Hanson UK

Padeswood Carbon Capture and Storage Project

Appendix – Amine Degradation Assessment

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RSK GENERAL NOTES

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1 INTRODUCTION

This technical appendix supports the assessment of emissions to air associated with the proposed permit variation application for the installation of a Carbon Capture and Storage plant at the Padeswood Works facility (EPR/BL1096IB).

The proposed variation will result in the routing of emissions from the existing kiln stack to a post-combustion carbon capture and compression (PCCC) plant, thus removing carbon dioxide emissions (CO_2) and emitting the kiln's exhaust gas through a new dedicated PCCC stack. In addition, a new combined heat and power (CHP) plant will be installed to provide the energy required for the PCCC plant, with emissions also routed via the PCCC to the new PCCC stack.

This technical appendix has been prepared to assess the air quality impacts of emissions of amines and their reaction products resulting from the use of an amine-based solvent within the carbon capture process. The assessment (ref: 444770-01) associated with the changes in direct emissions resulting from the kiln and CHP emissions being treated in the PCCC and passing through the new PCCC stack should be read in conjunction with this technical appendix.

The approximate centre of the site is 329196, 362196, which is in the administration area of Flintshire County Council (FCC). Figure 1.1 details the location of the PCCC plant within the site.

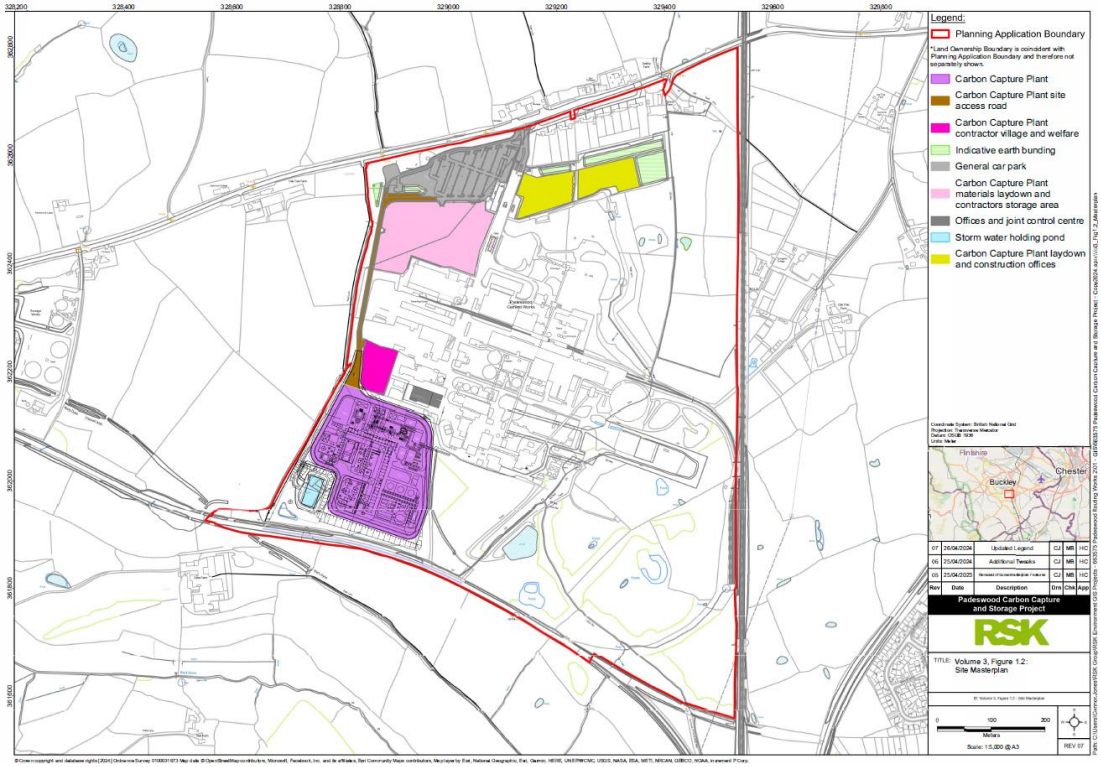

Figure 1.1: Proposed Development Site Location

2 OVERVIEW OF AMINE CHEMISTRY WITHIN CSS

Amines are organic derivatives of ammonia (NH_3), wherein one or more of the hydrogen (H) atoms are replaced by a hydrocarbon group (R). The type of amine can be defined as primary, secondary, or tertiary based on the number of H atoms that are replaced:

- Primary amine ($R\text{-}NH_2$) where 1 H-atom is replaced
    - e.g., Monoethanolamine, MEA
- Secondary amine ($R_2\text{-}NH$) where 2 H-atoms are replaced
    - e.g., Dimethylamine, DMA
- Tertiary amine ($R_3\text{-}N$) where 3 H-atoms are replaced
    - e.g., Trimethylamine, TMA

Amine-based solvents are used in the carbon capture process to remove carbon dioxide (CO_2) from combustion flue gases prior to being exhausted from the stack. While the process is designed to recover the solvent, this is not fully effective, and some of the amines contained within the solvent are emitted to atmosphere within the flue gas.

In addition to the release of amine compounds described above, the amine compounds included within the solvent can react with substances other than CO_2 to create new, potentially harmful compounds (e.g., nitrosamines, nitramines, aldehydes etc.). This can occur within the carbon capture process by oxidative or thermal degradation or within the atmosphere following the release of amines within the treated post-combustion flue gas. Collectively, these are known as 'indirect emissions. The relative contribution to indirect emission from each process will depend on the solvent used, the conditions within the carbon capture process and the technology used.

The chemical structure of nitrosamines is $R_2N\text{-}NO$ and the structure of nitramines is $R_2N\text{-}NO_2$, formed from the original amine, where R is usually an alkyl group. Nitrosamines are susceptible to photodegradation and therefore generally short-lived in the atmosphere (~5 min). In contrast, nitramines are more stable and will have longer atmospheric residence times (~2 days). As such, the stability of nitramines indicates an increased potential for accumulation in the atmosphere relative to nitrosamines.

The mechanisms for the formation of nitrosamines and nitramines in the atmosphere are complex. However, the main formation of amines in the atmosphere is due to the initial amine reaction with hydroxyl (OH) radicals. This is followed by reactions with NO and NO_2 to from nitrosamines and nitramines. However. they can further degrade in the atmosphere (e.g., through photo-oxidation and subsequent reaction with oxygen molecules to form imines, which are relatively stable and non-toxic compounds).

Existing toxicological data indicates that most nitrosamines are carcinogenic, with the most widely researched nitrosamine being N-nitrosodimethylamine (NDMA). With higher uncertainty on the toxicity of other nitrosamines, the Environment Agency (EA) has only derived an Environmental Assessment Levels (EAL) for NDMA. Less is known about nitramines, but they have the potential to be mutagenic and carcinogenic although typically less potent than nitrosamines, with some research studies indicating that nitramines are at least six times less toxic (Gjernes, 2013) and fifteen times less mutagenic (Wagner, 2014) than nitrosamines.

3 Assessment Criteria

As part of their regulatory position, Natural Resources Wales (NRW) has adopted the EALs produced by the EA and the Department for Environment, Food and Rural Affairs (Defra). These have been produced in order to regulate hazardous pollutants produced by industry that are not captured within the Air Quality Regulations. These are non-statutory guideline values and are contained within the Air Emissions Risk (AER) guidance[1]. Typically, a site's compliance with these EALs would be based on a cost-benefit analysis and discussions with NRW. The EALs applicable to this assessment (i.e. substances that could potentially be emitted from the stack or are known indirect pollutant species) are provided in **Table 3.1.**

Table 3.1: EALs for Applicable Amines, Nitramines, Nitrosamines and Aldehydes

Substance	Averaging period	Ground level concentration limit (µg/m^3)
Monoethanolamine (MEA)	24 hours	100
	1 hour	400
N-Nitrosodimethylamine (NDMA)	Annual	0.0002
Acetaldehyde	1 hour	9,200
	Annual	370
Formaldehyde	30 minute	100
	Annual	5

3.1.1 Derivation of additional Environmental Assessment Levels for Carbon Capture

Mitsubishi Heavy Industries (MHI) is supporting multiple companies in the deployment of Carbon Capture and Storage (CCS) technology in the UK and are the selected technology providers for the Padeswood CCS project. The suite of EALs published by the EA is limited, and many of the chemicals potentially released from MHI's CCS plant do not have EALs. MHI has derived specific EALs for the compounds released by their CCS process. The EALs derived by MHI that are relevant to emissions from the proposed CCS plant are presented in **Table 3.2.**

Table 3.2: Amine EALs Derived by MHI

Substance	Emission Period	Concentration in µg/m^3
Diethanolamine	24 hours	3
Diethylamine	24 hours	33
	1 hour	330
Piperazine	24 hours	15
Methylamine	Hourly	1,900

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

Substance	Emission Period	Concentration in µg/m^3
	Annual	15
Ethylamine	Hourly	2,800
	Annual	22
Dimethylamine	Hourly	2,800
	Annual	22
N,N-dimethylethylenediamine	Hourly	417
	Daily	104
N-(2-hydroxyethyl)acetamide	Annual	0.085
N-(2-hydroxyethyl)formamide	Annual	86

4 METHODOLOGY

The effects of the amines (and their degradation products) from the Proposed CSS plant have been undertaken using dispersion modelling. In general, the modelling approach to predicting ground-level concentrations of the above pollutants has been to consider the direct release of known amines (and nitrosamines, nitramines, aldehydes etc.) and the indirect effects of nitrosamines and nitramines. While modelled atmospheric chemistry reactions have been considered to predict the ground-level concentrations of nitrosamines and nitramines, it is considered more conservative to compare direct emissions of amines against the relevant EALs, therefore, assuming no degradation of amines into its subsequent nitrosamines and nitramines. This has been undertaken to reduce the uncertainty associated with atmospheric amine chemistry and due to the understanding that amines are easily oxidised in the atmosphere.

The general approach to this assessment follows the guidance within Defra's and the EA's Air emissions risk assessment for your environmental permit guidance[2], which is generally adopted by Natural Resources Wales (NRW). However, very limited specific guidance is available from NRW on the appropriate modelling methodology for modelling amines, instead, the assessment has been based on the following guidance notes produced by the EA's Air Quality and Modelling Assessment Unit (AQMAU):

- AQMAU recommendations for the assessment and regulation of impacts to air quality from amine-based post-combustion carbon capture plants[3]; and
- Proposed assessment method to include amines and degradation products in nutrient nitrogen deposition estimations at ecological sites[4].

In addition, the supplementary user guide[5] produced by Cambridge Environmental Research Consultants (CERC) for their amine model, the only commercially available modelling software to evaluate the potential impacts of amines atmospheric reaction products, has also been used.

Unless stated within this technical appendix, the modelling approach is the same as presented in Section 7.1.4 – 7.1.9 of the main air quality report (ref: 444770-01). For example, the model inputs for buildings, meteorological data, surface roughness length, Monin-Obukhov length, terrain and discrete receptors are consistent with the main air quality report.

This assessment has considered the effects on both sensitive human and ecological receptors.

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

[3] https://ukccsrc.ac.uk/wp-content/uploads/2021/11/AQMAU-C2025-RP01.pdf

[4] https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010103/EN010103-002888-Appendix%201%20-%20Main%20Letter%20-%20AQMAU%20Assessment%20Methodology.pdf

[5] https://cerc.co.uk/environmental-software/assets/data/doc_userguides/CERC_ADMS_6_Amine_chemistry_supplement.pdf

4.1 Modelling Software

The impact assessment of the site was undertaken using ADMS 6 (Version 6.0.0.1). This model uses detailed information regarding the pollutant releases, local building effects and local meteorological conditions to predict pollutant concentrations at specific locations selected by the user and is approved by NRW for regulatory applications. CERC's amine module (detailed further below) has been used to model the effect of indirect amine atmospheric reaction products.

4.2 Modelled Domain

A nested 10 km x 10 km uniform cartesian grid[6] centered over the PCCC stack was used within this assessment. The grid receptor heights were set at 1.5 m.

The discrete receptors included within the assessment were the same as used within the main air quality report (ref: 444770-01).

4.3 Emission Sources and Operating profile

The physical characteristics, efflux parameters and operational profiles for the emissions from the proposed PCCC plant are the same as those presented in Table 7.3 of the main air quality report (ref: 444770-01).

4.4 Modelling of Amine Compounds

4.4.1 Modelling of Direct Emissions

Direct emissions of amines (and nitrosamines, nitramines, aldehydes etc.) from the CCS process of the Proposed Scheme have been modelled in the same way as traditional pollutants (NOx and PM etc.), i.e., no use of ADMS 6's chemistry or amine modules.

The compounds anticipated to be exhausted from the stack and their emission limits values (ELVs) have been provided by MHI. The details of emission substances modelled are shown in Appendix A. Emission rates have been calculated based on the volume flow rates for each mode used within the main air quality report (ref: 444770-01). The efflux parameters, ELVs and amine emission rates for the proposed PCCC plant are presented in Table 4.1.

[6] Three grid spacings are used in the nested grid. The grids with 30m and 50m spacing are applied to 2km x 2km and 4km x 4 km model domain respectively. Further from the source, the grid with 100m spacing is applied to cover the 10km x 10km model domain.

Table 4.1: Amines Emission Rates and Efflux Parameters for the Proposed PCCC Plant Included in the Direct Amine Assessment

	Mode 1	Mode 2	Mode 3	Mode 4
Operating hours	5379	2069	745	83
Stack height above PCCC datum level (m)	117.9			
Stack diameter (m)	3.1			
Temperature (°C)	100	100	100	100
Oxygen Content (vol%-dry)	8.35	7.89	7.11	6.51
Moisture Content (vol%)	8.96	8.92	9.04	9.11
Volumetric Flow Rate (m^3/s) – Actual	126.84	117.60	112.94	103.56
Volumetric Flow Rate (m^3/s) – Ref[1]	97.31	93.57	95.12	90.95
Actual stack exit velocity (m/s)	16.80	15.58	14.96	13.72
NO_x exhaust emission concentration (mg/Nm^3)[1]	200			
Amines (Group 1) emission concentration (mg/Nm^3)[1,2]	1			
Amines (Group 2) emission concentration (mg/Nm^3) [1,3]	0.0006			
Amines (Group 3) emission concentration (mg/Nm^3) [1,4]	0.0002			
Amines (Group 4) emission concentration (mg/Nm^3) [1,5]	0.0001			
N-Nitrosomethylethylamine (NMEA) emission concentration (mg/Nm^3) [1]	0.0028			
Formaldehyde emission concentration (mg/Nm^3) [1]	2.1			
Acetaldehyde emission concentration (mg/Nm^3) [1]	9.9			
Ethylethanolamine emission concentration (mg/Nm^3) [1]	0.5			
Ethyldiethanolamine emission concentration (mg/Nm^3) [1]	0.3			
Piperazine emission concentration (mg/Nm^3) [1]	0.2			
NO_x exhaust emissions rate (g/s)	19.46	18.71	19.02	18.19
Amines (Group 1) emission rate (g/s)[2]	0.09731	0.09357	0.09512	0.09095
Amines (Group 2) emission rate (g/s)[3]	0.00006	0.00006	0.00006	0.00005
Amines (Group 3) emission rate (g/s)[4]	0.00002	0.00002	0.00002	0.00002
Amines (Group 4) emission rate (g/s)[5]	0.00001	0.00001	0.00001	0.00001
N-Nitrosomethylethylamine (NMEA) emission rate (g/s)	0.00027	0.00026	0.00027	0.00025
Formaldehyde	0.20435	0.19650	0.19975	0.19099

emission rate (g/s)				
Acetaldehyde emission rate (g/s)	0.96335	0.92635	0.94169	0.90039
Ethylethanolamine emission rate (g/s)	0.04865	0.04679	0.04756	0.04547
Ethyldiethanolamine emission rate (g/s)	0.029	0.028	0.029	0.027
Piperazine emission emission rate (g/s)	0.019	0.019	0.019	0.018
Stack location	X: 328915 Y: 362079			

Note 1: Emission Concentration Release Conditions (REF): 273K, 101.3kPa, dry gas, 10% oxygen
Note 2: Group 1 Amines includes: Methylamine, Ethylamine, Dimethylamine, Diethylamine, Ethylmethylamine, Monoethanolamine, Diethanolamine, N,N-dimethylethylenediamine, N-(2-hydroxyethyl)acetamide, and N-(2-hydroxyethyl)formamide
Note 3: Group 2 Amines includes: N-Nitrosodimethylamine (NDMA) and N-Ethyl-N-(2-hydroxyethyl)nitrosamine (EHEN)
Note 4: Group 3 Amines includes: N-Nitrosodiethylamine (NDEA), N-Nitrosodiethanolamine (NDELA), 1,4-Dinitrosopiperazine (DNPZ), 2-(ethylnitroamino)ethanol and 1-nitropiperazine
Note 5: Group 4 Amines includes: 1-Nitrosopiperazine (NPZ) and N-Nitrosomorpholine (NMOR)

For the avoidance of any doubt, the naming convention (Group 1 etc.) in the above table has been used to simplify the reporting of multiple pollutants with the same emission concentrations and rates. Therefore, all pollutants in Group 1 have been modelled at the stated emission rate, and they **do not** represent a combined emission rate for all pollutants. Furthermore, the majority of pollutants in Group 1 are expected to have emission concentrations that are an order of magnitude lower than modelled (see Appendix A); however, they have been modelled this way to assess worst case impacts at the request of the proposed operator.

4.4.2 Modelling of Indirect Emissions

The assessment of Indirect emissions considers nitrosamines and nitramines associated with the reaction of proprietary amine-based solvents within the atmosphere. The mechanisms for the formation of nitrosamines and nitramines in the atmosphere are complex, and the only practical means to undertake such an assessment is to model the chemical reactions within the Amine Chemistry Module of ADMS 6. The reaction scheme contained within ADMS 6's Amine Chemistry Module is given below:

AMINE + hydroxyl radical (•*OH*)	→	amino RADICAL + H_2O	(1a)
	→	non-amine radical ($RN(H)C^{\bullet}H_2$) + H_2O	(1b)
amino RADICAL + O_2	→	imine + hydroperoxyl (HO_2)	(2)
amino RADICAL + *NO*	→	NITROSAMINE	(3)
amino RADICAL + NO_2	→	NITRAMINE	(4a)
	→	imine + nitrous acid (*HONO*)	(4b)
NITROSAMINE	$\xrightarrow{h\nu}$	amino RADICAL	(5)

While several amine compounds are proposed to be emitted, ADMS requires the input of a number of reaction constants to simulate the conversion of amines to nitrosamines and nitramines. At present, these reaction constants are only available for three of the amine compounds proposed for release; therefore, only the indirect emissions of nitrosamines and nitramines associated with the release of Monoethanolamine (MEA), Dimethylamine (DMA) and Ethylamine (EA) have been considered. Using the constants provided, the emissions for each amine (Amine 1 (MEA), Amine 2 (DMA) and Amine 3 (EA)) provide pollutant outputs for their respective nitrosamines and nitramines (i.e., Nitrosamine 1, Nitrosamine 2, Nitrosamine 3, Nitramine 1, Nitramine 2 and Nitramine 3).

As there are no specific EALs for the majority of nitrosamines and nitramines, the total predicted concentration (PC) of these nitrosamines and nitramines will be compared with the EAL of NDMA as a conservative approach. This is the only feasible way to undertake the study at this stage. While we are aware of specific nitrosamine and nitramine emitted (due to oxidations and thermal degradation), the exact compounds produced during atmospheric degradation are highly uncertain. As such, a conservative approach to the assessment has been undertaken.

In addition to the normal model setup detailed in Section 7.1.4 – 7.1.9 of the main air quality report (ref: 444770-01), to simulate the reaction of amine compounds to nitrosamines and nitramines, the additional model setup options have been used. Where necessary, they are discussed further below.

- Enabling of the chemistry module within ADMS;
- Inclusion of hourly background data of O_3, NO_2 and NOx;
- Provision of a primary NO_2 to NOx ratio;
- Provision of the 'c' constant;
- Dilution and entrainment option; and
- Provision of several reaction constants for each amine modelled.

4.4.2.1 Hourly Background Data

The amine reaction scheme requires hourly background levels of NOx and O_3 equivalent to the modelled meteorological year. The hourly background file uses the O_3 concentration and photolysis rates (provided by ADMS's met preprocessor) to dictate the hydroxyl radical concentration. Background NOx, O_3 and NO_2 concentrations are also used to dictate the availability of NO and NO_2 (in a similar fashion ADMS's traditional chemistry model) to model the formation of nitrosamines and nitramines, respectively, on an hourly basis.

Hourly data for these species were sourced from Defra's Wirral Tranmere AURN monitoring site, representing urban background levels, for the years 2018-2022 inclusive. Sensitivity to the use of rural background concentrations has also been undertaken, with NOx, NO_2 and O_3 concentrations taken from the AURN rural background site Aston Hill, near Bishop's Castle.

4.4.2.2 *Primary NO_2 to NOx Ratio*

When running the chemistry module, ADMS requires the fraction of NOx emitted as NO_2 to be specified to calculate the effects of the chemical reactions. Typically, (during non-amine chemistry runs) it is conservative to assume a higher amount of primary NO_2 is released. Information provided by the operator indicates that the primary NO_2 percentage from the kiln will be between 1% – 4%; however, there will be additional contributions from the CHP, which at this stage is unknown. To undertake a conservative assessment, a value of 10% will be used to account for the unknown primary NO_2 from the proposed CHP.

Due to the unknown impacts of this parameter on nitrosamine and nitramine ground-level concentrations, a sensitivity test using the model default of 5% has also been undertaken.

4.4.2.3 *Provision of an OH concentration constant*

ADMS 6 requires the user to provide a constant ('c') to calculate the hourly varying hydroxyl radical concentration (equation 1a above). This has been calculated using the methodology and equations provided by CERC within section 2.5.1 of their Amine Chemistry Supplement User guide[7]

To calculate 'c', the user is required to calculate the average hourly O_3*J_{NO2} value for each modelled year. The O_3 concentration was taken from Defra's Wirral Tranmere AURN monitoring site, with J_{NO2} calculated using the hourly incoming solar radiation value (W/m^2) provided within the ADMS .MOP file (when running a non-chemistry model). During the sensitivity test for rural backgrounds, the O_3 concentration was taken from Defra's AURN rural background site at Aston Hill.

The annual average hydroxyl radical concentration (ppb) is then divided by the average hourly O_3*J_{NO2} value. An upper limit OH concentration of 1.8×10^6 molecules cm^{-3} has been used (Walker, 2015), calculated based on summer daytime flights only.

4.4.2.4 *Dilution and Entrainment'*

As strongly recommended by CERC[6], the 'dilution and entrainment' scheme within the ADMS amines module has been used. The module improves the way pollutant concentrations are adjusted to account for dilution effects (i.e. removing primary pollutant dilution) and entrainment of background pollutants.

4.4.2.5 *Reaction constants.*

A number of reaction constants are required to be inputted into ADMS for the chemistry module to account for the amount of nitrosamines and nitramines formed in the atmosphere. This includes the branching ratio of the abstraction of an H atom from the amino group (N-H) (i.e. forming the amino RADICAL) to the abstraction from the methyl group (C-H) (i.e. forming the non-amine radical). However, a number of other variables

[7] https://www.cerc.co.uk/environmental-software/assets/data/doc_userguides/CERC_ADMS_6_Amine_chemistry_supplement.pdf

play an essential role in the potential formation of nitrosamines and nitramines in the atmosphere and constants to represent these are required. These constants include the:

- Amine/OH reaction rate constant (k1);
- Amino radical/O_2 reaction rate constant (k2);
- Rate constant for formation of nitrosamine (k3);
- Rate constant for formation of nitramine (k4a);
- Amino radical/NO_2 reaction rate constant (k4); and
- Ratio of J(nitrosamine) to J(NO_2).

Primary amines typically do not form stable nitrosamines, meaning that nitrosamines typically would be rapidly isomerised into imines. However, secondary and tertiary amines can form stable nitrosamines. The ADMS module includes an option to allow only unstable nitrosamines to be created. If selected by the model user, all nitrosamine concentration outputs are set to zero, and only nitramines will form. This option was not selected within the modelling undertaken for this assessment, regardless of the amine compound being emitted (i.e., primary, secondary, and/or tertiary), as it will give a worst-case result.

The input variables required by the amine chemistry module (described above) are provided in **Table 4.2**. It is noted that some of the amine data is not available at this stage. Data which is not available was taken from a literature review.

Table 4.2: Parameters relating to the ADMS Amine Chemistry Module

Parameter	Units	Notes	MEA (Amine 1)	DMA (Amine 2)	EA (Amine 3)	Source
Amine Emission	g/s	Emission rate for amine compounds	0.09095-0.09731*	0.09095-0.09731*	0.09095-0.09731*	As per Table 4.1
NO_x emission	g/s	Emission rate for NO_x	18.19 – 19.46*	18.19 – 19.46*	18.19 – 19.46*	As per Table 4.1
Amine compound & Molar mass	g/mol	Name of amine compounds included in ADMS Amine Chemistry Module	Amine 1 (MEA): 61 Amine 2 (DMA): 45 Amine 3 (EA): 45 Nitrosamine 1 (from MEA): 90 Nitrosamine 2 (from NDEA): 74 Nitrosamine 3 (from EA): 74 Nitramine 1 (from MEA):106 Nitramine 2 (from DMA): 90 Nitramine 3 (from EA): 90			CERC (2012)[8]
Amine/OH reaction rate constant, k1	/ppb/s	Relating to the reaction of the emitted	2.07	1.59	0.69	Data provided by MHI

[8] Cambridge Environmental Research Consultants (2012). Contract number 257430174: Atmospheric Chemistry Modelling. Activity 1: Gaseous Phase Chemistry Modelling (initiated by hydroxyl radical). Prepared for CO2 Capture Mongstad Project Gassnova SF

Parameter	Units	Notes	MEA (Amine 1)	DMA (Amine 2)	EA (Amine 3)	Source
		amine with the OH radical				and CERC[9] (Amine 3)
Amino radical/O2 reaction rate constant, k2	/ppb/s	Relating to the reaction of the amino radical with oxygen (forming imine)	4.90×10^{-8}	4.60×10^{-8}	3.33×10^{-9}	Data provided by MHI and CERC[7] (Amine 3)
Rate constant for formation of nitrosamine, k3	/ppb/s	Relating to the formation of nitrosamine from the reaction of the amino radical with NO	0.0037	0.0021	0.0022	Data provided by MHI and CERC[7] (Amine 3)
Rate constant for formation of nitramine, k4a	/ppb/s	Relating to the formation of nitramine from the reaction of the amino radical with NO2	0.004	0.0078	0.0085	Data Data provided by MHI and CERC[7] (Amine 3
Amino radical/NO_2 reaction rate constant, k4	/ppb/s	Relating to the reaction of the amino radical with NO2 (forming imine or nitramine)	0.0045	0.0089	0.0085	Data provided by MHI and CERC[7] (Amine 3)
Branching ratio for amine/OH reaction	Dimensionless	The ratio of H atom abstraction from amino group (N-H) to the methyl group (C-H)	0.10	0.40	0.09	Data provided by MHI and CERC[7] (Amine 3)
Ratio of j(nitrosamine)/jNO_2	Dimensionless	Ratio of photolysis rate constants for the nitrosamine and NO2	Not applicable to MEA	0.39	Not applicable to EA	Data provided by MHI
Constant, c, for OH concentration calculations	Dimensionless	Constant for calculating hourly varying OH concentrations, based on relationship between	Value of c ranges between 1.64×10^{-3} and 2.17×10^{-3} dependent on met year (modelling completed across five years of met data)			calculated

[9] https://ukccsrc.ac.uk/wp-content/uploads/2024/05/CERC_2024_Improving_Post-Combustion_Carbon_Capture_Air_Quality_Risk_Assessment_Techniques.pdf

Parameter	Units	Notes	MEA (Amine 1)	DMA (Amine 2)	EA (Amine 3)	Source
		annual average jNO2, O3 and OH concentrations				

*Depends on different operating mode

4.4.3 Ecological Assessment

The methodology for the ecological assessment has been based on the approach detailed within AQMAU's *Proposed assessment method to include amines and degradation products in nutrient nitrogen deposition estimations at ecological sites*[10] document.

This document advises a two-staged approach to ecological assessments for amines and their degradation products. The first stage is a screening step, where the direct deposition of amine, nitrosamine and nitramine PCs from each pollutant are compared with the nutrient nitrogen deposition critical load (detailed further in Section 4.43) at each ecological receptor. If impacts screen out, there is no need to continue onto stage 2. AQMAU does not provide a metric for screening out impacts; however, in this case, when considering that the main air quality assessment demonstrated a betterment in impacts on habitat sites due to the proposed variation, the 1% threshold of the site's critical load (as referenced in Section 4.5) is judged to be appropriate.

4.5 Results Processing

4.5.1 Direct Emissions

In the case of amine/aldehyde emissions, post-processing of annual emissions has been undertaken to account for the plant operating within four different modes (detailed further in Section 2 of the main air quality report). It is expected that the proposed PCCC plant will operate 8276 hrs/yr in four different modes of varying operational hours and exhaust gas oxygen content. As such, the annual results from each mode (assumed to be operating 8760 hours of the year) have been time factored based on the operational hours presented in Table 4.1. This is the same approach as has been used within the main air quality report.

No factoring has been undertaken for comparison of the facility's impacts against the short-term objectives. With regards to the short-term impacts of the multiple modes of operations, the results presented assume that the PCCC plant has been operating during the worst-case mode all year. In general, mode 4, which is 1% of operating hours all year, predicts worst-case impacts in terms of ground-level concentrations.

[10] https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010103/EN010103-002888-Appendix%201%20-%20Main%20Letter%20-%20AQMAU%20Assessment%20Methodology.pdf

The exception to the above is for the comparison of the formaldehyde process contribution (PC) against its 30-minute mean. The hourly PC has been multiplied by the 1-hour to 30-minute conversion factor (1.3), as recommended by the EA and Defra[11], prior to comparison against its EAL.

The emission of each pollutant listed in Table 4.1 has been compared against their applicable EAL (see Section 3). Where no EAL is available for a particular pollutant, the results have been compared against the pollutant with the lowest EAL (in this case, N-(2-hydroxyethyl)acetamide. Due to the limited availability of nitrosamine and nitramine EALs, the assessment has summed the direct emission's ground-level PCs for all species of nitrosamines and nitramines. These will be added to the indirect emission's PCs prior to comparison with the NDMA EAL.

4.5.2 Indirect Emissions

To ensure a conservative approach to the assessment of nitrosamines and nitramines, the modelled indirect concentrations of each nitrosamines and nitramines (nitrosamines1, nitrosamines2 etc.) have been summed. These indirect emissions have then been summed, then added to the direct emissions of nitrosamines and nitramines for comparison against the EAL for NDMA.

4.5.3 Nitrogen Deposition Calculations

Deposition rates were calculated using empirical methods recommended by the EA[12].

Dry deposition flux was calculated using the following equation:

Dry deposition flux ($\mu g/m^2/s$) = ground level concentration ($\mu g/m^3$) x deposition velocity (m/s)

Wet deposition occurs via the incorporation of the pollutant into water droplets, which are then removed in rain or snow and are not considered significant over short distances compared with dry deposition. As the screening stage within AQMAU's technical guidance[10] does not require the calculation of wet deposition (the method already being conservative), the assessment of wet deposition has not been considered.

For the purposes of this assessment, dry deposition rates of nitrogen equivalents at the identified ecological receptors have been calculated by applying the appropriate deposition velocities ('forest' or 'grassland) to the modelled annual mean concentrations of the amine and their degradation products . The deposition velocities of 0.03 m/s and 0.02 m/s for all amine compounds to represent ammonia, as conservative approach, have been undertaken, as suggested by EA[10].

The critical loads for nitrogen (N) are recorded in units of kgN/ha/yr. The deposition PC is converted from $\mu g/m^2/s$ to units of kgN/ha/year by multiplying the dry deposition flux by a conversion factor. The conversion factor for each amine compound has been calculated based on it's molecular weight, and are presented in **Table 4.3.**

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

[12] https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010103/EN010103-002888-Appendix%201%20-%20Main%20Letter%20-%20AQMAU%20Assessment%20Methodology.pdf

Table 4.3: Applied Conversion Factor

Amine Compounds	Conversion Factor
Methylamine	142
Ethylamine	98
Dimethylamine	98
Diethylamine	60
Ethylmethylamine	75
Monoethanolamine	72
Diethanolamine	42
N,N-dimethylethylenediamine	50
N-(2-hydroxyethyl)acetamide	43
N-(2-hydroxyethyl)formamide	50
Ethylethanolamine	50
Ethyldiethanolamine	33
Piperazine	51
Nitrosamine and Nitramines (as NDMA)*	60

*NDMA has the lowest molecular weight of all the directly emitted nitrosamines and nitramines. As such, provides the highest conversion factor. Therefore, as a conservative approach, all directly emitted nitrosamines and nitramines are assumed to be NDMA.

4.6 Significance Criteria

There is no guidance on how to determine the significance of the impacts; however, it is common practice to utilise the EA/NRW risk assessment insignificance screening criteria to assess significance. The insignificance screening criteria for long- and short-term impacts are provided below:

- if the short-term PC is less than 10% of the short term environmental standard, then a PC can be considered insignificant; and
- if the long-term PC is less than 1% of the long term environmental standard: then a PC can be considered insignificant.

Where emissions affect nature sites, the EA/NRW have similar screening criteria for the impacts (PCs) on internationally (SAC, SPA, Ramsar) or nationally (SSSI's) designated sites. Where the above screening criteria are not exceeded, the impacts at ecological sites can be classed as insignificant, with no further assessment needed. Impacts on locally designated sites can be considered insignificant where the PCs are less than 100% of the objective (for both long and short-term impacts).

As no background data for the pollutant modelled is available, a comparison of PECs has not been undertaken. Significance has therefore been determined using the above screening criteria and professional judgment, considering the predicted contribution (PC) to the EALs and the uncertainty/conservativeness within the modelling assessment.

4.7 Uncertainties and Assumptions

The following uncertainties and assumptions have been made in the air quality assessment:

- There will be uncertainties introduced because the modelling has simplified real-world processes into a series of algorithms. For example, it has been assumed that wind conditions measured at the Hawarden weather station for 2018 to 2022 were representative of wind conditions at and around the Site. Furthermore, it has been assumed that the subsequent dispersion of emitted pollutants will conform to a Gaussian distribution in order to simplify the real-world dilution and dispersion conditions.
- There is an element of uncertainty in all measured and modelled data. All values presented in this report are considered reasonable estimates. Where estimations in emissions are made, these are overestimated and hence the impacts on local air quality reported are considered to be conservative in nature. In some cases significantly lower than the proposed ELV and over less operational hours.
- Where information is not yet known, a conservative approach has been adopted and professional judgement has been used based on the scale of the Proposed Development and experience of working on similar schemes.
- Due to information not being available for all direct amine species, this assessment only assumes that three of the direct amines form indirect nitrosamines and nitramines species within atmosphere.
- This assessment assumes no degradation of modelled direct amines into its subsequent nitrosamines and nitramines.
- EALs for some amine and nitrosamines and nitramines species are not available. Where the EALs are not available, the lowest EAL for that compound group has been used. This assessment, therefore, assumes that the toxicity for the species with the lower EAL is greater than that for the species with no EAL; however, this is uncertain.
- This assessment assumes that all emissions (either direct or indirect) of nitrosamines and nitramines are NDMA.
- Ground level concentrations of ammonia and NOx/NO_2 from the combustion process within the kiln will result in a betterment due to the proposed variation. This is concluded within the main air quality assessment for the proposed variation.
- This assessment assumes that the deposition velocity of the modelled amines, nitrosamines and nitramines species is similar to that of ammonia.
- A 10% primary NO_2 percentage in the exhaust gas is adopted in the model as a conservative approach.

4.8 Sensitivity

In line with best practice requirements, modelling sensitivity has been undertaken in order to understand the likely uncertainty with the modelling parameters chosen. In this case, sensitivity has been chosen based on the modelled parameters with high uncertainties

related to the amine chemistry module. In addition to running the model for five meteorological years, the following sensitivity tests have been undertaken:

- sensitively to a rural NO_X, NO_2 and O_3 background concentrations, taken from Aston Hill AURN;
- sensitively to a primary NO_2 value of 5%; and
- sensitively to the Ratio of j(nitrosamine)/jNO_2 of 0.39 for Amine1 and Amine3 (the values are currently unknown and have been inputted as zero).

The results of the sensitivity testing are reported in Appendix B. The results indicate that realistic changes in the above parameters are not likely to effect the outcome of this modelling assessment.

5 ASSESSMENT OF IMPACTS IN OPERATIONAL PHASE

5.1 Impacts on Human Receptors (Direct Emission)

The maximum concentration of the direct emission of amine compounds at the assessed discrete receptors across all meteorological years modelled is described in Table 5.1 – Table 5.15 below. Direct emission of nitrosamines and nitramines have been presented within the indirect emissions assessment, as they are summed with the indirect PCs to predict a total (direct + indirect impact).

As shown below, predicted amine PCs resulting from the operation of the site are well below the relevant EALs at all discrete receptor locations and the location of maximum impact outside the site boundary.

Table 5.1: Predicted Methylamine Concentrations at Discrete Receptors - Highest Results for Each Receptor

Receptor ID	Annual Mean Methylamine Concentration (µg/m^3)		Hourly Mean Methylamine Concentration (µg/m^3)	
	PC (µg/m^3)	PC as % of Objective	PC (µg/m^3)	PC as % of Objective
R1	0.0005	<0.01%	0.1305	0.01%
R2	0.0007	<0.01%	0.1144	0.01%
R3	0.0013	0.01%	0.1283	0.01%
R4	0.0008	0.01%	0.1162	0.01%
R5	0.0017	0.01%	0.0878	<0.01%
R6	0.0017	0.01%	0.0748	<0.01%
R7	0.0013	0.01%	0.1023	0.01%
R8	0.0014	0.01%	0.0656	<0.01%
R9	0.0016	0.01%	0.0859	<0.01%
R10	0.0024	0.02%	0.0829	<0.01%
R11	0.0012	0.01%	0.0852	<0.01%
R12	0.0004	0.00%	0.1280	0.01%
R13	0.0011	0.01%	0.0675	<0.01%
Maximum Outside Boundary	0.0032	0.02%	0.2068	0.01%
AQS / EAL Objective	15 µg/m^3		1,900 µg/m^3	

Table 5.2: Predicted Ethylamine Concentrations at Discrete Receptors - Highest Results for Each Receptor

Receptor ID	Annual Mean Ethylamine Concentration (µg/m³)		Hourly Mean Ethylamine Concentration (µg/m³)	
	PC (µg/m³)	PC as % of Objective	PC (µg/m³)	PC as % of Objective
R1	0.0005	<0.01%	0.1305	<0.01%
R2	0.0007	<0.01%	0.1144	<0.01%
R3	0.0013	0.01%	0.1283	<0.01%
R4	0.0008	<0.01%	0.1162	<0.01%
R5	0.0017	0.01%	0.0878	<0.01%
R6	0.0017	0.01%	0.0748	<0.01%
R7	0.0013	0.01%	0.1023	<0.01%
R8	0.0014	0.01%	0.0656	<0.01%
R9	0.0016	0.01%	0.0859	<0.01%
R10	0.0024	0.01%	0.0829	<0.01%
R11	0.0012	0.01%	0.0852	<0.01%
R12	0.0004	<0.01%	0.1280	<0.01%
R13	0.0011	0.01%	0.0675	<0.01%
Maximum Outside Boundary	0.0032	0.01%	0.2068	0.01%
AQS / EAL Objective	22 µg/m³		2,800 µg/m³	

Table 5.3: Predicted Dimethylamine Concentrations at Discrete Receptors - Highest Results for Each Receptor

Receptor ID	Annual Mean Dimethylamine Concentration (µg/m³)		Hourly Mean Dimethylamine Concentration (µg/m³)	
	PC (µg/m³)	PC as % of Objective	PC (µg/m³)	PC as % of Objective
R1	0.0005	<0.01%	0.1305	<0.01%
R2	0.0007	<0.01%	0.1144	<0.01%
R3	0.0013	0.01%	0.1283	<0.01%
R4	0.0008	<0.01%	0.1162	<0.01%
R5	0.0017	0.01%	0.0878	<0.01%
R6	0.0017	0.01%	0.0748	<0.01%
R7	0.0013	0.01%	0.1023	<0.01%
R8	0.0014	0.01%	0.0656	<0.01%
R9	0.0016	0.01%	0.0859	<0.01%
R10	0.0024	0.01%	0.0829	<0.01%
R11	0.0012	0.01%	0.0852	<0.01%
R12	0.0004	<0.01%	0.1280	<0.01%

Receptor ID	Annual Mean Dimethylamine Concentration (µg/m³)		Hourly Mean Dimethylamine Concentration (µg/m³)	
	PC (µg/m³)	PC as % of Objective	PC (µg/m³)	PC as % of Objective
R13	0.0011	0.01%	0.0675	<0.01%
Maximum Outside Boundary	0.0032	0.01%	0.2068	0.01%
AQS / EAL Objective	22 µg/m³		2,800 µg/m³	

Table 5.4: Predicted Diethylamine Concentrations at Discrete Receptors - Highest Results for Each Receptor

Receptor ID	Daily Mean Diethylamine Concentration (µg/m³)		Hourly Mean Diethylamine Concentration (µg/m³)	
	PC (µg/m³)	PC as % of Objective	PC (µg/m³)	PC as % of Objective
R1	0.01054	0.03%	0.13052	0.04%
R2	0.01234	0.04%	0.11439	0.03%
R3	0.02244	0.07%	0.12832	0.04%
R4	0.02086	0.06%	0.11623	0.04%
R5	0.02048	0.06%	0.08779	0.03%
R6	0.02123	0.06%	0.07479	0.02%
R7	0.01882	0.06%	0.10230	0.03%
R8	0.02174	0.07%	0.06563	0.02%
R9	0.02098	0.06%	0.08590	0.03%
R10	0.02304	0.07%	0.08291	0.03%
R11	0.01901	0.06%	0.08516	0.03%
R12	0.01280	0.04%	0.12798	0.04%
R13	0.02127	0.06%	0.06747	0.02%
Maximum Outside Boundary	0.03204	0.10%	0.20679	0.06%
AQS / EAL Objective	33 µg/m³		330 µg/m³	

Table 5.5: Predicted Ethylmethylamine Concentrations at Discrete Receptors - Highest Results for Each Receptor

Receptor ID	Annual Mean Ethylmethylamine Concentration (µg/m³)	
	PC (µg/m³)	PC as % of Objective
R1	0.0005	0.63%
R2	0.0007	0.83%
R3	0.0013	1.52%
R4	0.0008	0.94%
R5	0.0017	1.97%

Receptor ID	Annual Mean Ethylmethylamine Concentration (µg/m³)	
	PC (µg/m³)	PC as % of Objective
R6	0.0017	1.96%
R7	0.0013	1.58%
R8	0.0014	1.63%
R9	0.0016	1.87%
R10	0.0024	2.81%
R11	0.0012	1.47%
R12	0.0004	0.46%
R13	0.0011	1.33%
Maximum Outside Boundary	0.0032	3.72%
AQS / EAL Objective	0.085* µg/m³ *No EAL is set for Ethylmethylamine. The lowest annual EAL among all assessed amine compounds has been applied. This represents the annual EAL of N-(2-hydroxyethyl)acetamide	

Table 5.6: Predicted Monoethanolamine Concentrations at Discrete Receptors - Highest Results for Each Receptor

Receptor ID	Daily Mean Monoethanolamine Concentration (µg/m³)		Hourly Mean Monoethanolamine Concentration (µg/m³)	
	PC (µg/m³)	PC as % of Objective	PC (µg/m³)	PC as % of Objective
R1	0.0105	0.01%	0.1305	0.03%
R2	0.0123	0.01%	0.1144	0.03%
R3	0.0224	0.02%	0.1283	0.03%
R4	0.0209	0.02%	0.1162	0.03%
R5	0.0205	0.02%	0.0878	0.02%
R6	0.0212	0.02%	0.0748	0.02%
R7	0.0188	0.02%	0.1023	0.03%
R8	0.0217	0.02%	0.0656	0.02%
R9	0.0210	0.02%	0.0859	0.02%
R10	0.0230	0.02%	0.0829	0.02%
R11	0.0190	0.02%	0.0852	0.02%
R12	0.0128	0.01%	0.1280	0.03%
R13	0.0213	0.02%	0.0675	0.02%
Maximum Outside Boundary	0.0320	0.03%	0.2068	0.05%
AQS / EAL Objective	100 µg/m³		400 µg/m³	

Table 5.7: Predicted Diethanolamine Concentrations at Discrete Receptors - Highest Results for Each Receptor

Receptor ID	Daily Mean Diethanolamine Concentration (µg/m³)	
	PC (µg/m³)	PC as % of Objective
R1	0.0105	0.35%
R2	0.0123	0.41%
R3	0.0224	0.75%
R4	0.0209	0.70%
R5	0.0205	0.68%
R6	0.0212	0.71%
R7	0.0188	0.63%
R8	0.0217	0.72%
R9	0.0210	0.70%
R10	0.0230	0.77%
R11	0.0190	0.63%
R12	0.0128	0.43%
R13	0.0213	0.71%
Maximum Outside Boundary	0.0320	1.07%
AQS / EAL Objective	3 µg/m³	

Table 5.8: Predicted N,N-dimethylethylenediamine Concentrations at Discrete Receptors - Highest Results for Each Receptor

Receptor ID	Daily Mean N,N-dimethylethylenediamine Concentration (µg/m³)		Hourly Mean N,N-dimethylethylenediamine Concentration (µg/m³)	
	PC (µg/m³)	PC as % of Objective	PC (µg/m³)	PC as % of Objective
R1	0.0105	0.01%	0.1305	0.03%
R2	0.0123	0.01%	0.1144	0.03%
R3	0.0224	0.02%	0.1283	0.03%
R4	0.0209	0.02%	0.1162	0.03%
R5	0.0205	0.02%	0.0878	0.02%
R6	0.0212	0.02%	0.0748	0.02%
R7	0.0188	0.02%	0.1023	0.02%
R8	0.0217	0.02%	0.0656	0.02%
R9	0.0210	0.02%	0.0859	0.02%
R10	0.0230	0.02%	0.0829	0.02%
R11	0.0190	0.02%	0.0852	0.02%
R12	0.0128	0.01%	0.1280	0.03%
R13	0.0213	0.02%	0.0675	0.02%

Receptor ID	Daily Mean N,N-dimethylethylenediamine Concentration (µg/m³)		Hourly Mean N,N-dimethylethylenediamine Concentration (µg/m³)	
	PC (µg/m³)	PC as % of Objective	PC (µg/m³)	PC as % of Objective
Maximum Outside Boundary	0.0320	0.03%	0.2068	0.05%
AQS / EAL Objective	104 µg/m³		417 µg/m³	

Table 5.9: Predicted N-(2-hydroxyethyl)acetamide Concentrations at Discrete Receptors - Highest Results for Each Receptor

Receptor ID	Annual Mean N-(2-hydroxyethyl)acetamide Concentration (µg/m³)	
	PC (µg/m³)	PC as % of Objective
R1	0.0005	0.63%
R2	0.0007	0.83%
R3	0.0013	1.52%
R4	0.0008	0.94%
R5	0.0017	1.97%
R6	0.0017	1.96%
R7	0.0013	1.58%
R8	0.0014	1.63%
R9	0.0016	1.87%
R10	0.0024	2.81%
R11	0.0012	1.47%
R12	0.0004	0.46%
R13	0.0011	1.33%
Maximum Outside Boundary	0.0032	3.72%
AQS / EAL Objective	0.085 µg/m³	

Table 5.10: Predicted N-(2-hydroxyethyl)formamide Concentrations at Discrete Receptors - Highest Results for Each Receptor

Receptor ID	Annual Mean N-(2-hydroxyethyl)formamide Concentration (µg/m³)	
	PC (µg/m³)	PC as % of Objective
R1	0.0005	<0.01%
R2	0.0007	<0.01%
R3	0.0013	<0.01%
R4	0.0008	<0.01%
R5	0.0017	<0.01%
R6	0.0017	<0.01%
R7	0.0013	<0.01%
R8	0.0014	<0.01%

Receptor ID	Annual Mean N-(2-hydroxyethyl)formamide Concentration (µg/m³)	
	PC (µg/m³)	PC as % of Objective
R9	0.0016	<0.01%
R10	0.0024	<0.01%
R11	0.0012	<0.01%
R12	0.0004	<0.01%
R13	0.0011	<0.01%
Maximum Outside Boundary	0.0032	<0.01%
AQS / EAL Objective	86 µg/m³	

Table 5.11: Predicted Formaldehyde Concentrations at Discrete Receptors - Highest Results for Each Receptor

Receptor ID	Annual Mean Formaldehyde Concentration (µg/m³)		30-minute Mean Formaldehyde Concentration (µg/m³)	
	PC (µg/m³)	PC as % of Objective	PC (µg/m³)	PC as % of Objective
R1	0.0011	0.02%	0.3563	0.36%
R2	0.0015	0.03%	0.3123	0.31%
R3	0.0027	0.05%	0.3503	0.35%
R4	0.0017	0.03%	0.3173	0.32%
R5	0.0035	0.07%	0.2397	0.24%
R6	0.0035	0.07%	0.2042	0.20%
R7	0.0028	0.06%	0.2793	0.28%
R8	0.0029	0.06%	0.1792	0.18%
R9	0.0033	0.07%	0.2345	0.23%
R10	0.0050	0.10%	0.2264	0.23%
R11	0.0026	0.05%	0.2325	0.23%
R12	0.0008	0.02%	0.3494	0.35%
R13	0.0024	0.05%	0.1842	0.18%
Maximum Outside Boundary	0.0066	0.13%	0.5645	0.56%
AQS / EAL Objective	5 µg/m³		100 µg/m³	

Table 5.12: Predicted Acetaldehyde Concentrations at Discrete Receptors - Highest Results for Each Receptor

Receptor ID	Annual Mean Acetaldehyde Concentration (µg/m³)		Hourly Mean Acetaldehyde Concentration (µg/m³)	
	PC (µg/m³)	PC as % of Objective	PC (µg/m³)	PC as % of Objective
R1	0.0053	<0.01%	1.2921	0.01%

Receptor ID	Annual Mean Acetaldehyde Concentration (µg/m³)		Hourly Mean Acetaldehyde Concentration (µg/m³)	
	PC (µg/m³)	PC as % of Objective	PC (µg/m³)	PC as % of Objective
R2	0.0070	<0.01%	1.1324	0.01%
R3	0.0128	<0.01%	1.2704	0.01%
R4	0.0079	<0.01%	1.1506	0.01%
R5	0.0165	<0.01%	0.8691	0.01%
R6	0.0165	<0.01%	0.7404	0.01%
R7	0.0133	<0.01%	1.0128	0.01%
R8	0.0137	<0.01%	0.6498	0.01%
R9	0.0158	<0.01%	0.8504	0.01%
R10	0.0237	0.01%	0.8208	0.01%
R11	0.0124	<0.01%	0.8431	0.01%
R12	0.0039	<0.01%	1.2670	0.01%
R13	0.0112	<0.01%	0.6680	0.01%
Maximum Outside Boundary	0.0313	0.01%	2.0472	0.02%
AQS / EAL Objective	370 µg/m³		9,200 µg/m³	

Table 5.13: Predicted Ethylethanolamine Concentrations at Discrete Receptors - Highest Results for Each Receptor

Receptor ID	Annual Mean Ethylmethylamine Concentration (µg/m³)	
	PC (µg/m³)	PC as % of Objective
R1	0.0003	0.32%
R2	0.0015	0.03%
R3	0.0027	0.05%
R4	0.0017	0.03%
R5	0.0035	0.07%
R6	0.0035	0.07%
R7	0.0028	0.06%
R8	0.0029	0.06%
R9	0.0033	0.07%
R10	0.0050	0.10%
R11	0.0026	0.05%
R12	0.0008	0.02%
R13	0.0024	0.05%
Maximum Outside Boundary	0.0066	0.13%
AQS / EAL Objective	0.085* µg/m³	

Receptor ID	Annual Mean Ethylmethylamine Concentration (µg/m³)	
	PC (µg/m³)	PC as % of Objective
	*No EAL is set for Ethylmethylamine. The lowest annual EAL among all assessed amine compounds has been applied. This represents the annual EAL of N-(2-hydroxyethyl)acetamide	

Table 5.14: Predicted Ethyldiethanolamine Concentrations at Discrete Receptors - Highest Results for Each Receptor

Receptor ID	Annual Mean Ethyldiethanolamine Concentration (µg/m³)	
	PC (µg/m³)	PC as % of Objective
R1	0.0002	0.19%
R2	0.0002	0.25%
R3	0.0004	0.46%
R4	0.0002	0.28%
R5	0.0005	0.59%
R6	0.0005	0.59%
R7	0.0004	0.47%
R8	0.0004	0.49%
R9	0.0005	0.56%
R10	0.0007	0.84%
R11	0.0004	0.44%
R12	0.0001	0.14%
R13	0.0003	0.40%
Maximum Outside Boundary	0.0009	1.12%
AQS / EAL Objective	0.085* µg/m³ *No EAL is set for Ethylmethylamine. The lowest annual EAL among all assessed amine compounds has been applied. This represents the annual EAL of N-(2-hydroxyethyl)acetamide	

Table 5.15: Predicted Piperazine Concentrations at Discrete Receptors - Highest Results for Each Receptor

Receptor ID	Daily Mean Piperazine Concentration (µg/m³)	
	PC (µg/m³)	PC as % of Objective
R1	0.002	0.01%
R2	0.002	0.02%
R3	0.004	0.03%
R4	0.004	0.03%
R5	0.004	0.03%
R6	0.004	0.03%
R7	0.004	0.03%
R8	0.004	0.03%
R9	0.004	0.03%

Receptor ID	Daily Mean Piperazine Concentration (µg/m³)	
	PC (µg/m³)	PC as % of Objective
R10	0.005	0.03%
R11	0.004	0.03%
R12	0.003	0.02%
R13	0.004	0.03%
Maximum Outside Boundary	0.006	0.04%
AQS / EAL Objective	15 µg/m³	

5.2 Impacts on Human Receptors (Indirect Emission)

Over a greater distances it is expected that further degradation of amines will occur, and, therefore, this results in the formation of nitrosamines and nitramines concentrations increasing with distance from the PCCC plant.

The concentration of total nitrosamines and nitramines compounds in direct emission at the assessed discrete receptors representative of relevant human exposure, assessed across any of the meteorological years modelled, is described in Table 5.1 below. Also, the concentration of indirect emission of nitrosamines and nitramines formed by the degradation of three amine compounds (MEA, DMA and EA) processed through the ADMS amines module and presented in Table 5.16.

As shown below, both the direct and indirect impacts of the nitrosamines and nitramines emissions and combined nitrosamines and nitramines emissions impacts (direct + indirect) resulting from the operation of the site are well below the EAL at all relevant discrete receptor locations and the location of maximum impact outside the site boundary.

Table 5.16: Predicted Nitrosamines and Nitramines Concentrations at Discrete Receptors - Highest Results for Each Receptor

Receptor ID	Nitrosamines and Nitramines Concentration (ng/m³)					
	Direct PC	Direct PC as % of Objective	Indirect PC	Indirect PC as % of Objective	Total PC	Total PC as % of Objective
R1	0.0028	1.4%	0.0006	0.3%	0.0034	1.7%
R2	0.0037	1.8%	0.0009	0.4%	0.0045	2.3%
R3	0.0067	3.4%	0.0017	0.9%	0.0084	4.2%
R4	0.0042	2.1%	0.0020	1.0%	0.0061	3.1%
R5	0.0087	4.3%	0.0018	0.9%	0.0105	5.3%
R6	0.0087	4.3%	0.0021	1.1%	0.0108	5.4%
R7	0.0070	3.5%	0.0012	0.6%	0.0081	4.1%
R8	0.0072	3.6%	0.0020	1.0%	0.0092	4.6%
R9	0.0083	4.1%	0.0019	0.9%	0.0102	5.1%
R10	0.0124	6.2%	0.0043	2.1%	0.0167	8.3%

Receptor ID	Nitrosamines and Nitramines Concentration (ng/m^3)					
	Direct PC	Direct PC as % of Objective	Indirect PC	Indirect PC as % of Objective	Total PC	Total PC as % of Objective
R11	0.0065	3.2%	0.0028	1.4%	0.0093	4.7%
R12	0.0020	1.0%	0.0010	0.5%	0.0030	1.5%
R13	0.0059	2.9%	0.0015	0.7%	0.0074	3.7%
Maximum Outside Boundary	0.0164	8.2%	0.0065	3.2%	0.0228	11.4%
AQS / EAL Objective	0.2 ng/m^3					

5.3 Impacts on Ecological Receptors

Amines, nitrosamines, and nitramines contain nitrogen in their chemical structure, thus have the potential to contribute to nutrification of habitats. The nitrogen deposition from the direct and indirect amine emission is presented in Table 5.17.

The results of the model run show that predicted fluxes to nitrogen deposition from the direct and indirect amine emission are below the criteria of 1% of the relevant critical level from the EA and Defra 2016 guidance at the discrete receptors representing SACs, SPAs and SSSIs. No exceedance of the EA threshold of 100% of the relevant critical levels is predicted at the ancient woodlands and LWS.

It is noted that beneficial reduction in impacts are predicted at all receptors when compared to the existing scenario permitted under the Environmental Permit

Table 5.17: Nitrogen Deposition Contribution at Ecological Sensitive Sites (E1 – E23 represent European Sites)

Receptor ID	Receptor	Broad Habitat Type	PC (Direct Emission of non-nitrosamine and non-nitramine) (kg N/ha/yr)	PC (Direct Emission of nitrosamine and nitramine) (kg N/ha/yr)	Total N Deposition (kg N/ha/yr)	Lower Critical Load	Process Contribution as a % of Lower Critical Load
E1	Buckley Claypits and Commons SSSI/ Deeside and Buckley Newt Sites SAC	Acidophilous Quercus forest	0.0163	6.56E-06	0.0163	10	0.16%
E2	Buckley Claypits and Commons SSSI/ Deeside and Buckley Newt Sites SAC	Acidophilous Quercus forest	0.0300	1.21E-05	0.0300	10	0.30%
E3	Buckley Claypits and Commons SSSI/ Deeside and Buckley Newt Sites SAC	Acidophilous Quercus forest	0.0538	2.16E-05	0.0538	10	0.54%
E4	Maes Y Grug SSSI/ Deeside and Buckley Newt Sites SAC	Acidophilous Quercus forest	0.0316	1.27E-05	0.0316	10	0.32%
E5	Connah's Quay Ponds and Woodland SSSI/Deeside and Buckley Newt Sites SAC	Acidophilous Quercus forest	0.0104	4.18E-06	0.0104	10	0.10%
E6	Afon Dyfrdwy (River Dee) SSSI/SAC/SPA	Acidophilous Quercus forest	0.0073	2.94E-06	0.0073	10	0.07%
E7	Afon Dyfrdwy (River Dee) SSSI/SAC/SPA	Acidophilous Quercus forest	0.0064	2.58E-06	0.0064	10	0.06%

Receptor ID	Receptor	Broad Habitat Type	PC (Direct Emission of non-nitrosamine and non-nitramine) (kg N/ha/yr)	PC (Direct Emission of nitrosamine and nitramine) (kg N/ha/yr)	Total N Deposition (kg N/ha/yr)	Lower Critical Load	Process Contribution as a % of Lower Critical Load
E8	Afon Dyfrdwy (River Dee) SSSI/SAC/SPA	Acidophilous Quercus forest	0.0051	2.07E-06	0.0051	10	0.05%
E9	Dee Estuary / Aber Afon Dyfrdwy SSSI/SAC	Coastal dune grasslands (grey dunes) - acid type European dry heaths	0.0053	2.12E-06	0.0053	5	0.11%
E10	Shotton Lagoons and Reedbeds SSSI	Coastal dune grasslands (grey dunes) - acid type European dry heaths	0.0056	2.25E-06	0.0056	10	0.06%
E11	Mynydd Y Fflint / Flint Mountain SSSI	Other: Other Tall Herb And Fern	0.0205	8.24E-06	0.0205	10	0.20%
E12	Coed Talon Marsh SSSI	Salix cinerea-Galium palustre woodland	0.0066	2.66E-06	0.0066	10	0.07%
E13	Chwarel Cambrian / Cambrian Quarry, Gwernymynydd SSSI	Rhinolophus hipposideros	0.0029	1.17E-06	0.0029	10	0.03%
E14	Alyn Valley Woods and Alyn Gorge Caves SSSI/SAC	Avenula pubescens grassland: Dactylis glomerata-Briza media subcommunity	0.0025	9.94E-07	0.0025	10	0.02%
E15	Bryn Alyn SSSI	Festuca ovina-Agrostis capillaris-	0.0030	1.20E-06	0.0030	10	0.03%

Receptor ID	Receptor	Broad Habitat Type	PC (Direct Emission of non-nitrosamine and non-nitramine) (kg N/ha/yr)	PC (Direct Emission of nitrosamine and nitramine) (kg N/ha/yr)	Total N Deposition (kg N/ha/yr)	Lower Critical Load	Process Contribution as a % of Lower Critical Load
		Thymus praecox grassland: Trifolium repens-Luzula campestris subcommunity					
E16	Glaswelltiroedd Eryrys (Eryrys Grasslands) SSSI	Low and medium altitude hay meadows	0.0031	1.25E-06	0.0031	10	0.03%
E17	Llay Bog SSSI	Broadleaved deciduous woodland	0.0106	4.26E-06	0.0106	10	0.11%
E18	Chwarel Singret SSSI	Broadleaved and mixed woodlands	0.0131	5.28E-06	0.0131	10	0.13%
E19	Marford Quarry SSSI	Broadleaved and mixed woodlands	0.0092	3.71E-06	0.0092	10	0.09%
E20	Halkyn Mountain / Mynydd Helygain SAC	Arctic-alpine calcareous grassland	0.0077	3.11E-06	0.0077	5	0.15%
E21	Berwyn a Mynyddoedd De Clwyd / Berwyn and South Clwyd Mountains SAC	Arctic-alpine calcareous grassland Blanket bogs	0.0029	1.15E-06	0.0029	5	0.06%
E22	Berwyn a Mynyddoedd De Clwyd / Berwyn and South Clwyd Mountains SAC	Arctic-alpine calcareous grassland Blanket bogs	0.0022	8.95E-07	0.0022	5	0.04%
E23	Vicarage Moss SSSI/Ramsar	Fen - topogenous mires in valleys, basins and flood plains-	0.0102	4.09E-06	0.0102	5	0.20%

Receptor ID	Receptor	Broad Habitat Type	PC (Direct Emission of non-nitrosamine and non-nitramine) (kg N/ha/yr)	PC (Direct Emission of nitrosamine and nitramine) (kg N/ha/yr)	Total N Deposition (kg N/ha/yr)	Lower Critical Load	Process Contribution as a % of Lower Critical Load
E24	Price's Hill Wood Ancient Woodland/ Flintshire Wildlife Site	Broadleaved woodland and scrub	0.0358	1.44E-05	0.0358	10	0.36%
E25	Bistre Wood Ancient Woodland/ Flintshire Wildlife Site	Broadleaved woodland and scrub	0.0340	1.37E-05	0.0341	10	0.34%
E26	Black Pool Plantation Flintshire Wildlife Site	Fen	0.0081	3.27E-06	0.0081	5	0.16%
E27	Hartsheath Flintshire Wildlife Site	Lowland pasture and parkland	0.0144	5.77E-06	0.0144	20	0.07%
E28	Pontblyddyn Marsh and Coppa Wood Flintshire Wildlife Site	Pasture/ meadow and scrub Broadleaved woodland and scrub	0.0139	5.57E-06	0.0139	10	0.14%
E29	Padeswood Pool Flintshire Wildlife Site	Wet woodland/ Fen	0.0156	6.27E-06	0.0156	10	0.16%
E30	Padeswood Pasture Flintshire Wildlife Site	Pasture/ meadow and scrub	0.0146	5.87E-06	0.0146	20	0.07%
E31	Marleyfield Meadow Flintshire Wildlife Site	Pasture/meadow and scrub Broadleaved woodland and scrub	0.0303	1.22E-05	0.0303	10	0.30%
E32	Padeswood Marsh LWS	Broadleaved woodland and scrub	0.0141	5.66E-06	0.0141	10	0.14%

Receptor ID	Receptor	Broad Habitat Type	PC (Direct Emission of non-nitrosamine and non-nitramine) (kg N/ha/yr)	PC (Direct Emission of nitrosamine and nitramine) (kg N/ha/yr)	Total N Deposition (kg N/ha/yr)	Lower Critical Load	Process Contribution as a % of Lower Critical Load
E33	Etna Road Pools LWS	Broadleaved woodland and scrub	0.0290	1.17E-05	0.0290	10	0.29%
E34	Plas Newydd Farm Lake LWS	Broadleaved woodland and scrub	0.0145	5.84E-06	0.0145	10	0.15%
E35	Riding School Wood and Grassland LWS	Broadleaved woodland and scrub	0.0215	8.63E-06	0.0215	10	0.21%
E36	Garth Wood and Hartsheath LWS	Broadleaved woodland and scrub	0.0353	1.42E-05	0.0353	10	0.35%
E37	Warred Dingle LWS	Broadleaved woodland and scrub	0.0127	5.12E-06	0.0127	10	0.13%
E38	Ancient Woodland 1	Broadleaved woodland and scrub	0.0073	2.92E-06	0.0073	10	0.07%
E39	Ancient Woodland 2	Broadleaved woodland and scrub	0.0695	2.79E-05	0.0695	10	0.70%
E40	Ancient Woodland 3	Broadleaved woodland and scrub	0.0128	5.15E-06	0.0128	10	0.13%
E41	Ancient Woodland 4	Broadleaved woodland and scrub	0.0145	5.81E-06	0.0145	10	0.14%
E42	Ancient Woodland 5	Broadleaved woodland and scrub	0.0121	4.86E-06	0.0121	10	0.12%
E43	Ancient Woodland 6	Broadleaved woodland and scrub	0.0117	4.69E-06	0.0117	10	0.12%

Receptor ID	Receptor	Broad Habitat Type	PC (Direct Emission of non-nitrosamine and non-nitramine) (kg N/ha/yr)	PC (Direct Emission of nitrosamine and nitramine) (kg N/ha/yr)	Total N Deposition (kg N/ha/yr)	Lower Critical Load	Process Contribution as a % of Lower Critical Load
E44	Ancient Woodland 7	Broadleaved woodland and scrub	0.0137	5.50E-06	0.0137	10	0.14%
E45	Ancient Woodland 8	Broadleaved woodland and scrub	0.0293	1.18E-05	0.0293	10	0.29%
E46	Ancient Woodland 9	Broadleaved woodland and scrub	0.0259	1.04E-05	0.0259	10	0.26%
E47	Ancient Woodland 10	Broadleaved woodland and scrub	0.0172	6.91E-06	0.0172	10	0.17%
E48	Ancient Woodland 11	Broadleaved woodland and scrub	0.0109	4.38E-06	0.0109	10	0.11%
E49	Ancient Woodland 12	Broadleaved woodland and scrub	0.0138	5.55E-06	0.0138	10	0.14%
E50	Ancient Woodland 13	Broadleaved woodland and scrub	0.0116	4.67E-06	0.0116	10	0.12%
E51	Ancient Woodland 14	Broadleaved woodland and scrub	0.0139	5.61E-06	0.0140	10	0.14%
E52	Ancient Woodland 15	Broadleaved woodland and scrub	0.0166	6.68E-06	0.0166	10	0.17%
E53	Ancient Woodland 16	Broadleaved woodland and scrub	0.0137	5.52E-06	0.0137	10	0.14%
E54	Ancient Woodland 17	Broadleaved woodland and scrub	0.0128	5.16E-06	0.0128	10	0.13%

Receptor ID	Receptor	Broad Habitat Type	PC (Direct Emission of non-nitrosamine and non-nitramine) (kg N/ha/yr)	PC (Direct Emission of nitrosamine and nitramine) (kg N/ha/yr)	Total N Deposition (kg N/ha/yr)	Lower Critical Load	Process Contribution as a % of Lower Critical Load
E55	Ancient Woodland 18	Broadleaved woodland and scrub	0.0119	4.77E-06	0.0119	10	0.12%
E56	Ancient Woodland 19	Broadleaved woodland and scrub	0.0214	8.61E-06	0.0214	10	0.21%
E57	Ancient Woodland 20	Broadleaved woodland and scrub	0.0239	9.61E-06	0.0239	10	0.24%
E58	Ancient Woodland 21	Broadleaved woodland and scrub	0.0296	1.19E-05	0.0296	10	0.30%
E59	Ancient Woodland 22	Broadleaved woodland and scrub	0.0290	1.17E-05	0.0290	10	0.29%
E60	Ancient Woodland 23	Broadleaved woodland and scrub	0.0271	1.09E-05	0.0271	10	0.27%
E61	Ancient Woodland 24	Broadleaved woodland and scrub	0.0276	1.11E-05	0.0276	10	0.28%

5.4 Overall Results

The effects on nearby human receptors due to the emissions of amines and their reaction products due to the proposed variation can be summarised below:

- the modelled specific receptors were kept consistent with the previous assessment; however, due to the degradation of amines within the plume over time, the chosen receptors may not represent the maximum impacts at nearby human receptors. Analysis of the results across the grid indicates that the maximum predicted impacts on the grid are predicted to be within an urban area not represented by a specific receptor (see Appendix C). Therefore, the following observations relate to the presented maximum on the grid.
- there are no predicted exceedances of the 1% or 10% screening thresholds due to the direct amine emissions of nitrosamines, nitramines and aldehydes from the proposed PCCC stack. The exception is for the emissions of ethyldiethanolamine, ethylmethylamine and N-(2-hydroxyethyl)acetamide, where the largest impacts are 3.72% of the EAL. In the case of ethylmethylamine and ethyldiethanolamine, no EAL is available, so it has conservatively been compared against the lowest EAL used within this study (N-(2-hydroxyethyl)acetamide).
- there are predicted to be exceedances of the 1% screening threshold for the combined direct and indirect nitrosamines and nitramines emissions, with the highest impacts on the grid being 11.4% of the NDMA EAL.
- In isolation, the predicted impacts of both the indirect and direct emissions exceed the 1% screening threshold for NDMA.
- The above assessment is judged to be conservative in the following ways:
    - All nitrosamines and nitramines emissions have been compared against the EAL for NDMA. As demonstrated in Table 4.1, not all direct emissions of nitrosamines and nitramines will be NDMA;
    - all emissions are proposed to be emitted at their ELV during the entire operation; and
    - no consideration of the degradation of direct amine[13] or nitrosamines and nitramines emissions.
- The assessment has used a deliberately conservative approach in order to account for the uncertainties in the complex reaction chemistry of amines within the atmosphere and the unknown EALs and toxicity of some of the emitted pollutants.

The effects on nutrient nitrogen deposition fluxes at nearby ecological receptors due to the proposed variation can be summarised below:

- there are no predicted exceedances of the 1% screening threshold at any modelled ecological receptors due to the combined direct emissions of amines, nitrosamines and nitramines.
- This assessment does not detail the total impacts of the proposed variation on nearby ecological sites; the impacts of the proposed variation emissions of NOx and ammonia on nitrogen deposition being undertaken within the main assessment.

[13] As per the described methodology, the indirect formation of nitrosamines and nitramines within the atmosphere have been considered using a separate model run using ADMS 6's chemistry amine module.

Impacts from the emissions of NOx and ammonia are predicted to exceed the 1% screening threshold; however, as there is a betterment in nitrogen deposition fluxes between the existing and proposed kiln operations (as per the main assessment), the total change in impacts due to the proposed variation is still concluded to be below 1% of the screening threshold.

- There are widespread predicted PEC exceedances of the nutrient nitrogen deposition critical loads. This is due to the background concentration already exceeding the critical level/loads, which is common across most parts of the U.K.

6 CONCLUSIONS

An assessment of amines and their reaction products resulting from the use of an amine-based solvent within the carbon capture process associated with the Padeswood Carbon Capture and Storage Project has been undertaken.

The maximum predicted impacts at modelled locations across five modelled meteorological years have been reported and compared to the relevant EALs. Where relevant, the modelling methodology used has been conservative methodology, in line with industry guidance.

With the exception of the annual mean ground-level concentrations of ethyldiethanolamine, ethylmethylamine and N-(2-hydroxyethyl) acetamide, concentrations are not predicted to exceed the 1% or 10% insignificance screening thresholds at nearby human receptors due to the direct emissions from the proposed PCCC stack. Furthermore, both the direct and indirect predicted ground-level concentrations of nitrosamines and nitramines are predicted to exceed the 1% insignificance screening threshold.

The assessment has used a deliberately conservative approach in order to account for the uncertainties in the complex reaction chemistry of amines within the atmosphere and the unknown ELVs for some of the emitted pollutants. These main assumptions include all pollutants assumed to being emitted at their ELVs, all direct emissions assume no degradation within the atmosphere, and all pollutants with unknown EALs are compared against the most stringent EAL for other assessed pollutants. Considering the above conservative assumptions and the total concentrations predicted at nearby receptors being well below the EALs, the impact of the proposed variation on human health is judged to be not significant.

For ecological receptors, there are predicted to be no exceedances of the long-term insignificance screening thresholds against nitrogen deposition critical loads at any designated site due to the release of amines and their reaction products.

This assessment does not detail the total impacts of the proposed variation on nearby ecological sites; the impacts of the proposed variation's emissions of NOx and ammonia on nitrogen deposition have been undertaken within the main assessment. Impacts from the emissions of NOx and ammonia are predicted to exceed the 1% insignificance screening threshold; however, as there is a betterment in nitrogen deposition fluxes between the existing and proposed combustion kiln operations, the total change in impacts due to the proposed variation can still be concluded to be below 1% of the screening threshold, and not significant.

Overall, the effects of the amines and their reaction products associated with the proposed variation are judged not to be significant.

7 REFERENCES

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APPENDIX A AMINE EMISSION SUBSTANCES

This appendix contains the amine emission substances provided by MHI. It is noted that the conservative figure (1 mg/Nm^3) has been used for some amine compounds for modelling and is not the same figures shown in this appendix.

Figure A1: Amine Emission Substances

Table 1 Emission substances

Table 1 shows emission substances from KM CDR Process™ in HMUK project in the UK.

Substance name		MW	Boiling Point	HMUK	Remark
Degradants name	Formula	g/mol	℃	mg/Nm3 (10% O2)	
Total primary amine	-	-	-	<1.3	
Total secondary amine	-	-	-	<1.5	
Total tertiary amine	-	-	-	<0.4	
Total nitrosamine	-	-	-	4.8μg/Nm3	
Total nitramine	-	-	-	0.4μg/Nm3	
Total ammonia	-	-	-	3.5	
Total aldehyde	-	-	-	12.1	
Methylamine	CH_3NH_2	31.06	40	<0.1	Remark [1]
Ethylamine	$CH_3CH_2NH_2$		39	1.0	
Dimethylamine	$(CH_3)_2NH$	45.09	40	<0.1	Remark [1]
Diethylamine	$(CH_3CH_2)_2NH$	73.14	55	<0.1	Remark [1]
Ethylmethylamine	$CH_3CH_2NHCH_3$	59.11	35	0.3	Remark [1]
Monoethanolamine	$H_2NCH_2CH_2OH$	61.08	170	<0.1	Remark [1]
Diethanolamine	$HN(CH_2CH_2OH)_2$	105.14	217	<0.1	Remark [1]
N,N-dimethylethylenediamine	$(CH_3)_2NCH_2CH_2NH_2$	88.15	107	<0.1	Remark [1]
Ammonia	NH_3	17.03	60	3.5	It is calculated for HMUK conditions.
N-(2-hydroxyethyl)acetamide	$CH_3CONHCH_2CH_2OH$	103.12	167	<0.1	Remark [1]
N-(2-hydroxyethyl)formamide	$HCONHCH_2CH_2OH$	89.09	181	<0.1	Remark [1]
N-Nitrosodimethylamine (NDMA)	$(CH_3)_2NNO$	74.08	153	0.6μg/Nm3	Remark [1]
N-Nitrosodiethylamine (NDEA)	$(CH_3CH_2)_2NNO$	102.14	177	0.2μg/Nm3	Remark [1]
N-Nitrosomethylethylamine (NMEA)	$C_3H_8N_2O$	88.11	170	2.8μg/Nm3	Remark [1]
N-Nitrosodiethanolamine (NDELA)	$C_4H_{10}N_2O_3$	134.14	114	0.2μg/Nm3	Remark [1]
N-Ethyl-N-(2-hydroxyethyl)nitrosamine (EHEN)	$CH_3CH_2N(CH_2CH_2OH)NO$	118.13	103 (*)	0.6μg/Nm3	(*) Boiling point 103 deg C at 0.4kPa. Remark [1]
1-Nitrosopiperazine (NPZ)	$C_4H_9N_3O$	115.13	80-85	0.1μg/Nm3	Remark [1]
1,4-Dinitrosopiperazine (DNPZ)	$C_4H_8N_4O_2$	144.13	no information	0.2μg/Nm3	Remark [1]
N-Nitrosomorpholine (NMOR)	$C_4H_8N_2O_2$	116.12	225	0.1μg/Nm3	Remark [1]
2-(ethylnitroamino)ethanol	$CH_3CH_2N(CH_2CH_2OH)NO_2$	134.13		0.2μg/Nm3	Remark [1]
1-nitropiperazine	$C_4H_9N_3O_2$	131.13	no information	0.2μg/Nm3	Remark [1]
Formaldehyde	HCHO	30.03	100	2.1	It is calculated for HMUK conditions.
Acetaldehyde	CH_3CHO	44.05	21	9.9	It is calculated for HMUK conditions.
Ethylethanolamine	C4H11NO	89.14	169	0.5	It is calculated for HMUK conditions.
Ethyldiethanolamine	C6H15NO2	133.19	251	0.3	Remark [1]
Piperazine	C4H10N2	86.14	146	0.2	Remark [1]

Remark [1] This is calculated based on Test data and adjusted based on HMUK process data.
Adjustment includes process parameter compensation (temperature, pressure), gas composition, effect of MHI emission countermeasures including acid wash and MHI proprietary demister.
If the emission is lower than 0.1, it is set as <0.1 mg/Nm3 for safety

APPENDIX B SENSITIVITY TEST

The sensitivity of the model to various indirect amine input parameters has been tested and are reported in this Appendix. The parameters that have been varied in the model input include:

- sensitively to a rural NO_X, NO_2 and O_3 background concentrations, taken from Aston Hill AURN;
- sensitively to a primary NO_2 value of 5%; and
- sensitively to the Ratio of j(nitrosamine)/jNO_2 of 0.39 for Amine1 and Amine3 (the values are currently unknown and have been inputted as zero).

Table B.1: Summary of PC Results at the Maximum Modelled Receptor Location during 2021 for Various Sensitivity Tests

Model Input Varied	Indirect Amine PC (ng/m^3)	% of AQAL
Main Assessment (2021)	0.0038	1.9%
Applying the percentage of primary NO_2 within the NOx emission at 5%	0.0037	1.9%
Aston Hill Monitoring Station BackgroundDate	0.0035	1.8%
Ratio of 0.39 j(nitrosamine)/jNO_2 to all the amine compound	0.0039	2.0%

APPENDIX C CONTOUR PLOTS

This Appendix contains contour plots (isopleths) illustrating the dispersion profiles of emission components released from the plant. The data is based on the meteorological data year (2021).

Figure C1 - Predicted Annual Average Direct Nitrosamines and Nitramines (ng/m^3) PCs– 2021 met data

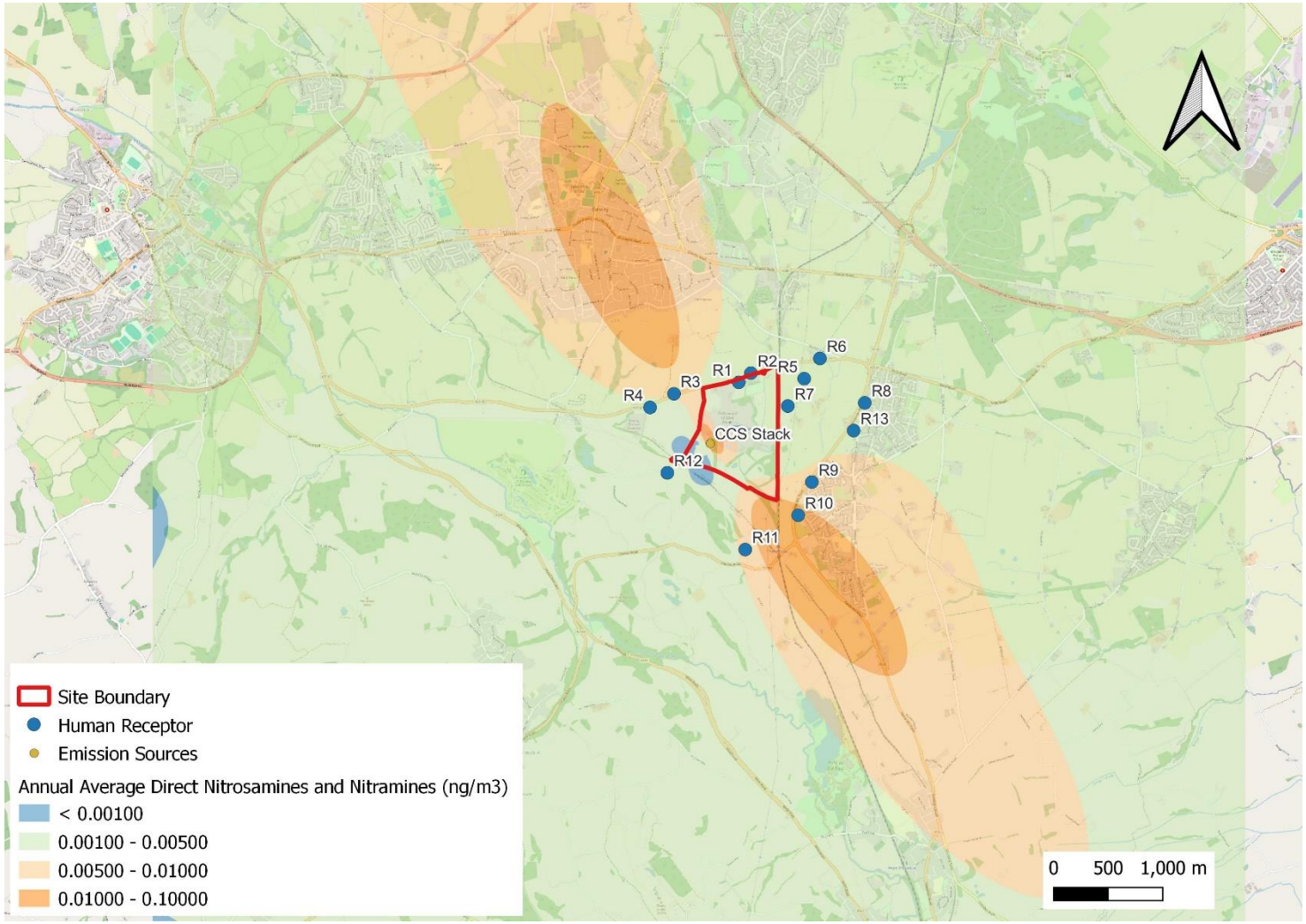

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Figure C2 Predicted Annual Average Indirect Nitrosamines and Nitramines (ng/m^3) PCs– 2021 met data

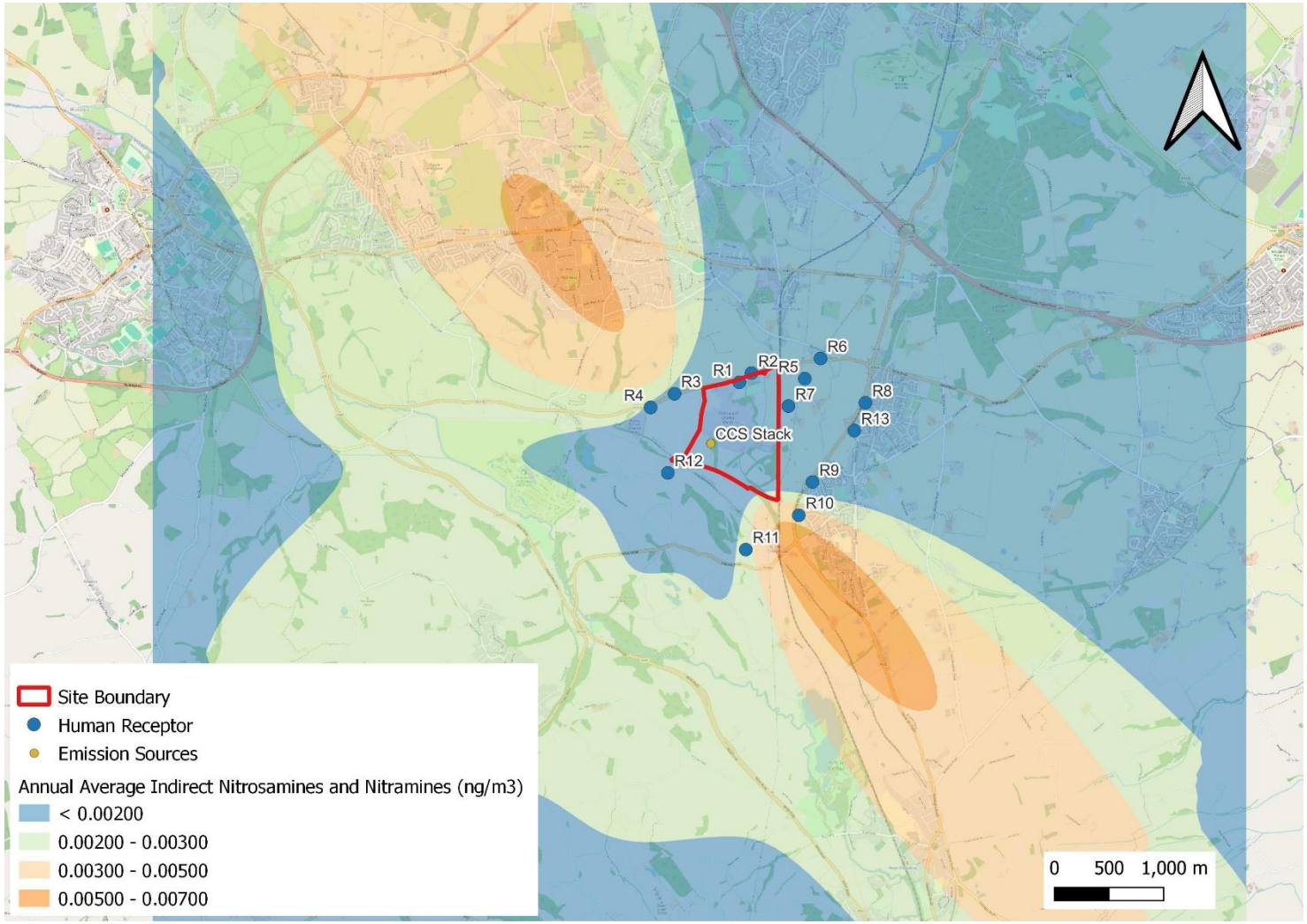

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Figure C3 Predicted Annual Average Total (indirect + Direct) Nitrosamines and Nitramines (ng/m^3) PCs– 2021 met data

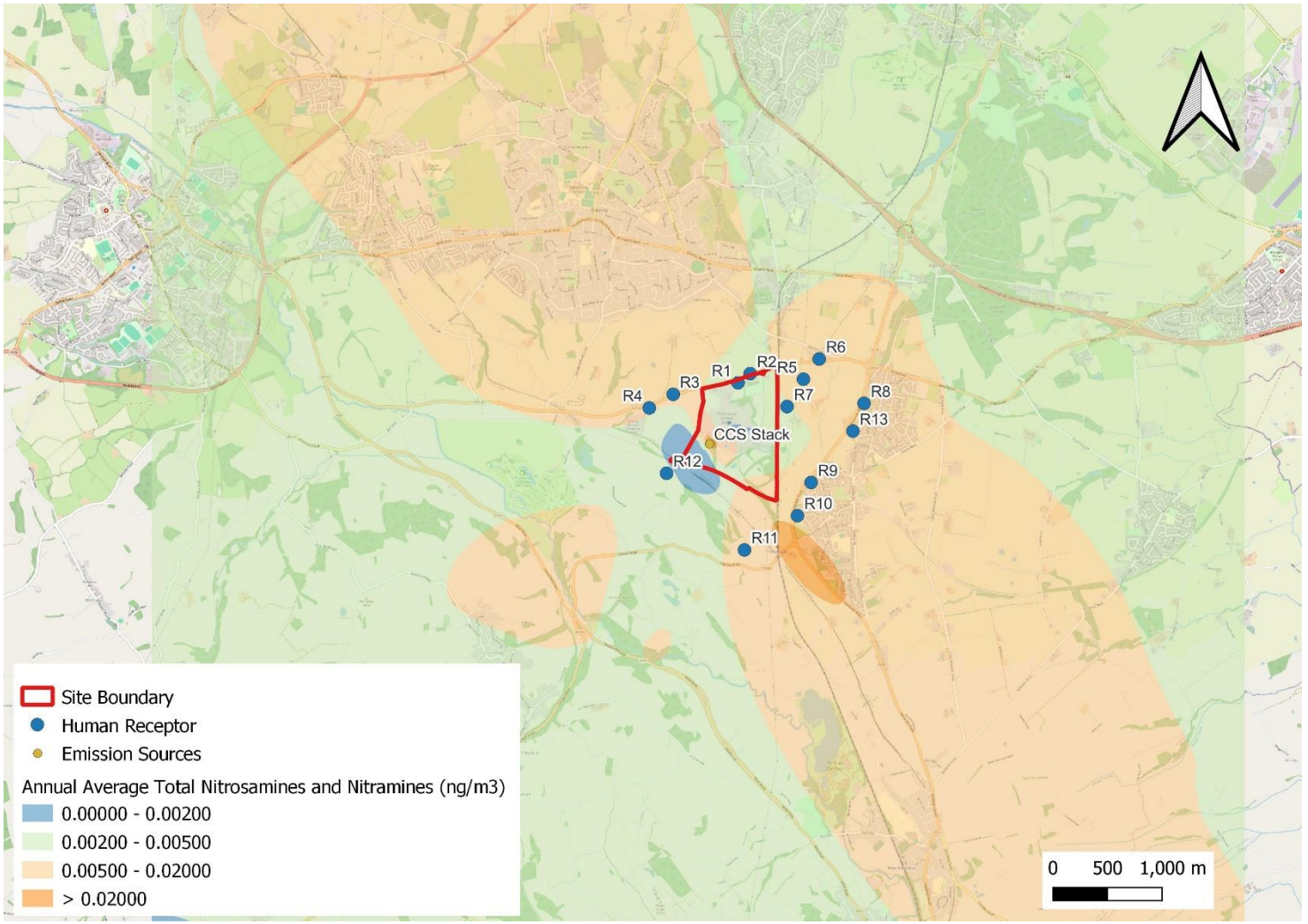

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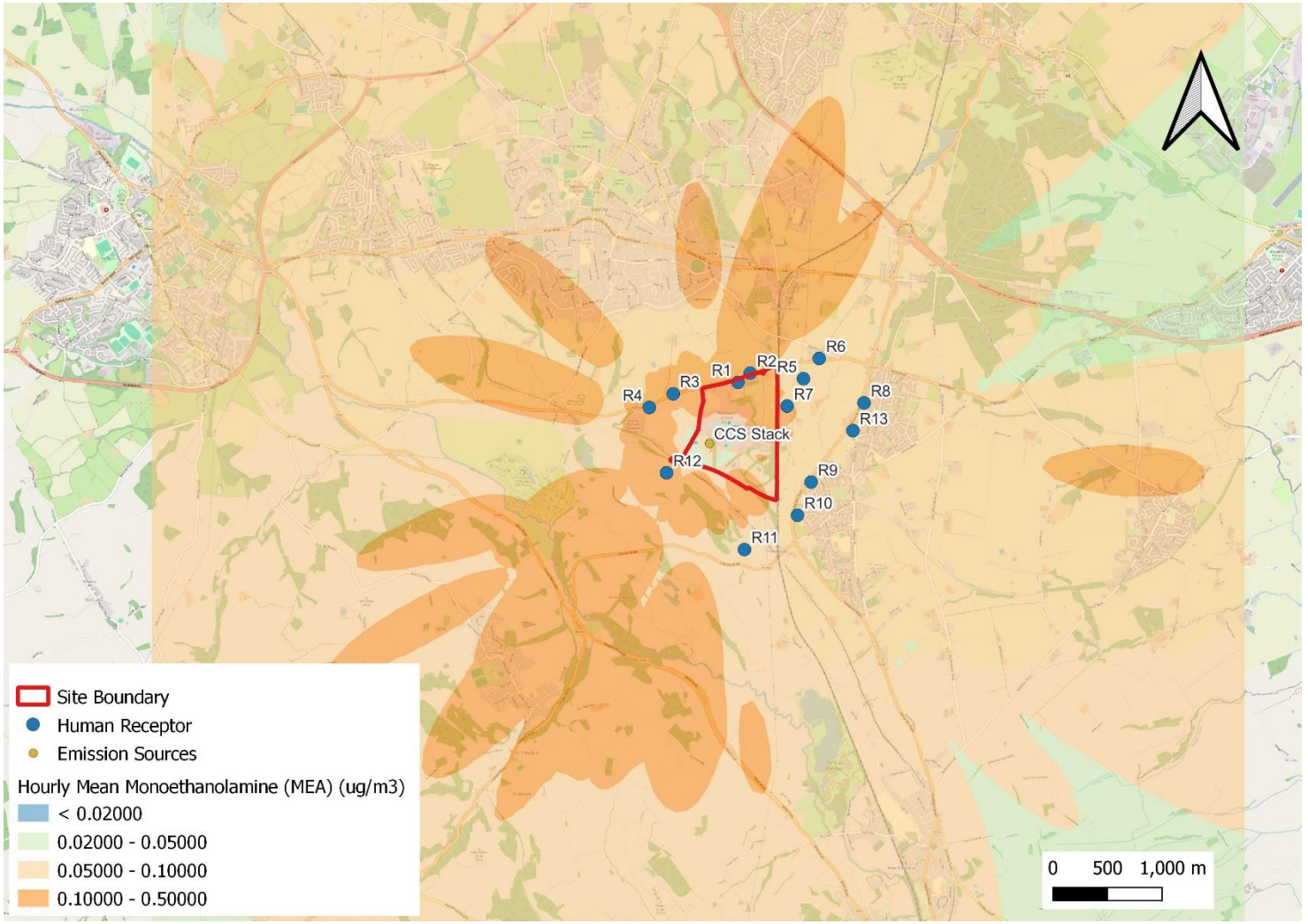
Figure C4 Predicted Hourly Mean Monoethanolamine (MEA) Concentration (ug/m^3) PCs– 2021 met data



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