of extreme weather events) and professional judgement, based on knowledge and experience of other similar schemes. The likelihood categories and associated frequencies are provided in Table 14-11~~Table 14-11~~.

Table 14-11 - Likelihood categories

Likelihood category	Description (probability and frequency of occurrence)
Very high	The event occurs multiple times during the lifetime of the project (60 years) e.g., approximately annually, typically 60 events.
High	The event occurs several times during the lifetime of the project (60 years) e.g., approximately once every five years, typically 12 events.
Medium	The event occurs limited times during the lifetime of the project (60 years) e.g., approximately once every 15 years, typically 4 events.
Low	The event occurs during the lifetime of the project (60 years) e.g., once in 60 years.
Very low	The event can occur once during the lifetime of the project (60 years).

Table Notes: Project lifetime is considered to include construction and operational phases; project lifetime is take to be 60 years in line with LA114

Table Source: DMRB Climate: LA114 Table 3.39a (June, 2021).

Stage 3 - Assess the consequence of impacts

14.18.9. The consequence of climate change impacts on the Scheme receptors are categorised using the criteria in Table 14-12~~Table 14-12~~.

Table 14-12 - Measure of consequence

Consequence of impact	Example description
Very large adverse	Operation – national level (or greater) disruption to strategic route(s) lasting more than 1 week.
Large adverse	Operation – national level disruption to strategic route(s) lasting more than 1 day but less than 1 week or regional level disruption to strategic route(s) lasting more than 1 week.
Moderate adverse	Operation – regional level disruption to strategic route(s) lasting more than 1 day but less than 1 week.

Consequence of impact	Example description
Minor adverse	Operation – regional level disruption to strategic route(s) lasting less than 1 day.
Negligible	Operation – disruption to an isolated section of a strategic route lasting less than 1 day.

Table Source: DMRB Climate: LA114 Table 3.39b (June, 2021).

Table Note: Consequences can be adverse or beneficial. Beneficial consequences would result in a beneficial outcome in stage 4.

Stage 4 – Determine significance of impacts

14.18.10. The results of the likelihood and consequence assessments are combined to derive a significance classification as outlined in Table 14-13~~Table 14-13~~.

Table 14-13 - Significance matrix

Impact consequence	Impact likelihood				
	Very low	Low	Medium	High	Very high
Very large	NS	S	S	S	S
Large	NS	NS	S	S	S
Moderate	NS	NS	S	S	S
Minor	NS	NS	NS	NS	NS
Negligible	NS	NS	NS	NS	NS

Table notes: NS = Not Significant, S = Significant. Impacts can be adverse or beneficial (where consequence is beneficial).

Table Source: DMRB LA114 Table 3.41 (June, 2021).

14.18.11. The assessment is undertaken with consideration of the Scheme design and mitigation.

Limits of deviation

14.18.12. The assessment has been conducted within the Limits of Deviation (LoD) outlined within Chapter 2 - The Scheme (A~~a~~pplication document TR010063/~~ – ~~APP/~~-~~6.2). The vertical and lateral LoD for the Scheme have been reviewed with respect to sensitive receptors identified within this ES chapter, and would not affect the conclusions of the assessment reported in this chapter.

14.19. Consultation

14.19.1. A climate chapter was published as part of the PEIR and consulted on during the statutory consultation.

14.19.2. In relation to flood risk and drainage design, requirements in the NPS and NPPF and Environment Agency design guidance[35] relating to climate change apply. A detailed Flood Risk Assessment (FRA) was completed in September 2021 (Appendix 8.1 of the ES (A~~a~~pplication document TR010063/~~ – ~~APP/~~-~~6.15)). The FRA uses the latest climate change allowances published by the relevant authority. The purpose of consultation on the FRA has been to agree it's scope and specific approaches regarding:

- Assessment of the baseline flood risk - determining the required return periods for modelling.
- Upfront flood modelling informing design of any river crossings and associated flood defence schemes.
- Assessment of the with-scheme impacts to determine the required return periods for modelling.

[35] https://www.gov.uk/guidance/flood-risk-assessment-for-planning-applications

14.19.3. Consultation with the Environment Agency on flood risk has been undertaken, this has included:

- Telephone meeting 7 August 2019.
- Telephone meeting 17 January 2020.
- Telephone meeting 9 February 2021.
- Telephone meeting 29 April 2021.

14.19.4. The Environment Agency was supplied with a copy of the baseline model and its accompanying report for review. This model and the hydrology was reviewed by external consultants on behalf of the Environment Agency (14 April 2021).

14.19.5. Consultation has also been undertaken with Gloucestershire County Council as the Lead Local Flood Authority (LLFA), although principal matters have been dealt with by the Environment Agency. Full details of consultation on the FRA can be found in the Consultation Report (A~~a~~pplication document TR010063/~~—~~APP/~~-~~5.1).

14.19.6. A Statement of Common Ground has since been prepared with Gloucestershire County Council and the Environment Agency. It confirms that “the Scheme modelling report and hydraulic model has been issued to the Environment Agency (March 2022). These items support the Flood Risk Assessment (FRA) and Preliminary Environmental Impact Report (PEIR). The model has been reviewed by the EA who has approved its use. However, the EA has requested the detail of the storage before it can formally agree to the proposed mitigation for flood risk. It was also requested that any updates to the model should be noted in the appendices of the modelling report (13.01.2023).”

14.19.7. In addition to the above every opportunity has been taken through the design process to raise the importance of climate vulnerability with both the Schemes design leads and environmental topic leads. This has led to iterative design developments and mitigation improvements driven by early and ongoing consideration of how climate change resilience can be embedded into the decision making processes of the whole project team.

14.20. Baseline conditions

14.20.1. The baseline for climate change vulnerability is presented in two parts:

- The first section describes the current climatic conditions in the study area.
- The second presents a range of possible future climate projections in the study area.

14.20.2. It should be noted that climate change is not only a challenge for the future. The UK is already observing changes in its climate.

Current climate baseline

14.20.3. The Scheme is situated within the River Severn catchment. To inform adaptation decisions this section presents data from the Meteorological Office to summarise the River Severn’s catchment current climate. The Met Office's standard average data tables are used, they show the latest set of 30-year averages covering the period 1981-2010. Context to this is provided by including comparison to the equivalent national dataset (UK minimum, average and maximum temperatures).

14.20.4. To support the above average regional data a local dataset has also been collected from the closest long running climate station to the Scheme. The closest climate station is located at Ross-On-Wye (359800E, 223800N – approximately 20 miles west of the Scheme) and has been recording observations since 1931[36].

[36] https://www.metoffice.gov.uk/pub/data/weather/uk/climate/stationdata/rossonwyedata.txt

Current temperature

14.20.5. The climate in the River Severn catchment is one of relatively mild winters and warm summers. As shown in Figure 14-1 and Figure 14-2~~Figure 14-2~~, monthly average and mean maximum temperatures are high for the UK. Across the timeseries, 1981-2010, peak summer (July) average maximum temperatures of 22 °C in the River Severn catchment are equal to the maximum across the UK. Note that mean maximum temperatures are calculated as the monthly average of daily maximums – as such some individual days are likely to have recorded hotter temperatures than those stated.

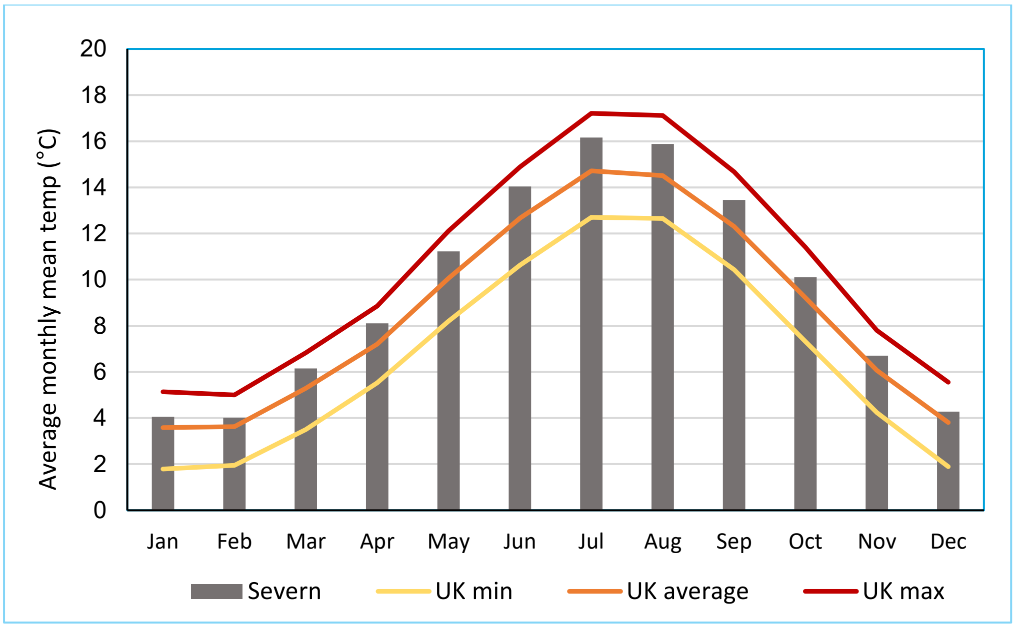

Figure 14-1 - Long-term average monthly mean temperature (°C) (1981-2010)

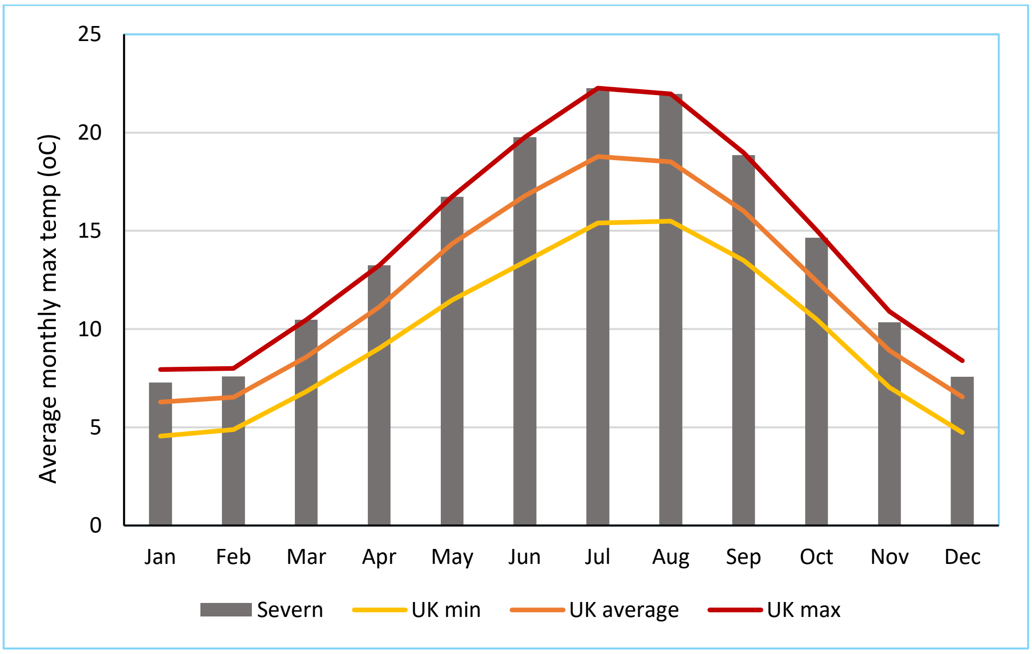

Figure 14-2 - Long-term average monthly maximum temperature (°C) (1981-2010)

Note: the maximum data presented is a monthly average of daily maximums.

14.20.6. Observations for the UK show that the decade leading up to the publication of UKCP18 (2008-2017) was on average 0.3°C warmer than the 1981-2010 average and 0.8 °C warmer than 1961-1990. All of the top ten warmest years have occurred since 2002[37].

14.20.7. The summer of 1976 was one of the hottest recorded in the UK and this is reflected in the temperature record at the Ross-On-Wye (Figure 14-3~~Figure 14-3~~). It was one of the driest, sunniest and warmest summers (June/July/August) in the 20th century. During that summer (1976) the hottest day was the 3 July where a temperature of 35.9 °C (96.6 °F) recorded in Cheltenham was the hottest in the UK[38]. Provisional data available for 2022 from the Ross-On-Wye shows August had an average summer maximum daily temperature of 25.4 °C – above all of the peaks shown on Figure 1-3.

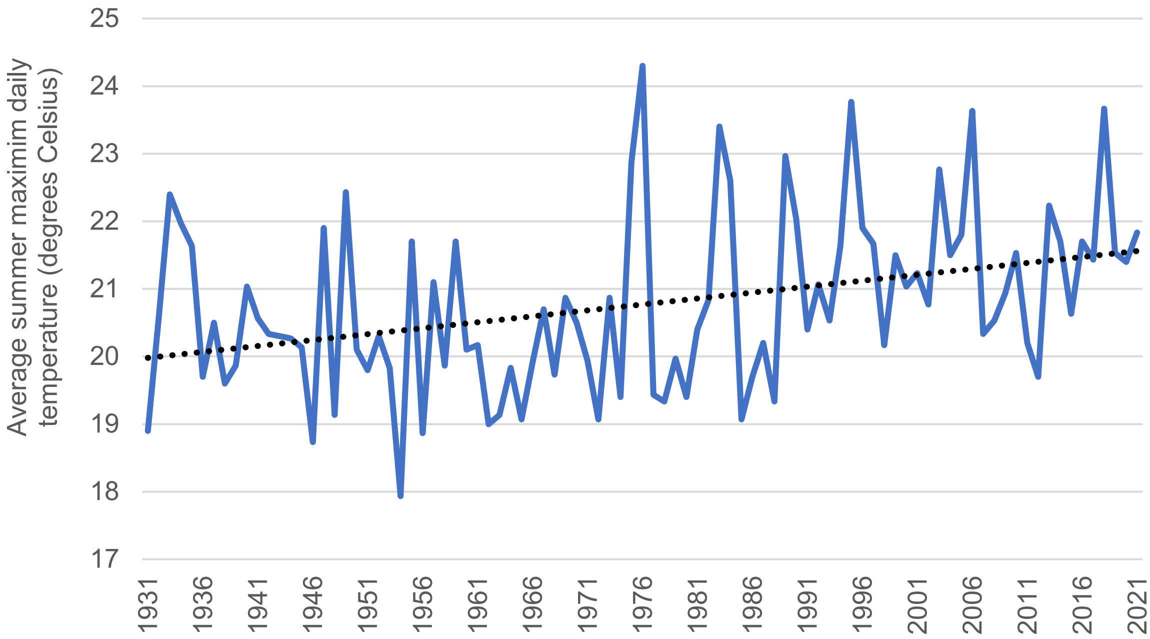

Figure 14-3 - Average summer maximum daily temperature (°C) (1930-2021) (Ross-On-Wye)

14.20.8. Observation from the Ross-On-Wye climate station reveal that two of the four highest monthly mean daily maximum temperatures (t-max) it has recorded have been since 2006. The 7 hottest years shown on Figure 14-3~~Figure 14-3~~ have all been in the second half of the data series. The data from the met station also shows that over the period 1930 to 2021 both the average daily summer maximum temperatures and average daily winter maximum temperatures have been increasing (conclusion based on linear trendlines on Figure 14-3~~Figure 14-3~~ and Figure 14-4~~Figure 14-4~~).

[37] https://www.metoffice.gov.uk/about-us/press-office/news/weather-and-climate/2019/state-of-the-uk-climate-2018
[38] https://www.bbc.co.uk/news/newsbeat-40358961

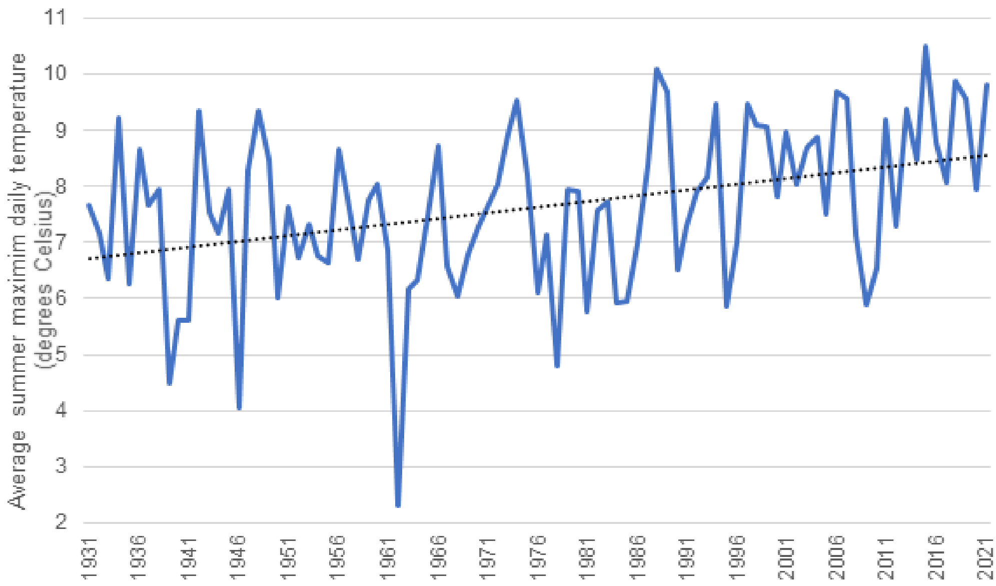

Figure 14-4 - Average winter maximum daily temperature (°C) (1930-2021) (Ross-On-Wye)

14.20.9. As shown in Figure 14-5 the long-term average days with ground frost (1981-2010) in the River Severn catchment are close to average for the UK.

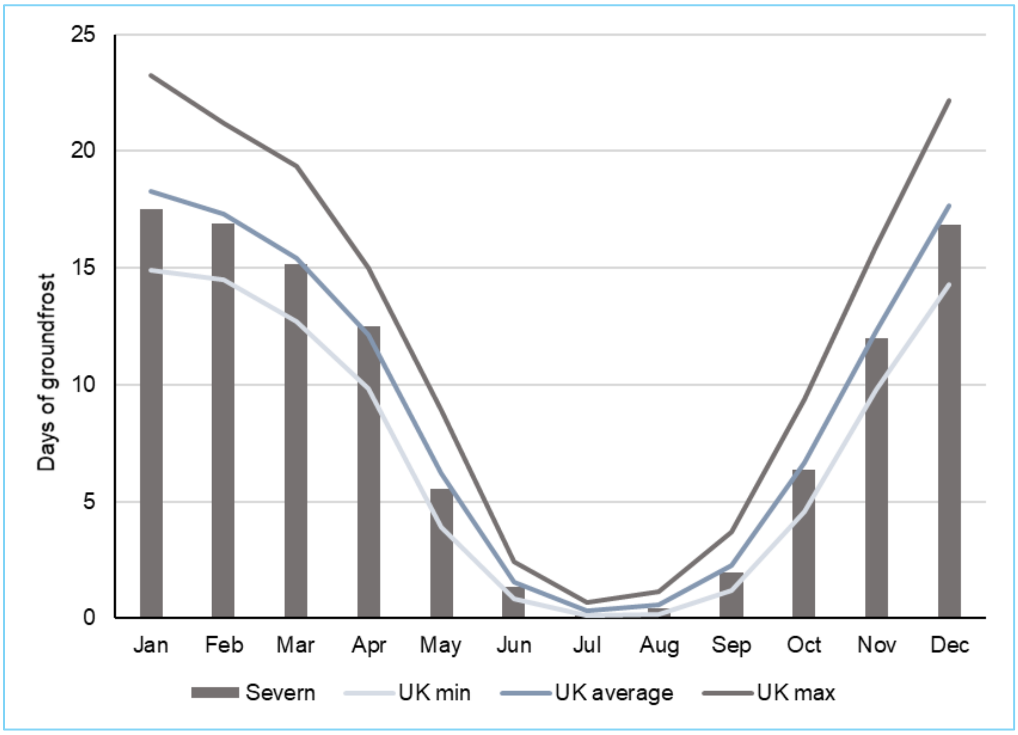

Figure 14-5 - Long-term average days with ground frost (1981-2010)

14.20.10. In accordance with the observed increasing winter temperatures (see Figure 14-4) the linear trendline on Figure 14-6 shows the number of days with air frost each winter has been reducing since 1930.

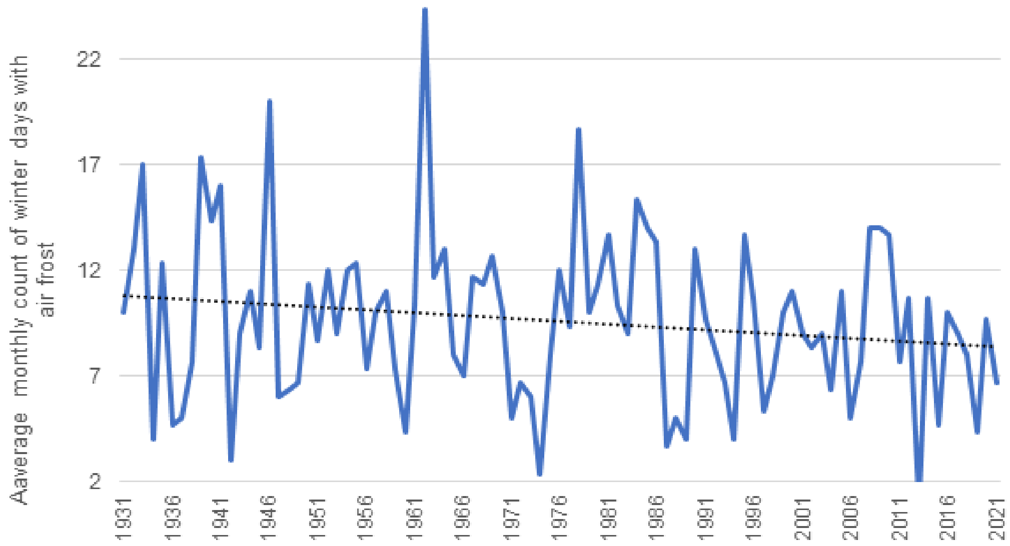

Figure 14-6 - Average monthly count of winter days with air frost (1930-2019) (Ross-On-Wye)

Current precipitation

14.20.11. Observations across the UK show a high level of variability in precipitation from year to year, with a slight overall increase in UK winter precipitation in recent decades.

14.20.12. As shown in Figure 14-7~~Figure 14-7~~, long-term average monthly rainfall (1981-2010) in the River Severn catchment is below average for the UK.

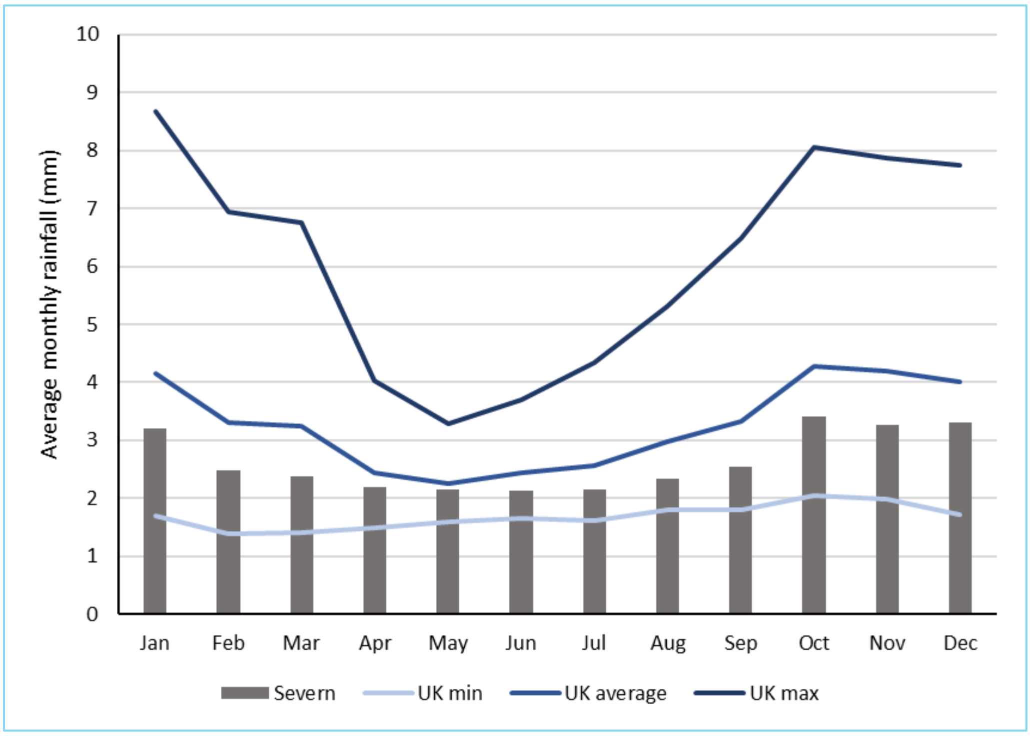

Figure 14-7 - Long-term average monthly rainfall (1981-2010)

14.20.13. Figure 14-8~~Figure 14-8~~ shows the long-term average number of days that had rainfall over 10mm. It shows that for most of the year the River Severn catchment experiences fewer heavy rainfall days than its usual (average) for the UK.

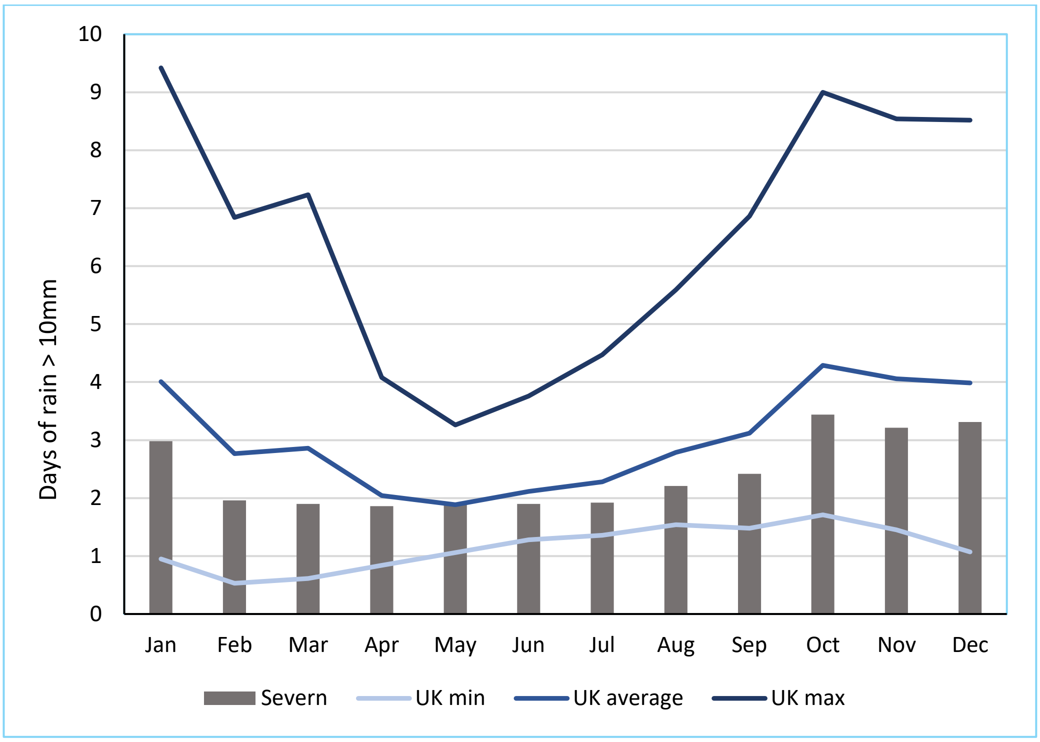

Figure 14-8 - Long-term average days with rainfall above 10mm (1981-2010)

14.20.14. Data from the Ross on Wye climate station shows that both summers and winters have variable precipitation and that rainfall in both these seasons has been increasing since 1930 (conclusion based on fit of linear trendline on Figure 14-9~~Figure 14-9~~ and Figure 14-10~~Figure 14-10~~). This is contrary to future projections, discussed later in the chapter, which indicate summers will get drier.

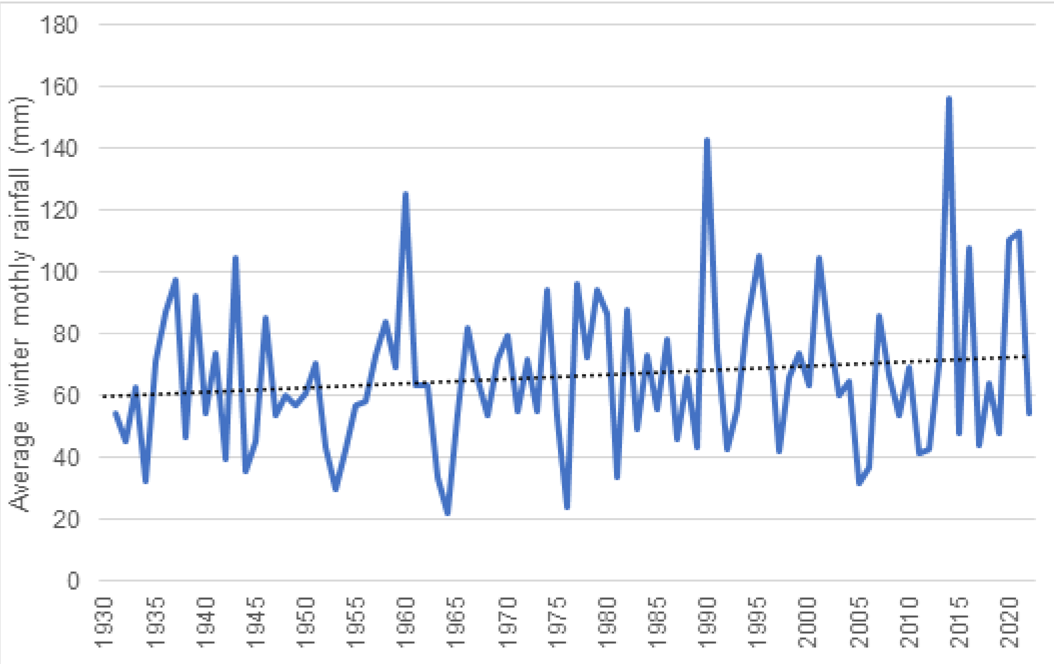

Figure 14-9 - Winter (Dec/Jan/Feb) average monthly rainfall (mm) (1930-2021) (Ross-On-Wye)

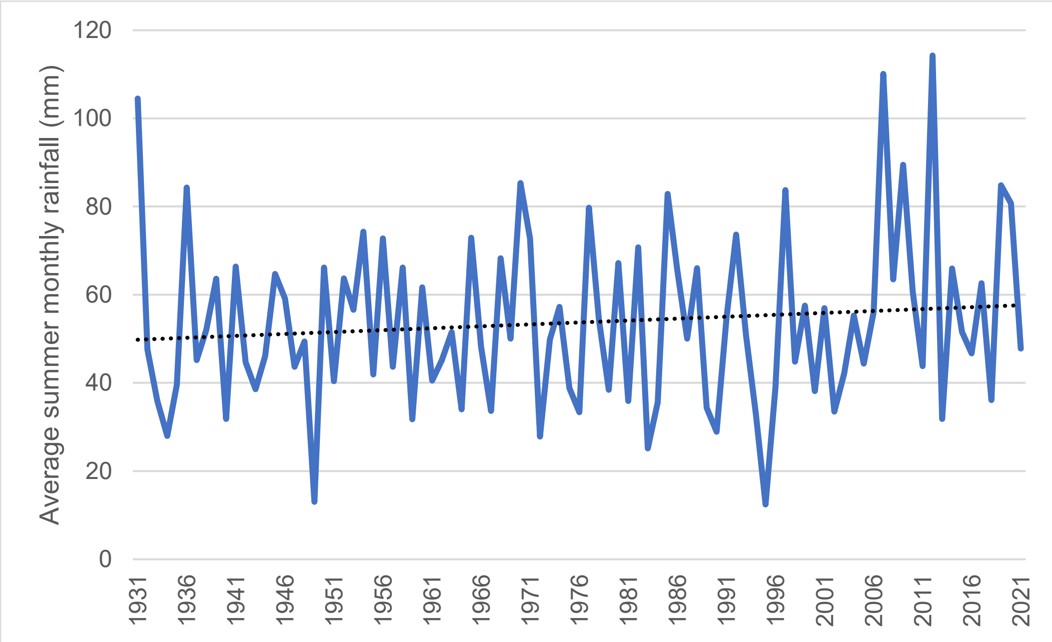

Figure 14-10 - Summer (June/July/Aug) average monthly rainfall (mm) (1930-2021) (Ross-On-Wye)

14.20.15. Across the UK the amount of rain from extremely wet days has increased by 17% when comparing the period 2008-2017 to 1961-1990 period (Met Office, 2018[39]). These changes are largest for Scotland and not significant for most of southern and eastern areas of England. Other extreme rainfall indices exhibit large inter-annual variability but are broadly consistent with increased rainfall over the UK. Other extreme rainfall indices exhibit large inter-annual variability but are broadly consistent with increased rainfall over the UK[40].

14.20.16. In the study area impacts from extreme weather have been recorded, for example:

- In October 2021 five flood warnings were issued across Gloucestershire. They covered the Bow and Piddle Brook, River Leadon catchment areas, River Lugg south of Leominster and the River Wye[41].
- In December 2020 drivers on the A435 were stranded when flash flooding inundated the road. Police closed the road to prevent further vehicles getting stranded[42].
- In July 2007 two month's rain (78 mm) fell in one day causing rapid and intense flash flooding that killed 3 people. Traffic on the M5 came to a standstill with about 10,000 motorists stuck overnight between junctions 10 and 12. Some 500 people were stranded at Gloucester Railway Station and rest centres were set up in Moreton-in-Marsh, Chipping Campden, Gloucester, Cheltenham and Tewkesbury for 2,000 people. Severn Trent Water's Mythe Water Treatment works was breached by floodwater leaving 350,000 people without clean, running water for 18 days. The following day the Castle Mead electricity sub-station was overwhelmed, cutting power to 48,000 people in Gloucester. 825 households – 1,950 people – had to leave their homes[43].

14.20.17. With regard to storminess, across the UK historical data provides no compelling trends as determined by maximum gust speeds from the UK wind network over the last four decades (UKCP18).

[39] https://www.metoffice.gov.uk/research/climate/understanding-climate/uk-and-global-extreme-events-heavy-rainfall-and-floods
[40] http://research.ncl.ac.uk/convex/ [accessed 21st February 2018]
[41] https://www.gloucestershirelive.co.uk/news/gloucester-news/flood-warnings-issued-gloucestershire-amid-6137749
[42] https://www.bbc.co.uk/news/uk-england-gloucestershire-55429889
[43] https://thefloods.gloucestershirelive.co.uk/

Projected future climates

14.20.18. This section presents the outputs of climate change models that cover the study area. In summary it finds that, on average, the UK is likely to experience hotter and drier summers and warmer and wetter winters. This is a widely agreed finding[44]. Alongside these changes in the average conditions, it is possible that climate change will also increase the frequency and severity of extreme weather events, such as heavy rainfall, storms and heatwaves.

14.20.19. Unless otherwise stated the climate projections presented in this section are probabilistic and from UKCP18. These projections have been developed by the Met Office Hadley Centre Climate Programme which is supported by the BEIS and DEFRA. They provide the most up-to-date assessment of how the climate of the UK may change over the 21st century. The projections presented are for the River Severn catchment, within which the Scheme is located. The data is presented as averages for the period 2071 to 2089 to align with the expected life of the Schemes assets (see Section 14.18.3). For temperature and precipitation seasonal data is provided for summer and winter only (not autumn and spring) as these seasons are where changes will be most extreme.

14.20.20. In accordance with LA114 (Section 3.28) the UKCP18 high emissions projections presented are for Relative Concentration Pathway 8.5 (RCP8.5). This is the most extreme emissions scenario, it represents a future where GHG emissions continue to rise, and the nations of the world choose not to switch to a low carbon future.

Temperature projections - Warmer winters

14.20.21. Figure 14-11~~Figure 14-11~~ shows that under RCP8.5 average winter temperatures in the River Severn catchment are expected to increase from 4.1ºC (observed average 1981-2010) to 7.0ºC (projected average 2071-2089), an increase of 2.9ºC (based on the central estimate, i.e. 50th percentile). The uncertainty around this estimate of change ranges from 1.1ºC to 4.8ºC (represented by the 10th and 90th percentiles respectively).

[44] https://www.daera-ni.gov.uk/articles/uk-climate-change-projections#:~:text=The%20projections-,The%20projections,to%204.9%C2%B0C%20hotter

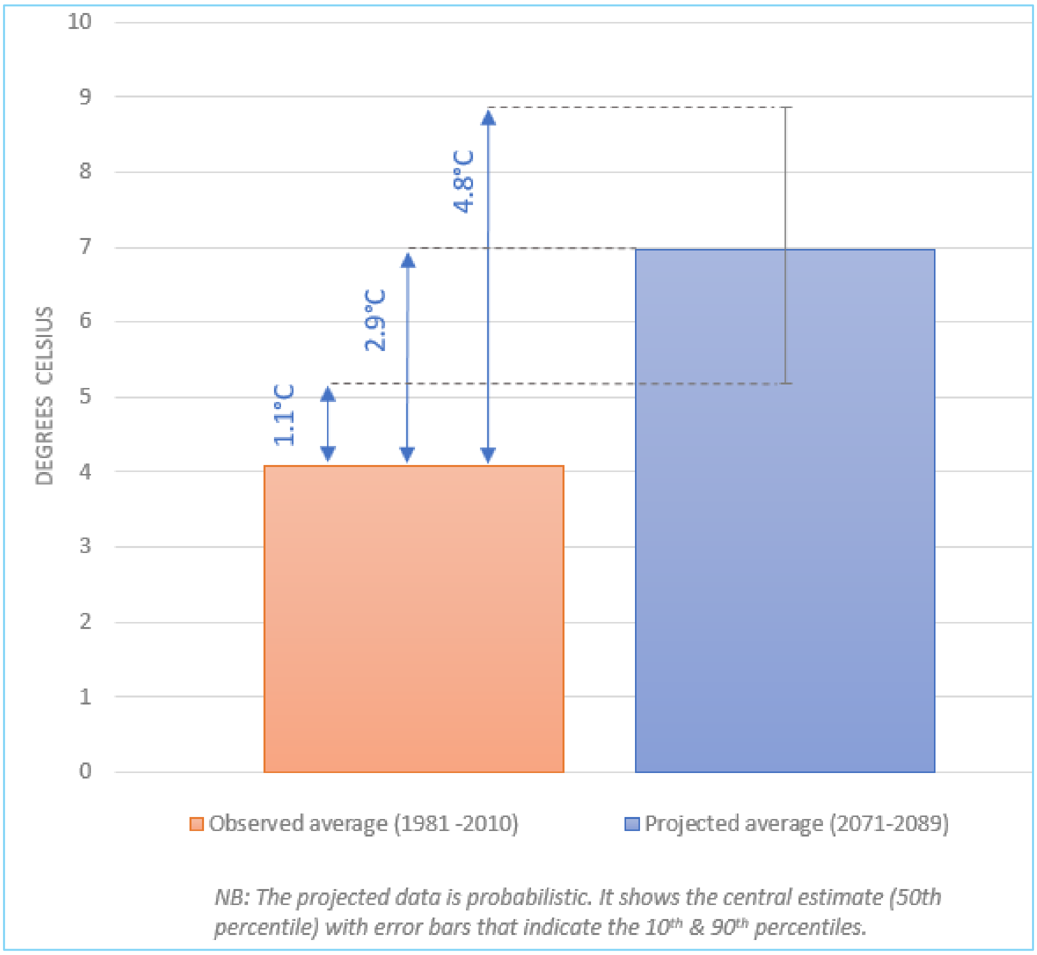

Figure 14-11 - Projected average mean winter temperatures (2071-2089)

14.20.22. In the UK, the heaviest snowfalls tend to occur when the air temperature is between zero and 2°C[45]. The projected increase in winter temperatures is therefore expected to reduce mean snowfall, number of snow days and heavy snow events[46]. While there is less certainty in the magnitude of these changes, there is confidence in the negative direction of the change[47]. This is supported by the fact that the decade leading up to the publication of UKCP18 (2008-2017) had 5% fewer days of air frost and 9% fewer days of ground frost compared to the 1981-2010 average, and 15% and 14% respectively compared to 1961-1990[48]. Figure 14-12~~Figure 14-12~~ shows a plume plot containing local results (2.2 km resolution) of RCP 8.5 projections for surface snow amount anomaly (mm), the median model result is highlighted. Only two of the twelve model outputs presented show positive values; and for both it is only within one year of the twenty-year time period presented. For the period 2061-2080, under a high emissions scenario (RCP8.5), the Regional (12km) and Local (2.2km) projections show a decrease in both falling and lying snow across the UK relative to the 1981-2000 baseline[49].

[45] Met Office. (2013). Met Office. [online] Available at: http://www.metoffice.gov.uk/learning/learn-about-the-weather/weather-phenomena
[46] Brown, S., Boorman, P. and Murphy, J. (2010). Interpretation and use of future snow projections from the 11member Met Office Regional Climate Model ensemble. UKCP09 Technical note, Met Office Hadley Centre, Exeter, UK
[47] McColl, L., Palin, E. J., Thornton, H. E., Sexton, D. M. H., Betts, R. and Mylne, K. (2012). Assessing the potential impact of climate change on the UK's electricity network. Climatic Change, 115: 821-835. OR McColl, L., Angelini, T. and Betts, R. (2012) UK Climate Change Risk Assessment for the Energy Sector. Department for Environment Food and Rural Affairs, London, UK
[48] Met Office, (2019) UKCP18 Science Overview Report, online: https://www.metoffice.gov.uk/pub/data/weather/uk/ukcp18/science-reports/UKCP18-Overview-report.pdf
[49] https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp18-factsheet-snow.pdf

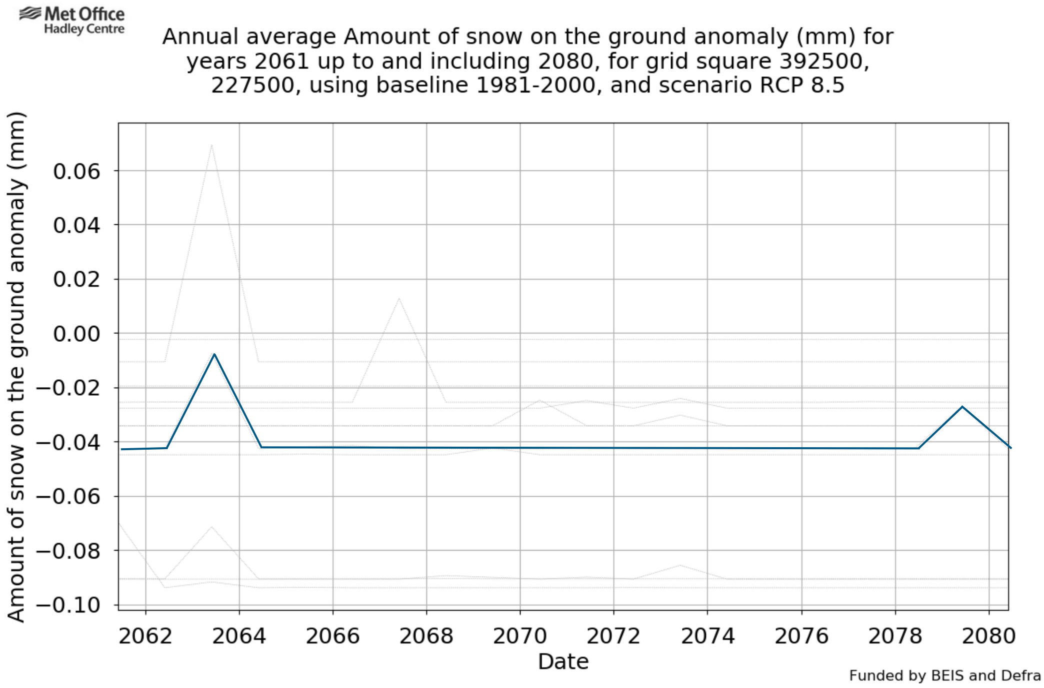

Figure 14-12 - Annual average amount of snow on the ground anomaly (mm) for years 2061 up to and including 2080 for the 5km grid square containing the Scheme (392500,227500)

Temperature projections - Hotter summers

14.20.23. In the recent past (1981-2000) the probability of seeing a summer as hot as 2018 in the UK was low (<10%). This probability has already increased due to climate change and is now estimated to be between 10-25%. With future warming, hot summers by the mid-century could become even more common (with probabilities of the order of 50% depending on the emissions scenario followed)[39]. The summer of 2022 was the joint, with 2018, hottest summer on record for England[50].

14.20.24. In the River Severn catchment, within which the Scheme is located, projected mean daily maximum summer temperatures have been obtained from the UKCP18 probabilistic projections for 2071-89. Since these are an average of summer daily maximum temperatures it should be noted that some days in this period are likely to be hotter than the values indicated below. Figure 14-13~~Figure 14-13~~ shows that an increase in summer temperatures is expected by the 2080s under RCP8.5. The central estimate (i.e., 50th percentile) projects an increase of 5.1ºC in summer mean daily maximum temperatures by 2071-89.

[50] https://www.metoffice.gov.uk/about-us/press-office/news/weather-and-climate/2022/joint-hottest-summer-on-record-for-england

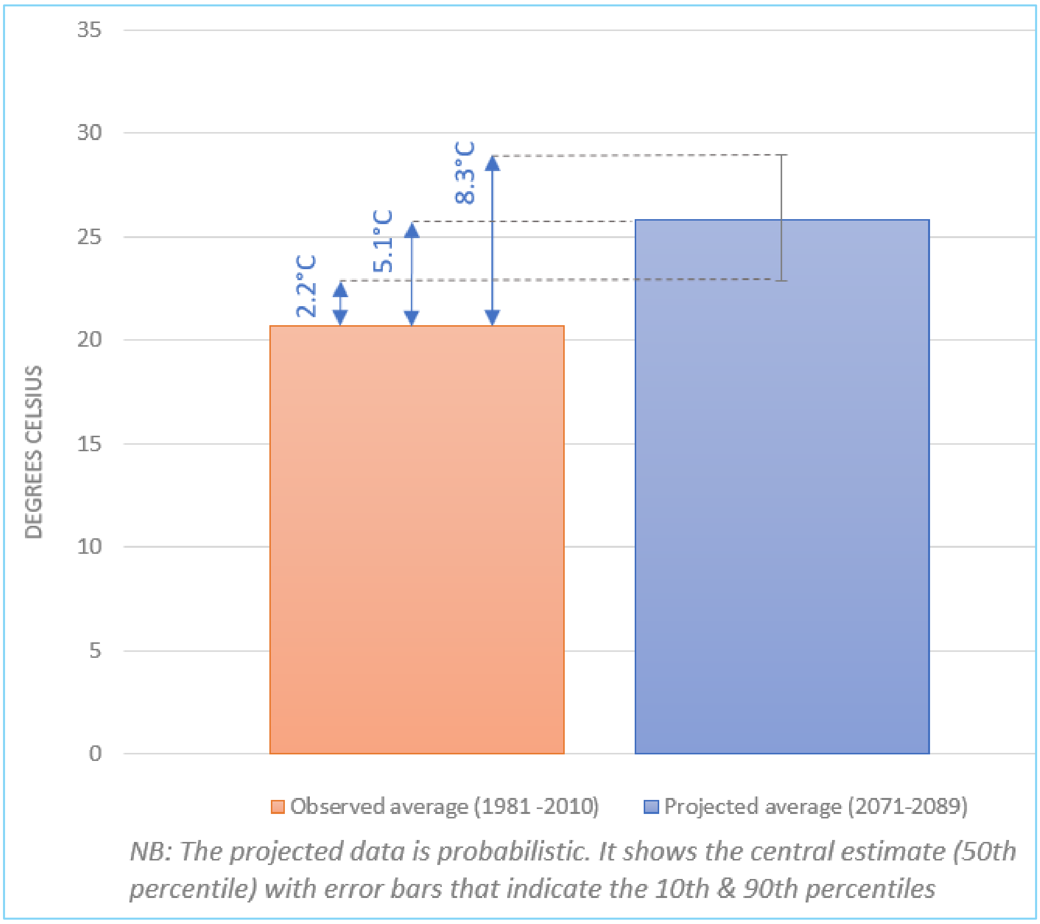

Figure 14-13 - Projected average maximum summer temperature (2071-2089)

Precipitation projections - Drier summers

14.20.25. Projected precipitation levels for RCP 8.5 have been averaged across the River Severn catchment, within which the Scheme is located, to give a range of projected average rainfall change between the 10% and 90% probability levels. As shown in Figure 14-14~~Figure 14-14~~ by 2071-89 this range amounts to a decrease in rainfall of between 0.1mm (7%) to 1.4mm (66%). The central estimate of change (i.e., 50th percentile) in mean summer precipitation for the same period is a 0.7mm reduction. These projections suggest that future average rainfall trends are uncertain, but it is more likely than not that summer rainfall will decrease. It is noted that historic observations recorded at the Ross-on-Wye climate station show average summer rainfall may have increased between 1930-2019 (see Figure 14-10~~Figure 14-10~~). This supports the finding that future average rainfall trends are uncertain.

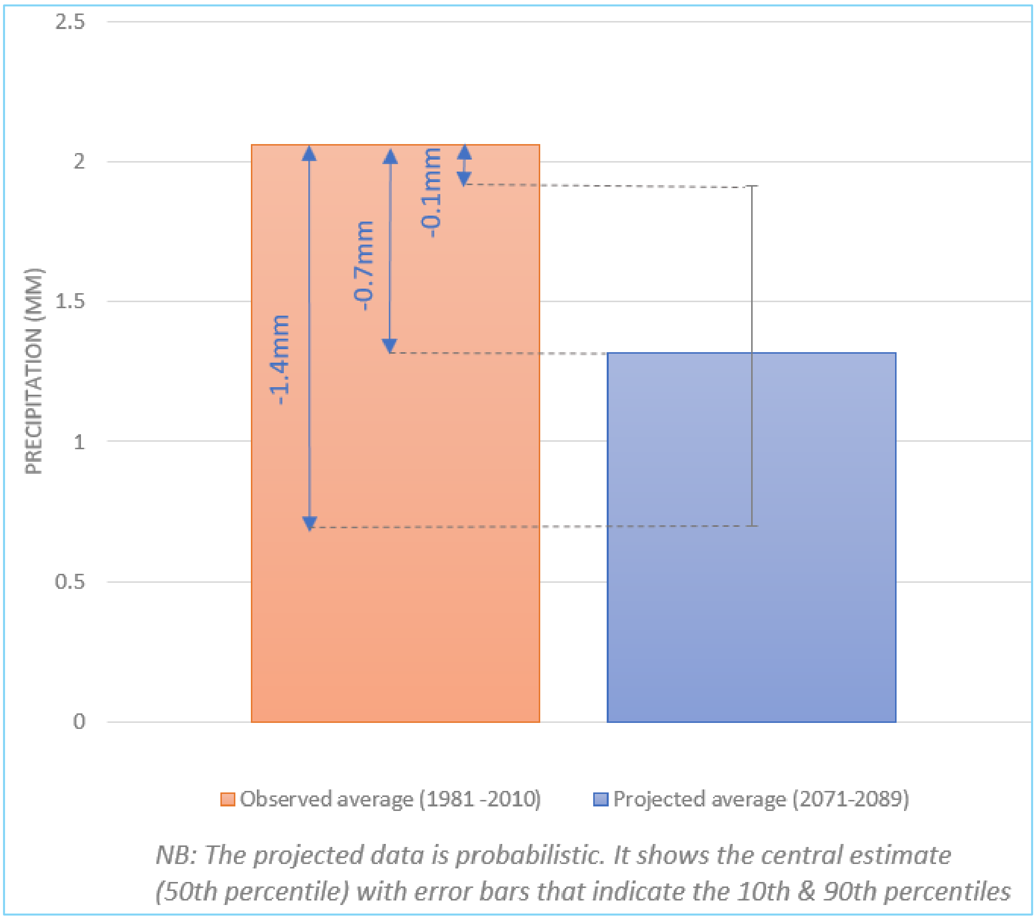

Figure 14-14 - Projected average summer precipitation (2071-2089)

Precipitation projections - Heavier rainfall and wetter winters

14.20.26. Figure 14-15~~Figure 14-15~~ shows that UKCP18 climate projections forecast that by 2071-89, under RCP 8.5 central estimate (~~i.e.~~i.e., 50th percentile), winter mean precipitation will increase by 0.5 mm. However, it should be noted that year to year levels are expected to continue to vary widely. This is demonstrated in the recent historical record in which the winter of 2013-14 stands out as having particularly high amounts of rainfall (Figure 14-9~~Figure 14-9~~), with over 150% of the 1981-2010 average UK winter rainfall.

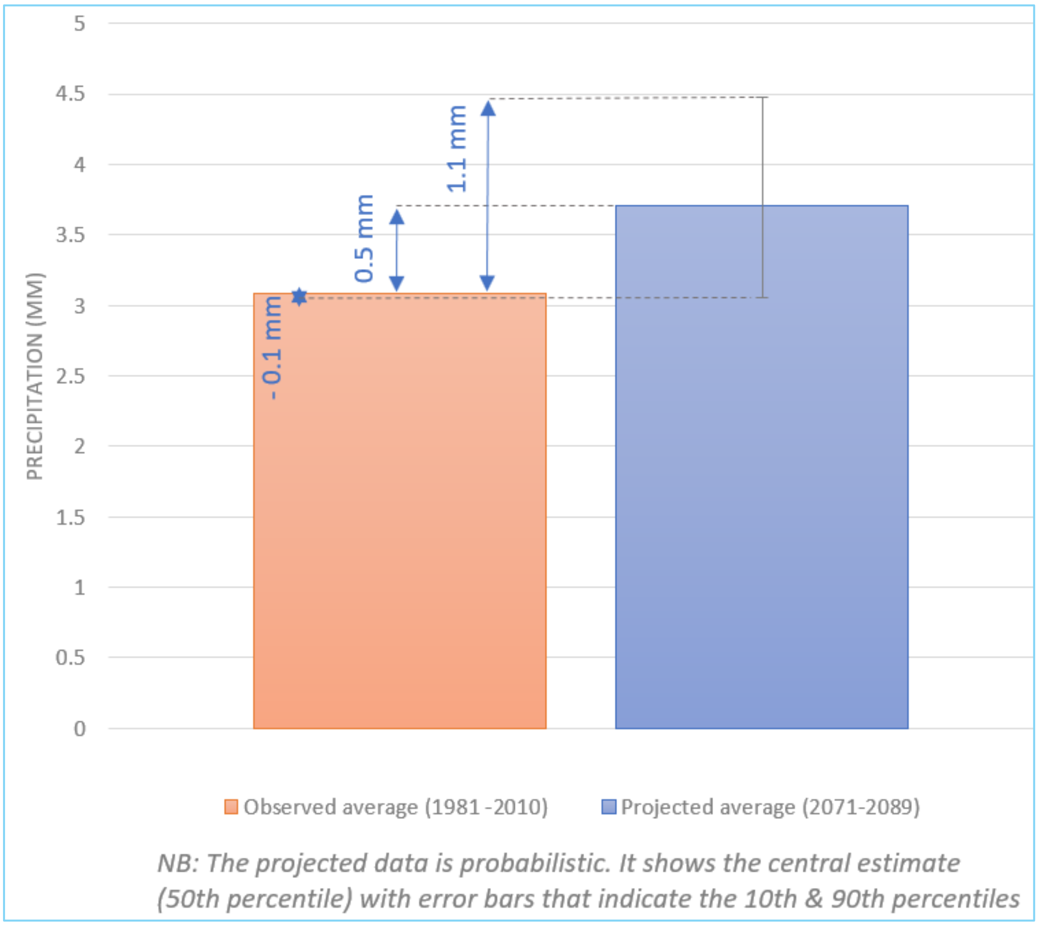

Figure 14-15 - Projected average winter precipitation (2071-2089)

14.20.27. Across the UK the amount of rain from extremely wet days has increased by 17% when comparing 2008-2017 with the 1961-1990 period[51]. Changes have been the largest for Scotland and are not significant for most of southern and eastern areas of England. Other extreme rainfall indices exhibit large inter-annual variability but are broadly consistent with increased rainfall over the UK.

Extreme weather projections

14.20.28. Future projections of storms and high winds are uncertain. They depict a wide spread of future changes in mean surface wind speed, see Figure 14-16~~Figure 14-16~~ which shows UKCP18 data specific to the 12 km grid square within which the Scheme is located. This uncertainty is partly due to large uncertainty in projected changes in circulation over the UK, and also because of wide ranging natural climate variability[52]. It is therefore difficult to represent extreme winds and gusts within regional climate models[41]. Global projections show an increase in near surface wind speeds over the UK for the second half of the 21st century for the winter season[53]. These studies suggest that climate-driven storm changes are less distinct in the Northern than Southern hemisphere[54]. There is some agreement of a projected poleward shift in storm tracks across the Atlantic Ocean. However, for mid-Atlantic storms, such as those that affected the UK in early 2014, projections are less certain[55]. Potentially, those mid-Atlantic storms may become more intense, particularly

[51] Met Office, UK extreme events, 2018, https://www.metoffice.gov.uk/research/climate/understanding-climate/uk-extreme-events-_heavy-rainfall-and-floods
[52] Brown, S., Boorman, P., McDonald, R., and Murphy. J. (2012) Interpretation for use of surface wind speed projections from the 11-member Met Office Regional Climate Model ensemble. Post-launch technical documentation for UKCP09. Met Office Hadley Centre, Exeter, UK. Crown copyright
[53] Met Office, UKCP18 Factsheet: Wind, www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp18-fact-sheet-wind.pdf
[54] Bengtsson, L., Hodges, K. I. (2005). Storm Tracks and Climate Change. Journal of Climate, 19: 3518-3543. http://dx.doi.org/10.1175/JCLI3815.1
[55] Slingo, J., Belcher, S., Scaife, A., McCarthy, M., Saulter, A., McBeath, K., Jenkins, A., Huntingford, C., Marsh, T., Hannaford, J. and Parry, S. (2014). The recent storms and floods in the UK, Met Office, Exeter, 29pp

with the long-term warming of the sub-tropical Atlantic that could increase the amount of moisture that those storms carry[56]. However, such is the wide range of inter-model variation, robust projections of changes in storm tracks over the UK are not yet possible, and there is low confidence in the direction of future changes in the frequency, duration or intensity of storms affecting the UK.

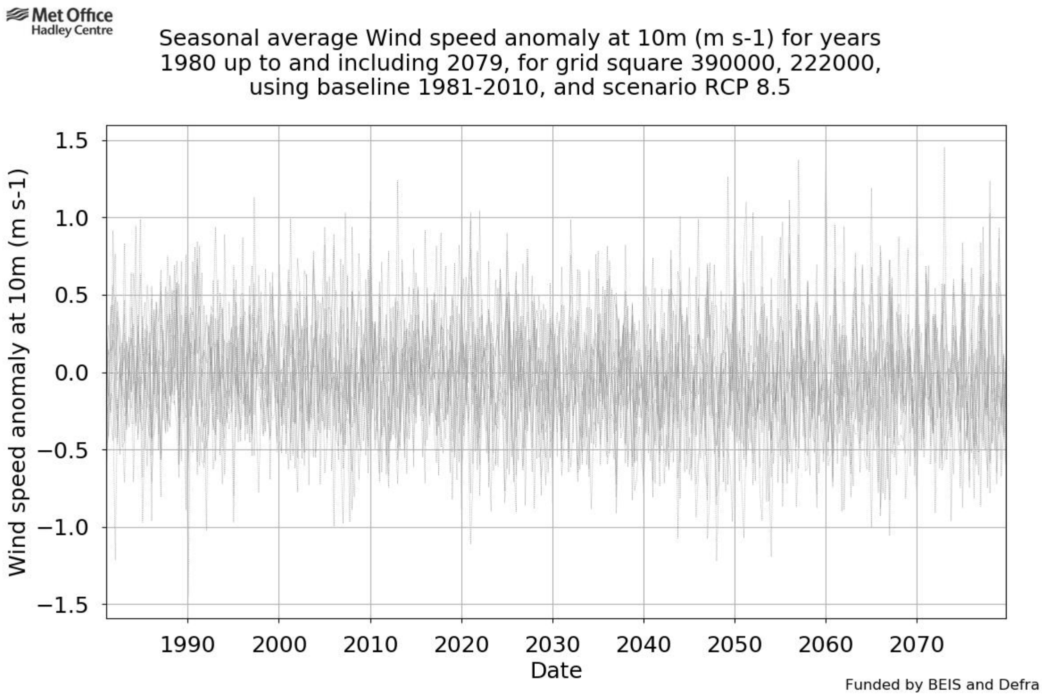

Figure 14-16 - Projected seasonal average wind speed anomaly (1980-2080)

14.21. Potential impacts

14.21.1. This section summarises the potential impacts of climate change on the Scheme that are assessed in detail later in this chapter.

Potential construction impacts

14.21.2. Construction related climate vulnerability impacts were scoped out of further assessment within the climate chapter of this ES. However, the current climate has changed significantly when compared to the baseline period of 1981-2010 (see the Climate Vulnerability Baseline, Section 14.20). Construction impacts associated with the current climate are not expected to impact construction unless construction coincides with extreme weather event(s) such as heatwaves, droughts or storms. These are not assessed in this chapter as, where they are potentially significant, they are addressed as required by the other topics within this report, for example see Chapter 8 - Road Drainage and the Water Environment (Aapplication document TR010063/—APP/-6.6) for the assessment of construction impacts associated with flood risk. A climate change allowance of a 53% increase in flow has been used in the flood modelling and assessment presented in Chapter 8.

Potential operational impacts

14.21.3. Potential operational impacts on assets (including their operation, maintenance and refurbishment) are listed below under the heading of the receptor they could affect:

- Road surfaces and pavements:
  - Warmer winters could reduce winter maintenance and associated traffic disruption (less road salting and freeze thaw damage).

[56] Ibid

  - Hotter summers could damage materials (rutting, shrinkage, and expansion) increasing maintenance requirements and associated traffic disruption.
  - Heavier rain and wetter winters could increase pothole formation (by weakening the soil beneath the carriageway) increasing maintenance requirements and associated traffic disruption.
- Structures (including embankments, earthworks, and bridges):
  - Hotter summers could reduce the asset lives of structures (over expansion and buckling) increasing maintenance requirements and associated traffic disruption.
  - Drier summers could cause soil instability (intensify and extend soil moisture deficits and impact groundwater levels and earth pressures) increasing maintenance requirements and associated traffic disruption.
- Drainage infrastructure:
  - Drier summers in combination with hotter temperatures could dry out soils and subsequently increase erosion. This may cause sedimentation within the Scheme's drainage infrastructure that reduces its drainage capacity and so increases the risk of flooding causing traffic disruption. Additional maintenance work to prevent flooding may also cause traffic disruption.
  - Heavier rain and wetter winters could increase the risk of pluvial or surface flooding. Flooding and additional associated maintenance requirements could both cause traffic disruption.
  - Warmer winters could reduce freeze thaw erosion which can damage underground assets. Reducing maintenance requirements and associated traffic disruption.
- Road technology and street furniture:
  - The frequency of extreme weather impacts on electrical equipment may increase, for example lightning strikes become more regular and extreme, humidity increases[57] and/or hot temperatures become more common causing thermal over loading of circuits. Repair and maintenance may cause traffic disruption.
  - High winds in more regular storms could overload small structures and signage and damage roadside planting and furniture. Repair and maintenance may cause traffic disruption.
- Landscaping:
  - Drier summers could damage the Scheme's landscaping. Moreover, hotter drier summers could more regularly create wildfire conditions. Fires would primarily affect landscaping but could potentially also affect other scheme assets e.g., road side furniture. Emergency responses and more regular preventative maintenance may cause traffic disruption.

14.21.4. Potential operational impacts on end-users are listed below, the potential receptor for all of these would be driver experience:

- Warmer winters could improve winter driver safety (less ice) and so reduce traffic disruption caused by accidents.
- Hotter summers could increase the number of vehicle breakdowns and so increase traffic disruption and the number of associated accidents.
- Hotter summers could increase accident rates and so increase traffic disruption.
- Heavier rain and wetter winters could reduce driver safety and so increase traffic disruption associated with accidents.

[57] https://www.metoffice.gov.uk/about-us/press-office/news/weather-and-climate/2020/scientists-investigate-humidity---the-second-pillar-of-climate-change

- Storms and high winds could reduce driver safety and so increase traffic disruption associated with accidents.

14.21.5. Potential operational impacts on environmental receptors that are related to, or could be intensified by, climate change are assessed as cumulative effects. These are summarised in Section 14.24.

Potential impacts related to a credible maximum climate change scenario

14.21.6. The preceding sections on potential construction and operational climate vulnerability impacts consider impacts that could arise based on the latest set of UK climate projections from UKCP18.

14.21.7. LA114, specifically Section 3.30 thereof, requires consideration of future climate scenarios that test the sensitivity of vulnerable safety critical features, to ensure that such features will not be affected by more radical changes to the climate that are beyond those projected in the latest set of UK climate projections. These extreme scenarios are referred to as credible maximum climate change scenarios. They are helpful for contingency planning, particularly for infrastructure that could have an operational lifetime beyond the end of the century.

14.21.8. The UKCP09 H++ scenarios[58] are a credible maximum climate change scenario and they are considered here to assess the impacts of low probability, high impact climate events including heat waves, drought, extreme winds, sea level rise and storm surge. It is noted that the Met Office has not produced new H++ allowances as part of UKCP18. They consider it is still appropriate to use the UKCP09 H++ allowances.

14.21.9. With regard to the Schemes design the safety critical features are considered to be:

- **Road safety technology** – The design will utilise various elements of motorway technology which will combine to create a safer driving environment. Specifically, to monitor traffic conditions, Motorway Incident Detection and Automatic Signalling (MIDAS) system will be provided. Post mounted Entry Stop Signals will also be provided to provide motorists with any advisory speed limit. In addition, Pan Tilt Zoom (PTZ) Closed Circuit Television (CCTV) will be sited to provide coverage of the carriageway for the purpose of traffic monitoring, incident control and management. There will also be Variable Message Signs (VMS) to display real time information designed to improve safety and journey times.
- **Flood risk design**– Essential for managing flood related impacts.

14.21.10. Extreme impacts on the above listed safety critical features will be managed as follows:

- An extreme climate change scenario is mostly likely to affect road safety technology by causing National Grid infrastructure to fail, i.e. via power cuts. It is noted that most of the Schemes road safety technology is advisory rather than safety critical - drivers are responsible to drive in a safe manner regardless of the technology. Accordingly, no back up power supplies are required for most of the road safety technology. The proposed communication network transmission station at J10 is an exception to this, it has power backup which would be used to report the loss of equipment (due to a power cut). In the event of a power cut the electrical supply to the Scheme would be treated as a priority supply for power restoration.
- The Scheme's FRA (Appendix 8.1, application document TR010063 – APP 6.15) includes consideration of upper end credible maximum peak river flows.

[58] https://www.theccc.org.uk/wp-content/uploads/2015/10/Met-Office-for-the-ASC-Developing-H-climate-change-scenarios-for-heatwaves-droughts-floods-windstorms-and-cold-snaps3.pdf

14.22. Mitigation measures

14.22.1. To understand the exposure and resilience of the Scheme design to climate change, information has been gathered from the design team and the environmental team about the Schemes climate mitigation measures.

14.22.2. The assessment of climate vulnerability impacts is undertaken after consideration of the Scheme design and mitigation. Embedded mitigation (part of the design), as well as mitigation that is additional to this (additional mitigation), that is specific to each potential impact is identified in Table 14-14~~Table 14-14~~ and Table 14-15~~Table 14-15~~.

14.23. Residual effects

14.23.1. The likelihood of each potential impact has been assessed along with the consequence of that impact if it occurred, with embedded mitigation in place. These assessments along with the resulting significance of effect are presented in two tables, one for each type of receptor:

- The assets and their operation, maintenance, and refurbishment (Table 14-14~~Table 14-14~~).
- End-users (Table 14-15~~Table 14-15~~).

Table 14-14 - Potential operational impacts on asset receptors (including their operation, maintenance, and refurbishment)

Climate trend	Potential impact	Embedded mitigation	Additional mitigation	Likelihood	Consequence	Significance
Road surfaces and pavements						
Warmer winters	The projected increase in winter temperatures and decrease in snowfall suggests a reduction in frequency of winter road maintenance (salting). Additionally, since freeze thaw erosion can damage underground assets, milder temperatures projected in the future may reduce the need for maintenance work that would otherwise disturb road surfaces and pavements.	NA as impact is beneficial.	NA as impact is beneficial.	**Medium** – Following the DMRB LA 114 standards and in line with the UKCP18 projections and the precautionary principle it is considered that there is high certainty that winter mean temperatures will increase over the Scheme's lifetime (in winter, under RCP 8.5, mean temperature is likely to increase by approximately 2.9ºC [central estimate]). However, projected changes to snowfall and the number of nights below freezing are less certain so the likelihood of this impact is found to be Medium.	**Minor beneficial** - During the Scheme's operation, road and pavement maintenance, upgrade works, and associated road traffic delays could reduce (minor beneficial). The reduced requirement for the operation of slow-moving salting vehicles would also avoid potential minor traffic disruption.	**Not significant**

Climate trend	Potential impact	Embedded mitigation	Additional mitigation	Likelihood	Consequence	Significance
Hotter summers	Hotter summers with longer warm spells[59] could damage materials, for example: • Ageing bituminous binders (deformation and rutting of road surfaces). • Softening, deforming, and damaging bitumen in asphalt. • Over expansion and buckling of concrete roads. • Failure of expansion joints. or • Wider temperature variations causing shrinkage and expansion that leads to cracking.	Best practice construction techniques and appropriate material quality standards will be followed to ensure the design lives specified can be met. For example, roads and pavements will use sufficiently hard binders in the asphalt. Polymer modified bitumen will be used in the pavement surface course and a resistance to permanent deformation will be specified as a requirement. Furthermore, heavy-duty macadam will be used in the binder and base course below which has an increased rut resistance. The drainage design will ensure the bound material is constructed on a sound foundation that should perform at it's optimum over the design life. To further improve the Scheme's longevity the design will investigate the use of warm mix asphalt, which has a reduced binder ageing during production as it is not heated to the same high temperatures as the conventional hot mix asphalt.	None	**Medium** - Following LA114 and in line with the UKCP18 projections and the precautionary principle it is considered that there is high certainty that summer mean temperatures will increase over the Scheme's lifetime (by 2071-89 summer mean daily maximum temperatures could be up to +5.1°C warmer [central estimate under emissions scenario RCP8.5]).	**Minor adverse** - Emergency repairs and more regular maintenance interventions may be required, in response to changes in deterioration rates. These would create associated traffic delays (minor adverse). Under extreme temperature, certain maintenance activities may be required to be undertaken at night, to keep work to schedule, thus incurring higher programme costs (e.g., labour and illumination) but causing less traffic disruption (negligible).	**Not significant**

[59] https://www.metoffice.gov.uk/research/climate/understanding-climate/uk-and-global-extreme-events-heatwaves

Climate trend	Potential impact	Embedded mitigation	Additional mitigation	Likelihood	Consequence	Significance
Heavier rain and wetter winters	Heavier rain and wetter winters will weaken the soil beneath the carriageway. Loads from traffic may then stress the surface past its breaking point.	The design will ensure continuity of drainage in the pavement and road layers. This will reduce the risk of water getting trapped in the foundation layers which could lead to an increase in moisture content and thus a decrease in performance i.e. lack of sufficient support to the overlaying bound material. A minimum water sensitivity category of 80 (indirect tensile strength ratio) and a minimum binder content based on the requirements of MCHW #942 will be specified where Thin Surface Course Systems (TSCS) are being applied. The design will specify that all materials within 450mm of the finished road level shall not be frost susceptible and in accordance with SHW Cl. 801.7 and 901.7. This may be reduced to 350mm if the Mean Annual Frost Index of the site is less than 50.	None	**Negligible** - Following National Highways guidance and in line with the UKCP18 projections and the precautionary principle it is considered that there is medium certainty that winter rainfall will increase over the Scheme's lifetime. Emission scenario RCP 8.5 suggests that a central estimate of mean winter precipitation change is an increase of 0.5 mm by 2071-89. Changes to extreme rainfall are less clear. The effect on pothole formation may be offset by the summers being drier and the winters being warmer (less freeze thaw erosion and less frost heaving; which are both significant contributors to pothole formation). It is therefore uncertain what the net impact of climate change will be. With the embedded mitigation the likelihood of impact is therefore determined to be Negligible.	**Minor adverse** - There may, in the future, be an increase in the number and severity of potholes in the study area. Potholes can damage tires, wheels, and vehicle suspension. In extreme circumstances they can also cause road accidents, particularly where there are higher speed limits. To avoid this there would need to be an increase in maintenance and repair works. All the above could create traffic disruption (minor adverse).	**Not significant**

Climate trend	Potential impact	Embedded mitigation	Additional mitigation	Likelihood	Consequence	Significance
Structures (including embankments, earthworks, bridges)						
Hotter summers	Hotter summers could reduce the asset lives of structures, for example causing: • Over expansion and buckling (e.g., of culverts or kerbs); or • Failure of expansion joints.	The design will ensure structures can adapt to expected future variations in temperature. The Eurocodes[60] used for the three bridges in the Scheme stipulate design to a temperature range of -18°C to 34°C which is adjusted to take account of altitude, material type and depth of surfacing thickness, etc.	Structures will be monitored throughout the life of the Scheme.	**Medium** - Following LA114 and in line with the UKCP18 projections and the precautionary principle it is considered that there is high certainty that summer mean temperatures will increase over the Scheme's lifetime (by 2071-89 summer mean daily maximum temperatures could be up to +5.1ºC warmer [central estimate under emissions scenario RCP8.5]).	**Minor adverse** - Emergency repairs and more regular maintenance interventions may be required, in response to changes in deterioration rates. These would create associated traffic delays (minor adverse). Under extreme temperature, certain maintenance activities may be required to be undertaken at night, to keep work to schedule, thus incurring higher programme costs (e.g., labour and illumination) but causing less traffic disruption (negligible).	**Not significant**

[60] The Eurocodes are European standards specifying how structural design should be conducted within the European Union. These were developed by the European Committee for Standardisation upon the request of the European Commission.

Climate trend	Potential impact	Embedded mitigation	Additional mitigation	Likelihood	Consequence	Significance
Drier summers and wetter winters	Climate change could adversely affect soil stability impacting structures. This could affect physical assets (e.g., foundations) as well as semi natural features (e.g. embankments) and natural structures (e.g. trees). Impact pathways include: • The expected reduction in summer average rainfall is likely to intensify and extend soil moisture deficits and impact groundwater levels. This could impact soil stability, for example causing subsidence or increasing earth pressures. • Wetter winters could cause soil instability as heave causes the upward movement of the ground; usually associated with the expansion of clay soils which swell when wet. • Wetter winters and heavier rain could cause weakening or washout of structural soils. • Wetter winters may increase regularity of soil saturation and increase risk of embankment collapse, i.e., landslip.	Risk will be managed by best practice design and construction. The geotechnical design will be in accordance with BS EN 1997-1:2004 Eurocode 7 Geotechnical Design Part 1 General rules. So, for example, cuttings and embankment works will be designed based on slope-stability analysis using site specific soil parameters. Additionally, to avoid waterlogging around embankments appropriate drainage will be included, for example so that runoff is collected and stored before being released gradually to infiltrate after a storm has passed, see DMRB, CG501 - Design of highway drainage systems. The geotechnical construction will be in line with DMRB Standards (DMRB CD 622 Managing Geotechnical Risk) so risks will be controlled, for example, by: • Providing appropriate soil compaction. • Completing stability assessments as part of design. Including analysis and modelling to predict maximum and permittable magnitude of movement. • Undertaking appropriate ground investigations. • Collecting appropriate groundwater flow data. • Where foundations extend below the existing groundwater table or could extend below the future groundwater level, they are designed in accordance with industry standards. • Monitoring during the construction works to measure movements, with agreed trigger level and action plan. In addition to the above, existing vulnerable assets in the study area will be regularly inspected to assess movements. This will be supported by reference to the full arboricultural survey that is being completed for the site and identifies large and/or unstable trees.	Vulnerable assets in the study area will be regularly inspected to assess movements.	**Medium** - Following LA114 and in line with UKCP18 projections and the precautionary principle it is considered that there is medium certainty that summers will get drier over the Scheme's lifetime. The central estimate of change in mean summer precipitation by 2071-89 is -0.7 mm under RCP 8.5. The likelihood is not high because of the uncertainty ranges from a 0.1 mm reduction (7% less) to a 1.4 mm reduction (66% less) (represented by the 10th and 90th percentile respectively).	**Minor adverse** - Drier summers could damage assets and increase maintenance and upgrade works causing associated traffic disruption (minor adverse).	**Not significant**

Climate trend	Potential impact	Embedded mitigation	Additional mitigation	Likelihood	Consequence	Significance
Drainage infrastructure						
Drier summers	Drier summers combined with the projected increase in summer temperatures could lead to increased erosion as soils and their substrates dry out. This could affect the capacity of drainage infrastructure.	Embankments will be compacted and planted. topsoil retention systems may be used if necessary. Although the detailed drainage design is not yet available it is assumed that it will assist operational maintenance by including accessible sediment traps that will be regularly cleared. It is also expected that the design will include concrete channels and swales, which will collect eroded sediment. There will be a number of attenuation ponds, which will have sediment forebays with specific arrangements to remove sediment before the water reaches the watercourse outfall. Sizing and treatment configuration will be confirmed by a sediment transport assessment. In addition to the above Chapter 9 – Landscape and Visual (application document TR010063 – APP 6.7) of this ES has proposed the following embedded mitigation: • Retain existing trees and vegetation wherever possible. Replace areas of trees and grass lost to facilitate the works wherever practicable.	None	**Medium** - Following LA114 and in line with UKCP18 projections and the precautionary principle it is considered that there is medium certainty that summers will get drier over the Scheme's lifetime. The central estimate of change in mean summer precipitation by 2071-89 is -0.7mm under RCP 8.5. However, the uncertainty around this estimate ranges from a 0.1 mm reduction (7% less) to a 1.4mm reduction (66% less) (represented by the 10th and 90th percentile respectively)..	**Minor adverse** - Mobilisation of debris could lead to increased sedimentation within the Scheme's drainage infrastructure adversely affecting its capacity. This could increase maintenance requirements and risk of flooding which could both cause traffic disruption (minor adverse).	**Not significant**

Climate trend	Potential impact	Embedded mitigation	Additional mitigation	Likelihood	Consequence	Significance
Heavier rain and wetter winters	The projected climate trend of increasing frequency and intensity of heavy rainfall events (potentially during summer months) is likely to increase the risk of pluvial or surface flooding as surface run-off inundates small catchments and the urban landscape. Prolonged periods of excessive precipitation (e.g., wetter winters) saturates soil, increasing the risk of fluvial or river flooding. Above average precipitation for long periods can also lead to a raised water table, which can result in groundwater flooding in areas where the geological characteristics are favourable.	Drainage infrastructure is designed with consideration of projected future changes in precipitation, both gradual changes to average amounts and changes to maximum amounts from extreme events. The drainage system will be designed in line with current standards set out in DMRB CG 501[61]. This provides guidance for surface drainage for trunk roads including motorways. The design will include raising the riding surface, using an appropriate camber, and providing appropriate maintenance. With regard to pluvial flood risk on the road surface, the surface water drainage system is designed to control runoff rates up to 1 in 100-year return period. Although there are various design storm-periods for different aspects of highway construction, ultimately the absolute rainfall thresholds are highly dependent on the local topography, adjacent land-use, gradient, and location within the wider catchment. The DMRB standards highlight the importance of this local information to assess absolute rainfall thresholds. This information is provided in the Scheme's FRA (Appendix 8.1, application document TR010063 – APP 6.15) which also includes consideration and allowance for climate change. The FRA sets out the allowance that has been used for the surface water drainage design with adjustment factors in line with the latest information in the PPG, Environment Agency and LLFA requirements. In short, a 70% climate change allowance has been used for the preliminary design as per Section 5.7.7 of Flood & Water Management Supplementary Planning Document by Tewkesbury Borough Council (March 2018).	None	**Medium** - Following National Highways guidance and in line with the UKCP18 projections and the precautionary principle it is considered that there is medium certainty that rainfall will get heavier over the Scheme's lifetime. Emission scenario RCP 8.5 suggests that a central estimate of mean winter precipitation change is an increase of 0.5 mm by 2071-89. Changes to extreme rainfall are less clear.	**Minor adverse** - New assets could be damaged, for example by scour around structures, which would then require maintenance. Both flooding and additional maintenance/repair could cause road closures and associated traffic delays (minor adverse).	**Not significant**

[61] https://www.standardsforhighways.co.uk/prod/attachments/ada3a978-b687-4115-9fcf-3648623aaff2

Climate trend	Potential impact	Embedded mitigation	Additional mitigation	Likelihood	Consequence	Significance
		A climate change allowance has also been applied to fluvial flows for the design of the flood compensation and flood storage areas (to determine their volume) and to determine the freeboard needed between the soffit of structures and the design flood water level of the rivers being crossed. In consultation with the Environment Agency, the “upper end” allowance of +70% to peak flows has been used when investigating the designs resilience to climate change and the “higher central” (35%) allowance used to determine design levels. Since the programme of design, climate change allowances set out in the NPPF have been updated to include the H++ (90%) allowance. As such, a further sensitivity run of 90% increase in flows has been applied to examine the vulnerability of this type of development (Essential infrastructure) to future flood risk. Further information is presented in the Scheme’s FRA, see above for reference.				

Climate trend	Potential impact	Embedded mitigation	Additional mitigation	Likelihood	Consequence	Significance
Warmer winters	Warmer winters reduce freeze thaw erosion which can damage underground assets.	NA as impact is beneficial.	NA as impact is beneficial.	**Medium** - Following National Highways guidance and in line with the UKCP18 projections and the precautionary principle it is considered that there is high certainty that winter mean temperatures will increase over the Scheme's lifetime (in winter, under the RCP8.5 emissions scenario, mean temperature is likely to increase by approximately 2.9ºC [central estimate]). However, projected changes to snowfall and the number of nights below freezing are less certain so the likelihood of this impact is found to be Medium.	**Minor beneficial** - During the Scheme's operation maintenance and repair works and associated traffic disruption could reduce.	**Not significant**

Climate trend	Potential impact	Embedded mitigation	Additional mitigation	Likelihood	Consequence	Significance
Road technology and street furniture (including signs and signals)						
Changes to extreme weather	Extreme weather impacts on electrical equipment: • More regular and intense storms in the future could increase the regularity of lightning strikes on infrastructure which could damage electrical equipment. • Extreme hot temperatures increase thermal loadings on electrical and control equipment reducing their life • Changes in humidity may affect reliability of electrical equipment (higher humidity increases condensation which can lead to corrosion, e.g. rust, causing short circuits, premature deterioration of performance, overheating or even electrical fires.	At the detailed design stage, electrical calculations will be carried out for the lighting and a risk assessment detailed in Section 443 of BS7671:2018[62] will be undertaken to determine if protection against transient overvoltage (lighting strike) is required. In advance of this, based on professional judgement and consideration of the location of the lighting power supplies/feeder pillars, it is expected at this stage that transient overvoltage protection will be included in the final design.	Key electrical components will be regularly checked, and replacement cycles may be shortened if deterioration rates increase.	**Low** – Climate projections show there is low certainty of how climate change will alter extreme weather in the future.	**Minor adverse** – Failure of the Scheme's lighting could cause traffic delays (minor adverse). To avoid this more regular maintenance may be required. This may itself cause traffic disruption (minor adverse).	**Not significant**

[62] https://shop.bsigroup.com/ProductDetail?pid=000000000030342613

Climate trend	Potential impact	Embedded mitigation	Additional mitigation	Likelihood	Consequence	Significance
Changes to extreme weather	High winds in more regular and intense storms could overload small structures and damage roadside planting and furniture, for example traffic signs.	• The landscape design will adhere to the Specification for Highways Works set out in Series 3000 (Landscape and Ecology) of the MCHW[63]. The design, within the M5 corridor, will also adhere to DMRB LD 117 which sets out that shrubs must not be planted within 4.5 m of the carriageway and large trees not within 9 m of it. • Highways England's own Adaptation Assessment[64] found that the effect of wind on bridges is minimal as it is not the dominant load. Fatigue actions due to wind gusting shall be determined in accordance with BS EN 1991-1-4, DMRB 365 and DMRB 354.	**None**	**Low** – Climate projections show there is low certainty of how climate change will alter extreme weather in the future.	**Minor adverse** – Partial road closures for unplanned minor repairs could cause traffic disruption (minor adverse). To avoid this more regular maintenance may be required for example shorter intervention/ strengthening intervals.	**Not significant**

[63] Manual of Contract Documents for Highway Works (MCHW), 2019, www.standardsforhighways.co.uk/ha/standards/mchw/index.htm
[64] Highways England Climate Adaptation Risk Assessment, 2016, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/596812/climate-adrep-highways-england.pdf

Climate trend	Potential impact	Embedded mitigation	Additional mitigation	Likelihood	Consequence	Significance
Landscaping						
Hotter and drier summers	Hotter and drier summers will increase soil moisture deficits in the future which could negatively impact the Scheme's landscaping. The landscaping has aesthetic benefits but also prevents excessive aeolian soil erosion and protects structures from surface water runoff scour. Additionally, hotter drier summers could more regularly create wildfire conditions. Fires would primarily affect landscaping but could potentially also affect other scheme assets e.g., road side furniture.	The proposed landscape design will futureproof the Scheme in terms of climate change as well as in terms of pests/diseases by adhering to best practice. This will include diversifying planting species as much as possible, including drought tolerant species, whilst still having regard to the local character, and generally planting only native species. It will also adhere to best ecological practice. Fast growing species that are vulnerable to drought will be avoided to reduce wildfire risk.	None	**High** - Following LA114 and in line with the UKCP18 projections and the precautionary principle it is considered that there is high certainty that summer mean temperatures will increase over the Scheme's lifetime (by 2071-89 summer mean daily maximum temperatures could be up to +5.1ºC warmer [central estimate under emissions scenario RCP8.5]).	**Negligible** – Additional maintenance would cause minimal traffic disruption as it is unlikely to require lane closures.	**Not significant**

Climate trend	Potential impact	Embedded mitigation	Additional mitigation	Likelihood	Consequence	Significance
Maintenance workers						
Hotter and drier summers	Increased exposure of maintenance workers to uncomfortably high temperatures resulting in health problems such as heat stroke.		During heatwaves maintenance schedules will be reviewed, this may result in increased night work; when temperatures are lower. For daytime work additional PPE may be required and more regular water breaks may be necessary.	**High** - Following LA114 and in line with the UKCP18 projections and the precautionary principle it is considered that there is high certainty that summer mean temperatures will increase over the Scheme's lifetime (by 2071-89 summer mean daily maximum temperatures could be up to +5.1°C warmer [central estimate under emissions scenario RCP8.5]).	**Negligible** – Adjusted maintenance schedules are not likely to cause any traffic disruption, on the contrary they could potentially improve traffic flows.	**Not significant**

Table 14-15 - Potential operational impacts on end user receptors

Climate trend	Potential impact	Embedded mitigation	Additional mitigation	Likelihood	Consequence	Significance
Driver experience						
Warmer winters	Warmer winters will improve winter driver safety by reducing driving risks for road users as roads will be less icy and snowfall will reduce visibility less often.	NA as impact is beneficial.	NA as impact is beneficial.	**High** - Following National Highways guidance and in line with the UKCP18 projections and the precautionary principle it is considered that there is high certainty that winter temperatures will increase over the Scheme's lifetime (in winter, under emissions scenario RCP8.5, mean temperature is likely to increase by approximately 2.9ºC [central estimate]).	**Minor beneficial** - Reduction in road traffic accidents and associated traffic disruption. Although it is noted that this beneficial impact would be equally present both with and without the Scheme.	**Not significant**

Climate trend	Potential impact	Embedded mitigation	Additional mitigation	Likelihood	Consequence	Significance
Hotter summers	Climate change will increase average summer temperatures. Vehicle breakdowns are more common during warm weather because the heat puts stress on critical components.	The M5 through Junction 10 will have a continuous hard shoulder throughout. MIDAS queue detection, CCTV and Emergency Roadside Telephones (ERTs) will be used to monitor traffic and breakdowns in line with standard motorway operating procedures.	None	**High** - Following LA114 and in line with the UKCP18 projections and the precautionary principle it is considered that there is high certainty that summer mean temperatures will increase over the Scheme's lifetime (by 2071-89 summer mean daily maximum temperatures could be up to +5.1 ºC warmer [central estimate under emissions scenario RCP8.5]).	**Minor adverse** - Breakdowns can have the following adverse effects: • Cause drivers to lose control of their vehicle - e.g. in the event of a tyre blowout or brake failure (both can be associated with warmer weather). • Increase the likelihood of vehicle fires and associated risks for road users. • Be dangerous for drivers stranded in a live traffic lane, and • Cause secondary accidents involving other road users. All the above can cause minor adverse traffic disruption consequences (due to obstruction of traffic or as traffic slows to pass).	**Not significant**

Climate trend	Potential impact	Embedded mitigation	Additional mitigation	Likelihood	Consequence	Significance
Hotter drier weather	Climate change will increase average summer temperatures. During warm weather, accident rates typically increase. This is attributable to more solar glare, more people being out (particularly in the evening), more pedestrians and bikes on the road and an increase in fine particulates on the road surface which reduces skid resistance. Additionally, other contaminants, such as oil and tyre rubber can build up in drier weather acting as lubricants further reducing skid resistance.	The long-term landscape design does not include large areas of exposed soil that could become mobile in hot dry weather (blowing onto the road and reducing skid resistance). The design will utilise various elements of motorway technology which will combine to create a safer driving environment. Specifically, to monitor traffic conditions, Motorway Incident Detection and Automatic Signalling (MIDAS) system will be provided. Post or gantry mounted Advanced Motorway Indicators (AMIs) will also be provided to provide motorists with speed limit and lane control information. In addition, Pan Tilt Zoom (PTZ) Closed Circuit Television (CCTV) will be sited to provide coverage of the carriageway for the purpose of traffic monitoring, incident control and management. There will also be Variable Message Signs (VMS) to display real time information designed to improve safety and journey times. It is noted that risks associated with driving cannot be fully removed by changes to the Scheme design. This reflects the fact that the cause of most traffic accidents is composite and often includes driver error.	Regular maintenance assessments of the road will follow the National Highways skid policy which takes into account climate change[65].	**High** - Following LA114 and in line with the UKCP18 projections and the precautionary principle it is considered that there is high certainty that summer mean temperatures will increase over the Scheme's lifetime (by 2071-89 summer mean daily maximum temperatures could be up to +5.1 ºC warmer [central estimate under emissions scenario RCP8.5]).	**Minor adverse** – More dangerous driving conditions in the future could increase road traffic accidents and associated traffic disruption (minor adverse).	**Not significant**

[65] Skidding resistance requirements, 2019, http://www.standardsforhighways.co.uk/ha/standards/dmrb/vol7/section3/CS%20228%20Skidding%20resistance-web.pdf

Climate trend	Potential impact	Embedded mitigation	Additional mitigation	Likelihood	Consequence	Significance
Heavier rain and wetter winters	In the future heavier rain resulting from climate change will create dangerous driving conditions more often as spray reduces visibility, stopping distances increase and standing water creates an aquaplaning risk.	To inform the design of the Scheme an FRA (Appendix 8.1) has been completed along with a detailed Drainage Strategy and the Road Drainage and Chapter 8 – Road Drainage and the Water Environment (application document TR010063 – APP 6.6). This describes how the Scheme has ensured drainage will be sufficient for future rainfall. It is noted that risks associated with driving cannot be fully removed by changes to the Scheme design. This reflects the fact that the cause of most traffic accidents is composite and often includes driver error.	None	**Medium** - Following National Highways guidance and in line with the UKCP18 projections and the precautionary principle it is considered that there is medium certainty that rainfall will get heavier over the Scheme's lifetime. Emissions scenario RCP8.5 suggests that a central estimate of mean winter precipitation change is an increase of 0.5 mm by 2071-89. Changes to extreme rainfall are less clear.	**Minor adverse** - Accident rates could increase creating more traffic disruption (minor adverse).	**Not significant**

Climate trend	Potential impact	Embedded mitigation	Additional mitigation	Likelihood	Consequence	Significance
Changes to extreme weather	More frequent storms and high wind events could affect road user safety. High-sided vehicles can become unstable in gusts of wind over 45 mph. Windblown debris, including loads detached from vehicles and third-party structures blowing onto the network, as well as fallen trees could also be a hazard to vehicles traveling at speed.	The road alignment is not at a high elevation or particularly exposed, e.g., along a ridge. Significant traffic disruption related to wind exposure is therefore not expected. The landscape design will adhere to the Specification for Highways Works set out in Series 3000 (Landscape and Ecology) of the MCHW[66]. The design will also adhere to DMRB LD 117 which sets out that shrubs must not be planted within 4.5 m of the carriageway and large trees not within 9 m of it.	None	**Low** – Climate projections show there is very low certainty of how climate change will alter extreme weather in the future.	**Minor adverse** - road traffic accidents and associated traffic disruption (minor adverse).	**Not significant**

[66] Manual of Contract Documents for Highway Works (MCHW), 2019, www.standardsforhighways.co.uk/ha/standards/mchw/index.htm

14.24. Cumulative effects on vulnerability to climate change

14.24.1. There are two types of cumulative effect:

- **Intra-Scheme:** the combined impact of multiple effects relevant to a scheme on a single receptor, for example, considering how climate change could intensify any of the impacts on environmental receptors that are reported by the other topic chapters within this report. (Also known as an In-combination Climate Change Impacts (ICCI) Assessment);).
- **Inter-project:** This considers the effects of the Scheme and the Scheme interacting with other Reasonably Foreseeable Future Projects (RFFPs) on climate vulnerability receptors.

Intra-Scheme cumulative effects (ICCI Assessment) within topic

14.24.2. It is possible that intra-Scheme effects could arise due to the Scheme. The following sub sections present potential intra-Scheme cumulative climate impacts that are not covered elsewhere in this report, i.e. by the relevant topic chapters.

Intensification of air quality impacts

14.24.3. In the future air quality impacts caused, in part, by vehicle emissions enabled by the Scheme will be intensified as hotter summers brought on by climate change will increase the formation of ground-level ozone, which is a dangerous air pollutant. A detailed assessment of air quality impacts is provided in Chapter 5 - Air Quality (Aapplication document TR010063/—APP/-6.3). It is noted that air quality modelling undertaken to date does not account for expected climate changes that will intensify air quality impacts in the future. However, these impacts will likely be offset by the predicted future fleet wide shift toward electric and hybrid vehicles.

Reduced road salting providing benefit for water environment

14.24.4. Warmer winters in the future will reduce the requirement for road salting. This may have benefits for the water environment in the study area with regard to water quality as road salt can be transported in surface water runoff and, in large quantities, can be harmful to aquatic life.

Lower river levels intensifying impacts from surface water runoff discharges

14.24.5. Most of the surface water runoff associated with the Scheme, once operational, will ultimately be discharged to surface or groundwater. Hotter and drier summers may lower water levels in surface watercourses. In the future water quality impacts related to surface water drainage discharges, for example downstream of outfalls, could increase as the capability of these watercourses to dilute discharges reduces. The design includes SuDS, which will maintain and manage the water quality and flow of discharges within appropriate thresholds prior to discharge. The surface water discharges within the Scheme therefore do not rely upon dilution to avoid environmental impacts. The SuDS have been sized with consideration of the impacts of climate change (heavier rain and wetter winters).

More polluted surface water runoff impacting water environment

14.24.6. Climate change is projected to make summers drier, with occasional heavier convectional rainfall. Water quality in the watercourses that will receive surface water runoff due to the Scheme may therefore, in the future, become more vulnerable to impacts from first flush events. This is when long periods of dry weather enable contaminants to build up on road surfaces. These then mobilise in surface water runoff following a heavy rainfall event and enter aquatic systems via surface water runoff and drainage infrastructure at higher than normal concentrations. Pollutants in this runoff can be harmful to aquatic life.

14.24.7. Water quality impacts on the water environment are avoided by inclusion of adequate treatment within the Scheme (SuDS) infrastructure. This treatment is sized with regard to flood flows with a climate change allowance. The SuDS intercept any polluted run-off and treat it prior to discharge to a watercourse. The water treatment processes provided by the SuDS primarily comprises filtration and biological treatment within attenuation basins. The configuration of the SuDS and other treatment infrastructure is designed to manage the types of pollutant typically expected in road runoff.

Inter-project cumulative effects within topic

14.24.8. The inter-project cumulative effect climate change vulnerability assessment has been completed with reference to the list of RFFPs that has been developed for the Scheme. The list is based on a review of all developments known to the planning system using the methodology described in Chapter 4 – Environmental Assessment Methodology of the ES (Aapplication document TR010063/—APP/-6.2).

14.24.9. Following review of this list, no potential inter-project cumulative effects are identified. This is because the RFFPs will not affect the likelihood of climate hazards or their consequences on the Scheme in ways that have not already been considered within the climate vulnerability assessment. Whilst the construction and operation of the RFFPs would result in GHG emissions, the climate vulnerability baseline used in the assessment of the Scheme uses UKCP18 climate projections, which already take into account future emissions trends including expected GHG increases from development at a national scale. It is therefore not necessary to consider local inter-project cumulative effects on climate vulnerability impacts as their impact has already been considered in the assessment.

14.24.10. Given this Scheme's importance to regional transport, in addition to RFFPs, it is also prudent to consider potential inter-project effects associated with the wider regional transport network (built and planned), particularly with regard to their collective resilience to climate vulnerability impacts.

14.24.11. There are alternate road routes around the Scheme using A roads. Junction 9 is well connected to Junction 11a with A roads via the outskirts of Gloucester and Tewkesbury. This route, and others around the Scheme, including rail links, would provide resilience in the event of climate vulnerability impacts on the Scheme. In addition to the regional A roads around the Scheme, the study area also contains a reasonably high density of local roads that provide some flexibility at an unforeseen point of traffic disruption that caused re-routing.

14.24.12. Climate vulnerability impacts assessed in the Environmental Statement have been reviewed to identify which could cause the most significant worst case inter-project cumulative effects on the Scheme and existing transport schemes around it, i.e., on local and regional transport infrastructure. The impact identified is the projected climate trend of increasing frequency and intensity of heavy rainfall events that are likely to increase the risk of flooding in the study area, both pluvial and fluvial. Of all the potential climate vulnerability impacts described in Section 14.23, flood risk is considered to be the most likely to cause wide-spread disruption related to a climate event. This is as opposed to many of the other effects, which relate to slow onset climate changes, such as gradual increases in temperature – these slower onset impacts have consequences that can typically be more easily mitigated.

14.24.13. Without the Scheme, flooding after an extreme rainfall event could cause closures of some local roads around the Scheme and disruption on some of the larger roads around it e.g., lane closures. Adverse future changes to flood risk are likely to affect local roads most significantly; the SRN (trunk roads and motorways) and railway lines having a higher level of flood protection.

14.24.14. Similar impacts to those listed above could be expected in a with Scheme scenario, though to a lesser extent. The Scheme has been designed to relevant standards with regard to anticipated climate change effects on flood risk. It will therefore improve transport resilience by replacing old degrading assets that were designed with less resilience to climate change than the assets that will replace them. It will also improve accessibility in the study area – thereby reducing traffic disruption and increasing accessibility and so improving resilience to consequences caused by climate vulnerabilities, e.g. failures of surrounding local and regional transport networks, when (compared to the without Scheme scenario). Further details on the climate change mitigation that is embedded into the Scheme design can be found in Section 14.23.

14.25. Assumptions and limitations

14.25.1. The climate vulnerability assessment provides a broad, high-level indication of the potential impacts of climate change on the Scheme based on professional judgement.

14.25.2. The climate projections used are from UKCP18. The UKCP18 projections do not provide a single precise prediction of how weather and climate will change years into the future. Instead UKCP18 provides ranges that aim to capture a spread of possible climate responses. This better represents the uncertainty of climate prediction science. It should also be noted that the level of uncertainty of the projections is dependent on the climate variable, for example, there is greater confidence around changes in temperature than there is in wind. In the climate vulnerability assessment this is considered when assessing the likelihood of impacts.

14.25.3. The climate vulnerability assessment is based on data from RCP 8.5. This is a GHG concentration trajectory under which it is assumed that emissions continue to rise throughout the 21st century. There is considerable uncertainty regarding if, how far and how quickly emissions will be reduced in the future. Using RCP 8.5 represents a conservative position.

14.25.4. Other key caveats and limitations of UKCP18 data are presented on the Met Office website[67].

14.26. Chapter summary

14.26.1. This chapter has presented the Scheme's climate change vulnerability assessment. The assessment considered the potential impacts of extreme weather and possible future climatic conditions on the Scheme during both its construction and operation and has been undertaken in compliance with DMRB LA114.

14.26.2. Climate projections from UKCP18 have been examined. They confirm that the study areas climate is expected to change in the future. The climate change risk assessment finds that the Scheme could be vulnerable to operational impacts linked to these changes in the climate. Mitigation measures that either avoids these impacts, minimises them or reduces their consequences to acceptable levels are presented. After consideration of this mitigation none of the potential climate vulnerability impacts are found to be significant adverse. The assessment of potential inter scheme and intra scheme (ICCI) cumulative effects also did not identify any significant adverse impacts.

[67] www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp18-guidance---caveats-and-limitations.pdf

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