



# ENVIRONMENTAL STATEMENT: 6.3 APPENDIX 5.2: OPERATIONAL PHASE ASSESSMENT

DECARBONISATION

**Cory Decarbonisation Project**

**PINS Reference: EN010128**

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Revision A

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## 1. INTRODUCTION

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1.1.1. Atmospheric dispersion modelling was performed using the Cambridge Environmental Research Consultants (CERC) Atmospheric Dispersion Modelling System (ADMS version 6.0)<sup>1</sup> including the amine chemistry module. This model uses detailed information regarding the pollutant releases, local building effects and local meteorological conditions to predict pollution concentrations at specific locations selected by the user. It has been validated against both field studies and wind tunnel studies of dispersion and is widely used for air quality impact assessment in the UK. The CERC amine chemistry module reflects the latest understanding of the atmospheric degradation of amines. The modelling inputs and assumptions used are detailed in the following sections.

### 1.2. SCOPE

- 1.2.1. The dispersion modelling undertaken to inform **Chapter 5: Air Quality (Volume 1)** covers operational emissions from the following sources:
- marine vessel movements associated with the operation of the Proposed Scheme;
  - operation of the Riverside 1 and Riverside 2 pre-carbon capture;
  - operation of the Riverside 1 and Riverside 2 with Carbon Capture (the Riverside Campus); and
  - operation of the new backup power generator associated with the Proposed Scheme.
- 1.2.2. These sources have also been combined, where relevant, to produce a Full Proposed Scheme AQ Impact.
- 1.2.3. The scope assumes 100% availability of the Carbon Capture Facility. Any down-time would revert the contribution of the Proposed Scheme to ground level concentrations back to the Baseline for short term impacts and would reduce the maximum adverse (and beneficial) impacts of the Proposed Scheme on long term impacts. The scope, therefore, covers a conservative assessment.

### 1.3. KEY MODEL INPUTS

- 1.3.1. The general model inputs used in the air quality assessment are summarised in **Table 1-1** below.

**Table 1-1: Key Model Inputs**

Variable	Input	Commentary
<b>Meteorological Data</b>	5 years of hourly sequential data from London City Airport, 2018 to 2022	London City Airport is around 7.5km west of the Site Boundary and representative of conditions to the east of central London. Wind roses are shown in <b>Figure 1: Wind Roses for London City Airport (Volume 3)</b> of this appendix.  The prevailing wind is from the south-west in all years.
<b>Surface Roughness at Site</b>	1.0m	1.0m is the recommended value for 'cities' in ADMS. Sensitivity testing was undertaken for surface roughness between 0.3m to 1.0m. The selected value is conservative in that it gives the highest ground level impacts.
<b>Surface Roughness of Met Site (London City Airport)</b>	0.5m	London City Airport itself has an open aspect hence the roughness length was reduced to ADMS recommendation for 'open suburbia' for the meteorological site.
<b>Minimum Monin-Obukhov Length at Site</b>	100m	Selected value is the ADMS recommended values for large conurbations >1 million population. Both Met Site and the Site of the Proposed Scheme are located within the overall London conurbation.
<b>Minimum Monin-Obukhov Length at Met Site</b>	100m	
<b>Building Downwash</b>	Included in the Baseline: Riverside 1 and Riverside 2 housing units.  With the Proposed Scheme (as above plus):  2x Solvent Regeneration Systems	Downwash is the enhanced turbulent mixing of pollutants in the lee of buildings which can result in relatively elevated pollutant concentrations in the wake of the building. Buildings are included where they are within 5L of an emission point, where L is the lesser or the building height or crosswind width, and greater than 1/3 <sup>rd</sup> of the stack height. This follows best practice guidance <sup>2</sup> .  Building parameters are provided in <b>Figure 1-1</b> and visualised in <b>Figure 1-2</b> and <b>Figure 1-3</b> of this appendix.

Variable	Input	Commentary
	1 x Hybrid Cooling System 2 x Absorber Columns 1 x Liquified CO <sub>2</sub> Storage area.	The ADMS 'Main building' is source specific and set to be the housing units for Riverside 1 (for the Riverside 1 exhaust stack) and Riverside 2 (for the Riverside 2 exhaust stack) in the Baseline, and to the Riverside 1 housing unit for both Stack(s) with the Carbon Capture Facility (following sensitivity tests which showed the maximum impact from both the Absorber Column(s) and Stack(s) occurred when the Riverside 1 housing unit was selected as the Main Building.
<b>Receptors</b>	Gridded at variable resolution (100m within 5km, 250m to 15km)	Receptors set at height 0m. Resolution of fine grid is within the recommended minimum resolution of 1.5 x Stack(s) height (150m).  Impacts on human health are assessed against the maximum impact in the Study Area, irrespective of the presence of properties at the point of maximum impact.  Impacts on ecological receptors are assessed at grid points within each habitats site which were selected based on their presence within each ecological site.
<b>Terrain Data</b>	Not included	No significant terrain gradients within the Study Area, so no requirement to model terrain.
<b>Deposition</b>	No plume depletion	The Study Area is largely built up and there will be minimal plume depletion onto man-made surfaces. Deposition of pollutants to habitats sites is modelled using deposition velocity approach using the dry deposition velocities given by Environment Agency Guidance <sup>17</sup> , see <b>Table 1-3</b> .
<b>Amine Chemistry</b>	ADMS Amine Chemistry module	Details in <b>Section 1.4</b> below.

**Table 1-2: Buildings included in the modelling for the Baseline and with Proposed Scheme Scenarios**

Building	Shape	Easting	Northing	Height (m)	Length (m)	Width (m)	Angle (degrees)
<b>Existing Buildings (Baseline and With Proposed Scheme scenarios)</b>							
Riverside1	Rectangular	549438	180670	65	107	170	90.4
Riverside2	Rectangular	549692	180657	50	126	148	90.4
<b>New Buildings (With Proposed Scheme only)</b>							
Solvent Regeneration System 1	Circular	549521	180455	32	5	5	0
Solvent Regeneration System 2	Circular	549610	180444	32	5	5	0
Cooling System	Rectangular	549592	180228	24	49	60	89.4
LCO <sub>2</sub> Storage	Rectangular*	549538	180313	20	71	46	88.8
Note: *It is assumed that this building behaves as a single unit from an aerodynamic perspective regardless of its shape.							

**Table 1-3: Dry Deposition Velocities used in post-processing Model Outputs**

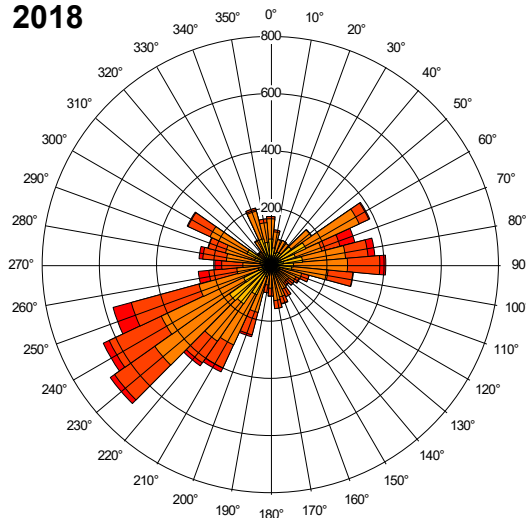
Chemical Species	Vegetation Type	Deposition Velocity (mm/s)
NO <sub>2</sub>	Short Vegetation	1.5
	Forest Vegetation	3
SO <sub>2</sub>	Short Vegetation	12
	Forest Vegetation	24
NH <sub>3</sub>	Short Vegetation	20
	Forest Vegetation	30



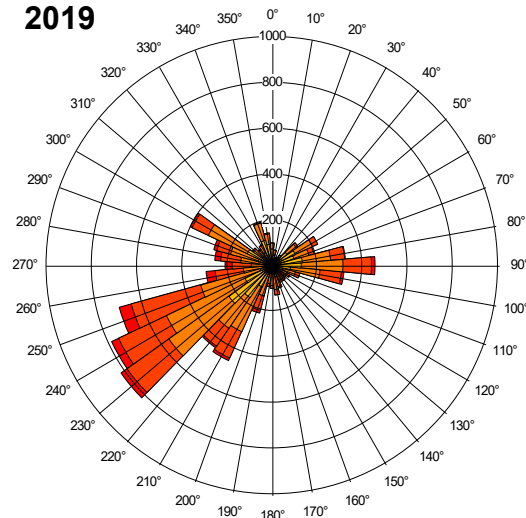
Chemical Species	Vegetation Type	Deposition Velocity (mm/s)
HCI	Short Vegetation	25
	Forest Vegetation	60
Amines and Degradation Products*	Short Vegetation	20
	Forest Vegetation	30

Note:  
 \*Amines and degradation products modelled using deposition velocity for ammonia.

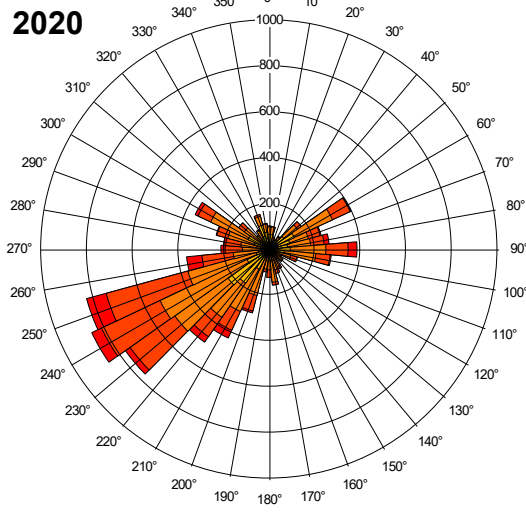
**2018**



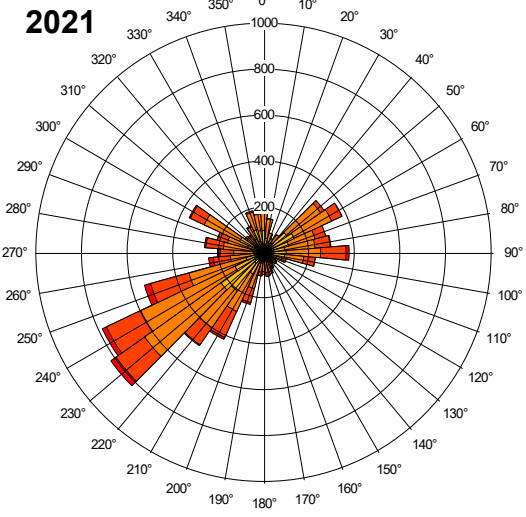
**2019**

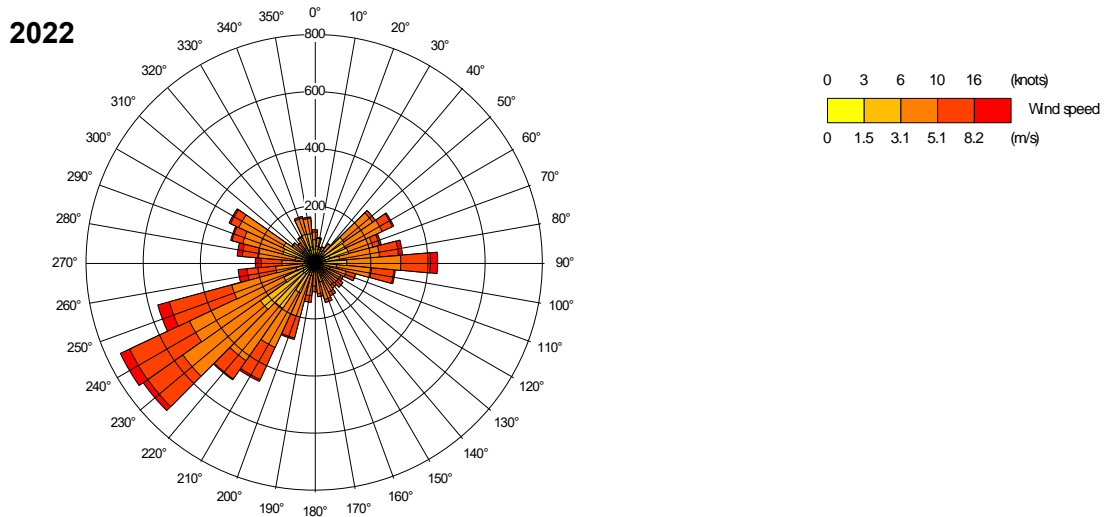


**2020**

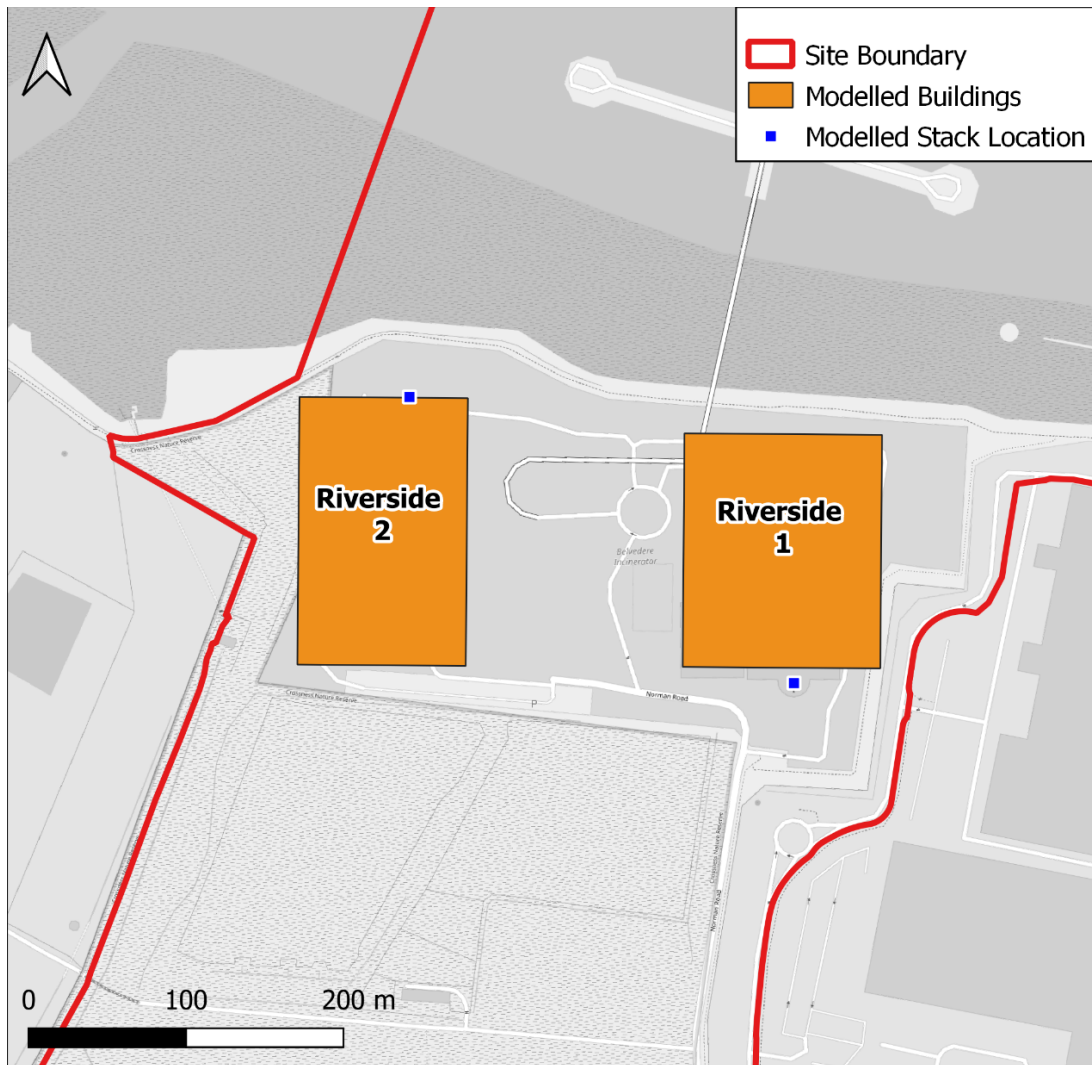


**2021**

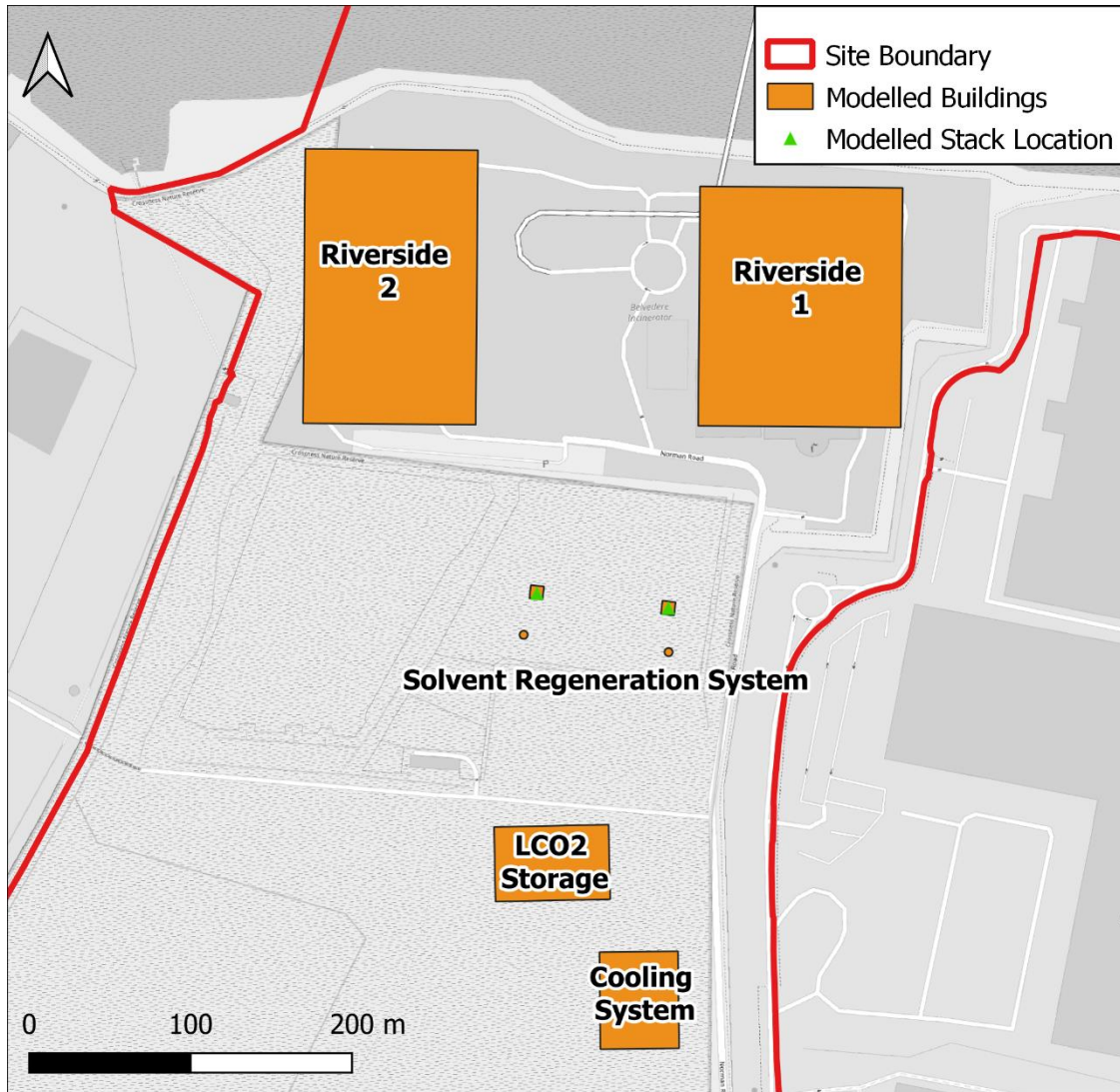




**Figure 1-1: Wind Roses for London City Airport**



**Figure 1-2: Indicative Modelled Building Layouts (Baseline) (Riverside 1 and Riverside 2 modelled stacks shown as blue squares)**



**Figure 1-3: Modelled Building Layouts (with the Proposed Scheme) (Carbon Capture Facility modelled Stack(s) shown as green squares)**

## 1.4. POST PROCESSING

### SUB-HOURLY IMPACTS

1.4.1. Meteorological data has been input to the model as hourly mean data. It is not, therefore, possible to directly model 15 minute peak concentrations, required for SO<sub>2</sub>, since the variability of meteorological data on sub-hourly timescales is not represented in the model inputs. Environment Agency provide scaling factors to adjust from hourly to sub-hourly peak concentrations and, as such, the 99.9<sup>th</sup> percentile of 15 minute SO<sub>2</sub> concentrations for assessment against the 15 minute air quality objective is modelled by using the model to output the 99.9<sup>th</sup> percentile of hourly mean concentrations and using the Environment Agency’s scaling factor of 1.34 to convert to a 15 minute averaging period. This approach results in higher, more conservative, modelled concentrations than directly outputting 15 minute average concentrations from the model itself.

## ATMOSPHERIC CHEMISTRY

### NOX to NO2

1.4.2. Emissions of NO<sub>x</sub> from combustion sources include both nitrogen dioxide NO<sub>2</sub> and nitric oxide (NO), with the majority being in the form of NO. In ambient air, NO is oxidised to form NO<sub>2</sub>, and it is NO<sub>2</sub> which has the more significant health impacts. For this assessment, the conversion of NO to NO<sub>2</sub> has been estimated using the worst case assumptions set out in Environment Agency guidance<sup>3</sup>, namely that:

- for the assessment of long term (annual mean) impacts, at receptors 70% of NO<sub>x</sub> is NO<sub>2</sub>; and
- for the assessment of short term (hourly mean) impacts, at receptors 35% of NO<sub>x</sub> is NO<sub>2</sub>.

1.4.3. The oxidation of NO to NO<sub>2</sub> is not, however, an instantaneous process, thus the Environment Agency worst case assumptions are very conservative for modelled impacts within a few hundred metres of any stack.

### Amines and Degradation Products

1.4.4. Amines are organic derivatives of ammonia (NH<sub>3</sub>), wherein one or more of the hydrogen (H) atoms are replaced by a substituent organic group I. The type of amine can be defined as primary, secondary, or tertiary, based on the number of H atoms that are replaced:

- Primary amine (R-NH<sub>2</sub>) where 1 H-atom is replaced;
  - e.g. Monoethanolamine, MEA.
- Secondary amine (R<sub>2</sub>-NH) where 2 H-atoms are replaced; and
  - e.g. Dimethylamine, DMA.
- Tertiary amine (R<sub>3</sub>-N) where 3 H-atoms are replaced.
  - e.g. Trimethylamine, TMA.

1.4.5. Amine-based solvents are used in the carbon capture process to remove carbon dioxide (CO<sub>2</sub>) from combustion flue gases (i.e. for the Proposed Scheme, removal of CO<sub>2</sub> from post-combustion gases associated with Riverside 1 and Riverside 2). The amine compounds included within the solvent make up can react with substances other than CO<sub>2</sub> to create new, potentially harmful compounds (e.g. nitrosamines and nitramines). These reactions can occur both within the carbon capture process itself and in the atmosphere following release of the treated post-combustion flue gases. Therefore, it is important that emissions to atmosphere, associated chemical transformations, and dispersion and deposition within the Study Area are represented within the air quality model.

1.4.6. Nitrosamines and nitramines are organic compounds, formed by reactions with nitrogen monoxide (NO) and nitrogen dioxide (NO<sub>2</sub>), respectively. The chemical structure of nitrosamines is R<sub>2</sub>N-NO and nitramines is R<sub>2</sub>N-NO<sub>2</sub>, formed from the original amine, where R is usually an alkyl group. Nitrosamines are susceptible to photodegradation and therefore generally short-lived in the atmosphere (~5 min). In contrast, nitramines are more stable and will have longer atmospheric residence times (~2 days). As such, the stability of nitramines indicates an increased potential for accumulation in the atmosphere relative to nitrosamines.

### **ADMS Amine Chemistry Module**

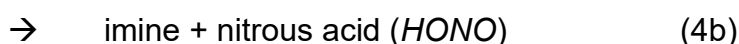
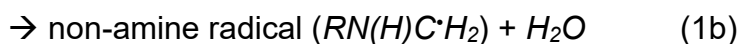
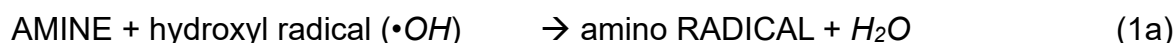
1.4.7. Direct emissions of amines and nitrosamines associated with potential solvent loss, degradation within the carbon capture process and entrainment within the flue gas, are expected to be low. Nevertheless, the ADMS amine chemistry module<sup>4</sup> has been used to model the chemical reactions associated with the release of amine compounds and the formation of associated nitrosamines and nitramines in the atmosphere.

1.4.8. Whilst the Environment Agency acknowledges that the uncertainty associated with modelling of amines is likely to be very high, its latest draft guidance<sup>5</sup> on the assessment of impacts to air quality from amine-based post-combustion carbon capture plants states “...*the only commercially available modelling software to evaluate the potential impacts from amines and amine degradation products releases is the amines module within ADMS. The amines chemistry module is based on established science considering published research on mechanisms of formation of toxic compounds. Although the validation of the module is not possible at the moment, the ADMS air dispersion modelling algorithms are continually validated against real world situations, field campaigns and wind tunnel experiments*”.

1.4.9. The mechanisms for the formation of nitrosamines and nitramines in the atmosphere are complex. However, the main initial reaction of amines in the atmosphere is with hydroxyl (OH) radicals and it is this reaction on which the ADMS amine chemistry module is based (CERC<sup>4</sup>). As described above, the subsequent formation of nitrosamines and nitramines are attributed to reactions with NO and NO<sub>2</sub>, however, they can further degrade in the atmosphere (e.g. through photo-oxidation and subsequent reaction with oxygen molecules to form imines, which are relatively stable and non-toxic compounds<sup>6</sup>).

1.4.10. Primary amines do not form stable nitrosamines, meaning that any such nitrosamines would be rapidly isomerised to the respective imine. However, secondary and tertiary amines do form stable nitrosamines. The ADMS amine chemistry module<sup>4</sup> includes an option to allow only unstable nitrosamines to be created (i.e. assuming emissions of primary amines only) which, if selected by the model user, sets all nitrosamine outputs to zero and only nitramines will form. This option was not selected for this assessment to ensure that the degradation of amines (primary, secondary or tertiary) is taken into account, and, as a worst case, nitrosamines formed from the degradation of primary amines were considered in the assessment<sup>7</sup>.

1.4.11. The general reaction scheme simulated by the ADMS amine chemistry module is as follows:



*h\nu*



Notes:

- R represents an alkyl group.
- Terms in capitals are the generic names given to the respective compounds for which input data are required for modelling in ADMS.

1.4.12. The amount of nitrosamine and nitramine formed in the atmosphere is dependent on the initial reaction of the amine with the OH radical – specifically the branching ratio of the abstraction of an H atom from the amino group (N-H) (i.e. forming the amino radical) to the abstraction from the methyl group (C-H) (i.e. forming the non-amine radical) – where a lower branching ratio will result in fewer amino radicals being made available and thus fewer nitrosamine/nitramine compounds being formed. However, other variables play an essential role in the potential formation of nitrosamines and nitramines in the atmosphere and are required for the ADMS amine chemistry module to run, including:

- Ambient concentrations of the OH radical:
  - A representative annual average OH radical concentration for the UK was sourced from published research<sup>8</sup>, based on measurements taken from a series of daytime and night-time flights over the UK in summer 2010 and winter 2011 using the fluorescence assay by gas expansion (FAGE) technique. In the absence of sunlight, OH is not formed at night and therefore OH was not detected above the instrument's limit of detection during any of the night-time or winter daytime flights.
  - An upper limit OH concentration of  $1.8 \times 10^6$  molecules  $\text{cm}^{-3}$  is reported, which is calculated based on summer daytime flights only.

- This is the value used to feed into the amine chemistry modelling and is likely to be conservative (skewed high) as an annual average (i.e. if more OH radicals are available in the atmosphere, daytime amine degradation increases, resulting in increased production of nitrosamine/nitramine compounds).
  - Photolysis rates applicable to the region of study:
    - The ADMS meteorological pre-processor provides hourly information with respect to incoming solar radiation (K) specific to the met year data and latitude. A subsequent calculation is completed using the K values to derive hourly photolysis rates, which are then used to calculate an annual average rate constant for NO<sub>2</sub> (jNO<sub>2</sub>) (CERC<sup>1</sup>).
    - The meteorological data used in the amines chemistry module aligns with that used for modelling of all other non-amine related pollutants, comprising hourly data for years 2018-2022 inclusive from London City Airport.
  - Ambient concentrations of ozone (O<sub>3</sub>) and NO<sub>x</sub> (i.e. NO and NO<sub>2</sub>):
    - The amine reaction scheme requires hourly background levels of NO<sub>x</sub> and O<sub>3</sub> equivalent to the year of meteorological data. Hourly data for these species were sourced from Defra's London Bloomsbury AURN monitoring site, representing urban background levels, for the years 2018-2022 inclusive.
    - Background NO<sub>x</sub> concentrations are used to dictate the availability of NO and NO<sub>2</sub> in the formation of nitrosamines and nitramines, respectively, on an hourly basis.
    - The hydroxyl radical concentration varies based on a number of factors, including solar radiation, latitude, and background levels of O<sub>3</sub>. The ADMS amine module requires a constant, 'c', which is used to calculate hourly varying OH radical concentrations for the region of study. The value for c is derived based on the relationship between annual average values for jNO<sub>2</sub>, O<sub>3</sub> and OH radical concentrations as described above.
- 1.4.13. The reaction rates and associated kinetic parameters input to ADMS v6.0 need to be defined by the model user.
- 1.4.14. The technology supplier for the Carbon Capture Facility has not yet been selected. As such, the post-carbon capture process emissions, set out in **Table 3-1** and **Table 3-2** are indicative and estimated from information provided by various suppliers. Furthermore, since the specific details of the process solvents for each supplier are confidential, the assessment has been undertaken on the basis that all of the amine releases are either MEA (primary amine) or DMA (secondary amine). Reaction rate data for these species are available, albeit with some variability, in publicly available literature. The values used are provided in **Table 1-4**. Acknowledging the uncertainty associated with modelling amines and their degradation, sensitivity testing has been undertaken and is reported below (**Table 4-1** and **Table 4-2**).

1.4.15. The general description of the ADMS amine chemistry module scheme can be summarised in five steps:

1. On an hourly basis, ADMS uses the above input parameters to model concentrations of the species of interest as well as the age of the primary pollutants (e.g. amines) at each receptor/grid point using the standard ADMS dispersion algorithms.
2. Using the 'dilution and entrainment' scheme within the ADMS amine chemistry module, the primary pollutant concentrations are adjusted to removed dilution effects (i.e. becoming increasingly conservative with distance from stack exit).
3. The chemistry reaction scheme requires consideration of timescales, so that after each hourly dispersion calculation, the 'age' of the pollutants is calculated based on the plume travel time. The chemical reaction equations are applied to all pollutants from the source.
4. At this point, the 'dilution and entrainment' scheme is used to dilute all pollutants as ambient air, containing the background pollutants, is entrained into the plume.
5. Steps 3 and 4 are repeated for each time step until time becomes equal to the pollutant 'age'.

### **Modelling Deposition of Amines in ADMS**

1.4.16. CERC<sup>1</sup> recommend the following method for calculating deposition of amines and associated products (nitrosamines, nitramines) in ADMS is undertaken based on the following approach:

1. Run the respective ADMS amine chemistry model runs with amine chemistry switched on and deposition switched off (i.e. as detailed above).
2. Run the same model set up as in Step 1, but with the ADMS amine chemistry module switched off and deposition switched on.
3. Run the same model set up as in Steps 1 and 2, but with both ADMS amine chemistry module and deposition switched off.

1.4.17. Based on the outputs from Step 2 (deposition switched on) and Step 3 (deposition switched off), the ratio of the concentration to deposition flux was calculated for each amine and at each receptor/grid location. This ratio is then multiplied by the concentration output from Step 1 (ADMS amine chemistry module switched on) to derive the amine deposition fluxes at all receptor and grid locations.

1.4.18. This approach has not been followed in this assessment since, as for other pollutants, deposition will be limited within the Study Area due to the predominance of man-made rather than vegetated surfaces. This has no material impact on the assessment but, if anything, it ensures a degree of conservatism in the output as pollutant concentrations will not drop-off as quickly.



- 1.4.19. Research published by Karl *et al* (2009)<sup>9</sup>, which reports on worst case studies for assessing deposition of amines from the carbon capture process, adopted a deposition velocity of 10mm/s for amines and 30mm/s for nitrosamines and nitramines. This reflects that the solubility of amines is relatively lower than that of nitrosamines and nitramines. However, in the absence of recommended deposition velocities for these compounds, a conservative approach has been adopted for the assessment of the Proposed Scheme, whereby the deposition velocity for all amine, nitrosamine, and nitramine compounds is assumed to be equivalent to that for ammonia (20mm/s or 30mm/s depending on vegetation type) (i.e. all gaseous amine compounds assumed to be highly soluble).

**Table 1-4: ADMS Amine Chemistry Module Reaction Rate Coefficients and Chemistry Module Inputs**

Parameter	Units	Notes	Input	Sensitivity Testing
<b>Amine emission</b>	g/s	Emission rate for amine compounds. Annual mean rate based on typical release given by technology suppliers. Daily mean rate assumed double typical release. For modelling, emissions are assumed to be either all MEA or all DMA.	As per Table 3-2	N/A
<b>Direct nitrosamine emission</b>	g/s	Emission rate for nitrosamine compounds, based on typical release given by technology suppliers, with emissions assumed to be associated with either MEA or DMA as relevant to the amine species.	As per Table 3-2	N/A
<b>NO<sub>x</sub> emission</b>	g/s	Emission rate for NO <sub>x</sub> , based on daily mean emission limits for each Riverside 1 and Riverside 2 as set in existing Environmental Permit.	As per Table 3-2	N/A
<b>% NO<sub>x</sub> emission as NO<sub>2</sub> in flue gas</b>	%	Proportion of NO <sub>x</sub> assumed to be as NO <sub>2</sub> in flue gas at Absorber Column(s) and Stack(s) exit.	5%	10%
<b>Amine / OH reaction rate constant, <i>k</i><sub>1</sub></b>	/ppb/s	Relating to the reaction of the emitted amine with the OH radical.	MEA: 2.07 DMA: 1.59	N/A
<b>Amino radical / O<sub>2</sub> reaction rate constant, <i>k</i><sub>2</sub></b>	/ppb/s	Relating to the reaction of the amino radical with oxygen (forming imine).	MEA: 4.96 x 10 <sup>-8</sup> DMA: 4.6 x 10 <sup>-8</sup>	

Parameter	Units	Notes	Input	Sensitivity Testing
Rate constant for formation of nitrosamine, $k_3$	/ppb/s	Relating to the formation of nitrosamine from the reaction of the amino radical with NO.	MEA: 0.0037 DMA: 0.0021	
Rate constant for formation of nitramine, $k_{4a}$	/ppb/s	Relating to the formation of nitramine from the reaction of the amino radical with NO <sub>2</sub> .	MEA: 0.004 DMA: 0.0078	
Amino radical / NO <sub>2</sub> reaction rate constant, $k_4$	/ppb/s	Relating to the reaction of the amino radical with NO <sub>2</sub> (forming imine or nitramine).	MEA: 0.0045 DMA: 0.0097	
Branching ratio for amine / OH reaction	Dimensionless	The ratio of H atom abstraction from amino group (N-H) to the methyl group (C-H).	MEA: 0.1 DMA: 0.4	
Ratio of $j(\text{nitrosamine}) / j\text{NO}_2$	Dimensionless	Ratio of photolysis rate constants for the nitrosamine and NO <sub>2</sub> .	MEA: 0 DMA: 0.39	
Constant, $c$ , for OH concentration calculations	s	Constant for calculating hourly varying OH concentrations, based on relationship between annual average $j\text{NO}_2$ , O <sub>3</sub> and OH concentrations.	0.003 (based on average of calculated values following CERC <sup>4</sup> for 2018 – 2022)	0.00232 – 0.00374 (based on range of calculated values following CERC <sup>4</sup> for 2018 – 2022)
Background NO <sub>x</sub> / NO <sub>2</sub> concentrations	µg/m <sup>3</sup>	Ambient hourly concentrations for each species sourced from representative monitoring location.	Defra AURN urban background	Monitored data from Thurrock urban

Parameter	Units	Notes	Input	Sensitivity Testing
<b>Background O<sub>3</sub> concentrations</b>	µg/m <sup>3</sup>		monitoring site at London Bloomsbury (aligned with meteorological years, 2018 – 2022)	background AURN site

Note:

\*MEA and DMA represent two of the most studied amine compounds relating to emissions from the carbon capture process, thus resulting in greater data availability relating to their respective reaction schemes. Specifically, DMA is a secondary amine from which the nitrosamine, NDMA, is formed. The assumption that all modelled direct and indirect nitrosamine and nitramine parameters associated with the Proposed Scheme will be equivalent to NDMA represents a worst case approach in terms of assessment versus the EAL, given that NDMA is one of the most toxic nitrosamines.

\*\*Range of reaction rates derived from range of published data from CERC 2012<sup>10</sup>, Manzoor et al 2015<sup>6</sup>, Nielsen 2011<sup>11</sup>.

## **ASSESSMENT STANDARDS FOR AMINES**

- 1.4.20. Existing toxicological data indicates that most nitrosamines are carcinogenic, with the most widely researched nitrosamine being N-nitrosodimethylamine (NDMA), formed from DMA, due to its toxicity. Accordingly, the EAL established by the Environment Agency for the assessment of nitrosamines is derived for NDMA. Less is known about nitramines, but they have the potential to be mutagenic and carcinogenic although typically less potent than nitrosamines, with some research studies indicating that nitramines are at least six times less toxic (Gjernes, 2013<sup>12</sup>) and fifteen times less mutagenic (Wagner, 2014<sup>13</sup>) than nitrosamines.
- 1.4.21. At present the Environment Agency has established EAL (non-statutory Environmental Assessment Levels) for MEA and NDMA only. This assessment assumes that the EAL for MEA can be applied to MEA and DMA, and that the EAL for NDMA can be applied to all nitrosamines and nitramines. This is, as stated above, a conservative assumption that follows current Environment Agency guidance<sup>5</sup>.

## 2. MARINE VESSEL MODELLING

### 2.1. MARINE EMISSIONS CALCULATIONS

2.1.1. The assessment of emissions uses the methodology proposed by European Environment Agency guidance<sup>14</sup> in which detailed methodologies for calculating emissions, specifically from shipping are presented. The guidance<sup>14</sup> adopts a tiered approach, with increasing sophistication, to inventory generation, as follows:

- Tier 1 – uses default emission rates based on fuel consumption;
- Tier 2 – emission rates based on fuel consumption and engine types in the fleet; and
- Tier 3 – emission rates for vessel movements stratified by engine technology either as mass/kWh or mass/hr.

2.1.2. For this assessment, taking into account data availability, a hybrid approach is used across the three tiers for each key emission sector, with emissions calculated for each of the following vessel activities during operation:

- Hotelling (HOT) – the term used for when a ship is docked in port;
- Manoeuvring (MAN) – the movement of a ship casting off or docking up; and
- Cruising (CRU) – the movement of a ship approaching or leaving the port.

2.1.3. **Table 5-6** in the **Chapter 5: Air Quality (Volume 1)** presents the vessel movement data for the operational phase that were used in the assessment.

2.1.4. A Tier 3 approach was used in which an emission factor is multiplied by an activity, e.g. energy used by vessel, to calculate the mass of emissions generated during the operational phase from marine vessels. The equation used to calculate the emissions from the marine vessels is set out below.

$$Emissions_{Marine} = \sum_{Vessels} EF_{Engine} \times P_{Engine} \times OL_{Mode} \times TM_{Vessel}$$

2.1.5. Where:

- Emissions<sub>Marine</sub> = Emissions (g) from all marine vessel movements;
- EF<sub>Engine</sub> = Emission Factor (g/kWh) for each engine;
- P<sub>Engine</sub> = Maximum Power of an engine (kW);
- OL<sub>Mode</sub> = Operating Load (%) of each engine for each mode; and
- TM<sub>Vessel</sub> = Time in Mode (hours) for each vessel.
- N.B. this will change depending on the averaging period considered (e.g. annual mean, daily mean, etc.).

2.1.6. Further details of the data used within the calculation of each element is set out below:

- **Emission Factor (g/kWh)** – emission factors vary by engine size and type and are set out in **Table 2-1**, below:

- For NO<sub>x</sub> emissions, the emission factor data were taken from different sources for the LCO<sub>2</sub> vessels and the tugs:
  - For LCO<sub>2</sub> vessels, it has been assumed that the vessels will be issued with an Engine International Air Pollution Prevention (EIAPP) Certificate to ensure that they comply with the requirements of the mandatory regulations<sup>a</sup>. Therefore, emissions rates were calculated using the NO<sub>x</sub> emission limit for vessel engines in g/kWh, based on the rated speed of the engine (i.e. the main engine being low speed and auxiliary engine being medium speed) for ships constructed after 1<sup>st</sup> January 2016.
  - For the tugs, as there is no information available regarding the age of the fleet that will be used, emission factor data were taken from EEA standard values<sup>14</sup> for high speed engines run on Marine Diesel Oil.
- For all other pollutants, emission factor data were taken from EEA standard values<sup>14</sup> for engines run on Marine Diesel Oil for relevant engine types.
- **Energy Used by Vessels (kW)** – a value for the energy used by each vessel was calculated for each of the relevant time periods (i.e. annual, daily, hourly, based on the averaging period for relevant pollutants):
  - Ship engine power (with main engines and auxiliary engines taken into account, kW) – this is set out in **Table 5-5 in Chapter 5: Air Quality (Volume 1)**;
  - Operating load (%) – this was taken from EEA standard values<sup>14</sup>, considered as a function of vessel activity for both the main and auxiliary engines. The values used within the assessment are set out in **Table 2-1**, below; and
  - Time in mode (hrs) – the time in mode was chosen to represent peak activity within the relevant averaging period for each pollutant standard, based on the expected operating profile for operational vessels. The values used within the assessment are set out in **Table 2-2** and **Table 2-3** below.
- **Section 5.4 of Chapter 5: Air Quality (Volume 1)** sets out the key assumptions made with regards to ship types, engine size and length of time during each activity for the construction phase (later referred to as also applying in the operation phase). Using this data, a reasonable worst case scenario for the time in mode for each vessel for each averaging period (i.e. annual, daily, hourly, 15 minute - associated with a relevant air quality standards during the operation phase).
- Operational dredging vessels have not been included in the assessment as dredging is only likely to occur once annually and is unlikely to contribute as a source of emissions. Dredging is only likely to occur for a small amount of time once annually and is unlikely to contribute as a source of emissions. The inclusion of these vessels will not materially change the results of the assessment.

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<sup>a</sup> 13.8 (NO<sub>x</sub> Technical Code 2008, resolutions MEPC. 177(59) and 5.3.2 (amendments to the aforementioned by resolution MEPC.251.(66))

- As a worked example, the worst case hours of operation per day of tugs is considered. At their peak, they would have 8.1 visits per week – for the worst case day, two visits were taken to be likely. Therefore, the cruising time in mode would be two times the duration of cruising ( $2 \times 0.82 = 1.64$ ). Each of the tugs would be manoeuvring for 1 hour (2 hours in total). As noted in the assumption notes for tugs, there is no hotelling at Site.

**Table 2-1: Engine Emission Factors used within the Assessment**

Ship Type	Engine	Engine Type	Fuel Type	Mode	NOx Emission Factor (g/kWh)	PM Emission Factor (g/kWh)	SO <sub>2</sub> Emission Factor (g/kWh)
LCO <sub>2</sub> Vessel	Main	Low Speed	Marine Diesel Oil (MDO) / Marine Fuel Oil (MFO)	CRU	3.4	0.18	0.356
				MAN	3.4	0.361	0.53
				HOT	3.4	0.361	0.53
	Aux	Medium Speed	MDO/MFO	CRU	2.4	0.284	0.468
				MAN	2.4	0.215	0.388
				HOT	2.4	0.215	0.388
Tugs	Main	High Speed	MDO/MFO	CRU	8.53	0.118	0.41
				MAN	11.7	0.367	0.608
				HOT	11.7	0.367	0.608
	Aux	High Speed	MDO/MFO	CRU	9.94	0.29	0.542
				MAN	8.53	0.221	0.448
				HOT	8.53	0.221	0.448



**Table 2-2: Engine Load Factors used within the Assessment**

Phase	% load of Maximum Continuous Rating Main Engine (MCR)	% time all Main Engine operating	% load of MCR Auxiliary Engine
CRU	80	100	30%
MAN	20	100	50%
HOT (LCO <sub>2</sub> Vessels)	20	5	40%
HOT (Tankers)	20	100	60%

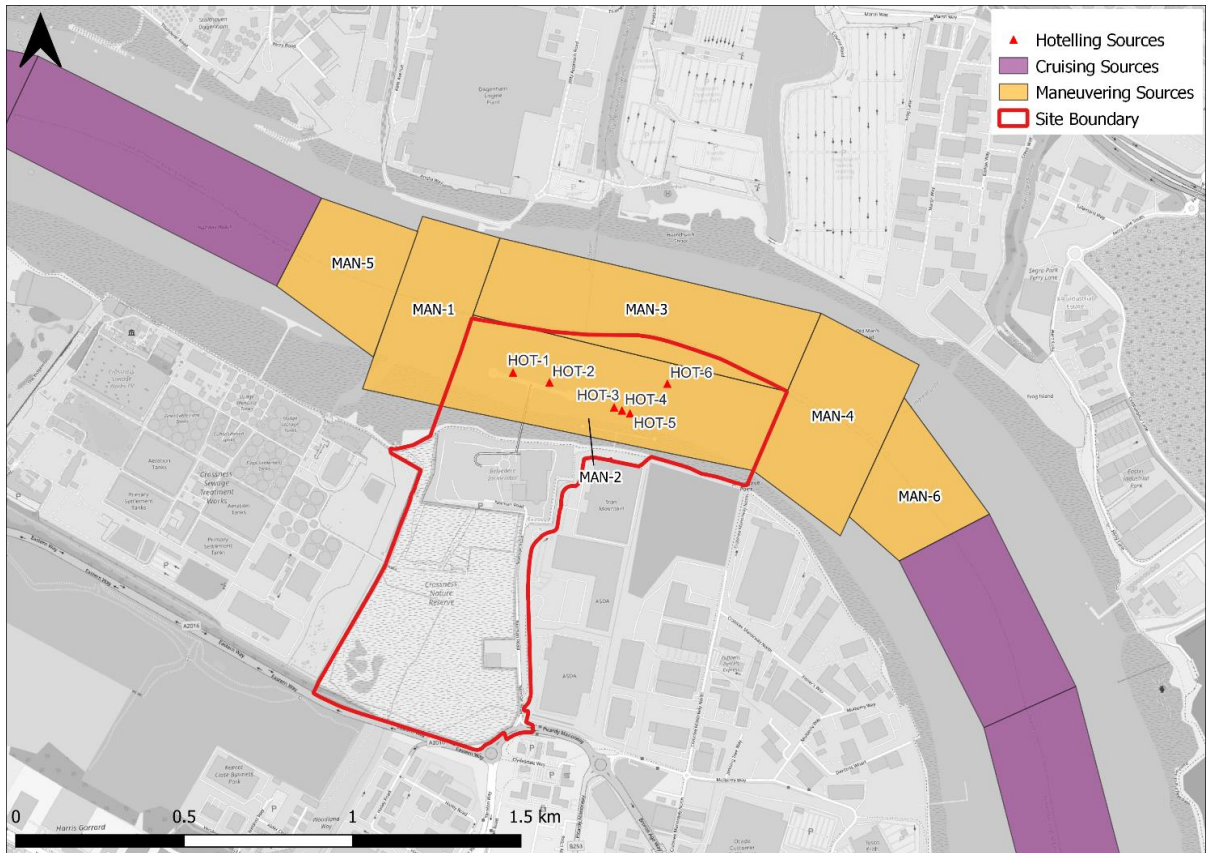
**Table 2-3: Engine Load Factors used within the Assessment**

Ship Type	Annual Operating Period (Hours per Year)			Daily Operating Period (Hours of Operation in Worst Day)			Hourly Operating Period (Hours of Operation in Worst Hour)		
	CRU	MAN	HOT	CRU	MAN	HOT	CRU	MAN	HOT
Tugs	345	421	0	1.6	2.0	0.0	0.55	0.45	0.00
LCO <sub>2</sub> Vessels	232	211	2527	1.1	1.0	12.0	0.55	0.45	0.00

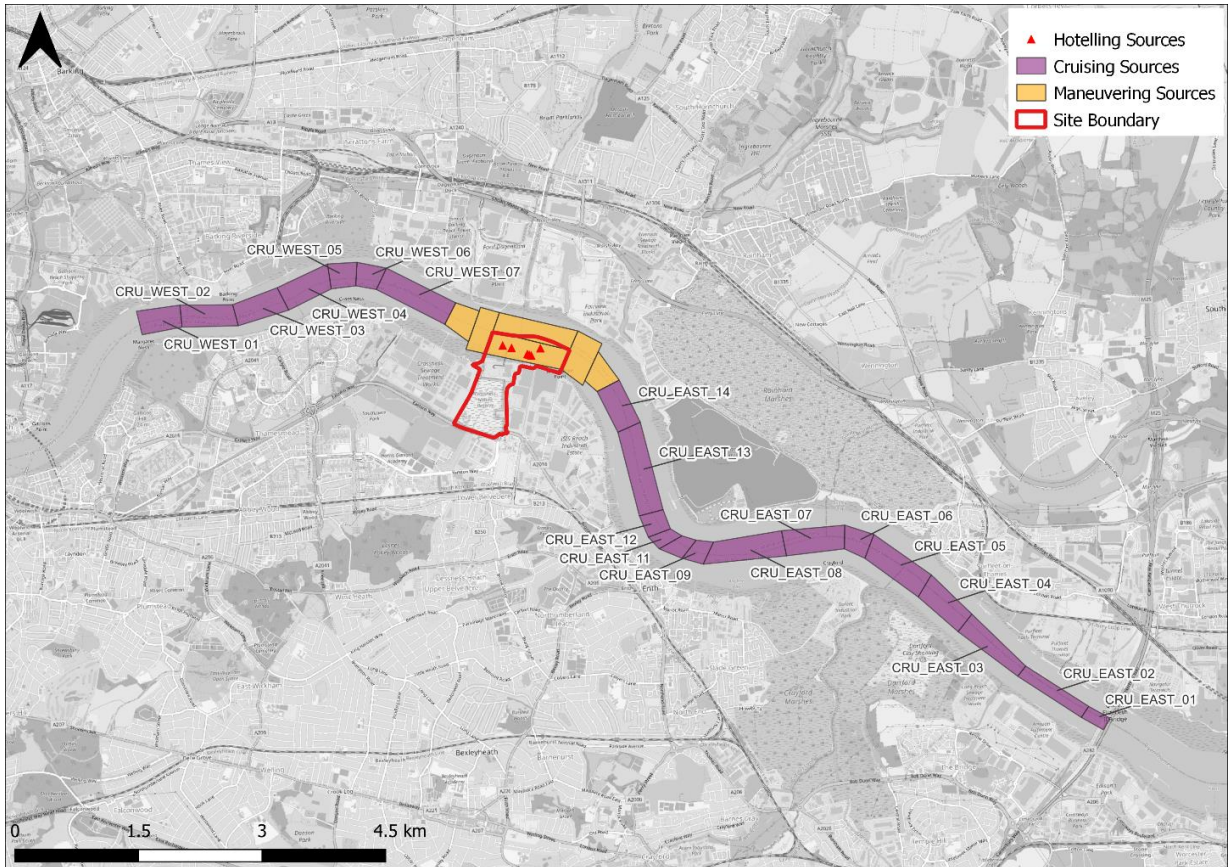
## 2.2. MARINE VESSEL DISPERSION MODEL INPUTS

- 2.2.1. The sources used within the dispersion model to represent the operational phase contribution to pollutant concentrations from marine vessels are shown in **Figure 2-1** and **Figure 2-2**. Further model source input data are set out in **Table 2-4** and

2.2.3. Table 2-5, below.



**Figure 2-1: Manoeuvring (MAN) and Hotelling (HOT) Sources used within the Dispersion Model for the Operation Phase**



**Figure 2-2: Cruising (CRU) Sources used within the Dispersion Model for the Operational Phase**

**Table 2-4: Marine Dispersion Model Sources and Inputs**

Source Name	Source Type	Height (m)	Cross-sectional Area (m <sup>2</sup> )	Volume (m <sup>3</sup> ) / Diameter (m)	Temperature (°C)	Velocity (m/s)*
HOT-3	Point	6	3.14	2	300	10
HOT-4	Point	6	3.14	2	300	10
HOT-5	Point	6	3.14	2	300	10
HOT-6	Point	6	3.14	2	300	10
MAN-1	Volume	27	127123	3432314	Ambient	Not required
MAN-2	Volume	27	255094	6887549	Ambient	Not required
MAN-3	Volume	27	237289	6406816	Ambient	Not required
MAN-4	Volume	27	171659	4634793	Ambient	Not required
MAN-5	Volume	27	111361	3006750	Ambient	Not required
CRU_West_01	Volume	27	143990	3887732	Ambient	Not required
CRU_West_02	Volume	27	173715	4690297	Ambient	Not required
CRU_West_03	Volume	27	172756	4664423	Ambient	Not required
CRU_West_04	Volume	27	187393	5059607	Ambient	Not required
CRU_West_05	Volume	27	96975	2618327	Ambient	Not required
CRU_West_06	Volume	27	86712	2341233	Ambient	Not required
CRU_West_07	Volume	27	271964	7343016	Ambient	Not required
CRU_East_01	Volume	27	48437	1307792	Ambient	Not required
CRU_East_02	Volume	27	145569	3930369	Ambient	Not required

Source Name	Source Type	Height (m)	Cross-sectional Area (m <sup>2</sup> )	Volume (m <sup>3</sup> ) / Diameter (m)	Temperature (°C)	Velocity (m/s)*
CRU_East_03	Volume	27	193959	5236906	Ambient	Not required
CRU_East_04	Volume	27	191253	5163830	Ambient	Not required
CRU_East_05	Volume	27	252316	6812521	Ambient	Not required
CRU_East_06	Volume	27	93441	2522912	Ambient	Not required
CRU_East_07	Volume	27	220228	5946159	Ambient	Not required
CRU_East_08	Volume	27	259534	7007410	Ambient	Not required
CRU_East_09	Volume	27	64047	1729271	Ambient	Not required
CRU_East_10	Volume	27	61398	1657745	Ambient	Not required
CRU_East_11	Volume	27	48540	1310575	Ambient	Not required
CRU_East_12	Volume	27	77163	2083409	Ambient	Not required
CRU_East_13	Volume	27	318056	8587519	Ambient	Not required
CRU_East_14	Volume	27	169300	4571095	Ambient	Not required

\*For volume sources an input for velocity is not required.

**Table 2-5: Marine Dispersion Model Source Emission Rates**

Source Name	Annual Emission Rate (g/s/m <sup>3</sup> )			Daily Emission Rate (g/s/m <sup>3</sup> )		Hourly Emission Rate (g/s/m <sup>3</sup> )	
	NO <sub>x</sub>	PM <sub>10</sub>	SO <sub>2</sub>	NO <sub>x</sub>	PM <sub>10</sub>	NO <sub>x</sub>	PM <sub>10</sub>
HOT-3	0	0	0	0	0	0	0
HOT-4	0	0	0	0	0	0	0
HOT-5	0	0	0	0	0	0	0
HOT-6	0.29329	0.0297	0.0462	0.8645	0.0875	0	0
MAN-1	1.1E-08	5E-10	9E-10	2E-08	1E-09	1.7E-07	1E-08
MAN-2	1.1E-08	5E-10	9E-10	2E-08	1E-09	1.7E-07	1E-08
MAN-3	1.1E-08	5E-10	9E-10	2E-08	1E-09	1.7E-07	1E-08
MAN-4	1.1E-08	5E-10	9E-10	2E-08	1E-09	1.7E-07	1E-08
MAN-5	1.1E-08	5E-10	9E-10	2E-08	1E-09	1.7E-07	1E-08
CRU_West_01	2.7E-08	4E-10	1E-09	5E-08	7E-10	3.8E-07	5E-09
CRU_West_02	2.7E-08	4E-10	1E-09	5E-08	7E-10	3.8E-07	5E-09
CRU_West_03	2.7E-08	4E-10	1E-09	5E-08	7E-10	3.8E-07	5E-09
CRU_West_04	2.7E-08	4E-10	1E-09	5E-08	7E-10	3.8E-07	5E-09
CRU_West_05	2.7E-08	4E-10	1E-09	5E-08	7E-10	3.8E-07	5E-09
CRU_West_06	2.7E-08	4E-10	1E-09	5E-08	7E-10	3.8E-07	5E-09

Source Name	Annual Emission Rate (g/s/m <sup>3</sup> )			Daily Emission Rate (g/s/m <sup>3</sup> )		Hourly Emission Rate (g/s/m <sup>3</sup> )	
	NO <sub>x</sub>	PM <sub>10</sub>	SO <sub>2</sub>	NO <sub>x</sub>	PM <sub>10</sub>	NO <sub>x</sub>	PM <sub>10</sub>
CRU_West_07	2.7E-08	4E-10	1E-09	5E-08	7E-10	3.8E-07	5E-09
CRU_East_01	4.8E-08	2E-09	4E-09	1E-07	4E-09	1.1E-06	4E-08
CRU_East_02	4.8E-08	2E-09	4E-09	1E-07	4E-09	1.1E-06	4E-08
CRU_East_03	4.8E-08	2E-09	4E-09	1E-07	4E-09	1.1E-06	4E-08
CRU_East_04	4.8E-08	2E-09	4E-09	1E-07	4E-09	1.1E-06	4E-08
CRU_East_05	4.8E-08	2E-09	4E-09	1E-07	4E-09	1.1E-06	4E-08
CRU_East_06	4.8E-08	2E-09	4E-09	1E-07	4E-09	1.1E-06	4E-08
CRU_East_07	4.8E-08	2E-09	4E-09	1E-07	4E-09	1.1E-06	4E-08
CRU_East_08	4.8E-08	2E-09	4E-09	1E-07	4E-09	1.1E-06	4E-08
CRU_East_09	4.8E-08	2E-09	4E-09	1E-07	4E-09	1.1E-06	4E-08
CRU_East_10	4.8E-08	2E-09	4E-09	1E-07	4E-09	1.1E-06	4E-08
CRU_East_11	4.8E-08	2E-09	4E-09	1E-07	4E-09	1.1E-06	4E-08
CRU_East_12	4.8E-08	2E-09	4E-09	1E-07	4E-09	1.1E-06	4E-08
CRU_East_13	4.8E-08	2E-09	4E-09	1E-07	4E-09	1.1E-06	4E-08
CRU_East_14	4.8E-08	2E-09	4E-09	1E-07	4E-09	1.1E-06	4E-08

## 2.3. MARINE VESSEL DISPERSION MODEL RESULTS

### HUMAN RECEPTORS

- 2.3.1. The modelled concentrations at human receptors for the operation phase from marine vessels are set out in **Table 2-6** (for all receptors, including those located within the River Thames) and **Table 2-7** (for impacts on land) below. A map of the impacts of operational emissions from marine vessels is provided in **Figure 2-3** by way of an indicative dispersion profile, showing hourly mean NO<sub>2</sub>.

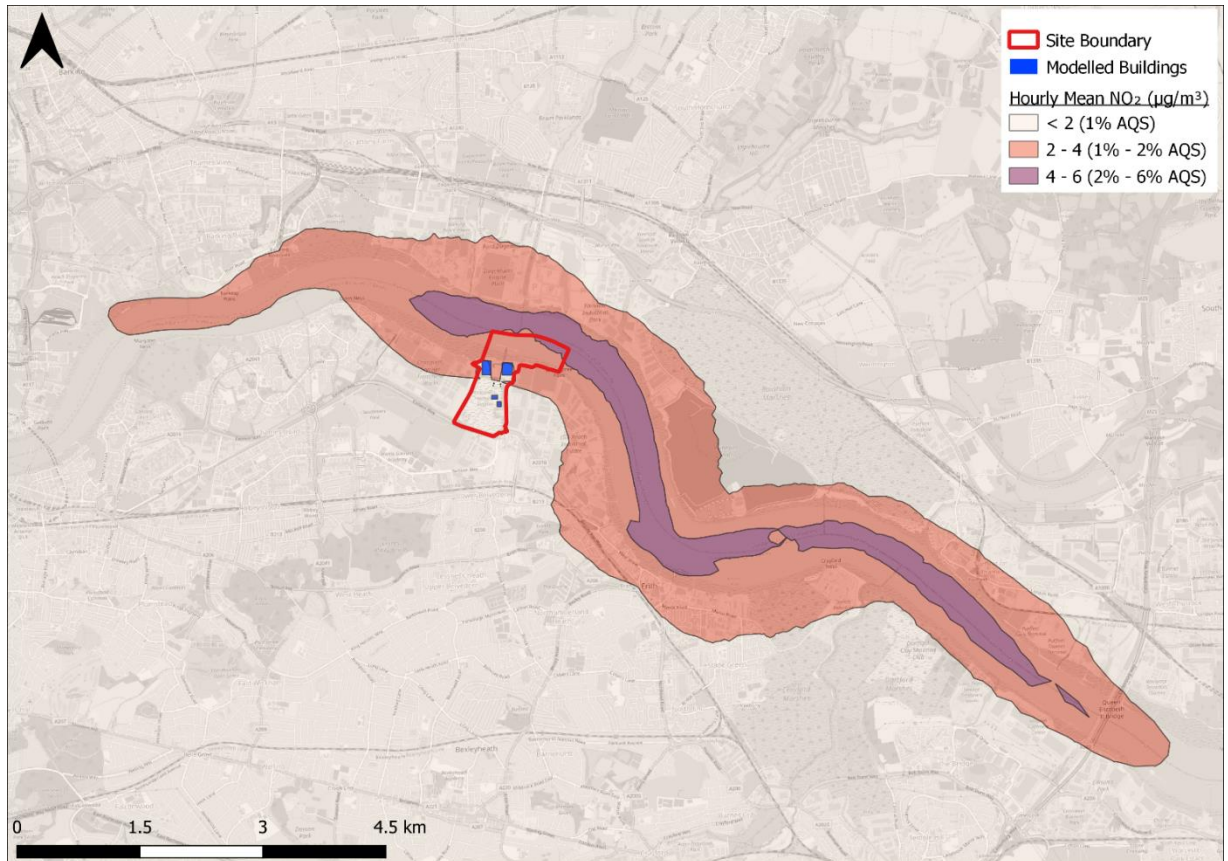


**Table 2-6: Maximum Impacts (From Marine Vessels Only) During Operation at all Modelled Receptors, including within the River Thames, on Human Health**

Pollutant	Averaging Period	Air Quality Standard (µg/m <sup>3</sup> )	All Receptors (including within the River Thames)					
			Max Impact (µg/m <sup>3</sup> )	Impact as % of AQS	Max Impact (µg/m <sup>3</sup> )	Location of Max Impact (X, Y)	Max PEC (µg/m <sup>3</sup> )	Location of Max PEC (X, Y)
NO <sub>2</sub>	Hourly	200	5.1	2.5%	34.2	551600, 178500	59.9	551600, 178500
	Annual	40	0.6	1.6%	26.1	550200, 181000	31.1	550200, 181000
PM <sub>2.5</sub>	Annual	20	0.1	0.4%	10.1	550200, 181000	13.4	550200, 181000
PM <sub>10</sub>	Daily	50	0.5	0.9%	15.1	550200, 181000	19.7	550200, 181000
	Annual	40	0.1	0.2%	14.7	550200, 181000	19.7	550200, 181000
SO <sub>2</sub>	15 minute	266	1.7	0.6%	4.7	549100, 181300	12.27	552900, 179000
	Hourly	350	1.2	0.3%	4.2	549000, 181300	11.98	552000, 179800
	Daily	125	0.7	0.6%	3.3	550200, 181000	11.46	552000, 179900

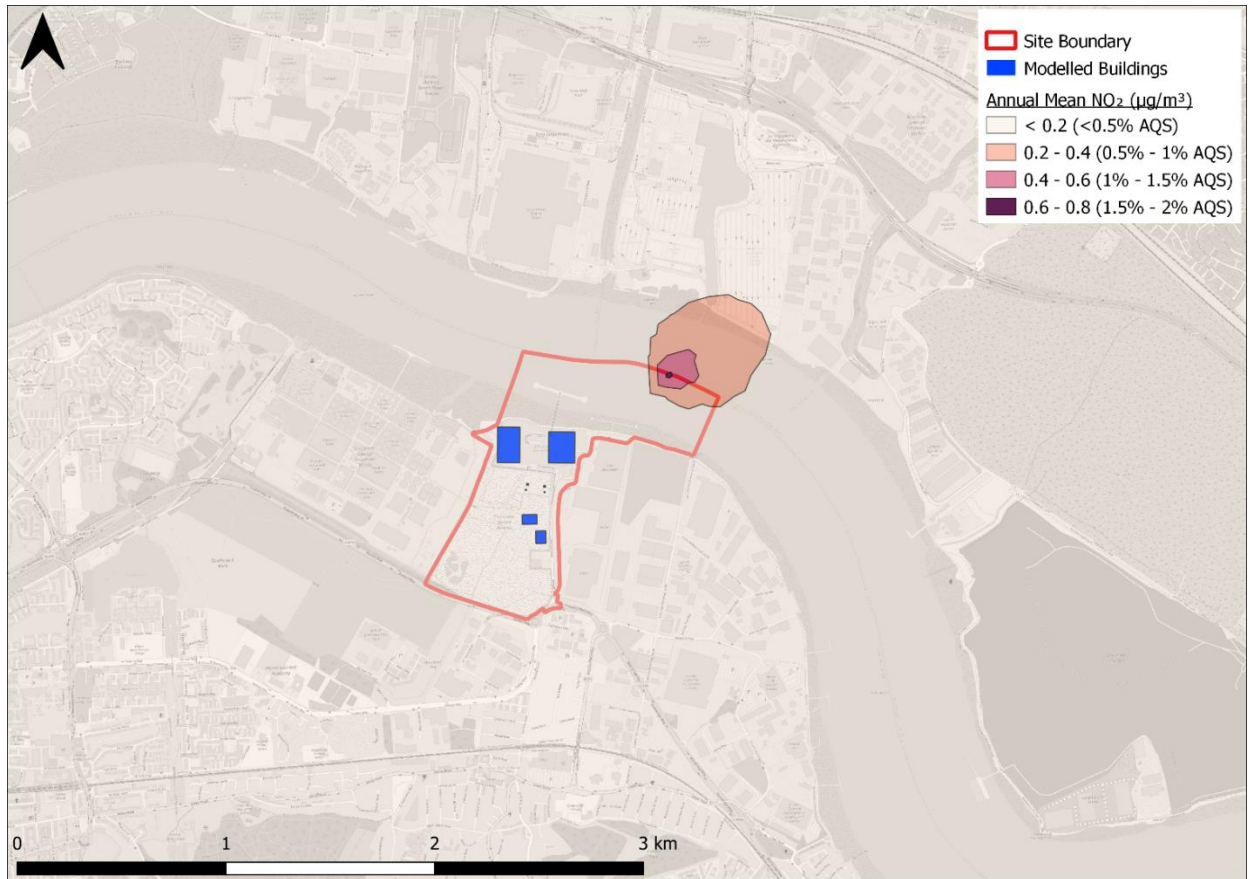
**Table 2-7: Maximum Impacts (From Marine Vessels only) During Operation at Land Based Receptors On Human Health**

Pollutant	Averaging Period	Air Quality Standard (µg/m <sup>3</sup> )	Receptors Located on Land					
			Max Impact (µg/m <sup>3</sup> )	Impact as % of AQS	Max Impact (µg/m <sup>3</sup> )	Location of Max Impact (X, Y)	Max Total (µg/m <sup>3</sup> )	Location of Max Total (X, Y)
NO <sub>2</sub>	Hourly	200	3.9	1.9%	40.5	550200, 181400	58.7	550200, 181400
	Annual	40	0.2	0.6%	19.7	550500, 181300	28.6	550500, 181300
PM <sub>2.5</sub>	Annual	20	0.03	0.1%	9.9	550500, 181300	13.4	550500, 181300
PM <sub>10</sub>	Daily	50	0.2	0.5%	15.1	549600, 180600	19.7	549600, 180600
	Annual	40	0.03	0.1%	14.6	550500, 181300	19.7	550500, 181300
SO <sub>2</sub>	15 minute	266	1.5	0.6%	4.5	549400, 181500	12.27	552900, 179000
	Hourly	350	0.9	0.3%	3.8	550100, 181400	11.98	552000, 179800
	Daily	125	0.3	0.2%	2.5	549400, 180500	11.46	552000, 179900



**Figure 2-3: Hourly Mean NO<sub>2</sub> Concentrations from Marine Emissions During Operation**

2.3.2. As can be seen in **Figure 2-3** (with reference to **Figure 2-1** and **Figure 2-2**), above, the maximum hourly mean concentrations during operation from marine vessels occurs along the River Thames, specifically in line with the cruising sources towards the east of the Site. This is caused by the increased operating load and the relatively high time in mode of the marine vessel engines during cruising (compared to hotelling and manoeuvring modes).



**Figure 2-4: Annual Mean NO<sub>2</sub> Concentrations from Marine Emissions During Operation**

2.3.3. As can be seen in **Figure 2-4** (with reference to **Figure 2-1** and **Figure 2-2**), above, the maximum concentrations from marine vessels during operation occur around the Proposed Jetty of the Site, within the River Thames, specifically in line with the hotelling/manoeuvring sources. This is caused by the increased operational load/time in mode during hotelling/manoeuvring respectively in the worst case day (compared to cruising).

**ECOLOGICAL RECEPTORS**

2.3.4. The maximum modelled concentrations (from marine emissions alone) at ecological receptors for the operation phase from marine vessels are set out in **Table 2-8** (daily mean NO<sub>x</sub>), **Table 2-9** (annual mean NO<sub>x</sub>) and **Table 2-10** (annual mean nitrogen deposition) below. A map of the impacts of operation emissions from marine vessels is provided in **Figure 2-5** by way of an indicative dispersion profile, showing daily mean NO<sub>x</sub>.

**Table 2-8: Daily Mean NOx Impacts from Marine Vessels During Operation on Ecological Sites**

Habitat Site	2030 Maximum Background (µg/m <sup>3</sup> )	Max Daily NOx Impact (µg/m <sup>3</sup> )	Impact as % of Objective	Maximum Total Concentration (µg/m <sup>3</sup> )
Epping Forest SAC, SSSI	53.06	0.07	0.04%	53.13
Ingrebourne Marshes SSSI	39.81	0.45	0.22%	40.26
Inner Thames Marshes SSSI	45.99	0.69	0.34%	46.68
Oxleas Woodlands SSSI	40.09	0.16	0.08%	40.25
West Thurrock Lagoon SSSI	94.39	0.41	0.20%	94.80
Crossness LNR	45.74	2.29	1.15%	48.03
Lesnes Abbey Wood LNR (comprising Ancient Woodland)	37.95	0.35	0.17%	38.30
Rainham Marshes LNR	45.82	0.69	0.34%	46.51

**Table 2-9: Annual Mean NOx Impacts from Marine Vessels During Operation on Ecological Sites**

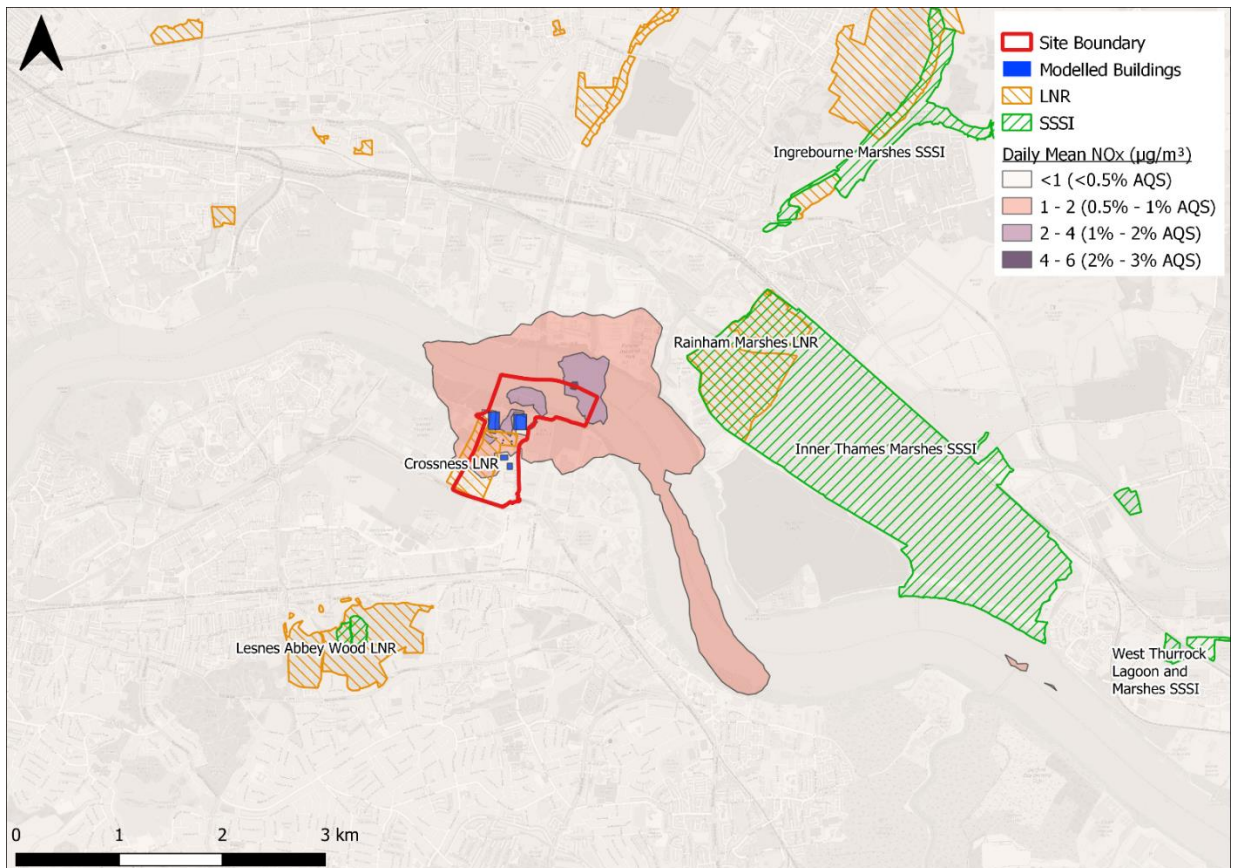
Habitat Site	2030 Maximum Background (µg/m <sup>3</sup> )	Max Daily NOx Impact (µg/m <sup>3</sup> )	Impact as % of Objective	Maximum Total Concentration (µg/m <sup>3</sup> )
Epping Forest SAC, SSSI	26.53	0.00	0.01	26.53
Ingrebourne Marshes SSSI	19.90	0.05	0.17	19.95
Inner Thames Marshes SSSI	23.00	0.10	0.34	23.10
Oxleas Woodlands SSSI	20.05	0.01	0.03	20.06

Habitat Site	2030 Maximum Background ( $\mu\text{g}/\text{m}^3$ )	Max Daily NOx Impact ( $\mu\text{g}/\text{m}^3$ )	Impact as % of Objective	Maximum Total Concentration ( $\mu\text{g}/\text{m}^3$ )
West Thurrock Lagoon SSSI	47.20	0.03	0.09	47.22
Crossness LNR	22.87	0.16	0.52	23.03
Lesnes Abbey Wood LNR (comprising Ancient Woodland)	18.97	0.03	0.09	19.00
Rainham Marshes LNR	22.91	0.10	0.34	23.01

**Table 2-10: Annual Mean Nitrogen Deposition Impacts from Marine Vessels During Operation on Ecological Sites**

Site Name	Site Type	Site Critical Load (kgN/ha/yr)	Background Nitrogen Deposition (kgN/ha/yr)	Proposed Scheme Nitrogen Deposition (kgN/ha/yr)	% Increase of Critical Load	Total Nitrogen Deposition (kgN/ha/yr)
Epping Forest SAC, SSSI	Long	10	32.22	0.0004	0.00	32.22
Ingrebourne Marshes SSSI	Short	15	14.33	0.005	0.03	14.33
Inner Thames Marshes SSSI	Short	10	14.37	0.010	0.10	14.38
Oxleas Woodlands SSSI	Long	15	28.34	0.002	0.01	28.34
West Thurrock Lagoon SSSI	Short	10	13.56	0.003	0.03	13.56
Crossness LRN	Short	10	14.60	0.016	0.16	14.62
Lesnes Abbey	Long	10	27.31	0.005	0.05	27.32

Site Name	Site Type	Site Critical Load (kgN/ha/yr)	Background Nitrogen Deposition (kgN/ha/yr)	Proposed Scheme Nitrogen Deposition (kgN/ha/yr)	% Increase of Critical Load	Total Nitrogen Deposition (kgN/ha/yr)
Wood LNR (comprising Ancient Woodland)						
Rainham Marshes LNR	Short	10	14.37	0.010	0.10	14.38



**Figure 2-5: Daily Mean NO<sub>x</sub> Impacts from Marine Emissions During Operation**

### 3. CARBON CAPTURE FACILITY MODELLING

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#### 3.1. MODELLED SCENARIOS

- 3.1.1. The scenarios modelled cover the combined continuous operation of Riverside 1 and Riverside 2 at full load, with annual waste incineration at their maximum permitted level, 850,000 tonnes per annum (tpa) and 805,920 tpa respectively. Specifically, two scenarios are modelled:
- Baseline: Operation without the Carbon Capture Facility; and
  - With the Proposed Scheme: Operation with the Carbon Capture Facility.
- 3.1.2. The impact of the inclusion of the Carbon Capture Facility is defined as the difference between the Proposed Scheme and Baseline scenarios (Proposed Scheme minus the Baseline).
- 3.1.3. The exhaust stack parameters and emission data for Riverside 2 has been taken from the Environmental Statement produced by the Applicant, as the facility is under construction (at the time of writing).

#### 3.2. STACK PARAMETERS

- 3.2.1. The exhaust stack parameters for Riverside 1 and Riverside 2, with and without the Proposed Scheme, are set out in **Table 3-1**.
- 3.2.2. Under existing operations, Riverside 1 has three waste incineration streams, all of equal capacity and each discharging into an individual flue. The three flues are contained within a common wind shield (one exhaust stack) of height 88m (above ground level (agl)). By design, Riverside 2 has two waste streams, with equal capacity, discharging into separate flues. The two flues are contained within two common wind shields (two exhaust stacks) of height 90m (agl).
- 3.2.3. Information on the design of the Carbon Capture Facility is provided in **Chapter 2: Site and Proposed Scheme Description (Volume 1)**.
- 3.2.4. The Baseline scenario has been modelled with two sources i.e. a source representing Riverside 1 and a separate source representing Riverside 2. This representation of the emissions is based on the assumption that the exhaust gases from the individual flues in each incineration plant will merge shortly after exit to ambient air. This is a conservative assumption in the context of this assessment. It minimises ground level concentrations for the Baseline since the plume resulting from the merging of flue gases has greater effective buoyancy than individual plumes from each flue. If ground level concentrations are minimised in the Baseline, the impact of the addition of carbon capture process will be maximised since the impact is calculated as the difference between the Proposed Scheme and Baseline scenarios. After the carbon capture process, the exhaust gases from each Carbon Capture Plant (encompassing the flues from Riverside 1 and Riverside 2) are fed through two individual Absorber Column(s) and Stack(s) and no assumptions regarding plume merging are required, as based on the design of the Proposed Scheme as described in **Chapter 2: Site and**



**Proposed Scheme Description (Volume 1)** these flues are too far apart to model as merged plumes. To use the merging assumption, they would have to be within one stack diameter of each other and given the scale of the Absorber Column(s) this will not be possible even if the Absorber Column(s) are next to one another.

- 3.2.5. Pollutant emission concentrations and rates (**Table 3-2**) are based on the respective Emission Limit Values (ELV) set out in the Environmental Permits for Riverside 1 (BK0825IU/V009) and Riverside 2 (GP3535QS). They align with ELV in the Industrial Emissions Directive (IED)<sup>15</sup> and/or associated EU Best Available Techniques (BAT) associated emission levels (BAT-AELs)<sup>16</sup>.
- 3.2.6. BAT-AELs have not yet been specified for the release of amines and degradation products and aldehydes from the carbon capture process. As such, the emission limits for these pollutants are set at values specified by potential technology suppliers.
- 3.2.7. For pollutants emitted by Riverside 1 and future Riverside 2 (i.e. all pollutants except amines/aldehydes), the mass emission rate of pollutants is assumed to be unaffected by the carbon capture process. This effectively assumes that, under Riverside 1 and Riverside 2 Environmental Permits, the emissions limit compliance assessment for any future process with carbon capture will be undertaken pre-carbon capture. It is possible that some pollutants will be removed with the CO<sub>2</sub> but to ensure a conservative assessment, it is assumed that all pollutants are retained within the exhaust gases. As such, the same mass emission rates are assumed for these pollutants in both the Baseline and with the Proposed Scheme scenarios.
- 3.2.8. For those pollutants introduced by the carbon capture process, namely amines and aldehydes, the emissions limit compliance assessment must apply post the carbon capture process, and this is reflected in the release rates set out in **Table 3-2**.
- 3.2.9. The IED<sup>15</sup> sets an ELV for the aggregate concentration of nine Group 3 metals. For this assessment, Environment Agency guidance on assessing Group 3 metal stack emissions from incinerators<sup>17</sup> has been followed to provide a case specific screening of impacts from the individual named metals (Antimony, Arsenic, Chromium, Cobalt, Copper, Lead, Manganese, Nickel and Vanadium and their compounds). The guidance acknowledges that a worst case assessment of impacts based on each metal individually comprising 100% of the ELV is theoretical only and likely to be overly conservative. As such, the guidance provides a method for producing a case specific screening that retains a degree of conservatism but uses more realistic emission rates than this theoretical worst case.
- 3.2.10. The case specific screening is, following the guidance, based on the maximum monitored emissions concentrations from 34 samples of municipal waste incinerators between 2007 and 2015 and the assumption that this provides a realistic upper bound on likely worst case emissions (**Table 3-3**). Monitored concentrations of metals at Riverside 1 have, for the past three years, been well below these screening ELV and the assessment is robust.

**Table 3-1: Bulk Exhaust Parameters (per Incineration Unit and as modelled, Pre and Post the Carbon Capture Process)**

Metric	Pre-Carbon Capture Process				Post-Carbon Capture Process	
	Riverside 1		Riverside 2		Riverside 1	Riverside 2
	Per Unit	Combined Plume (as modelled)	Per Unit	Combined Plume (as modelled)	Per Unit	Per Unit
No of Units	3	1	2	1	1	1
Actual Flow (Nm <sup>3</sup> /hr)	75.4	226.3	76.99	154.0	134.09	102.2
Temperature (°C)	140		125		80	80
O <sub>2</sub> (% actual)	6.3		5.5		8.5	7.3
H <sub>2</sub> O (% actual)	21.0		20.1		6.7	6.4
Normalised Flow (Nm <sup>3</sup> /s, 11% O <sub>2</sub> ,dry)	51.3	154.0	59.7	119.4	115.5	97.5
Easting (m)	-	549699	-	549455	549610	549528
Northing (m)	-	180577	-	180757	180471	180480
Stack(s) Diameter (m)	2.3	3.98 <sup>a</sup>	2.2	3.11	3.1 <sup>a</sup>	2.5
Stack(s) Height (m)	-	88	-	90	100 <sup>b</sup>	100 <sup>b</sup>
Exit Velocity (m/s)	-	18.2	-	20.3	17.8	20.8

Notes:

- a. Effective flue diameter for merged plume based on area of 3 x flues of diameter 2.3m (Riverside 1), and 2 x flues of diameter 2.2m (Riverside 2). Volume flow rate is based on combined volume flow rate from 3 flues or 2 flues respectively.
- b. Stack(s) heights tested from 73m to 130m.

**Table 3-2: Pollutant Emission Rates**

Metric	Riverside 1			Riverside 2		
	Emission Limit (mg/Nm <sup>3</sup> )	Emission Rate (per Unit) (g/s)	Emission Rate (per modelled source) (g/s)	Emission Limit (mg/Nm <sup>3</sup> )	Emission Rate (per Unit) (g/s)	Emission Rate (per modelled source) (g/s)
<b>Existing Exhaust Gas Pollutants (Baseline and With Scheme)</b>						
PM (30min)	30	1.54	4.62	30	1.79	3.58
PM (daily)	5	0.26	0.77	5	0.30	0.60
HCl (30min)	60	3.08	9.24	60	3.58	7.16
HCl (daily)	8	0.41	1.23	6	0.36	0.72
HF (30mins)	1	0.05	0.15	1	0.06	0.12
CO (10mins)	150	7.70	23.10	150	8.95	17.90
CO (daily)	50	2.57	7.70	50	2.98	5.97
SO <sub>2</sub> (30 min)	200	10.27	30.80	200	11.94	23.87
SO <sub>2</sub> (daily)	40	2.05	6.16	30	1.79	3.58
NOx (30min)	400	20.53	61.60	400	23.87	47.74
NOx (daily)	180	9.24	27.72	75	4.48	8.95
Cd + Th (30mins)	0.02	1.03E-03	3.08E-03	0.02	1.19E-03	2.39E-03
Hg (30mins)	0.02	1.03E-03	3.08E-03	0.02	1.19E-03	2.39E-03
Sb,As,Pb,Cr,Co,Cu,Mn,Ni,V (30min)*See paragraph on EA Guidance above	0.3	0.02	0.05	0.3	0.02	0.04

Metric	Riverside 1			Riverside 2		
	Emission Limit (mg/Nm <sup>3</sup> )	Emission Rate (per Unit) (g/s)	Emission Rate (per modelled source) (g/s)	Emission Limit (mg/Nm <sup>3</sup> )	Emission Rate (per Unit) (g/s)	Emission Rate (per modelled source) (g/s)
NH <sub>3</sub> (daily)	15	0.77	2.31	10	0.60	1.19
Dioxins and furans (ITEQ)	6E-08	3.08E-09	9.24E-09	4E-08	2.39E-09	4.77E-09
<b>Emissions Associated with the Proposed Scheme Only*</b>						
Primary Amine (daily)	2	0.10	0.31	2	0.12	0.24
Primary Amine (annual)	1	0.05	0.15	1	0.06	0.12
Nitrosamines	0.0001	5.13E-06	1.54E-05	0.0001	5.97E-06	1.19E-05
Secondary Amine (daily)	2	0.10	0.31	2	0.12	0.24
Secondary Amine (annual)	1	5.13E-02	1.54E-01	1	5.97E-02	1.19E-01
Nitrosamines	0.0001	5.13E-06	1.54E-05	0.0001	5.97E-06	1.19E-05
Aldehydes (annual)	5	0.26	0.77	5	0.30	0.60
Aldehydes (daily)	10	0.51	1.54	10	0.60	1.19

Notes:

\*Emissions post-carbon capture process are indicative, based on information provided by technology suppliers.

\*\*Mass emission rates post-carbon capture of existing pollutants (all except amines, degradation products and aldehydes) are unchanged from baseline. This implies that the concentration of these gases will be higher post-carbon capture than pre-carbon capture since the volume of gas into which the pollutants are mixed is reduced by the removal of CO<sub>2</sub>.

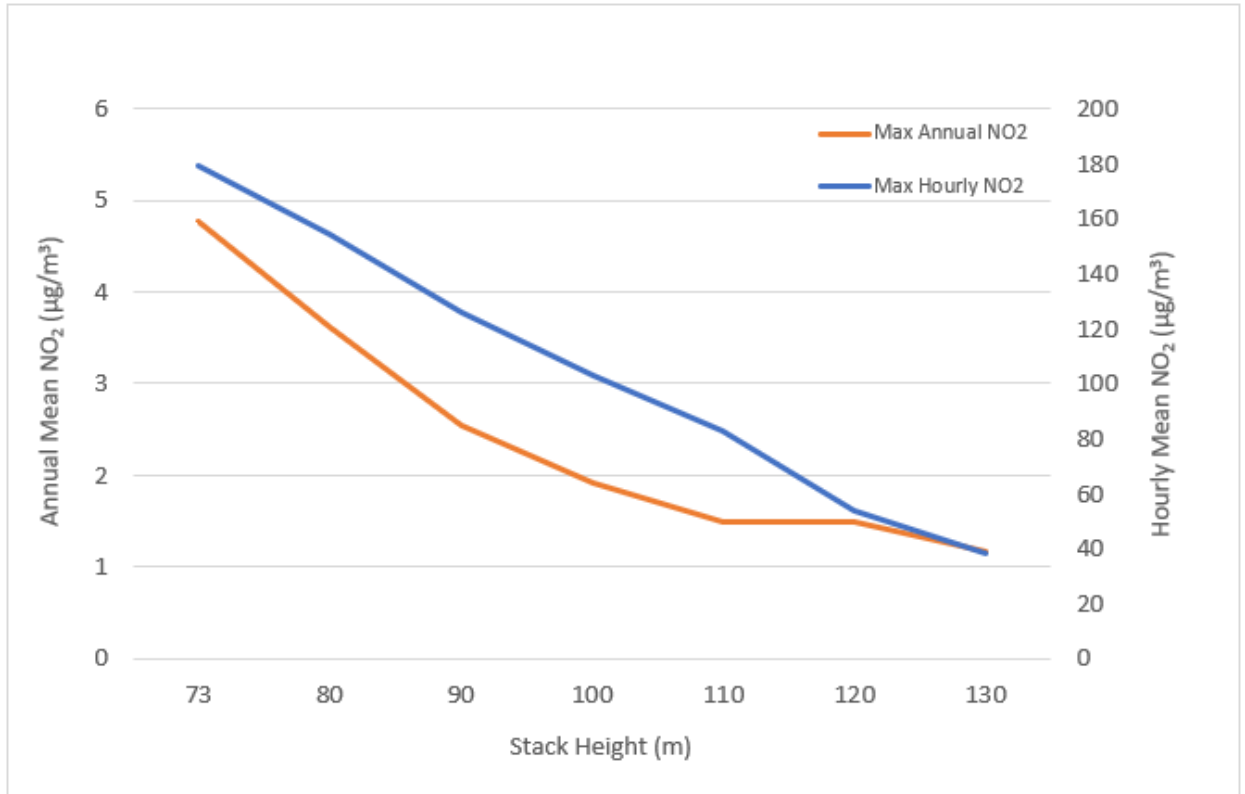
**Table 3-3: Modelled Emission Rates for Metals**

Pollutant	EA Max % of the IED Group 3 Emis. Limit Value	Riverside 1		Riverside 2	
		Emission Rate (per Unit) (g/s)	Emission Rate (per modelled source) (g/s)	Emission Rate (per Unit) (g/s)	Emission Rate (per modelled source) (g/s)
Antimony	2.3	3.54E-04	1.06E-03	4.12E-04	8.24E-04
Arsenic	5.0	7.70E-04	2.31E-03	8.95E-04	1.79E-03
Total Chromium	18.4	2.83E-03	8.50E-03	3.29E-03	6.59E-03
Chromium VI	0.03	4.62E-06	1.39E-05	5.37E-06	1.07E-05
Cobalt	1.1	1.69E-04	5.08E-04	1.97E-04	3.94E-04
Copper	5.8	8.93E-04	2.68E-03	1.04E-03	2.08E-03
Lead	10.1	1.56E-03	4.67E-03	1.81E-03	3.62E-03
Manganese	12.0	1.85E-03	5.54E-03	2.15E-03	4.30E-03
Nickel	44.0	6.78E-03	2.03E-02	7.88E-03	1.58E-02
Vanadium	1.2	1.85E-04	5.54E-04	2.15E-04	4.30E-04

- 3.2.11. Where emission limit values are provided at 30 minute and daily averaging periods e.g. PM, SO<sub>2</sub>, NO<sub>x</sub> etc, impacts with averaging periods less than 24 hours are assessed on the basis of the peak permitted 30 minute emission rate, and impacts with averaging periods of 24 hours or longer are assessed on the basis of the maximum daily average emissions. These are conservative assumptions in that pollutants will not be at their emission limits continuously.

### **POST-CARBON CAPTURE STACK(S) HEIGHT ASSESSMENT**

- 3.2.12. There will be up to two new Stack(s) for the venting of exhaust gases post the carbon capture process, located on top of the Absorber Column(s). For the purposes of this assessment, it is assumed that two Absorber Column(s) and Stack(s) will be used as this represents a more conservative assessment of emissions compared to a single Absorber Column and Stack scenario which would give increased plume buoyancy. In the parameters earlier in the design development of the Proposed Scheme, the height of the Absorber Columns varied from 50m to 70m. Initial model testing was undertaken to determine an appropriate stack height for a reasonable worst case assessment scenario, based on NO<sub>2</sub> impacts as a compound representative of both short and long term exposure to pollution. The results of the testing from 73m to 130m, of which 70m is the Absorber Column, are shown in **Figure 3-1: Stack Height Testing for Annual and Hourly Mean NO<sub>2</sub>**.
- 3.2.13. Ground level impacts decrease rapidly as the stack height increases from 73m (3m above the height of the Absorber Column(s)) to 130m. Taking into consideration the height of the existing stack on Site (Riverside 1, approximately 90m) and constraints on stack height at the Site location, the selected stack height for the purpose of this assessment for the Carbon Capture Facility is 100m (from development platform as built). Additional increases in stack height do not result in significant reductions in long term exposure to ground level concentrations of pollutants.
- 3.2.14. The sensitivity testing indicated that the ground level impacts were materially affected by the offset in distance between the Absorber Column(s) and the Riverside 1 and Riverside 2 housing units. The location of the new Stack(s) is based on the most up to date design information currently available and they lie approximately 100m from the Riverside 1 and Riverside 2 buildings, as shown on the **Works Plans (Document Reference 2.3)**. This is the minimum recommended distance and is secured pursuant to the parameters defined in the **Draft DCO (Document Reference 3.1)**.
- 3.2.15. To minimise any influence of the Absorber Column(s) on pollutant dispersion, for the purposes of this assessment a 30m offset has been assumed between the stack exit and the top of the Absorber Column(s).
- 3.2.16. All results are presented in **Chapter 5: Air Quality (Volume 1)** and this technical appendix relates to a 100m post-carbon capture Stack(s) height from development platform as built (unless otherwise stated).



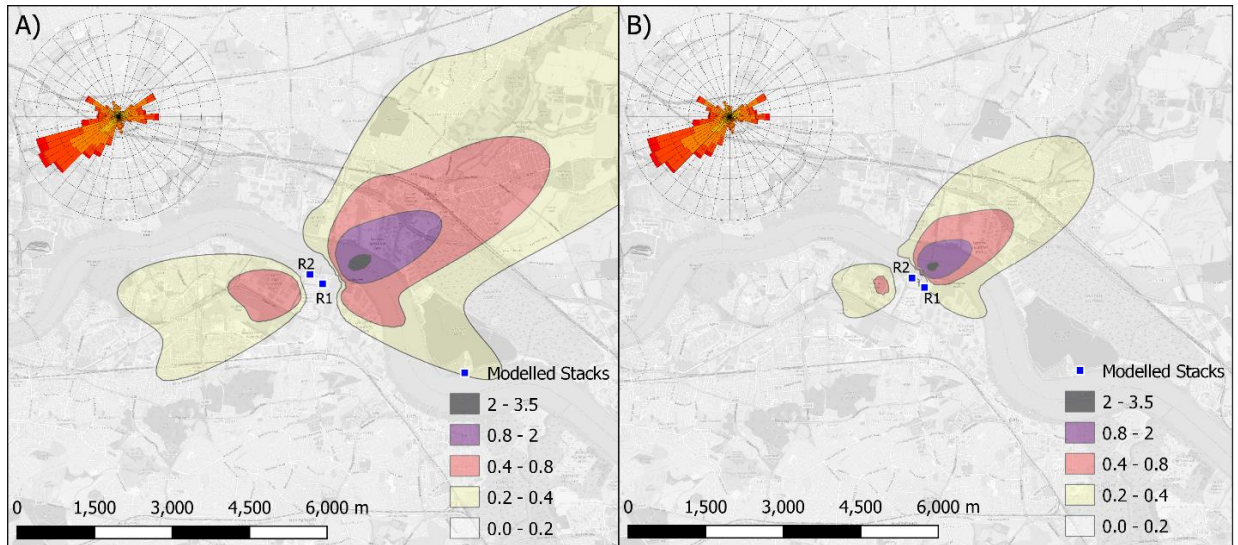
**Figure 3-1: Stack Height Testing for Annual and Hourly Mean NO<sub>2</sub>**

### MODEL RESULTS OVERVIEW AND EXPLANATION

- 3.2.17. The likely potential significant effects for air quality associated with the operation phase of the Proposed Scheme are summarised in **Chapter 5: Air Quality (Volume 1)**, with further model results provided in **Appendix 5-3: Detailed Model Pollutant Results (Volume 3)**.
- 3.2.18. The spatial distribution of modelled impacts that do not screen as negligible against IAQM criteria are shown in the following figures:
- **Figure 5-5: NO<sub>2</sub> Annual Baseline Process Contribution (Volume 2);**
  - **Figure 5-6: NO<sub>2</sub> Annual Carbon Capture Process Contribution (Volume 2);**
  - **Figure 5-7: NO<sub>2</sub> Annual Impact (Volume 2);**
  - **Figure 5-8: NO<sub>2</sub> 1 Hour Impact (Volume 2);**
  - **Figure 5-9: SO<sub>2</sub> 15 Minute Impact (Volume 2);**
  - **Figure 5-10: SO<sub>2</sub> 1 Hour Impact (Volume 2);**
  - **Figure 5-11: SO<sub>2</sub> 24 Hour Impact (Volume 2);**
  - **Figure 5-12: Total Nitrosamine and Nitramine Annual Impact (Volume 2); and**
  - **Figure 5-13: Aldehyde Annual Impact (Volume 2).**

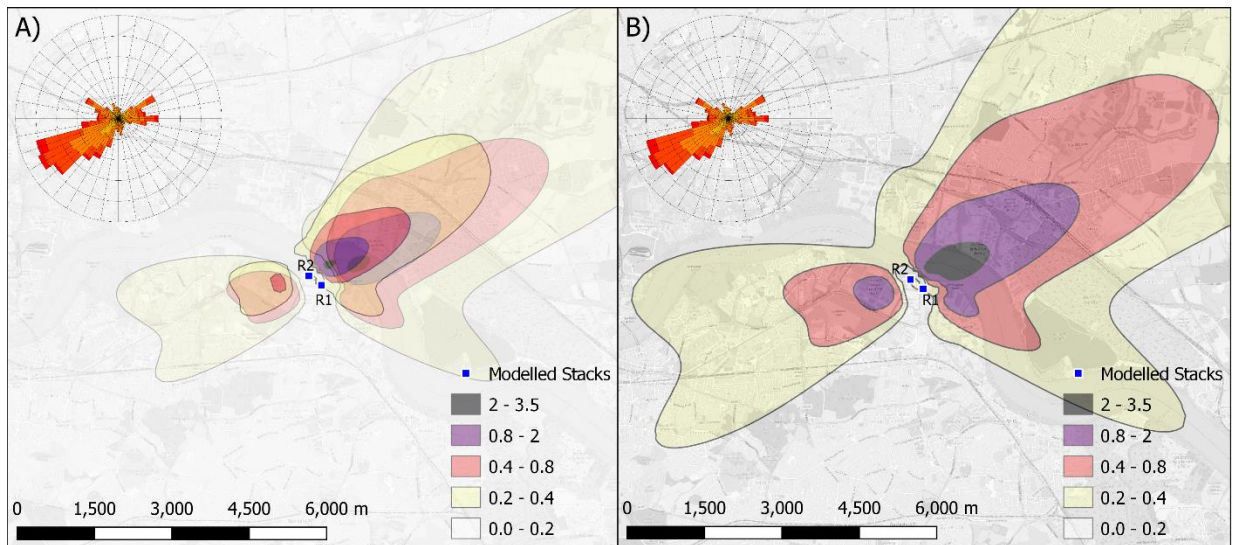
- 3.2.19. In this section, a description and explanation of the spatial distribution of modelled impacts is provided to aid interpretation of the model results tables and figures. For existing pollutants, this description is made with reference to impacts on annual mean and hourly mean NO<sub>2</sub>. They serve to illustrate the modelled long term (annual mean) and short term (hourly, sub-hourly) impacts on concentrations of other pollutants emitted by the existing incineration process.
- 3.2.20. As set out in **Table 3-1**, the bulk exhaust flue gas parameters will change with the Proposed Scheme due to the removal of CO<sub>2</sub> from the existing flue gas lines and the cooling of the exhaust gases prior to carbon capture. Furthermore, the distribution of impacts from the exhaust gases will change with the shift in release location from the existing Riverside 1 stack, and under-construction Riverside 2 exhaust stack, to the post-carbon capture Stack(s).
- 3.2.21. In combination, these changes result in a decrease in the maximum contribution of the Riverside Campus exhaust stacks emissions to annual mean concentrations and an increase in the contribution to hourly mean concentrations. However, these changes are not universal and within the Study Area the Proposed Scheme gives rise to impacts that are, in places, adverse i.e. tending to increase pollutant concentrations, and in other places, beneficial i.e. tending to reduce pollutant concentrations. The reasoning for this is set out below.
- 3.2.22. **Figure 3-2** shows the distribution of annual mean NO<sub>2</sub> resulting from the baseline operation of Riverside 1 and Riverside 2 individually, as modelled using 2020 meteorological data which was representative for all five years of meteorological data used in the modelling. The figure also shows the wind rose for 2020, reproduced from **Figure 1-1** and is shown with base mapping to facilitate the interpretation of the contours themselves.
- 3.2.23. The maximum impacts occur around 800m and 500m northeast of the stacks for Riverside 1 and Riverside 2 respectively. These maxima reflect the dispersion of pollutants on the prevailing south-westerly winds. Secondary maxima occur to the southeast of each Absorber Column(s) and Stack(s) driven by the north-easterly winds that occur less frequently than south-westerly winds but more frequently than winds from other directions. There is also a slight increase in pollutant concentrations to the southeast of the stacks resulting from the approximately 300 hours of north-westerly winds that occurred in 2020. Overall impacts from Riverside 1 exceed those of Riverside 2. This is due in part to the greater capacity of Riverside 1 but also to the fact that the permit emission limit for NO<sub>x</sub> for Riverside 2 is lower than for Riverside 1.





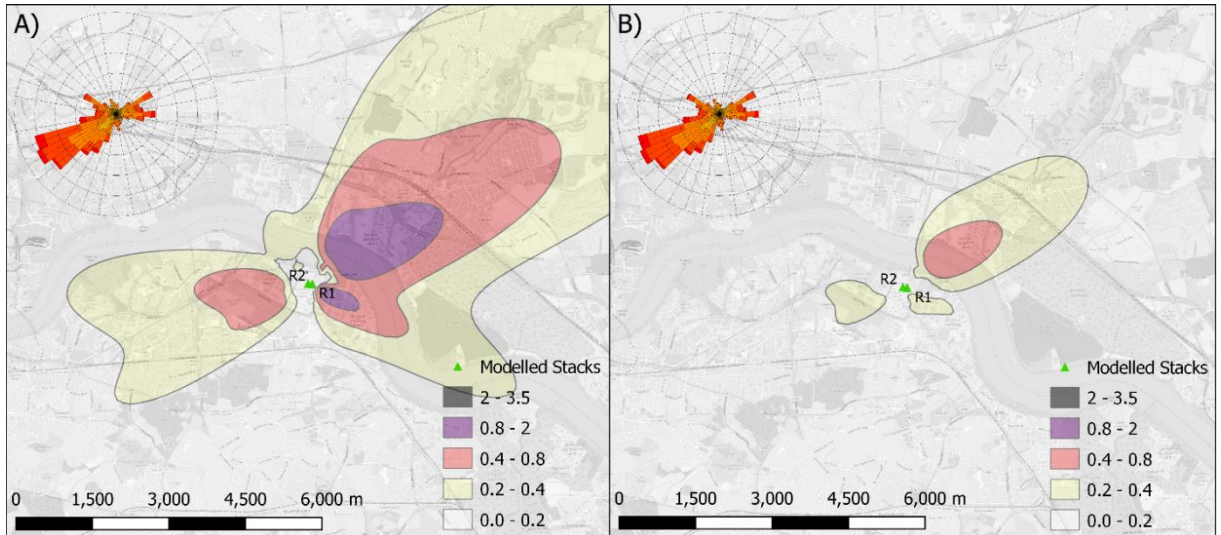
**Figure 3-2: Distribution of Pre-Carbon Capture Ground Level Concentrations of Annual Mean NO<sub>2</sub> (µg/M<sup>3</sup>) Resulting from the Full Load Operation of A) Riverside 1 (R1) and B) Riverside 2 (R2). The stacks are shown as blue squares**

3.2.24. The spatial offset in the points of maximum impact between the impacts of Riverside 1 and 2 is seen in **Figure 3-3A**, which shows the same contours as in **Figure 3-2A** and **Figure 3-2B**, but overlaid on top of one another, whilst **Figure 3-3B** shows the cumulative impact of the two facilities. The spatial offset is driven in part by the physical separation of the Riverside 1 and Riverside 2 stacks, and in part by the greater buoyancy of the Riverside 1 plume due to its higher temperature and greater volumetric flow than Riverside 2 (**Table 3-1**). The greater buoyancy of the Riverside 1 plume means that the plume rises higher after leaving the stack and the pollutants take longer to disperse back to ground level resulting in the point of maximum impact being slightly further from the stack than that from Riverside 2.

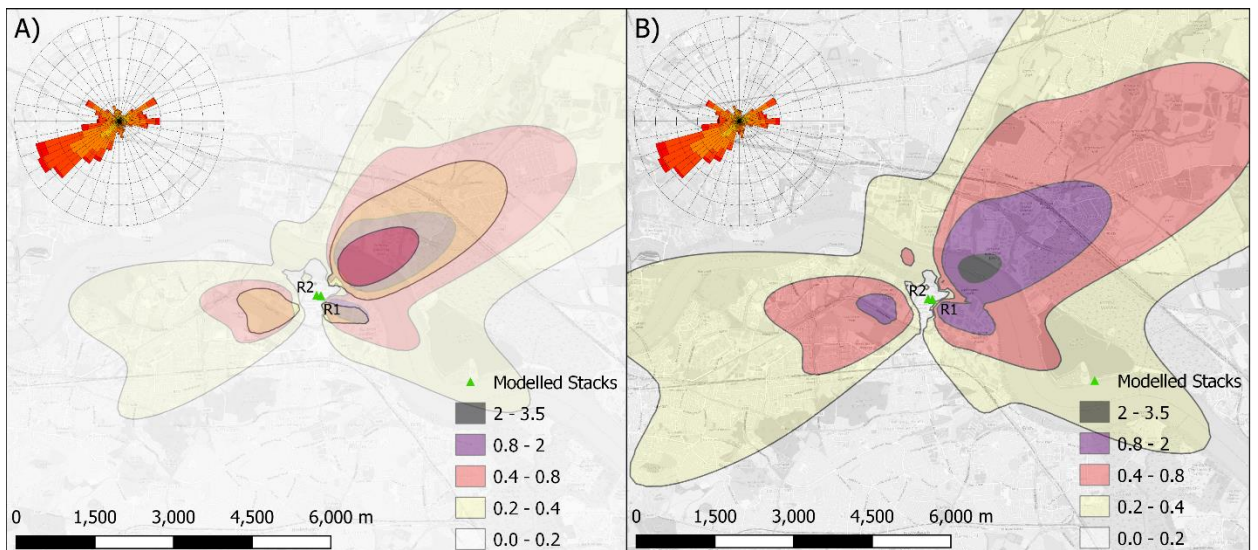


**Figure 3-3: Distribution of Pre-Carbon Capture Ground Level Concentrations of Annual Mean NO<sub>2</sub> (µg/M<sup>3</sup>) Resulting from the Full Load Operation of A) Riverside 1 (R1) and Riverside 2 (R2) Individually and B) Riverside 1 and Riverside 2 Cumulatively**

3.2.25. **Figure 3-4** and **Figure 3-5** show the equivalent plots for the impacts of the plumes from the Riverside Campus, post-carbon capture. The impacts of the exhaust stack associated with Riverside 2 remain lower than those of the exhaust stack associated with Riverside 1, but the spatial offset of the impacts is much reduced from the pre-carbon capture scenario since the Stack(s) associated with the Absorber Column(s) are much closer together and there is less difference in the buoyancy of the plumes.

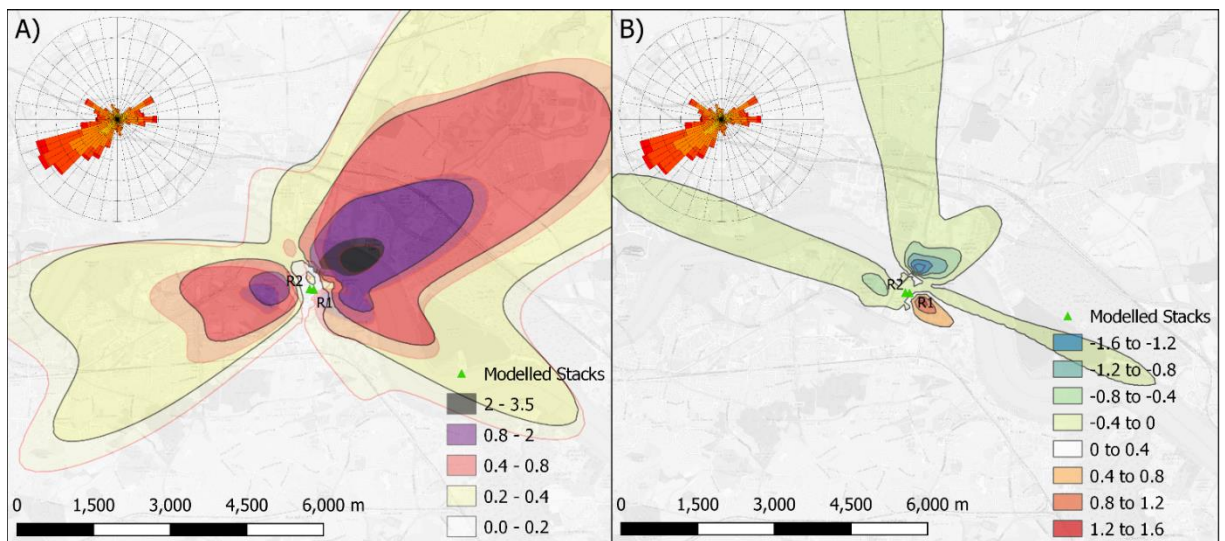


**Figure 3-4: Distribution of Proposed Scheme Ground Level Concentrations of Annual Mean NO<sub>2</sub> (µg/M<sup>3</sup>) Resulting from the Full Load Operation of A) Riverside 1 (R1) and B) Riverside 2 (R2) With Carbon Capture. The new Stack(s) are shown as green triangles**



**Figure 3-5: Distribution of Proposed Scheme ground level concentrations of Annual Mean NO<sub>2</sub> (µg/M<sup>3</sup>) Resulting from the Full Load Operation of A) Riverside 1 (R1) and Riverside 2 (R2) Individually and B) Riverside 1 and Riverside 2 Cumulatively with Carbon Capture**

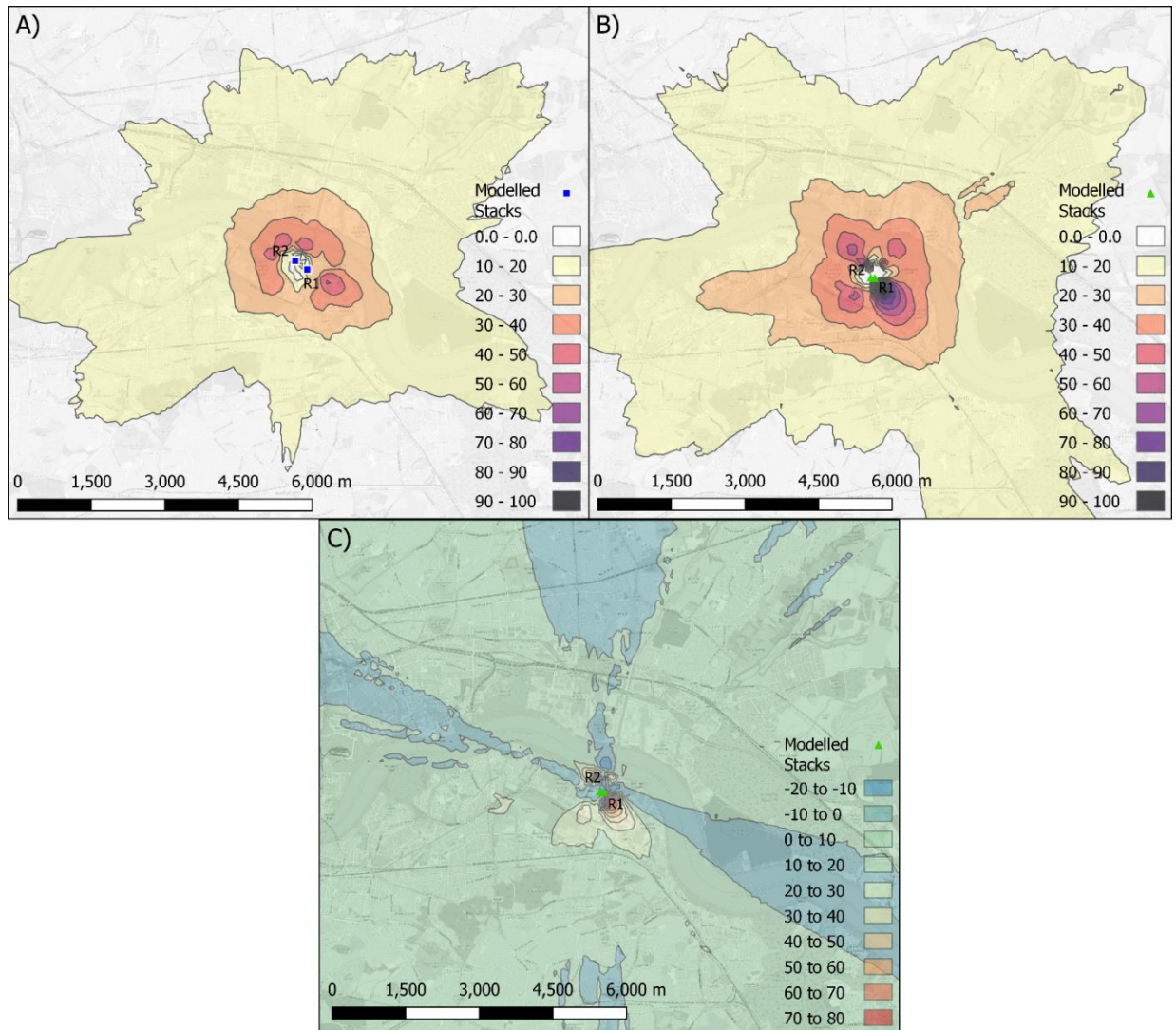
- 3.2.26. **Figure 3-6** shows the cumulative impacts of Riverside 1 and Riverside 2 as modelled for the pre- and post-carbon capture process, and the net impact resulting from the Proposed Scheme i.e. post carbon capture contribution to ground level concentrations minus the pre-carbon capture contribution (**Figure 3-3B** to **Figure 3-5B**).
- 3.2.27. The small offset in the points of maximum impact from the operation of the Riverside Campus pre- and post-carbon capture is apparent in **Figure 3-6A**, and this results in a net impact (**Figure 3-6B**) which shows both adverse (increases) and beneficial (decreases) in ground level concentrations.
- 3.2.28. Firstly, to the northeast of the new Stack(s), the point of maximum cumulative impacts with the Proposed Scheme (post-carbon capture) lies slightly further from the Stack(s) compared to the point of maximum cumulative impacts pre-carbon capture (**Figure 3-6A**). This results in a decrease in pollutant concentrations in this area (shown in blue shading in **Figure 3-6B**).
- 3.2.29. In contrast, to the southeast of the new Stack(s), the opposite is true and the point of maximum impact pre-carbon capture lies slightly closer to the Stack(s) compared to the point of maximum impact with the Proposed Scheme (**Figure 3-6A**). In this case, the offset between pre- and post-carbon capture impacts results in an increase in pollutant concentrations (shown in red shading in **Figure 3-6B**).



**Figure 3-6: Distribution of A) Cumulative Ground Level Concentrations of Annual Mean NO<sub>2</sub> (µg/M<sup>3</sup>) Resulting from the Full Load Operation of Riverside 1 (R1) and Riverside 2 (R2) with (red contours) and without (black contours) the Proposed Scheme and B) Net Change In Ground Level Concentrations of Annual Mean NO<sub>2</sub> with the Proposed Scheme**

- 3.2.30. A similar effect occurs to the west of the new Absorber Column(s) and Stack(s) with an area of decreased concentrations.
- 3.2.31. The contours shown in **Figure 3-6** are also shown in **Figures 5-4 to 5-13 (Volume 3)** with base mapping.

- 3.2.32. **Table 3-4** shows the modelled annual mean NO<sub>2</sub> concentrations pre- and post-carbon capture for all modelled meteorological years. The absolute maximum annual mean NO<sub>2</sub> pre-carbon capture (Baseline) is 3.2µg/m<sup>3</sup>. With the Proposed Scheme (post-carbon capture), the maximum modelled concentration is 2.4µg/m<sup>3</sup>. However, due to the offset in the location of the maximum impacts, the maximum adverse impact of the Proposed Scheme at any specific location is 1.3µg/m<sup>3</sup>, which is 3.3% of the objective and cannot be screened as negligible. The maximum beneficial impact at any specific location is 1.8µg/m<sup>3</sup>.
- 3.2.33. **Figure 3-7** shows the modelled hourly mean NO<sub>2</sub> concentrations pre- and post-carbon capture, modelled with meteorological data for 2020. In contrast to the annual mean concentrations, the distribution of maximum hourly mean concentrations is broadly concentric about the Absorber Column(s) and Stack(s). This is because poor dispersion conditions can occur under winds from any direction.
- 3.2.34. Maximum impacts occur around 500 to 600m from the EfW facility stacks pre-carbon capture and 300 to 400m from the new Exhaust Stack(s) with the Proposed Scheme. There is some influence of the buildings in the vicinity of the Absorber Column(s) and Stack(s) and the peak concentrations occur to the southeast and northwest pre-carbon capture, and primarily to the southwest post-carbon capture. The offset in the location of maximum impacts drives the pattern of adverse and beneficial impacts seen in **Figure 3-7C**.



**Figure 3-7: Distribution of Cumulative Ground Level Concentrations of 99.79<sup>th</sup> Percentile of hourly mean NO<sub>2</sub> (µg/m<sup>3</sup>) resulting from the Full Load Operation of Riverside 1 (R1) and Riverside 2 (R2) for A) the Pre Carbon Capture Scenario and B) the Post Carbon Capture Scenario. Net Change in Ground Level Concentrations of Hourly Mean NO<sub>2</sub> with the Proposed Scheme is shown in C)**

- 3.2.35. The maximum modelled hourly mean NO<sub>2</sub> concentration at ground level with the operation of the Proposed Scheme is 103.0µg/m<sup>3</sup> over the modelled meteorological years (
- 3.2.36. **Table 3-5)** and the maximum PEC with the Proposed Scheme is 139.2µg/m<sup>3</sup> which is within the air quality standard. The maximum adverse impact is 81.8µg/m<sup>3</sup>, which is 40.9% of the objective and cannot be screened as negligible. The maximum beneficial impact is 24.6µg/m<sup>3</sup>.
- 3.2.37. The annual mean and hourly mean NO<sub>2</sub> impacts can, as stated above, be taken to illustrate the impacts of the Proposed Scheme on long and short term pollutant concentrations respectively.

- 3.2.38. For those pollutants that are only emitted with the Proposed Scheme (amines and aldehydes), the impact distribution is adverse over the Study Area since the offset between points of maximum impacts does not apply to these pollutants i.e. the pre-carbon capture concentrations are zero everywhere.
- 3.2.39. **Table 3-4** and
- 3.2.40. **Table 3-5** show that interannual variability in modelled pollutant concentrations does not affect the conclusions set out above. The variability is less than +/-25% in terms of maximum modelled concentrations and maximum impacts, but, for NO<sub>2</sub>, cannot be screened as negligible in any year. The assessment of significance of effects on human health during operation presented in **Chapter 2: Air Quality (Volume 2)** is, in any case, always based on the maximum modelled impact over the five meteorological years tested.

**Table 3-4: Maximum Ground Level Annual Mean NO<sub>2</sub> Concentrations as a Function of Meteorological Year**

Year	Baseline Max PC (µg/m <sup>3</sup> )	With Development Max PC (µg/m <sup>3</sup> )	Max Adverse Impact (µg/m <sup>3</sup> )	Max Beneficial Impact (µg/m <sup>3</sup> )	Adverse Impact % of Objective (40µg/m <sup>3</sup> )	Beneficial Impact % of Objective (40µg/m <sup>3</sup> )	At Location of Maximum Impact		
							2030 Background NO <sub>2</sub> (µg/m <sup>3</sup> )	PEC (µg/m <sup>3</sup> )	PEC % of Objective (40µg/m <sup>3</sup> )
2018	2.4	1.9	1.0	-1.4	2.4	-3.4	15.1	16.2	40.6
2019	2.8	2.2	1.2	-1.6	3.0	-4.0	15.1	16.5	41.2
2020	3.2	2.4	1.3	-1.8	3.3	-4.	15.1	16.6	41.6
2021	2.4	2.0	1.1	-1.4	2.9	-3.5	15.0	16.2	40.
2022	2.4	1.9	1.1	-1.4	2.7	-3.5	15.1	16.3	40.8

**Table 3-5: Maximum Ground Level Hourly Mean NO<sub>2</sub> Concentrations as a Function of Meteorological Year**

Year	Baseline Max PC (µg/m <sup>3</sup> )	With Development Max PC (µg/m <sup>3</sup> )	Max Adverse Impact (µg/m <sup>3</sup> )	Max Beneficial Impact (µg/m <sup>3</sup> )	Adverse Impact % of Objective (200µg/m <sup>3</sup> )	Beneficial Impact % of Objective (200µg/m <sup>3</sup> )	At Location of Maximum Impact		
							2030 Background NO <sub>2</sub> (µg/m <sup>3</sup> )	PEC (µg/m <sup>3</sup> )	PEC % of Objective (200µg/m <sup>3</sup> )
2018	50.6	98.6	74.6	-24.6	37.3	-12.3	30.0	126.6	63.3
2019	50.5	100.7	75.9	-21.8	38.0	-10.9	29.7	127.2	63.6
2020	50.8	99.2	78.5	-22.2	39.3	-11.1	30.0	129.2	64.6
2021	49.4	101.2	76.6	-21.9	38.3	-11.0	29.9	131.1	65.6
2022	50.4	103.0	81.8	-23.1	40.9	-11.5	29.7	131.5	65.7

## 4. AMINE DEGRADATION SENSITIVITY TESTING

- 4.1.1. This section presents the results of the sensitivity testing of the amine chemistry module in the dispersion modelling. The parameters tested were set out in **Table 2-4**, above, and testing was undertaken using meteorological data for 2020. The results are shown in **Table 4-1** and **Table 4-2** below.
- 4.1.2. To recap, the modelling of amine degradation has been based on MEA and DMA as compounds representative of the degradation of primary and secondary amines. Primary amines do not form stable nitrosamines. However, this assessment has included the nitrosamines formed from MEA on a precautionary basis. The base case results for the amine modelling were summarised in **Section 5.8** of **Chapter 5: Air Quality (Volume 1)**, with a breakdown for each meteorological year presented in **Appendix 5-3: Detailed Model Pollutant Results**.

**Table 4-1: Maximum Ground Level Annual Mean Nitrosamine and Nitramine Concentrations as a Function of Sensitivity Test (Based on Meteorological Data for 2020 and Annual Mean Emission Rates)**

Sensitivity Test	Total Nitroamines and Nitrosamines (ng/m <sup>3</sup> )	Nitrosamine from MEA (ng/m <sup>3</sup> )	Nitrosamine from DMA (ng/m <sup>3</sup> )	Nitramine from MEA (ng/m <sup>3</sup> )	Nitramine from DMA (ng/m <sup>3</sup> )
Base Case (as reported in Chapter 5: Air Quality (Volume 1))	0.0250	0.0055	0.0074	0.0018	0.0136
Lower limit of reaction coefficients (best case)	0.0221	0.0048	0.0070	0.0012	0.0122
Upper limit of reaction coefficients (worst case)	0.2586	0.0381	0.0343	0.0521	0.1385
Increased primary NO <sub>2</sub> in Stack(s) emissions	0.0273	0.0056	0.0074	0.0020	0.0155
Background NO <sub>2</sub> /NO <sub>x</sub> /O <sub>3</sub> concs. From Thurrock AURN	0.0249	0.0057	0.0079	0.0016	0.0127



Sensitivity Test	Total Nitroamines and Nitrosamines (ng/m <sup>3</sup> )	Nitrosamine from MEA (ng/m <sup>3</sup> )	Nitrosamine from DMA (ng/m <sup>3</sup> )	Nitramine from MEA (ng/m <sup>3</sup> )	Nitramine from DMA (ng/m <sup>3</sup> )
Upper limit of constant, c, for OH reaction	0.0304	0.0062	0.0086	0.0022	0.0166
Lower limit of constant, c, for OH reaction	0.0200	0.0049	0.0063	0.0014	0.0107

**Table 4-2: Maximum Ground Level Daily and Hourly Mean Amine Concentrations as a Function of Sensitivity Test (Based on meteorological data for 2020 and Daily Mean Emission Rates).**

Sensitivity Test	Daily Mean Concentration			Hourly Mean Concentration		
	Total Amines (µg/m <sup>3</sup> )	Amine 1 (µg/m <sup>3</sup> )	Amine 2 (µg/m <sup>3</sup> )	Total Amines (µg/m <sup>3</sup> )	Amine 1 (µg/m <sup>3</sup> )	Amine 2 (µg/m <sup>3</sup> )
Base Case (as reported in Chapter 5: Air Quality (Volume 1))	1.39	0.693	0.693	3.35	1.675	1.683
Lower limit of reaction coefficients (best case)	1.39	0.693	0.693	3.36	1.669	1.684
Upper limit of reaction coefficients (worst case)	0.93	0.472	0.461	1.84	0.910	0.930

4.1.3. In general, the sensitivity of the modelled nitrosamines and nitramines to varying input parameters to the amine chemistry module lies within +/-20% of the base case. This level of uncertainty has been taken into account in the assessment of the significance of the effects arising from emissions of amines with the Proposed Scheme.

- 4.1.4. The exception to this sensitivity range is the test in which all reaction coefficient rates were set to the upper limit of their published values, or more correctly to the value giving rise to maximum nitrosamine and nitramine formation. This is a conservative approach and the resulting maximum ground level concentrations are considerably higher than the base case reported in the **Chapter 5: Air Quality (Volume 1)**. Notwithstanding this, additional sensitivity testing undertaken in which the individual reaction rates were increased sequentially demonstrated that the sensitivity to variations in the reaction rates lay within the +/-20% range noted above, for all reaction coefficients except that for the reaction between the amino radical and oxygen to form an imine (termed  $k_2$ ). In this case, the worst case reaction coefficient minimises the formation of imines (i.e.  $k_2$  is minimised), resulting in greater availability of the amino radical to react with NO and NO<sub>2</sub> to form nitrosamines and nitramines.
- 4.1.5. The lower limit for  $k_2$  was taken from Manzoor *et al* (2015)<sup>6</sup>, derived from experimental data from a study reported 1979. In their theoretical study of amine reaction rates, they did not apply this lower rate of  $k_2$  within their modelling, deferring to a value calculated theoretically since the theoretical value could account for thermal and pressure effects in ambient air. The value applied by Manzoor *et al*<sup>6</sup> in their modelling, more closely aligns with the  $k_2$  value used in the base case modelling. It is therefore concluded that the worst case reaction rate sensitivity test is likely to be overly conservative and not representative of worst likely case impacts.
- 4.1.6. Notwithstanding this, the sensitivity testing demonstrates that, once a technology supplier has been identified, additional testing will be required using process specific amine compounds and reaction rates will be required to set appropriate emission limit values for amines. This will be undertaken during the application for an Environmental permit for the Proposed Scheme and will ensure that impacts from amines and their degradation products are acceptable.
- 4.1.7. The sensitivity testing serve to demonstrate no significant impact on amine concentrations. The upper limits on total daily and hourly amine concentrations (modelled in sensitivity tests when the formation of degradation products is minimised) are only marginally higher than those reported for the base case. In the test in which the formation of degradation products is minimised (considered overly conservative for the production of degradation products), the concentration of amines is correspondingly lower than in the base case. This has no impact on the conclusions of the assessment.

## 5. NEW BACKUP POWER GENERATOR MODELLING

- 5.1.1. This section presents further information on the dispersion modelling of the new Backup Power Generator associated with the Proposed Scheme.
- 5.1.2. The proposed new diesel-powered Backup Power Generator will operate for a maximum of 50 hours per year and is, therefore, exempt from compliance with the MCPD emission limits. Notwithstanding this, the Environmental Permitting Regulations require that all installations use appropriate measures to reduce emissions to air through the application of BAT. The Environment Agency recently issued guidance on BAT for emergency Backup diesel generators<sup>18</sup>. This states that Backup generators should be emissions optimised (rather than efficiency optimised) and comply with the international build standards '2g TA-Luft' or the US EPA Tier 2. Therefore, emissions from the Backup power generator will be required to meet 2000mg/Nm<sup>3</sup> (2g/Nm<sup>3</sup>, at 5% O<sub>2</sub>, dry) and 80mg/Nm<sup>3</sup> for particulate matter.

### 5.2. DISPERSION MODEL INPUTS

- 5.2.1. At the time of writing only the power output of the new Backup Power Generator and run time (0.2MW at 50 hours per year) were available, but based on professional judgement and similar project experience, together with the requirement to meet BAT, the inputs stated in **Table 5-1** below were used on a worst case basis.

**Table 5-1: New Backup Power Generator Stack Inputs**

Parameter	Generator
Stack Location (X, Y)	549609, 180367
Stack height (m)	6.0
Stack diameter (m)	0.5
Release temperature (°C)	450
Volume flux (m <sup>3</sup> /s)	0.668
NO <sub>x</sub> emission rate (g/s)	0.299

- 5.2.2. The new Backup Generator housing and buildings associated with the Carbon Capture Facility (as described in **Table 1-2**) were included in the modelling. **Table 5-2** below summarises the inputs for the generator housing.

**Table 5-2: ADMS Building Inputs for New Backup Power Generator**

Building Parameter	Generator Housing
Location (X, Y)	549609, 180367
Height (m)	2.5
Length (m)	3
Width (m)	10
Angle (°)	0

### 5.3. SELECTION OF SENSITIVE RECEPTORS

- 5.3.1. To complete the assessment of impacts from the new Backup Power Generator a bespoke grid of receptors was utilised (i.e. it is a separate set of receptors to those used for assessing impacts from marine vessels and the Carbon Capture Facility). A much finer resolution grid was used to understand the maximum impacts within the Site.
- 5.3.2. The following resolutions were used for the grid:
- 10m resolution out to 500m from the new Backup Power Generator; and
  - 50m resolution out to 2km from the new Backup Power Generator.

### 5.4. MODEL RESULTS

- 5.4.1. **Table 5-3** below presents the results from the dispersion modelling of the new Backup Power Generator. To reiterate, the model was run with a constant emission rate over each year of meteorological data to generate the worst hour or day of the year that could occur, assuming that the generator could be used at any time.

**Table 5-3: Summary of Modelled Results for the New Backup Power Generator**

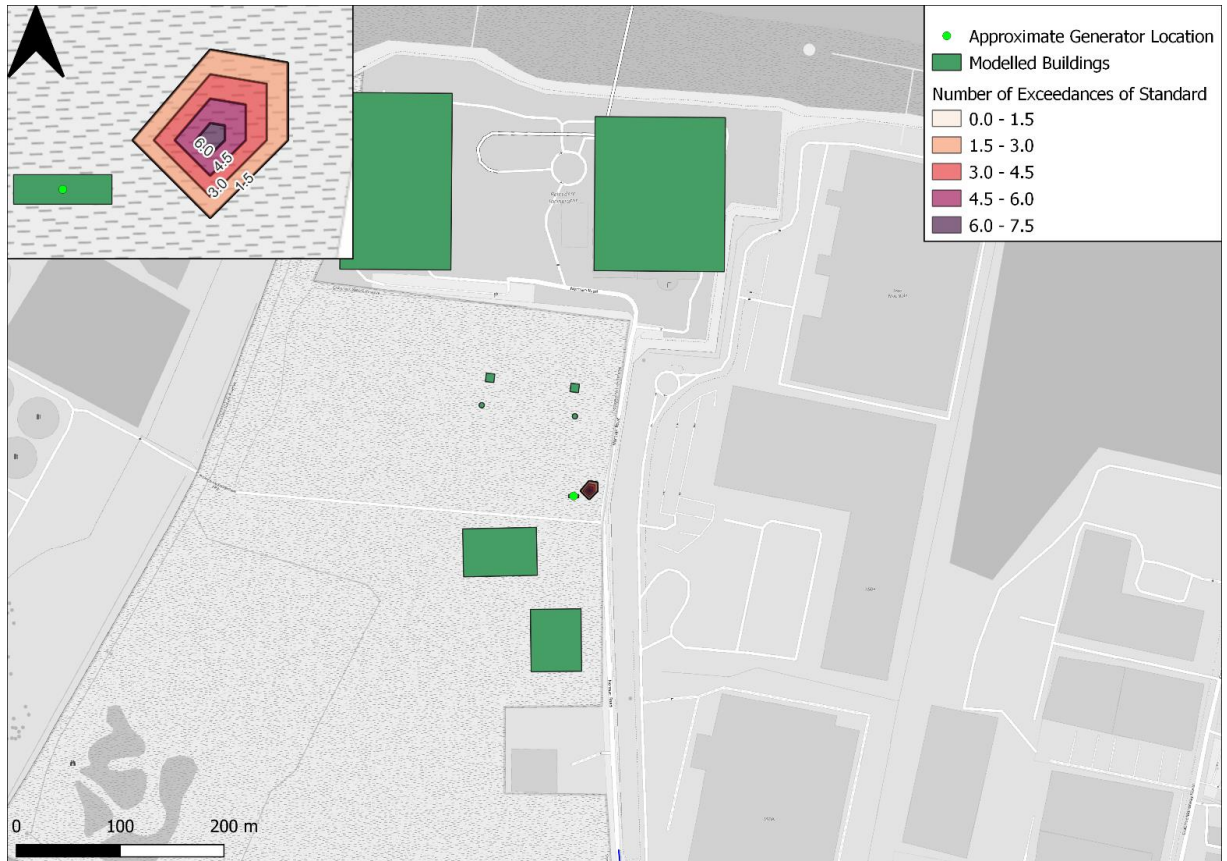
Averaging Period	Maximum Modelled Concentration (across any meteorological year, Process Contribution) ( $\mu\text{g}/\text{m}^3$ )	Maximum Number of Exceedances of the Relevant Standard in a year ( $\mu\text{g}/\text{m}^3$ )
Hourly $\text{NO}_2$	76.5	0 hours
Daily $\text{NO}_x$	202.1	7 days

- 5.4.2. **Figure 5-1** to **Figure 5-3** below present the spatial distribution of the impacts from the new Backup Power Generator.



**Figure 5-1: 100th Percentile Process Contribution to Daily NO<sub>x</sub> 2020**

5.4.3. The dispersion modelling shows that for 2020 meteorological data the maximum process contribution to daily NO<sub>x</sub> occurs between 10m and 20m from the new Backup Power Generator, with a maximum concentration of just over 200µg/m<sup>3</sup>. The process contribution drops to below the standard of 175µg/m<sup>3</sup> at approximately 25m from the generator, assuming a background concentration of 25µg/m<sup>3</sup>.



**Figure 5-2: Maximum Number of Exceedances of the Daily NO<sub>x</sub> AQS**

5.4.4. The maximum number of exceedances of daily NO<sub>x</sub> across the grid of receptors is seven days. This maximum occurs approximately 16m from the new Backup Power Generator. Assuming 50 hours of possible operation of the diesel generator over a year this amounts to a 4% probability of exceedance of the critical level. Environment Agency guidance<sup>3</sup> is that, with a plant lifetime of around 20 years, exceedance of the critical level is unlikely. However, there is an insignificant risk of exceedance of the critical level at distances over 25m from the new Backup Power Generator.



**Figure 5-3: 100th Percentile Process Contribution to Hourly NO<sub>2</sub> 2020**

5.4.5. Over all five years of meteorological data, there were no hours in which modelled concentrations exceed the hourly standard of 200ug/m<sup>3</sup> across the receptor grid. This implies that even if operation of the generator coincided with meteorological conditions giving rise to poor dispersion, hourly mean concentrations would still not exceed the standard and the risk of exceedance of the standard is very low.

## 6. HUMAN HEALTH RISK ASSESSMENT

### 6.1. METHODOLOGY

- 6.1.1. The methodology for undertaking the assessment follows the US EPA Human Health Risk Assessment (HHRA) Protocol for hazardous waste combustion facilities<sup>19</sup>. The HHRA considers the intake of dioxins (the term dioxins is used for brevity to cover emissions of dioxins, furans and dioxin-like PCB) and metals directly via inhalation and indirectly via the food chain, taking into account the bio-accumulation of dioxins deposited onto soil in plant and animal tissue. It is noted that the HHRA Protocol applies to those pollutants considered by the USEPA HHRA Protocol (dioxins and metals). Potential impacts associated with emissions of amines and their degradation products are considered with reference to the Environment Assessment Levels<sup>3</sup> for these MEA and DMA as set out in **Table 5-8 of Chapter 5: Air Quality (Volume 1)**.
- 6.1.2. In HHRA, it is customary to consider worst case possible intake of the pollutant(s) of concern and specifically two receptor types, namely subsistence farmers (who eat all locally grown produce) and residents who consume a lower proportion of locally grown produce. Furthermore, the intake of adults and children are considered separately.
- 6.1.3. Exposure is assessed via the following pathways:
- inhalation;
  - ingestion including:
    - milk from home-reared cows;
    - eggs from home-reared chickens;
    - home-reared beef;
    - home-reared pork;
    - home-reared chicken;
    - home-grown vegetable and fruit produce
  - soil (inadvertent); and
  - intake of breastmilk is also considered for infants.
- 6.1.4. The receptor locations selected for the assessment are set out in **Table 5-11 of Chapter 5: Air Quality (Volume 1)** and shown in **Figure 5-3: Operation Study Area (Volume 2)**. As noted above, farmers are assumed to consume all locally grown produce via the above pathways. Whilst this theoretical maximum exposure has been assessed, when taking the nature of the land use surrounding the Proposed Scheme into consideration, it is clear that the farmer and resident scenarios described above are highly conservative intake scenarios. Furthermore, the assessment of impacts is based on the maximum modelled concentration of dioxins/metals at any given location over five years of meteorological data which adds to the conservatism of the assessment.



- 6.1.5. The first step in the HHRA is to model the concentration of pollutants in air. The overarching dispersion modelling methodology has been described above. In modelling the impacts for HHRA purposes, the only addition to the modelling methodology is to model both dry and wet deposition (of the vapour and particle bound fractions of the dioxins/metals). ADMS<sup>1</sup> default parameters were used for modelling wet deposition, and US EPA<sup>19</sup> defaults for gas and particle dry deposition (0.5cm/s and 1cm/s respectively).
- 6.1.6. The emission rates for metals are set out above in **Table 3-3**.
- 6.1.7. Dioxins and furans emissions comprise multiple compounds, each of which has its own degree of toxicity. To express the overall toxicity of the total emissions, it is necessary to use the concept of Toxic Equivalents. For consistency with the Industrial Emissions Directive<sup>20</sup>, the NATO International Toxic Equivalents Factors (TEF)<sup>21</sup> has been used. Where concentrations or deposition rates have been equivalenced, they are clearly identified as g-ITEQ in the units. The most toxic of the dioxins, 2,3,7,8-TetraCDD, has a TEF of 1 and all other congeners have factors (less than 1) that relate their toxicity to that of 2,3,7,8-TetraCDD. The emission limit values for dioxins are set with respect to total dioxin and furans and equate to 0.06ng-ITEQ/m<sup>3</sup> for Riverside 1 and 0.04ng-ITEQ/m<sup>3</sup> for Riverside 2. For the HHRA, the profile of the individual congeners within this total limit was set with reference to average monitored profile from May 2023 at Riverside 1.
- 6.1.8. To re-emphasize this assumption, the total emissions of dioxins equates to the maximum permitted emissions on a toxic-equivalent basis. This implies that, for example, if all emissions were of congener 2,3,7,8-TetraCDF, which has a TEF of 0.1 (i.e. it is 10 times less toxic than 2,3,7,8-TetraCDD), the permitted mass of dioxins emitted could be 10 times higher than the mass emitted if the dioxins were all 2,3,7,8-TetraCDD. The toxic equivalence of these emissions, say 1g/s of 2,3,7,8-TetraCDD versus 10g/s of 2,3,7,8-TetraCDF, would, however, be the same.
- 6.1.9. **Table 6-1** sets out the congener profile from May 2023 and the assumed emission concentrations of each congener on a toxic equivalent and pure mass basis based on the emission limit values of 0.06ng-ITEQ/m<sup>3</sup> for Riverside 1 and 0.04ng-ITEQ/m<sup>3</sup> for Riverside 2. **Table 6-2** shows the corresponding mass emission rates.
- 6.1.10. The majority of the HHRA parameters used for the intake assessments are taken directly from the default values in the US EPA<sup>19</sup> HHRA Protocol, and companion database to the HHRA Protocol, including food consumption rates, exposure frequencies, and chemical parameters.
- 6.1.11. The site-specific meteorological parameters required for the HHRA are set out in
- 6.1.12. **Table 6-3**.
- 6.1.13. Adults are assumed to have a body weight of 70kg and children 15kg.
- 6.1.14. Farmers eat all contaminated produce (locally produced, including dairy, eggs and meat) whereas residents are only assumed to eat contaminated vegetable produce (home grown).

- 6.1.15. For the purposes of this assessment, where emissions limits would be expected to tighten, the Proposed Scheme is assumed to operate for 30 years, and the exposure durations are set to the default 30 years for resident adults, 40 years for farmer adults and 6 years for children.

**Table 6-1: Dioxin Conger Profile and Corresponding Emission Concentrations**

Congener	ITEQ	May 2023 R1 Monitoring (ng-ITEQ/m <sup>3</sup> )			Average Proportion by ITEQ (%)	Riverside 1		Riverside 2	
		Line 1	Line 2	Line 3		ng-ITEQ/m <sup>3</sup>	ng/m <sup>3</sup> (mass basis)	ng-ITEQ/m <sup>3</sup>	ng/m <sup>3</sup> (mass basis)
<b>2,3,7,8-TCDD</b>	1	3.85E-03	2.21E-03	1.82E-03	5.9	0.00351	0.0035	0.0023	0.0023
<b>1,2,3,7,8-PeCDD</b>	0.5	1.94E-02	1.46E-03	6.30E-03	15.5	0.00929	0.0186	0.0062	0.0124
<b>1,2,3,4,7,8-HxCDD</b>	0.1	5.40E-03	8.03E-04	1.91E-03	4.9	0.00295	0.0295	0.002	0.0196
<b>1,2,3,7,8,9-HxCDD</b>	0.1	5.34E-04	2.98E-03	6.89E-03	8.4	0.00505	0.0505	0.0034	0.0336
<b>1,2,3,6,7,8-HxCDD</b>	0.1	2.18E-04	1.69E-03	3.38E-03	4.4	0.00263	0.0263	0.0018	0.0176
<b>1,2,3,4,6,7,8-HpCDD</b>	0.01	1.54E-04	1.45E-03	2.90E-03	3.8	0.00225	0.2251	0.0015	0.1501
<b>OCDD</b>	0.001	-	1.16E-04	2.44E-04	0.	0.00018	0.181	0.0001	0.1207
<b>2,3,7,8-TCDF</b>	0.1	1.09E-03	1.19E-03	1.22E-03	2.8	0.00169	0.0169	0.0011	0.0113
<b>2,3,4,7,8-PeCDF</b>	0.5	8.25E-04	7.25E-04	7.20E-04	1.8	0.00107	0.0021	0.0007	0.0014
<b>1,2,3,7,8-PeCDF</b>	0.05	2.91E-02	1.03E-02	1.95E-02	39.8	0.02389	0.4778	0.0159	0.3186
<b>1,2,3,4,7,8-HxCDF</b>	0.1	1.90E-03	8.42E-04	1.28E-03	2.8	0.00169	0.0169	0.0011	0.0113
<b>1,2,3,7,8,9-HxCDF</b>	0.1	1.77E-03	1.01E-03	2.05E-03	3.5	0.00207	0.0207	0.0014	0.0138

Congener	ITEQ	May 2023 R1 Monitoring (ng-ITEQ/m <sup>3</sup> )			Average Proportion by ITEQ (%)	Riverside 1		Riverside 2	
		Line 1	Line 2	Line 3		ng-ITEQ/m <sup>3</sup>	ng/m <sup>3</sup> (mass basis)	ng-ITEQ/m <sup>3</sup>	ng/m <sup>3</sup> (mass basis)
<b>1,2,3,6,7,8-HxCDF</b>	0.1	2.40E-03	1.35E-03	3.31E-03	5.	0.003	0.03	0.002	0.02
<b>2,3,4,6,7,8-HxCDF</b>	0.1	1.49E-04	1.50E-04	2.23E-04	0.	0.00024	0.0024	0.0002	0.0016
<b>1,2,3,4,6,7,8-HpCDF</b>	0.01	3.07E-04	2.16E-04	3.91E-04	0.7	0.0004	0.0404	0.0003	0.0269
<b>1,2,3,4,7,8,9-HpCDF</b>	0.01	3.59E-05	3.55E-05	6.32E-05	0.1	6.2E-05	0.0062	4E-05	0.0041
<b>OCDF</b>	0.001	8.00E-07	8.20E-06	9.90E-06	0.0	1E-05	0.0102	7E-06	0.0068
<b>Aroclor 1016</b>	0.1	N/A	N/A	N/A	N/A	0.01	0.1	0.01	0.1

\*Mathematical notation: Very small numbers are shown in exponential notation, replacing part of the number with E+n, in which E (exponent) multiplies the preceding number by 10 to the nth power. For example, 1E-01 = 0.1, 1 E-02 = 0.01. 1E-03 = 0.001.

**Table 6-2: Dioxin Conger Profile and Corresponding Emission Concentrations**

Congener	Iteq	Riverside 1	Riverside 2
		g/s (mass basis)	g/s (mass basis)
<b>2,3,7,8-TCDD</b>	1	5.41E-10	2.79E-10
<b>1,2,3,7,8-PeCDD</b>	0.5	2.86E-09	1.48E-09
<b>1,2,3,4,7,8-HxCDD</b>	0.1	4.54E-09	2.34E-09
<b>1,2,3,7,8,9-HxCDD</b>	0.1	7.77E-09	4.02E-09
<b>1,2,3,6,7,8-HxCDD</b>	0.1	4.06E-09	2.10E-09
<b>1,2,3,4,6,7,8-HpCDD</b>	0.01	3.47E-08	1.79E-08
<b>OCDD</b>	0.001	2.79E-08	1.44E-08
<b>2,3,7,8-TCDF</b>	0.1	2.60E-09	1.34E-09
<b>2,3,4,7,8-PeCDF</b>	0.5	3.29E-10	1.70E-10
<b>1,2,3,7,8-PeCDF</b>	0.05	7.36E-08	3.80E-08
<b>1,2,3,4,7,8-HxCDF</b>	0.1	2.61E-09	1.35E-09
<b>1,2,3,7,8,9-HxCDF</b>	0.1	3.20E-09	1.65E-09
<b>1,2,3,6,7,8-HxCDF</b>	0.1	4.62E-09	2.39E-09
<b>2,3,4,6,7,8-HxCDF</b>	0.1	3.74E-10	1.93E-10
<b>1,2,3,4,6,7,8-HpCDF</b>	0.01	6.23E-09	3.22E-09
<b>1,2,3,4,7,8,9-HpCDF</b>	0.01	9.50E-10	4.91E-10
<b>OCDF</b>	0.001	1.57E-09	8.13E-10
<b>Aroclor 1016</b>	0.1	1.54E-08	1.19E-8

\*Mathematical notation: Very small numbers are shown in exponential notation, replacing part of the number with E+n, in which E (exponent) multiplies the preceding number by 10 to the nth power. For example, 1E-01 = 0.1, 1 E-02 = 0.01. 1E-03 = 0.001

**Table 6-3: Site Specific Meteorological Parameters for Human Health Risk Assessment**

Parameter	Units	Value
Annual Average Rainfall	mm/year	900 (estimated maximum from London City Airport 2018 – 2022)
Annual Average Run-off	mm/year	90 (estimated as 10% of rainfall, as per US EPA <sup>19</sup> )
Annual Average Wind Speed	m/s	4.1 (at 10m, estimated maximum from London City Airport 2018 – 2022)

## 6.2. ASSESSMENT OF NON-CARCINOGENIC AND CARCINOGENIC RISK

- 6.2.1. For pollutants that are potentially carcinogenic, risks are assessed against the US EPA<sup>19</sup> cancer slope factors and unit risk factors for ingestion and inhalation respectively.
- 6.2.2. For each relevant pollutant the USEPA has calculated a Carcinogenic Slope Factor (CSF) for ingestion and the risk is calculated as the dose times the slope factor, where the dose includes all ingestion routes. The inhalation risk is calculated by multiplying the concentration in air by the USEPA specific Unit Risk Factor (URF). A summary of the CSF and URF are provided in **Table 6-4** for metals and **Table 6-5** for dioxins. Pollutants not listed in the table or with a risk factor of zero are not classed as carcinogenic via the specified pathway.
- 6.2.3. For non-carcinogenic effects, the Hazard Identification (HI) is calculated as the sum of hazard quotients (HQ) for each pollutant and exposure routes. Where the hazard quotient is the ratio of the intake of a pollutant to the US EPA reference dose for the ingestion pathway, or the ratio of the pollutant concentration in air to the US EPA reference concentration for the inhalation route. A cumulative HI of less than 1 for non-carcinogenic effects is classed by US EPA as protective. The reference doses are provided in **Table 6-4** for metals and **Table 6-5** for dioxins.
- 6.2.4. In addition, as set out in **Section 5.4 of Chapter 5: Air Quality (Volume 1)**, the intake of dioxins, furans and dioxin-like PCB is evaluated against the concept of a tolerable daily intake (TDI). The UK’s Committee on Toxicology recommends a TDI of 2 pg ITEQ/kg-bw/day<sup>22</sup>. Median dioxin intakes in the UK were estimated by the Environment Agency<sup>23</sup> to be 0.7 pg ITEQ/kg-bw/day for adults and 1.8pg ITEQ/kg-bw/day for children and decreasing over time.

**Table 6-4: Toxicity Factors for Metals**

Compound	Ingestion Reference Dose	Inhalation Reference Dose	Ingestion Carcinogenic Slope Factor	Inhalation Unit Risk Factor
Antimony	0.0004	0.0014	0	0
Arsenic	0.0003	0.00003	1.5	0.0043
Cadmium	0.0004	0.0002	0.38	0.0018
Chromium III	1.5	5.3	0	0
Chromium VI	0.003	0.000008	0	0.012
Lead	0.0004	0.0015	0.0085	0.000012
Nickel	0.02	0.0002	0	0.00024
Thallium	0.000080	0	0	0
Elemental Mercury	0.000086	0.0003	0	0
Mercuric Chloride	0.0003	0.0011	0	0
Methyl Mercury	0.0001	0.0004	0	0
Benzo(a)pyrene	0	0	7.3	0.0011

**Table 6-5: Toxicity Factors for Dioxins**

Compound	Ingestion Reference Dose	Inhalation Reference Dose	Ingestion Carcinogenic Slope Factor	Inhalation Unit Risk Factor
2,3,7,8-TCDD	1.00E+09	0	150000	38
1,2,3,7,8-PeCDD	0	0	150000	38
1,2,3,4,7,8-HxCDD	0	0	15000	3.8
1,2,3,7,8,9-HxCDD	0	0	6200	3.8
1,2,3,6,7,8-HxCDD	0	0	6200	3.8

Compound	Ingestion Reference Dose	Inhalation Reference Dose	Ingestion Carcinogenic Slope Factor	Inhalation Unit Risk Factor
1,2,3,4,6,7,8-HpCDD	0	0	1500	0.38
OCDD	0	0	15	0.011
2,3,7,8-TCDF	0	0	15000	3.8
2,3,4,7,8-PeCDF	0	0	75000	11.4
1,2,3,7,8-PeCDF	0	0	7500	1.14
1,2,3,4,7,8-HxCDF	0	0	15000	3.8
1,2,3,7,8,9-HxCDF	0	0	15000	3.8
1,2,3,6,7,8-HxCDF	0	0	15000	3.8
2,3,4,6,7,8-HxCDF	0	0	15000	3.8
1,2,3,4,6,7,8-HpCDF	0	0	15000	3.8
1,2,3,4,7,8,9-HpCDF	0	0	1500	0.38
OCDF	0	0	15	0.011
Aroclor	7.00E-05	2.50E-04	0	00-Jan

### 6.3. ASSESSMENT RESULTS

- 6.3.1. The human health risk assessment results are summarised in **Section 5-8 of Chapter 5: Air Quality (Volume 1)** and demonstrates no significant adverse risk to human health.
- 6.3.2. The impact of the Proposed Scheme is assessed as the difference between the risks in the Baseline scenario and with the Proposed Scheme.



## 7. FULL PROPOSED SCHEME AQ IMPACT

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### 7.1. METHODOLOGY

- 7.1.1. For each phase of the Proposed Scheme the impacts from the various modelled sources have been combined to produce a Full Proposed Scheme Impact. Where appropriate, short term and long term impacts have been summed for the following sources of emissions:
- Operation Phase Full Proposed Scheme Impact:
    - Baseline during Operation:
      - ~ Baseline operation of Riverside 1 and Riverside 2 (no carbon capture).
    - With Proposed Scheme during Operation:
      - ~ Marine vessel movements; and
      - ~ Riverside Campus with Carbon Capture Facility in operation.
- 7.1.2. The operation of the proposed new Backup Power Generator has not been included in the Operation Full Proposed Scheme Impact since its operation is not planned or even expected in a typical year. Furthermore, as has been demonstrated, impacts during operation of the new Backup Power Generator are highly localised to the generator and there is no significant potential for combined impacts.
- 7.1.3. The ‘impact’ of the Full Proposed Scheme is defined as the difference between the With Proposed Scheme and Baseline operation scenarios during both the construction and operation phase. For the operation phase, the impacts take account of the change in impacts from Riverside 1 and Riverside 2 themselves, plus the operational LCO<sub>2</sub> marine vessel movements.
- 7.1.4. It should be noted that the maximum process contribution and impact for a single pollutant from the Stack(s) may not occur at the same location as the maximum impact from the marine vessels. The results presented below, therefore, may not be identical to the marine vessel results presented above, noting that ground level concentrations are generally dominated by emissions from the Absorber Column(s) and Stack(s).
- 7.1.5. The summation of short term impacts from the Absorber Column(s) and Stack(s) and marine vessels has been undertaken on a conservative basis, with the maximum short term impacts from each source added without consideration of whether maximum impacts would, in reality, occur under the same meteorological conditions or at the same time.
- 7.1.6. The Human Health Risk Assessment in respect of the emissions from the Carbon Capture Facility also covers the risks associated with the Full Proposed Scheme AQ Impact during operation. This is because the compounds that are persistent in the environment, such as metals and dioxins, are not emitted by the marine (or road) vessels.

## 7.2. WORKED EXAMPLES OF MODEL RESULTS

- 7.2.1. The results of the Full Proposed Scheme Impact during construction are presented in **Section 5.8 of Chapter 5: Air Quality (Volume 1)**. The breakdown for each meteorological year (where appropriate) is presented in **Appendix 5-3: Detailed Model Pollutant Results**.
- 7.2.2. The following sections present worked examples of the worst case results showing the contribution from each source of emissions.

### HUMAN RECEPTORS

- 7.2.3. **Table 7-1** below presents an example of the summation of the various sources that contribute to a Full Proposed Scheme impact from the operation of the Carbon Capture Facility and the operation of marine vessels associated with the Proposed Scheme.

**Table 7-1: Example Source Contributions to Full Proposed Scheme AQ Impact, Process Contribution Across the Modelled Study Area During Operation**

Pollutant	Averaging Time	Receptor (Easting, Northing)	Maximum Full Proposed Scheme PC ( $\mu\text{g}/\text{m}^3$ )	CCF Stacks PC at location of Max Full Proposed Scheme PC (Proposed Scheme Scenario) ( $\mu\text{g}/\text{m}^3$ )	Marine PC at location of Max Full Proposed Scheme PC (Operation only) ( $\mu\text{g}/\text{m}^3$ )
NO <sub>2</sub>	1 hour	535100, 174350	104.5	103.0	1.5
NO <sub>2</sub>	Annual	536100, 181600	2.8	2.2	0.6
PM <sub>10</sub>	Daily	536100, 181600	0.9	0.4	0.5
PM <sub>10</sub>	Annual	536100, 181600	0.2	0.1	0.1
SO <sub>2</sub>	15 minutes	535100, 174600	215.6	215.0	0.6
SO <sub>2</sub>	1 hour	535100, 174350	145.1	144.7	0.4
SO <sub>2</sub>	Daily	535350, 169350	10.7	10.6	0.1

### ECOLOGICAL RECEPTORS

- 7.2.4. The tables below present the maximum Full Proposed Scheme process contribution at each site for each modelled pollutant, and the respective contribution to the maximum from each source.

**Table 7-2: Example source contributions to Full Proposed Scheme AQ Impact, Annual NO<sub>x</sub> During Operation at Ecological Sites**

<b>Receptor</b>	<b>Maximum Full Proposed Scheme PC (µg/m<sup>3</sup>)</b>	<b>CCF Stacks PC at location of Max Full Proposed Scheme PC (Proposed Scheme Scenario) (µg/m<sup>3</sup>)</b>	<b>Marine PC at location of Max Full Proposed Scheme PC (Operation only) (µg/m<sup>3</sup>)</b>
<b>Epping Forest – SAC, SSSI</b>	0.08	0.08	0.00
<b>Ingrebourne Marshes – SSSI</b>	1.26	1.21	0.05
<b>Inner Thames Marshes – SSSI</b>	2.29	2.19	0.10
<b>Oxleas Woodlands – SSSI</b>	0.31	0.30	0.01
<b>West Thurrock Lagoon and Marshes – SSSI</b>	0.26	0.23	0.03
<b>Crossness – LNR</b>	1.25	1.18	0.07
<b>Lesnes Abbey Woods – LNR (comprising Ancient Woodland)</b>	0.57	0.54	0.02
<b>Rainham Marshes – LNR</b>	2.29	2.19	0.10

**Table 7-3: Example Source Contributions to Full Proposed Scheme AQ Impact, Daily NO<sub>x</sub> During Operation at Ecological Sites**

<b>Receptor</b>	<b>Maximum Full Proposed Scheme PC (µg/m<sup>3</sup>)</b>	<b>CCF Stacks PC at location of Max Full Proposed Scheme PC (Proposed Scheme Scenario) (µg/m<sup>3</sup>)</b>	<b>Marine PC at location of Max Full Proposed Scheme PC (Operation only) (µg/m<sup>3</sup>)</b>
<b>Epping Forest – SAC, SSSI</b>	1.55	1.48	0.07
<b>Ingrebourne Marshes – SSSI</b>	7.46	7.01	0.45
<b>Inner Thames Marshes – SSSI</b>	11.71	11.08	0.63
<b>Oxleas Woodlands – SSSI</b>	3.96	3.81	0.15
<b>West Thurrock Lagoon and Marshes – SSSI</b>	2.82	2.54	0.28
<b>Crossness – LNR</b>	27.88	26.99	0.89
<b>Lesnes Abbey Woods – LNR (comprising Ancient Woodland)</b>	9.96	9.61	0.35
<b>Rainham Marshes – LNR</b>	11.54	10.99	0.56

**Table 7-4: Example Source Contributions to Full Proposed Scheme AQ Impact, Annual SO<sub>2</sub> During Operation at Ecological Sites**

<b>Receptor</b>	<b>Maximum Full Proposed Scheme PC (µg/m<sup>3</sup>)</b>	<b>CCF Stacks PC at location of Max Full Proposed Scheme PC (Proposed Scheme Scenario) (µg/m<sup>3</sup>)</b>	<b>Marine PC at location of Max Full Proposed Scheme PC (Operation only) (µg/m<sup>3</sup>)</b>
<b>Epping Forest – SAC, SSSI</b>	0.02	0.02	0.00
<b>Ingrebourne Marshes – SSSI</b>	0.33	0.32	0.01
<b>Inner Thames Marshes – SSSI</b>	0.61	0.60	0.01
<b>Oxleas Woodlands – SSSI</b>	0.09	0.09	0.00
<b>West Thurrock Lagoon and Marshes – SSSI</b>	0.06	0.06	0.00
<b>Crossness – LNR</b>	0.33	0.32	0.01
<b>Lesnes Abbey Woods – LNR (comprising Ancient Woodland)</b>	0.16	0.16	0.00
<b>Rainham Marshes – LNR</b>	0.61	0.60	0.01

**Table 7-5: Example Source Contributions to Full Proposed Scheme AQ Impact, Nitrogen Deposition During Operation At Ecological Sites**

Receptor	Maximum Full Proposed Scheme PC (kg/N/ha/yr)	CCF Stacks PC at location of Max Full Proposed Scheme PC (Proposed Scheme Scenario) (kg/N/ha/yr)	Marine PC at location of Max Full Proposed Scheme PC (Operation only) (kg/N/ha/yr)
Epping Forest – SAC, SSSI	0.08	0.08	0.00
Ingrebourne Marshes – SSSI	0.76	0.76	0.00
Inner Thames Marshes – SSSI	1.38	1.37	0.01
Oxleas Woodlands – SSSI	0.34	0.34	0.00
West Thurrock Lagoon and Marshes – SSSI	0.15	0.15	0.00
Crossness – LNR	0.78	0.77	0.01
Lesnes Abbey Woods – LNR (comprising Ancient Woodland)	0.59	0.58	0.00
Rainham Marshes – LNR	1.38	1.37	0.01

**Table 7-6: Example Source Contributions to Full Proposed Scheme AQ Impact, Acid Deposition During Operation at Ecological Sites**

Receptor	Maximum Full Proposed Scheme PC (keq/ha/yr)	CCF Stacks PC at location of Max Full Proposed Scheme PC (Proposed Scheme Scenario) (keq/ha/yr)	Marine PC at location of Max Full Proposed Scheme PC (Operation only) (keq/ha/yr)
Epping Forest – SAC, SSSI	0.012	0.011	0.000
Oxleas Woodlands – SSSI	0.047	0.047	0.000

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