**FICHTNER**

Consulting Engineers Limited

# Protos ERF EP Variation

**Encyclis**

Dispersion Modelling Assessment

ENGINEERING + CONSULTING

# Document approval

| | Name | Signature | Position | Date |
|---|---|---|---|---|
| Prepared by: | Rosalind Flavell | RFlavell | Senior Environmental Consultant | 21/11/2023 |
| Checked by: | Stuart Nock | | Associate Senior Environmental Consultant | 21/11/2023 |

# Document revision record

| Revision no | Date | Details of revisions | Prepared by | Checked by |
|---|---|---|---|---|
| 0 | 05/09/2023 | Draft for Client comment | RSF | SMN |
| 1 | 12/09/2023 | For Client approval | RSF | SMN |
| 2 | 13/09/2023 | For submission | RSF | SMN |
| 3 | 30/10/2023 | Updated to include metals results and updated layout | RSF | JRS |
| 4 | 21/11/2023 | For client review | RSF | JRS |
| 5 | 21/11/2023 | For submission | RSF | JRS |

# Management Summary

Fichtner Consulting Engineers Ltd (“Fichtner”) has been engaged by Encyclis Limited to undertake a Dispersion Modelling Assessment to support the application for a variation to the Environmental Permit (EP) for the Protos Energy Recovery Facility (herein referred to as the Facility). The Facility comprises two incineration lines. Encyclis is proposing to install a carbon capture (CC) facility with two lines to extract carbon dioxide ($CO_2$) from the emissions produced by each line of the ERF. Full details of the proposed changes being applied for can be found in the Supporting Information document.

## Dispersion Modelling of Emissions

The ADMS dispersion model is routinely used for air quality assessments to the satisfaction of the Environment Agency (EA). The model uses weather data from the local area to predict the spread and movement of the exhaust gases from the stack for each hour over a five-year period. The model takes account of wind speed, wind direction, temperature, humidity and the amount of cloud cover, as all of these factors influence the dispersion of emissions. The model also takes account of the effects of buildings and terrain on the movement of air.

Dispersion modelling has been carried out for the following scenarios:

1. Permitted Facility – the ERF operating as per the conditions of the existing EP; and
2. Proposed Facility – the emissions from each line of the ERF being ducted to the CC facility.

To set up the model, it has been assumed that the ERF operates for the whole year and releases emissions at the emission limits set out in the existing EP continuously and these are either emitted from the main stack of the ERF or pass through to the CC facility before emitting to atmosphere. The CC process alters the flue gas composition. The difference in the flue gas composition (temperature, moisture content and volume) as a result of the CC process has been accounted for. However, for modelling purposes it is assumed that the CC facility does not offer any additional abatement of emissions which is extremely conservative given that the CC facility includes a water and acid wash system which and is likely to reduce emissions of many of the pollutants released in particular acid gases, particulates and ammonia by more than 80%.

Dispersion modelling has also been carried out to determine the impact of venting of $CO_2$.

The model has been used to predict the ground level concentration of pollutants on a long-term and short-term basis across a grid of points. In addition, concentrations have been predicted at the identified sensitive receptors.

## Approach and Assessment of Impact on Air Quality – Protection of Human Health

The air quality impact on human health has been assessed using a standard approach based on guidance provided by the EA. Using this approach, in relation to the Air Quality Assessment Levels (AQALs) set for the protection of human health the following can be concluded from the assessment.

1. Emissions from the operation of the Proposed Facility will not cause a breach of any AQAL.
2. There is predicted to be an increase in the impacts as a result of the proposed EP variation, but the overall impact of the Proposed Facility is not significant this includes for the additional products released from the CC facility such as amines, nitrosamine and nitramines.

3. There is no risk of exceeding an AQAL for any metal either on a long or short term basis.

## Approach and Assessment of Impact on Air Quality – Protection of Ecosystems

The impact of air quality on ecology has been assessed using a standard approach based on guidance provided by the EA. Using this approach the following can be concluded from the assessment.

1. Two European designated receptors have been identified as requiring assessment.
2. At the Mersey Estuary, and functionally linked land, the peak impact of emissions of oxides of nitrogen, ammonia and nitrogen deposition are predicted to exceed 1% of the Critical Level and Critical Load and in the case of ammonia and nitrogen deposition the baseline exceeds the Critical Level and Critical Load.
3. At Midland Meres and Mosses, which is located 9.2 km from the Facility, the peak impact nitrogen and acid deposition are predicted to exceed 1% of the Critical Load and the baseline exceeds the Critical Load.
4. At all local ecological sites, the contribution from the Proposed Facility can be screened out 'insignificant' as it is less than the Critical Levels and Critical Loads.
5. These impacts assume that the CC facility does not offer any additional abatement of emissions and the emissions from the ERF and the emissions assuming operating at the ELVs are passed through the CC facility before emitting to atmosphere. The CC facility includes a water and acid wash system which is likely to abate emissions of acid gases, particulates and ammonia by more than 80%, as such it is unlikely that impacts would exceed the 1% of the long term Critical Level or Critical Load at any ecological site. Therefore, impacts would be insignificant at the identified ecological receptors.

## Plume visibility

The potential impact of visible plumes from the CC facility has been considered. This has considered the releases from the absorber columns and the hybrid coolers within the CC facility. The initial analysis of the exhaust parameters has shown that the exhaust gases would be below 100% relative humidity. This has been confirmed with the dispersion modelling which has shown that there is not likely to be a visible plume from the CC facility.

## Carbon dioxide venting

The CC facility include a $CO_2$ vent which would be used in the event that $CO_2$ does not meet the pipeline specifications and cannot be exported. The $CO_2$ stack is proposed to be the same height as the stacks on top of the absorber columns. The dispersion model has been run assuming the continuous operation of the $CO_2$ vent. This considered the impact at ground level and at elevated working platforms. This analysis has shown that the maximum impact can be screened out as 'insignificant'.

## Summary and conclusions

In summary, the assessment has shown that the air quality impact of the Proposed Facility would not have a significant impact on local air quality, the general population or the local community. As such there should be no air quality constraint in granting a variation to the existing EP to include the CC facility.

# Contents

# 1 Introduction

## 1.1 Background

Fichtner Consulting Engineers Ltd ("Fichtner") has been engaged by Encyclis Limited to undertake a Dispersion Modelling Assessment to support the application for a variation to the Environmental Permit (EP) for the Protos Energy Recovery Facility (ERF). The ERF comprises two incineration lines. Encyclis is proposing to install a carbon capture (CC) facility with two lines to extract carbon dioxide ($CO_2$) from the emissions produced by each line of the ERF with a common compression system for injection into the HyNet transport and storage system. Full details of the proposed changes being applied for can be found in the Supporting Information document.

This assessment has considered the following scenarios:

- the "Permitted Facility" – the impact of the ERF operating at the maximum permitted emission limit values (ELVs); and
- the "Proposed Facility" – the impact of the ERF including the CC facility assuming operation of the ERF at the ELVs.
- The difference in impact has been quantified to determine the impact of this variation application.

The existing EP for the Facility (EPR/LP3132FX) implements the requirements of the Waste Incineration Best Available Techniques (BAT) Reference Document (the WI BREF) and as such for certain substances has two sets of ELVs which need to be complied; one up to 02 December 2023, and a more stringent ELV post this date. The changes proposed as part of this EP variation will only take place after 02 December 2023 and as such the ELVs for the Permitted Facility have been taken as those relevant after 02 December 2023.

When considering the impact on human health, the predicted atmospheric concentrations have been compared to the Air Quality Assessment Levels (AQALs) for the protection of human health. It is noted that for dioxins the AQAL is a Tolerable Daily Intake (TDI) which considers the combination of the intake from inhalation and ingestion. As such it is not possible to demonstrate compliance with the assessment level with just reference to the air concentration. A separate Dioxin Pathway Intake Assessment has been undertaken to assess the pathway intake of these pollutants and impacts compared to the TDI. This is provided as a separate technical report and is included as Appendix D.2 of the EP application.

When considering the impact on ecosystems the predicted atmospheric concentrations have been compared to the Critical Levels for the protection of ecosystems. It is noted that deposition of emissions over a prolonged period can have nutrification and acidification impacts. An assessment of the long-term deposition of pollutants has been undertaken and the results compared to the habitat specific Critical Loads.

This assessment also includes consideration of the impact of the Facility during abnormal operations of the ERF as defined within the Industrial Emissions Directive (IED) (Directive 2010/75/EU) for the combustion of waste.

## 1.2 Structure of the report

This report has the following structure.

- National and international air quality legislation and guidance are considered in section 2.
- The residential properties and ecological receptors which are sensitive to changes in air quality associated with the Facility and identified in section 3.
- The background levels of ambient air quality are described in section 4.
- The inputs used for the dispersion model are contained in section 5.
- Details of the sensitivity analysis carried out is presented in section 6.
- A discussion of the validity of the model and uncertainty is presented in section 7.
- The assessment methodology and results of the assessment of the impact of emissions on human health is presented in section 8.
- The assessment methodology and results of the assessment of the impact of emissions at ecological sites is presented in section 9.
- An assessment of the potential for a visible plume from the CC facility is contained in section 10.
- An assessment of the impact of venting of $CO_2$ on air quality is contained in section 11.
- An overview of potential effect on the abnormal operations as defined within the IED are set out in section 12.
- The conclusions of the assessment are set out in section 13.
- The Appendices include illustrative figures and detailed results tables.

# 2 Legislation Framework and Policy

## 2.1 Air quality assessment levels

In the UK, Ambient Air Directive (AAD) Limit Values, Targets, and air quality standards and objectives for major pollutants are described in The Air Quality Strategy (AQS). In addition, the Environment Agency (EA) include Environmental Assessment Levels (EALs) for other pollutants in the environmental management guidance 'Air Emissions Risk Assessment for your Environmental Permit'[1] ("Air Emissions Guidance"), which are also considered. The long-term and short-term EALs from these documents have been used when the AQS does not contain relevant objectives. Standards and objectives for the protection of sensitive ecosystems and habitats are also contained within the Air Emissions Guidance and the Air Pollution Information System (APIS).

AAD Target and Limit Values, AQS Objectives, and EALs are set at levels well below those at which significant adverse health effects have been observed in the general population and in particularly sensitive groups. For the remainder of this report these are collectively referred to as AQALs. Table 1 to Table 4 summarise the air quality objectives and guidelines used in this assessment.

*Table 1: Air Quality Assessment Levels (AQALs)*

| Pollutant | AQAL (µg/m³) | Averaging Period | Frequency of Exceedances | Source |
|---|---:|---|---|---|
| Nitrogen dioxide ($NO_2$) | 200 | 1 hour | 18 times per year (99.79th percentile) | AAD Limit Value |
| | 40 | Annual | - | AAD Limit Value |
| Sulphur dioxide ($SO_2$) | 266 | 15 minutes | 35 times per year (99.9th percentile) | AQS Objective |
| | 350 | 1 hour | 24 times per year (99.73rd percentile) | AAD Limit Value |
| | 125 | 24 hours | 3 times per year (99.18th percentile) | AAD Limit Value |
| Particulate matter ($PM_{10}$) | 50 | 24 hours | 35 times per year (90.41st percentile) | AQS Objective |
| | 40 | Annual | - | AQS Objective |
| Particulate matter ($PM_{2.5}$) | 10 | Annual | - | Environmental Targets (fine particulate matter) (England) regulations 2023 |

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[1] https://www.gov.uk/guidance/air-emissions-risk-assessment-for-your-environmental-permit#environmental-standards-for-air-emissions

| Pollutant | AQAL ($\mu g/m^3$) | Averaging Period | Frequency of Exceedances | Source |
|---|---|---|---|---|
| Carbon monoxide (CO) | 10,000 | 8 hours, running | - | AAD Limit Value |
| | 30,000 | 1 hour | - | Air Emissions Guidance |
| Hydrogen chloride (HCl) | 750 | 1 hour | | Air Emissions Guidance |
| Hydrogen fluoride (HF) | 160 | 1 hour | - | Air Emissions Guidance |
| | 16 | Annual | - | Air Emissions Guidance |
| Ammonia ($NH_3$) | 2,500 | 1 hour | - | Air Emissions Guidance |
| | 180 | Annual | - | Air Emissions Guidance |
| Benzene ($C_6H_6$) | 5 | Annual | - | Air Emissions Guidance |
| | 30 | 24 hours | - | Air Emissions Guidance |
| Polychlorinated biphenyls (PCBs) | 6 | 1-hour | - | Air Emissions Guidance |
| | 0.2 | Annual | - | Air Emissions Guidance |
| Polycyclic Aromatic Hydrocarbons (PAHs) | 0.00025 | Annual | - | AQS Objective |
| Formaldehyde ($CH_2O$) | 100 | 30-minute | - | Air Emissions Guidance |
| | 5 | Annual | - | Air Emissions Guidance |
| Monoethanolamine (MEA) | 400 | 1-hour | - | Air Emissions Guidance |
| | 100 | 24 hour | - | Air Emissions Guidance |
| Total nitrosamines (as NDMA(1)) | 0.0002 | Annual | | Air Emissions Guidance |
| Total nitrosamines + nitramines (as NDMA) | 0.0003 | Annual | | NIPH(2) |
| Carbon dioxide ($CO_2$) | 5,000 ppm | 8-hour | - | EH40/2005 Workplace exposure limits |
| | 15,000 ppm | 15-minute | - | |

*Notes:*
*(1) NDMA is N-nitrosodimethylamine*

| Pollutant | AQAL (μg/m$^3$) | Averaging Period | Frequency of Exceedances | Source |
|---|---|---|---|---|
| [2] *Norwegian Institute for Public Health* | | | | |

In the first instance the total impact of all amines has been compared to the EAL published by the EA for MEA. However, as outlined in Section 5.3 the CC facility will also release small amounts of DMA and DEA. The EA has not currently published EALs for these substances. Therefore, EAL have been derived using the EA approach as set out within Appendix G. In summary the following EALs are proposed for DMA and DEA:

*Table 2: EALs for Additional Amines*

| Amine | 24-hour (μg/m$^3$) | 1-hour (μg/m$^3$) |
|---|---|---|
| DEA | 0.2 | None recommended |
| DMA | 3.3 | None recommended |

*Table 3: Air Quality Assessment Levels for Metals*

| Metal | AAD Limit / Target (ng/m$^3$) | EALs (ng/m$^3$) – EA 2023 | |
|---|---|---|---|
| | | Long-term | Short-term |
| Arsenic (As) | 6 | 6 | - |
| Antimony (Sb) | - | 5,000 | 150,000 |
| Cadmium (Cd) | 5 | - | - |
| Chromium (II & III) (Cr) | - | 5,000 | 150,000 |
| Chromium (VI) (Cr (VI)) | - | 0.25 | - |
| Cobalt (Co) | - | - | - |
| Copper (Cu) | - | 10,000 | 200,000 |
| Lead (Pb) | 500 (250 AQS Target) | 250 | - |
| Manganese (Mn) | - | 150 | 1,500,000 |
| Mercury (Hg) | - | 250 | 7,500 |
| Nickel (total nickel compounds in the PM$_{10}$ fraction) (Ni) | 20 | - | - |
| Nickel and inorganic compounds (as Ni) | - | - | - |
| Nickel, organic compounds (as Ni) | | - | - |
| Thallium (Tl) | - | - | - |
| Vanadium (V) | - | - | 1,000 |

*Notes:*

*Short term EAL is maximum hourly mean with the exception of vanadium which is the daily mean.*

*Table 4: Critical Levels for the Protection of Vegetation and Ecosystems*

| **Pollutant** | **Concentration ($\mu g/m^3$)** | **Measured as** | **Source** |
|---|---|---|---|
| Nitrogen oxides NOx)<br>(as $NO_2$) | 75/200* | Daily mean | APIS |
| | 30 | Annual mean | AAD Critical Level |
| Sulphur dioxide ($SO_2$) | 10 | Annual mean<br>where lichens and bryophytes are an important part of the ecosystem's integrity | Air Emissions Guidance / APIS |
| | 20 | Annual mean<br>for all higher plants | AAD Critical Level |
| Hydrogen fluoride (HF) | 5 | Daily mean | Air Emissions Guidance / APIS |
| | 0.5 | Weekly mean | Air Emissions Guidance / APIS |
| Ammonia ($NH_3$) | 1 | where lichens and bryophytes are an important part of the ecosystem's integrity | APIS |
| | 3 | Annual mean<br>for all higher plants | APIS |

*Notes:*
**only for detailed assessments where the ozone is below the AOT40 Critical Level and sulphur dioxide is below the lower Critical Level of 10 $\mu g/m^3$.*
The *AOT40 for ozone is 3,000 ppb.h (6,000 $\mu g/m^3$.h) calculated from accumulated hourly ozone concentrations – AOT40 means the sum of the difference between each hourly daytime (08:00 to 20:00 Central European Time, CET) ozone concentration greater than 80 $\mu g/m^3$ (40 ppb) and 80 $\mu g/m^3$, for the period between 01 May and 31 July.*

In addition to the Critical Levels set out in Table 4, APIS provides habitat specific Critical Loads for nitrogen and acid deposition. Full details of the habitat specific Critical Loads can be found in Appendix B.

There is no AQAL for dioxins and dioxin-like PCBs. As there are other intake pathways besides inhalation for these substances, a separate assessment has been undertaken in which the total intake via inhalation and ingestion has been compared to the Tolerable Daily Intake (TDI). This assessment is presented in the Dioxin Pathway Intake Assessment submitted with this application to vary the EP.

## 2.2 Areas of relevant exposure

The AQALs apply only at areas of exposure relevant to the assessment level. The following table extracted from Local Authority Air Quality Technical Guidance (TG22) (2022) (LAQM.TG(22)) explains where the AQALs apply.

*Table 5: Guidance on Where AQALs Apply*

| **Averaging period** | **AQALs should apply at:** | **AQALs should generally not apply at:** |
|---|---|---|
| Annual mean | All locations where members of the public might be regularly exposed. Building façades of residential properties, schools, hospitals, care homes etc. | Building façades of offices or other places of work where members of the public do not have regular access.<br>Hotels, unless people live there as their permanent residence.<br>Gardens of residential properties.<br>Kerbside sites (as opposed to locations at the building façade), or any other location where public exposure is expected to be short-term. |
| 24-hour mean and 8-hour mean | All locations where the annual mean AQAL would apply, together with hotels. Gardens of residential properties. | Kerbside sites (as opposed to locations at the building façade), or any other location where public exposure is expected to be short-term. |
| 1-hour mean | All locations where the annual mean and 24 and 8-hour mean AQALs apply.<br>Kerbside sites (for example, pavements of busy shopping streets).<br>Those parts of car parks, bus stations and railway stations etc. which are not fully enclosed, where members of the public might reasonably be expected to spend one hour or more.<br>Any outdoor locations where members of the public might reasonably be expected to spend one hour or longer. | Kerbside sites where the public would not be expected to have regular access. |
| 15-minute mean | All locations where members of the public might reasonably be exposed for a period of 15-minutes or longer. | |

*Source: Box 1.1 LAQM.TG(22)*

## 2.3 Industrial pollution regulation

Atmospheric emissions from industrial processes are controlled in England through the Environmental Permitting Regulations (2016) (and subsequent amendments). The Facility currently has an EP to operate. The EP includes conditions to ensure that the environmental impact of the operations is minimised. This includes conditions to prevent fugitive emissions of dust and odour beyond the boundary of the permitted activity, and limits on emissions to air.

The Industrial Emissions Directive (IED) (Directive 2010/75/EU), was adopted on 07 January 2013, and is the key European Directive which covers almost all regulation of industrial processes in the European Union (EU). Within the IED, the requirements of the relevant sector BREF (Best Available Techniques Reference documents) become binding as BAT (Best Available Techniques) guidance, as follows.

- Article 15, paragraph 2, of the IED requires that ELVs are based on best available techniques, referred to as BAT.
- Article 13 of the IED, requires that 'the Commission' develops BAT guidance documents (referred to as BREFs).
- Article 21, paragraph 3, of the IED, requires that when updated BAT conclusions are published, the Competent Authority (in Scotland this is SEPA) has up to four years to revise permits for facilities covered by that activity to comply with the requirements of the sector specific BREF.

The EA explain that ‘BAT’ means the available techniques which are the best for preventing or minimising emissions and impacts on the environment where ‘techniques’ include both the technology used and the way the installation is designed, built, maintained, operated and decommissioned.

The Waste Incineration BREF was published by the European Integrated Pollution Prevention and Control (IPPC) Bureau in December 2019. The existing EP has been varied to comply with the requirements of the Waste Incineration BREF.

## 2.4 Local air quality management

In accordance with Section 82 of the Environment Act (1995) (Part IV), local authorities are required to periodically review and assess air quality within their area of jurisdiction, under the system of Local Air Quality Management (LAQM). This review and assessment of air quality involves assessing present and likely future ambient pollutant concentrations against AQALs. If it is predicted that levels at the façade of buildings where members of the public are regularly present (normally residential properties) are likely to be exceeded, then the local authority is required to declare an Air Quality Management Area (AQMA). For each AQMA, the local authority is required to produce an Air Quality Action Plan (AQAP), the objective of which is to reduce pollutant levels in pursuit of the relevant AQALs.

# 3 Sensitive Receptors

## 3.1 Human sensitive receptors

The general approach to the assessment is to evaluate the highest predicted process contribution to ground level concentrations. In addition, the predicted process contribution at a number of sensitive receptors has been evaluated. These sensitive receptors are displayed in Figure 2 of Appendix A and listed in Table 6.

These receptors are a representative sample of the residential properties, schools, hospitals, care homes (typically within 2 km of the Facility) and allotments within the modelling domain. Allotments have been identified using aerial mapping. It is not possible to include every occupied area and as such the assessment also considers the point of maximum impact and by interpretation of plot files.

*Table 6: Sensitive Receptors*

| ID | Receptor name | Location | | Distance from the absorber stacks (km) |
|---|---|---|---|---|
| | | X (m) | Y (m) | |
| R1 | Allotments off Queens Drive – Helsby | 348520 | 375350 | 2.0 |
| R2 | Marsh Lane - Ince | 345000 | 376500 | 2.0 |
| R3 | Coppice Green – Elton | 346160 | 375700 | 1.2 |
| R4 | Spring Farm | 348385 | 376077 | 1.5 |
| R5 | View Farm | 348620 | 376504 | 1.7 |
| R6 | Jessamine Farm | 347155 | 374154 | 2.5 |
| R7 | New Dairy Farm | 345747 | 374846 | 2.1 |
| R8 | Hall Farm | 344765 | 376947 | 2.2 |
| R9 | Holme Farm | 345572 | 377117 | 1.5 |
| R10 | Lower Rake Lane – Helsby | 348638 | 375860 | 1.8 |
| R11 | Smithy Lane – Helsby | 349075 | 376050 | 2.2 |
| R12 | Vale Gardens – Helsby | 348891 | 375825 | 2.1 |
| R13 | Chester Road – Helsby | 348982 | 375720 | 2.2 |

## 3.2 Ecological sensitive receptors

A study was undertaken to identify the following sites of ecological importance in accordance with the EA's Air Emissions Guidance criteria:

- Special Protection Areas (SPAs), Special Areas of Conservation (SACs), Ramsar sites, or Sites of Special Scientific Interest (SSSIs) within 10 km of the Facility; and
- National Nature Reserves (NNR), Local Nature Reserves (LNRs), Local Wildlife Sites and ancient woodlands within 2 km of the Facility.

The sensitive ecological receptors identified are presented by distance from absorber column stacks in Table 7 and are displayed in Figure 3 and Figure 4 of Appendix A. A review of the citation for each site has been undertaken to determine if lichens are an important part of the ecosystem's integrity for the purposes of determining the relevant Critical Level for the habitat.

*Table 7: Sensitive Ecological Receptors*

| ID | Name | Location | | Distance from absorber stacks at closest point (km) |
|---|---|---|---|---|
| | | X (m) | Y (m) | |
| **European and UK designated sites** | | | | |
| E1 | Mersey Estuary SPA / Ramsar / SSSI | Point of maximum impact within designated site | | 1.0 |
| E2 | Midland Meres and Mosses Ramsar – Hatch Mere* | 354880 | 372370 | 9.2 |
| E7 | Midland Meres and Mosses Ramsar – Flaxmere Moss SSSI* | 355550 | 372470 | 9.5 |
| E8 | Midland Meres and Mosses Ramsar – Linmere Moss SSSI* | 354720 | 370880 | 9.7 |
| **Local sites** | | | | |
| E3 | Frodsham and Helsby and Ince Marshes | Point of maximum impact within designated site | | Surrounding the Facility |
| E4 | Station Road Railway Site | 345473 | 375857 | 1.7 |
| *Notes:*<br>** identified within APIS that sensitive lichens or bryophytes may be present* | | | | |

The Mersey Estuary extends across a wide area. When undertaking the assessment the maximum impact within the designated site has been considered. The Facility is located within the Frodsham and Helsby and Ince Marshes Local Wildlife Site (LWS) and the designated site surrounds the Facility. As with the Mersey Estuary, the maximum impact within the designated site has been considered.

In addition, reference has been made to the impact at land potentially functionally linked to the Mersey Estuary. These zones are shown on Figure 4 of Appendix A. These includes the ecological mitigation area A within the Protos site and the grassland to the north-east of the Site.

Reference should be made to Appendix B for full details of the habitats present at each site and the habitat-specific Critical Loads.

# 4 Baseline Air Quality

The Facility is located on the Protos site in Ince within Cheshire West and Cheshire Council (CWACC) area. It is located approximately 2 km to the north-west of the village of Helsby and 1 km to the north-east of the village of Elton, to the south of the River Mersey. The location of the Site is shown in Figure 1 of Appendix A.

Within this section a review of the existing air quality has been carried out with reference to local monitoring data. Where local monitoring data is not available reference has been made to national datasets from a similar setting.

## 4.1 Air quality management areas

The closest AQMA to the Site is the Thornton le Moors AQMA No 4 located approximately 2.8 km to the south-west of the Site. This has been declared by CWACC due to elevated short-term concentrations of sulphur dioxide around the Stanlow (Essar) Refinery. Measures are being implemented at the Refinery to improve air quality, which have included trails for de-SOx additives. The latest monitoring has shown that concentrations of sulphur dioxide have reduced in this area, although there have been exceedences of the AQAL these have been within the tolerable number within the year. CWACC has confirmed that the AQMA will remain in place in this area for the foreseeable future. No other AQMAs have been declared within 5 km of the Site. The extents of the AQMA are displayed in Figure 5 of Appendix A. The impact of the proposed variation upon this AQMA has been quantified within this assessment.

## 4.2 AURN monitoring data

The UK Automatic Urban and Rural Network (AURN) is a country-wide network of air quality monitoring stations operated on behalf of the Defra. This includes automatic monitoring of oxides of nitrogen, nitrogen dioxide, sulphur dioxide, ozone, carbon monoxide and particulates.

The closest AURN monitoring stations to the Facility are in Widnes and Liverpool Speke. The Widnes station (Milton Road), an urban traffic site located approximately 10 km to the north. Roadside sites are predominately determined by emissions from nearby traffic and are only representative of air quality for the immediate area of the analyser. Therefore, data from this analyser is not representative of concentrations in the vicinity of the Site and data from this site has not been considered further in this analysis. The Liverpool Speke site is classified as an ‘Urban Industrial’ site. A review of this site shows that although it is classified as ‘Urban Industrial’, there is only light industry in the area and the site it is not located close to any significant road or heavy industrial pollutant sources. Therefore, the Liverpool Speke site can be considered a representative background site. Background sites are positioned that they are not influenced significantly by any single source or street but rather by the integrate contribution from all sources upwind of the station and are considered broadly representative for several square kilometres.

Monitoring data from the Liverpool Speke AURN has been obtained from the most the UK-air website and is presented in the following table.

*Table 8: Liverpool Speke AURN Monitoring*

| Pollutant | Concentration (µg/m³) | | | | | | |
|---|---|---|---|---|---|---|---|
| | AQAL | Mapped Bg 2018 | 2018 | 2019 | 2020 | 2021 | 2022 |
| **Annual mean concentrations** | | | | | | | |
| Nitrogen dioxide | 40 | 20 | 18 | 19 | 12 | 16 | 15 |
| Particulate matter (as $PM_{10}$) | 40 | 13 | 14 | 17 | 15 | 11 | 15 |
| Particulate matter (as $PM_{2.5}$) | 20 | 9 | 9 | 9 | 7 | 6 | 9 |
| **Exceedance statistics** | | | | | | | |
| **Nitrogen dioxide** | | | | | | | |
| 99.79%ile of hourly means | 200 | - | 73 | 87 | 69 | 73 | 81 |
| **Sulphur dioxide** | | | | | | | |
| 99.18%ile of daily means | 125 | - | 11 | 5 | 7 | 9 | 7 |
| 99.73%ile of hourly means | 350 | - | 27 | 18 | 18 | 30 | 24 |
| 99.9%ile of 15-minute means | 266 | - | 46 | 38 | 26 | 63 | 39 |
| **Particulate matter (as $PM_{10}$)** | | | | | | | |
| 90.41%ile of daily means | 50 | - | 23 | 28 | 27 | 16 | 23 |

*Source: © Crown 2021 copyright Defra via uk-air.defra.gov.uk, licenced under the Open Government Licence (OGL).*

As shown, monitored pollutant concentrations are well below the relevant AQALs. There is little difference between the mapped background and the monitored concentration, so it can be concluded that the mapped background concentration is representative of concentrations in the vicinity of the monitoring Site. In addition, there have been no exceedences of the short term AQAL.

## 4.3 LAQM monitoring data

In addition to the national AURN, local authorities undertake monitoring of a range of pollutants as part of the LAQM review process. A review of the monitoring undertaken by CWACC has shown that they operate seven continuous analysers, of which three are classified as ‘roadside’, two are classified as ‘urban background’ and two are classified as ‘industrial’ locations. Of the background and industrial locations, four are located within 10 km of the Facility. A summary of the monitoring data from ‘background’ and ‘industrial’ continuous analysers within 10 km of the Facility is presented in the following tables.

*Table 9: CWACC – Automatic Monitoring Locations Within 10 km*

| **Site** | **Location** | | **Distance and bearing from Facility** | **Pollutants monitored** |
|---|---|---|---|---|
| | **X (m)** | **Y (m)** | | |
| Elton | 345642 | 375522 | 1.5 km south-west | Sulphur dioxide |
| Frodsham | 352445 | 378031 | 5.9 km north-east | Nitrogen dioxide, $PM_{10}$ |
| Central Library[(1)] | 340258 | 376602 | 6.5 km west | Nitrogen dioxide, Sulphur dioxide, $PM_{10}$ |
| Thornton-Le-Moors | 344103 | 374330 | 3.5 km south-west | Nitrogen dioxide, Sulphur dioxide, $PM_{10}$ |

*Notes:*

*(1) Central library was decommissioned at the end of 2019.*

*Table 10: CWACC Automatic Monitoring Results*

| **Site** | **Concentration (µg/m³)** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **AQAL** | **Mapped Bg 2018** | **2018** | **2019** | **2020** | **2021** | **2022** |
| **Nitrogen dioxide** | | | | | | | |
| Frodsham (FMH) | 40 | 17 | 14 | 15 | 13 | 15 | - |
| Central Library (LR) | 40 | 17 | 19 | - | - | - | - |
| Thornton-le-Moors (TLP) | 40 | 14 | 13 | 13 | 9 | 11 | - |
| **Particulate matter (as $PM_{10}$)** | | | | | | | |
| Frodsham (FMH) | 40 | 14 | 16 | 15 | 12 | 13 | - |
| Central Library (LR) | 40 | 12 | 12 | - | - | - | - |
| Thornton-le-Moors (TLP) | 40 | 12 | 13 | 14 | 13 | 13 | - |

*Notes:*

*Data has not been published from 2022 at the time of writing this assessment.*

*Source: CWACC LAQM Annual Status Report 2022*

As shown, the mapped background is broadly similar to the monitored nitrogen dioxide and $PM_{10}$ concentrations at all monitoring locations.

The latest Annual Status Report (2022) also presents exceedance data for sulphur dioxide. This has shown that there were exceedances of the 15-minute AQAL for sulphur dioxide at both the Elton and Thornton-le-Moors monitoring stations. However, the number of exceedances was well below the number of allowable exceedances (35).

In addition to the continuous analysers, CWACC undertake diffusion tube monitoring of nitrogen dioxide as part of the LAQM process. However, there are no diffusion tube monitoring locations classified as 'background' or 'industrial' within 10 km of the Facility and no roadside monitoring locations within the modelling domain (i.e. within 3 km of the Facility). As such, diffusion tube monitoring has not been considered within this analysis.

## 4.4 National modelling – mapped background data

In order to assist local authorities with their responsibilities under LAQM, the Department for Environment Food and Rural Affairs (Defra) provides modelled background concentrations of pollutants throughout the UK on a 1 km by 1 km grid. This model is based on known pollution sources and background measurements and is used by local authorities in lieu of suitable monitoring data. In addition, mapped atmospheric concentrations of ammonia are available from Centre for Ecology and Hydrology (CEH). Concentrations will vary over the modelling domain area. Therefore, the maximum mapped background concentration data within 3 km of the Site have been downloaded along with the concentrations for the grid squares containing the Site. A summary is presented in Table 11.

*Table 11: Mapped Background Data*

| Pollutant | Annual mean concentration ($\mu g/m^3$) | | Dataset |
|---|---|---|---|
| | At Site | Max within 3 km of Site | |
| Nitrogen dioxide | 13.3 | 19.7 | Defra 2018 |
| Sulphur dioxide | 5.7 | 6.6 | Defra 2001 |
| Particulate matter (as $PM_{10}$) | 13.5 | 14.4 | Defra 2018 |
| Particulate matter (as $PM_{2.5}$) | 9.6 | 9.6 | Defra 2018 |
| Carbon monoxide | 336 | 356 | Defra 2001 |
| Benzene | 0.6 | 1.1 | Defra 2001 |
| Ammonia | 4.7 | 4.9 | APIS mid year 3 year average 2019 to 2021 |

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## 4.5 Protos monitoring

Monitoring of particulate matter (as $PM_{10}$ and $PM_{2.5}$), metals, dioxins and PAHs been carried out on behalf of Peel NRE since 2020 at a site in Helsby approximately 1 km to the south-east of the Site. Prior to this two 12-month periods of monitoring was carried out pre and post commissioning of the Ince Biomass Power Plant. The initial monitoring was carried out from 19 October 2016 to 18 October 2017, with the second phase from 3 July 2019 to 2 July 2020. Therefore, since July 2019 there has been a continuous dataset from this monitoring station. For the purposes of this assessment the annual mean data has been considered therefore this has just considered the data as presented in the annual reports which cover the period since 2020.

A summary of the annual monitoring carried out since 2019 is provided in Table 12.

*Table 12: Protos Monitoring Results*

| Pollutant | AQAL (µg/m³) | Annual mean concentration (µg/m³) | | | Max as % of AQAL |
|---|---|---|---|---|---|
| | | 2020 | 2021 | 2022 | |
| Particulate matter (as $PM_{10}$) | 40 | 11.2 | 11.4 | 12.2 | 30.5% |
| Particulate matter (as $PM_{2.5}$) | 10 | 6.7 | 7.1 | 7.4 | 74.0% |
| | | Concentration (ng/m³) | | | |
| Cadmium | 5 | 3.8* | 3.1* | 3.0* | 76.0% |
| Thallium | - | 7.5* | 6.2* | 6.0* | - |
| Mercury | 250 | 3.8* | 3.1* | 3.0* | 1.5% |
| Antimony | 5,000 | 3.6 | 2.8 | 3.4 | 0.1% |
| Arsenic | 6 | 3.4 | 2.5* | 2.4* | 56.7% |
| Chromium | 5,000 | 11.0 | 9.2 | 8.4 | 0.2% |
| Chromium (VI) | 0.25 | 1.3* | 0.9* | 1.0* | 520% |
| Cobalt | - | 1.5* | 1.2* | 1.2* | - |
| Copper | 10,000 | 13.0 | 13.0 | 13.0 | 0.1% |
| Lead | 250 | 11.0 | 8.9 | 7.8 | 4.4% |
| Manganese | 150 | 6.9 | 6.8 | 4.8 | 4.6% |
| Nickel | 20 | 3.6 | 2.7 | 2.5 | 18.0% |
| Vanadium | 5,000 | 2.7 | 3.1 | 2.5 | 0.1% |
| Benzen(a)pyrene | 0.25 | 0.071 | 0.06 | 0.092 | 36.8% |
| | | Concentration (fg/m³ TEF) | | | |
| Dioxins and furans | - | 17.3 | 13.9 | 23.8 | - |
| Dioxin like - PCBs | - | 0.73 | 1.79 | 1.04 | - |

*Notes:*

** reported value in all months less than the limit of detection, the concentration is therefore the maximum LOD rather than an annual average.*

*Data from 2022 only 5 months as the remaining samples were lost in transit.*

*Source: Air Quality in Helsby Annual Reports available at https://protos.co.uk/media-centre/community-downloads/#air-quality-documents*

A review of the monitoring data has shown that in many instances the monthly value used to calculate the annual average was the limit of detection (LOD). Therefore, concentrations are likely to be lower than this. This is particularly apparent with the cadmium and chromium IV reported concentration where the annual average presented is 76% and 520% of the AQAL respectively. Reference has been made to other monitoring carried out as part of the national monitoring network to compare this local data within section 4.6.

## 4.6 Other national monitoring networks data

Neither the Defra mapped background dataset, AURN, or LAQM include monitoring of other pollutants released from the Facility such as hydrogen chloride, hydrogen fluoride, or VOCs. As such reference has been made to national modelling to determine a suitable background concentration for these pollutants.

### 4.6.1 Hydrogen chloride

Hydrogen chloride was measured until the end of 2015 on behalf of Defra as part of the UK Eutrophying and Acidifying Atmospheric Pollutants (UKEAP) project. This consolidates the previous Acid Deposition Monitoring Network (ADMN), and National Ammonia Monitoring Network (NAMN). Monitoring of hydrogen chloride ceased at the end of 2015 and none of the historic sites were located within 10 km of the Site. Prior to the cessation of the monitoring concentrations were fairly constant.

The maximum annual average monitored within the UK between 2011 and 2015 was 0.71 µg/m$^3$. In lieu of any recent representative monitoring this has been used as the background concentration for this assessment as a conservative estimate.

### 4.6.2 Hydrogen fluoride

Baseline concentrations of hydrogen fluoride are neither measured locally nor nationally, since these are not generally of concern in terms of local air quality. However, the EPAQS report ‘Guidelines for halogens and hydrogen halides in ambient air for protecting human health against acute irritancy effects’ contains some estimates of baseline levels, reporting that measured concentrations have been in the range of 0.036 µg/m$^3$ to 2.35 µg/m$^3$.

In lieu of any local monitoring, the maximum measured baseline hydrogen fluoride concentration has been used as the background concentration for the purpose of this assessment as a conservative estimate.

### 4.6.3 Ammonia

Ammonia is also measured as part of the UKEAP project at rural background locations. There are no UKEAP monitoring locations within 10 km of the Site. The nearest monitoring site is at Ladybower, 71 km to the east. In lieu of any local UKEAP monitoring, the maximum mapped background value from APIS for the grid square containing the Site has been used for the purpose of this assessment (4.9 µg/m$^3$) when considering the impact with reference to the AQALs for the protection of human health, and the maximum background concentration across the designated site from APIS has been used when evaluating the impact at ecological receptors if needed.

### 4.6.4 Volatile Organic Compounds

As part of the Automatic and Non-Automatic Hydrocarbon Network, benzene concentrations are measured at sites co-located with the AURN across the UK. The closest monitoring site to the Site is Liverpool Speke, a non-automatic monitoring site 7.9 km to the north. The measured concentration of benzene is broadly similar to the mapped background dataset. As such the maximum mapped background concentration within the 3 km of the Facility has been used. This value is 1.1 µg/m$^3$.

### 4.6.5 Metals

In addition to the local monitoring, metals are measured as part of the Rural Metals and UK Urban/Industrial Networks (previously the Lead, Multi-Element and Industrial Metals Networks). A site was located at Runcorn Weston Point, an urban industrial site 6 km to the north-east. However, this site closed in March 2019. Monitoring from this site from 2015 is presented in the Table 13.

*Table 13: Annual Mean Metals Concentrations – Runcorn Weston Point*

| **Substance** | **Annual mean concentration (ng/m³)** | | | | | | **Max (as % of AQAL)** |
|---|---|---|---|---|---|---|---|
| | **AQAL** | **2015** | **2016** | **2017** | **2018** | **2019*** | |
| Cadmium | 5 | 0.09 | 0.12 | 0.09 | 0.09 | 0.12 | 2.4% |
| Thallium | 1,000 | - | - | - | - | - | - |
| Mercury | 250 | 19 | 15 | 19 | 16 | - | 7.6% |
| Antimony | 5,000 | - | - | - | - | - | - |
| Arsenic | 6 | 0.56 | 0.68 | 0.62 | 0.68 | 0.83 | 13.8% |
| Chromium | 5,000 | 1.50 | 1.10 | 1.60 | 1.70 | 1.50 | 0.03% |
| Cobalt | 200 | 0.19 | 0.14 | 0.19 | 0.39 | 0.10 | - |
| Copper | 10,000 | 5.30 | 6.00 | 5.50 | 5.09 | 4.70 | 0.06% |
| Lead | 250 | 5.09 | 5.90 | 4.90 | 4.70 | 7.00 | 2.8% |
| Manganese | 150 | 2.80 | 3.30 | 3.20 | 3.20 | 3.30 | 2.2% |
| Nickel | 20 | 1.50 | 1.10 | 1.10 | 0.83 | 0.78 | 7.5% |
| Vanadium | - | 1.00 | 0.96 | 1.10 | 0.97 | 1.00 | - |
| *Notes:*<br>** Only data up to 14 March 2019.* | | | | | | | |

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Reference has also been made to the maximum monitored concentration at any urban background site in the UK as set out in Table 14.

*Table 14: Annual Mean Metals Concentrations – Maximum at Urban Backgrounds Sites*

| **Substance** | **Annual mean concentration (ng/m³)** | | | | | | **Max (as % of AQAL)** |
|---|---|---|---|---|---|---|---|
| | **AQAL** | **2018** | **2019** | **2020** | **2021** | **2022** | |
| Cadmium | 5 | 0.43 | 0.35 | 0.42 | 0.35 | 0.29 | 8.6% |
| Thallium | 1,000 | - | - | - | - | - | - |
| Mercury | 250 | 16 | - | - | - | - | 6.4% |
| Antimony | 5,000 | - | - | - | - | - | - |
| Arsenic | 6 | 1.00 | 1.00 | 1.00 | 0.98 | 0.90 | 16.7% |
| Chromium | 5,000 | 39.00 | 25.00 | 21.00 | 33.00 | 33.00 | 0.78% |
| Cobalt | 200 | 0.92 | 0.56 | 0.84 | 0.65 | 1.50 | - |
| Copper | 10,000 | 26.00 | 22.00 | 18.00 | 16.00 | 18.00 | 0.26% |
| Lead | 250 | 20.00 | 13.00 | 12.00 | 22.00 | 51.00 | 20.4% |
| Manganese | 150 | 36.00 | 26.00 | 23.00 | 35.00 | 35.00 | 24.0% |
| Nickel | 20 | 2.20 | 1.80 | 1.70 | 2.20 | 2.50 | 12.5% |

| Substance | Annual mean concentration (ng/m³) | | | | | | Max (as % of AQAL) |
|---|---|---|---|---|---|---|---|
| | AQAL | 2018 | 2019 | 2020 | 2021 | 2022 | |
| Vanadium | - | 1.70 | 1.50 | 3.00 | 3.00 | 1.90 | - |

*Notes:*

*Nickel excludes data from Sheffield Tinsley and Swansea Coedgwilym. Although these are urban background sites they are located close to major industrial metal processing installations and as such are not representative of general urban background conditions in the UK.*

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In addition to the suite of metals monitored at urban background monitoring sites there would be releases of thallium, mercury and antimony from the Facility. With reference to these pollutants:

- Thallium is not routinely monitored as part of the metals network.
- Monitoring of mercury ceased in August 2018 and at from 2016 this was only carried out at two sites across the UK - London Westminster and Runcorn Weston Point. Concentrations at both sites were well below the AQAL.
- Monitoring of antimony across the UK ceased at the end of 2013. The maximum monitored at any background site in 2013 was 1.30 ng/m³ at Detling, but the maximum local monitored concentration was 3.6 ng/m³.

A review of the baseline monitoring at Helsby, Runcorn Weston Point and the maximum from an urban background site is provided in Table 15.

*Table 15: Annual Mean Metals Concentrations – Summary*

| Substance | Annual mean concentration (as % of AQAL) | | | |
|---|---|---|---|---|
| | AQAL | Helsby | Runcorn Weston Point | Maximum National Urban Background (2018-2022) |
| Cadmium | 5 | 76.0%* | 2.4% | 8.6% |
| Thallium | 1,000 | - | - | - |
| Mercury | 250 | 1.5%* | 7.6% | 1.1% |
| Antimony | 5,000 | 0.1% | - | - |
| Arsenic | 6 | 56.7%* | 13.8% | 16.7% |
| Chromium | 5,000 | 0.2% | 0.03% | 0.78% |
| Cobalt | 200 | - | - | - |
| Copper | 10,000 | 0.1% | 0.06% | 0.26% |
| Lead | 250 | 4.4% | 2.8% | 20.4% |
| Manganese | 150 | 4.6% | 2.2% | 24.0% |
| Nickel | 20 | 18.0% | 7.5% | 12.5% |
| Vanadium | - | - | - | - |

This analysis shows that for those metals which the local monitored concentration was below the LOD the maximum from the urban background sites and at Runcorn Weston Point was significantly lower. For instance, locally monitored cadmium concentration was 76% of the AQAL, whereas the maximum monitored at Runcorn Weston Point and from the maximum at any urban background site in the UK was only 2.4% and 8.6% respectively.

For each of the metals the following assumptions have been used for the baseline:

- Cadmium, arsenic and cobalt – maximum from an urban background site from 2018 to 2022. This is considered appropriate given the local monitoring was below the LOD in all years but if it is assumed that the monitored concentration is at the LOD the concentration is significantly higher than any other similar site in the UK.
- Thallium is not routinely monitored as part of the metals network. This assessment has considered the total impact of cadmium and thallium and has used the cadmium background and AQAL.
- Mercury - the maximum monitored annual mean concentration from Runcorn Weston Point from 2015-2019. This is considered appropriate given the local monitoring was below the LOD in all years but if it is assumed that the monitored concentration is at the LOD the concentration is significantly higher than any other similar site in the UK.
- Antimony – the maximum monitored annual mean concentration from Helsby. Noting that there is not any other recent monitoring to compare this value to.
- Chromium, copper, lead, manganese, nickel, vanadium – the maximum monitored annual mean concentration from Helsby which is lower than the maximum monitored at a UK urban background site with the exception of nickel which is slightly higher.

### 4.6.6 Dioxins, furans and polychlorinated biphenyl (PCBs)

Dioxins, furans and PBCs are monitored on a quarterly basis at a number of urban and rural stations in the UK as part of the Toxic Organic Micro Pollutants (TOMPs) network. There are no national monitoring locations within 10 km of the Site. The closest site is located in Manchester.

A summary of dioxin and furan and PCB concentrations from all monitoring sites across the UK is presented in Table 16 and Table 17. Note that monitoring data for dioxins and furans is only available up to the end of 2016 from the UK-Air website. For PCBs, data is only available up to the end of 2018 from the UK-Air website.

*Table 16: Dioxin and Furans Monitoring*

| Site | Annual mean concentration (fgTEQ/m$^3$) | | | | |
|---|---|---|---|---|---|
| | 2012 | 2013 | 2014 | 2015 | 2016 |
| Auchencorth Moss | 0.13 | 0.86 | 0.01 | 0.01 | 0.13 |
| Hazelrigg | 8.75 | 2.02 | 2.61 | 5.27 | 4.59 |
| High Muffles | 4.32 | 0.6 | 1.07 | 0.54 | 2.73 |
| London Nobel House | 15.42 | 3.47 | 2.89 | 4.34 | 21.27 |
| Manchester Law Courts | 32.99 | 10.19 | 16.52 | 5.94 | 12.23 |
| Weybourne | 9.3 | 2.34 | 1.61 | 1.42 | 16.32 |

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The maximum monitored concentration at Helsby between 2020 and 2022 was 23.8 fg TEF/m$^3$ which is comparable to the monitored concentrations not in rural areas.

*Table 17: PCB Monitoring*

| **Site** | **Annual mean concentration (pg/m³)** | | | | |
|---|---|---|---|---|---|
| | **2014** | **2015** | **2016** | **2017** | **2018** |
| Auchencorth Moss | 23.23 | 24.27 | 25.32 | 19.09 | 12.31 |
| Hazelrigg | 25.84 | 41.68 | 52.58 | 33.15 | 22.22 |
| High Muffles | 26.11 | 33.43 | 37.76 | 31.63 | 8.86 |
| London Nobel House | 107.49 | 121.39 | 110.46 | 121.87 | 46.63 |
| Manchester Law Courts | 128.93 | 97.99 | 92.6 | 97.27 | 40.10 |
| Weybourne | 17.00 | 20.95 | 38.61 | 32.26 | 11.23 |

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The monitored concentration of PCBs at Helsby is reported in fgTEF/m$^3$ and refers to dioxin-like PCBs. The PCB monitoring from TOMPS includes all PCBs and is reported as a pg/m$^3$ basis. Therefore, it is not directly comparable.

This analysis shows that the concentrations vary significantly between sites and years. The maximum monitored concentration from the past 5 years of available monitoring data has been used as the background concentration within this assessment. These values are 32.99 fg/TEQ/m$^3$ for dioxins and furans and 128.93 pg/m$^3$ for PCBs.

### 4.6.7 Polycyclic Aromatic Hydrocarbons (PAHs)

Polycyclic Aromatic Hydrocarbons (PAHs) are monitored at a number of stations in the UK as part of the PAH network. For the purpose of this assessment, benzo(a)pyrene is considered as this is the only PAH which an AQAL has been set. The closest monitoring station to the Facility is at Liverpool Speke.

Due to the mixture of rural, residential and industrial nature of the land around the Facility, the monitored concentrations at Liverpool Speke are likely to be reasonably representative. However, the monitoring site is across the large expanse of the Mersey estuary from the Facility. In order to be conservative, the assessment has considered monitored data from urban background sites, shown in Table 18.

*Table 18: Benzo(a)pyrene*

| **Site** | **AQAL (ng/m³)** | **Annual mean concentration (ng/m³)** | | | | |
|---|---|---|---|---|---|---|
| | | **2018** | **2019** | **2020** | **2021** | **2022** |
| Min | 0.25 | 0.06 | 0.06 | 0.04 | 0.05 | 0.08 |
| Max | | 0.25 | **0.50** | 0.24 | 0.22 | **0.29** |
| Average | | 0.16 | 0.21 | 0.15 | 0.16 | 0.20 |
| Liverpool Speke | | 0.10 | 0.14 | 0.06 | 0.08 | 0.18 |
| Helsby | | - | - | 0.07 | 0.06 | 0.09 |

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As shown, the concentrations monitored at Helsby are well within the AQAL, however, the maximum at any urban background site exceeds the AQAL. The maximum monitored concentration from Helsby has been used as the background concentration within this assessment (0.09 ng/m$^3$).

### 4.6.8 Aldehydes

Baseline concentrations of aldehydes are neither measured locally nor nationally, since these are not generally of concern in terms of local air quality. Formaldehyde is the aldehyde with the most stringent AQAL. The Defra report 'Non-methane Volatile Organic Compounds in the UK'[2] presents the results of some monitoring studies, reporting a maximum measured formaldehyde concentration in the UK of 2.37 µg/m$^3$.

In lieu of any local monitoring, the maximum measured baseline formaldehyde concentration has been used for the purpose of this assessment as a conservative estimate.

### 4.6.9 Amines, nitrosamines and nitramines

The concentrations of amines and amine degradation products (i.e. nitrosamines and nitramines) in ambient air, and their consequent impacts on human health, are active areas of research. Inhalation of these compounds is only one potential pathway, with other known sources including dietary exposure, drinking water, and some pharmaceuticals. Nitrosamines have been detected in food and drink, particularly those with high concentrations of nitrites such as processed meat, cheese, alcoholic beverages and processed vegetables. However, this assessment is concerned only with exposure via inhalation, and has therefore only considered ambient air concentrations.

The EA's Air Quality Modelling and Assessment Unit (AQMAU) produced a report in 2021[3] which details their recommendations for the assessment of emissions from amine-based CCS systems. With regard to baseline concentrations, the report states:

> *"we found no ambient air measurements of amines, nitrosamines or nitramines in the UK."*

Nitrosamines, which are the compounds with the greatest potential human health effects, have short atmospheric lifetimes on the order of hours before undergoing photolysis. As such, only local sources would contribute significantly to baseline concentrations. There are no known industrial sources of amines to the atmosphere in the local area.

No existing local sources of point source emissions of amines have been identified. Therefore, in the first instance it has been assumed that ambient air concentrations of these pollutants in the vicinity of the Site are below the LOD of any currently available monitoring techniques and have been assumed to be zero.

## 4.7 Summary of background concentration used in assessment

In summary, there is some local monitoring of particulate matter, metals, dioxins and PAHs. The analysis has shown that the monitored concentrations at the closest background sites is similar to the Defra mapped background concentration. This suggests that the mapped background model is

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[2] Defra Air Quality Expert Group, Non-methane Volatile Organic Compounds in the UK, 2020

[3] AQMAU (Environment Agency), Recommendations for the assessment and regulation of impacts to air quality from amine-based post-combustion carbon capture plants, November 2021

performing well in the local area and can be used as a source of baseline concentrations at background locations.

The concentrations of road traffic pollutants (nitrogen dioxide and particulate matter) vary spatially across the modelling domain. As such for these pollutants additional consideration will be given to determine the baseline concentration for these pollutants taking into account the local monitoring data, and the contribution from other local point sources.

For other pollutants in the first instance, it will be assumed that baseline concentrations are as per those set out in the following table. These are based on a mixture of monitoring at modelled data sets. Where the contribution from the Proposed Facility cannot be screened out as 'insignificant' (see Section 8.1 for methodology), the choice of baseline concentration will be given additional consideration taking into account the local monitoring and the contribution from the other local point sources.

*Table 19: Summary of Baseline Concentrations*

| Pollutant | Annual mean concentration | Units | Justification |
|---|---:|---|---|
| Nitrogen dioxide | 19.7 | µg/m³ | Maximum mapped background concentration within 3 km of the Site (2018 Defra dataset) |
| Sulphur dioxide | 6.6 | µg/m³ | Maximum mapped background concentration within 3 km of the Site (2001 Defra dataset) |
| Particulate matter (as $PM_{10}$) | 14.4 | µg/m³ | Maximum mapped background concentration within 3 km of the Site (2018 Defra dataset) |
| Particulate matter (as $PM_{2.5}$) | 9.6 | µg/m³ | Maximum mapped background concentration within 3 km of the Site (2018 Defra dataset) |
| Carbon monoxide | 356 | µg/m³ | Maximum mapped background concentration within 3 km of the Site (2001 Defra dataset) |
| Hydrogen chloride | 0.71 | µg/m³ | Maximum monitored concentration across the UK 2011 to 2015 |
| Hydrogen fluoride | 2.35 | µg/m³ | Maximum measured concentration from EPAQS report |
| Ammonia | 4.9 | µg/m³ | Mapped background concentration from APIS 2019 to 2021 3-year average |
| Benzene | 1.1 | µg/m³ | Maximum mapped background concentration within 3 km of the Site (2001 Defra dataset) |
| Mercury | 19 | ng/m³ | Maximum monitored annual mean concentration from Runcorn Weston Point from 2015-2019 |
| Cadmium | 0.43 | ng/m³ | Maximum UK monitored concentration across the UK between 2017 and 2022 from an urban background site. |
| Arsenic | 1.00 | ng/m³ | |
| Cobalt | 1.50 | ng/m³ | |

| **Pollutant** | **Annual mean concentration** | **Units** | **Justification** |
|---|---:|---|---|
| Chromium | 11.0 | ng/m$^3$ | Maximum monitored concentration from Helsby between 2020 and 2022, chromium VI assumed to be 20% of total chromium in line with EA guidance. |
| Chromium VI | 2.2 | ng/m$^3$ | |
| Copper | 13.0 | ng/m$^3$ | |
| Lead | 11.0 | ng/m$^3$ | |
| Manganese | 6.9 | ng/m$^3$ | |
| Nickel | 3.6 | ng/m$^3$ | |
| Vanadium | 3.1 | ng/m$^3$ | |
| Antimony | 3.6 | ng/m$^3$ | |
| Dioxins and furans | 32.99 | fg/m$^3$ | Maximum UK monitored concentration between 2012 and 2016 |
| Polychlorinated biphenyl (PCBs) | 128.93 | pg/m$^3$ | Maximum UK monitored concentration between 2014 and 2018 |
| Benzo(a)pyrene (PAHs) | 0.09 | ng/m$^3$ | Maximum monitored concentration from Helsby between 2020 and 2022 |
| Formaldehyde | 2.37 | µg/m$^3$ | Maximum measured concentration from Defra report |
| Amines | 0 | - | No monitoring available. Assumed to be below the LOD of current monitoring techniques and effectively zero. |
| Nitramines | 0 | - | |
| Nitrosamines | 0 | - | |

## 4.8 Baseline conditions at ecological sites

The Air Pollution Information System (APIS) database sets out the baseline concentrations on a grid across the UK. Atmospheric concentrations of oxides of nitrogen, ammonia, acid and nitrogen deposition are provided on a 1 km x 1 km grid. Data is provided for the maximum across the ecological site. This data is the 2019 to 2021 average as presented on APIS.

*Table 20: APIS Data for Ecological Sites*

| **ID** | **Site** | **Maximum concentration (µg/m$^3$)** | | |
|---|---|---:|---:|---:|
| | | **Oxides of nitrogen** | **Sulphur dioxide** | **Ammonia** |
| **Annual mean Critical Level** | | **30** | **10 / 20** | **1 / 3** |
| E1 | Mersey Estuary SPA / Ramsar / SSSI | 15.5 | 3.4 | 4.9 |
| E2 | Midland Meres and Mosses Ramsar * – Hatch Mere SSSI | 8.2 | 1.5 | 2.7 |
| E7 | Midland Meres and Mosses Ramsar * – Flaxmere Moss SSSI | 8.2 | 1.3 | 2.7 |
| E8 | Midland Meres and Mosses Ramsar * – Linmere Moss SSSI | 7.7 | 1.4 | 2.9 |

| ID | Site | Maximum concentration (µg/m$^3$) | | |
|---|---|---|---|---|
| | | Oxides of nitrogen | Sulphur dioxide | Ammonia |
| E3 | Frodsham and Helsby and Ince Marshes | 16.9 | 3.4 | 4.9 |
| E4 | Station Road Railway Site | 16.5 | 3.7 | 3.8 |
| E5 | Functionally linked grassland A | 19.9 | 3.9 | 3.9 |
| E6 | Functionally linked grassland B | 13.9 | 3.2 | 4.7 |

*Notes:*

*Maximum across each site by extracting from APIS from the map tool.*

** identified within APIS that sensitive lichens or bryophytes may be present and therefore the more stringent Critical Level applies*

*Source: APIS*

As shown, the baseline data presented in APIS shows that maximum concentrations of oxides of nitrogen and sulphur dioxide are below the annual mean Critical Level at all sites. However, baseline concentrations of ammonia exceed the Critical Level.

Table 21: APIS data for Ecological Sites – Deposition

| ID | Site | N deposition (kgN/ha/yr) | | Acid deposition (keq/ha/yr | |
|---|---|---|---|---|---|
| | | Grassland | Woodland | Grassland | Woodland |
| E1 | Mersey Estuary SPA / Ramsar / SSSI | 24.3 | 41.9 | 1.9 | 3.2 |
| E2 | Midland Meres and Mosses Ramsar – Hatch Mere SSSI | 24.8 | 41.5 | 1.9 | 3.1 |
| E7 | Midland Meres and Mosses Ramsar – Flaxmere Moss SSSI | 24.4 | 40.8 | 1.9 | 3.1 |
| E8 | Midland Meres and Mosses Ramsar – Linmere Moss SSSI | 25.4 | 42.5 | 1.9 | 3.2 |
| E3 | Frodsham and Helsby and Ince Marshes | 24.3 | - | 1.93 | - |
| E4 | Station Road Railway Site | 23.8 | - | 1.85 | - |
| E5 | Functionally linked grassland A | 23.4 | - | 1.85 | - |
| E6 | Functionally linked grassland B | 24.3 | - | 1.93 | - |

*NOTE:*

*Maximum across each site by extracting from APIS from the map tool.*

*Acid deposition grid not available on APIS map, so for the E4, E5 or E6 this has been determined using the search by location tool.*

*Source: APIS*

The values presented in Table 20 and Table 21 are grid square averaged values provided as a rolling 3-year mean and derived from a mixture of interpolation from measured data, and modelled data as set out in APIS. The APIS website explains that the use of a 3-year mean has been demonstrated to be a suitable time period to smooth out some of the inter-annual variations in deposition which occur due to the natural variability in annual weather patterns.

# 5 Modelling Methodology

## 5.1 Selection of model

Detailed dispersion modelling was undertaking using the model ADMS 6, developed and supplied by Cambridge Environmental Research Consultants (CERC) This is a new generation dispersion model, which characterises the atmospheric boundary layer in terms of the atmospheric stability and the boundary layer height. In addition, the model uses a skewed Gaussian distribution for dispersion under convective conditions, to take into account the skewed nature of turbulence. The model also includes modules to take account of the effect of buildings and complex terrain.

ADMS is routinely used for modelling of emissions for environmental permitting purposes to the satisfaction of the EA. An analysis of the variation in model outputs has been undertaken and the maximum predicted concentration for each pollutant and averaging period has been used to determine the significance of any potential impacts.

## 5.2 Source and emissions data – ERF – i.e. the Permitted Facility

The source and emissions input data utilised within the modelling for the ERF are presented in Table 23 to Table 24. These are presented per line and are based on operation at the design nominal case which represents a thermal input of 151.0 MW. These inputs have been used to determine the impact for the Permitted Facility.

*Table 22: Stack Data - ERF*

| Item | Unit | ERF |
|---|---|---:|
| Height | m | 100 |
| Internal diameter (each line) | m | 2.13 |
| Number of lines | - | 2 |
| Stack location | m, m | 346724, 376646 |

*Table 23: Flue Gas Conditions – Per Line - ERF*

| Item | Unit | ERF – Per Line |
|---|---|---:|
| Temperature | °C | 135.2 |
| Exit moisture content | % v/v | 17.84% |
| | kg/kg | 0.130 |
| Exit oxygen content | % v/v dry | 6.41% |
| Reference oxygen content | % v/v dry | 11.00% |
| Volume at reference conditions (273.15K, dry, ref $O_2$) | $Nm^3/h$ | 156,822 |
| | $Nm^3/s$ | 44.12 |
| Volume at actual conditions | $Am^3/h$ | 197,820 |
| | $Am^3/s$ | 54.95 |
| Flue gas exit velocity | m/s | 15.42 |

*Table 24: Stack Emissions Data - Per Line - ERF*

| **Pollutant** | **Daily or periodic** | | **Half-hourly** | |
|---|---|---|---|---|
| | **ELV (mg/Nm$^3$, unless stated)** | **Release rate (g/s, unless stated)** | **ELV (mg/Nm$^3$, unless stated)** | **Release rate (g/s, unless stated)** |
| Oxides of nitrogen (as $NO_2$) | 180 | 7.941 | 400 | 17.647 |
| Sulphur dioxide | 40 | 1.765 | 200 | 8.823 |
| Carbon monoxide(1) | 50 | 2.206 | 150(1) | 6.618 |
| Total dust (PM)(2) | 5 | 0.221 | 30 | 1.324 |
| Hydrogen chloride | 8 | 0.353 | 60 | 2.647 |
| Volatile organic compounds (as TOC) | 10 | 0.441 | 20 | 0.882 |
| Hydrogen fluoride | 1 | 0.044 | - | - |
| Ammonia | 15 | 0.662 | - | - |
| Cadmium and thallium | 0.02 | 0.882 mg/s | - | - |
| Mercury | 0.02 | 0.882 mg/s | - | - |
| Other metals(3) | 0.3 | 13.235 mg/s | - | - |
| Benzo(a)pyrene (PAHs)(4) | 0.2 µg/Nm$^3$ | 8.823 µg/s | - | - |
| Dioxins and furans | 0.08 ng/Nm$^3$ | 3.529 ng/s | - | - |
| PCBs(5) | 5 µg/Nm$^3$ | 0.221 mg/s | - | - |

*Notes:*

*All emissions are expressed at reference conditions of dry gas, 11% oxygen, 273.15K.*

(1) *Averaging period for carbon monoxide is 95% of all 10-minute averages in any 24-hour period.*

(2) *As a worst-case it has been assumed that the entire dust emissions consist of either $PM_{10}$ or $PM_{2.5}$ for comparison with the relevant AQALs.*

(3) *Other metals consist of antimony (Sb), arsenic (As), lead (Pb), chromium (Cr), cobalt (Co), copper (Cu), manganese (Mn), nickel (Ni) and vanadium (V).*

(4) *0.2 µg/m$^3$ is the maximum recorded at a UK plant (2019 Waste Incineration BREF, Figure 8.121). This is assumed to be the emission concentration for the ERF.*

(5) *Table 3.8 of the 2006 Waste Incineration BREF states that the annual average total PCBs is less than 0.005 mg/Nm$^3$ (dry, 11% oxygen, 273K). In lieu of other available operational data, this has been assumed to be the emission concentration for the ERF.*

If the ERF continually operated at the half-hourly limits, the daily limits would be exceeded. The ERF is designed to achieve the daily limits and as such will only operate at the short-term ELVs for short periods on rare occasions.

The contractual availability of the ERF is 92%. However, as a conservative assumption it has been assumed that the ERF continually operates at the ELVs. Where additional analysis has been carried out taking into account the availability this has been set out.

## 5.3 Source and emissions data – CC facility

The source and emissions input data utilised within the modelling for the CC facility are presented in Table 25 to Table 27. These have been used to determine the impact for the Proposed Facility. These are presented per line and are based on emissions from the ERF operating at point B (operation at MCR with the design fuel NCV of 10.5 MJ/kg) in the firing diagram being ducted to the CC facility for abatement and then the exhaust gases released to atmosphere via a stack on the top of each absorber column. The mass release rate of emissions of pollutants emitted from the ERF is assumed to be unchanged.

As set out in the Supporting Information, the design of the CC facility has been optimised to have the greatest temperature of the release without significant loss of the efficiency on the ERF. A detailed stack height analysis has been carried out to determine what height would be needed to have a similar impact to the Permitted Facility. However, due to the significantly different temperature of the release and increased mass of pollutants per volume of air emitted, a similar impact cannot be achieved without a stack height of approximately 140 m. It has been deemed that a stack height of 105 m could be constructed without significant complexities to the civils works and the interface between the absorber and stack, as such this is deemed to be the maximum stack height for the CC facility. This is the stack height which is being applied for as part of this EP application.

*Table 25: Stack Data – CC facility*

| Item | Unit | CC facility |
|---|---|---:|
| Height | m | 105 |
| Internal diameter (each line) | m | 1.58 |
| Stack location – absorber 1 | m, m | 346962.5, 376607.3 |
| Stack location – absorber 2 | m, m | 346965.8, 376608.1 |

*Table 26: Flue Gas Conditions – Per Line – CC facility*

| Item | Unit | CC facility – per line |
|---|---|---:|
| Temperature | °C | 100 |
| Exit moisture content | % v/v | 7.36% |
| | kg/kg | 0.048 |
| Exit oxygen content | % v/v dry | 7.31% |
| Reference oxygen content | % v/v dry | 11% |
| Volume at reference conditions (273.15K, dry, ref $O_2$) | $Nm^3/h$ | 130,866 |
| | $Nm^3/s$ | 36.35 |
| Volume at actual conditions | $Am^3/h$ | 140,751 |
| | $Am^3/s$ | 39.10 |
| Flue gas exit velocity | m/s | 20 |

*Table 27: Stack Emissions Data - Per Line – CC facility*

| Pollutant | Daily or periodic | | Half-hourly | |
|---|---|---|---|---|
| | ELV (mg/Nm³, unless stated) | Release rate (g/s, unless stated) | ELV (mg/Nm³, unless stated) | Release rate (g/s, unless stated) |
| Oxides of nitrogen (as $NO_2$) | - | 7.941 | - | 17.647 |
| Sulphur dioxide | - | 1.765 | - | 8.823 |
| Carbon monoxide(1) | - | 2.206 | - | 6.618 |
| Total dust (PM)(2) | - | 0.221 | - | 1.324 |
| Hydrogen chloride | - | 0.353 | - | 2.647 |
| Volatile organic compounds (as TOC) | - | 0.441 | - | 0.882 |
| Hydrogen fluoride | - | 0.044 | - | - |
| Ammonia | - | 0.662 | - | - |
| Cadmium and thallium | - | 0.882 mg/s | - | - |
| Mercury | - | 0.882 mg/s | - | - |
| Other metals(3) | - | 13.235 mg/s | - | - |
| Benzo(a)pyrene (PAHs)(4) | - | 8.823 µg/s | - | - |
| Dioxins and furans | - | 3.529 ng/s | - | - |
| PCBs(5) | - | 0.221 mg/s | - | - |
| MEA - primary amine(6) | 5 | 0.182 | - | - |
| Nitrosamines from MEA(7) | None emitted | None emitted | - | - |
| Nitramines from MEA(8) | 0.095 µg/Nm³ | 3.453 ng/s | - | - |
| Diethanolamine (DEA) – secondary amine(6) | 0.125 | 0.005 | - | - |
| Nitrosamines from DEA(9) | 0.050 µg/Nm³ | 1.818 ng/s | - | - |
| Nitramines from DEA(8) | 0.003 µg/Nm³ | 0.091 ng/s | - | - |
| Dimethylamine (DMA) – secondary amine(6) | 0.125 | 0.005 | | |
| Nitrosamines from DMA(9) | 0.050 µg/Nm³ | 1.818 ng/s | | |
| Nitramines from DMA(8) | 0.003 µg/Nm³ | 0.091 ng/s | | |
| Aldehydes | 5 | 0.182 | - | - |

*Notes:*

*All emissions are expressed at reference conditions of dry gas, 11% oxygen, 273.15K.*

*For those pollutants with an ELV from the ERF the same g/s release rate has been assumed from the CC facility.*

*(1) Averaging period for carbon monoxide is 95% of all 10-minute averages in any 24-hour period.*

*(2) As a worst-case it has been assumed that the entire dust emissions consist of either $PM_{10}$ or $PM_{2.5}$ for comparison with the relevant AQALs.*

<table>
<tr><th rowspan="2">Pollutant</th><th colspan="2">Daily or periodic</th><th colspan="2">Half-hourly</th></tr>
<tr><th>ELV ($mg/Nm^3$, unless stated)</th><th>Release rate (g/s, unless stated)</th><th>ELV ($mg/Nm^3$, unless stated)</th><th>Release rate (g/s, unless stated)</th></tr>
<tr><td colspan="5"><em>(3) Other metals consist of antimony (Sb), arsenic (As), lead (Pb), chromium (Cr), cobalt (Co), copper (Cu), manganese (Mn), nickel (Ni) and vanadium (V).</em><br><em>(4) 0.2 $\mu g/m^3$ is the maximum recorded at a UK plant (2019 Waste Incineration BREF, Figure 8.121). This is assumed to be the emission concentration for the ERF.</em><br><em>(5) Table 3.8 of the 2006 Waste Incineration BREF states that the annual average total PCBs is less than 0.005 $mg/Nm^3$ (dry, 11% oxygen, 273K). In lieu of other available operational data, this has been assumed to be the emission concentration for the ERF.</em><br><em>(6) MEA based system with the main primary amine being MEA with trace amounts of DEA and DMA. Emissions of DEA and DMA in total assumed to be 5% of the MEA emissions with a 50/50 split of each.</em><br><em>(7) No nitrosamines from MEA emitted.</em><br><em>(8) Total nitramines assumed to be 0.1 $ng/Nm^3$ apportioned as per the amine concentration – i.e. 95% from MEA, with 2.5% from DEA and DMA.</em><br><em>(9) Total nitrosamines assumed to be 0.1 $\mu g/m^3$ apportioned equally across DEA and DMA.</em></td></tr>
</table>

The emissions concentrations presented in Table 27 for amines, nitrosamines, nitramines and formaldehyde are not intended as proposed ELVs for the CC facility but are included as the likely upper end of long-term average emissions from the CC facility to allow the impact to be quantified. The ELVs to be included in the EP will be confirmed with the EA during the determination of the application to vary the EP.

The contractual availability of the ERF is 92% and the CC facility would have a predicted availability of 97%. However, as a conservative assumption it has been assumed that the CC facility continually operates at the ELVs. Where additional analysis has been carried out taking into account the availability this has been set out.

## 5.4 Source and emissions data – hybrid coolers

The CC facility includes two types of coolers, dry cooler and hybrid coolers. Dry coolers are not expected to give rise to a visible plume and as such have not been considered, but the hybrid cooling towers have the potential for a visible plume and as such have been considered further. The exit temperature and moisture content will vary with ambient conditions. However, as a screening exercise the model has been run for two scenarios, one with the highest temperature and moisture content, and one with the lowest temperature and moisture content. The inputs used are presented in Table 28 and Table 29.

*Table 28: Stack Data – Hybrid Coolers*

| Item | Unit | Hybrid coolers |
|---|---|---|
| Height | m | 15 |
| Internal diameter (each line) | m | 7 |
| Stack location – cooler 1 | m, m | 346887.5, 376658.9 |
| Stack location – cooler 2 | m, m | 346897.8, 376661.0 |

*Table 29: Flue Gas Conditions – Each Hybrid Cooler*

| Item | Unit | Hybrid cooler – per unit | |
|---|---|---|---|
| | | Lowest temp | High temp |
| Temperature | °C | 9 | 50 |
| Exit moisture content | % v/v | 0.36% | 6.79% |
| | kg/kg | 0.002 | 0.044 |
| Exit velocity | m/s | 6.32 | 6.33 |

## 5.5 Source and emissions data – $CO_2$ vent

The CC facility includes a vent for $CO_2$ full details of when this vent would be operational are set out in the Supporting Information. Venting would not occur continuously. However, as a screening exercise the model has been run assuming a constant release. Therefore, the operation of the $CO_2$ vent during the worst-case conditions for dispersion is captured. The inputs used are presented in Table 30 and Table 31.

*Table 30: Stack Data – $CO_2$ Vent*

| Item | Unit | $CO_2$ vent |
|---|---|---|
| Height | m | 105 |
| Internal diameter | m | 0.73 |
| Stack location | m, m | 346963.6, 376609.8 |

*Table 31: Flue Gas Conditions – $CO_2$ vent*

| Item | Unit | $CO_2$ vent |
|---|---|---|
| Temperature | °C | -10 |
| Volume at actual conditions | $Am^3/h$ | 25,614 |
| Flue gas exit velocity | m/s | 17 |
| Heat capacity (Cp) | J/°C/kg | 846 |
| Molar mass | g | 44.01 |
| Release rate of $CO_2$ | tph | 51.6 |
| | g/s | 14,333 |

| Item | Unit | $CO_2$ vent |
|---|---|---|
| *Notes:*<br>*Release rate of $CO_2$ based on operating at 105% MCR, as a worst-case.* | | |

## 5.6 Other inputs

Modelling has been undertaken over a grid of 6 km x 6 km with grid spacing of 60 m which is less than 1.5 times the stack height. Reference should be made to Figure 6 of Appendix A for a graphical representation of the modelling domain.

*Table 32: Modelling Domain*

| Parameter | Grid |
|---|---|
| Grid Spacing (m) | 60 |
| Grid Start X | 344300 |
| Grid Finish X | 350300 |
| Grid Start Y | 374100 |
| Grid Finish Y | 380100 |

### 5.6.1 Meteorological data and surface characteristics

The impact of meteorological data has been taken into account by using meteorological data from the Liverpool Airport meteorological recording station for the years 2018 – 2022 sourced from Air Pollution Services (APS) Limited. Liverpool Airport is located approximately 6.5 km to the north-east of the Facility. The location of the meteorological site is shown on Figure 6 of Appendix A. Wind roses for each year of meteorological data can be found in Figure 10 of Appendix A.

The minimum Monin-Obukhov length utilised in ADMS can be selected for both the dispersion site and meteorological site. This is a measure of the minimum stability of the atmosphere and can be adjusted to account for urban heat island effects which prevent the atmosphere in urban areas from ever becoming completely stable. Surface conditions surrounding the Facility are generally rural grassland with areas of industry whilst conditions at Liverpool Airport are grassland with the edge of the Liverpool City conurbation to the north. As such, the minimum Monin-Obukhov length has been set to 10 m at the dispersion site which is appropriate for non-urbanised area surrounding the Site and 30 m at the meteorological site which is appropriate for given the location on the edge of the city area.

The surface roughness length utilised in ADMS can additionally be selected for both the dispersion site and meteorological site. The surface roughness length varies widely across the modelling domain, from very low values over the estuary to much higher values over built-up areas. To account for the varying surface roughness length, spatially-varying surface roughness files have been generated for each of the output grid extents shown in Table 36. The land-use class for each point in the file has been extracted from the CEH Land Cover database[4] and cross-referenced with

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[4] Marston, C.; Rowland, C.S.; O'Neil, A.W.; Morton, R.D. (2022). Land Cover Map 2021 (10m classified pixels, GB). NERC EDS Environmental Information Data Centre

the most likely surface roughness length value[5]. Reference should be made to Figure 7 of Appendix A for a visualisation of the surface roughness file used.

*Table 33: Terrain and Surface Roughness Extents*

| Terrain and surface roughness | Grid |
|---|---|
| Processing resolution | 64 x 64 |
| Grid Start X | 343750 |
| Grid Finish X | 350850 |
| Grid Start Y | 373550 |
| Grid Finish Y | 380650 |

*Table 34: Surface Roughness Lengths Used for Different Land Use Classes*

| Land Use Classification | Corine 2018 Land Use Codes | Surface Roughness Length (m) |
|---|---|---|
| Continuous urban fabric | 111 | 1.2 |
| Broad-leaved forest | 311 | 0.75 |
| Green urban areas | 141 | 0.6 |
| Discontinuous urban fabric, industrial or commercial units, sport and leisure facilities, port areas | 112, 121, 142, 123 | 0.5 |
| Road and rail networks and associated land | 122 | 0.075 |
| Non-irrigated arable land, inland marshes | 211, 411 | 0.05 |
| Pastures, natural grasslands | 231, 321 | 0.03 |
| Salt marshes, sparsely vegetated areas, mineral extraction sites | 421, 333, 131 | 0.005 |
| Intertidal flats | 423 | 0.0005 |
| Water(1) | 523, 512, 511 | 0.0001 |
| *Notes:*<br>*(1) The 'most likely' value for water is given as zero. ADMS cannot model a surface roughness length of zero, so areas of water have been assigned a roughness length of 0.0001 m which is the value recommended by CERC for 'sea'.* | | |

The surface roughness for the meteorological site has been set to 0.5 m which is appropriate considering the immediate land use surrounding the meteorological recording site.

A summary of the meteorological parameters used in the dispersion modelling is shown in Table 35.

*Table 35: Meteorological parameters*

| Parameter | Dispersion Site Value (m) | Met Site Value (m) |
|---|---|---|
| Surface roughness length | Variable | 0.5 |

---

[5] Taken from "Roughness length classification of Corine Land Cover classes", Megajoule Consultants, 2007

| Parameter | Dispersion Site Value (m) | Met Site Value (m) |
|---|---:|---:|
| Minimum Monin-Obukhov length | 10 | 30 |

### 5.6.2 Terrain

It is recommended that by CERC, where gradients within 500 m of the modelling domain are greater than 1 in 10, the complex terrain module within ADMS (FLOWSTAR) should be used. A terrain file to cover the output grid of points set out in Table 33 was created using Ordnance Survey Terrain 50 data. Reference should be made to Figure 8 of Appendix A for a visualisation of the terrain file used.

One of the ecological receptors lie outside of the extents of the variable surface roughness and terrain. As such the results for these locations have been obtained by running the model without terrain and surface roughness files. In this instance a constant surface roughness value of 0.3 m has been used.

### 5.6.3 Buildings

The presence of adjacent buildings can significantly affect the dispersion of the atmospheric emissions in various ways:

- Wind blowing around a building distorts the flow and creates zones of turbulence. The increased turbulence can cause greater plume mixing.
- The rise and trajectory of the plume may be depressed slightly by the flow distortion. This downwash leads to higher ground level concentrations closer to the stack than those which would be present without the building.

It is recommended that buildings should be included in the modelling if they are both:

- Within 5L of the stack (where L is the smaller of the building height and maximum projected width of the building); and
- Taller than 40% of the stack.

The ADMS 6 user guide also states that buildings less than one third of the stack height will not have any effect on the dispersion calculations in the model.

A review of the Site layout has been undertaken and the details of the applicable buildings are presented in Table 36. A plan showing which buildings have been included in the model is presented in Figure 9 of Appendix A. A review of the buildings in the vicinity of the Site greater than 40% of the stack height and it has been deemed appropriate to include in the buildings for the Ince Biomass Power Plant.

*Table 36: Building Details*

| Buildings | Centre point | | Height (m) | Width (m) | Length (m) | Angle (°) |
|---|---:|---:|---:|---:|---:|---:|
| | X (m) | Y (m) | | | | |
| **CC facility** | | | | | | |
| Absorber A | 346956.9 | 376606.1 | 42 | 7.1 | - | - |
| Absorber B | 346970.8 | 376609.0 | 42 | 7.1 | - | - |
| Cooler | 346998 | 376644 | 21 | 98 | 22 | 348 |
| **ERF** | | | | | | |
| EfW A2 | 346726 | 376691 | 30 | 55 | 45 | 79 |

| **Buildings** | **Centre point** | | **Height (m)** | **Width (m)** | **Length (m)** | **Angle (°)** |
|---|---|---|---|---|---|---|
| | **X (m)** | **Y (m)** | | | | |
| EfW B2 | 346713 | 376757 | 51 | 55 | 89 | 79 |
| EfW C2 | 346702 | 376810 | 27 | 55 | 20 | 79 |
| EfW D2 | 346699 | 376827 | 23 | 55 | 14 | 79 |
| **Ince Biomass Power Plant** | | | | | | |
| A | 346789 | 376607 | 42 | 47 | 33 | 348 |
| B | 346797 | 376566 | 33 | 35 | 33 | 348 |
| C | 346817 | 376593 | 21 | 50 | 17 | 348 |
| ACC | 346840 | 376603 | 23 | 55 | 17 | 348 |
| Reception | 346714 | 376595 | 12 | 35 | 73 | 348 |
| Fuel Storage | 346587 | 376539 | 13 | 73 | 58 | 348 |

### 5.6.4 Wind turbines

Wind turbines have the potential to affect the dispersion of emissions if the wind is blowing from the stack towards the turbines, or from the turbines to the stack, causing a wake. This can be accounted for within ADMS by using the wind turbines module. However, wind turbine wakes are generally dissipated within 12-15 rotor diameters, with the wind turbine effects becoming more noticeable when the stack is within a few rotor diameters of the turbine.

The Frodsham wind farm is located approximately 700 m to the east of the Site, and consists of 13 turbines each with a rotor diameter of 90 m and hub height of 80 m. The wind farm is split into two sections with the eastern section closest to the Site consisting of 19 Nordex N90 turbines. The closest turbine within the eastern section is 3.8 km from the Site. The western turbines are located at a distance significantly greater than 15 rotor diameters away from the Site and as such these turbines are unlikely to affect the dispersion of emissions from the Facility and these have been excluded from the dispersion model. However, the eastern turbines have been considered. The location of the wind farm in relation to the Facility is presented in Figure 6 of Appendix A.

*Table 37: Wind Turbine Locations*

| **Turbine No.** | **X (m)** | **Y (m)** |
|---|---|---|
| T1 | 347599 | 376950 |
| T2 | 347865 | 377111 |
| T3 | 348058 | 376779 |
| T4 | 347433 | 377285 |
| T5 | 347586 | 377504 |
| T6 | 347841 | 377648 |
| T7 | 348102 | 377288 |
| T8 | 348365 | 377490 |
| T9 | 348081 | 377804 |
| T10 | 348312 | 377965 |
| T11 | 348657 | 377637 |

| Turbine No. | X (m) | Y (m) |
|---|---:|---:|
| T12 | 348526 | 377159 |
| T13 | 348868 | 377157 |

## 5.7 Plume depletion

Within ADMS when modelling deposition an option is to include plume depletion where the concentration of pollutants in the plume reduce as the pollutants are deposited. This has not been included in the model as a conservative assumption.

## 5.8 Chemistry

The Facility will release nitric oxide (NO) and nitrogen dioxide ($NO_2$) which are collectively referred to as oxides of nitrogen (NOx). In the atmosphere, NO will be converted to $NO_2$ in a reaction with ozone ($O_3$) which is influenced by solar radiation. Since the AQALs are expressed in terms of $NO_2$, it is important to be able to assess the conversion rate of NO to $NO_2$.

Ground level NOx concentrations have been predicted through dispersion modelling. $NO_2$ concentrations reported in the results section assume 70% conversion from NOx to $NO_2$ for annual means and a 35% conversion for short term (hourly) concentrations, based upon the worst-case scenario specified in the EA's guidance for dispersion modelling[6] which is appropriate where the primary $NO_2$ to NOx ratio is less than 10%. Given the short travel time to the areas of maximum concentrations, this approach is considered conservative.

### 5.8.1 Amine chemistry

Directly-emitted amines have the potential to react in the atmosphere to form amine degradation products – nitramines and nitrosamines. The ADMS 6 amine chemistry module calculates concentrations of amines, nitramines and nitrosamines based on the release rate of pollutants and a number of user-defined parameters. The parameters used in the dispersion modelling of amine releases are detailed in Table 38.

The primary amine emitted by the CC facility would be MEA. However, it has been assumed that trace amounts of both DEA and DMA would also be emitted. Amines can form both nitrosamines and nitramines. However, the nitrosamines formed from primary amines such as MEA are unstable, forming isomers known as imines within a few seconds. Imines are not reactive nor significantly harmful to human health. Therefore, any directly emitted nitrosamines will be formed from another, secondary amine formed from reactions within the absorber tower. The exact type of secondary amine(s) and resultant nitrosamine(s) are not known at this stage. For the purpose of this assessment tit has been assumed that the secondary amines emitted are equal concentrations of DMA and DEA, and the directly emitted nitrosamines are consequently equal concentrations of NDMA (formed from DMA) and n-nitrosodiethanolamine (NDELA, formed from DEA).

The amine chemistry module requires the user to input reaction rate parameters for a number of reactions which are detailed in Appendix F. The values used for the main model runs are detailed in Table 38.

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[6] https://www.gov.uk/guidance/environmental-permitting-air-dispersion-modelling-reports

*Table 38: Amine Chemistry Module Input Parameters*

| **Parameter** | **Units** | **MEA** | **DMA** | **DEA** |
|---|---|---|---|---|
| k1 amine/OH reaction rate constant[(1)] | $ppb^{-1}s^{-1}$ | 1.900 | 1.625 | 2.525 |
| k2 amino radical/$O_2$ reaction rate constant[(1)] | $ppb^{-1}s^{-1}$ | $3.10 \times 10^{-9}$ | $3.10 \times 10^{-9}$ | $4.45 \times 10^{-10}$ |
| k3 rate constant for formation of nitrosamine[(1)] | $ppb^{-1}s^{-1}$ | $2.13 \times 10^{-3}$ | $2.13 \times 10^{-3}$ | $1.78 \times 10^{-2}$ |
| k4a rate constant for formation of nitramine[(1)] | $ppb^{-1}s^{-1}$ | $7.95 \times 10^{-3}$ | $7.95 \times 10^{-3}$ | $7.95 \times 10^{-3}$ |
| k4 Amino radical/$NO_2$ reaction rate constant[(1)] | $ppb^{-1}s^{-1}$ | $9.70 \times 10^{-3}$ | $9.70 \times 10^{-3}$ | $9.70 \times 10^{-3}$ |
| Branching ratio for amine/OH reaction[(1)] | Unitless | 0.08 | 0.41 | 0.41 |
| Ratio of J(nitrosamine)to J($NO_2$) [(1)(2)] | Unitless | 0.53 | 0.34 | 0.34 |
| Constant for OH concentration calculations[(3)] | Unitless | 0.00016 | | |
| Formation of stable nitrosamines[(4)] | - | No | Yes | Yes |

*Notes:*

*[(1)] Taken from the Carbon Capture and Storage Association (CCSA) Position Paper 'Carbon Capture Chemistry Parameters, N-Amines Chemistry'[7], except for the values for DEA. Refer to Appendix F for references for the values for DEA.*

*[(2)] J refers to the photolysis rate of each molecule.*

*[(3)] Calculated using methodology from CERC Amine Chemistry Supplement, estimated from typical concentrations of OH, ozone and $jNO_2$. Background ozone taken from Liverpool Speke.*

*[(4)] The CERC Amine Chemistry Supplement states that the nitrosamine produced by primary amines is unstable and will rapidly isomerise to form an imine. Therefore, primary amines will not form stable nitrosamines.*

In addition, the amine chemistry module requires the user to input hourly varying background concentrations of nitric oxide (NO), nitrogen dioxide ($NO_2$), and ozone ($O_3$). The most recent five years of background data from Liverpool Speke has been used. Any missing data in a given year has been infilled using the average for that hour from the remaining years of data.

The two absorber towers are modelled as separate sources in ADMS. The amine chemistry module applies the chemistry scheme to pollutants from each source independently, then sums the resultant pollutants. This could potentially affect the results, as the amines from each source are competing for finite levels of the OH radical and NOx. However, consultation with CERC has confirmed that any effect on the results would be negligible, as the OH radical is constantly reacting with other atmospheric species on a timescale of around a second, i.e. much shorter than the overall amine chemistry timescales, and NOx concentrations in the plume and in ambient air are high enough that they would not be significantly depleted by reactions with the amino radical.

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[7] C.Hazell-Marshall, C Nielsen, Carbon Capture Chemistry Parameters, N-Amines Chemistry, CCSA, September 2022

The amine chemistry parameters and other aspects of modelling amine chemistry are subject to uncertainties. A detailed explanation of the ADMS amine chemistry module and analysis of the sensitivity of model results to the choice of amine chemistry parameters is presented in Appendix F.

## 5.9 Other local point sources of emissions

A review of local point source emissions has been undertaken and an additional local point source (with and EP to operate) have been identified which may have an in-combination impact with the Facility. This is the Ince Biomass Power Plant, which has been operational since 2018. All other local point sources have been operational for many years and therefore the contribution these make is already included in the background monitoring and the Defra mapped background dataset.

It is not necessary to consider the Permitted Facility as a point source in the assessment of emissions from the Proposed Facility, as the flue gas will be emitted from either the ERF stacks or the absorber stacks, but not both at the same time. Potentially one line of the ERF will emit from the existing stack and one absorber stack be operational at the same time, but due to the distance between the sources the maximum impacts would not overlap and would not be greater than the maximum impacts presented in this assessment.

The model inputs used for the other point sources are set out in Appendix E.

The Runcorn Energy Recovery Facility (ERF) is located approximately 5.6 km to the north-east of the Site. At this distance the contribution from the Facility is insignificant, including for amines, nitrosamines and nitramines. An EIA scoping request has been submitted to Halton Borough Council (HBC) for the development of a CC facility at the Runcorn ERF. HBC responded with a scoping opinion (Ref: 23/08032/PREAPP) in July 2023. A qualitative discussion of the potential cumulative impact is presented in section 8.2.4.

## 5.10 Baseline concentrations

Background concentrations for the assessment have been derived from monitoring and national mapping as summarised in Table 19. For short term averaging periods, the background concentration has been assumed to be twice the long-term ambient concentration following the EA recommendation within the Air Emission Guidance.

The background concentration set out in Table 19 has been used to define the total PEC. However, where the contribution from the Facility cannot be screened out as insignificant additional consideration has been made of the contribution from other local sources and road sources to determine an appropriate baseline concentration for the specific receptors of concern. This is then combined with the contribution from the Proposed Facility to determine the PEC.

# 6 Sensitivity Analysis

The following section details the sensitivity of the model to certain input parameters. This has considered the impact of emissions from the CC facility assuming continual operation with the ERF operating at the ELVs and this exhaust being ducted to the CC facility.

## 6.1 Surface roughness

The sensitivity of the results to using varying surface roughness length has been considered by running the model with a variable surface roughness file and a constant surface roughness value across the modelling domain. For all sensitivity analysis the impact of changing model parameters on the maximum annual mean and short-term concentrations of oxides of nitrogen have been considered.

The following parameters have been kept constant:

- CC facility operating at capacity;
- Stack height on top of absorber columns – 105 m;
- Grid – 6 km x 6 km;
- Buildings – included;
- Terrain file – included;
- Meteorological site surface roughness – 0.5 m;
- Dispersion site Monin-Obukhov length – 10 m;
- Meteorological site Monin-Obukhov length – 30 m; and
- Meteorological data used – Liverpool Airport 2022.

The contribution of oxides of nitrogen emissions from the absorber stacks at the point of maximum ground level impact and the maximum impacted receptor are presented in Table 39. In addition, the difference between in impact using the variable surface roughness file has been calculated. Where the impact is less than using the variable surface roughness file this is highlighted in green, and where the impact is greater this is highlighted in yellow.

*Table 39: Surface Roughness Sensitivity Analysis*

| Surface roughness (m) | Concentration (µg/m³) | | | |
|---|---|---|---|---|
| | Point of maximum impact – ground level | | Maximum impacted receptor | |
| | Annual mean | Max 1-hour mean | Annual mean | Max 1-hour mean |
| Variable | 1.32 | 50.06 | 0.86 | 29.57 |
| 0.3 m | 1.11 | 53.31 | 0.83 | 24.99 |
| **As % of variable surface roughness file** | | | | |
| 0.3 m | 119% | 94% | 104% | 118% |

As shown, using a constant surface roughness value of 0.3 m leads to higher annual mean impacts at the point of maximum at ground level and at the receptors. However, the maximum 1-hour impacts are lower.

Due to the variability in the surface roughness values across the modelling domain it is considered appropriate to use a variable surface roughness file.

## 6.2 Terrain

The sensitivity of the results to the effect of terrain has been considered by running the model with and without the terrain file.

The following parameters have been kept constant:

- CC facility operating at capacity;
- Stack height on top of absorber columns – 105 m;
- Grid – 6 km x 6 km;
- Buildings – included;
- Dispersion site surface roughness – variable;
- Meteorological site surface roughness – 0.5 m;
- Dispersion site Monin-Obukhov length – 10 m;
- Meteorological site Monin-Obukhov length – 30 m; and
- Meteorological data used – Liverpool Airport 2022.

The contribution of oxides of nitrogen emissions from the absorber stacks at the point of maximum ground level impact and the maximum impacted receptor are presented in Table 40. In addition, the difference between in impact using a terrain file with a 64 x 64 resolution has been calculated. Where the impact is less than using a resolution of 64 x 64 this is highlighted in green, and where the impact is greater this is highlighted in yellow.

*Table 40: Effect of Terrain and Surface Roughness*

| Scenario | Concentration (µg/m³) | | | |
|---|---|---|---|---|
| | Point of maximum impact | | Maximum impacted receptor | |
| | Annual mean | Max 1-hour mean | Annual mean | Max 1-hour mean |
| Excluding terrain and variable surface roughness | 1.31 | 49.62 | 0.86 | 21.82 |
| Excluding terrain, including variable surface roughness | 1.12 | 52.64 | 0.84 | 22.15 |
| Including terrain, excluding variable surface roughness | 1.32 | 50.06 | 0.86 | 29.57 |
| Including terrain and variable surface roughness | 1.11 | 53.31 | 0.83 | 24.99 |
| **As % of 64 x 64 terrain and variable surface roughness resolution** | | | | |
| Excluding terrain and variable surface roughness | 117% | 93% | 105% | 87% |

| Scenario | Concentration (µg/m³) | | | |
|---|---|---|---|---|
| | Point of maximum impact | | Maximum impacted receptor | |
| | Annual mean | Max 1-hour mean | Annual mean | Max 1-hour mean |
| Excluding terrain, including variable surface roughness | 100% | 99% | 101% | 89% |
| Including terrain, excluding variable surface roughness | 119% | 94% | 104% | 118% |

*Table 41: Effect of Terrain and Surface Roughness Resolution*

| Scenario | Concentration (µg/m³) | | | |
|---|---|---|---|---|
| | Point of maximum impact | | Maximum impacted receptor | |
| | Annual mean | Max 1-hour mean | Annual mean | Max 1-hour mean |
| 64 x 64 | 1.11 | 53.31 | 0.83 | 24.99 |
| 128 x 128 | 1.13 | 52.91 | 0.83 | 24.92 |
| 256 x 256 | 1.12 | 52.34 | 0.83 | 24.86 |
| **As % of 64 x 64 terrain and variable surface roughness resolution** | | | | |
| 128 x 128 | 101% | 99% | 100% | 100% |
| 256 x 256 | 101% | 98% | 100% | 99% |

As shown, the resolution of the terrain and surface roughness file in ADMS has a very slight effect. For the purpose of this assessment the 64 x 64 resolution is considered appropriate which is a balance between computational power and sensitivity of the modelling.

## 6.3 Building parameters

ADMS 6 has a buildings effects module to account for the impact of buildings when it calculates the air flow and dispersion of pollutants from a source. The model works by combining the inputted individual buildings into a single effective building for each wind direction.

The sensitivity of the results to the effect of buildings has been considered by running the model with and without the buildings presented in Table 36.

The following parameters have been kept constant:

- CC facility operating at capacity;
- Stack height on top of absorber columns – 105 m;
- Grid – 6 km x 6 km including the nested grid;
- Terrain file – included at 64 x 64 resolution;
- Dispersion site surface roughness – variable at 64 x 64 resolution;
- Meteorological site surface roughness – 0.5 m;
- Dispersion site Monin-Obukhov length – 10 m;
- Meteorological site Monin-Obukhov length – 30 m; and

- Meteorological data used – Liverpool Airport 2022.

The contribution of oxides of nitrogen emissions from the absorber stacks at the point of maximum ground level impact and the maximum impacted receptor are presented in Table 42. In addition, the difference between in impact including the buildings has been calculated. Where the impact is less than including buildings this is highlighted in green, and where the impact is greater this is highlighted in yellow.

*Table 42: Effect of Buildings*

| **Scenario** | **Concentration (µg/m³)** | | | |
|---|---|---|---|---|
| | **Point of maximum impact – ground level** | | **Maximum impacted receptor** | |
| | **Annual Mean** | **Max 1-hour mean** | **Annual Mean** | **Max 1-hour mean** |
| Including buildings | 1.11 | 53.31 | 0.83 | 24.99 |
| Excluding buildings | 0.71 | 53.31 | 0.65 | 22.49 |
| **As % of including buildings** | | | | |
| Excluding buildings | 64% | 100% | 79% | 90% |

As shown the inclusion of buildings has an effect on the predicted impacts, in particular the annual mean impacts. Therefore, the effect of buildings has been included in the modelling.

## 6.4 Wind turbines

ADMS 6 has a module which can be used to account for the effect of the wakes from wind turbines on the dispersion of emissions. Table 43 presents the predicted concentration as a percentage of the predicted concentration without the turbines modelled. As shown the turbines have very little effect on the peak concentration as an annual mean or the maximum 1-hour. There is a slight increase in impacts using 2021 and 2022 data on the maximum 1-hour concentration at the maximum impacted receptor.

*Table 43: Effect of Wind Turbines*

| **Met data** | **Concentration with turbines as % of conc. without** | | | |
|---|---|---|---|---|
| | **Point of maximum impact – ground level** | | **Maximum impacted receptor** | |
| | **Annual Mean** | **Max 1-hour mean** | **Annual Mean** | **Max 1-hour mean** |
| 2018 | 100.1% | 99.9% | 100.1% | 101.8% |
| 2019 | 100.1% | 100.0% | 100.0% | 108.0% |
| 2020 | 100.1% | 100.0% | 100.0% | 100.7% |
| 2021 | 100.0% | 99.6% | 100.0% | 148.6% |
| 2022 | 100.1% | 100.1% | 100.0% | 124.0% |

To run the model with the amine chemistry and wind turbines takes a considerable amount of time. As the turbines have very little effect on the maximum predicted concentration which is used as the basis of the assessment the model has been run without the turbine module.

## 6.5 Operating below the design point

Dispersion modelling has been undertaken using the emission parameters based on the design nominal case for the ERF and these emissions feeding into the CC facility. The ERF will be operated as a commercial plant, so it is beneficial to operate at full capacity. If loading does fall below the design point the volumetric flow rate of the exhaust gases would reduce. The effect of this would be to decrease the quantity of pollutants emitted. The reduced volume would reduce the buoyancy of the emissions from the CC facility. The reduction in buoyancy, which would lead to reduced dispersion, would be more than offset by the decrease in the quantity of pollutants being emitted, so that the impact of the CC facility when the ERF is running below the design point would be reduced.

# 7 Model Validation and Uncertainty

In line with the EA's Air Emissions Guidance the level of uncertainty in the predictions is estimated. To do so, the results of the model validation documentation and the sensitivities have been considered, and the conservatism in the modelling has been reviewed.

## 7.1 Validation of ADMS model

### 7.1.1 Introduction

Dispersion modelling of process emission from the Facility has been carried out using ADMS (version 6) produced by CERC.

This section of the report describes the model and explains why it is considered appropriate for modelling the impacts of the Facility.

### 7.1.2 Model description

ADMS is a new generation dispersion model which characterises the atmospheric boundary layer in terms of the atmospheric stability and the boundary layer height. In addition, the model uses a skewed Gaussian distribution for dispersion under convective conditions, to take into account the skewed nature of turbulence. The model also includes modules to take account of the effect of buildings and complex terrain.

Within ADMS, the FLOWSTAR module is used to generate a new flow and turbulence field based on the terrain. This simulates the changes to the movement of air in the horizontal and vertical direction as a result of the terrain features in that the air flow is simulated flowing above and around raised ground. This modified flow field is then used by the model to adjust the plume height and plume spread parameters calculated by the flat terrain model. The ADMS model can also handle cases of strongly stable flow using a separate plume impingement model.

The technical specification document for the complex terrain module[8] explains that *"terrain should have no more than moderate slopes (up to 1:3) although the model is useful even when this criterion is not met (say up to 1:2)"*.

The surroundings of the Site are generally flat or gently sloping, with only a few areas where the gradient is greater than 1:10 and no areas where it is greater than 1:3. CERC notes that during very low wind stable conditions in hilly terrain, horizontal gradients in density can cause katabatic (downslope) winds, which may influence the background flow in deep valleys[9]. These effects are not specifically accounted for in ADMS. However, the local area does not include such valleys and as such this limitation of the model is not relevant to this project.

ADMS 6 includes the option to model the effect of coastlines on diurnal air flows. However, it is not possible to include the effect of buildings or complex terrain and variable surface roughness when modelling the effect of the coastline. As shown in section 6 the model results are sensitive to the spatially varying surface roughness, terrain, and building effects. Therefore, it is considered that model results are likely to be more accurate with these effects included and the coastline effect excluded. The exclusion of coastline effects however is a limitation to the modelling methodology.

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[8] CERC, P14/01S/17 Complex Terrain Module, March 2020

[9] CERC, Note 110 Temperature Inversions in ADMS, 20 April 2017

### 7.1.3 Model validation

CERC validates its models against available measured data obtained from real world situations, field campaigns and wind tunnel experiments. Validation studies are published on the CERC website[10] Not all of the validation studies are for settings similar to the study area (flat and/or gently sloping terrain within an urban conurbation). There are two validation studies that are considered to be in locations similar to the study area. These are detailed in Table 44.

*Table 44: Model Validation Studies*

| **Study** | **Notes** |
|---|---|
| Baldwin Power Plant | Characterised as "complex terrain below the stack height".<br>Complex terrain is included in model for the Facility but it does not rise above the stack height within the study area. |
| Kincaid, Indianapolis and Prairie Grass experiments | Kincaid – flat farmland with lakes<br>Indianapolis – flat land, mixed industrial/commercial/urban.<br>Although the model for the Facility includes terrain effects, these are relatively minor (see section 6.2).<br>Prairie Grass experiment – ground level release, not relevant to Facility study area. |

The validation studies include scatter plots, quantile-quantile plots, and a comparison between the observed and modelled maximum and robust highest concentration (Baldwin Power Station only).

- The scatter plots compare predicted and measured concentrations at a particular location at a particular time.
- The quantile-quantile plots compare the distribution of predicted and measured concentrations during the period having abandoned the (x,t) pairing – i.e. comparing the first highest concentration from the monitored with the first highest concentration predicted.
- The highest concentration is subject to extreme variations. Therefore, the robust highest concentration (RHC) is used due to its stability which is based on a tail exponential fit to the upper end of the distribution. The RHC is strongly related to the average and standard deviation.

The most useful visual aid for evaluating model performance is the quantile-quantile plot which shows how the model performs across the full range of modelled and observed concentrations. The quantile-quantile plots for each validation study are shown below.

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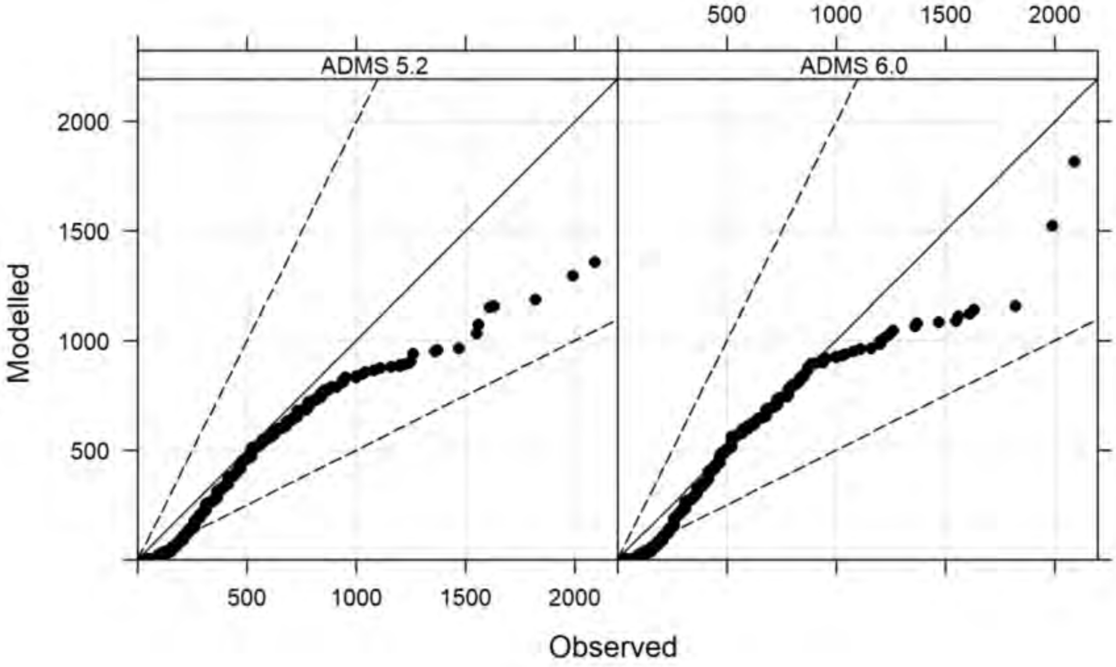
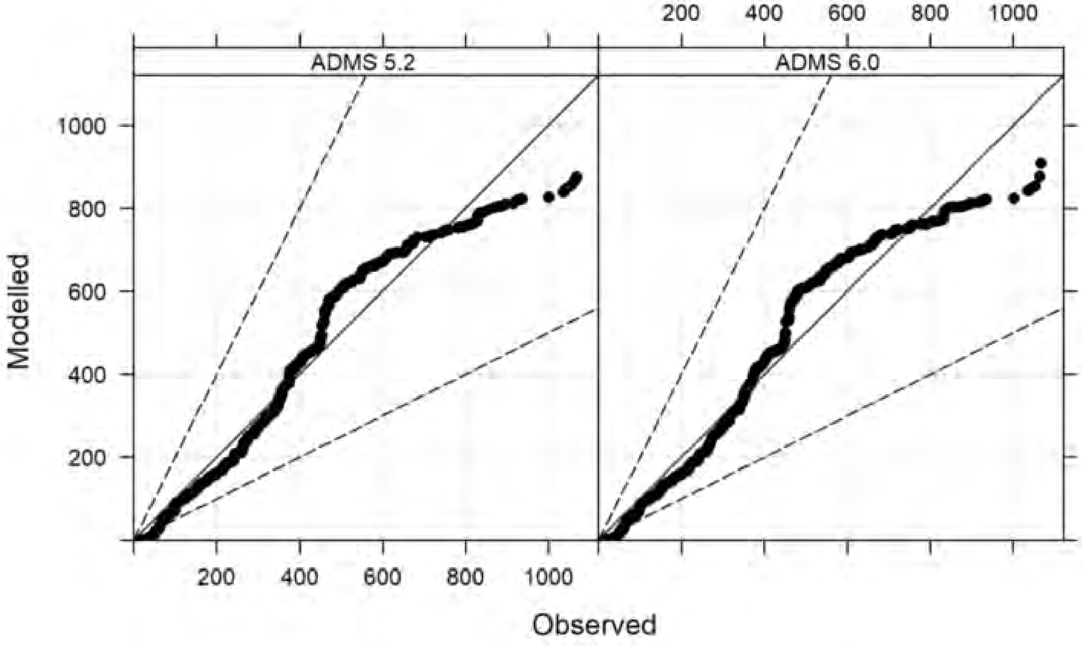
[10] https://www.cerc.co.uk/environmental-software/model-validation.html

*Quantile – Quantile Plot – Baldwin Power Station*



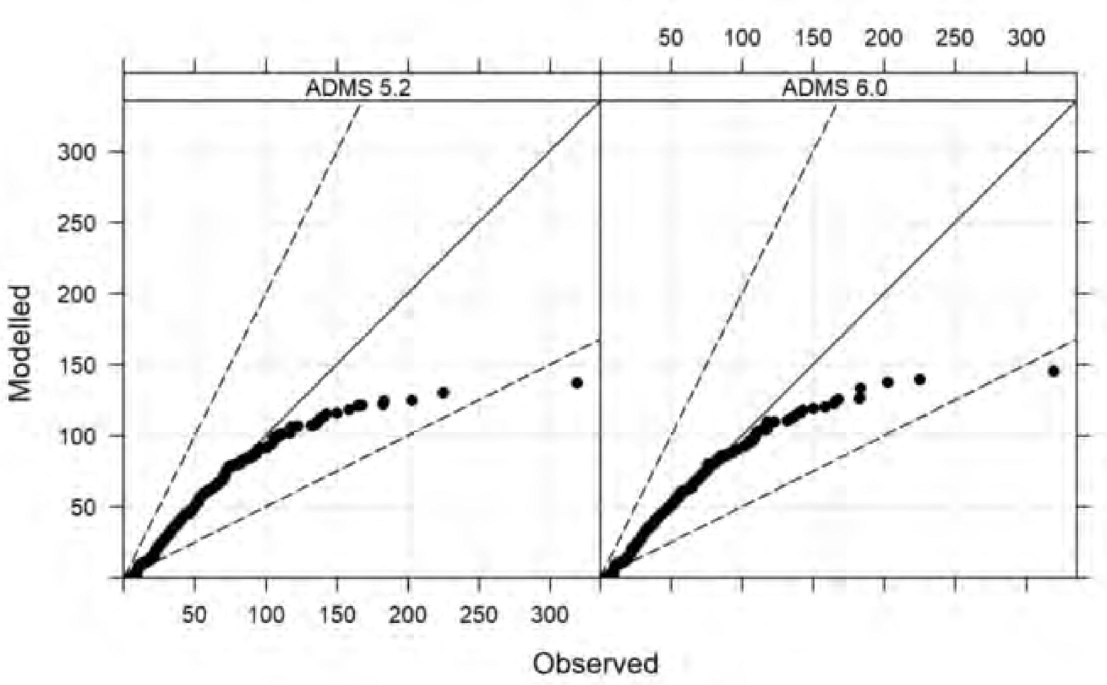
*Source: CERC, ADMS 6 Complex Terrain Validation Baldwin Power Plant, April 2023*

*Quantile – Quantile Plot – Indianapolis*



*Source: CERC, ADMS 6 Flat Terrain Validation Kincaid, Indianapolis and Prairie Grass, April 2023*

*Quantile – Quantile Plot – Kincaid*



*Source: CERC, ADMS 6 Flat Terrain Validation Kincaid, Indianapolis and Prairie Grass, April 2023*

These plots show that at the most common (median) concentrations the modelled and observed concentrations are very similar, giving high confidence in annual mean concentrations. However, the maximum concentrations tended to be under-predicted in two out of the three studies (Baldwin and Kincaid), albeit these are based on a very small sample size.

For the Baldwin Power Plant validation is carried out against sulphur dioxide concentrations. In the validation document[11] CERC explain that there are issues with using sulphur dioxide as a tracer which include:

- The limitations of detection are usually of the order of 16 µg/m$^3$, and concentrations below these are set to one-half of the limit. This leads to considerable inaccuracy when modelled concentrations are low.
- Sulphur dioxide is released from other sources. If estimates of these background concentrations are not available, then the model will underestimate concentrations, particularly long-term averages.

CERC does not report the modelled long-term or annual average concentration against the observed concentration and has only reported the RHC for the Baldwin Power Station study. This is reported for 1 hour, 3 hour and 24 hour averages. The ratio of mean to observed concentrations for the RHC varies from 0.67 to 0.71 across these averaging periods, indicating that the model may be under-estimating the very highest concentrations by up to 33%.

Taking the above into account, it is likely that annual mean concentrations are modelled with a high degree of accuracy. However, the extreme maximum concentrations are less certain, subject to up to 33% uncertainty based on the Baldwin validation study, and potentially over 50% based on the quantile-quantile plot for the Kincaid validation study.

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[11] CERC, ADMS 5 Complex Terrain Validation Baldwin Power Plant, November 2016

## 7.2 Uncertainty

The validation documentation shows that the levels of uncertainty in the ADMS model with respect to the peak predicted concentrations are typically within 10% of the hourly and daily concentrations, with accuracy over long time frames expected to be at least as high as this.

The sensitivity analysis in section 6 shows that varying surface roughness and terrain parameters leads to changes in the peak results of up to around 18%, which is a similar order to the modelling uncertainty.

Variations in weather data are more complex and feed into the inter-annual variability discussed below.

In order to allow for modelling uncertainty, this assessment includes a number of conservative assumptions. These are explained and quantified in this section.

### 7.2.1 Interannual variability

The detailed results tables presented in in Appendix C and Appendix D include the breakdown of the peak concentration using each year of meteorological data. The maximum predicted impact over the 5-years of data was then used as the basis of the assessment. Table 45 provides a breakdown of the range of the predicted impacts from the Proposed Facility at the point of maximum impact for each averaging period.

*Table 45: Interannual Variability*

| Averaging time | Impact from Proposed Facility as percentage of maximum | |
|---|---|---|
| | Minimum | Average |
| Annual mean | 89% | 94% |
| Max 1-hour | 85% | 92% |
| 99.79%ile 1-hour | 93% | 97% |
| 99.73%ile 1-hour | 95% | 97% |
| 99.9%ile 15-min | 78% | 85% |
| Max 24-hour | 63% | 74% |

For the point of maximum impact, the annual average over all five years of weather data is 94% of the highest year, and the minimum is 89% of the highest year. This suggests that using the peak year introduces a conservatism of around 6%. There is more inter-annual variability for shorter-term impacts which are reported as percentile values, where an 8-15% conservatism is introduced. For maximum hourly concentrations the average is only 85% of the maximum, such that the use of the maximum over the 5 years is also likely to over-estimate the maximum hourly concentrations that occur in any given year.

### 7.2.2 Plant availability

The results are based on the assumption that the CC facility would operate for 100% of the time. This is a very conservative assumption. Both the CC facility and the ERF would be offline for periods of maintenance. Routine maintenance would be managed so that the CC facility and ERF are offline at the same time. The CC facility would only be able to operate when the ERF is operational and emissions are suitably stable. The ERF has an availability of 92% and of this the CC facility would be operating for approximately 97% of the time the ERF is available. Therefore, in reality the impact would be lower.

### 7.2.3 Emission limits

The results are based on the assumption that the ERF will operate at the long term ELVs for 100% of the time. However, the ERF is designed to operate below these with a safety margin. It is assumed that the mass release rate of pollutants from the ERF at the ELVs is released via the CC facility with no allowance for any additional abatement of emissions which would occur within the CC facility.

The technology suppliers' experience is that 80-90% of the residual dust and hydrogen chloride in the flue gas and more than 90% of the sulphur dioxide is removed is removed in the DCC. Therefore, actual emissions of sulphur dioxide, hydrogen chloride and any substances in the particulate phase including metals and dioxins would be reduced by at least 80%. In addition, a multi-stage wash will be implemented in the absorber tower to reduce emissions of amines and ammonia. Therefore, the impacts predicted for these pollutants from the CC facility are expected to be significantly lower than set out in this assessment.

### 7.2.4 Short term impacts

For short term impacts it has been assumed that the period when the ERF would need to operate at the half-hourly ELV would occur on both lines concurrently for an entire hour, during the worst-case weather conditions for dispersion and these emissions would transfer through to the CC facility and no further abatement of the pollutants would take place. This is a highly conservative assumption. In order to achieve the daily ELV, the ERF will be operated to achieve the daily ELV for each hour, with only occasional emissions above this and as set out in Section 7.2.3 the CC facility would provide some additional abatement of pollutants.

Furthermore, the half-hourly ELV is that from the IED. The Waste Incineration BAT Conclusions introduce a lower daily limit for oxides of nitrogen and sulphur dioxide which has been transposed into the existing EP. The IED half-hourly limit for oxides of nitrogen is 2 times the IED daily limit, whilst the half-hourly limit for sulphur dioxide is 4 times the daily limit. With the reduced ELVs in the existing EP, the half-hourly limit will be 2.2 times the daily ELV for oxides of nitrogen, and 5 times the daily ELV for sulphur dioxide. Therefore, it is unlikely that peaks in short term emissions would be this high given that a lower daily ELV needs to be achieved.

## 7.3 Overall effect on results

The conservative assumptions explained above mean that the overall impacts presented in this assessment will be overestimates.

1. Annual mean impacts are overstated by around 10% due to plant availability, by around 6-16% when inter-annual variability is considered and by at least 10% when allowing for operation below the emission limits. This means that, overall, the annual mean impacts in this assessment have inbuilt conservatism of at least 25-30%.
2. For short term impacts (where these are expressed as percentiles), selecting the worst case weather conditions across all five years of weather data introduces conservatism of at least 8%, and assuming operation at the short term ELVs introduces conservatism of as much as 50-70%.
3. The validation documentation shows that the level of uncertainty in the model are on average within 10% of the hourly and daily concentrations, with accuracy over long time frames expected to be at least as high as this.

4. The sensitivity analysis presented in section 6 shows that variations in modelling assumptions leads to changes in the peak concentrations of up to 10%.

Therefore, it is considered that the results presented in this assessment are robust as the inbuilt conservatism is of a similar order to the uncertainty in the modelling.

# 8 Impact on Human Health

## 8.1 Screening criteria

The Air Emissions Guidance states that to screen out 'insignificant' PCs:

- *the long-term PC must be less than 1% of the long-term environmental standard; and*
- *the short-term PC must be less than 10% of the short-term environmental standard.*

As part of this assessment, predicted PCs have been compared to the AQALs detailed in section 2.1.

If the above criteria are achieved, it can be concluded that it is not likely that emissions would lead to significant environmental impacts and the PCs can be screened out.

The long-term 1% PC threshold is based on the judgement that:

- it is unlikely that an emission at this level will make a significant contribution to air quality; and
- the threshold provides a substantial safety margin to protect health and the environment.

The short-term 10% PC threshold is based on the judgement that:

- spatial and temporal conditions mean that short-term PCs are transient and limited in comparison with long-term PCs; and
- the threshold provides a substantial safety margin to protect health and the environment.

For the purpose of this assessment, if the impact can be screened out as 'insignificant' at the point of maximum impact, further assessment is not required. If PCs cannot be screened out, assessment will be undertaken for the following:

- the Predicted Environmental Concentration (PEC, defined as the PC plus the background concentration) at the point of maximum impact; and
- the PC and PEC at areas of public exposure.

If the long-term PEC is below 70% of the AQAL, or the short-term PC is less than 20% of the headroom[12], it can be concluded that "there is little risk of the PEC exceeding the AQAL", and the impact can be considered 'not significant'.

For the assessment of group 3 metals, guidance taken from the EA document 'Guidance on assessing group 3 metals stack emissions from incinerators – V.4 June 2016' ('EA metals guidance') has been used. The EA metals guidance states that where the process contribution for any metal exceeds 1% of the long term or 10% of the short term environmental standard (in this case the AQAL), this is considered to have potential for significant pollution. Where the process contribution exceeds these criteria, the PEC should be compared to the AQAL. The PEC can be screened out if is less than the AQAL. Where the impact is within these parameters it can be concluded that there is no significant risk of exceeding the AQAL.

## 8.2 Results

Detailed results tables for the Permitted Facility for each year of weather data are provided in Appendix C and Appendix D for the Proposed Facility. Results have been presented at the point of maximum ground level impact of emissions from the Facility.

Results are based on the following:

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[12] Calculated as the AQAL minus twice the long-term background concentration.

- Modelling domain size – 6 km x 6 km;
- Buildings – included;
- Stack height on top of the absorber column – 105 m;
- 5 years of weather data 2018 to 2022 from Liverpool Airport meteorological recording station;
- Operation at the long term ELVs for the entire year;
- Operation at the short term ELVs during the worst-case conditions for dispersion of emissions;
- Worst case conversion of NOx to nitrogen dioxide;
- The entire dust emissions consist of either $PM_{10}$ of $PM_{2.5}$;
- The entire VOC emissions are assumed to consist entirely of benzene;
- Cadmium and thallium are released at the combined emission limit for cadmium and thallium;
- All amines are summed for comparison with the AQAL for MEA;
- All nitrosamines and nitramines are summed for comparison with the AQAL for NDMA;
- There is no additional abatement of emissions through the CC facility.

Process contributions that cannot be screened out as ‘insignificant’ are highlighted. Where the process contribution cannot be screened out as ‘insignificant’, further analysis has been undertaken.

As shown the peak process contribution from the CC facility is predicted to be greater than the ERF. This is attributed to the cooler release of the emissions post the CC process.

At the point of maximum impact the impact of the following cannot be screened out as ‘insignificant’ and further analysis has been undertaken:

- Annual mean nitrogen dioxide impacts;
- Annual mean VOC impacts (as benzene);
- Annual mean cadmium impacts;
- Annual mean nitrosamines and nitramines impacts;
- Hourly mean nitrogen dioxide impacts when operating at the half-hourly ELV; and
- 15-minute sulphur dioxide impacts when operating at the half-hourly ELV.

### 8.2.1 Further analysis – annual mean nitrogen dioxide

As shown in the detailed tables in Appendix C and Appendix D, there is predicted to be an increase in annual mean nitrogen dioxide impacts as a result of the proposed EP variation.

The maximum annual mean contribution from the Proposed Facility is 1.95% of the AQAL compared to 1.23% for the Permitted Facility.

Further analysis has been carried out to determine the cumulative impact with the emissions from the Ince Biomass Power Plant. This has shown that at the point of maximum impact of emissions from the Proposed Facility the additional contribution from the Ince Biomass Power Plant is 1.1% of the AQAL. The location of this peak is away from any significant road sources. Therefore, the use of the mapped background concentration plus the contribution from the Ince Biomass Power Plant is considered appropriate. The PEC at this point is predicted to be 52.3% of the AQAL. This is less than 70% of the AQAL and it can be concluded that there is little risk of the PEC exceeding the AQAL at the point of maximum impact, and the impact can be considered ‘not significant’.

Figure 12 of Appendix A shows the distribution of emissions from the Proposed Facility and the area where the process contribution cannot be screened out as ‘insignificant’ and further consideration of baseline concentrations is needed. As shown, this does not extend to any areas close to roads, therefore the use of the mapped background concentration plus the contribution from the Ince Biomass Plant is considered appropriate. The PEC within this area is not predicted to exceed 70% of the AQAL. As such it can be concluded that there is little risk of the PEC exceeding the AQAL at any point where the contribution from the Proposed Facility cannot be screened out as insignificant.

Table 46 sets out the process contribution from the Proposed Facility in addition to that from the Ince Biomass Power Plant as shown at all receptor locations the contribution from the Proposed Facility can either be screened out as insignificant or the PEC is less than 70% of the AQAL and it can be concluded that there is little risk of the PEC exceeding the AQAL.

*Table 46: Annual Mean Nitrogen Dioxide - Impacts at Receptors*

| **Receptor** | **Annual mean concentration as % of AQAL** | | |
|---|---|---|---|
| | **Proposed Facility** | **Ince Biomass Power Plant** | **PEC** |
| R1 | 0.8% | 0.5% | 50.5% |
| R2 | 0.5% | 0.3% | 50.0% |
| R3 | 0.2% | 0.2% | 49.6% |
| R4 | 1.4% | 0.8% | 51.4% |
| R5 | 1.0% | 0.5% | 50.7% |
| R6 | 0.2% | 0.1% | 49.6% |
| R7 | 0.2% | 0.1% | 49.5% |
| R8 | 0.4% | 0.3% | 49.9% |
| R9 | 0.7% | 0.4% | 50.3% |
| R10 | 1.2% | 0.6% | 51.1% |
| R11 | 0.9% | 0.5% | 50.7% |
| R12 | 1.0% | 0.5% | 50.8% |
| R13* | 0.95% | 0.5% | 50.7% |

*Notes:*

*PEC includes mapped background concentration of 19.7 µg/m$^3$ or 49.3% of the AQAL.*

*Maximum impact using 5-years of weather data.*

** Close to the road so the baseline may be higher but the maximum impact from the Proposed Facility is 0.96% of the AQAL and as such the impact screened out as ‘insignificant’.*

### 8.2.2 Further analysis – annual mean VOCs

As shown in the detailed tables in Appendix C and Appendix D, there is predicted to be an increase in annual mean VOC impacts as a result of the proposed EP variation.

The maximum annual mean contribution from the Proposed Facility is 1.24% of the AQAL for benzene compared to 0.78% for the Permitted Facility.

Further analysis has been carried out to determine the cumulative impact with the emissions from the Ince Biomass Power Plant. This has shown that at the point of maximum impact of emissions from the Proposed Facility the additional contribution from the Ince Biomass Power Plant is 0.6% of the AQAL. The use of the mapped background concentration plus the contribution from the Ince

Biomass Power Plant is considered appropriate for the location of the peak impact. The PEC at this point is predicted to be 23.70% of the AQAL. This is less than 70% of the AQAL and it can be concluded that there is little risk of the PEC exceeding the AQAL at the point of maximum impact, and the impact can be considered 'not significant'.

Figure 13 of Appendix A shows the distribution of emissions from the Proposed Facility and the area where the process contribution cannot be screened out as 'insignificant' and further consideration of baseline concentrations is needed. Road vehicles are not considered a significant source of VOCs. As shown, this does not extend to any areas close to roads, therefore the use of the mapped background concentration plus the contribution from the Ince Biomass Plant is considered appropriate. The PEC within this area is not predicted to exceed 70% of the AQAL. As such it can be concluded that there is little risk of the PEC exceeding the AQAL at any point where the contribution from the Proposed Facility cannot be screened out as insignificant.

Table 47 sets out the process contribution from the Proposed Facility in addition to that from the Ince Biomass Power Plant as shown at all receptor locations the contribution from the Proposed Facility can be screened out as insignificant or the PEC is less than 70% of the AQAL and it can be concluded that there is little risk of the PEC exceeding the AQAL.

*Table 47: Annual Mean VOC (as benzene) - Impacts at Receptors*

| **Receptor** | **Annual mean concentration as % of AQAL** | | |
|---|---|---|---|
| | **Proposed Facility** | **Ince Biomass Power Plant** | **PEC** |
| R1 | 0.5% | 0.3% | 22.5% |
| R2 | 0.3% | 0.2% | 22.3% |
| R3 | 0.1% | 0.1% | 22.0% |
| R4 | 0.9% | 0.4% | 23.1% |
| R5 | 0.6% | 0.3% | 22.7% |
| R6 | 0.1% | 0.1% | 22.0% |
| R7 | 0.1% | 0.1% | 22.0% |
| R8 | 0.3% | 0.2% | 22.2% |
| R9 | 0.4% | 0.2% | 22.4% |
| R10 | 0.8% | 0.4% | 22.9% |
| R11 | 0.6% | 0.3% | 22.7% |
| R12 | 0.6% | 0.3% | 22.7% |
| R13 | 0.6% | 0.3% | 22.7% |

*Notes:*

*PEC includes mapped background concentration of 1.09 µg/m$^3$ or 21.8% of the AQAL.*

*Maximum impact using 5-years of weather data.*

### 8.2.3 Further analysis – annual mean cadmium

As shown in the detailed tables in Appendix C and Appendix D, there is predicted to be an increase in annual mean cadmium impacts as a result of the proposed EP variation.

The maximum annual mean contribution from the Proposed Facility is 2.48% of the AQAL for cadmium compared to 1.74% for the Permitted Facility.

Further analysis has been carried out to determine the cumulative impact with the emissions from the Ince Biomass Power Plant. This has shown that at the point of maximum impact of emissions from the Proposed Facility the additional contribution from the Ince Biomass Power Plant is 2.1% of the AQAL. The use of the background concentration plus the contribution from the Ince Biomass Power Plant is considered appropriate at this point. The PEC at this point is predicted to be 13.1% of the AQAL. This is less than 70% of the AQAL and it can be concluded that there is little risk of the PEC exceeding the AQAL at the point of maximum impact, and the impact can be considered 'not significant'. This conservatively assumes that both the ERF and the Ince Biomass Power Plant operate at the ELV for total cadmium and thallium and this only consists of cadmium.

Figure 14 of Appendix A shows the distribution of emissions from the Proposed Facility and the area where the process contribution cannot be screened out as 'insignificant' and further consideration of baseline concentrations is needed. The use of the constant background concentration plus the contribution from the Ince Biomass Plant is considered appropriate. The PEC within this area is not predicted to exceed 70% of the AQAL. As such it can be concluded that there is little risk of the PEC exceeding the AQAL at any point where the contribution from the Proposed Facility cannot be screened out as insignificant.

Table 48 sets out the process contribution from the Proposed Facility in addition to that from the Ince Biomass Power Plant as shown at all receptor locations the contribution from the Proposed Facility can either be screened out as insignificant or the PEC is less than 70% of the AQAL and it can be concluded that there is little risk of the PEC exceeding the AQAL.

*Table 48: Annual Mean Cadmium - Impacts at Receptors*

| **Receptor** | **Annual mean concentration as % of AQAL** | | |
|---|---|---|---|
| | **Proposed Facility** | **Ince Biomass Power Plant** | **PEC** |
| R1 | 1.0% | 0.9% | 10.4% |
| R2 | 0.6% | 0.5% | 9.7% |
| R3 | 0.3% | 0.3% | 9.2% |
| R4 | 1.8% | 1.4% | 11.9% |
| R5 | 1.2% | 0.9% | 10.7% |
| R6 | 0.2% | 0.3% | 9.1% |
| R7 | 0.2% | 0.2% | 9.0% |
| R8 | 0.5% | 0.5% | 9.6% |
| R9 | 0.8% | 0.7% | 10.2% |
| R10 | 1.5% | 1.2% | 11.3% |
| R11 | 1.2% | 0.9% | 10.7% |
| R12 | 1.3% | 1.0% | 10.9% |
| R13 | 1.2% | 0.9% | 10.7% |

*Notes:*

*PEC includes mapped background concentration of 0.43 ng/m$^3$ or 8.6% of the AQAL.*

*Maximum impact using 5-years of weather data.*

### 8.2.4 Further analysis – annual mean nitrosamines and nitramines

As shown in the detailed tables in Appendix D, at the point of maximum impact of emissions the total impact of nitrosamine and nitramines when summed and compared to the AQAL[13] for NDMA is predicted to be 1.01% of the AQAL. The annual mean contribution from each substance has been summed for each grid point and the maximum of all grid points determined. This approach has been used as the peak impact for each substance occurs in different locations owing to the atmospheric reactions. This conservatively assumes that the CC facility continually operates and no allowance for periods when the CC facility would be offline have been accounted for. Additional consideration of the sensitivity of the modelling to the choice of amine chemistry inputs has been carried out within Appendix F. This shows that whilst there is some variability in the results based on the choice of value used the impact remains low and there is no risk of the AQAL being exceeded.

As noted in Section 5.9 it is known that there is a CC facility proposed for the Runcorn ERF, approximately 5.6 km north-east of the Facility. As the Runcorn ERF processes over 1 million tonnes of waste per annum, just over twice the capacity of the Facility, and has a similar stack height, it is anticipated that the maximum impact of the Runcorn ERF CC facility on concentrations of amines and amine degradation products would be approximately twice the maximum impact of the Facility. On this basis, even if the maximum impacts of the Facility and the Runcorn ERF CC facility occurred in the same location, the total concentration of nitrosamines + nitramines would be around 3% of

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[13] AQAL is taken to be the NIPH limit of 0.3 ng/m$^3$. Although this AQAL was derived for NDMA, it is explicitly described in its supporting documentation as being applicable to total nitrosamines + nitramines. The total concentration of nitrosamines + nitramines is 1.52% of the EA's EAL for NDMA.

the AQAL for NDMA. In reality the cumulative impact would be much less than this due to the distance between the emission sources. As such, there is no risk of the AQAL being exceeded and the cumulative impact would not be significant.

### 8.2.5 Further analysis – hourly nitrogen dioxide

As shown in the detailed tables in Appendix C and Appendix D, there is predicted to be an increase in the short term nitrogen dioxide impacts as a result of the proposed EP variation. If it is assumed that both lines of the ERF operate at the half-hourly ELVs and these emissions are passed through to the CC facility and that this occurs during the worst-case conditions for dispersion at the point of maximum impact the contribution from the Proposed Facility is 10.8% of the AQAL and cannot be screened out as ‘insignificant’.

Figure 15 of Appendix A shows the area where impacts cannot be screened out as ‘insignificant’. As shown, this does not cover any area where members of the public are expected to spend a period of an hour or more. In addition, this is less than 20% of the headroom. Therefore, it can be concluded that there is little risk of the PEC exceeding the AQAL.

### 8.2.6 Further analysis – 15-minute sulphur dioxide

As shown in the detailed tables in Appendix C and Appendix D, there is predicted to be an increase in the short term sulphur dioxide impacts as a result of the proposed EP variation. If it is assumed that both lines of the ERF operate at the half-hourly ELVs and these emissions are passed through to the CC facility and that this occurs during the worst-case conditions for dispersion at the point of maximum impact the contribution from the Proposed Facility is 17.45% of the AQAL and cannot be screened out as ‘insignificant’, however, this is less than 20% of the headroom. When operating at the daily ELV, which still is a conservative assumption, the peak impact is only 3.5% of the AQAL. Therefore, it can be concluded that there is little risk of the PEC exceeding the AQAL at the point of maximum impact.

In addition, the technology supplier has stated that more than 90% of the sulphur dioxide emissions would be removed during the quench stage in the CC process. Therefore, actual emissions of sulphur dioxide are expected to be significantly lower than presented.

### 8.2.7 Further analysis – impact in AQMA

As detailed in Section 4.1, there is a local AQMA declared due to concern over 15-minute sulphur dioxide concentrations as a result of operations at the Stanlow Refinery. The location of the AQMA is shown on Figure 5 of Appendix A. As shown, the contribution from the Proposed Facility at this location is minimal and can be screened out as ‘insignificant’. As such the proposed EP variation is not predicted to have a significant impact on the AQMA.

### 8.2.8 Heavy metals – at the point of maximum impact

The detailed results tables in Appendix D detail the predicted impact of emissions of metals from the Proposed Facility.

If the process contribution is greater than 1% of the AQAL when it is assumed that each metal is emitted at the total metal ELV, further analysis has been undertaken. The EA’s metals guidance details the maximum monitored concentrations of Group 3 metals emitted by Municipal Waste Incinerators and Waste Wood Co-Incinerators as a percentage of the ELV for Group 3 metals. The maximum monitored emission presented in the EA's analysis has been used as a conservative assumption.

As shown, if it is assumed that the entire emissions of metals consist of only one metal, the impact of the operation of the Proposed Facility is generally less than 1% of the long term, with the exception of annual mean impacts of arsenic, chromium VI, manganese and nickel. If it is assumed that the ERF would perform no worse than the maximum monitored concentration from the EA metals guidance, the impact of the Proposed Facility would be below 1% of the long term AQAL for all pollutants with the exception of arsenic and nickel. The PEC is only predicted to exceed the long term AQAL for chromium (VI) which is due to the high assumed background concentration, the process contribution from the Proposed Facility is well below 1% of the AQAL (0.32%).

When considering the annual mean impact of emissions of arsenic the contribution from the Proposed Facility would be 2.6% of the AQAL, at this point the additional contribution from the Ince Biomass Power Plant would be 1.3% of the AQAL. The PEC including the contribution from the Ince Biomass Power Plant would be 20.5% of the AQAL. This is well below the AQAL and therefore it can be concluded that there is no significant risk of exceeding the AQAL for arsenic.

When considering the annual mean impact of emissions of nickel the contribution from the Proposed Facility would be 6.8% of the AQAL, at this point the additional contribution from the Ince Biomass Power Plant would be 3.4% of the AQAL. The PEC including the contribution from the Ince Biomass Power Plant would be 28.2% of the AQAL. This is well below the AQAL and therefore it can be concluded that there is no significant risk of exceeding the AQAL for nickel.

When considering short term impacts the detailed results tables show that if it is assumed that the ERF would perform no worse than maximum monitored concentration from the EA metals guidance, the process contribution is below 10% of the short term AQAL for all pollutants for the Proposed Facility.

This analysis has shown there is no risk of exceeding an AQAL for any metals either on a long-term or short-term basis as a result of emissions from the Proposed Facility. This analysis conservatively assumes that the CC facility would continually operate and there is no additional abatement of metals through the CC process. The preceding analysis has shown that when accounting for availability, and when including the contribution from ERF when the CC facility is offline the impact would be lower.

### 8.2.9 Further analysis – amines

The above analysis has compared the total sum of amines to the EAL for MEA published by the EA in lieu of any EALs for the other amines (namely DEA and DMA) published by the EA. EALs for have been derived using the EA approach as set out within Appendix G.

Table 49 provides a summary of the peak impact of each amine with reference to the EALs.

*Table 49: Further Analysis Amines*

| Amine | Averaging period | EAL (µg/m$^3$) | Maximum PC | |
|---|---|---|---|---|
| | | | Conc. (µg/m$^3$) | As % of EAL |
| Total amines(1) | Maximum 1-hour mean | 400 | 1.51 | 0.38% |
| | Maximum daily mean | 100 | 0.34 | 0.34% |
| MEA | Maximum 1-hour mean | 400 | 1.43 | 0.36% |
| | Maximum daily mean | 100 | 0.32 | 0.32% |
| DEA | Maximum 1-hour mean | - | 0.04 | |

| Amine | Averaging period | EAL ($\mu$g/m$^3$) | Maximum PC | |
|---|---|---|---|---|
| | | | Conc. ($\mu$g/m$^3$) | As % of EAL |
| | Maximum daily mean | 0.2 | 0.0088 | 4.4% |
| DMA | Maximum 1-hour mean | - | 0.04 | - |
| | Maximum daily mean | 3.3 | 0.0088 | 0.27% |

Notes:

Maximum PC across the modelling domain using all 5-years of weather data.

(1) Total amines calculated by summing the contribution from each amine and taking the maximum across the modelling domain. This impact has been compared to the EAL for MEA as per the main analysis.

As shown, the process contribution can be screened out as ‘insignificant’ even if it is conservatively assumed that the CC facility continually operates i.e. with no allowance for periods when the plant may be offline.

# 9 Impact at Ecological Receptors

## 9.1 Screening

The EA's Air Emissions Guidance states that to screen out impacts as 'insignificant' at European and UK statutory designated sites:

- the long-term PC must be less than 1% of the long-term environmental standard (i.e. the Critical Level or Load); and
- the short-term PC must be less than 10% of the short-term environmental standard.

If the above criteria are met, no further assessment is required. If the long-term PC exceeds 1% of the long-term environmental standard, the PEC must be calculated and compared to the standard. If the resulting PEC is less than 70% of the long-term environmental standard, the Air Emissions Guidance states that the emissions are 'insignificant' and further assessment is not required. In accordance with the guidance, calculation of the PEC for short-term standards is not required.

The EA's Air Emissions Guidance states further that to screen out impacts as 'insignificant' at local nature sites[14]:

- the long-term PC must be less than 100% of the long-term environmental standard; and
- the short-term PC must be less than 100% of the short-term environmental standard.

In accordance with the guidance, calculation of the PEC for local nature sites is not required. However, this has been calculated for completeness.

## 9.2 Daily mean Critical Level

The closest site which monitors ozone and sulphur dioxide concentrations is Liverpool Speke, located approximately 3.6 km to the north of the Site.

To supplement the monitoring at Liverpool Speke a review of the monitoring of ozone from all sites across the UK has been carried out. The AO40 has been calculated and results graphed up showing where the baseline concentration exceeds the AO40 in each year in Figure 11 of Appendix A. As shown, there are locations across the UK where the AO40 exceeded the Critical Level but on average very few sites recorded exceedances of the AO40 level in the UK and these were located in the south of the UK. In the north west there were a few exceedences of the AO40 in 2018 but since then the levels have been below the Critical Level.

The APIS baseline sulphur dioxide concentrations presented in Table 20 shows that the baseline sulphur dioxide concentrations are well below the Critical Level.

This analysis demonstrates that the concentrations of sulphur dioxide are well below the Critical Level in the areas affected by emissions from the Facility and on average the ozone concentration is below the Critical Level. As such it is considered that the daily mean NOx Critical Level of 200 $\mu g/m^3$ is relevant and has been used for the purpose of this assessment.

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[14] Ancient woodlands, local wildlife sites and national and local nature reserves.

## 9.3 Methodology

### 9.3.1 Atmospheric emissions – Critical Levels

The impact of emissions has been compared to the Critical Levels listed in Table 4. Further assessment would be undertaken where the process contribution of a particular pollutant is greater than 1% of the long term or 10% of the short-term Critical Level for European and UK designated sites, and where the process contribution of a particular pollutant is greater than 100% of the Critical Level for locally designated sites.

### 9.3.2 Deposition of emissions – Critical Loads

In addition to the Critical Levels for the protection of ecosystems, habitat specific Critical Loads for nature conservation sites at risk from acidification and nitrogen deposition (eutrophication) are outlined in APIS. In terms of acid deposition, the APIS Database contains a maximum critical load for sulphur (ClmaxS), a minimum Critical Load for nitrogen (CLminN) and a maximum Critical Load for nitrogen (ClmaxN). These components define the Critical Load function for acid deposition. Where the acid deposition flux falls within the area under the Critical Load function, no exceedances are predicted.

An assessment has been made for each habitat feature identified in APIS and identified in the SSSI citation for the specific site. The map function tool has been used to identify the features and habitat specific Critical Loads. However, the APIS database does not include many of the local wildlife sites. As such the project ecologist has been consulted to determine the most appropriate Critical Load for assessment purposes. The relevant Critical Loads are presented in Appendix B. The lowest Critical Load for each designated site has been used to ensure a robust assessment.

### 9.3.3 Calculation methodology

#### 9.3.3.1 Nitrogen deposition

The impact of deposition has been assessed using the methodology detailed within the Habitats Directive AQTAG 6 (March 2014). The steps to this method are as follows.

1. Determine the annual mean ground level concentrations of nitrogen dioxide, ammonia and amines at each site.
2. Calculate the dry deposition flux (µg/m$^2$/s) at each site by multiplying the annual mean ground level concentration by the relevant deposition velocity presented in Table 50.
3. Convert the dry deposition flux into units of kgN/ha/yr using the conversion factors presented in Table 50.
4. Compare this result to the nitrogen deposition Critical Load.

*Table 50: Deposition Factors*

| **Pollutant** | **Deposition velocity (m/s)** | | **Conversion factor (µg/m$^2$/s to kg/ha/year)** |
|---|---|---|---|
| | **Grassland** | **Woodland** | |
| Nitrogen dioxide | 0.0015 | 0.003 | 96.0 |
| Sulphur dioxide | 0.0120 | 0.024 | 157.7 |
| Ammonia | 0.0200 | 0.030 | 259.7 |

| Pollutant | Deposition velocity (m/s) | | Conversion factor ($\mu g/m^2/s$ to kg/ha/year) |
|---|---|---|---|
| | Grassland | Woodland | |
| Hydrogen chloride | 0.0250 | 0.060 | 306.7 |
| MEA | 0.0200 | 0.030 | 72.2 |
| DEA | | | 41.9 |
| DMA | | | 97.8 |

*Source: AQTAG 6 (March 2014), except for amines which are detailed below.*

The contribution of nitrosamine and nitramines to total nitrogen and acid deposition has been excluded given their exceptionally low concentration in comparison to amines. As amines are derived from ammonia, as a screening assumption it has been assumed that amines have the same deposition velocity as ammonia. The conversion factor from $\mu g/m^2/s$ to kg/ha/year for each amine has been derived from the percentage of the molecular mass of each amine that is nitrogen (each amine contains one nitrogen atom).

### 9.3.3.2 Acidification

Deposition of nitrogen, sulphur, hydrogen chloride, ammonia and amines can cause acidification and should be taken into consideration when assessing the impact of the Facility.

The steps to determine the acid deposition flux are as follows.

1. Determine the dry deposition rate in kg/ha/yr of nitrogen, sulphur, hydrogen chloride, ammonia and amines using the methodology outlined in Section 9.3.3.
2. Apply the conversion factor for N outlined in Table 51 to the nitrogen, ammonia and amine deposition rate in kg/ha/year to determine the total keq N/ha/year.
3. Apply the conversion factor for S to the sulphur deposition rate in kg/ha/year to determine the total keq S/ha/year.
4. Apply the conversion factor for HCl to the hydrogen chloride deposition rate in kg/ha/year to determine the dry keq Cl/ha/year.
5. Add the contribution from S to HCl and treat this sum as the total contribution from S.
6. Plot the results against the Critical Load functions.

*Table 51: Conversion Factors*

| Pollutant | Conversion factor (kg/ha/year to keq/ha/year) |
|---|---|
| Nitrogen | Divide by 14 |
| Sulphur | Divide by 16 |
| Hydrogen chloride | Divide by 35.5 |

*Source: AQTAG (March 2014)*

The March 2014 version of the AQTAG 6 document states that, for installations with an HCl emission, the PC of HCl, in addition to S and N, should be considered in the acidity Critical Load assessment. The H+ from HCl should be added to the S contribution (and treated as S in APIS tool). This should include the contribution of HCl from wet deposition.

Consultation with AQMAU confirmed that the maximum of the wet or dry deposition rate for HCl should be included in the calculation. For the purpose of this analysis, it has been assumed that wet deposition of HCl is double dry deposition.

The contribution from the Facility has been calculated using APIS formula:

*Where PEC N Deposition < CLminN:*

*PC as % of CL function = PC S deposition / ClmaxS*

*Where PEC N Deposition > CLminN:*

*PC as % of CL function = (PC S + N deposition) / ClmaxN*

## 9.4 Results

Detailed results tables for the Permitted Facility for each year of weather data are provided in Appendix C and Appendix D for the Proposed Facility. Results have been presented at the point of maximum ground level impact of emissions from the Facility.

Results are based on the following:

- Modelling domain size – 6 km x 6 km;
- Buildings – included;
- Stack height on top of the absorber column – 105 m;
- 5 years of weather data 2018 to 2022 from Liverpool Airport meteorological recording station;
- Operation at the long term ELVs for the entire year;
- Operation at the short term ELVs during the worst-case conditions for dispersion of emissions;
- Worst case conversion of NOx to nitrogen dioxide;
- The nitrogen deposition impacts include the contribution from nitrogen dioxide, ammonia and amine emissions;
- The acid deposition impacts include the contribution from nitrogen dioxide, ammonia, amines, sulphur dioxide and hydrogen chloride;
- Wet deposition of HCl has been included in the acid S calculation as double dry deposition;
- It has been assumed the most sensitive habitat is present at the point of maximum impact of emissions in each site; and
- There is no additional abatement of emissions through the CC facility.

Process contributions that cannot be screened out as ‘insignificant’ are highlighted. Where the process contribution cannot be screened out as ‘insignificant’, further analysis has been undertaken.

As shown the peak process contribution from the CC facility is predicted to be greater than the ERF. This is attributed to the cooler release of the emissions post the CC process.

### 9.4.1 European and UK designated sites

#### 9.4.1.1 Mersey Estuary

The peak annual mean impact of emissions of oxides of nitrogen and ammonia and nitrogen deposition impacts from the Proposed Facility cannot be screened out as ‘insignificant’. All other impacts can be screened out as ‘insignificant’ as the contribution from the Proposed Facility is less than 1% of the long term and less than 10% of the short term Critical Levels and Loads.

The following table sets out a summary of the peak impact across the designated site for the Permitted Facility and Proposed Facility.

*Table 52: Peak Impact Mersey Estuary*

| Parameter | Peak impact in site as % of Critical Level or Critical Load | |
|---|---|---|
| | Permitted Facility | Proposed Facility |
| Annual mean NOx | 1.69% | 1.66% |
| Annual mean $NH_3$ | 1.41% | 1.38% |
| Nitrogen deposition – lower CL | 2.71% | 2.83% |
| Nitrogen deposition – upper CL | 1.35% | 1.42% |

As shown in both scenarios the impacts cannot be screened out as ‘insignificant’. There is predicted to be a slight decrease in the peak concentration oxides of nitrogen and ammonia impact from the Proposed Facility compared to the Permitted Facility, but the deposition impact is slightly increased owing to the additional contribution from the amines. Reference should be made to the following figures within Appendix A which show the distribution of emissions. The maximum from all 5-years across each grid point has been used to produce the contours. As such the contour represents the worst-case as the dispersion patterns slightly change each year. As shown for the Proposed Facility the area where impacts cannot be screened out as ‘insignificant’ is slightly larger than for the Permitted Facility.

- Figure 16 – Annual mean oxides of nitrogen impacts
- Figure 17 – Annual mean sulphur dioxide impacts
- Figure 18 – Nitrogen deposition impacts – as % of lower Critical Load
- Figure 19 – Nitrogen deposition impacts – as % of upper Critical Load

The following table sets out the APIS mapped background concentration, the peak contribution from the Ince Biomass Power Plant, the peak contribution from the Proposed Facility and the peak in combination impact from both. This analysis shows that the peak impact from both plants does not occur in the same location with the peak in combination impact being slightly lower than the peak from each individually.

*Table 53: Mersey Estuary - Annual Mean NOx Impacts*

| Source | Max across Mersey Estuary designated site | | Maximum across functionally linked land | |
|---|---|---|---|---|
| | $\mu g/m^3$ | % of Critical Level | $\mu g/m^3$ | % of Critical Level |
| APIS background | 15.50 | 51.67% | 13.90 | 46.33% |
| Maximum from Ince Biomass Power Plant | 0.52 | 1.74% | 0.44 | 1.48% |
| Maximum from Proposed Facility | 0.50 | 1.66% | 0.51 | 1.70% |

| Source | Max across Mersey Estuary designated site | | Maximum across functionally linked land | |
|---|---|---|---|---|
| | µg/m³ | % of Critical Level | µg/m³ | % of Critical Level |
| Maximum combined Ince Biomass Plant and Proposed Facility | 0.97 | 3.23% | 0.90 | 3.00% |
| Maximum PEC | 16.47 | 54.90% | 14.80 | 49.33% |
| *Notes:*<br>*Critical level of 30 µg/m³ applied.*<br>*PEC calculated as the maximum APIS background across the designated site plus maximum combined Ince Biomass Power Plant and Proposed Facility.* | | | | |

*Table 54: Mersey Estuary - Annual Mean Ammonia Impacts*

| Source | Max across Mersey Estuary designated site | | Maximum across functionally linked land | |
|---|---|---|---|---|
| | µg/m³ | % of Critical Level | µg/m³ | % of Critical Level |
| APIS background | 4.90 | 163.33% | 4.70 | 156.67% |
| Maximum from Ince Biomass Power Plant | 0.03 | 0.87% | 0.02 | 0.74% |
| Maximum from Proposed Facility | 0.04 | 1.38% | 0.04 | 1.42% |
| Maximum combined Ince Biomass Plant and Proposed Facility | 0.97 | 32.32% | 0.90 | 29.95% |
| Maximum PEC | 5.87 | 195.66% | 5.60 | 186.62% |
| *Notes:*<br>*Critical level of 3 µg/m³ applied.*<br>*PEC calculated as the maximum APIS background across the designated site plus maximum combined Ince Biomass Power Plant and Proposed Facility.* | | | | |

*Table 55: Mersey Estuary - Annual Mean N Deposition Impacts*

| Source | Max across Mersey Estuary designated site | | Maximum across functionally linked land | |
|---|---|---|---|---|
| | kgN/ha/yr | % of Critical Load | kgN/ha/yr | % of Critical Load |
| APIS background | 24.30 | 243.00% | 13.90 | 139.00% |
| Maximum from Ince Biomass Power Plant | 0.19 | 1.89% | 0.16 | 1.59% |
| Maximum from Proposed Facility | 0.28 | 2.83% | 0.29 | 2.90% |

| Source | Max across Mersey Estuary designated site | | Maximum across functionally linked land | |
|---|---|---|---|---|
| | kgN/ha/yr | % of Critical Load | kgN/ha/yr | % of Critical Load |
| Maximum combined Ince Biomass Plant and Proposed Facility | 0.45 | 4.48% | 0.43 | 4.27% |
| Maximum PEC | 24.75 | 247.48% | 14.33 | 143.27% |
| *Notes:*<br>*Critical level of 10 kgN/ha/yr applied.*<br>*PEC calculated as the maximum APIS background across the designated site plus maximum combined Ince Biomass Power Plant and Proposed Facility including the nutrification impacts from amines.* | | | | |

This further analysis shows that the peak NOx concentration even in combination with the Ince Biomass Power Plant is predicted to be well below 70% of the Critical Level and as such the emissions are ‘insignificant’. However, the peak ammonia and N deposition contribution from the Proposed Facility is predicted to exceed 1% of the Critical Level and Critical Load and when combined with the Ince Biomass Power Plant and the APIS background the total PEC is predicted to exceed the Critical Level and Critical Load.

Whilst the peak impact of ammonia and nitrogen deposition from the Proposed Facility cannot be screened out as ‘insignificant’. This is based on conservative modelling assumptions including that the CC facility will continually operate at the ELVs for the entire year. As set out both the ERF and the CC facility will be offline for maintenance so are unlikely to operate for a full year at full load, and the CC system includes a multi-stage wash which will reduce emissions of amines and ammonia. Therefore, the impacts predicted for these pollutants from the CC facility are expected to be significantly lower than set out in this assessment. Based on this it is unlikely that impacts upon the Mersey Estuary or functionally linked land would exceed 1% of the Critical Level or Critical Load.

#### 9.4.1.2 Midland Meres and Mosses

The peak annual mean impact of emissions of nitrogen and acid deposition impacts from the Proposed Facility cannot be screened out as ‘insignificant’. All other impacts can be screened out as ‘insignificant’ as the contribution from the Proposed Facility is less than 1% of the long term and less than 10% of the short term Critical Levels and Loads.

The following table sets out a summary of the impact at the closest point within each SSSI which make up Midland Meres and Mosses Ramsar to the Proposed Facility (Hatch Mere).

*Table 56: Impact Midland Meres and Mosses*

| Parameter | Max Impact as % of Critical Load | |
|---|---|---|
| | Permitted Facility | Proposed Facility |
| **Midland Meres and Mosses – Flaxmere Moss** | | |
| Nitrogen deposition – lower CL (5 kgN/ha/yr) | 0.83% | 1.08% |
| Nitrogen deposition – upper CL (15 kgN/ha/yr) | 0.28% | 0.36% |

| Parameter | Max Impact as % of Critical Load | |
|---|---|---|
| | Permitted Facility | Proposed Facility |
| Acid deposition – lower CL (CLMax N = 0.5552 keq/ha/yr) | 1.17% | 1.48% |
| **Midland Meres and Mosses – Linmere Moss** | | |
| Nitrogen deposition – lower CL (15 kgN/ha/yr) | 0.22% | 0.29% |
| Nitrogen deposition – upper CL (25 kgN/ha/yr) | 0.13% | 0.17% |
| Acid deposition – lower CL (CLMax N = 0.5552 keq/ha/yr) | 0.95% | 1.20% |

This is the maximum impact using 5-years of weather data and assuming continuous operation at the ELVs. As explained in section 9.4.1.1 impacts predicted for these pollutants from the CC facility are expected to be significantly lower than set out in this assessment. Based on this it is unlikely that impacts upon the Midland Meres would exceed 1% of the Critical Load for either nitrogen or acid deposition.

### 9.4.2 Local sites

As shown in Appendix D, the process contribution is not predicted to exceed the Critical Level or Load. Applying the EA's screening criteria the impact can be screened out as 'insignificant'.

# 10 Plume Visibility

The dispersion model has been run with the plume visibility module to determine if there is likely to be a visible plume from either the absorber stacks or the hybrid coolers. The initial analysis of the input parameters has shown that the exhausts are below 100% relative humidity. The model has been run for all 5-years of weather data and there are not predicted to be any visible plumes from the CC facility.

# 11 Carbon Dioxide Venting

The CC facility is designed to compress and treat the $CO_2$ for injection into the HyNet $CO_2$ pipeline. If the quality of the $CO_2$ does not meet pipeline specifications, it cannot be exported and must be vented to atmosphere.

Venting can occur in two locations in the process:

1. Upstream of the compressor – in the case that the compressor is not in operation or there is a stop in production of $CO_2$.
2. Downstream of the $CO_2$ analyser – in the case that the $CO_2$ quality does not meet the specification.

By building in redundancy and reliability into the CC process, periods of venting can be reduced to a minimum. In both instances the gases are released via the $CO_2$ vent stack. Full details of the scenarios in which $CO_2$ venting could occur are detailed in the Supporting Information.

It is proposed to have a $CO_2$ vent stack the same height as the stacks on the absorber columns (i.e. 105 m). This solution has been determined to ensure that the impact of $CO_2$ venting on the environment with respect to the workplace exposure limits (WEL) set out in the EH40. This has considered the impact at ground level, but also at elevated working platforms where workers may be present in the event that $CO_2$ is vented.

The dispersion model has been run with the input parameters set out in Section 5.5. Impacts have been predicted for ground level and at receptors including those representing exposure at 1.5 m above the top of each of the buildings. The maximum 15-minute and 8-hour concentration has been predicted and the impacts compared to the AQALs (in this case the WEL). A summary is provided in Table 57.

*Table 57: Impact of $CO_2$ Vent*

| Averaging period | Maximum as a % of the WEL | | |
|---|---:|---:|---:|
| | Ground level | At an identified receptor | At an elevation of 1.5m above the height of buildings |
| Maximum 15-mintue | 8.06% | 1.90% | 4.64% |
| Maximum 8-hour | 1.29% | 0.30% | 0.92% |

The following table provides a break-down of the peak 15-minute impact using each year of meteorological data. As shown, the 99th percentile is significantly lower, indicating that the peak is predicted to occur as a result of a specific abnormal meteorological conditions not typically occurring. The modelling assumes that the $CO_2$ vent operates during the worst-case weather conditions for dispersion. Even with this assumption there is little risk of exceeding the AQAL (in this case the WEL) as such the impact can be considered to be ‘insignificant’.

*Table 58: Impact of $CO_2$ vent - breakdown point of maximum impact - $CO_2$*

| Met data year | Maximum 15-minute mean | | 99%ile of 15-minute mean | |
|---|---:|---:|---:|---:|
| | Conc. (ppm) | % of AQAL | Conc. (ppm) | % of AQAL |
| 2018 | 1208.3 | 8.1% | 47.4 | 0.3% |
| 2019 | 1184.9 | 7.9% | 65.9 | 0.4% |
| 2020 | 979.0 | 6.5% | 55.5 | 0.4% |

| Met data year | Maximum 15-minute mean | | 99%ile of 15-minute mean | |
|---|---|---|---|---|
| | Conc. (ppm) | % of AQAL | Conc. (ppm) | % of AQAL |
| 2021 | - | - | - | - |
| 2022 | 1178.2 | 7.9% | 74.0 | 0.5% |
| Max | 1208.3 | 8.1% | 74.0 | 0.5% |

# 12 Abnormal Operations

## 12.1 Background

The Environmental Permitting Regulations require that abnormal event scenarios are considered. Article 46(6) of the Industrial Emissions Directive (IED) states that:

*"… the waste incineration plant … shall under no circumstances continue to incinerate waste for a period of more than 4 hours uninterrupted where emission limit values are exceeded.*

*The cumulative duration or operation in such conditions over 1 year shall not exceed 60 hours."*

Article 47 continues with:

*"In the case of a breakdown, the operator shall reduce or close down operations as soon as practicable until normal operations can be restored."*

The conditions detailed in Article 46(6) are considered to be "abnormal operating conditions" for the purpose of this assessment applies to the Facility.

## 12.2 Identification of abnormal operating conditions

The following are considered to be examples of abnormal operating conditions which may lead to 'abnormal emission levels' of pollutants:

1. Reduced efficiency of lime injection system such as through blockages or failure of fans leading to elevated acid gas emissions (with the exception of hydrogen chloride);
2. Complete failure of the lime injection system leading to unabated emissions of hydrogen chloride. (Note: this would require the ERF to have complete failure of the bag filter system. As an ERF of modern design the ERF would have shut down before reaching these operating conditions);
3. Reduced efficiency of particulate filtration system due to bag failure and inadequate isolation, leading to elevated particulate emissions and metals in the particulate phase;
4. Reduced efficiency of the Selective Non-Catalytic Reduction (SNCR) system as a result of blockages or failure of ammonia injection system, leading to elevated oxides of nitrogen emissions; and
5. Complete failure of the activated carbon injection system and loss of temperature control leading to high levels of dioxin reformation and their unabated release.

The CC facility is designed to treat flue gas during normal operation. Depending on the cause of abnormal operating conditions, the CC facility would be bypassed during abnormal operation.

If the lime injection and/or SNCR system failed, elevated NOx and acid gas concentrations would significantly degrade the amine solvent in the CC facility. High levels of metals and particulates resulting from a failure of the bag filter and/or activated carbon filter would also degrade the amine solvent and the reduce the overall performance of the CC facility. Therefore, as soon as any failure of abatement technology was identified, bypass of the CC facility would be implemented.

Depending on detailed design and development of operational procedures, the CCS system may also be bypassed during periods when the continuous emissions monitoring system (CEMS) is unavailable, i.e. the pollutant concentrations are unknown. If the CC facility is not bypassed during these periods, the monitoring of the combustion, reagent dosing and CCS processes would be used as proxies to ensure that the processes and resulting emissions remain controlled.

As the flue gas would bypass the CC facility and be emitted from the main stacks during abnormal operation, the impact of emissions during abnormal operation would be no worse than previously assessed for the Facility.

## 12.3 ERF start-up and shutdown

The CC facility requires steam from the combustion process to operate. Therefore, the CC facility will be bypassed during start-up and shut-down of the ERF[15]. Start-up of the ERF from cold will be conducted with clean support fuel (low sulphur light fuel oil). Waste is not introduced onto the grate unless the temperature is above the minimum requirement (850ºC) and other operating parameters (for example, air flow and oxygen levels) are within the range stipulated in the permit. During the warming up period the gas cleaning plant will be operational as will be the control systems and monitoring equipment.

The same is true during plant shutdown. The waste remaining on the grate is allowed to burn out, the temperature not being permitted to drop below 850ºC by the simultaneous introduction of clean support auxiliary fuel. After complete burnout of the waste, the burners are turned off and the ERF is allowed to cool. During this period, the gas cleaning equipment, control systems and monitoring equipment will be fully operational.

It should also be noted that start-up and shutdown are infrequent events; the ERF is designed to operate continuously, and ideally only close down for its annual maintenance programme.

In relation to the magnitude of dioxin emissions during plant start-up and shutdown, research has been undertaken by AEA Technology on behalf of the EA. Whilst elevated emissions of dioxins (within one order of magnitude) were found during shutdown and start-up phases where the waste was not fully established on the grate, the report concluded that:

*"The mass of dioxin emitted during start-up and shutdown for a 4-5 day planned outage was similar to the emission which would have occurred during normal operation in the same period. The emission during the shutdown and restart is equivalent to less than 1 % of the estimated annual emission (if operating normally all year)."*

There is therefore no reason why such start-up and shutdown operations will affect the long term impact of the Facility.

## 12.4 Summary

The CC facility will be bypassed during any periods of abnormal operation during which elevated emissions may occur. Therefore, the impact of emissions during abnormal operation as permissible under the IED (Article 46) would be no worse than currently allowed for within the EP for the Facility.

---

[15] This is referring "abnormal operations" as defined in the IED.

# 13 Conclusions

This Dispersion Modelling Assessment has been undertaken to support an application for a variation to the EP for the Facility. The modelling has assumed that the ERF operates at the ELVs in the existing EP, and these are passed through to the CC facility before emitting to atmosphere. It is assumed that the CC facility does not offer any additional abatement of emissions which is extremely conservative given that the CC facility is likely to reduce emissions of acid gases and particulates by more than 80%.

This assessment has included a review of baseline pollution levels, dispersion modelling of emissions and quantification of the impact of these emissions on local air quality.

The primary conclusions of the assessment are presented below.

1. In relation to the impact on human health:
    a. Emissions from the operation of the Proposed Facility will not cause a breach of any AQAL.
    b. There is predicted to be an increase in the impacts as a result of the proposed EP variation, but the overall impact of the Proposed Facility is not significant this includes for the additional products released from the CC facility such as amines, nitrosamine and nitramines.
    c. There is no risk of exceeding an AQAL for any metal either on a long or short term basis.
2. In relation to the impact on ecologically sensitive sites:
    a. At the Mersey Estuary, and functionally linked land, the peak impact of emissions of oxides of nitrogen, ammonia and nitrogen deposition are predicted to exceed 1% of the Critical Level and Critical Load and in the case of ammonia and nitrogen deposition the baseline exceeds the Critical Level and Critical Load.
    b. At Midland Meres and Mosses, which is located 9.2 km from the Facility, the peak impact of emissions of oxides of nitrogen and acid deposition are predicted to exceed 1% of the Critical Load and the baseline exceeds the Critical Load.
    c. At all local ecological sites, the contribution from the Proposed Facility can be screened out 'insignificant' as it is less than the Critical Levels and Critical Loads.
    d. These impacts assume that the CC facility does not offer any additional abatement of emissions and the emissions from the ERF operating at the ELVs are passed through the CC facility before emitting to atmosphere. The CC facility is likely to abate emissions of acid gases and ammonia by more than 80%, as such it is unlikely that impacts would exceed the 1% of the long term Critical Level or Critical Load at any ecological site. Therefore, impacts would be insignificant at the identified ecological receptors.
3. $CO_2$ venting would have an insignificant impact on air quality.

In summary, the assessment has shown that the air quality impact of the Proposed Facility would not have a significant impact on local air quality, the general population or the local community. As such there should be no air quality constraint in granting a variation to the existing EP to include the CC facility.

# Appendices

# A Figures

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**Legend**

🟩 Installation Boundary

Title:

Figure 1. Site Location

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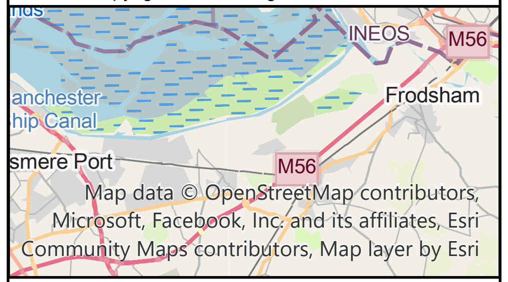

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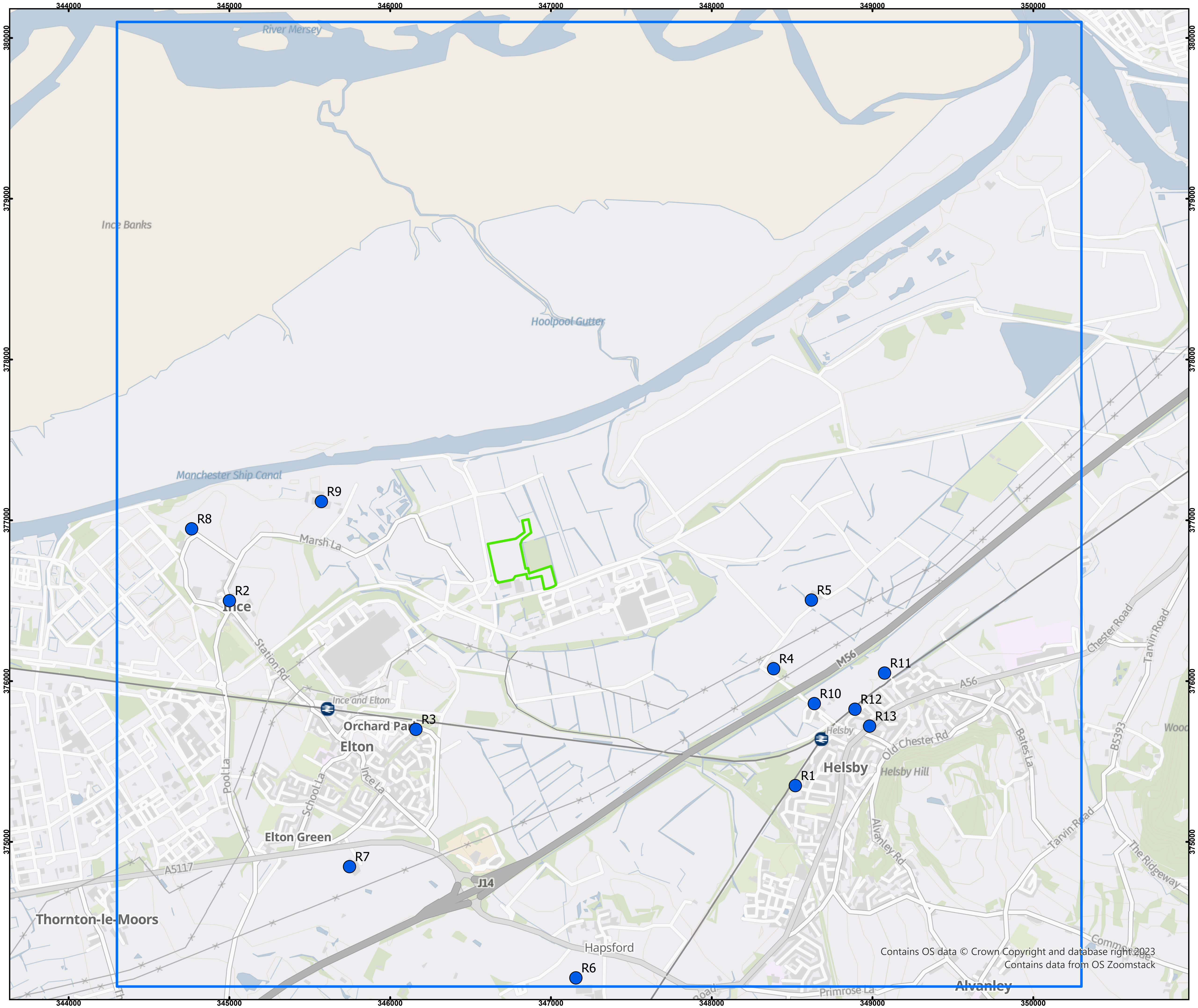
Tel: 0161 476 0032
Fax: 0161 474 0618



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**Legend**

| | |
|---|---|
| ● | Human Receptors |
| ▭ | Output Grid Extent |
| 🟩 | Installation Boundary |

Title:

Figure 2. Human Sensitive Receptors

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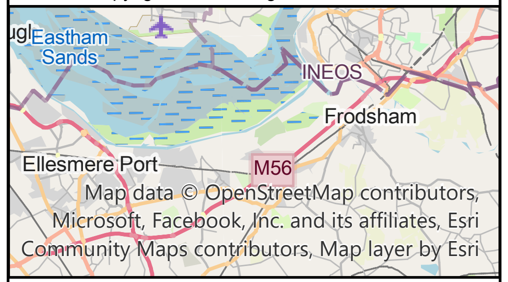

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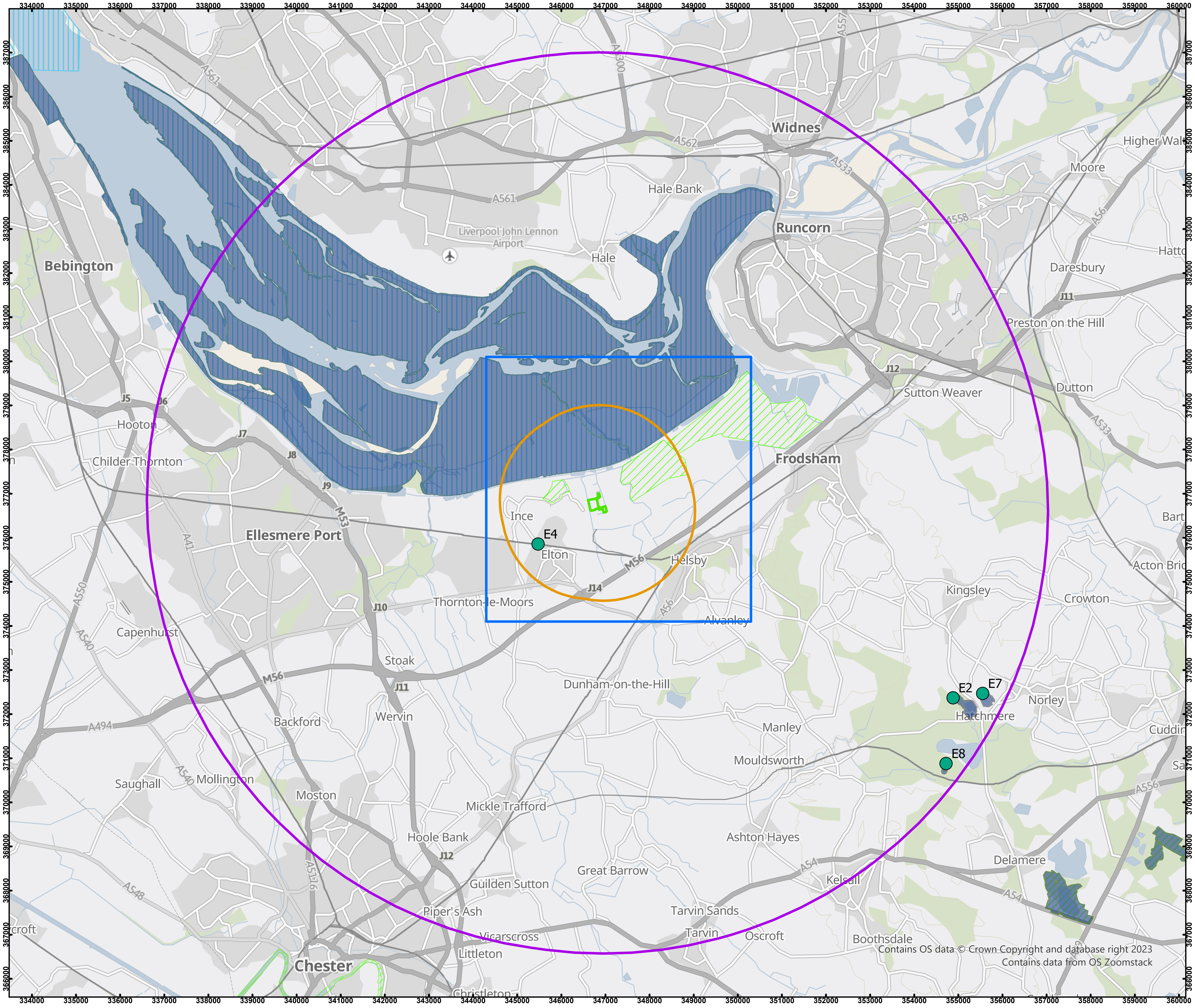

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**Legend**

- ● Eco Receptor Points
- 🟧 2km Installation Buffer
- 🟪 10km Installation Buffer
- 🟦 Output Grid Extent
- 🟩 Installation Boundary
- ▨ Potentially functionally linked grassland
- ■ Ramsars
- ▨ SACs
- ▥ SPAs

Title:

Figure 3. Ecologically Sensitive Receptors

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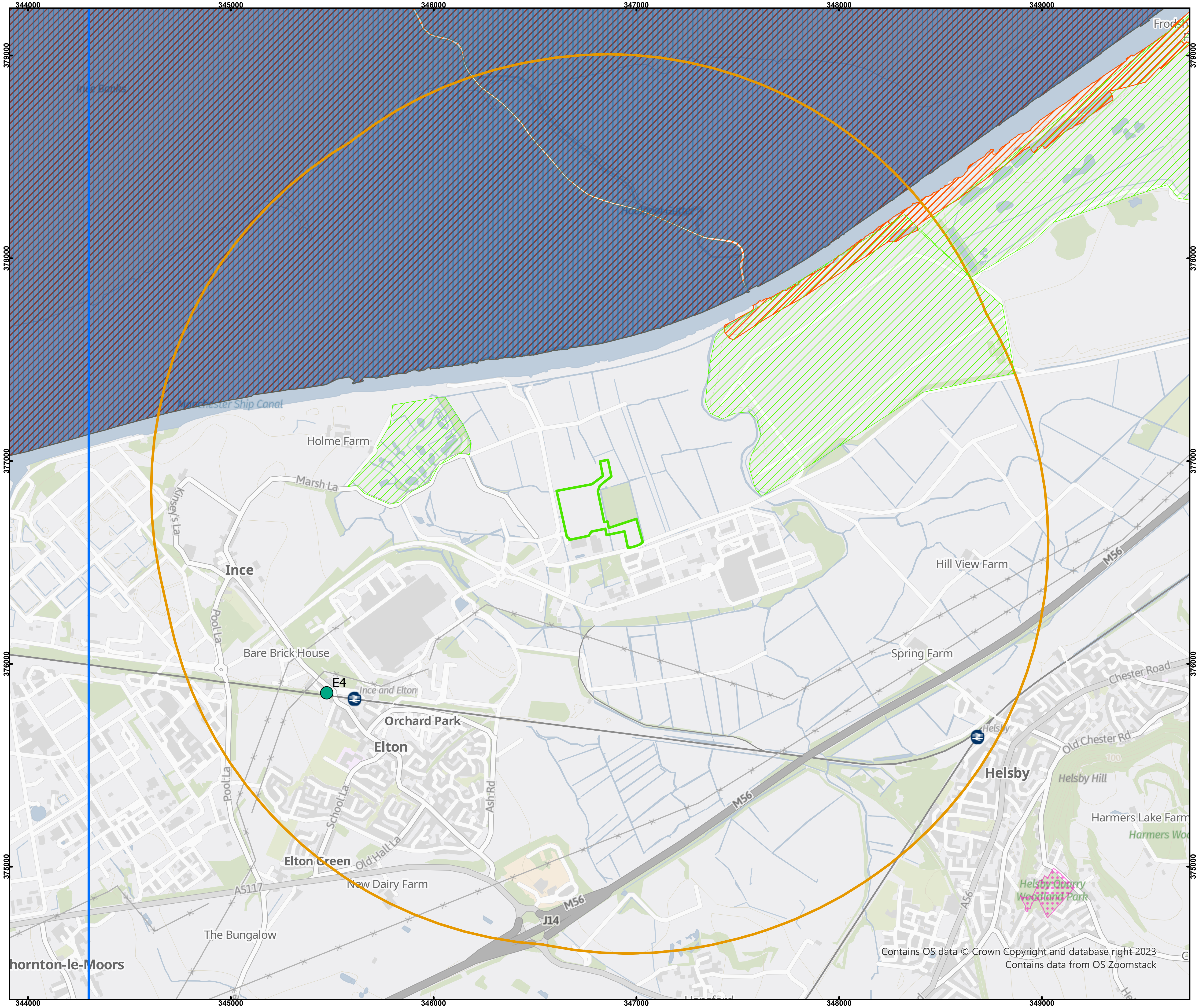

**Legend**

- ● Eco Receptors Points
- 🟩 Installation Boundary
- 🟦 Output Grid Extent
- ▨ Potentially functionally linked grassland
- 🟧 2km Installation Buffer
- ■ Ramsars
- ▨ SACs
- ▥ SPAs
- ▨ SSSIs
- ▤ NNRs
- ⁘ LNRs
- ■ Ancient Woodlands

Title:

Figure 4. Ecologically Sensitive Receptors - Zoom

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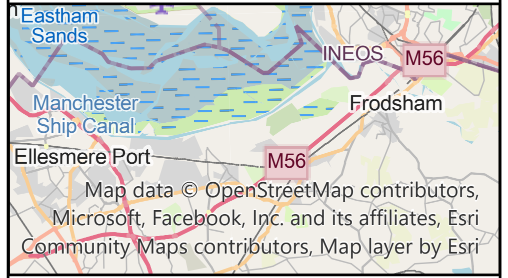

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0 0.17 0.35 0.7 km

N

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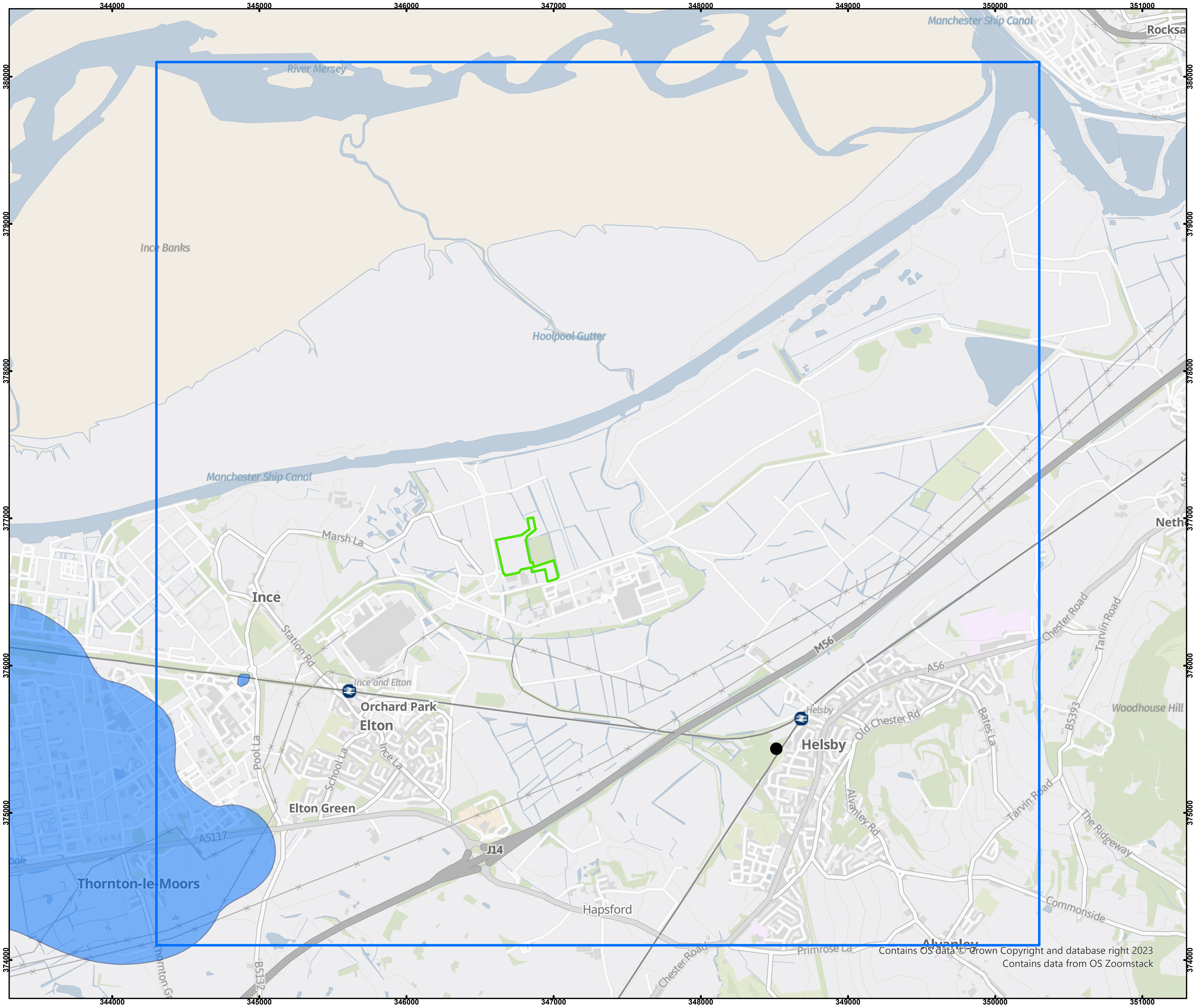

**Legend**

● Helsby AQ Analyser

☐ Output Grid Extent

☐ Installation Boundary

▨ AQMAs

Title:

Figure 5. Monitoring Sites and AQMAs

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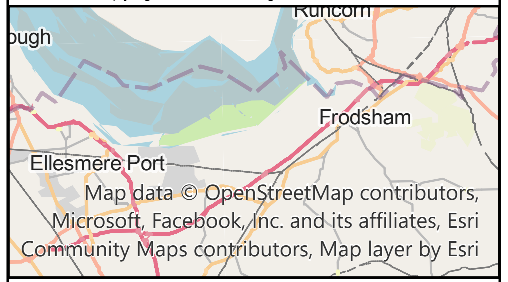

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0 0.23 0.45 0.9 km

N

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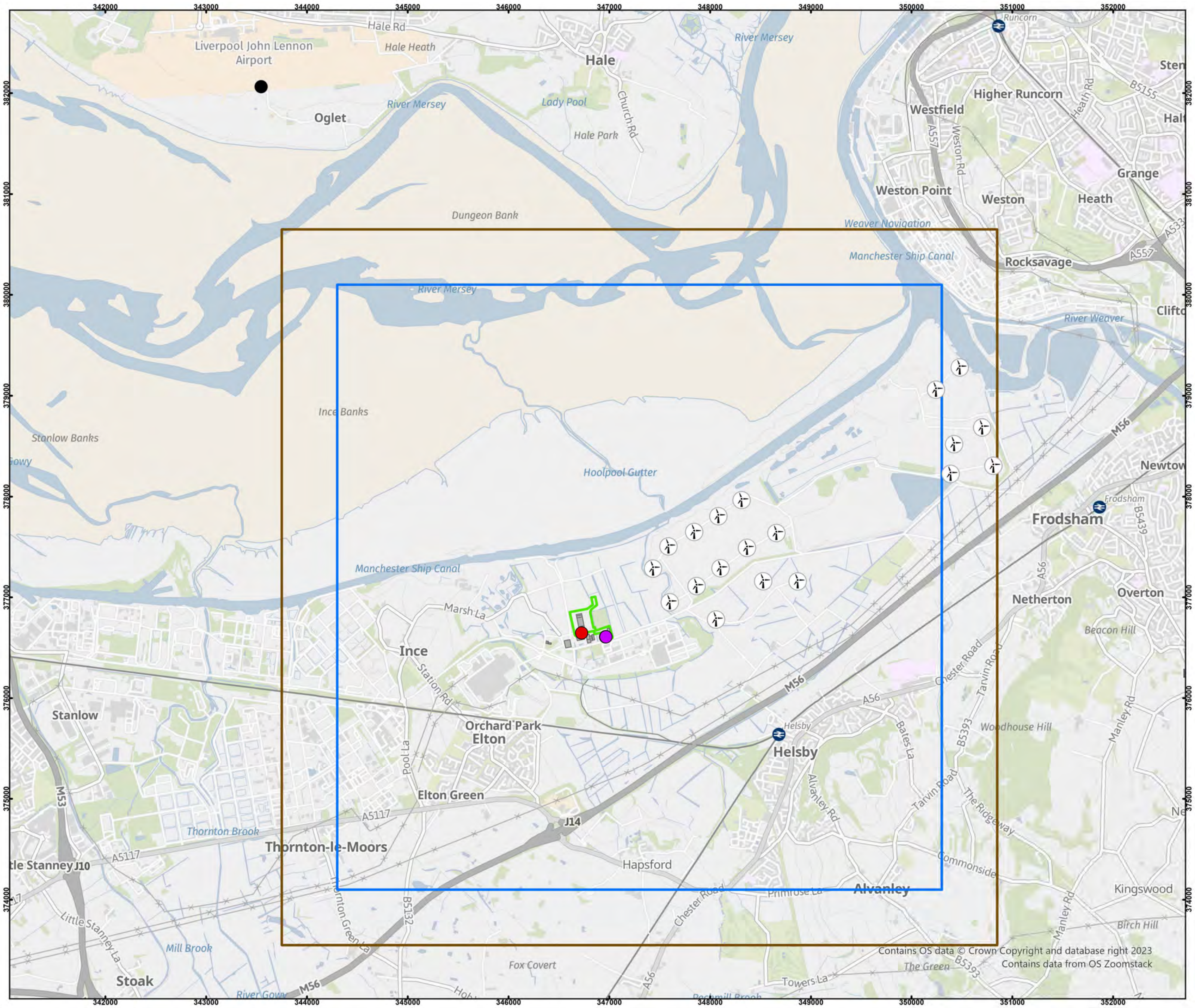


**Legend**

● Liverpool Speke Airport Met Site

Frodsham Wind Farm B

Frodsham Wind Farm A

● CC Facility

● CC Vent Stack

● ERF

▨ Buildings

☐ Output Grid Extent

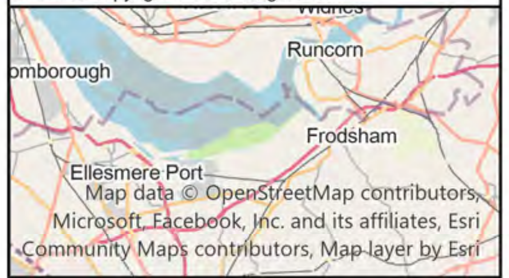
☐ Terrain and Surface Roughness Extent

☐ Installation Boundary

Title:

Figure 6. Model Inputs

| Drawn by: RSF | Date: 22/11/2023 |
|---|---|



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0 0.35 0.7 1.4 km

N

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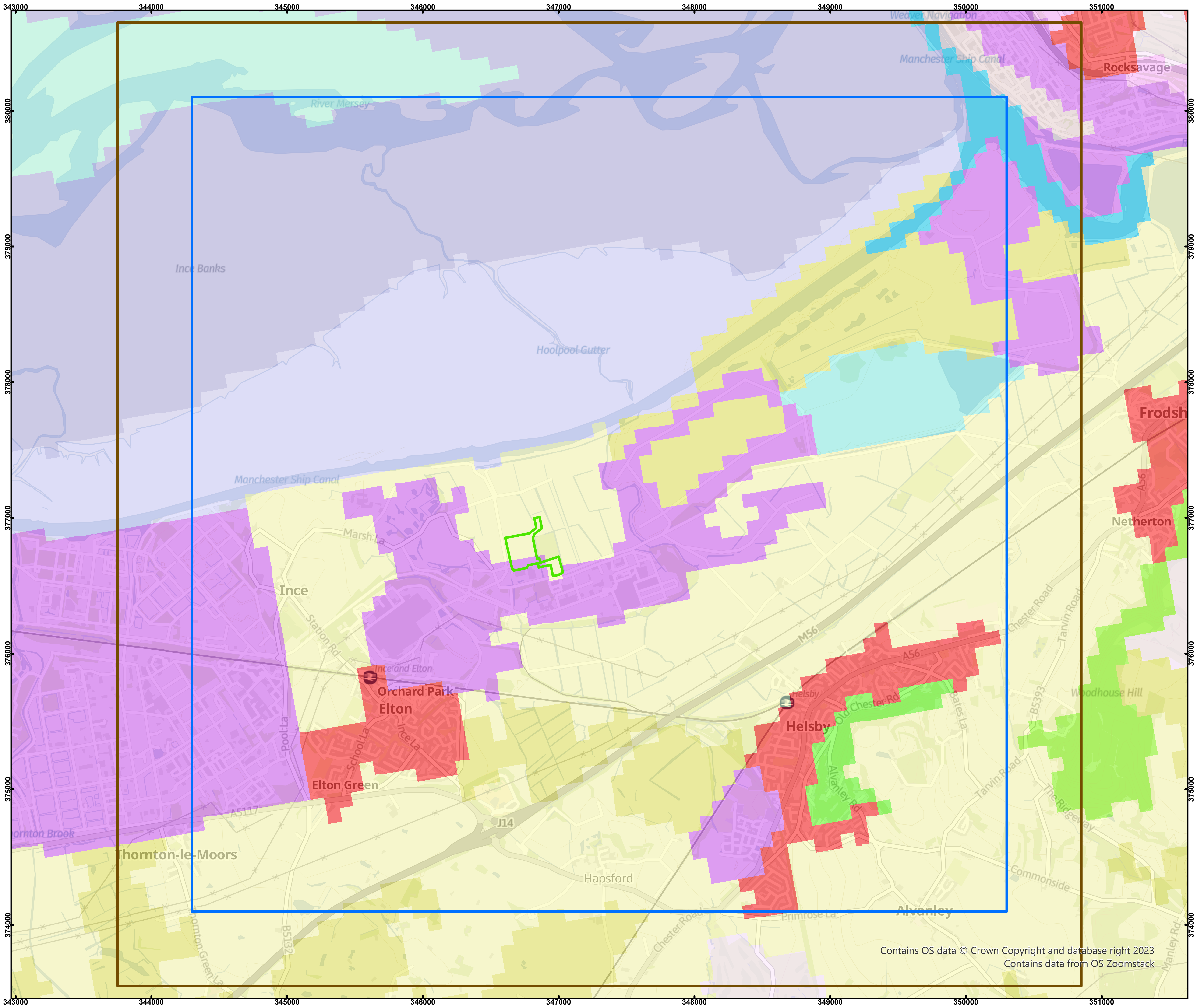

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**Legend**

▭ Terrain and Surface Roughness Extent

Land Cover Type

| | |
|---|---|
| 🟥 | Discontinuous urban fabric |
| 🟪 | Industrial or commercial units |
| ⬜ | Port areas |
| ⬜ | Green urban areas |
| ⬜ | Sport and leisure facilities |
| 🟨 | Non-irrigated arable land |
| 🟨 | Pastures |
| 🟩 | Broad-leaved forest |
| 🟩 | Mixed forest |
| ⬜ | Salt marshes |
| ⬜ | Intertidal flats |
| 🟦 | Water courses |
| 🟦 | Water bodies |
| ⬜ | Estuaries |

Title:

Figure 7. Variable Surface Roughness Visualisation

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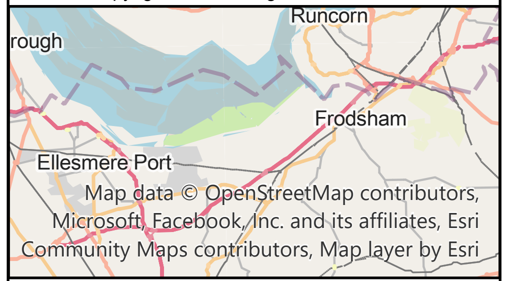

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0 0.25 0.5 1 km

N

Scale: 1:26,000

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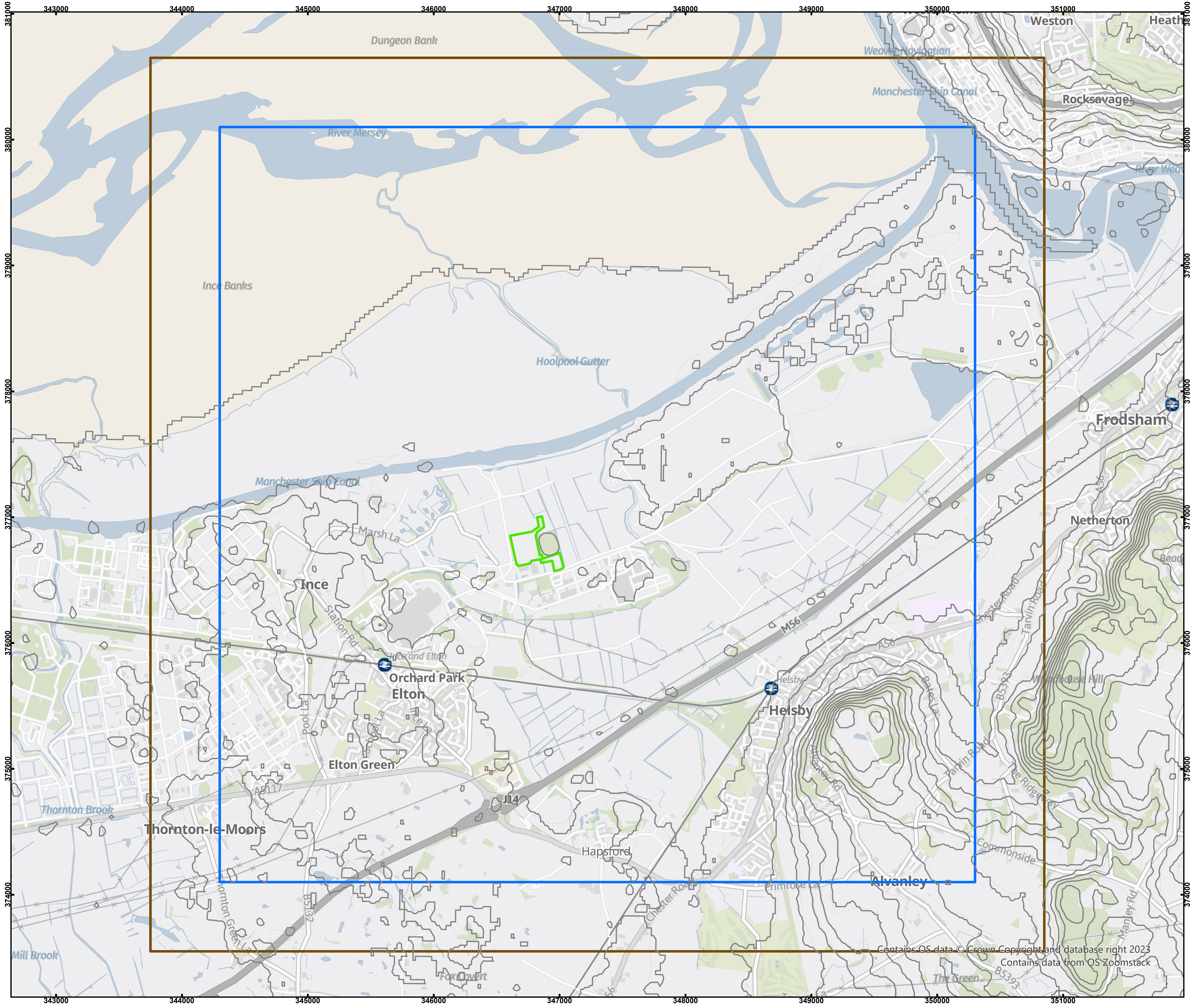

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**Legend**

— c10mContours

▭ Output Grid Extent

▭ Terrain and Surface Roughness Extent

▭ Installation Boundary

Title:

Figure 8. Terrain Visualisation

| Drawn by: RSF | Date: |
|---|---|

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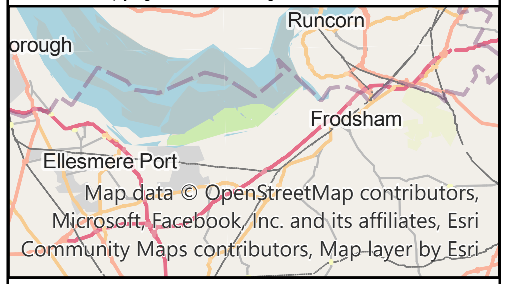

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0 0.28 0.55 1.1 km

Scale: 1:27,948

N

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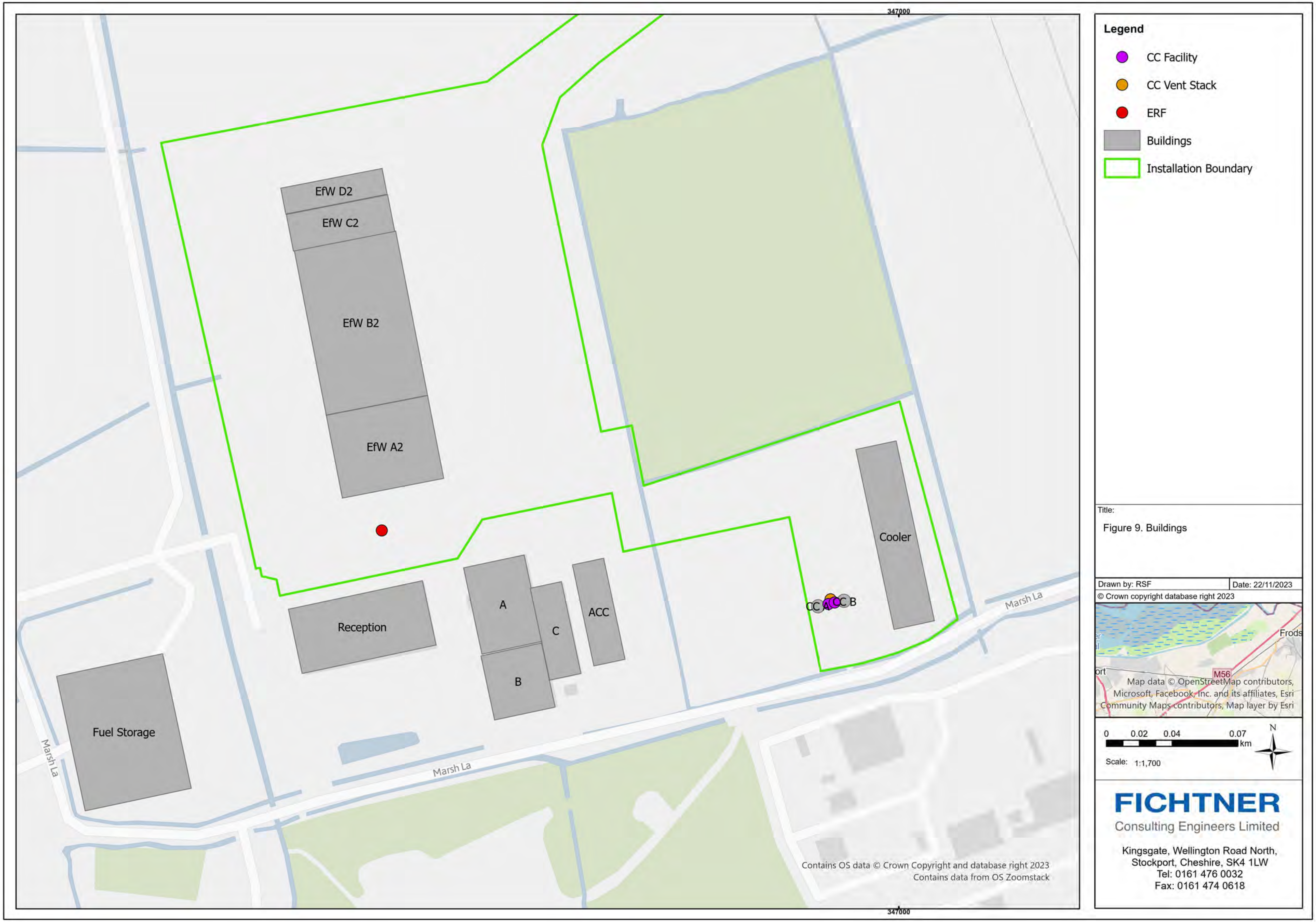

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Title:

Figure 9. Buildings

Drawn by: RSF

Date: 22/11/2023

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Scale: 1:1,700

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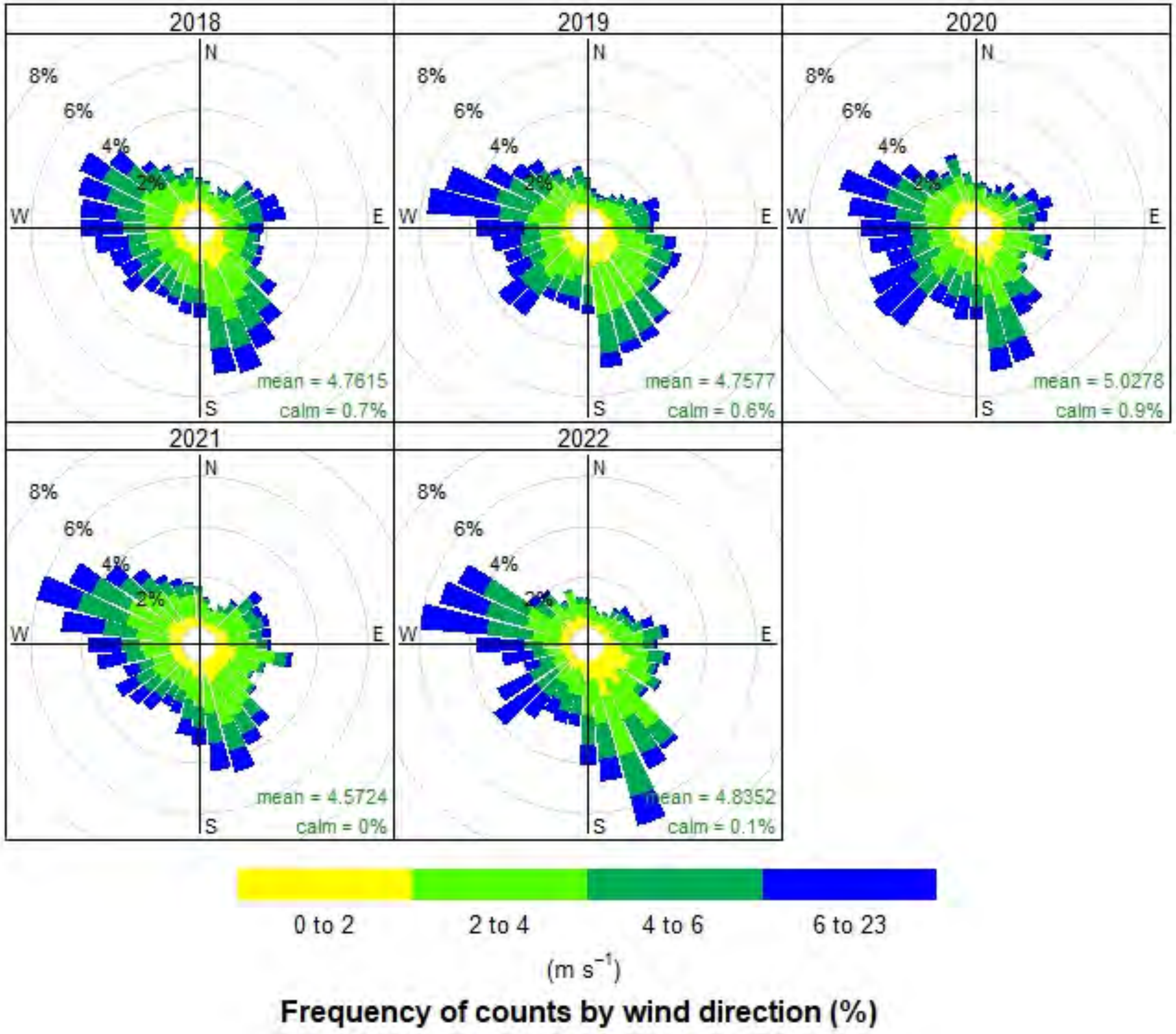
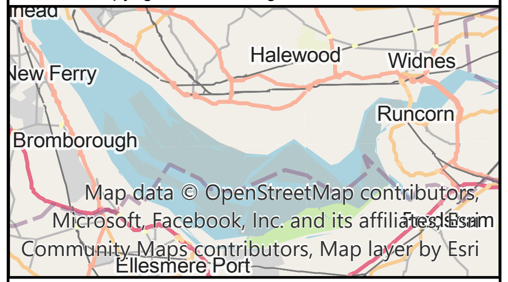


*Notes:*
*Data from Liverpool Airport*

Title:

Figure 10. Wind Roses

| Drawn by: RSF | Date: |
|---|---|



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0 0.25 0.5 1 km
N
Scale: 1:24,354

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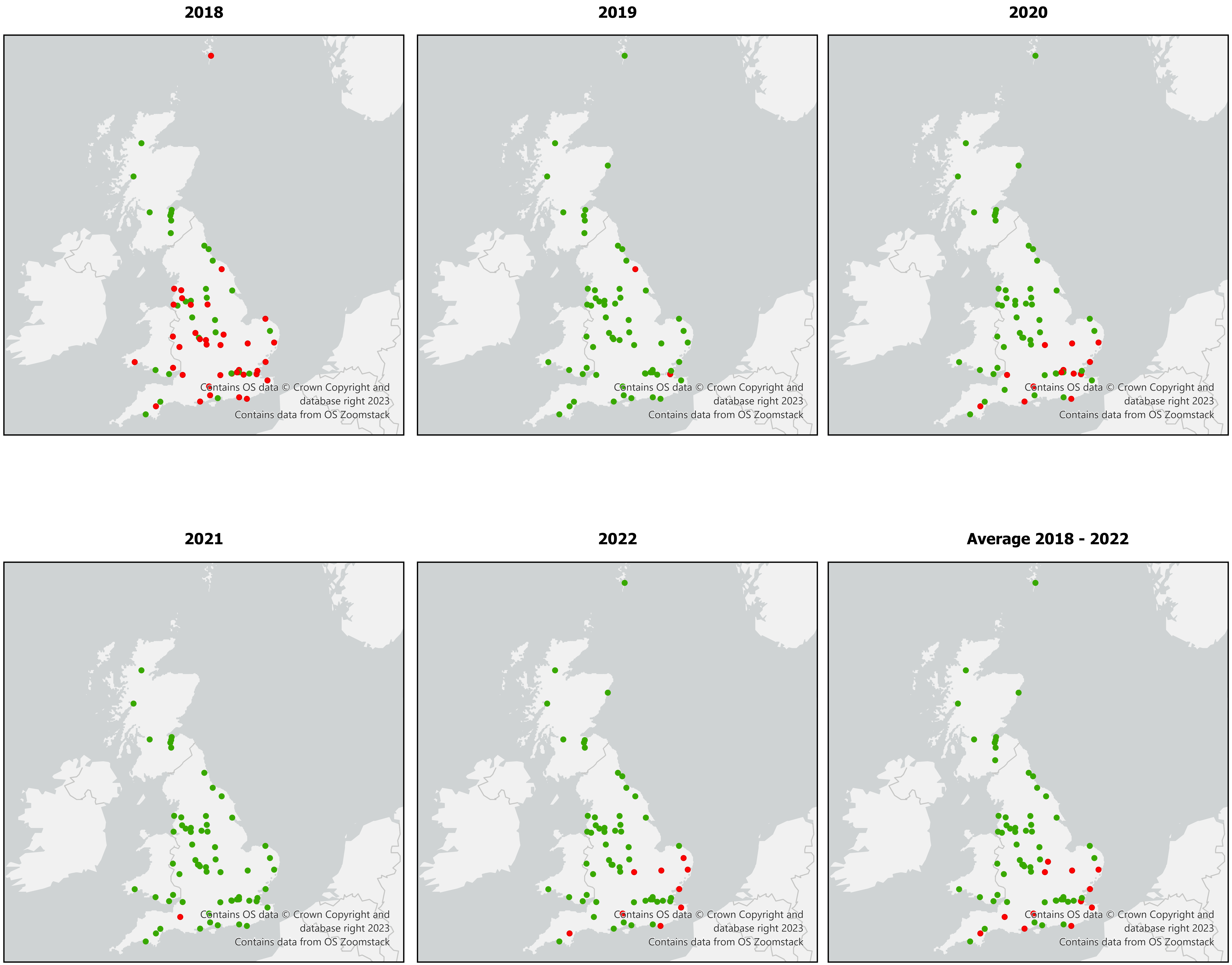


**Legend**

AOT40

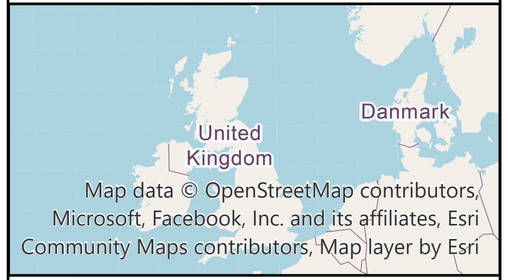
- 🟢 < 3,000 ppb.hr
- 🔴 > 3,000 ppb.hr

AOT40 calculated from accumulated hourly ozone concentrations - sum of the difference between each hourly daytime (08:00 to 20:00 Central European Time) ozone concentration greater than 40 ppb and 40 ppb for the period between 01 May and 31 July

Title:

Figure 11 - Ozone Analysis

| Drawn by: RSF | Date: 20/02/2023 |
|---|---|



0 115 230 460
km

Scale: 1:11,000,000

N

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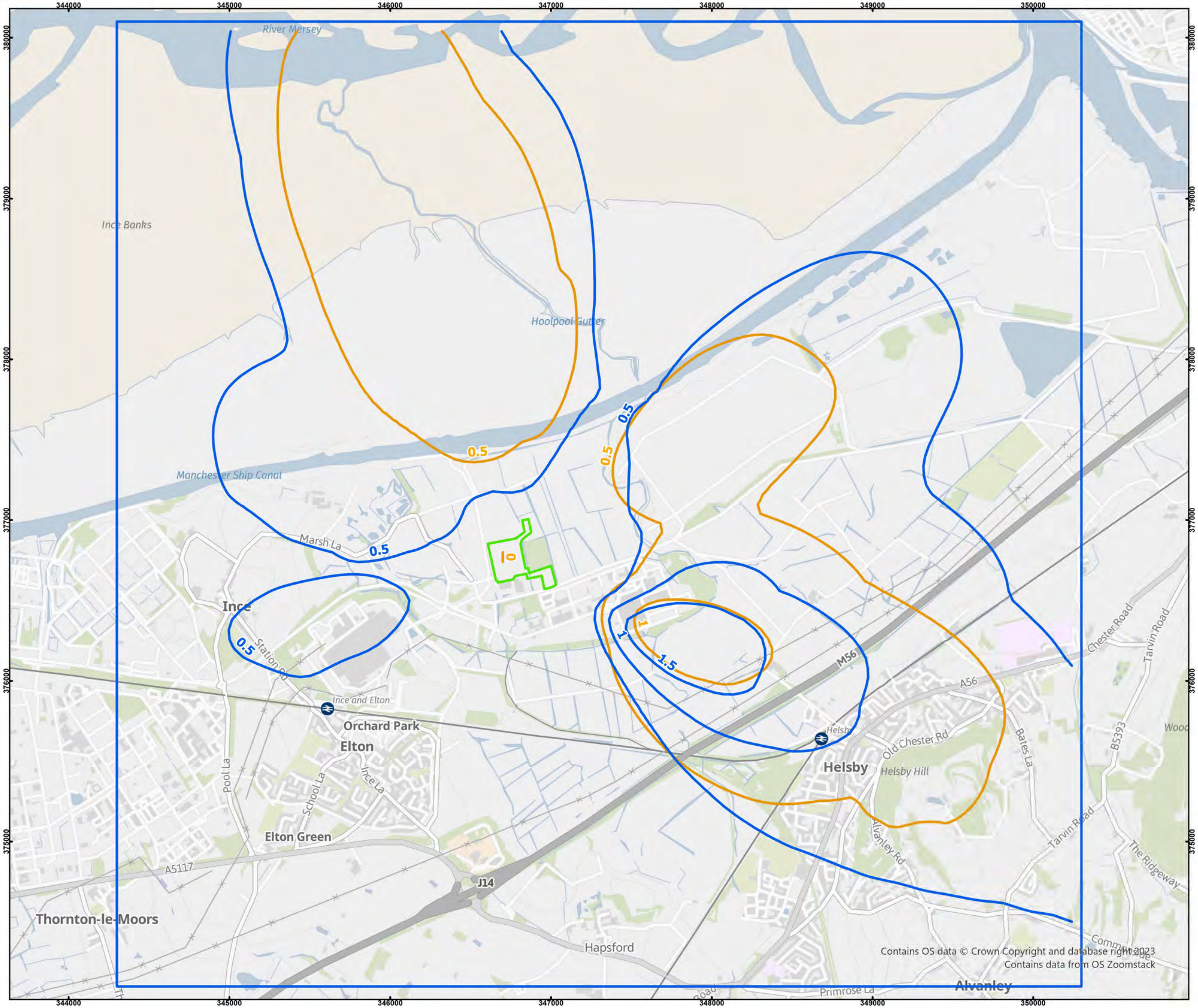

**Legend**

- Proposed
- Permitted
- Output grid extent
- Installation Boundary

*Notes:*
*Annual mean PC as % of AQAL*
*Assumes 70% NOx to NO2 conversion rate*

Title:

Figure 12. Annual Mean Nitrogen Dioxide

| Drawn by: RSF | Date: 22/11/2023 |
|---|---|

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0 0.23 0.45 0.9 km

Scale: 1:22,000

N

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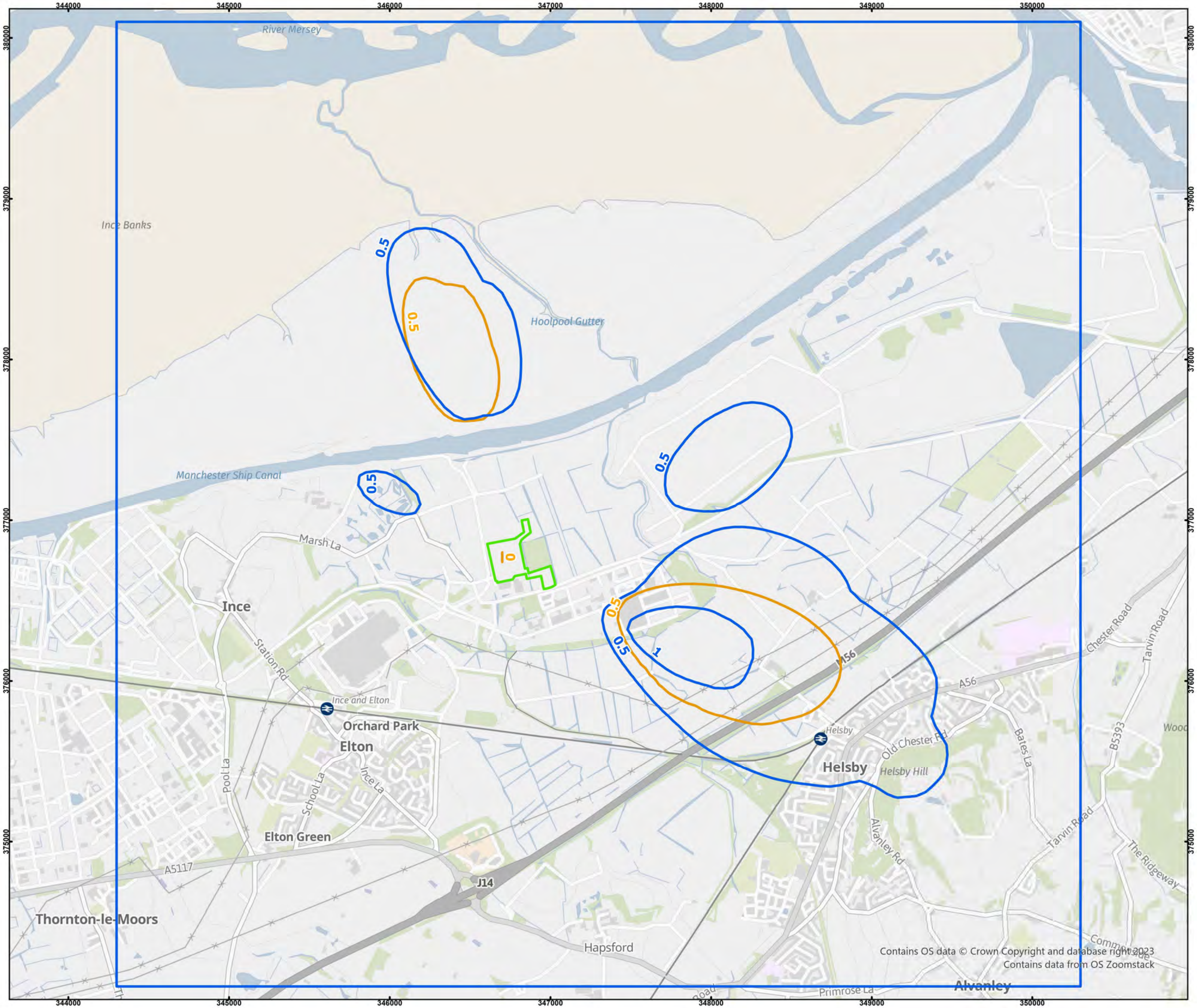

**Legend**

- Proposed
- Permitted
- Output grid extent
- Installation Boundary

*Notes:*
*Annual mean PC VOCs as % of AQAL for benzene*

Title:

Figure 13. Annual Mean VOCs

Drawn by: RSF | Date: 22/11/2023

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Scale: 1:22,000

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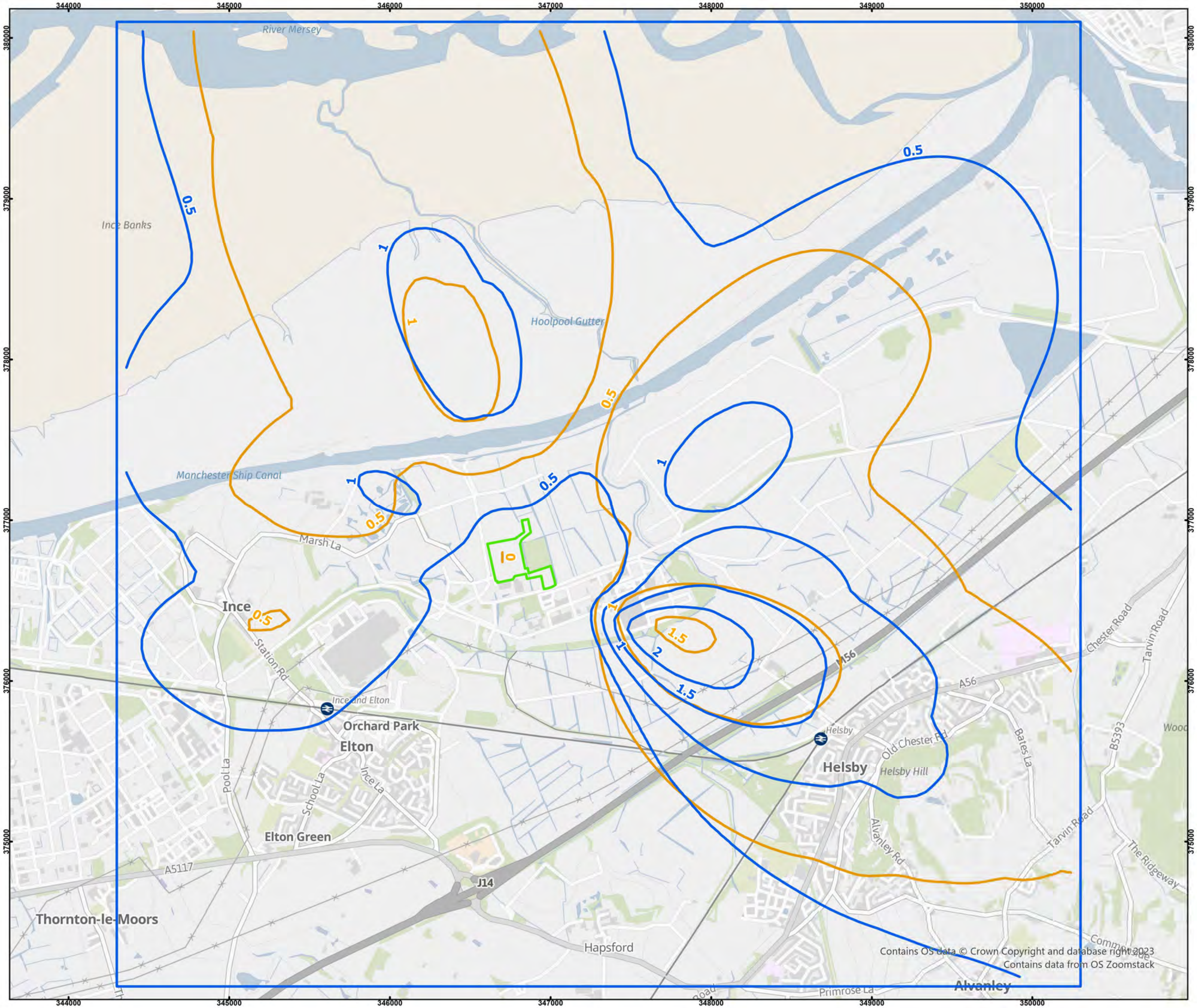

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**Legend**

Proposed

Permitted

Output grid extent

Installation Boundary

*Notes:*
*Annual mean PC as % of AQAL for cadmium, assumes entire cadmium and thallium emissions are just cadmium*

Title:

Figure 14. Annual Mean Cadmium

| Drawn by: RSF | Date: 22/11/2023 |
|---|---|

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0 0.23 0.45 0.9 km

Scale: 1:22,000

N

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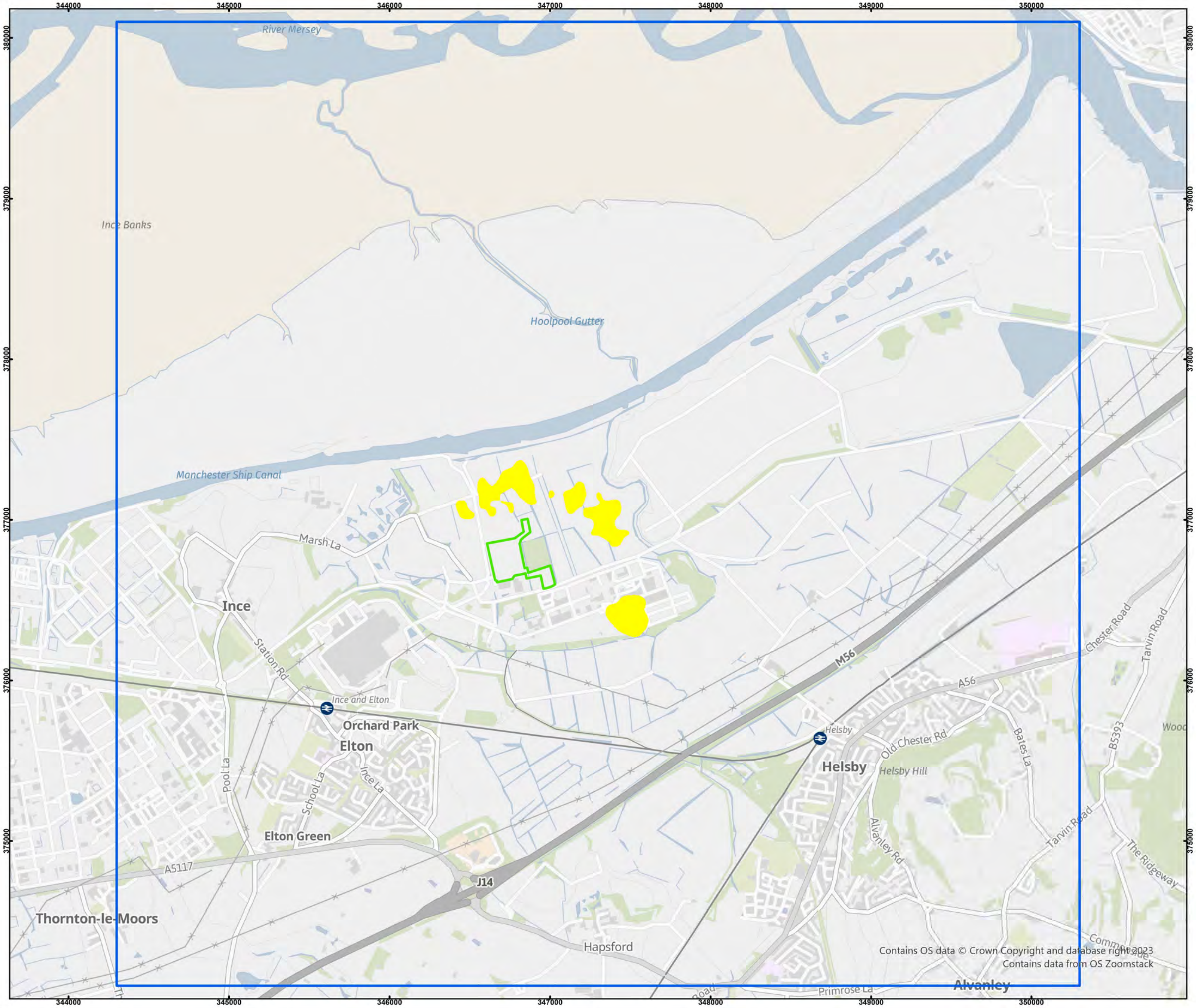

**Legend**

Proposed

<10% of AQAL

🟨 >10% of AQAL

☐ Output grid extent

☐ Installation Boundary

*Notes:*
*99.79%ile of 1-hour nitrogen dioxide PC as a % of AQAL.*
*Assumes 35% NOx to NO2 conversion rate*

Title:

Figure 15. 1-hour Nitrogen Dioxide

| Drawn by: RSF | Date: 22/11/2023 |
|---|---|

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Scale: 1:22,000

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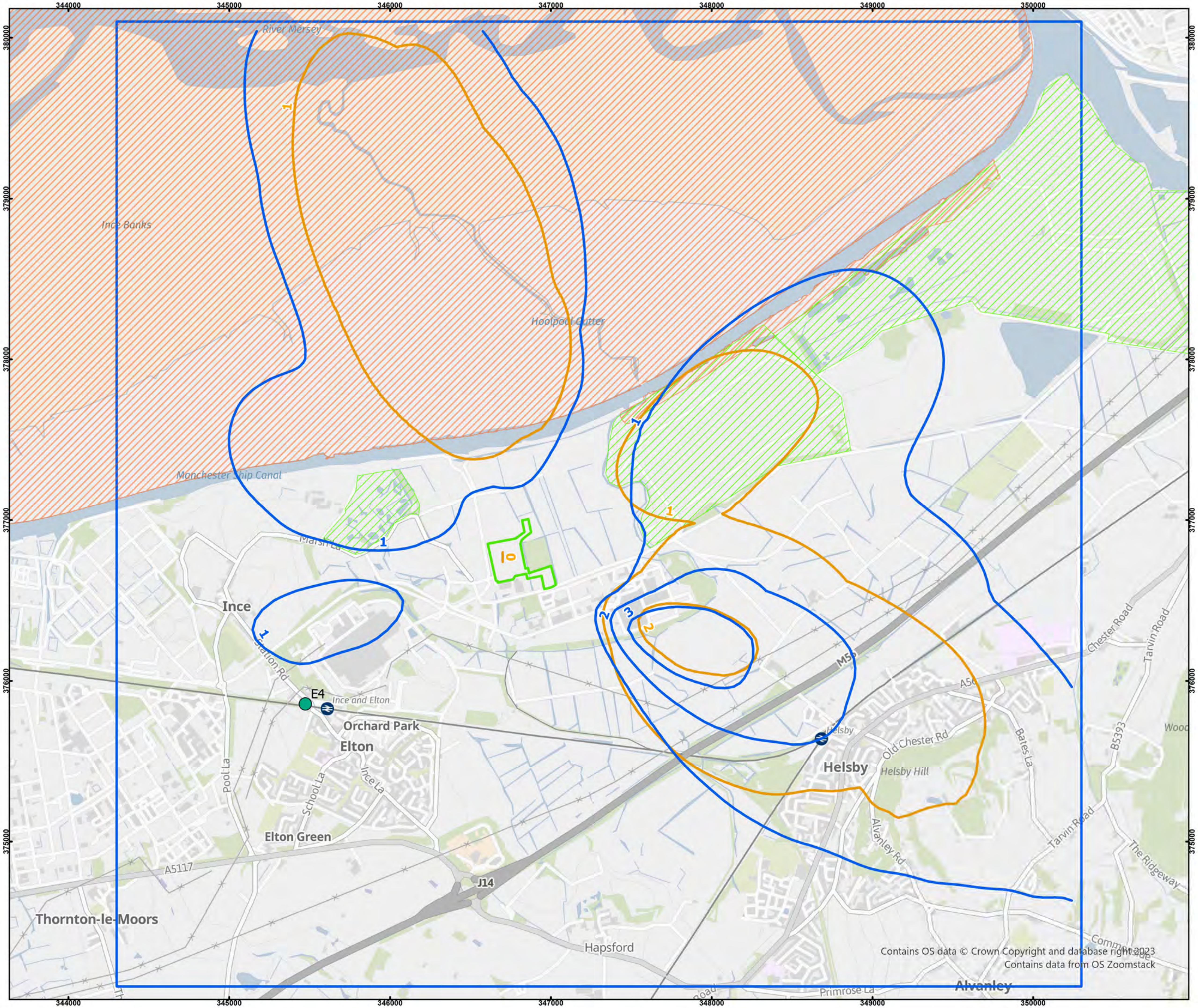

**Legend**

Proposed

Permitted

● Eco Receptors Points

▨ Potentially functionally linked grassland

▨ SSSIs

☐ Output grid extent

☐ installation Boundary

*Notes:*
*Annual mean PC as % of Critical Level*

Title:

Figure 16. Annual Mean Oxides of Nitrogen

| Drawn by: RSF | Date: 22/11/2023 |
|---|---|

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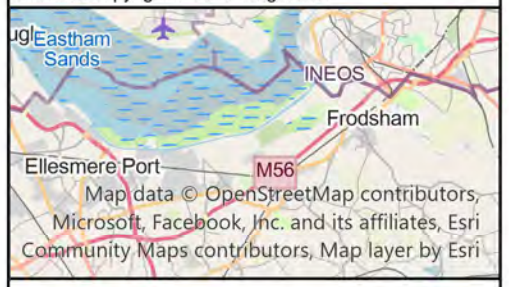

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0 0.23 0.45 0.9 km

N

Scale: 1:22,000

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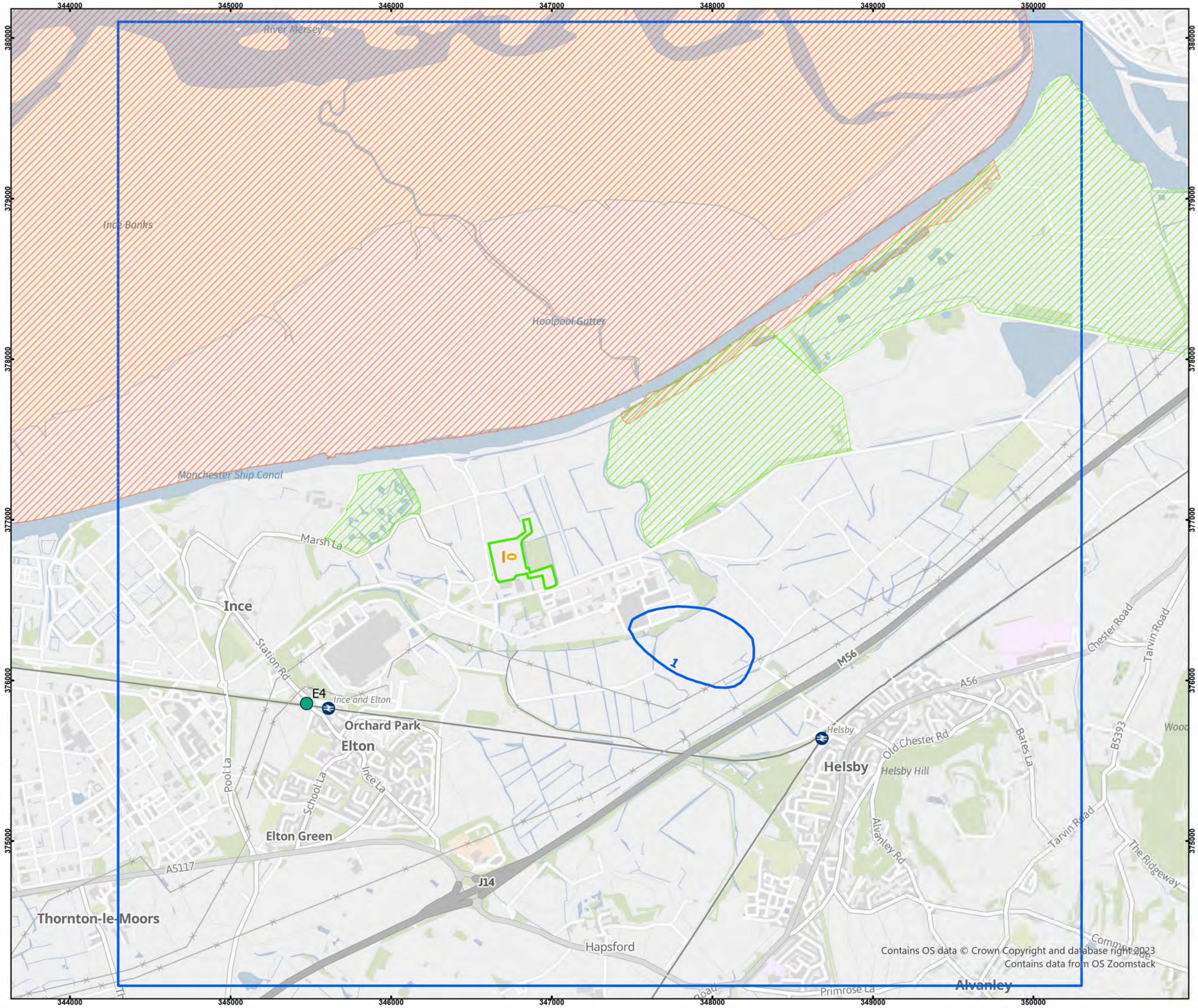

**Legend**

| | |
|---|---|
| ━ | Proposed |
| ━ | Permitted |
| ● | Eco Receptors Points |
| ▨ | Potentially functionally linked grassland |
| ▨ | SSSIs |
| ☐ | Output grid extent |
| ☐ | Installation Boundary |

*Notes:*
*Annual mean PC as % of Critical Level 20 µg/m3*

Title:

Figure 17. Annual Mean Sulphur Dioxide

Drawn by: RSF

Date: 22/11/2023

0 0.23 0.45 0.9 km

Scale: 1:22,000

N

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**Legend**

- ― Proposed
- ― Permitted
- ● Eco Receptors Points
- ▨ Potentially functionally linked grassland
- ▨ SSSIs
- ☐ Output grid extent
- ☐ Installation Boundary

*Notes:*
*N deposition as % of Critical Load 10 kgN/ha/yr*

Title:

Figure 18. Annual Mean N Deposition

| Drawn by: RSF | Date: 22/11/2023 |
|---|---|

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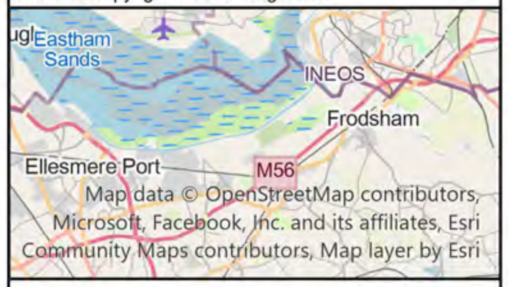

0 0.23 0.45 0.9 km

Scale: 1:22,000

N

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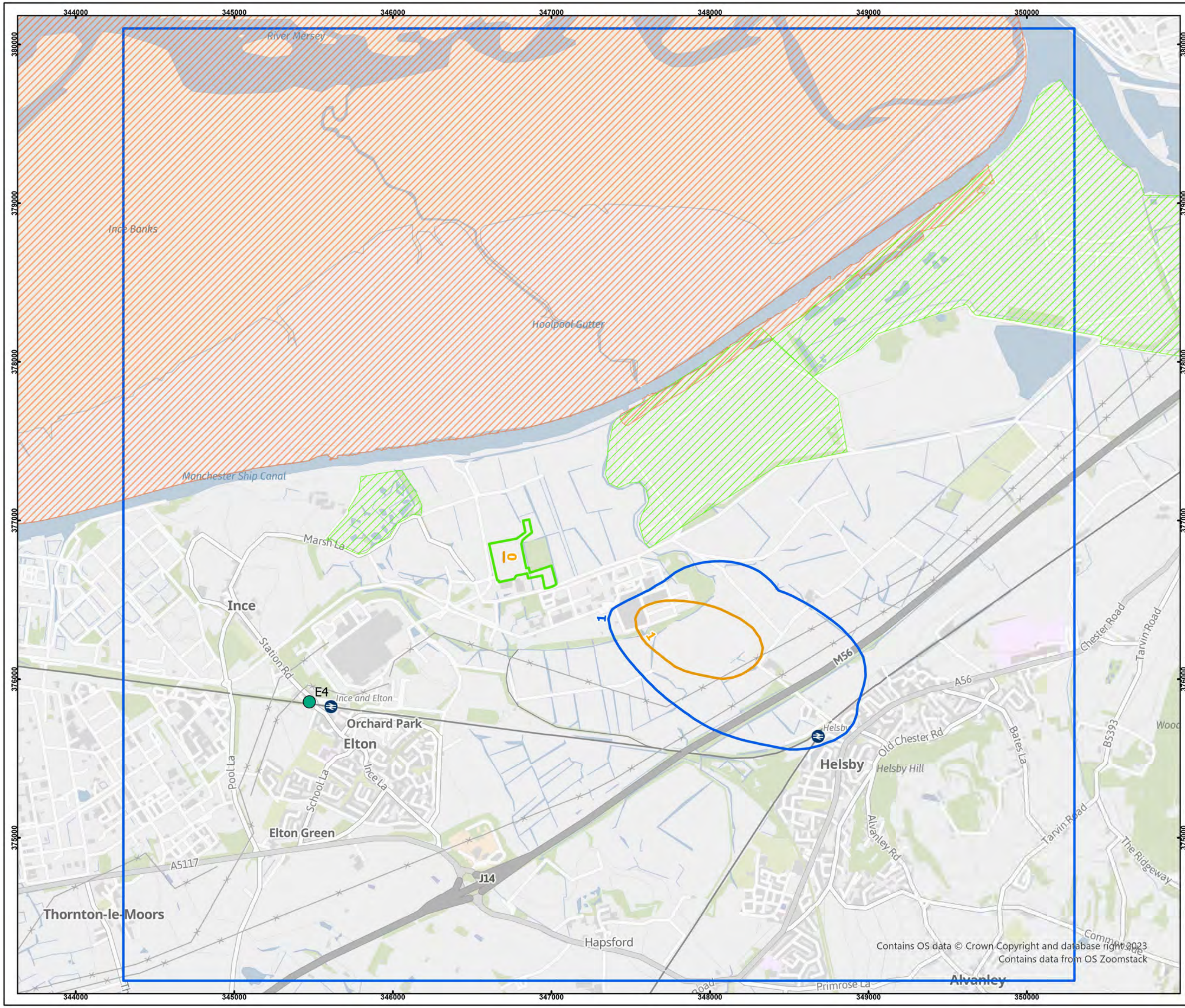

**Legend**

Proposed

Permitted

● Eco Receptors Points

▨ Potentially functionally linked grassland

▨ SSSIs

☐ Output grid extent

☐ Installation Boundary

*Notes:*
*Acid deposition as a % of Critical Load 5.071 keq/ha/yr*

Title:

Figure 19. Annual Mean Acid Deposition

Drawn by: RSF

Date: 22/11/2023

0 0.23 0.45 0.9 km

Scale: 1:22,000

N

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# B APIS Critical Loads

*Table 59: Nitrogen Deposition Critical Loads*

| ID | Site | Species/Habitat Type | NCL Class | kgN/hr/yr | | |
|---|---|---|---|---|---|---|
| | | | | Lower Critical Load | Upper Critical Load | Max. Bg. |
| **European and UK designated sites** | | | | | | |
| E1 | Mersey Estuary | Atlantic upper-mid & mid-low salt marshes | Atlantic upper-mid & mid-low salt marshes | 10 | 20 | 24.3 |
| E5 | Functionally linked land to the Mersey Estuary A | Low and medium altitude hay meadows | Low and medium altitude hay meadows | 10 | 20 | 24.28 |
| E6 | Functionally linked land to the Mersey Estuary B | Low and medium altitude hay meadows | Low and medium altitude hay meadows | 10 | 20 | 24.28 |
| E2 | Midland Meres and Mosses – Hatch Mere SSSI* | Standing water | Not sensitive | - | - | 26.6 |
| E7 | Midland Meres and Mosses Ramsar – Flaxmere Moss SSSI* | Raised and blanket mires | Raised and blanket bogs | 5 | 15 | 24.4 |
| E8 | Midland Meres and Mosses Ramsar – Linmere Moss SSSI* | Rich fens | Rich fens | 15 | 25 | 25.4 |
| **Local ecological sites** | | | | | | |
| E3 | Frodsham and Helsby and Ince Marshes | Low and medium altitude hay meadows | Low and medium altitude hay meadows | 10 | 20 | 24.28 |
| E4 | Station Road Railway Site | Low and medium altitude hay meadows | Low and medium altitude hay meadows | 10 | 20 | 24.28 |

*Source: APIS*

*Table 60: Acid Deposition Critical Loads*

| ID | Site | Species/Habitat Type | Acidity Class | Lower Critical Load Function (keq/ha/yr) | | | Upper Critical Load Function (keq/ha/yr) | | | Maximum Background (keq/ha/yr) (N+S) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | CLminN | CLmaxN | CLmaxS | CLminN | CLmaxN | CLmaxS | |
| **European and UK designated sites** | | | | | | | | | | |
| E1 | Mersey Estuary | | Calcareous grassland (using base cation) | 1.071 | 5.071 | 4 | 0.856 | 4.856 | 4 | 1.9 |
| E5 | Functionally linked land to the Mersey Estuary A | Calcareous grassland | Calcareous grassland (using base cation) | 1.071 | 5.071 | 4 | - | - | - | 1.85 |
| E6 | Functionally linked land to the Mersey Estuary B | Calcareous grassland | Calcareous grassland (using base cation) | 1.071 | 5.071 | 4 | - | - | - | 1.93 |
| E2 | Midland Meres and Mosses – Hatch Mere SSSI | Standing water | Not sensitive | - | - | - | - | - | - | 1.9 |
| E7 | Midland Meres and Mosses Ramsar – Flaxmere Moss SSSI | Raised and blanket mire | Bogs | 0.321 | 0.552 | 0.231 | 0.321 | 0.552 | 0.231 | 1.9 |
| E8 | Midland Meres and Mosses Ramsar – Linmere Moss SSSI | Raised and blanket mire | Bogs | 0.321 | 0.552 | 0.231 | 0.321 | 0.552 | 0.231 | 1.9 |
| **Local ecological sites** | | | | | | | | | | |
| E3 | Frodsham and Helsby and Ince Marshes | Calcareous grassland | Calcareous grassland (using base cation) | 1.071 | 5.071 | 4 | - | - | - | 1.93 |
| E4 | Station Road Railway Site | Calcareous grassland | Calcareous grassland (using base cation) | 1.071 | 5.071 | 4 | - | - | - | 1.85 |

*Source: APIS*

# C Detailed Results Tables – Permitted Facility

*Table 61: Dispersion Modelling Results – PC at Point of Maximum Ground Level Impact - Daily ELVs - Permitted Facility*

| Pollutant | Quantity | Units | AQAL | Bg Conc. | 2018 | 2019 | 2020 | 2021 | 2022 | Max | Max as % of AQAL | PEC | PEC as % of AQAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrogen dioxide | Annual mean | $\mu g/m^3$ | 40 | 19.7 | 0.36 | 0.45 | 0.40 | 0.42 | 0.49 | 0.49 | 1.23% | 20.19 | 50.48% |
| | 99.79th %ile of hourly means | $\mu g/m^3$ | 200 | 39.4 | 5.56 | 5.31 | 4.93 | 5.28 | 5.26 | 5.56 | 2.78% | 44.96 | 22.48% |
| Sulphur dioxide | 99.18th %ile of daily means | $\mu g/m^3$ | 125 | 13.2 | 0.99 | 1.18 | 1.08 | 1.21 | 1.26 | 1.26 | 1.01% | 14.46 | 11.57% |
| | 99.73rd %ile of hourly means | $\mu g/m^3$ | 350 | 13.2 | 3.39 | 3.13 | 3.04 | 3.07 | 3.12 | 3.39 | 0.97% | 16.59 | 4.74% |
| | 99.9th %ile of 15 min. means | $\mu g/m^3$ | 266 | 13.2 | 4.76 | 4.07 | 4.00 | 4.37 | 4.25 | 4.76 | 1.79% | 17.96 | 6.75% |
| Particulates ($PM_{10}$) | Annual mean | $\mu g/m^3$ | 40 | 14.4 | 0.01 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.05% | 14.42 | 36.05% |
| | 90.41st %ile of daily means | $\mu g/m^3$ | 50 | 28.8 | 0.06 | 0.07 | 0.06 | 0.06 | 0.07 | 0.07 | 0.15% | 28.87 | 57.75% |
| Particulates ($PM_{2.5}$) | Annual mean | $\mu g/m^3$ | 9.6 | 0.01 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.20% | 9.62 | 96.20% | 9.6 |
| Carbon monoxide | 8 hour running mean | $\mu g/m^3$ | 10,000 | 712 | 5.73 | 3.43 | 3.63 | 3.57 | 3.44 | 5.73 | 0.06% | 717.73 | 7.18% |
| | Hourly mean | $\mu g/m^3$ | 30,000 | 712 | 9.27 | 7.97 | 6.85 | 6.72 | 7.18 | 9.27 | 0.03% | 721.27 | 2.40% |
| Hydrogen chloride | Hourly mean | $\mu g/m^3$ | 750 | 1.42 | 1.48 | 1.27 | 1.09 | 1.07 | 1.15 | 1.48 | 0.20% | 2.90 | 0.39% |
| Hydrogen fluoride | Annual mean | $\mu g/m^3$ | 16 | 2.35 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02% | 2.35 | 14.71% |
| | Hourly mean | $\mu g/m^3$ | 160 | 4.7 | 0.19 | 0.16 | 0.14 | 0.13 | 0.14 | 0.19 | 0.12% | 4.89 | 3.05% |
| Ammonia | Annual mean | $\mu g/m^3$ | 180 | 4.9 | 0.04 | 0.05 | 0.05 | 0.05 | 0.06 | 0.06 | 0.03% | 4.96 | 2.75% |
| | Hourly mean | $\mu g/m^3$ | 2,500 | 9.8 | 2.78 | 2.39 | 2.05 | 2.01 | 2.16 | 2.78 | 0.11% | 12.58 | 0.50% |

| Pollutant | Quantity | Units | AQAL | Bg Conc. | 2018 | 2019 | 2020 | 2021 | 2022 | Max | Max as % of AQAL | PEC | PEC as % of AQAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| VOCs (as benzene) | Annual mean | µg/m³ | 5 | 1.09 | 0.03 | 0.04 | 0.03 | 0.03 | 0.04 | 0.04 | 0.78% | 1.13 | 22.58% |
|  | Daily mean | µg/m³ | 30 | 2.18 | 0.38 | 0.34 | 0.37 | 0.41 | 0.39 | 0.41 | 1.38% | 2.59 | 8.64% |
| Mercury | Annual mean | ng/m³ | 250 | 19 | 0.06 | 0.07 | 0.06 | 0.07 | 0.08 | 0.08 | 0.03% | 19.08 | 7.63% |
|  | Hourly mean | ng/m³ | 7,500 | 38 | 3.71 | 3.19 | 2.74 | 2.69 | 2.87 | 3.71 | 0.05% | 41.71 | 0.56% |
| Cadmium | Annual mean | ng/m³ | 5 | 0.43 | 0.06 | 0.07 | 0.06 | 0.07 | 0.08 | 0.08 | 1.57% | 0.51 | 10.17% |
|  | Hourly mean | ng/m³ | - | 0.86 | 3.71 | 3.19 | 2.74 | 2.69 | 2.87 | 3.71 | - | 4.57 | - |
| PaHs | Annual mean | pg/m³ | 250 | 90 | 0.57 | 0.72 | 0.64 | 0.67 | 0.78 | 0.78 | 0.31% | 90.78 | 36.31% |
| Dioxins and Furans | Annual mean | fg/m³ | - | 32.99 | 0.23 | 0.29 | 0.25 | 0.27 | 0.31 | 0.31 | - | 33.30 | - |
| PCBs | Annual mean | ng/m³ | 200 | 0.13 | 0.01 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.01% | 0.15 | 0.07% |
|  | Hourly mean | ng/m³ | 6,000 | 0.26 | 0.93 | 0.80 | 0.68 | 0.67 | 0.72 | 0.93 | 0.02% | 1.18 | 0.02% |

*Note:*
*Assumes continuous operation of both lines of the ERF at the daily ELVs.*

*Table 62: Dispersion Modelling Results – PC at Point of Maximum Ground Level Impact - Short-Term ELVs - Permitted Facility*

| Pollutant | Quantity | Units | AQAL | Bg Conc. | 2018 | 2019 | 2020 | 2021 | 2022 | Max | Max as % of AQAL | PEC | PEC as % of AQAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrogen dioxide | 99.79th %ile of hourly means | µg/m³ | 200 | 39.4 | 25.91 | 22.29 | 19.13 | 18.77 | 20.08 | 25.91 | 12.95% | 65.31 | 32.65% |
| Sulphur dioxide | 99.73rd %ile of hourly means | µg/m³ | 350 | 13.2 | 16.93 | 15.65 | 15.18 | 15.35 | 15.60 | 16.93 | 4.84% | 30.13 | 8.61% |
|  | 99.9th %ile of 15 min. means | µg/m³ | 266 | 13.2 | 23.80 | 20.33 | 20.00 | 21.86 | 21.24 | 23.80 | 8.95% | 37.00 | 13.91% |
| Carbon monoxide | 8 hour running mean | µg/m³ | 10,000 | 712 | 17.18 | 10.30 | 10.88 | 10.70 | 10.32 | 17.18 | 0.17% | 729.18 | 7.29% |
|  | Hourly mean | µg/m³ | 30,000 | 712 | 27.81 | 23.92 | 20.54 | 20.15 | 21.55 | 27.81 | 0.09% | 739.81 | 2.47% |
| Hydrogen chloride | Hourly mean | µg/m³ | 750 | 1.42 | 11.11 | 9.55 | 8.20 | 8.05 | 8.61 | 11.11 | 1.48% | 12.53 | 1.67% |
| Hydrogen fluoride | Hourly mean | µg/m³ | 160 | 4.7 | 0.74 | 0.64 | 0.55 | 0.54 | 0.57 | 0.74 | 0.46% | 5.44 | 3.40% |

*Note:*
*Assumes continuous operation of both lines of the ERF at the short term ELVs.*

*Table 63: Long-Term Metals Results – Point of Maximum Impact*

| **Metal** | **AQAL** | **Baseline conc.** | **Metals emitted at combined metal limit** | | | | **Metal as % of ELV (1)** | **Each metal emitted at the maximum concentration from the EA metals guidance document** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | **PC** | | **PEC** | | | **PC** | | **PEC** | |
| | **ng/m$^3$** | **ng/m$^3$** | **ng/m$^3$** | **as % AQAL** | **ng/m$^3$** | **as % AQAL** | | **ng/m$^3$** | **as % AQAL** | **ng/m$^3$** | **as % AQAL** |
| Arsenic | 6 | 1.00 | 1.17 | 19.58% | 2.17 | 36.24% | 8.3% | 0.10 | 1.63% | 1.10 | 18.30% |
| Antimony | 5,000 | 3.60 | 1.17 | 0.02% | 4.77 | 0.10% | 3.8% | 0.05 | 0.001% | 3.65 | 0.07% |
| Chromium | 5,000 | 11.00 | 1.17 | 0.02% | 12.17 | 0.24% | 30.7% | 0.36 | 0.01% | 11.36 | 0.23% |
| Chromium (VI) | 0.25 | 2.20 | 1.17 | 469.8% | 3.37 | 1349.8% | 0.043% | 0.00 | 0.20% | 2.20 | 880.20% |
| Cobalt | - | 1.50 | 1.17 | - | 2.67 | - | 1.9% | 0.02 | - | 1.52 | - |
| Copper | 10,000 | 13.00 | 1.17 | 0.01% | 14.17 | 0.14% | 9.7% | 0.11 | 0.001% | 13.11 | 0.13% |
| Lead | 250 | 11.00 | 1.17 | 0.47% | 12.17 | 4.87% | 16.8% | 0.20 | 0.08% | 11.20 | 4.48% |
| Manganese | 150 | 6.90 | 1.17 | 0.78% | 8.07 | 5.38% | 20.0% | 0.23 | 0.16% | 7.13 | 4.76% |
| Nickel | 20 | 3.60 | 1.17 | 5.87% | 4.77 | 23.87% | 73.3% | 0.86 | 4.31% | 4.46 | 22.31% |
| Vanadium | - | 6.20 | 1.17 | - | 7.37 | - | 2.0% | 0.02 | - | 6.22 | - |

*Notes:*

(1) *Metal as maximum percentage of the group 3 metals ELV, recalculated from the data presented in EA metals guidance document (V.4) Table A1.*

*Table 64: Short-Term Metals Results – Point of Maximum Impact*

| Metal | AQAL | Baseline conc. | Metals emitted at combined metal limit | | | | Metal as % of ELV (1) | Each metal emitted at the maximum concentration from the EA metals guidance document | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | PC | | PEC | | | PC | | PEC | |
| | ng/m$^3$ | ng/m$^3$ | ng/m$^3$ | as % AQAL | ng/m$^3$ | as % AQAL | | ng/m$^3$ | as % AQAL | ng/m$^3$ | as % AQAL |
| Arsenic | - | 2.00 | 55.62 | - | 57.62 | - | 8.3% | 4.64 | - | 6.64 | - |
| Antimony | 150,000 | 7.20 | 55.62 | 0.04% | 62.82 | 0.04% | 3.8% | 2.13 | 0.001% | 9.33 | 0.01% |
| Chromium | 150,000 | 22.00 | 55.62 | 0.04% | 77.62 | 0.05% | 30.7% | 17.06 | 0.01% | 39.06 | 0.03% |
| Chromium (VI) | - | 4.40 | 55.62 | - | 60.02 | - | 0.043% | 0.02 | - | 4.42 | - |
| Cobalt | - | 3.00 | 55.62 | - | 58.62 | - | 1.9% | 1.04 | - | 4.04 | - |
| Copper | 200,000 | 26.00 | 55.62 | 0.03% | 81.62 | 0.04% | 9.7% | 5.38 | 0.003% | 31.38 | 0.02% |
| Lead | - | 22.00 | 55.62 | - | 77.62 | - | 16.8% | 9.33 | - | 31.33 | - |
| Manganese | 1,500,000 | 13.80 | 55.62 | 0.00% | 69.42 | 0.00% | 20.0% | 11.12 | 0.001% | 24.92 | 0.002% |
| Nickel | - | 7.20 | 55.62 | - | 62.82 | - | 73.3% | 40.79 | - | 47.99 | - |
| Vanadium (24-hour mean) | 1,000 | 6.20 | 12.38 | 1.24% | 18.58 | 1.86% | 2.0% | 0.25 | 0.025% | 6.45 | 0.64% |

*Notes:*

*All impacts maximum 1-hour PC with the exception of vanadium which is the maximum 24-hour PC.*

(1) *Metal as maximum percentage of the group 3 metals ELV, recalculated from the data presented in EA metals guidance document (V.4) Table A1.*

*Table 65: Impact at Ecological Sites - Permitted Facility*

| ID | Site | Oxides of nitrogen (ng/m$^3$) | | Sulphur dioxide (ng/m$^3$) | Hydrogen fluoride (ng/m$^3$) | | Ammonia (ng/m$^3$) |
|---|---|---|---|---|---|---|---|
| | | Annual mean | Daily mean | Annual mean | Weekly mean | Daily mean | Annual mean |
| **European and UK designated sites** | | | | | | | |
| E1 | Mersey Estuary | 506.59 | 7099.53 | 112.60 | 13.72 | 39.52 | 42.30 |
| E5 | Functionally linked land to the Mersey Estuary A | 266.72 | 6032.26 | 59.28 | 13.05 | 33.58 | 22.27 |
| E6 | Functionally linked land to the Mersey Estuary B | 391.36 | 4869.24 | 86.98 | 7.99 | 27.10 | 32.67 |
| E2 | Midland Meres and Mosses – Hatch Mere SSSI | 80.59 | 697.26 | 17.91 | 1.60 | 3.88 | 6.73 |
| E7 | Midland Meres and Mosses – Flaxmere Moss SSSI | 77.32 | 661.20 | 17.19 | 1.44 | 3.68 | 6.46 |
| E8 | Midland Meres and Mosses – Linmere Moss SSSI | 62.66 | 593.30 | 13.93 | 1.40 | 3.30 | 5.23 |
| **Local ecological sites** | | | | | | | |
| E3 | Frodsham and Helsby and Ince Marshes | 703.41 | 7372.97 | 156.34 | 18.69 | 41.04 | 58.73 |
| E4 | Station Road Railway Site | 150.60 | 4547.21 | 33.47 | 10.57 | 25.31 | 12.57 |
| *Notes:*<br>*Assumes continuous operation of both lines of the ERF at the daily ELVs.* | | | | | | | |

*Table 66: Impact at Ecological Sites - Permitted Facility*

| **ID** | **Site** | **Oxides of nitrogen (% CL)** | | **Sulphur dioxide (% CL)** | **Hydrogen fluoride (% CL)** | | **Ammonia (% CL)** |
|---|---|---|---|---|---|---|---|
| | | **Annual mean** | **Daily mean** | **Annual mean** | **Weekly mean** | **Daily mean** | **Annual mean** |
| **Critical level (µg/m$^3$)** | | **30** | **200** | **10/20** | **0.5** | **5** | **1/3** |
| **European and UK designated sites** | | | | | | | |
| E1 | Mersey Estuary | **1.69%** | 9.47% | 0.56% | 2.74% | 0.79% | **1.41%** |
| E5 | Functionally linked land to the Mersey Estuary A | 0.89% | 8.04% | 0.30% | 2.61% | 0.67% | 0.74% |
| E6 | Functionally linked land to the Mersey Estuary B | **1.30%** | 6.49% | 0.43% | 1.60% | 0.54% | **1.09%** |
| E2 | Midland Meres and Mosses – Hatch Mere SSSI* | 0.27% | 0.93% | 0.18% | 0.32% | 0.08% | 0.67% |
| E7 | Midland Meres and Mosses – Flaxmere Moss SSSI* | 0.26% | 0.88% | 0.17% | 0.29% | 0.07% | 0.65% |
| E8 | Midland Meres and Mosses – Linmere Moss SSSI* | 0.21% | 0.79% | 0.14% | 0.28% | 0.07% | 0.52% |
| **Local ecological sites** | | | | | | | |
| E3 | Frodsham and Helsby and Ince Marshes | 2.34% | 9.83% | 0.78% | 3.74% | 0.82% | 1.96% |
| E4 | Station Road Railway Site | 0.50% | 6.06% | 0.17% | 2.11% | 0.51% | 0.42% |

*Notes:*

*Assumes continuous operation of both lines of the ERF at the daily ELVs.*

** Impacts presented as % of lower Critical Level appropriate for lower plant communities.*

*Table 67: Annual Mean PC used for Deposition Analysis - Permitted Facility*

| ID | Site | Annual mean PC (ng/m$^3$) | | | |
|---|---|---|---|---|---|
| | | Nitrogen dioxide | Sulphur dioxide | Hydrogen chloride | Ammonia |
| E1 | Mersey Estuary | 354.62 | 112.58 | 22.52 | 42.30 |
| E5 | Functionally linked land to the Mersey Estuary A | 186.71 | 59.27 | 11.86 | 22.27 |
| E6 | Functionally linked land to the Mersey Estuary B | 273.95 | 86.97 | 17.40 | 32.67 |
| E2 | Midland Meres and Mosses – Hatch Mere SSSI | 56.41 | 17.91 | 3.58 | 6.73 |
| E7 | Midland Meres and Mosses – Flaxmere Moss SSSI | 54.13 | 17.18 | 3.44 | 6.46 |
| E8 | Midland Meres and Mosses – Linmere Moss SSSI | 43.86 | 13.92 | 2.79 | 5.23 |
| E3 | Frodsham and Helsby and Ince Marshes | 492.38 | 156.31 | 31.27 | 58.73 |
| E4 | Station Road Railway Site | 105.42 | 33.47 | 6.69 | 12.57 |

*Note:*

*Assumes continuous operation of both lines of the ERF at the daily ELVs.*

*Table 68: Deposition Calculation - Grassland - Permitted Facility*

| ID | Site | Deposition (kg/ha/yr) | | | | Total N Deposition (kg/ha/yr) | Acid Deposition (keq/ha/yr) | |
|---|---|---|---|---|---|---|---|---|
| | | Nitrogen dioxide | Sulphur dioxide | Hydrogen chloride | Ammonia | | N | S |
| E1 | Mersey Estuary | 0.051 | 0.213 | 0.345 | 0.220 | 0.271 | 0.019 | 0.023 |
| E5 | Functionally linked land to the Mersey Estuary A | 0.027 | 0.112 | 0.182 | 0.116 | 0.143 | 0.010 | 0.012 |
| E6 | Functionally linked land to the Mersey Estuary B | 0.039 | 0.165 | 0.267 | 0.170 | 0.209 | 0.015 | 0.018 |
| E2 | Midland Meres and Mosses – Hatch Mere SSSI | 0.008 | 0.034 | 0.055 | 0.035 | 0.043 | 0.003 | 0.004 |
| E7 | Midland Meres and Mosses – Flaxmere Moss SSSI | 0.008 | 0.033 | 0.053 | 0.034 | 0.041 | 0.003 | 0.004 |
| E8 | Midland Meres and Mosses – Linmere Moss SSSI | 0.006 | 0.026 | 0.043 | 0.027 | 0.033 | 0.002 | 0.003 |
| E3 | Frodsham and Helsby and Ince Marshes | 0.071 | 0.296 | 0.480 | 0.305 | 0.376 | 0.027 | 0.032 |
| E4 | Station Road Railway Site | 0.015 | 0.063 | 0.103 | 0.065 | 0.080 | 0.006 | 0.007 |

*Note:*

*Assumes continuous operation of both lines of the ERF at the daily ELVs at the daily ELVs.*

*Table 69: Nitrogen Deposition - Permitted Facility*

| ID | Site | NCL Class | Lower CL (kgN/ha/yr) | Upper CL (kgN/ha/yr) | Background (kgN/ha/yr) | PC (kgN/ha/yr) | Process Contribution | | Predicted Environmental Concentration | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | % of Lower CL or Bg | % of Upper CL | % of Lower CL | % of Upper CL |
| **European and UK designated sites** | | | | | | | | | | |
| E1 | Mersey Estuary | Atlantic upper-mid & mid-low salt marshes | 10 | 20 | 24.3 | 0.271 | **2.71%** | **1.35%** | **245.71%** | **122.85%** |
| E5 | Functionally linked land to the Mersey Estuary A | Low and medium altitude hay meadows | 10 | 20 | 24.28 | 0.143 | **1.43%** | 0.71% | **244.23%** | **122.11%** |
| E6 | Functionally linked land to the Mersey Estuary B | Low and medium altitude hay meadows | 10 | 20 | 24.28 | 0.209 | **2.09%** | **1.05%** | **244.89%** | **122.45%** |
| E2 | Midland Meres and Mosses – Hatch Mere SSSI | Standing water – not sensitive | - | - | - | 0.043 | - | - | - | - |
| E7 | Midland Meres and Mosses – Flaxmere Moss SSSI | Raised and blanket bogs | 5 | 15 | 26.4 | 0.041 | 0.83% | 0.28% | 488.83% | 162.94% |
| E8 | Midland Meres and Mosses – Linmere Moss SSSI | Rich fens | 15 | 25 | 25.4 | 0.033 | 0.22% | 0.13% | 169.56% | 101.73% |
| **Local ecological sites** | | | | | | | | | | |
| E3 | Frodsham and Helsby and Ince Marshes | Low and medium altitude hay meadows | 10 | 20 | 24.28 | 0.376 | 3.76% | 1.88% | **246.56%** | **123.28%** |
| E4 | Station Road Railway Site | Low and medium altitude hay meadows | 10 | 20 | 24.28 | 0.080 | 0.80% | 0.40% | **238.70%** | **119.35%** |

*Table 70: Acid Deposition - Permitted Facility*

| ID | Site | Acidity class | Min CL (CLmaxN) | Max CL (CLmaxN) | Background | Process Contribution | | | | Predicted Environmental Concentration | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | N+S (kgN/ha/yr) | N (kg/ha/yr) | S (kgS/ha/yr) | % of Lower CL | % of Upper CL | % of Lower CL | % of Upper CL |
| **European and UK designated sites** | | | | | | | | | | | |
| E1 | Mersey Estuary | Calcareous grassland (using base cation) | 5.071 | 4.856 | 1.90 | 0.019 | 0.023 | 0.84% | 0.87% | 38.30% | 40.00% |
| E5 | Functionally linked land to the Mersey Estuary A | Calcareous grassland (using base cation) | 5.071 | - | 1.85 | 0.010 | 0.012 | 0.44% | - | 36.92% | - |
| E6 | Functionally linked land to the Mersey Estuary B | Calcareous grassland (using base cation) | 5.071 | - | 1.93 | 0.015 | 0.018 | 0.65% | - | 38.71% | - |
| E2 | Midland Meres and Mosses – Hatch Mere SSSI | Standing water – not sensitive | - | - | - | 0.003 | 0.004 | **-** | **-** | **-** | **-** |
| E7 | Midland Meres and Mosses – Flaxmere Moss SSSI | Raised and blanket bog | 0.552 | 0.552 | 1.90 | 0.003 | 0.004 | **1.17%** | **1.17%** | **345.37%** | **345.37%** |
| E8 | Midland Meres and Mosses – Linmere Moss SSSI | No info available – so used raised and blanket bog | 0.552 | 0.552 | 1.90 | 0.002 | 0.003 | 0.95% | 0.95% | **345.15%** | **345.15%** |
| **Local ecological sites** | | | | | | | | | | | |
| E3 | Frodsham and Helsby and Ince Marshes | Calcareous grassland (using base cation) | 5.071 | - | 1.93 | 0.027 | 0.032 | 1.16% | - | 39.22% | - |
| E4 | Station Road Railway Site | Calcareous grassland (using base cation) | 5.071 | - | 1.85 | 0.006 | 0.007 | 0.25% | - | 36.73% | - |

# D Detailed Results Tables – Proposed Facility

This section details the impact of the CC facility operating for 100% of the time. In reality the CC facility may be offline and the ERF operating. In this case emissions would be from the ERF rather than the CC facility. However, the modelling has shown that the impact of the CC facility is greater than that of the ERF. Therefore, basing the impact of the Proposed Facility on that from the CC facility is conservative.

*Table 71: Dispersion Modelling Results – PC at Point of Maximum Ground Level Impact - Daily ELVs - CC Facility*

| Pollutant | Quantity | Units | AQAL | Bg Conc. | 2018 | 2019 | 2020 | 2021 | 2022 | Max | Max as % of AQAL | PEC | PEC as % of AQAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrogen dioxide | Annual mean | µg/m³ | 40 | 19.7 | 0.70 | 0.72 | 0.70 | 0.78 | 0.78 | 0.78 | 1.95% | 20.48 | 51.20% |
| | 99.79th %ile of hourly means | µg/m³ | 200 | 39.4 | 9.74 | 9.36 | 9.04 | 9.37 | 9.57 | 9.74 | 4.87% | 49.14 | 24.57% |
| Sulphur dioxide | 99.18th %ile of daily means | µg/m³ | 125 | 13.2 | 1.64 | 1.81 | 1.84 | 1.82 | 1.85 | 1.85 | 1.48% | 15.05 | 12.04% |
| | 99.73rd %ile of hourly means | µg/m³ | 350 | 13.2 | 5.82 | 5.61 | 5.52 | 5.57 | 5.68 | 5.82 | 1.66% | 19.02 | 5.43% |
| | 99.9th %ile of 15 min. means | µg/m³ | 266 | 13.2 | 9.28 | 7.47 | 7.75 | 7.27 | 7.91 | 9.28 | 3.49% | 22.48 | 8.45% |
| Particulates ($PM_{10}$) | Annual mean | µg/m³ | 40 | 14.4 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.08% | 14.43 | 36.08% |
| | 90.41st %ile of daily means | µg/m³ | 50 | 28.8 | 0.10 | 0.11 | 0.10 | 0.11 | 0.12 | 0.12 | 0.24% | 28.92 | 57.84% |
| Particulates ($PM_{2.5}$) | Annual mean | µg/m³ | 10 | 9.6 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.31% | 9.63 | 96.31% |
| Carbon monoxide | 8 hour running mean | µg/m³ | 10,000 | 712.0 | 11.70 | 5.38 | 7.35 | 5.83 | 5.63 | 11.70 | 0.12% | 723.70 | 7.24% |
| | Hourly mean | µg/m³ | 30,000 | 712.0 | 17.53 | 15.69 | 16.27 | 16.34 | 14.84 | 17.53 | 0.06% | 729.53 | 2.43% |
| Hydrogen chloride | Hourly mean | µg/m³ | 750 | 1.4 | 2.80 | 2.51 | 2.60 | 2.61 | 2.37 | 2.80 | 0.37% | 4.22 | 0.56% |
| Hydrogen fluoride | Annual mean | µg/m³ | 16 | 2.4 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.04% | 2.36 | 14.73% |
| | Hourly mean | µg/m³ | 160 | 4.7 | 0.35 | 0.31 | 0.33 | 0.33 | 0.30 | 0.35 | 0.22% | 5.05 | 3.16% |
| Ammonia | Annual mean | µg/m³ | 180 | 4.9 | 0.08 | 0.09 | 0.08 | 0.09 | 0.09 | 0.09 | 0.05% | 4.99 | 2.77% |
| | Hourly mean | µg/m³ | 2,500 | 9.8 | 5.26 | 4.71 | 4.88 | 4.90 | 4.45 | 5.26 | 0.21% | 15.06 | 0.60% |

| Pollutant | Quantity | Units | AQAL | Bg Conc. | 2018 | 2019 | 2020 | 2021 | 2022 | Max | Max as % of AQAL | PEC | PEC as % of AQAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| VOCs (as benzene) | Annual mean | µg/m³ | 5 | 1.1 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 1.24% | 1.15 | 23.04% |
| | Daily mean | µg/m³ | 30 | 2.2 | 0.78 | 0.49 | 0.53 | 0.52 | 0.57 | 0.78 | 2.61% | 2.96 | 9.88% |
| Mercury | Annual mean | ng/m³ | 250 | 19.0 | 0.11 | 0.11 | 0.11 | 0.12 | 0.12 | 0.12 | 0.05% | 19.12 | 7.65% |
| | Hourly mean | ng/m³ | 7,500 | 38.0 | 7.01 | 6.28 | 6.51 | 6.54 | 5.93 | 7.01 | 0.09% | 45.01 | 0.60% |
| Cadmium | Annual mean | ng/m³ | 5 | 0.4 | 0.11 | 0.11 | 0.11 | 0.12 | 0.12 | 0.12 | 2.48% | 0.55 | 11.08% |
| | Hourly mean | ng/m³ | - | 0.9 | 7.01 | 6.28 | 6.51 | 6.54 | 5.93 | 7.01 | - | 7.87 | - |
| PaHs | Annual mean | pg/m³ | 250 | 90.0 | 1.11 | 1.14 | 1.11 | 1.24 | 1.24 | 1.24 | 0.50% | 91.24 | 36.50% |
| Dioxins and Furans | Annual mean | fg/m³ | - | 33.0 | 0.44 | 0.46 | 0.44 | 0.50 | 0.50 | 0.50 | - | 33.49 | - |
| PCBs | Annual mean | ng/m³ | 200 | 0.1 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.02% | 0.16 | 0.08% |
| | Hourly mean | ng/m³ | 6,000 | 0.3 | 1.75 | 1.57 | 1.63 | 1.63 | 1.48 | 1.75 | 0.03% | 2.01 | 0.03% |
| Sum of amines (as MEA) | Hourly mean | µg/m³ | 400 | 0 | 1.51 | 1.35 | 1.40 | 1.41 | 1.28 | 1.51 | 0.38% | 1.51 | 0.38% |
| | Daily mean | µg/m³ | 100 | 0 | 0.34 | 0.21 | 0.23 | 0.22 | 0.25 | 0.34 | 0.34% | 0.34 | 0.34% |
| Sum of NS (as NDMA) | Annual mean | pg/m³ | 200 | 0 | 1.01 | 0.99 | 0.93 | 1.02 | 1.04 | 1.04 | 0.52% | 1.04 | 0.52% |
| Sum of NS + NA(as NDMA) | Annual mean | pg/m³ | 300 | 0 | 3.03 | 2.72 | 2.62 | 2.52 | 2.61 | 3.03 | 1.01% | 3.03 | 1.01% |
| Aldehydes (as formaldehyde) | Annual mean | µg/m³ | 5 | 2.37 | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 | 0.03 | 0.51% | 2.40 | 47.91% |
| | 30-minute mean | µg/m³ | 100 | 4.74 | 1.47 | 1.32 | 1.37 | 1.38 | 1.25 | 1.47 | 1.47% | 6.21 | 6.21% |

*Note:*

*Assumes continuous operation of both lines of the ERF at the daily ELVs and emitting via the CC facility.*

*Sum of NS = sum of nitrosmaines, Sum of NS + NA = sum of nitrosamines and nitramines*

*Table 72: Dispersion Modelling Results – PC at Point of Maximum Ground Level Impact - Short-Term ELVs - CC Facility*

| **Pollutant** | **Quantity** | **Units** | **AQAL** | **Bg Conc.** | **2018** | **2019** | **2020** | **2021** | **2022** | **Max** | **Max as % of AQAL** | **PEC** | **PEC as % of AQAL** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrogen dioxide | 99.79th %ile of hourly means | µg/m³ | 200 | 39.4 | 21.64 | 20.81 | 20.08 | 20.82 | 21.26 | 21.64 | 10.82% | 61.04 | 30.52% |
| Sulphur dioxide | 99.73rd %ile of hourly means | µg/m³ | 350 | 13.2 | 29.08 | 28.07 | 27.58 | 27.86 | 28.42 | 29.08 | 8.31% | 42.28 | 12.08% |
| | 99.9th %ile of 15 min. means | µg/m³ | 266 | 13.2 | 46.41 | 37.33 | 38.73 | 36.36 | 39.55 | 46.41 | 17.45% | 59.61 | 22.41% |
| Carbon monoxide | 8 hour running mean | µg/m³ | 10,000 | 712.0 | 35.10 | 16.15 | 22.05 | 17.50 | 16.88 | 35.10 | 0.35% | 747.10 | 7.47% |
| | Hourly mean | µg/m³ | 30,000 | 712.0 | 52.60 | 47.07 | 48.80 | 49.03 | 44.51 | 52.60 | 0.18% | 764.60 | 2.55% |
| Hydrogen chloride | Hourly mean | µg/m³ | 750 | 1.4 | 21.01 | 18.80 | 19.49 | 19.58 | 17.77 | 21.01 | 2.80% | 22.43 | 2.99% |
| Hydrogen fluoride | Hourly mean | µg/m³ | 160 | 4.7 | 1.40 | 1.26 | 1.30 | 1.31 | 1.19 | 1.40 | 0.88% | 6.10 | 3.81% |

*Notes:*
*Assumes continuous operation of both lines of the ERF at the short term ELVs and emitting via the CC facility.*

*Table 73: Long-Term Metals Results – Point of Maximum Impact*

| Metal | AQAL | Baseline conc. | Metals emitted at combined metal limit | | | | Metal as % of ELV [(1)] | Each metal emitted at the maximum concentration from the EA metals guidance document | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | PC | | PEC | | | PC | | PEC | |
| | ng/m$^3$ | ng/m$^3$ | ng/m$^3$ | as % AQAL | ng/m$^3$ | as % AQAL | | ng/m$^3$ | as % AQAL | ng/m$^3$ | as % AQAL |
| Arsenic | 6 | 1.00 | 1.86 | 31.03% | 2.86 | 47.69% | 8.3% | 0.16 | 2.59% | 1.16 | 19.25% |
| Antimony | 5,000 | 3.60 | 1.86 | 0.04% | 5.46 | 0.11% | 3.8% | 0.07 | 0.001% | 3.67 | 0.07% |
| Chromium | 5,000 | 11.00 | 1.86 | 0.04% | 12.86 | 0.26% | 30.7% | 0.57 | 0.01% | 11.57 | 0.23% |
| Chromium (VI) | 0.25 | 2.20 | 1.86 | 744.6% | 4.06 | 1624.6% | 0.043% | 0.001 | 0.32% | 2.20 | 880.32% |
| Cobalt | - | 1.50 | 1.86 | - | 3.36 | - | 1.9% | 0.03 | - | 1.53 | - |
| Copper | 10,000 | 13.00 | 1.86 | 0.02% | 14.86 | 0.15% | 9.7% | 0.18 | 0.002% | 13.18 | 0.13% |
| Lead | 250 | 11.00 | 1.86 | 0.74% | 12.86 | 5.14% | 16.8% | 0.31 | 0.12% | 11.31 | 4.52% |
| Manganese | 150 | 6.90 | 1.86 | 1.24% | 8.76 | 5.84% | 20.0% | 0.37 | 0.25% | 7.27 | 4.85% |
| Nickel | 20 | 3.60 | 1.86 | 9.31% | 5.46 | 27.31% | 73.3% | 1.37 | 6.83% | 4.97 | 24.83% |
| Vanadium | - | 6.20 | 1.86 | - | 8.06 | - | 2.0% | 0.04 | - | 6.24 | - |

*Notes:*

(1) *Metal as maximum percentage of the group 3 metals ELV, recalculated from the data presented in EA metals guidance document (V.4) Table A1.*

*Table 74: Short-Term Metals Results – Point of Maximum Impact*

| Metal | AQAL | Baseline conc. | Metals emitted at combined metal limit | | | | Metal as % of ELV (1) | Each metal emitted at the maximum concentration from the EA metals guidance document | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | PC | | PEC | | | PC | | PEC | |
| | ng/m$^3$ | ng/m$^3$ | ng/m$^3$ | as % AQAL | ng/m$^3$ | as % AQAL | | ng/m$^3$ | as % AQAL | ng/m$^3$ | as % AQAL |
| Arsenic | - | 2.00 | 105.21 | - | 107.21 | - | 8.3% | 8.77 | - | 10.77 | - |
| Antimony | 150,000 | 7.20 | 105.21 | 0.07% | 112.41 | 0.07% | 3.8% | 4.03 | 0.003% | 11.23 | 0.01% |
| Chromium | 150,000 | 22.00 | 105.21 | 0.07% | 127.21 | 0.08% | 30.7% | 32.26 | 0.02% | 54.26 | 0.04% |
| Chromium (VI) | - | 4.40 | 105.21 | - | 109.61 | - | 0.043% | 0.05 | - | 4.45 | - |
| Cobalt | - | 3.00 | 105.21 | - | 108.21 | - | 1.9% | 1.96 | - | 4.96 | - |
| Copper | 200,000 | 26.00 | 105.21 | 0.05% | 131.21 | 0.07% | 9.7% | 10.17 | 0.005% | 36.17 | 0.02% |
| Lead | - | 22.00 | 105.21 | - | 127.21 | - | 16.8% | 17.64 | - | 39.64 | - |
| Manganese | 1,500,000 | 13.80 | 105.21 | 0.01% | 119.01 | 0.01% | 20.0% | 21.04 | 0.001% | 34.84 | 0.002% |
| Nickel | - | 7.20 | 105.21 | - | 112.41 | - | 73.3% | 77.15 | - | 84.35 | - |
| Vanadium (24-hour mean) | 1,000 | 6.20 | 23.49 | 2.35% | 29.69 | 2.97% | 2.0% | 0.47 | 0.047% | 6.67 | 0.67% |

*Notes:*

*All impacts maximum 1-hour PC with the exception of vanadium which is the maximum 24-hour PC.*

(1) *Metal as maximum percentage of the group 3 metals ELV, recalculated from the data presented in EA metals guidance document (V.4) Table A1.*

*Table 75: Impact at Ecological Sites - Proposed Facility*

| ID | Site | Oxides of nitrogen (ng/m$^3$) | | Sulphur dioxide (ng/m$^3$) | Hydrogen fluoride (ng/m$^3$) | | Ammonia (ng/m$^3$) |
|---|---|---|---|---|---|---|---|
| | | Annual mean | Daily mean | Annual mean | Weekly mean | Daily mean | Annual mean |
| **European and UK designated sites** | | | | | | | |
| E1 | Mersey Estuary | 497.32 | 7655.42 | 110.54 | 14.80 | 42.61 | 41.52 |
| E5 | Functionally linked land to the Mersey Estuary A | 474.59 | 8859.78 | 105.49 | 18.23 | 49.31 | 39.62 |
| E6 | Functionally linked land to the Mersey Estuary B | 509.43 | 7732.65 | 113.23 | 10.11 | 43.04 | 42.53 |
| E2 | Midland Meres and Mosses – Hatch Mere SSSI | 100.46 | 1013.41 | 22.33 | 2.07 | 5.64 | 8.39 |
| E7 | Midland Meres and Mosses – Flaxmere Moss SSSI | 95.02 | 852.40 | 21.12 | 1.78 | 4.74 | 7.93 |
| E8 | Midland Meres and Mosses – Linmere Moss SSSI | 76.83 | 779.74 | 17.08 | 1.71 | 4.34 | 6.41 |
| **Local ecological sites** | | | | | | | |
| E3 | Frodsham and Helsby and Ince Marshes | 1114.81 | 14068.70 | 247.78 | 28.44 | 78.31 | 93.08 |
| E4 | Station Road Railway Site | 253.93 | 4788.20 | 56.44 | 11.33 | 26.65 | 21.20 |

*Notes:*

*Assumes continuous operation of both lines of the ERF at the short term ELVs and emitting via the CC facility.*

*Table 76: Impact at Ecological Sites - Proposed Facility*

| **ID** | **Site** | **Oxides of nitrogen (% CL)** | | **Sulphur dioxide (% CL)** | **Hydrogen fluoride (% CL)** | | **Ammonia (% CL)** |
|---|---|---|---|---|---|---|---|
| | | **Annual mean** | **Daily mean** | **Annual mean** | **Weekly mean** | **Daily mean** | **Annual mean** |
| **Critical level (µg/m$^3$)** | | **30** | **200** | **10/20** | **0.5** | **5** | **1/3** |
| **European and UK designated sites** | | | | | | | |
| E1 | Mersey Estuary | 1.66% | 3.83% | 0.55% | 2.96% | 0.85% | 1.38% |
| E5 | Functionally linked land to the Mersey Estuary A | 1.58% | 4.43% | 0.53% | 3.65% | 0.99% | 1.32% |
| E6 | Functionally linked land to the Mersey Estuary B | 1.70% | 3.87% | 0.57% | 2.02% | 0.86% | 1.42% |
| E2 | Midland Meres and Mosses – Hatch Mere* | 0.33% | 0.51% | 0.22% | 0.41% | 0.11% | 0.84% |
| E7 | Midland Meres and Mosses – Flaxmere Moss SSSI* | 0.32% | 0.43% | 0.21% | 0.36% | 0.09% | 0.79% |
| E8 | Midland Meres and Mosses – Linmere Moss SSSI* | 0.26% | 0.39% | 0.17% | 0.34% | 0.09% | 0.64% |
| **Local ecological sites** | | | | | | | |
| E3 | Frodsham and Helsby and Ince Marshes | 3.72% | 7.03% | 1.24% | 5.69% | 1.57% | 3.10% |
| E4 | Station Road Railway Site | 0.85% | 2.39% | 0.28% | 2.27% | 0.53% | 0.71% |

*Notes:*

*Assumes continuous operation of both lines of the ERF at the short term ELVs and emitting via the CC facility.*

** Impacts presented as % of lower Critical Level appropriate for lower plant communities.*

*Table 77: Annual Mean PC used for Deposition Analysis - Proposed Facility*

| ID | Site | Annual mean PC (ng/m$^3$) | | | |
|---|---|---|---|---|---|
| | | Nitrogen dioxide | Sulphur dioxide | Hydrogen chloride | Ammonia |
| E1 | Mersey Estuary | 177.8 | 56.4 | 11.3 | 21.2 |
| E5 | Functionally linked land to the Mersey Estuary A | 348.1 | 110.5 | 22.1 | 41.5 |
| E6 | Functionally linked land to the Mersey Estuary B | 780.4 | 247.8 | 49.6 | 93.1 |
| E2 | Midland Meres and Mosses – Hatch Mere SSSI | 332.2 | 105.5 | 21.1 | 39.6 |
| E7 | Midland Meres and Mosses – Flaxmere Moss SSSI | 356.6 | 113.2 | 22.6 | 42.5 |
| E8 | Midland Meres and Mosses – Linmere Moss SSSI | 70.3 | 22.3 | 4.5 | 8.4 |
| E3 | Frodsham and Helsby and Ince Marshes | 66.5 | 21.1 | 4.2 | 7.9 |
| E4 | Station Road Railway Site | 53.8 | 17.1 | 3.4 | 6.4 |

*Notes:*

*Assumes continuous operation of both lines of the ERF at the short term ELVs and emitting via the CC facility.*

*Table 78: Deposition Calculation - Grassland - Proposed Facility*

| ID | Site | Deposition (kg/ha/yr) | | | | | Total N Deposition (kgN/ha/yr | Acid Deposition (keq/ha/yr) | |
|---|---|---|---|---|---|---|---|---|---|
| | | Nitrogen dioxide | Sulphur dioxide | Hydrogen chloride | Ammonia | Amines | | N | S |
| E1 | Mersey Estuary | 0.026 | 0.107 | 0.173 | 0.110 | 0.145 | 0.010 | 0.012 | 0.026 |
| E5 | Functionally linked land to the Mersey Estuary A | 0.050 | 0.209 | 0.339 | 0.216 | 0.283 | 0.020 | 0.023 | 0.050 |
| E6 | Functionally linked land to the Mersey Estuary B | 0.112 | 0.469 | 0.760 | 0.483 | 0.635 | 0.045 | 0.051 | 0.112 |
| E2 | Midland Meres and Mosses – Hatch Mere SSSI | 0.048 | 0.200 | 0.324 | 0.206 | 0.270 | 0.019 | 0.022 | 0.048 |
| E7 | Midland Meres and Mosses – Flaxmere Moss SSSI | 0.051 | 0.214 | 0.347 | 0.221 | 0.290 | 0.021 | 0.023 | 0.051 |
| E8 | Midland Meres and Mosses – Linmere Moss SSSI | 0.010 | 0.042 | 0.068 | 0.044 | 0.057 | 0.004 | 0.005 | 0.010 |
| E3 | Frodsham and Helsby and Ince Marshes | 0.010 | 0.040 | 0.065 | 0.041 | 0.054 | 0.004 | 0.004 | 0.010 |
| E4 | Station Road Railway Site | 0.008 | 0.032 | 0.052 | 0.033 | 0.044 | 0.003 | 0.003 | 0.008 |

*Notes:*

*Assumes continuous operation of both lines of the ERF at the short term ELVs and emitting via the CC facility.*

*Deposition of amines has been calcualed separately for each amine and then summed. As the maximum concentration occurs at different locations for each amine for E1,E5,E6 and E3 the deposition for each amine has been calculated for each grid point then summed. The maximum across each site of this summed deposition of total amines has then been determined.*

*Table 79: Nitrogen Deposition - Proposed Facility*

| ID | Site | NCL Class | Lower CL (kgN/ha/yr) | Upper CL (kgN/ha/yr) | Background (kgN/ha/yr) | PC (kgN/ha/yr) | Process Contribution | | Predicted Environmental Concentration | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | % of Lower CL or Bg | % of Upper CL | % of Lower CL | % of Upper CL |
| **European and UK designated sites** | | | | | | | | | | |
| E1 | Mersey Estuary | Atlantic upper-mid & mid-low salt marshes | 10 | 20 | 24.30 | 0.283 | 2.83% | 1.42% | 245.83% | 122.92% |
| E5 | Functionally linked land to the Mersey Estuary A | Low and medium altitude hay meadows | 10 | 20 | 24.28 | 0.270 | 2.70% | 1.35% | 245.50% | 122.75% |
| E6 | Functionally linked land to the Mersey Estuary B | Low and medium altitude hay meadows | 10 | 20 | 24.28 | 0.290 | 2.90% | 1.45% | 245.70% | 122.85% |
| E2 | Midland Meres and Mosses – Hatch Mere SSSI | Bogs / Valley mires, poor fens and transition mires | 5 | 15 | 26.60 | 0.057 | - | - | - | - |
| E7 | Midland Meres and Mosses – Flaxmere Moss SSSI | Raised and blanket bogs | 5 | 15 | 26.4 | 0.054 | 1.08% | 0.36% | 489.08% | 163.03% |
| E8 | Midland Meres and Mosses – Linmere Moss SSSI | Rich fens | 15 | 25 | 25.4 | 0.044 | 0.29% | 0.17% | 169.62% | 101.77% |
| **Local ecological sites** | | | | | | | | | | |
| E3 | Frodsham and Helsby and Ince Marshes | Low and medium altitude hay meadows | 10 | 20 | 24.28 | 0.635 | 6.35% | 3.17% | 249.15% | 124.57% |
| E4 | Station Road Railway Site | Low and medium altitude hay meadows | 10 | 20 | 23.79 | 0.145 | 1.45% | 0.72% | 239.35% | 119.67% |

*Table 80: Acid Deposition - Proposed Facility*

| ID | Site | Acidity class | Min CL (CLmaxN) | Max CL (CLmaxN) | Background | Process Contribution | | | | Predicted Environmental Concentration | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | N+S (kgN/ha/yr) | N (kg/ha/yr) | S (kgS/ha/yr) | % of Lower CL | % of Upper CL | % of Lower CL | % of Upper CL |
| **European and UK designated sites** | | | | | | | | | | | |
| E1 | Mersey Estuary | Calcareous grassland (using base cation) | 5.071 | 4.856 | 1.90 | 0.020 | 0.023 | 0.84% | 0.88% | 38.31% | 40.01% |
| E5 | Functionally linked land to the Mersey Estuary A | Calcareous grassland (using base cation) | 5.071 | - | 1.85 | 0.019 | 0.022 | 0.81% | - | 37.29% | - |
| E6 | Functionally linked land to the Mersey Estuary B | Calcareous grassland (using base cation) | 5.071 | - | 1.93 | 0.021 | 0.023 | 0.87% | - | 38.92% | - |
| E2 | Midland Meres and Mosses – Hatch Mere SSSI | Standing water – not sensitive | - | - | - | 0.004 | 0.005 | - | - | - | - |
| E7 | Midland Meres and Mosses – Flaxmere Moss SSSI | Raised and blanket bog | 0.552 | 0.552 | 1.90 | 0.004 | 0.004 | 1.48% | 1.48% | 345.69% | 345.69% |
| E8 | Midland Meres and Mosses – Linmere Moss SSSI | No info available – so used raised and blanket bog | 0.552 | 0.552 | 1.90 | 0.003 | 0.003 | 1.20% | 1.20% | 345.40% | 345.40% |
| **Local ecological sites** | | | | | | | | | | | |
| E3 | Frodsham and Helsby and Ince Marshes | Calcareous grassland (using base cation) | 5.071 | - | 1.93 | 0.045 | 0.051 | 1.89% | - | 39.95% | - |
| E4 | Station Road Railway Site | Calcareous grassland (using base cation) | 5.071 | - | 1.85 | 0.010 | 0.012 | 0.43% | - | 36.91% | - |

# E Other Point Sources

## E.1 Operational sources – Ince Biomass Power Plant

The following table sets out the model inputs used for the Ince Biomass Power Plant these have been sourced from the original EP application.

*Table 81: Source Data – Ince Biomass Power Plant*

| Item | Unit | Ince Biomass Power Plant |
|---|---|---|
| **Stack data** | | |
| No of lines | - | 1 |
| Height | m | 85 |
| Internal diameter | m | 1.847 |
| Location | m, m | 346800, 376543 |
| **Flue gas conditions** | | |
| Temperature | °C | 140 |
| Exit moisture content | % v/v | - |
| Exit oxygen content | % v/v dry | 6% |
| Reference oxygen content | % v/v dry | 6% |
| Volume at reference conditions (dry, ref $O_2$) | $Nm^3/s$ | 27.71 |
| Volume at actual conditions | $Am^3/s$ | 48.23 |
| Flue gas exit velocity | m/s | 18.00 |

*Table 82: Stack Emissions Data – Ince Biomass Power Plant*

| Pollutant | Daily or periodic | | Half-hourly | |
|---|---|---|---|---|
| | ELV ($mg/Nm^3$, unless stated) | Release rate (g/s, unless stated) | ELV ($mg/Nm^3$, unless stated) | Release rate (g/s, unless stated) |
| Oxides of nitrogen (as $NO_2$) | 300 | 14.469 | 600 | 28.938 |
| Sulphur dioxide | 75 | 3.617 | 300 | 14.469 |
| Carbon monoxide$^{(1)}$ | 75 | 3.617 | 150 | 7.235 |
| Total dust (PM)$^{(2)}$ | 15 | 0.723 | 45 | 2.170 |
| Hydrogen chloride | 15 | 0.723 | 90 | 4.341 |
| Volatile organic compounds (as TOC) | 15 | 0.723 | 30 | 1.447 |
| Hydrogen fluoride | 3 | 0.145 | - | - |
| Ammonia $^{(2)}$ | 15 | 0.723 | - | - |
| Cadmium and thallium | 0.05 | 0.002 | - | - |

| **Pollutant** | **Daily or periodic** | | **Half-hourly** | |
|---|---|---|---|---|
| | **ELV (mg/Nm³, unless stated)** | **Release rate (g/s, unless stated)** | **ELV (mg/Nm³, unless stated)** | **Release rate (g/s, unless stated)** |
| Mercury | 0.05 | 0.002 | - | - |
| Other metals[3] | 0.5 | 0.024 | - | - |
| Dioxins and furans | 0.1 ng/Nm$^3$ | 4.823 ng/s | - | - |

*Notes:*

*All emissions are expressed at reference conditions of dry gas, 6% oxygen, 273.15K.*

*(1) As a worst-case it has been assumed that the entire dust emissions consist of either $PM_{10}$ or $PM_{2.5}$ for comparison with the relevant AQALs.*

*(2) The EP does not include an ELV for ammonia, a concentration of 15 mg/Nm$^3$ has been assumed in line with other projects.*

*(3) Other metals consist of antimony (Sb), arsenic (As), lead (Pb), chromium (Cr), cobalt (Co), copper (Cu), manganese (Mn), nickel (Ni) and vanadium (V).*

If the Ince Biomass Power Plant continually operated at the half-hourly limits, the daily limits would be exceeded. The plant is designed to achieve the daily limits and as such will only operate at the short-term ELVs for short periods on rare occasions.

# F Amine Chemistry Modelling

## F.1 Introduction

The proposed CC facility would use an amine-based solution to capture carbon dioxide from the flue gas. Amines are nitrogen-based compounds which are structurally similar to ammonia ($NH_3$), with one or more of the hydrogen atoms substituted by a substituent which is typically a functional group such as a methyl or alcohol group. Amines are categorised as primary, secondary or tertiary, depending on whether one, two, or three of the hydrogen atoms are substituted.

Amines are highly effective at absorbing carbon dioxide, which is the process that takes place in the absorber column. The ‘rich’ amine, combined with the carbon dioxide, is transported to the stripper column where the mixture is heated to release the carbon dioxide to be taken for storage, while the ‘lean’ amine is returned to the absorber column to repeat the process. Full details of the process are provided in the supporting information submitted with the application to vary the EP.

Amines can react with oxides of nitrogen either in the absorber column or the atmosphere. The reaction with nitric oxide (NO) forms nitrosamines, and the reaction with nitrogen dioxide ($NO_2$) forms nitramines. The most toxic nitrosamine, NDMA, is categorised by the International Agency for Research on Cancer as a group 2A carcinogen, meaning it is “probably carcinogenic to humans”. NDMA is a known carcinogen in animals. Other nitrosamines and nitramines are also toxic and/or carcinogenic, albeit to a lesser degree or with greater uncertainty than is known for NDMA. NDMA is the only nitrosamine or nitramine for which an AQAL has been set.

As shown in Table 1 this assessment has applied the EA’s EAL of 0.2 ng/m³ for NDMA as the AQAL for total nitrosamines, and the NIPH’s value of 0.3 ng/m³, nominally for NDMA, as the AQAL for total nitrosamines and nitramines. This is considered appropriate as the supporting documentation published by the NIPH[16] explicitly recommends that the total amount of nitrosamines and nitramines should not exceed 0.3 ng/m³.

Although the process will be designed to minimise emissions of amines, nitrosamines, and nitramines, there will be small quantities released. An MEA solvent is to be used in the CC facility and as such it has been assumed that all emissions of the primary amine are of MEA. It is also likely that much smaller quantities of secondary amines would be released. For the purpose of this assessment it has been assumed to be equally proportioned between DMA and DEA. DMA is the precursor to NDMA, which is the only nitrosamine for which there is an AQAL.

## F.2 Amine chemistry reaction scheme

ADMS 6 includes an amine chemistry reaction scheme which models the chemical reactions which occur once amines, nitrosamines and nitramines are released into the atmosphere. The reaction scheme does not account for reactions that occur prior to release, which are accounted for in the release rate of direct emissions of nitrosamines and nitramines.

The amine chemistry reaction scheme accounts for reactions that occur in the atmosphere that cause amines and amine degradation products to react and form different compounds. The first reaction that occurs is between the amine and the hydroxyl radical (OH), labelled k1. The OH radical attacks the amine at either an N-H bond, which results in the formation of an amino radical, or at a C-H bond, forming other compounds which are not significantly harmful to human health and are therefore not relevant to this assessment. The ratio of the attack on the N-H bond and C-H bond is

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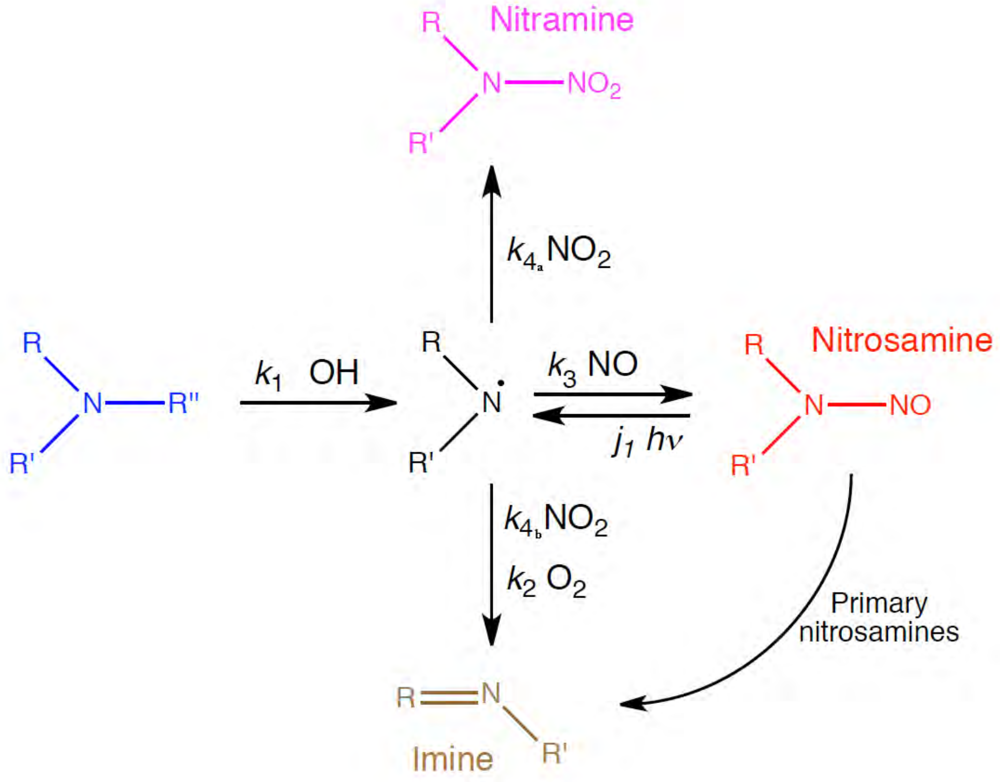
[16] NIPH, Health effects of amines and derivatives associated with $CO_2$ capture, 2011

called the branching ratio. Similar reactions occur with nitrate ions ($NO_3$), but these reactions are much slower than the OH radical reactions[17] and are not considered further in this assessment. The amino radical can then react with nitric oxide (NO) to form a nitrosamine (k3), nitrogen dioxide ($NO_2$) to form a nitramine (k4a) or an imine (k4b), or oxygen ($O_2$) to form an imine (k2). Nitrosamines do not have a long atmospheric lifetime and undergo photolysis (i.e., are broken down to the amino radical by sunlight). Furthermore, nitrosamines formed from primary amines are unstable and rapidly change structure to form imines within around 1 second of formation. Imines are not significantly harmful to human health and therefore are not relevant to this assessment. A schematic of the reactions included in the scheme is shown in Figure 20.

*Figure 20: Reactions included in ADMS Chemistry Reaction Scheme*



*Source: Adapted from Nielsen et al (2012)*[18]

The ADMS amine chemistry module requires the user to input values for the kinetic parameters (i.e. reaction rates) for these reactions, along with the branching ratio for the k1 reaction, the ratio between the photolysis rate (J) of nitrosamine compared to the photolysis rate of nitrogen dioxide, and a constant to determine the OH radical concentration, which is based on estimated annual average background OH, ozone and NOx concentrations, and incoming solar radiation.

A number of studies have been published in literature which attempt to determine the values for these parameters, either theoretically or experimentally. For some parameters there is broad agreement, while for others there is a wide range of published values. In September 2022 the CCSA published an updated position paper which was most recently updated in January 2023 (referenced in section 5.8.1), co-authored by Claus Nielsen who is a recognised authority on the atmospheric chemistry of amines, which "seeks to provide one consolidated set of amines chemistry data for

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[17] CERC, Atmospheric Chemistry Modelling Executive Summary, May 2012

[18] Nielsen et al, Atmospheric Degradation of Amines – Summary report from atmospheric chemistry studies of amines, nitrosamines, nitramines and amides, February 2012

use in modelling of amine emissions". The values presented in the CCSA paper and reproduced in Table 38 in section 5.8.1 have been used in the main model runs, with the exception of the values for DEA as these are not provided in the CCSA position paper. The values for DEA have been provided by CERC via direct email correspondence. The references for each value are given in Table 83. Where values specific to DEA are unknown, the values have been assumed to be the same as for DMA.

The ADMS amine chemistry module requires the user to input the amine, nitrosamine and nitramine species modelled. As noted above, the nitrosamine formed from a primary amine rapidly forms an imine. Therefore, the direct emissions of nitrosamines have been split equally between NDMA (formed from DMA) and NDELA (formed from DEA). The direct emissions of nitramines have been apportioned to those formed from MEA, DMA, and DEA in the same proportions as the emissions of their parent amines.

The amine chemistry module treats these direct releases of nitrosamines the same as those formed in atmospheric chemical reactions, so that the nitrosamines undergo photolysis and the resultant amino radical can react with atmospheric NO, $NO_2$ and $O_2$. A sensitivity analysis has been undertaken assuming that the nitrosamines do not undergo chemical reactions after release, and a further sensitivity analysis undertaken with no direct emissions of nitrosamines and nitramines, to determine the quantity formed indirectly via atmospheric reactions compared to those directly emitted from the stack (refer to section F.3).

The amine chemistry scheme allows the user to select the option 'low concentration dilution and entrainment' which improves the way the model accounts for dilution of pollutant species and the entrainment of background pollutants into the plume. CERC strongly recommends that this option is selected when running the amine chemistry module, so this option has been selected.

The amine chemistry scheme also allows the user to model aqueous partitioning of amines, nitrosamines, and nitramines. As many amines and their degradation products are soluble, they will dissolve in any liquid water contained within the plume. This reduces their concentration in ambient air, and their availability for atmospheric reactions. A sensitivity analysis has been run to determine the effect of including aqueous partitioning (refer to section F.3).

## F.3 Sensitivity analysis

A series of sensitivity analyses have been undertaken the kinetic parameters and other inputs to the amine chemistry modules, using a range of values from available published literature. The values used and their sources are presented in Table 83. Where it has not been possible to determine alterative values that are higher or lower than the mid-range value, the relevant cells have been left blank.

*Table 83: Amine Chemistry Module Inputs*

| Parameter | Units | Value | MEA | DEA | DMA |
|---|---|---|---|---|---|
| k1 - Amine/OH reaction rate constant | $ppb^{-1}s^{-1}$ | Low | 0.775(B) | 2.318(E) | 1.623(D) |
| | | Mid | 1.900 | 2.525(F) | 1.625 |
| | | High | 2.328(C) | - | 1.775(D) |
| k2 - Amino radical/O2 reaction rate constant | $ppb^{-1}s^{-1}$ | Low | $2.39x10^{-9}$(B) | - | $2.39x10^{-9}$(B) |
| | | Mid | $3.10x10^{-9}$ | $4.45x10^{-10}$(G) | $3.10x10^{-9}$ |
| | | High | - | - | - |
| k3 - Rate constant for formation of nitrosamine | $ppb^{-1}s^{-1}$ | Low | $1.41x10^{-3}$(C) | - | - |
| | | Mid | $2.13x10^{-3}$ | $1.78x10^{-2}$(G) | $2.13x10^{-3}$ |
| | | High | $4.78x10^{-3}$(B) | - | $4.78x10^{-3}$(B) |
| k4a - Rate constant for formation of nitramine | $ppb^{-1}s^{-1}$ | Low | $2.10x10^{-4}$(C) | - | - |
| | | Mid | $7.95x10^{-3}$(A) | $7.95x10^{-3}$ | $7.95x10^{-3}$ |
| | | High | - | - | - |
| k4 - Amino radical/NO2 reaction rate constant | $ppb^{-1}s^{-1}$ | Low | $3.14x10^{-4}$(C) | $8.20x10^{-3}$(C) | $8.20x10^{-3}$(C) |
| | | Mid | $9.70x10^{-3}$ | $9.70x10^{-3}$ | $9.70x10^{-3}$ |
| | | High | - | - | - |
| k1 branching ratio | Unitless | Low | - | 0.37(C) | 0.37(C) |
| | | Mid | 0.08 | 0.41 | 0.41 |
| | | High | 0.38(H) | 0.42(B) | 0.42(B) |
| Ratio of J(nitrosamine) to J($NO_2$) | Unitless | Low | - | 0.32(B) | 0.32(B) |
| | | Mid | - | 0.34 | 0.34 |
| | | High | - | 1.24(C) | 1.24(C) |

| **Parameter** | **Units** | **Value** | **MEA** | **DEA** | **DMA** |
|---|---|---|---|---|---|
| *References:*<br>*A – CCSA, Carbon Capture Chemistry Parameters, N-Amines Chemistry, January 2023. Refer to CCSA paper for original source of each value. All ‘mid’ values taken from CCSA paper.*<br>*B – Nielsen et al, Atmospheric Degradation of Amines Summary Report, February 2012, as used by CERC in “Atmospheric Chemistry Modelling Executive Summary”. May 2012.*<br>*C – Manzoor et al, Atmospheric chemistry modelling of amine emissions from post combustion CO2 capture technology, 2014.*<br>*D – Lee & Wexler, Atmospheric amines - Part III: Photochemistry and toxicity, 2013.*<br>*E – Carter, Reactivity Estimates for Selected Consumer Product Compounds, 2008.*<br>*F – da Silva et al, Protocol for evaluation of solvents – process and atmospheric chemistry, 2010.*<br>*G – Liu et al, Mechanism and predictive model development of reaction rate constants for N-center radicals with $O_2$, 2019.*<br>*H – Onel et al, Branching ratios for the reactions of OH with ethanol amines used in carbon capture and the potential impact on carcinogen formation in the emission plume from a carbon capture plant, 2015.* | | | | | |

The effect of varying each of the parameters on concentrations of nitramines and nitrosamines is summarised in Table 84.

*Table 84: Effect of Increasing Amine Chemistry Parameters*

| Parameter | Effect of Increase on Nitrosamines | Effect of Increase on Nitramines |
|---|---|---|
| k1 amine/OH reaction rate constant | Increase – faster reaction rate results in more amino radical, the precursor to both nitrosamines and nitramines | |
| k2 amino radical/$O_2$ reaction rate constant | Decrease – this reaction forms an imine, which is a sink for the amino radical | |
| k3 rate constant for formation of nitrosamine | Increase | Decrease – less amino radical available to form nitramine |
| k4a rate constant for formation of nitramine | Decrease – less amino radical available to form nitrosamine | Increase. |
| k4 Amino radical/$NO_2$ reaction rate constant | Decrease – less amino radical available to form nitrosamine | Increase – some reactions from this path form nitramine (via k4a) |
| Branching ratio for amine/OH reaction | Increase – higher values result in more amino radical formation | |
| Ratio of J(nitrosamine)to J($NO_2$) | Decrease – as this increases the rate of photolysis of the nitrosamine back to the amino radical | Increase – more radical available to form nitramine |

Based on the relationships detailed in Table 84 the model has been run with the parameters that produce the maximum and minimum concentrations of nitramines and nitrosamines. The results are presented in Table 87.

The sensitivity of the model results to other parameters used in the amine chemistry scheme has been tested. The model is sensitive to the total NOx emission concentration and the percentage of the NOx release which is $NO_2$, as these values affect the amount of NO and $NO_2$ available to react with the amino radical, as well as the constant 'c' used to determine the concentration of the OH radical. This constant is directly proportional to the annual mean OH concentration. Advice from CERC and published literature[19] is that OH concentrations are typically $1x10^6$ molecules/$cm^3$ at UK latitudes, but values are up to 3 times higher at equatorial latitudes. Therefore, a 2x multiplier has been applied to the OH radical constant as a reasonable assumption for the sensitivity analysis.

The parameters tested and their modelled values are presented in Table 85.

*Table 85: Additional Sensitivity Analysis Parameters*

| Parameter | Units | Minimum | Main Runs | Maximum |
|---|---|---|---|---|
| NOx emission concentration | mg/$Nm^3$ | 50(1) | 180 | **180** |
| % of primary NOx as $NO_2$ | % | 5% | 5% | **10%** |
| Constant 'c' for OH concentration | s | 0.00016 | 0.00016 | **0.00032** |

*Note:*

*(1) NOx concentration of 50 mg/$Nm^3$ represents use of selective catalytic reduction (SCR)*

The proportion of nitrosamines and nitramines formed from atmospheric chemical reactions (indirect emissions) has also been compared to those emitted from the stack (direct emissions). A further sensitivity analysis has been undertaken assuming that directly emitted nitrosamines and nitramines do not undergo any chemical reactions following release.

As noted in Section 5.8.1, when more than one source is modelled in the ADMS 6 amine chemistry scheme, the amine chemistry module applies the chemistry scheme to pollutants from each source independently, then sums the resultant pollutants. A sensitivity analysis has been run assuming a single source for emissions from both absorbers.

Finally, a sensitivity analysis has been run using the aqueous partitioning scheme included in the ADMS 6 amine chemistry module. As amines, nitrosamines and nitramines are soluble in water, when there is liquid water in the atmosphere or the plume, some of these substances dissolve, decreasing the concentration of pollutants in the gaseous phase and reducing their availability for gaseous phase reactions. This option requires the user to input Henry's Law constants for each amine modelled and their resultant nitrosamine and nitramine species. The values used are presented in Table 86.

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[19] Stevenson et al, Trends in global tropospheric hydroxyl radical and methane lifetime since 1850 from AerChemMIP, 2020

*Table 86: Henry's Law Constants Used in Aqueous Partitioning Scheme*

| **Parent Amine Species** | **Henry's Law Solubility Constant (mol/L atm)** | | |
|---|---|---|---|
| | **Amine** | **Nitrosamine** | **Nitramine** |
| MEA | $6.08 \times 10^{6(1)}$ | - | $6.08 \times 10^{7(5)}$ |
| DEA | $2.53 \times 10^{7(2)}$ | $2.03 \times 10^{8(2)}$ | $2.03 \times 10^{8(5)}$ |
| DMA | $56.7^{(3)}$ | $618^{(4)}$ | $618^{(5)}$ |

*Notes:*

*(1) Bone et al., Solvent effects on equilibria of addition of nucleophiles to acetaldehyde and the hydrophilic character of diols, 1983*

*(2) HSDB: Hazardous Substances Data Bank, TOXicology data NETwork (TOXNET), National Library of Medicine (US), 2015*

*(3) Christie & Crisp, Activity coefficients on the n-primary, secondary and tertiary aliphatic amines in aqueous solution, 1967*

*(4) Klein, Calculations and measurements on the volatility of N-nitrosamines and their aqueous solutions, 1982.*

*(5) No published values available for nitramines. Tan et al., Experimental and Theoretical Study of the OH-Initiated Degradation of Piperazine under Simulated Atmospheric Conditions, 2020, states "There are no data for the Henry's law solubility constants for nitramines, but to a first approximation, they are expected to be the same as those of the nitrosamines." Nielsen et al., Atmospheric chemistry and environmental impact of the use of amines in carbon capture and storage (CCS), 2012, states "In general, the Henry's Law constants for nitrosamines are an order of magnitude smaller than that of the corresponding amine".*

*Therefore, where there is a published value for a certain nitrosamine, the same value has been assumed for the corresponding nitramine. As the Nielsen et al. reference reports the Henry's Law constants in reciprocal units to those required as an input for ADMS, where there are no values available for the nitrosamine or nitramine, these have been assumed to be an order of magnitude* greater *than for the corresponding amine.*

The sensitivity analysis runs have been run for a single year (2022) and the maximum results for nitrosamine and nitramine concentrations at the point of maximum impact are presented in Table 87. The maximum amine, nitrosamine and nitramine concentrations and the percentage change from the main model run has been presented.

*Table 87: Sensitivity Analysis Results – Amine Chemistry Parameters*

| **Scenario** | **Annual mean concentration** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Max amines** | | **Max nitrosamines** | | **Max nitramines** | | **Max nitrosamines + nitramines** | |
| | **µg/m$^3$** | **As % of main run** | **pg/m$^3$** | **As % of main run** | **pg/m$^3$** | **As % of main run** | **pg/m$^3$** | **As % of main run** |
| Main model run | 26.89 | | 1.04 | | 1.96 | - | 2.61 | - |
| Minimum nitramine formation | 26.93 | 100.1% | 1.01 | 97.0% | 0.86 | 43.8% | 1.86 | 71.3% |
| Maximum nitramine formation | 26.88 | 100.0% | 0.91 | 87.7% | 10.86 | 554.2% | 11.29 | 432.2% |
| Minimum nitrosamine formation | 26.93 | 100.1% | 0.81 | 77.7% | 0.92 | 47.1% | 1.70 | 65.1% |
| Maximum nitrosamine formation | 26.88 | 100.0% | 1.15 | 110.8% | 10.78 | 549.8% | 11.53 | 441.4% |
| NOx emission at 50 mg/Nm$^3$ | 26.89 | 100.0% | 0.94 | 90.4% | 1.93 | 98.6% | 2.53 | 96.7% |
| Primary NO$_2$ = 10% | 26.89 | 100.0% | 1.03 | 99.0% | 2.04 | 104.0% | 2.69 | 103.1% |
| 2x increase in OH conc. | 26.84 | 99.8% | 1.61 | 155.1% | 3.66 | 186.7% | 4.78 | 183.0% |
| Aqueous partitioning | 26.61 | 98.9% | 1.03 | 99.0% | 1.91 | 97.7% | 2.56 | 97.9% |
| No direct NS + NA emissions | 26.89 | 100.0% | 0.58 | 55.8% | 1.74 | 88.8% | 2.21 | 84.7% |
| No direct amine emissions (NS+NA only) | - | - | 0.50 | 48.3% | 0.54 | 27.5% | 1.04 | 39.8% |
| No amine chemistry (direct emissions only) | - | - | 0.51 | 54.4% | 0.51 | 26.4% | 1.02 | 40.5% |
| Emissions modelled as a single source | | | | | | | | |

The following conclusions can be drawn from these results:

- The concentration of amines is not sensitive to any of the parameters. This is because the large majority of the amine remains unreacted in all scenarios.
- Varying the amine chemistry reaction parameters leads to a range of 79% - 111% of the main model result for nitrosamines and 44% - 550% of the main model result for nitramines. The nitramine results are considerably more sensitive because the majority are formed from MEA; there is a large range of parameters relating to nitramine formation from MEA (see Table 83).
- The concentrations of nitrosamines and nitramines are not highly sensitive to either the NOx emission concentration or the percentage of NOx emission that is primary $NO_2$.
- Increasing the OH concentration by a factor of 2 results in a near doubling of the concentrations of nitramines and nitrosamines.
- Including aqueous partitioning results in only a slight decrease in concentrations of amines, nitrosamines and nitramines. This is likely due to the reheat of the flue gas to 100$^o$C which prevents the formation of liquid water droplets in the plume.
- When there are no direct emissions of nitrosamines and nitramines (i.e. they are all formed from atmospheric reactions) the concentrations are reduced by nearly half for nitrosamines, but only around 10% for nitramines. Therefore, around half the nitrosamines and nearly 90% of the nitramines in the main model run are formed via atmospheric reactions.
- When there are no emissions of amines and amine chemistry is enabled the concentrations of nitrosamines are reduced by about half and nitramines by over 70%. When chemistry is not enabled the concentration of nitramines is almost unchanged, while the concentration of nitrosamines is slightly higher. This indicates that a portion of the directly-emitted nitrosamine would undergo photolysis.
- When the emissions are modelled as a single source the resultant peak concentration is lower than when modelled as a single source. Analysis of the difference in impact for substances not affected by the chemistry option shows that modelling as a single source results in a similar reduction therefore the difference is attributable to the buoyancy differences when modelling as a single source rather than differences in differences attributable to modelling as two separate sources and applying the chemistry scheme to each source independently.

The use of a 2x multiplier for the OH concentration constant would be overly conservative, as there is no evidence that OH concentrations are this high at UK latitudes.

The main model scenario, in which there are direct emission of amines, nitrosamines and nitramines, and amine chemistry is enabled, is considered to be the most realistic scenario.

Under the worst-case scenario that the worst-case amine reaction parameters for the formation of nitrosamines are correct and the total concentration of nitrosamines and nitramines is ~440% of the value predicted in the main model run, the maximum concentration of nitrosamines and nitramines combined would be 3.03 pg/m³, which is 1.51% of the AQAL of 0.2 ng/m³ set for NDMA, or 1.01% of the AQAL for total nitrosamines and nitramines of 0.3 ng/Nm³. As such, even under these-worst case assumptions, the PEC of total nitrosamines and nitramines would remain well below the AQAL and no significant effects would occur.

# G EALs for DMA and DEA

**Encyclis**

# Protos ERF Carbon Capture

Derivation of environmental assessment levels for dimethylamine (DMA)

## 1 Dimethylamine (CAS Number 124-40-3)

Dimethylamine (DMA) is a water-soluble, basic secondary aliphatic amine which produces an odour similar to that of ammonia and/or rotting fish (US EPA, 2008). DMA is a flammable gas and forms explosive mixtures with air in the range 2.8% to 14.4% volume in air (NIPH, 2011). DMA is present in many foods, including cabbage and fish, and is also formed endogenously from DMA precursors by bacteria in the gut. It is widely used in industry as a precursor and is a raw material in the production of agrichemicals and pharmaceuticals. DMA is rapidly biodegradable in the environment and has an estimated phototransformation half-life in air of about two hours (ECHA dossier).

## 2 Regulatory standards

- None

## 3 Recommended environmental assessment level (EAL) in air

- Long-term EAL – 0.0033 mg/m$^3$ as a 24-hour mean.
- Short-term EAL – none (constrained by compliance with long-term EAL).

## 4 Overview

There are a few authoritative reviews on the adverse effects from exposure to DMA (US EPA (2008), NIPH (2011) and the industry registration, evaluation, authorisation and restriction of chemicals (REACH) dossier). It is a strong respiratory, ocular and skin irritant, which induces adverse effects when inhaled or ingested.

## 5 Toxicokinetics

There is limited information available on the metabolism and disposition of DMA by humans. Pharmacokinetic studies indicate that DMA is absorbed from the gastrointestinal tract rapidly ($t_{1/2}$ = 8 min) and extensively (bioavailability = 82%) (US EPA, 2008). The industry REACH dossier indicates that systemic uptake of DMA can occur via inhalation or dermal routes, in addition to the oral route (ECHA dossier). Following uptake, it can be found in human saliva, gastric juices, blood, urine and faeces (Tricker et al., 1992). Investigations of workers in a factory processing DMA showed excretion of the substance in urine when workers were exposed to the amine in air (Bittersohl and Heberer, 1980).

In a study on the metabolism of DMA in mammals McNulty and Heck (1983) studied the disposition and metabolism of DMA in male rats following inhalation of $^{14}$C-DMA in concentrations of either 10 or 175 ppm for six hours. 72 hours after the end of exposure, the disposition of recovered radioactivity was similar for each concentration of DMA. The vast majority of the DMA was excreted (predominately in urine) without being metabolised, whilst 7-8% of radioactivity was distributed around the body in internal organs and other tissues, including the nasal mucosa, olfactory mucosa, kidneys, liver and lungs. In vitro studies also carried out by McNulty and Heck (1983) showed that DMA is metabolised by microsomes from rat liver and nasal and tracheal mucosa.

# 6 Short- and long-term exposures

DMA is a strong irritant to the eyes, skin and mucous membranes (NIPH, 2011). Exposure to the vapour can also result in temporary hazy vision (glaucopsy) which has been reported for amine production workers on several occasions (Mellerio, 1966). Direct contact between DMA vapor or aqueous solutions and skin can cause concentration-dependant damage, particularly in the eyes. Several ocular adverse effects are induced when a 1% DMA solution is applied to the rabbit eye including photophobia, blepharospasm and conjunctivitis, whilst solutions of 5% DMA or more caused severe damage such as vascularisation and clouding of the cornea (MAK Value Documentation, 2012).

Repeated inhalation toxicity of DMA was investigated in F344 rats and B6C3F1 mice[1] who showed significant lesions in the nasal passages when repeatedly exposed to 175 ppm of DMA for six hours a day, five days a week for 12 months (Buckley, 1985). More extensive olfactory lesions were developed in the rats compared to mice, and even when exposed to a concentration of 10 ppm, the animals developed minor lesions. In an investigation of the lethal concentration of DMA, Steinhagen et al. (1982) observed ulceration, necrosis, tracheitis and emphysema, resulting in mortality with a lethal concentration 50 ($LC_{50}$) value of 4,540 ml/m$^3$ for rats which had inhaled DMA for six hours.

Darad et al. (1985) investigated the effects of repeated dose oral exposure of DMA on rats by administering 0.2% DMA through drinking water over nine months. The results indicate that DMA may induce free radical-mediated damage to the cellular and subcellular membranes, thus disturbing the protective function of the skin. Ingested DMA has been shown to cause a number of effects in rats, such as coordination disorders, severe irritation of mucous membranes and bleeding of stomach walls, resulting in death. An oral lower dose 50 ($LD_{50}$) for rats was found to be 689 mg/kg body weight (MAK Value Documentation, 2012).

Guinea pigs exposed to a 0.5 M solution of DMA through a patch test of Magnusson and Kligman produced positive allergenic reactions to the solution. However, no sensitisation of humans handling DMA has been observed to date (MAK Value Documentation, 2012).

Evidence for neurobehavioural effects in humans from DMA inhalation exposure has not been reported (US EPA, 2008). However, a study by Simenhoff et al. (1977) found a correlation between serum levels of DMA and two neurophysiological parameters in uremic dialysis patients: choice reaction time (CRT) and abnormal electroencephalograms (EEG), noting that uremic patients have elevated levels of DMA in the blood, cerebrospinal fluid and brain.

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[1] These are common inbred rats and hybrid strains of mice which are available commercially for use in toxicological studies.

There is very limited research on the reproductive and developmental toxicity of DMA. A study involving intraperitoneal injection of DMA, in doses of up to 137.7 mg/kg, into pregnant Swiss mice observed no toxic effects on dams of foetuses (Varma et al., 1990). However, in vitro experiments performed in the same study found that DMA causes a concentration-dependant reduction in embryo ribonucleic acid (RNA), deoxyribonucleic acid (DNA) and proteins.

## 6.1 Genotoxicity and carcinogenicity

Green (1978) found DMA to be a weak mutagen in the Ames test of mutagenicity with liver metabolic activation. However, other studies (e.g., Zeiger et al., 1987) have not been able to confirm this result and have concluded that DMA does not cause cytotoxic or genotoxic effects. DMA has not been found to be carcinogenic in rats or mice after exposure via inhalation for 24 months (ECHA dossier) and there has been no evidence to indicate carcinogenic effects in humans.

However, there is the potential for DMA to react with nitrosating agents in the body, to produce N-nitrosodimethylamine (NDMA), which is a potent carcinogen that reacts with DNA to form adducts (NIPH, 2011). This has been shown to occur in vitro, but to date no studies have shown that DMA is carcinogenic in vivo. Fay et al. (1997) investigated whether consuming frozen fish with very high DMA levels, with ingested nitrate, would result in elevated urinary adducts as a result of NDMA formation, but no genetic damage was found. NDMA is also mutagenic and clastogenic. The effects of NDMA and its associated EALs has been reported by the Environmental Agency.[2]

## 6.2 Pivotal studies

The US EPA (2008) summarised the Mitchell et al. (1982) 90-day inhalation toxicology study in F344 rats which was used as the basis for their derivation of acute exposure guidance levels (AEGL-1). In this study, 10 rats per sex per dose group (80 total) were exposed to DMA for six hours a day, five days a week, for 90 days at concentrations ranging from 0 to 100 ppm.

In the 10 ppm group, no treatment related effects were observed. A slightly lower weight gain was observed in the first two-week period in males and/or females at 30 ppm and 100 ppm, but over the total 13-weeks, weight gain for all groups was similar to that observed for the control groups.

After 13-weeks, all rats were necropsied. In three of the ten females exposed to 100 ppm, gross lesions of the liver red areas were observed with an increased incidence. This was not observed in any other group. Otherwise, no histopathological differences in tissue between the control and test groups were observed in microscopic analysis.

For males at 100 ppm and females at 30 ppm there was an increase in lung weight (approximately 20%). Females at 30 ppm and or 100 ppm also showed increased weight of heart, liver and kidneys (6-11%). The significance of this was unclear.

In a chronic inhalation study cited as the key source by the industry REACH dossier for DMA, male and female F344 rats and B6C3F1 mice were subjected to inhalation exposure of 0, 10, 50, or 175 ppm DMA for six hours a day, five days a week, for 12 months. Groups of 9-10 male and female rats and mice underwent necropsy after six and 12 months of exposure. Notably, no male mice were sacrificed at 12 months due to a high rate of premature deaths in that group, but this was attributed to fighting.

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[2] https://www.gov.uk/government/consultations/environmental-assessment-levels-eals-used-in-air-emissions-risk-assessments/public-feedback/appendix-c-summary-of-toxicological-evidence-for-mea-and-ndma#fnref:1

Rats and mice exposed to 175 ppm DMA experienced a decrease in mean body weight gain to approximately 90% of the control after 3 weeks of exposure. This continued throughout the 12-month period.

The sole other changes linked to treatment were lesions in the nasal passages, which were dose dependent. These lesions occurred in two distinct nasal locations: the respiratory epithelium in the anterior nasal passages and the olfactory epithelium, particularly in the anterior dorsal meatus. In rats, the severity of lesions progressed between six to 12 months in the olfactory epithelium, but there was no progression observed in mice.

Rats exhibited more extensive olfactory lesions compared to mice at the 175 ppm exposure level, showing hyperplasia of small basophilic cells adjacent to the basement membrane. Even at 10 ppm, a 12-month exposure led to a small degree of loss of olfactory sensory cells and their axons in the nasal passages of a few rats and mice. These findings suggested a high sensitivity of olfactory sensory cells to DMA's toxic effects.

The comprehensive two-year study conducted by the Chemical Industry Institute of Toxicology (CIIT, 1990), of which Buckley et al. (1985) reported the first-year portion, served as the foundation for the Scientific Committee of Occupational Exposure Limits (SCOEL, 1991) occupational exposure limit (OEL) recommendation to the Health and Safety Executive (HSE). The study was summarised by the US EPA in their 2008 document where they derived the AEGLs. As described above, female and male F344 rats and B6C3F1 mice were subjected to inhalation exposure of 0, 10, 50, or 175 ppm DMA for six hours a day, five days a week. The total duration of the study was two years. The rats were observed twice a day and weighed weekly or biweekly.

In addition to the six- and 12-month interim sacrifices previously described a further interim sacrifice at 18 months of 9-10 animals per species was undertaken. This only applied to females, as excessive fighting in males lead to high mortality (which also prevented male sacrifice at the 12-month mark).

Decreased gain in body weight persisted throughout the study compared to the control group. Additionally, severity of nasal lesions increased after 18 months. At 10 ppm, minimal lesions were observed in the respiratory epithelium of rats and in the olfactory epithelium in both species. When exposed to 50 ppm, both species showed minimal alterations in the respiratory epithelium and moderate changes in the olfactory epithelium, coupled with mild chronic inflammation. Exposure to 175 ppm resulted in rats developing mild goblet cell hyperplasia, while both species experienced moderate chronic inflammation. Additionally, severe lesions were found in both the respiratory and olfactory epithelium, with these lesions being slightly more extensive in rats than in mice.

# 7 HBGV for short-term exposure

The industry REACH dossier, HSE (2020) and US EPA (2008) have proposed health based guidance values (HBGVs) for short-term exposure of DMA. The World Health Organisation (WHO) have not recommended any assessment levels for short-term exposure.

## 7.1 REACH chemical dossier

The industry REACH dossier for DMA on the ECHA dissemination portal derived a derived no effect level (DNEL) of 21.33 mg/m$^3$ to protect the general population from systemic effects from acute exposure via inhalation (REACH chemical dossier). It was based on a NOAEC of 184.85 mg/m$^3$

(100 ppm). ECHA applied modified Haber's law[3] using an exponent of 3 to the NOAEC to adjust the NOAEC from a six-hour exposure period to a 15-minute exposure period. The REACH chemical dossier then applied an uncertainty factor[4] (UF) of 25 (a factor of 2.5 for interspecies variation and a factor of 10 for intraspecies variation). ECHA didn't state from which source the NOAEC was taken. However, it is assumed that it was Mitchell et al. (1982) on the basis that they observed the same NOAEC, and their study was also used as the pivotal study for the AEGL-1 derivation by the US EPA.

## 7.2 United States Environmental Protection Agency

To assess the observed effects of inhalation of DMA, the US EPA reviewed various studies and derived acute exposure guideline levels (AEGLs) for different classifications of exposure levels, averaged over a number of different time frames, as shown in Table 1.

*Table 1: Summary of AEGL Values for Dimethylamine*

| **Classification** | **10-min** | **30-min** | **1-h** | **4-h** | **8-h** |
|---|---:|---:|---:|---:|---:|
| AEGL-1<br>(Non-disabling) | 10 ppm<br>(18 mg/m$^3$) | 10 ppm<br>(18 mg/m$^3$) | 10 ppm<br>(18 mg/m$^3$) | 10 ppm<br>(18 mg/m$^3$) | 10 ppm<br>(18 mg/m$^3$) |
| AEGL-2<br>(Disabling) | 130 ppm<br>(240 mg/m$^3$) | 85 ppm<br>(160 mg/m$^3$) | 66 ppm<br>(120 mg/m$^3$) | 40 ppm<br>(74 mg/m$^3$) | 32 ppm<br>(59 mg/m$^3$) |
| AEGL-3<br>(Lethal) | 480 ppm<br>(880 mg/m$^3$) | 320 ppm<br>(590 mg/m$^3$) | 250 ppm<br>(460 mg/m$^3$) | 150 ppm<br>(280 mg/m$^3$) | 120 ppm<br>(220 mg/m$^3$) |

*Source: US EPA (2008)*

The AEGL-1 (non-disabling exposure level) was based on NOAEL for histopathological lesions of the nasal passages of rats following exposure to 100 ppm for six hours/day over 13 weeks, where no nasal lesions were observed (Mitchell et al., 1982). Inter- and intraspecies uncertainty factors of 3 each were applied for a total UF of 10, in accordance with the NRC (2001). The value of 10 ppm was not time-scaled as there is an adaptation to the mild irritation that defines the AEGL-1.

The AEGL-2 (disabling exposure level) was based on a study by Gross et al. (1987), in which rats were exposed to 175 ppm DMA for six hours/day and showed extensive nasal lesions. A total UF of 10 was applied, with UFs of 3 for the inter- and intraspecies uncertainty. Additionally, an adjustment value of 0.5 was applied as the effect was considered mild and below the definition of an AEGL-2 effect. Time-scaling was performed using the relationship $C^n \times t = k$ (ten Berge et al., 1986), where n = 2.8 as derived from a linear regression of $LC_{50}$ studies.

The AEGL-3 (lethal exposure level) was based on a 2-hour $BMCL_{05}$ of 1978 ppm for mice, where internal organ haemorrhages were observed. A total UF of 10, with an UF of 3 for species variability and 3 for human variability was applied, and time-scaling was performed as per ten Berge et al. (1986).

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[3] Modified Haber's law is used by REACH for time extrapolation when the exposure period for the point of departure is different to the desired HGBV exposure period. The law is $c^n * t = k$ where c is concentration, n is an exponent (n = 1 for extrapolating from shorter to longer exposure durations, n=3 for longer to shorter durations), t is the exposure time and k is a constant. The calculation by REACH to derive the adjusted NOAEC was as follows: $184.85\ ^3\ mg/m^3 \times 6\ hours\ = 37897417.4\ ;\ \sqrt[3]{\frac{37897417.4}{0.25\ hours}} = 533.2\ mg/m^3$

[4] Uncertainty factors (UFs), also known as safety factors or assessment factors, are numerical factors used to account for uncertainty when extrapolating data to derive HBGVs. When setting an UF, consideration is usually given to interspecies variability, intraspecies variability, point of departure used to derive the HBGV, completeness of the database, and steepness of the dose response curve. See Appendix A for further detail.

## 7.3 Health and Safety Executive

The HSE (2020) state a 15-minute short term exposure limit (STEL) of 11 mg/m$^3$ in their latest workplace exposure limits guidance. This has been highlighted since it is UK authoritative guidance. However, it is unclear how this was derived and the study on which it was based.

# 8 HBGVs for long-term exposure

The sections below outline the HBGVs which have been proposed for long-term exposure of DMA by the industry REACH dossier and the HSE.

## 8.1 REACH chemical dossier

ECHA derived 2 long-term REACH DNELs for inhalation for the general population, one systemic and one local. Both derivations were obtained from the findings of Buckley et al. (1985) study. Buckley et al. observed a LOAEC of 18.5 mg/m$^3$ (10 ppm) based on exposure six hours per day, five days per week for one year. Lesions in the nasal passageways of the rats and mice were the only effect observed at this concentration.

ECHA applied the UF of 30 to the LOAEC (10 for intraspecies differences and 3 for the use of LOAEC) to derive the local DNEL of 0.615 mg/m$^3$. ECHA did not correct for continuous exposure when calculating the local DNEL but it is unknown why.

The derived systemic REACH DNEL of 0.33 mg/m$^3$ is based on the NOAEC for systemic effects of 92.26 mg/m$^3$ (presumed to be from Mitchell et al. 1982). The NOAEC is corrected for continuous exposure, and an uncertainty factor of 50 is used (2 for extrapolation of subchronic to chronic exposure duration, 2.5 for interspecies differences, and 10 for intraspecies differences).

## 8.2 The HSE

In 2020, the HSE outlined a long-term exposure limit (8-hour TWA ref period) of 3.8 mg/m$^3$. This value was based on a SCOEL recommendation (SCOEL, 1991) which was derived from a CIIT study (CIIT, 1990), where a LOAEC of 10 ppm (18.5 mg/m$^3$) was observed. The CIIT (1990) study was the continuation of the Buckley et al. (1985) study for a further year. Therefore, the LOAEC was based on exposure for six hours per day, five days per week for two years. An UF of 5 was applied to calculate the workplace exposure limit (WEL) to account for absence of human data and use of LOAEC.

# 9 Summary

Although the overall toxicological database is small, several authoritative organisations have proposed HBGVs for DMA.

Short-term exposure guidelines have been proposed by the industry REACH dossier and US EPA (2008) based on nasal irritation observed in rats. Table 2 shows a summary of these guidance values.

*Table 2: Summary of health-based guidance values for short-term exposures*

| **Guideline** | **Value (mg/m$^3$)** | **Duration** | **Critical effect** | **Pivotal reference(s)** |
|---|---|---|---|---|
| Current EAL | None | - | - | - |
| REACH DNEL | 21.33 | 15 minutes | Irritation | Mitchell et al. 1982 (assumed) |
| AEGL-1 | 18 | 10 mins to 8 hours | Irritation | Mitchell et al. 1982 |
| HSE STEL | 11 | 15 minutes | Unknown | Unknown |

Long-term chronic exposure guidelines have been proposed by the industry REACH dossier and HSE (2020) based on nasal irritation and depressed weight gain observed in rats. Table 3 shows a summary of these guidance values.

*Table 3: Summary of health-based guidance values for long-term exposures*

| **Guideline** | **Value (mg/m$^3$)** | **Duration** | **Critical effect** | **Pivotal reference(s)** |
|---|---|---|---|---|
| Current EAL | None | - | - | - |
| REACH DNEL (systemic) | 0.33 | 24 hours | Decreased body weight gain | Buckley et al. 1985 |
| REACH DNEL (local) | 0.615 | 24 hours | Irritation | Buckley et al. 1985 |
| SCOEL/HSE LTEL | 3.8 | 8 hours, 5 days a week | Irritation | CIIT 1990 |

# 10 Recommendations

## 10.1 Short-term EAL

The primary acute effect from short-term inhalation exposure of DMA is considered to be upper respiratory tract irritation. The HSE (2020) HBGV was not considered in determining the appropriate EAL value due to insufficient detail on the pivotal reference. The ECHA REACH DNEL and the US EPA AEGL-1 both used the same pivotal study: Mitchell et al. (1982). In this study, the rats were exposed to DMA for six hours a day, five days a week, for 90 days. The test concentrations were 0, 10, 30, or 100 ppm DMA, and there were 10 rats per sex per dose group.

Both ECHA and US EPA used the NOAEC of 100 ppm as the point of departure. However, the HBGVs are slightly different as a result of different UFs being applied, and ECHA's use of modified Haber's law to the NOAEC to adjust for a 15-minute exposure period. The US EPA did not adjust for time scale due to irritation being a concentration dependent effect over shorter periods. To be consistent with the Environment Agency's (EA's) 2009 guidance on assessment of contaminants in soil, it is proposed that the UF of 100 (10 for interspecies variation, 10 for intraspecies variation) is instead applied to the NOAEC with no adjustment for time scale For more detail about UFs, see Appendix A. This would provide the short term EAL of 1.8 mg/m$^3$. However, this is significantly higher than 24 * the long term EAL. Therefore, in accordance with the EA guidance (2020) on compliance constraints for threshold effects, a short term EAL is not recommended.

## 10.2 Long-term EAL

The critical health effects from long-term inhalation exposure of DMA are considered to be upper respiratory tract irritation and depressed weight gain. The proposed EAL of 0.0033 mg/m$^3$ is derived from the LOAEC that was used to derive the HSE (2020) WEL, since this was used by a UK authoritative body. The pivotal study used to derive the REACH DNEL, Buckley et al. (1985) is the first-year portion of the two-year CIIT (1990) study that was used to derive the HSE (2020) WEL. In these studies, male and female F344 rats and B6C3F1 mice were subjected to inhalation exposure of 0, 10, 50, or 175 ppm dimethylamine (DMA) for six hours a day, five days a week. Groups of 9-10 male and female rats and mice underwent necropsy after 6, 12, 18 and 24 months of exposure.

The point of departure used by ECHA to derive the REACH DNEL and the HSE to derive the WEL was the same. Differences in the HGBVs are the result of different UFs being used and the values applying to different time periods. To derive the long term EAL of 0.0033 mg/m$^3$, it is proposed that an UF of 1000 is used after correcting the LOAEC of 18.5 mg/m$^3$ for continuous exposure $(LOAEC \times \frac{6\ hours}{24\ hours} \times \frac{5\ days}{7\ days} = 3.33\ mg/m^3)$. The UF accounts for the following uncertainties: 10 for interspecies variation, 10 for intraspecies variation, and 10 for use of a LOAEC. This uncertainty factor was chosen in line with the EA 2009 guidance on assessment of contaminants in soil. For more detail about UFs, see Appendix A.

## 10.3 Summary

Table 4 summarises the recommended EALs as described in sections 10.1 and 10.2.

*Table 4: Recommended EALs for DMA*

| | |
|---|---|
| Short-term EAL | None - (constrained by compliance with the long-term EAL) |
| Long-term EAL | 0.0033 mg/m$^3$ as a 24-hour mean |

*Source: Fichtner*

# Appendices

# A Uncertainty factors

Uncertainty factors, also known as safety factors or assessment factors, are numerical factors used to account for uncertainty when extrapolating data to derive health-based guidance values (HBGVs). There are differences in the approach to the application of the uncertainty factors among groups that derive HBGVs.

Table 5 provides examples of the typical uncertainty factors used in chemical risk assessment, highlighted in the EA's 2009 guidance on assessment of contaminants in soil (EA, 2009).

*Table 5: Examples of uncertainty factors used in chemical risk assessment*

| **Consideration** | **Typical uncertainty factor applied** |
|---|---|
| Interspecies variability | A 10-fold factor is normally used to account for variability in species susceptibility between humans and the animal species in which the chemical was tested. |
| Intraspecies variability | A 10-fold factor is normally used to account for variability of responses in human populations which may not be present in the inbred strains of animals used for toxicity testing. |
| LOAEL to NOAEL | A 10-fold factor may be used when a LOAEL instead of a NOAEL is used in the derivation. For a minimal LOAEL, an intermediate factor of three may be used. It is inappropriate to use a LOAEL if the NOAEL is likely to be more than 10 times less than the NOAEL. |
| Data gaps | A factor, usually 3- to 10-fold, may be used for "incomplete" databases (with missing studies, such as no chronic bioassays or no reproductive toxicity data). It accounts for the inability of any study to consider all toxic endpoints. |
| Steep dose-response curve | Where the dose-response curve is steep and a small error in the extrapolation would have dramatic consequences, an additional factor may be applied. |

*Source: Environment Agency (2009)*

# B Abbreviations and definitions

**AEGL -** Acute exposure guideline level

**AEGL-1**

The airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic, non-sensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure.

**AEGL-2**

The airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.

**AEGL-3**

The airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience life-threatening health effects or death.

**$BMCL_{05}$ -** Benchmark concentration, 95% lower confidence limit with 5% response

**CIIT -** Chemical Industry Institute of Toxicology

**CRT -** Choice reaction time

**DMA -** Dimethylamine

**DNA -**Deoxyribonucleic acid

**DNEL -** Derived no-effect level

**EAL -** Environmental assessment level

**ECHA -** European Chemicals Agency

**EEG -** Electroencephalogram

**HBGV -** Health-based guidance value

**HSE -** Health and Safety Executive

**$LC_{50}$ -** Lethal concentration 50

**$LD_{50}$ -** Lethal dose 50

**LOAEL/C -** Lowest observed adverse effect level / concentration

**LTEL -** Long term exposure limit

**MAK -** Maximale Arbeitsplatz-Konzentration (maximum workplace concentration)

**NDMA -** N-nitrosodimethylamine

**NIOSH -** National Institute for Occupational Safety and Health

**NIPH -** Norwegian Institute of Public Health

**NOAEL/C -** No observed adverse effect level / concentration **UF - Uncertainty factor**

**US EPA - United States Environmental Protection Agency**

**WEL -** Workplace exposure limit

**WHO -** World Health Organisation

# C References

(2012). Dimethylamine [MAK Value Documentation, 1996]. In The MAK-Collection for Occupational Health and Safety (eds and ).

Bittersohl, G. and H. Heberer. 1980. [Results of job site and urine analyses in exposure to aliphatic amines] [Article in German]. Z. Ges. Hyg. 26: 258-259.

Buckley LA, Morgan KT, Swenberg JA, James RA, Hamm TE Jr, Barrow CS. 1985. The toxicity of dimethylamine in F-344 rats and B6C3F1 mice following a 1-year inhalation exposure. Fundam Appl Toxicol 1985;5:341-52.

CIIT (Chemical Industry Institute of Toxicology). 1990. Twenty four month final report. Inhalation toxicity of dimethylamine in F-344 rats and B6C3F1 mice and third party audit report summary. Report issued June 15, 1990.

Darad, R., De, A.K. and Aiyar, A.S., 1983. Toxicity of nitrite and dimethylamine in rats. Toxicology Letters, 17(1-2), pp.125-130.

ECHA dossier. European Chemicals Agency toxicology summary for dimethylamine (CAS number 124-40-3)

Environment Agency. 2009. Human health toxicological assessment of contaminants in soil.

Environment Agency. 2012. Using our 2012 methodology to derive new Environmental Assessment Levels for emissions to air.

Fay LB, et al. 1997. Urinary excretion of 3-methyladenine after consumption of fish containing high levels of dimethylamine. Carcinogenesis 1997;18:1039-44.

Green NR, Savage JR. 1978. Screening of safrole, eugenol, their ninhydrin positive metabolites and selected secondary amines for potential mutagenicity. Mutat Res 1978;57:115-21.

Gross, E.A., D.L. Patterson, and K.T. Morgan. 1987. Effects of acute and chronic dimethylamine exposure on mucociliary apparatus in the nose of the F-344 rat. Toxicol. Appl. Pharmacol. 90: 359-376.

HSE. 2020. EH40/2005 Workplace exposure limits. Available at https://www.hse.gov.uk/pubns/priced/eh40.pdf. Accessed on 1st November 2023.

McNulty, M J, and H D Heck. 1983. Disposition and pharmacokinetics of inhaled dimethylamine in the Fischer 344 rat. Drug metabolism and disposition: the biological fate of chemicals vol. 11,5: 417-20.

Mellerio, J. and Weale, R.A., 1966. Hazy vision in amine plant operatives. Occupational and Environmental Medicine, 23(2), pp.153-154.

Mitchell, R.I., K.L. Pavkov, W.D. Kerns, and M.M. Connell. 1982. Final Report on a 90-day inhalation toxicology study in rats exposed to dimethylamine. Conducted by Battelle Laboratories, Columbus OH, for the CIIT. CIIT Docket #216N2. Submitted to U.S. EPA 02/03/1983; Doc. ID FYI-OTS-0282-0213SU.

NIOSH, 1994. Immediately Dangerous To Life or Health (IDLH) Values – Dimethylamine.

NIPH, 2011. Health Effects of Amines and Derivatives Associated with CO2 Capture: Nitrosamines and Nitramines. Norwegian Institute of Public Health: Oslo.

NRC (National Research Council). 2001. Standing Operating Procedures for Developing Acute Exposure Guideline Levels for Hazardous Chemicals. Washington, DC: National Academy Press.

SCOEL (Scientific Committee on Occupational Exposure Limits). 1991. Recommendation from Scientific Expert Group on Occupational Exposure Limits for Dimethylamine

Simenhoff, M.L., H.E. Ginn, and P.E. Teschan. 1977. Toxicity of aliphatic amines in uremia. Trans. Am. Soc. Artif. Intern. Organs 23: 560-565.

Steinhagen, W. H., J. A. Swenberg, C. S. Barrow. 1982. Acute inhalation toxicity and sensory irritation of dimethylamine, Am. Ind. Hyg. Assoc. J. 43, 411

ten Berge, W.F., A. Zwart and L.M. Appelman. 1986. Concentration-time mortality response relationship of irritant and systemically acting vapors and gases. J. Haz. Mat. 13:302-309.

Tricker AR, Pfundstein B, Kalble N, Preussmann R. 1992. Secondary amine precursors to nitrosamine in human saliva, gastric-juice, blood, urine and feces. Carcinogenesis 1992;40:563-8.

US EPA, 2008. Acute Exposure Guideline Levels (AEGLs) for Dimethylamine.

Varma, D. R., I. Guest, S. Smith, S. Mulay. 1990. Dissociation between maternal and fetal toxicity of methyl isocyanate in mice and rats, J. Toxicol. Environm. Health 30, 1

Zeiger E, Anderson B, Haworth S, Lawlor T, Mortelmans K, Speck W. 1987. Salmonella Mutagenicity Tests: iii. Results From The Testing Of 255 Chemicals. Environ Mutagen 1987;9(Suppl.9):1-109.

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# Protos ERF Carbon Capture

Derivation of environmental assessment levels for diethanolamine (DEA)

## 1 Diethanolamine (CAS Number 111-42-2)

Diethanolamine (DEA) is a colourless, viscous liquid with a mild ammonia odour (IARC, 2000). It is highly soluble in water and non-flammable (ECHA Dossier). In industry, DEA is used as an emulsifier and dispersing agent for agricultural chemicals and as an intermediate in the rubber chemical industry. DEA is also used in the manufacture of a range of consumer products, such as shampoos, cosmetics, and pharmaceuticals (US EPA, 2016). DEA is readily biodegradable in the environment (Gannon et al. 1978) and has an estimated phototransformation half-life in air of about four hours.

## 2 Regulatory standards

- None

## 3 Recommended environmental assessment level (EAL) in air

- Long-term EAL – 0.0002 mg/m$^3$ as a 24-hour mean.
- Short-term EAL – none recommended due to insufficient evidence.

## 4 Overview

There are few authoritative reviews on the adverse effects from exposure to DEA. According to the industry registration, evaluation, authorisation and restriction of chemicals (REACH) dossier, the American Conference of Government Industrial Hygienists (ACGIH) and the Office of Environmental Health Hazard (OEHHA) the primary adverse effects are:

1. as an ocular and skin irritant (US EPA, 2016); and
2. as a disruptor of the metabolism of lipids which has been shown to cause systemic toxicity in the nervous system, liver, kidney and blood system in rodents (OEHHA, 2008).

## 5 Toxicokinetics

Exposure of the general public to DEA is most common via the dermal route through use of consumer products containing DEA (IARC, 2012).

Occupational exposure may occur by inhalation from the use of lubricants containing DEA which are used in machine building and metallurgy (US EPA, 2016). DEA is also absorbed via the oral route. Whilst there is limited quantitative data on human absorption of DEA, absorption by mammals was assessed by Mathews et al. (1997) who found that DEA is well absorbed following oral administration in rats (57%) and absorbed to a lesser degree through the skin (3-16% in rats and 25-60% in mice). Moreover, the higher the concentration of DEA applied to the skin, the higher the quantity of DEA that was absorbed. The route of absorption was not observed to affect the distribution of DEA in tissues.

Pharmocokinetic studies revealed that DEA is incorporated into membrane phospholipids and interacts with lipid metabolism, for example by inhibiting the incorporation of choline and ethanolamine into phospholipids in rat liver and kidneys (IARC, 2000). DEA is primarily excreted in urine, with lesser amounts excreted in faeces (IARC, 2012). It is eliminated from tissues with a half-life of approximately six days (Mathews, 1997). Whilst the majority of DEA is not metabolised and is excreted, small proportions of O-phosphorylated and N-methylated metabolites are produced, notably N-methyldiethanolamine (N-MDEA) and N,N-dimethyldiethanolamine (N,N-DMDEA) (PubChem, 2023).

# 6 Short- and long-term exposures

There have been no controlled or epidemiological studies of chronic DEA exposure in humans (OEHHA, 2001), although there has been a single report of occupational asthma due to handling of a cutting fluid containing DEA (Piipari et al., 1998). Bronchial provocation tests were performed with the cutting fluid and DEA aerosol at two different concentrations below the ACGIH threshold limit value of 2 mg/m$^3$ (ACGIH, 2022). DEA was found to cause asthmatic airway obstruction at both concentrations; however, IgE-antibodies for DEA were not found.

DEA replaces choline in phospholipids, interfering with lipid metabolism (Blum et al., 1972). By blocking choline uptake and competing for utilisation in the CDP-choline pathway, DEA reversibly inhibits phosphatidylcholine synthesis (Lehman-McKeeman and Gamsky, 1999). These effects can cause systemic toxicity to occur in various tissues including the nervous system, liver, kidney and blood system (OEHHA, 2008).

The National Toxicology Program (1992) conducted toxicology studies of DEA on Fischer 344 rats and B6C3F1 mice[1] of both sexes to compare the effects of oral and dermal exposure. Rats and mice were given drinking water containing DEA in concentrations up to 10,000 ppm for durations of either 2 or 13 weeks. Rats and mice of both sexes in the 10,000 ppm group died before the end of the two-week study, with female rats also dying but at a lower concentration of 5,000 ppm. Rats receiving DEA developed poorly regenerative, microcytic anaemia in both studies, and depressed weight gains in the higher concentration groups. In the two week study, male and female rats showed renal tubular cell necrosis and decreased renal function, whilst in the 13-week study, rats also showed increased incidences and severity of nephropathy, tubular necrosis, mineralisation and demyelination in the medulla oblongata and spinal cord. In mice, dose-dependent increases in liver weight were observed in the 2-week study, as well as cytologic alternation and necrosis of individual hepatocytes in the highest dose group. Other conditions were observed in the 13-week study, including degeneration of cardiac myocytes and hepatocellular necrosis.

The same report (NTP, 1992) discussed 2 and 13-week dermal studies of rats and mice. Doses of DEA were administered in 95% ethanol in concentrations up to 2,500 mg/kg, five days per week. Early deaths of all rodents occurred in the two week study at the highest dose groups, and body weight gains were also reduced in the higher dermal dose groups. The symptoms shown by the rats and mice were largely comparable to those observed in the oral studies, however rats in the dermal

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[1] These are common inbred rats and hybrid strains of mice which are available commercially for use in toxicological studies.

studies also exhibited ulcerative skin lesions at the site of application, accompanied by inflammatory cell infiltration, hyperkeratosis and acanthosis of the epidermis. Ulceration was also observed in mice at the site of application, and where mice had been given lower doses of DEA, acanthosis without ulceration or inflammatory cell infiltration was observed.

There is very limited research on the neurotoxicity of DEA. In a study of the inhalation toxicity of DEA, Wistar rats were exposed to a liquid aerosol of DEA at concentrations up to 400 mg/m$^3$ for six hours daily over a course of 90 days (Gamer et al., 2008). There were a few isolated differences in motor activity between the treated animals and the control group, however, the authors considered these incidental. They concluded that no neurotoxic effects were induced by DEA in the study.

Evidence for developmental and reproductive effects in humans from DEA has not been reported (IARC, 2000). Marty et al. (1999) painted an aqueous solution of DEA on the skin of rats on days 6 – 15 of gestation at doses of 0, 150, 500 and 1,500 mg/kg body weight (bw) per day. The two higher dose levels caused severe skin irritation, but there was no effect on foetal weight, and no external, visceral or skeletal abnormalities were induced. However, at the highest dose level, delayed ossification of the axial skeleton and distal appendages were observed in foetuses. Degeneration of seminiferous tubules and reduced sperm count was observed in a 13-week subchronic study where male rats were given drinking water with a DEA concentration of 2500 ppm (Melnick et al., 1994).

## 6.1 Genotoxicity and carcinogenicity

DEA was tested for mutagenicity in several in vivo and in vitro studies. Male and female mice were administered DEA once per day to the uncovered skin in concentrations up to 600 mg/ml for 13 weeks. No induction of micronuclei was noted at any dose level (NTP, 1999). No sister chromatid exchanges or chromosomal aberrations were observed in cultured Chinese hamster ovary cells exposed to DEA at concentrations from 150 – 1,500 µg/ml (Loveday, 1989). In a study of the effects of DEA in bacterial mutation assays, no mutagenic effect was observed in Salmonella typhimurium or Escherichia coli (Dean et al., 1985).

In a rodent oncogenicity study by the National Toxicology Program (1999), where ethanolic DEA solutions were received topically by rats and mice in concentrations up to 64 mg/kg bw and 160 mg/kg bw, respectively, no evidence of carcinogenic activity of diethanolamine in male or female rats was found after the 2-year dermal study. However, for both male and female mice, the incidences of hepatocellular adenoma and carcinoma were significantly higher in dosed groups compared to the control. Renal tubule adenoma was also observed in male mice at the high dose level at a low incidence. The liver tumours were considered to be directly related to the increase in cellular proliferation rate due to enzyme induction, weak peroxisome proliferation and choline depletion. Based on the increased S-phase synthesis observed in the kidney, it is suggested that a non-genotoxic mode of action involving choline deficiency is responsible for the benign kidney tumours (ECHA Dossier). B6C3F1 mice are highly sensitive to non-genotoxic effects and have shown a high incidence of spontaneous liver tumours. Short term tests on the carcinogenicity of DEA found no carcinogenic effects in mice (Spalding et al., 2000). Mechanistic research on DEA indicates that the mechanism by which DEA can potentially induce tumours in mice is not relevant to humans, and therefore, based on the available data, DEA is not considered carcinogenic for humans (ECHA Dossier).

## 6.2 Pivotal studies

The Gamer et al. (1996) study was summarised by California Environmental Protection Agency's Office of Environmental Health Hazard Assessment (OEHHA) in their 2008 Technical Supporting Document for Non cancer RELs Appendix D3. The Gamer et al. (1996) study was used as the basis for the OEHHA chronic reference exposure limit (REL) to DEA of 0.003 mg/m$^3$.

In their study, Gamer et al. (1996) exposed groups of 26 Wistar rats (13 per sex) to a liquid aerosol of DEA for six hours daily, five days a week, for 90 days at concentrations of 15 mg/m$^3$, 100 mg/m$^3$ and 400 mg/m$^3$. There was no functional or morphological evidence of neurotoxicity.

Body weight gain reduction was observed in males exposed to the highest dose. At low doses, no systemic effects were evident, while the high concentration dose group displayed systemic effects in the liver, kidney, male reproductive system, and red blood cells. In the mid-dose group, mild effects on the liver and kidney were observed. Both the high and mid-dose groups exhibited local irritation of the larynx and trachea, with laryngeal irritation also noted in the low dose group. According to this study, 15 mg/m$^3$ represents a NOAEL for liver and kidney effects, and a LOAEL for laryngeal irritation.

The Gamer et al. (2008) study was used as the basis for the United States Environmental Protection Agency's (US EPA) 2012 chronic inhalation provisional reference concentration (p-RfC) of 0.0002 mg/m$^3$. In their 2008 work, two separate nose-only inhalation experiments took place. In the first study, groups of 26 Wistar rats (13 per sex) were exposed to a liquid aerosol of DEA for 6-hours a day, 5-days a week, for 90 days at concentrations of 0 mg/m$^3$, 15 mg/m$^3$, 150 mg/m$^3$ and 400 mg/m$^3$. In the second, groups of 20 Wistar rats (10 per sex) were exposed to aerosolised DEA at concentrations of 0 mg/m$^3$, 1.5 mg/m$^3$, 3 mg/m$^3$ and 8 mg/m$^3$ for 6 hours a day, 5-days a week for 90 days.

In the first study, systemic toxicity was induced at 150 mg/m$^3$ and 400 mg/m$^3$. Body and organ weight changes were observed, as well as histopathological changes suggesting mild blood, liver, kidney and testicular effects. At all concentrations, metaplasia at the base of the epiglottis was observed. At 150 mg/m$^3$ and 400 mg/m$^3$ concentration-dependent increase in squamous laryngeal hyperplasia was observed, and increased incidence and severity of inflammation in the larynx and trachea.

In the second study, respiratory irritation was observed at concentrations at and above 3 mg/m$^3$. This was demonstrated by reversible metaplasia at the base of the epiglottis and inflammation extending into the trachea. No treatment related histopathological changes in the larynx were observed at 1.5 mg/m$^3$ exposure, making this concentration the no adverse effect concentration (NOAEC) for local irritation.

In both the Gamer et al. (2008) studies, no evidence of neurotoxicity was present.

# 7 Health based guidance values (HBGVs) for short-term exposure

There are no appropriate known HBGVs for short-term exposure to DEA. The European Chemicals Agency (ECHA) dossier does not derive a short-term derived no effect level (DNEL) for short-term exposure stating that there is "low hazard". The justification for this statement is unclear.

# 8 HBGVs for long-term exposure

The ECHA dossier, US EPA (2012) and California Environmental Protection Agency's Office of Environmental Health Hazard Assessment (OEHHA) (2001) have proposed HBGVs for long-term exposure to DEA.

## 8.1 ECHA chemical dossier

ECHA chemical dossier has stated a long term DNEL for the general population of 0.125 mg/$m^3$ for inhalation exposure to DEA. This is based on an unnamed study conducted in 2002 submitted under the REACH application for DEA. In the 2002 90-day sub-chronic study, a NOAEC of 3 mg/$m^3$ was observed for DEA exposure six hours daily, five days a week (65 exposures in the 90-day period).

The REACH DNEL for the general population was calculated by adjusting a DNEL for local effects already derived for workers. The workers DNEL of 0.5 mg/$m^3$ was derived by applying an uncertainty factor (UF) of 6 to the NOAEC of 3 mg/$m^3$: 2 for extrapolation of sub-chronic to chronic duration of exposure and 3 for intraspecies differences. This DNEL was based on local effects of respiratory tract irritation. The calculation of the DNEL for the general population from the workers DNEL was as follows:

$$0.5\, mg/m^3 \times \frac{10\, m^3}{20\, m^3} \times \frac{5}{10} = 0.125\, mg/m^3.$$

The 10 $m^3$/ 20 $m^3$ factor was due to the assumption that the respiratory volume of workers over an 8-hour period would be 10 $m^3$ while the respiratory volume of the general population would be 20 $m^3$ over 24-hours. The ECHA chemical dossier states that the 5/10 factor was used because an UF of 5 was applied for intraspecies differences in the workers calculation, whereas an UF of 10 would be applied for intraspecies differences in the general population. However, it appears that the factor applied for intraspecies differences in the workers calculation was actually 3.

It is possible that the DNEL for the general population was meant to be calculated based on the systemic DNEL for workers which was 0.75 mg/$m^3$ (instead of the DNEL for local effects). In the derivation for the systemic DNEL for workers, the intraspecies portion of the UF was 5, which supports this theory. In this case, applying the same calculation as above to the 0.75 mg/$m^3$ value would result in a DNEL of 0.188 mg/$m^3$. However, there is not enough evidence to be confident in this.

## 8.2 California Environmental Protection Agency's Office of Environmental Health Hazard Assessment (OEHHA)

OEHHA (2001) proposed a chronic inhalation reference exposure limit (REL) of 0.003 mg/$m^3$ based on laryngeal lesions in Wistar rats in a sub-chronic study (Gamer et al., 1996). Gamer et al. (1996) observed a lowest adverse effect (LOAEC) of 15 mg/$m^3$ for exposure to DEA 6 hours / day, 5 days / week for 90 days. The OEHHA (2001) corrected the observed LOAEC for equivalent continuous exposure, to obtain 2.7 mg/$m^3$ $(15\, mg/m^3 \times \frac{6\, hours}{24\, hours} \times \frac{5\, days}{7\, days} = 2.7\, mg/m^3)$. The OEHHA then applied an UF[2] of 1000 based on: 3 for use of LOAEC instead of NOAEC, 3 for subchronic length of study, 10 for interspecies uncertainty and 10 for intraspecies uncertainty. The OEHHA remarked

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[2] Uncertainty factors (UFs), also known as safety factors or assessment factors, are numerical factors used to account for uncertainty when extrapolating data to derive HBGVs. When setting an UF, consideration is usually given to interspecies variability, intraspecies variability, point of departure used to derive the HBGV, completeness of the database, and steepness of the dose response curve. See page 13 for further detail.

that the use of a sub-chronic study was due to the absence of chronic inhalation studies in the peer-reviewed literature.

## 8.3 United States Environmental Protection Agency (US EPA)

The US EPA (2012) has issued a p-RfC for inhalation exposure to DEA of 0.0002 mg/m$^3$. The p-RfC is based on a sub-chronic rat inhalation study performed by Gamer et al., (2008). There were no chronic inhalation studies available to consider. In the 90-day Gamer et al. (2008) study, a NOAEC of 1.5 mg/m$^3$ was observed for 6-hour exposure on 65 days.

Using the incidence data from the Gamer et al. (2008) study, the US EPA (2012) performed a benchmark concentration (BMC) analysis. To do this, each concentration used in the study (0 mg/m$^3$, 1.5 mg/m$^3$, 3.0 mg/m$^3$, 8.0 mg/m$^3$) was corrected for continuous exposure. Following this, dosimetric adjustment factors (DAFs) were calculated to obtain the human equivalent concentration (HEC). These are factors that account for the regional deposited dose ratio (RDDR) for particles in various regions of the respiratory tract. The DAFs were calculated using the EPA's RDDR software. For each concentration, a DAF was calculated for males and females separately, and for both respiratory (in the tracheobronchial region) and extra-respiratory effects (such as increases in relative liver weight). This meant that for each concentration, 4 DAFs were calculated.

Each DAF was then multiplied by the appropriate adjusted concentration, which generated the HECs. All HECs, for all concentrations tested, both sexes, and for both respiratory and extra-respiratory effects, were then used as inputs to the BMC analysis using EPA BMDS (version 2.1.1) (U.S. EPA, 2011). For both respiratory and extra-respiratory effects, models were fitted to the data to produce benchmark concentrations for the lower confidence limit at 10% extra risk ($BMCL_{10HEC}$) and benchmark concentrations at 10% extra risk ($BMC_{10HEC}$).

Based on respiratory and extra-respiratory effects of the BMDS modelling output, a $BMCL_{10HEC}$ of 0.63 mg/m$^3$ from respiratory effects in male rats was selected as the point of departure for derivation of the chronic p-RfC. This was lower than the $BMCL_{10HEC}$ of 2.03 mg/m$^3$ from extra respiratory effects. The $BMCL_{10HEC}$ of 0.63 mg/m$^3$ would therefore be protective for both respiratory and extra-respiratory effects in both sexes (US EPA, 2012).

To derive the chronic p-RfC, the US EPA (2012) applied an UF of 3000 to the $BMCL_{10HEC}$ of 0.63 mg/m$^3$ (3 for the toxicodynamic portion of interspecies differences not addressed by use of DAFs, 10 for intraspecies differences, 10 for extrapolation from a sub-chronic duration of study, and 10 for lack of data in the toxicological database). The resultant value was 0.0002 mg/m$^3$.

# 9 Summary

Although the overall toxicological database is small, several authoritative organisations have proposed HBGVs for long term exposure to DEA.

Long-term chronic exposure guidelines have been proposed by the ECHA dossier, the OEHHA (2001) and the US EPA (2012) based on respiratory tract irritation in rats. Table 1 shows a summary of these guidance values.

*Table 1: Summary of HBGVs for long-term exposures*

| **Guideline** | **Value ($mg/m^3$)** | **Duration** | **Critical effect** | **Pivotal reference(s)** |
|---|---|---|---|---|
| Current EAL | None | - | - | - |
| REACH DNEL general population | 0.125 | 24 hours | Respiratory tract irritation | Unnamed 2002 study |
| OEHHA REL | 0.003 | 24 hours | Respiratory tract irritation | Gamer et al. 1996 |
| US EPA p-RfC | 0.0002 | 24 hours | Respiratory tract irritation | Gamer et al. 2008 |

# 10 Recommendations

## 10.1 Short-term EAL

No short-term EAL is proposed due to insufficient evidence.

## 10.2 Long-term EAL

The critical health effect from long-term inhalation exposure to DEA is considered to be respiratory tract irritation. The proposed EAL of 0.0002 $mg/m^3$ is based on the US EPA chronic p-RfC for inhalation exposure to DEA. The pivotal study used to derive the p-RfC was Gamer et al. (2008). In the relevant portion of this study, groups of 20 Wistar rats (10 per sex) were exposed to aerosolised DEA at concentrations of 0 $mg/m^3$, 1.5 $mg/m^3$, 3 $mg/m^3$ and 8 $mg/m^3$ for six hours daily, five days a week for 90 days. In this study, a NOAEC of 1.5 $mg/m^3$ was observed for irritation to the respiratory tract.

The US EPA (2012) applied BMC analysis to derive the point of departure for the p-RfC, which was the $BMCL_{10HEC}$ of 0.63 $mg/m^3$ from respiratory effects in male rats. The UF of 3000 was then applied to derive the p-RfC. This UF is in line with EA guidance on use of UFs, as described in Appendix A. This HBGV was selected in preference to the OEHHA (2001) REL of 0.003 $mg/m^3$, because the Gamer et al. (2008) study tested lower concentrations of DEA exposure and derived the NOAEC of 1.5 $mg/m^3$, while the OEHHA REL was based on the Gamer et al. (1996) LOAEC of 15 $mg/m^3$. Additionally, BMC analysis was confirmed by the European Food Safety Authority (EFSA) Scientific Committee to be a scientifically more advanced approach than applying NOAECs. This is because it makes extended use of the dose–response data and accounts for statistical limitations in the data (EFSA, 2017).

The REACH DNEL of 0.125 mg/m$^3$ was not considered for the long-term EAL due to insufficient information on the study from which it was derived and inconsistencies in the calculation.

## 10.3 Summary

*Table 2: Recommended EALs for DMA*

| | |
|---|---|
| **Short-term EAL** | None (insufficient evidence) |
| **Long-term EAL** | 0.0002 mg/m$^3$ as a 24-hour mean |

*Source: Fichtner*

# Appendices

# A Uncertainty factors

Uncertainty factors, also known as safety factors or assessment factors, are numerical factors used to account for uncertainty when extrapolating data to derive health-based guidance values (HBGVs). There are differences in the approach to the application of the uncertainty factors among groups that derive HBGVs.

Table 3 provides examples of the typical uncertainty factors used in chemical risk assessment, highlighted in the Environment Agency's 2009 guidance on assessment of contaminants in soil (Environment Agency, 2009).

*Table 3: Examples of uncertainty factors used in chemical risk assessment*

| Consideration | Typical uncertainty factor applied |
|---|---|
| Interspecies variability | A 10-fold factor is normally used to account for variability in species susceptibility between humans and the animal species in which the chemical was tested. |
| Intraspecies variability | A 10-fold factor is normally used to account for variability of responses in human populations which may not be present in the inbred strains of animals used for toxicity testing. |
| LOAEL to NOAEL | A 10-fold factor may be used when a LOAEL instead of a NOAEL is used in the derivation. For a minimal LOAEL, an intermediate factor of three may be used. It is inappropriate to use a LOAEL if the NOAEL is likely to be more than 10 times less than the NOAEL. |
| Data gaps | A factor, usually 3- to 10-fold, may be used for "incomplete" databases (with missing studies, such as no chronic bioassays or no reproductive toxicity data). It accounts for the inability of any study to consider all toxic endpoints. |
| Steep dose-response curve | Where the dose-response curve is steep and a small error in the extrapolation would have dramatic consequences, an additional factor may be applied. |

*Source: Environment Agency (2009)*

# B Abbreviations and definitions

**ACGIH -** American Conference of Governmental Industrial Hygienists

**BMC -** Benchmark concentration

**BMC$_{10HEC}$ -** Benchmark concentration at 10% extra risk, human equivalent concentration

**BMCL$_{10HEC}$ -** Benchmark concentration for the lower confidence limit at 10% extra risk, human equivalent concentration

**CDP-choline -** Cytidine 5'-diphosphocholine

**DAF -** Dosimetric adjustment factors

**DEA** - Diethanolamine

**DNEL -** Derived no effect level

**EA -** Environment Agency

**EAL -** Environmental assessment level

**ECHA -** European Chemicals Agency

**EFSA -** European Food Safety Authority

**HBGV -** Health-based guidance value

**IARC -** International Agency for Research on Cancer

**IgE -** Immunoglobulin E

**LOAEC -** Lowest adverse effect concentration

**NOAEC -** No adverse effect concentration

**N-MDEA -** N-methyldiethanolamine

**N,N-DMDEA - N,N-dimethyldiethanolamine**

**NTP -** National Toxicology Program

**OEHHA -** (California) Office of Environmental Health Hazard Assessment

**Ppm -** Parts per million

**REACH -** Registration, evaluation, authorisation and restriction of chemicals

**REL -** Reference exposure limit

**UF -** Uncertainty factor

**US EPA -** United States Environmental Protection Agency

# C References

ACGIH. 2022. Diethanolamine. Accessed Nov. 17. 2023

Blum K, Huizenga CG, Ryback RS, Johnson DK, and Geller I. 1972. Toxicity of diethanolamine in mice. Toxicol. Appl. Pharmacol. 22:175-185

Dean, B.J., Brooks, T.M., Hodson-Walker, G. & Hutson, D.H. 1985. Genetic toxicology testing of 41 industrial chemicals. Mutat. Res., 153, 57–77

ECHA dossier. European Chemicals Agency toxicology summary for diethanolamine (CAS number 111-42-2)

EFSA. 2017. Use of the benchmark dose approach in risk assessment. EFSA Journal, 15(1):4658

Gamer, A.O., Mellert, W., Leibold, E., Deckard, K., Kaufman, W., and Hildebrand, B. 1996. Diethanolamin – Subchronic inhalation toxicity and neurotoxicity study in Wistar rats. 90-day liquid aerosol exposure-. BASF Project No. 50I0075/93011. Heidelberg, FRG: BASF.

Gamer, A.O., Rossbacher, R., Kaufmann, W., van Ravenzwaay, B. 2008. Food and Chemical Toxicology. 46: 2173-2183.

Gannon, J E et al. 1978. “Microbial degradation of diethanolamine and related compounds.” Microbios vol. 23,91: 7-18.

IARC. 2000. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans Volume 77: Diethanolamine

IARC. 2012. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). p. V101 128

Lehman-McKeeman LD, and Gamsky EA. 1999. Diethanolamine inhibits choline uptake and phosphatidylcholine synthesis in Chinese hamster ovary cells. Biochem. Biophys. Res. Commun. 262(3):600-604

Loveday, K.S., Lugo, M.H., Resnick, M.A., Anderson, B.E. & Zeiger, E. 1989. Chromosome aberrations and sister chromatid exchanges in Chinese hamster ovary cells in vitro. II. Results with 20 chemicals. Environ. mol. Mutag., 13, 60–94

Marty, M.S., Neeper-Bradley, T.L., Neptun, D.A. & Carney, E.W. 1999. Developmental toxicity of diethanolamine applied cutaneously to CD rats and New Zealand White rabbits. Regul. Toxicol. Pharmacol., 30, 169–181

Mathews, J M et al. 1997. “Diethanolamine absorption, metabolism and disposition in rat and mouse following oral, intravenous and dermal administration.” Xenobiotica; the fate of foreign compounds in biological systems vol. 27,7: 733-46.

Melnick, R.L., Mahler, J., Bucher, J.R., Thompson, M., Hejtmancik, M., Ryan, M.J. and Mezza, L.E. 1994. Toxicity of diethanolamine: 1. Drinking water and topical application exposures in F344 rats. J. appl. Toxicol., 14, 1–9

Mendrala, A L et al. 2001. “The pharmacokinetics of diethanolamine in Sprague-Dawley rats following intravenous administration.” Food and chemical toxicology vol. 39,9: 931-9.

National Toxicology Program (NTP). 1992. NTP technical report on the toxicity studies of Diethanolamine (CAS No. 111-42-2) Administered Topically and in Drinking Water to F344/N Rats and B6C3F1 Mice. Toxicity report series vol. 20: 1-D10.

National Toxicology Program (NTP). 1999. Toxicology and Carcinogenesis Studies of Diethanolamine (CAS No. 111-42-2) in F344/N Rats and B6C3F1 Mice (Dermal Studies) (Tech. Rep. Ser. No. 478; NIH Publ. No. 99-3968), Research Triangle, NC

OEHHA. 2008. Technical Supporting Document for Noncancer RELs, Appendix D3

Piipari R, Tuppurainen M, Tuomi T, Mantyla L, Henriks-Eckerman ML,Keskinen H, and Nordman H. 1998. Diethanolamine-induced occupational asthma, a case report. Clin. Exp. Allergy 28(3):358-362.

PubChem. 2023. National Center for Biotechnology Information. Compound Summary for CID 8113, Diethanolamine. Accessed Nov. 17, 2023.

Spalding, J W et al. 2000. “Responses of transgenic mouse lines p53(+/-) and Tg.AC to agents tested in conventional carcinogenicity bioassays.” Toxicological sciences : an official journal of the Society of Toxicology vol. 53,2: 213-23.

US EPA. 2011. Benchmark dose software (BMDS). Available online at http://www.epa.gov/NCEA/bmds/about.html.

US EPA. 2012. Provisional Peer-Reviewed Toxicity Values (PPRTV) for Diethanolamine (CASRN 111-42-2)

US EPA. 2016. Diethanolamine

ENGINEERING CONSULTING

FICHTNER
Consulting Engineers Limited

Kingsgate (Floor 3), Wellington Road North,
Stockport, Cheshire, SK4 1LW,
United Kingdom

t: +44 (0)161 476 0032
f: +44 (0)161 474 0618

www.fichtner.co.uk