ExxonMobil Chemical Limited

Assessment of Air Quality Impacts from the Operation of a New Enclosed Ground Flare at Fife Ethylene Plant

Report to accompany planning application

Wood Group UK Limited – April 2021

Report for

ExxonMobil Chemical Limited

Main contributors

[redacted]

Issued by

.....

[redacted]

Approved by

.....

[redacted]

Wood Group UK Limited

Block 2, Level 1
Booths Park
Knutsford WA16 8QZ
United Kingdom
Tel +44 (0)1565 652100

Doc Ref. 190711-WOOD-XX-XX-RP-OA-00002_A_C1.0_2021 Planning.docx

n:\projects\40787 aq fife ethylene plant flaring study\d - design\2021 modelling\reports\190711-wood-xx-xx-rp-oa-00002_a_c1.0_2021 planning.docx

Management systems

This document has been produced by Wood Group UK Limited in full compliance with our management systems, which have been certified to ISO 9001, ISO 14001 and ISO 45001 by Lloyd's Register.

Document revisions

No.	Details	Date
1	Draft Report	April 2021
2	Final Report	April 2021

Contents

1. Introduction

1.1 Background, aims and objectives

In 2019, Wood Group UK Limited ('Wood') undertook assessments to quantify the potential impacts on local air quality associated with emissions to air from the Fife Ethylene Plant (FEP)[1], operated by ExxonMobil Chemical Limited ('EMCL'), and the Fife Natural Gas Liquids (FNGL) Mossmorran Fractionation Plant, operated by Shell UK Limited ('Shell'). The assessments had a particular emphasis on flare emissions, but also included the other process and combustion plant emitting to atmosphere at the two installations.

The 2019 assessments concluded that emissions from FEP and FNGL plants, in isolation and in combination, would not result in an exceedance of any statutory air quality standard or non-statutory guideline value, with background emission sources (e.g., roads, domestic combustion etc.) the largest contributor to modelled ground level concentrations of key air quality pollutants. These pollutants included nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO), fine particulate matter (PM_{10} and $PM_{2.5}$) and certain speciated volatile organic compounds (VOCs) such as benzene.

The 2019 assessment was undertaken to update a previous assessment by Entec UK Limited in 2009[2] and in response to complaints from members of the public concerning the potential human health effects during non-routine flaring from the elevated flare at FEP. These complaints also cited noise and vibration, and visual impact concerns.

EMCL completed a Best Available Technique (BAT) assessment in 2019 which identified installation of a new, enclosed ground flare (EGF) would represent BAT for reducing noise and visual impacts, allowing operation of the elevated flare to be substantially reduced. However, due to the lower release height of the EGF compared to the elevated flare, the potential for small increases in ground level concentrations of certain combustion products with the EGF operating needed to be considered.

Consequently, this assessment investigates the potential changes in ground level concentrations and deposition rates of key pollutants at human receptors and habitat sites with the EGF operational.

This report is designed to accompany an application by EMCL for planning permission in relation to air quality effects. A companion report is designed to accompany an application to the Scottish Environmental Protection Agency (SEPA) for an environmental permit, and is attached as Annex 1. The permitting report also contains a more detailed technical description of the assessment methodology

1.2 Site location and description

FEP is located approximately 3 km south-east of the town of Cowdenbeath in Fife. The site produces ethylene using ethane as its primary feedstock. The major source of ethane arrives at the installation from the adjacent FNGL plant, having first been pumped from offshore oil and gas fields via the Shell/Exxon gas processing plant at St Fergus as a mixture of Natural Gas Liquids (NGL). The ethane is heated in a steam mix which cracks the ethane into ethylene, hydrogen and other various by-products. Uncracked ethane is recycled and all other by-product gases are used as fuel in the plant's furnaces and turbines.

[1] Wood, 2019. 'Assessment of Air Quality Impacts from Flaring at Fife Ethylene Plant' Report 40787-WOOD-XX-XX-RP-OA-0001_A_C01

[2] Entec, 2009. 'Local Air Quality Modelling Study for the Fife Ethylene Plant and Mossmorran Fractionation Plant – Impact Assessment of Flare and Process Stack Emissions from the Mossmorran Fractionation Plant'

Ethylene is transported by pipeline to the Braefoot Bay marine terminal, where it is shipped to other markets, with some of the ethylene distributed via the UK ethylene pipeline to other manufacturing plants in the UK.

The current FEP flare system consists of two different types of flare:

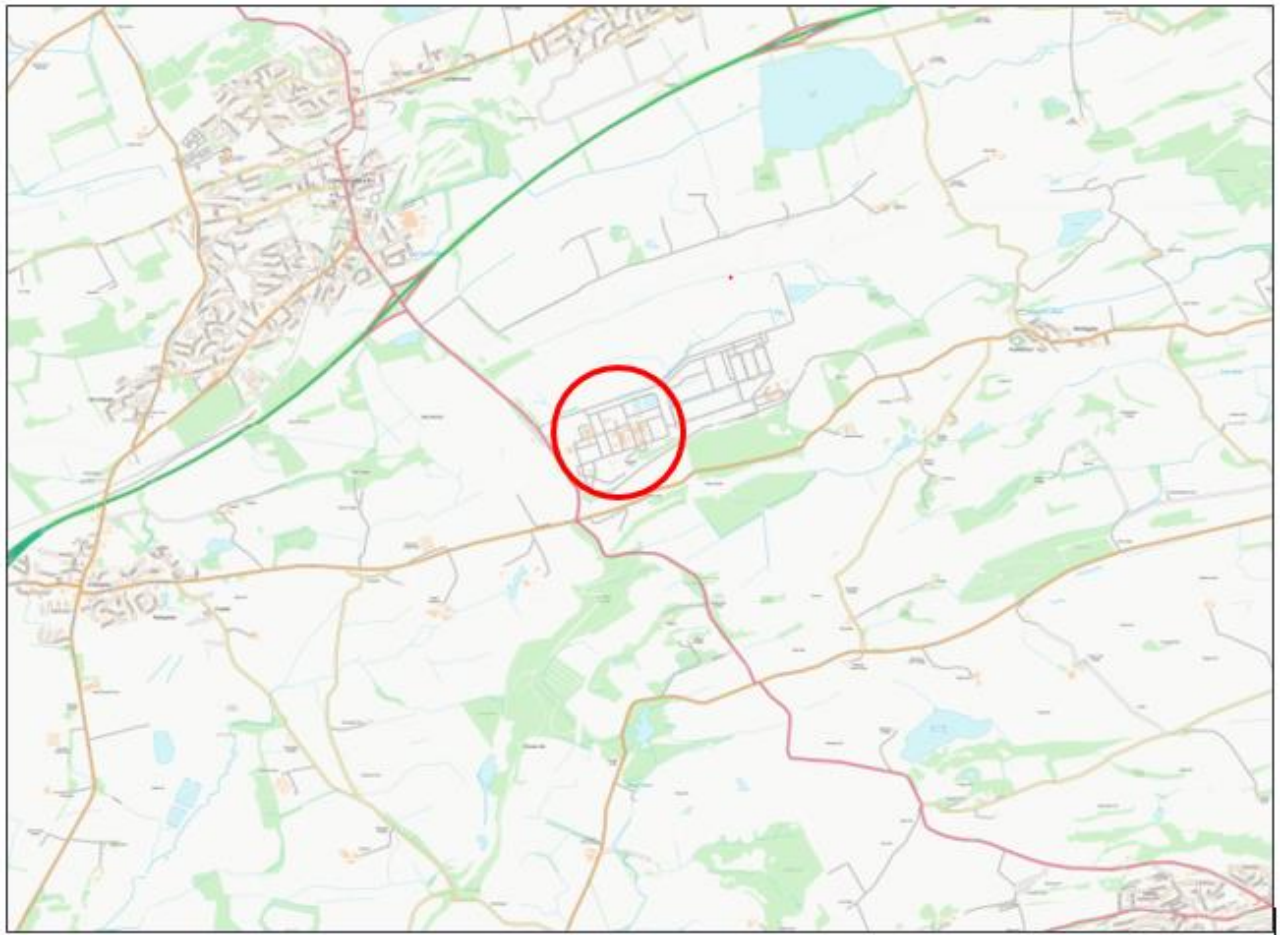
- An elevated flare, 100 m in height above ground level; and
- Two ground flares. These are operated by Shell but can be used by both sites as required.

Flaring occurs at low rates during normal operation of FEP ('base-load flaring'), with the Shell ground flares being preferentially used when available. Flaring can, however, increase significantly for short periods of time during unplanned process upsets (e.g., compressor or turbine trips) or before and/or following planned maintenance ('flaring event'). In all instances, flaring is an essential safety mechanism to allow excess gas, or out of specification gas, that cannot be processed at the installation to be combusted in a safe and controlled manner.

EMCL are proposing to replace the use of the existing shared ground flares with a new, larger enclosed ground flare (EGF) intended for sole use by EMCL. With the new EGF operational, the use of the elevated flare would be reduced considerably, with the EGF being the primary flare in operation during normal operation and most non-routine operations.

Figure 1.1 provides a site location map.

Figure 1.1 Site location map



2. Relevant legislation, planning policy, technical guidance

2.1 Legislation

The following legislation is relevant to the assessment of effects on air quality receptors.

EU legislation

Although the UK withdrew from the European Union on 31 January 2020, with EU law ceasing to apply to the UK after that date under the European Union (Withdrawal Agreement) Act 2020, the provisions of the following legislation remain largely applicable under the UK Withdrawal from the European Union (Continuity) (Scotland) Act 2021.

Directive 2008/50/EC on Ambient Air Quality and Cleaner Air for Europe

Directive 2008/50/EC (the 'Directive'), which came into force in June 2008, consolidates existing EU-wide air quality legislation (with the exception of Directive 2004/107/EC) and provides a new regulatory framework for $PM_{2.5}$.

The Directive sets limit values, or target levels, for selected pollutants that are to be achieved by specific dates and details procedures EU Member States should take in assessing ambient air quality. The limit values and target levels relate to concentrations in ambient air. At Article 2(1), the Directive defines ambient air as:

> *"…outdoor air in the troposphere, excluding workplaces as defined by Directive 89/654/EEC where provisions concerning health and safety at work apply and to which members of the public do not have regular access."*

In accordance with Article 2(1), Annex III, Part A, paragraph 2 details locations where compliance with the limit values does not need to be assessed:

> *"Compliance with the limit values directed at the protection of human health shall not be assessed at the following locations:*
>
> *a) any locations situated within areas where members of the public do not have access and there is no fixed habitation;*
>
> *b) in accordance with Article 2(1), on factory premises or at industrial installations to which all relevant provisions concerning health and safety at work apply; and*
>
> *c) on the carriageway of roads; and on the central reservation of roads except where there is normally pedestrian access to the central reservation.*

Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control)

Directive 2010/75/EU (the Industrial Emissions Directive, or IED) requires Competent Authorities in European Union member states to control and reduce the impact of certain industrial emissions on the environment. Operators of activities listed in Annex I of IED are required to apply to the relevant Competent Authority (the 'Regulator') for a permit to operate their installation. Regulators must set conditions in permits so as to achieve a high level of protection for the environment as a whole, based on the use of the best available techniques (BAT). Amongst others, emissions to air from permitted installations must meet the Best Available

Technique Associated Emission Levels (BAT-AEL) set in the relevant sectoral BAT Conclusions and ensure no significant pollution is caused.

In Scotland, the Scottish Environmental Protection Agency (SEPA) acts as the Competent Authority and regulates relevant activities under the Pollution Prevention and Control (Scotland) Regulations 2012, as amended. FEP already operates under an environmental permit issued and regulated by SEPA and will be required to apply for a variation to this permit to allow operation of the Proposed Development.

Scottish legislation

The Air Quality Standards (Scotland) Regulations 2010

The Air Quality Standards (Scotland) Regulations 2010 (the 'Regulations') came into force on the 11th June 2010 and transpose Directive 2008/50/EC into Scottish legislation. The Directive's limit values are transposed into the Regulations and commonly known as 'Air Quality Standards' (AQS) with attainment dates in line with the Directive.

These standards are legally binding concentrations of pollutants in the atmosphere which can broadly be taken to achieve a certain level of environmental quality. The standards are based on the assessment of the effects of each pollutant on human health including the effects of sensitive groups or on ecosystems.

Similar to Directive 2008/50/EC, the Regulations define ambient air as;

> *"…outdoor air in the troposphere, excluding workplaces where members of the public do not have regular access."*

with direction provided in Schedule 1, Part 1, Paragraph 2 as to where compliance with the AQS does not need to be assessed:

> *"Compliance with the limit values directed at the protection of human health does not need to be assessed at the following locations:*
>
> *a) any location situated within areas where members of the public do not have access and there is no fixed habitation;*
>
> *b) on factory premises or at industrial locations to which all relevant provisions concerning health and safety at work apply; and*
>
> *c) on the carriageway of roads and on the central reservation of roads except where there is normally pedestrian access to the central reservation."*

The Air Quality (Scotland) Regulations 2000, as amended

The Air Quality (Scotland) Regulations 2000, as amended provide health-based criteria for certain air pollutants; these criteria are based on medical and scientific reports on how and at what concentration each pollutant affects human health. The air quality objectives (AQOs) derived from these criteria are policy targets often expressed as a maximum ambient concentration not to be exceeded, without exception or with a permitted number of exceedances, within a specified timescale. The AQOs are central to the 2007 Air Quality Strategy, which clarifies that the objectives are:

> *"…a statement of policy intentions or policy targets. As such, there is no legal requirement to meet these objectives except where they mirror any equivalent legally binding limit values…"*

Paragraph 4(2) of The Air Quality (Scotland) Regulations 2000 states:

"The achievement or likely achievement of an air quality objective prescribed by paragraph (1) shall be determined by reference to the quality of air at locations – which are situated outside of buildings or other natural or man-made structures above or below ground; and where members of the public are regularly present"

Consequently, compliance with the AQOs should focus on areas where members of the general public are present over the entire duration of the concentration averaging period specific to the relevant objective.

The Air Quality (Scotland) Regulations 2000 were last amended in 2016 by the Air Quality (Scotland) Amendment Regulations 2016. These amended regulations introduce an AQO for $PM_{2.5}$ which is consistent with the World Health Organisation (WHO) guideline level. The new AQO is to be complied at all locations within Scotland outside of buildings or other natural or man-made structures above or below ground, and where members of the public are regularly present, by the 31st December 2020.

Table 2.1 provides the AQS and AQOs that are relevant to this assessment.

Table 2.1 Air Quality Standards and Objectives relevant to this assessment

Pollutant	AQS/AQO	Averaging period	Value (µg/m^3)
Nitrogen dioxide, NO_2 (Human Receptor)	AQS/AQO	Annual mean	40
	AQS/AQO	1-hour mean, not to be exceeded more than 18 times a year (equivalent to 99.79 percentile)	200
Oxides of nitrogen, NOx (Ecological Receptor)	AQS	Annual mean	30
Carbon monoxide, CO (Human Receptor)	AQS/AQO	Rolling 8-hour mean	10,000
Sulphur dioxide, SO_2 (Human Receptor)	AQS/AQO	1-hour mean not to be exceeded more than 24 times a year (equivalent to 99.73 percentile)	350
	AQS/AQO	24-hour mean, not to be exceeded more than 3 times a year (equivalent to 99.18 percentile)	125
	AQO	15-min mean, not to be exceeded more than 35 times a year (equivalent to 99.9 percentile)	266
SO_2 (Ecological Receptor)	AQS	Annual mean	20
Particulate matter less than 10 µm, PM_{10} (Human Receptor)	AQO	Annual mean	18
	AQO	24-hour mean, not to be exceeded more than 7 times a year (equivalent to 98.08 percentile)	50
Particulate matter less than 2.5 µm, $PM_{2.5}$ (Human Receptor)	AQO	Annual mean	10

The Environment Act 1995

Part IV of the Environment Act 1995 requires that Local Authorities periodically review air quality within their individual areas. This process of Local Air Quality Management (LAQM) is an integral part of delivering the Government's AQOs.

To carry out an air quality Review and Assessment under the LAQM process, the Government recommends a three-stage approach. This phased review process uses initial simple screening methods and progresses through to more detailed assessment methods of modelling and monitoring in areas identified to be at potential risk of exceeding the objectives in the Regulations.

Review and assessments of local air quality aim to identify areas where national policies to reduce vehicle and industrial emissions are unlikely to result in air quality meeting the Government's air quality objectives by the required dates.

For the purposes of determining the focus of Review and Assessment, Local Authorities should have regard to those locations where members of the public are likely to be regularly present and are likely to be exposed over the averaging period of the objective.

Where the assessment indicates that some or all of the objectives may be potentially exceeded, the Local Authority has a duty to declare an Air Quality Management Area (AQMA). The declaration of an AQMA requires the Local Authority to implement an Air Quality Action Plan (AQAP), to reduce air pollution concentrations so that the required AQOs are met.

Pollution Prevention and Control (Scotland) Regulations 2012

The Pollution Prevention and Control (Scotland) Regulations 2012 (PPC 2012) came into force on 7 January 2013 to implement the requirements of the EU Industrial Emissions Directive (IED). The PPC regulations apply an integrated environmental approach to the regulation of certain industrial activities. Operators of installations that fall under the PPC regulations must have a permit in order to operate.

In Scotland, SEPA acts as the Competent Authority and regulates relevant activities under the Pollution Prevention and Control (Scotland) Regulations 2012, as amended. FEP already operates under an environmental permit issued and regulated by SEPA and will be required to apply for a variation to this permit to allow operation of the Proposed Development.

The Environmental Protection Act 1990

Under Part III Section 79 (1)(d) of the Environmental Protection Act 1990 *(c. 43)*, dust and odour can both be statutory nuisances. However, there are no statutory standards for dust deposition or odour which can be used to assess whether a nuisance has occurred, principally due to the normal variability of atmospheric dust and odours.

The precise distance from which a receptor may be susceptible to soiling from a dust emission source will depend on the nature of the activity on site, wind direction, wind speed, particle size distribution and moisture content, which all influence whether the potential for dust annoyance exists. The degree of annoyance depends on the rate of deposition, and is discernible at two levels:

- Annoyance experienced when the dust cover is sufficient to be visible when contrasted to an adjacent clean surface, such as when a finger is wiped across the surface. This is particularly annoying when it occurs regularly over long periods; and
- Severe annoyance experienced when the dust cover is perceptible without a clean reference surface for comparison.

Annoyance complaints are usually associated with periods of peak deposition, occurring during particular weather conditions. There is a 'normal' level of dust deposition in every community (i.e. the existing baseline)

and it is only when the rate of deposition is considered high relative to the existing baseline that complaints tend to occur. The effect of dust on a community will therefore be determined by three main factors:

- Short term dust events/ emissions during periods of dry weather;
- The frequency or regularity with which these occur; and
- The duration of activities which contribute to dust emissions.

The smallest particles of dust (i.e. in the size range of 0–30 µm) have the potential to travel the furthest from where they are generated, but these normally make up only a small proportion of the dust that originates from most construction, mineral or waste sites.

The levels of dust that might be considered typical for a range of areas are given in Table 2.2. In this case, deposition is measured using British Standard (BS) Deposit Gauges (BS1747 Part 1). Alternatively, dust levels can be measured based in terms of soiling (obscurance) of a surface. In such circumstances, the unit used is based on effective area coverage of a white background in terms of the percentage covered per day (% EAC/day[3]).

Table 2.2 Typical levels for deposition and obscuration dust gauges

Situation	Deposition (mg/m^2/day)	% EAC/day[3]
Rural	10-50	0.01-0.5
Suburban/ small town	30-80	0.2
Urban	N/A	0.3-0.4
Town Centre/ Industrial	80-160	0.8-1

Source: HMSO (1996). The Environmental Effects of Dust from Surface Mineral Workings

The historical data demonstrates that a wide monthly variation in monitored results is relatively common in all environments. Short-term (daily) variations will be even greater and could be expected to extend to 2–5 times the upper monthly value and these factors tend to undermine the value of this type of monitoring.

In the UK, a criterion of 200 mg/m^2/day, based on monthly averages, has been used as a threshold for nuisance in the past. This is comparable with the 'complaints likely' guideline reported by Vallack and Shilitto (1998), as summarised in Table 2.3. However, as stated earlier, there is no accepted UK standard for nuisance dust deposition rates and this, combined with the limitations of the standard monitoring techniques, again undermines the value of the use of the criterion in air quality assessments.

Table 2.3 Suggested likelihood of nuisance guidelines for monthly mean dust deposition as insoluble deposition (mg/m^2/day)

Location	British Standard deposit gauge		Dry frisbee gauge complaints possible	Equivalent complaints likely
	Complaints Possible	***Complaints Likely***		
Open country	80	100	N/A	N/A
Residential areas and Outskirts of towns	110	150	150	200
Commercial centres of towns	150	190	200	260

[3] EAC: Effective Area Coverage

With respect to odours, whether a particular odour will cause an annoyance reaction from human beings in their normal everyday environment is determined by a number of different but interacting factors, including:

- The concentration of the odour in the atmosphere;
- The nature of the odour (how objectionable it is perceived to be); and
- How frequently it occurs and for how long.

Odour concentration is expressed as European odour units per cubic metre at standard conditions for olfactometry (ou_E/m^3) as compared to a European reference concentration of a known standard odorant in air (n-butanol). The odour concentration, in simple terms, is the number of times an odorous sample of air has to be diluted with odour-free air to reach its odour threshold. Exposure is usually quantified in terms of a frequency of occurrence over a year of hourly average concentrations above a certain limit odour concentration.

Odours are not generally additive in the same way as other parameters such as decibels for noise. This reflects the way in which the brain responds to odour. The human brain has a tendency to 'screen out' those odours which are always present or those that are in context to their surroundings. For example, an individual is more likely to be tolerant of an odour from a factory in an industrial area than in the countryside. The human brain will also develop a form of acceptance to a constant background of local odours.

With regard to the concentrations of odour in the atmosphere that can be detected and recognised by the human olfactory system, and the levels which would cause annoyance or give rise to complaint, there are clearly a number of factors involved. These factors are commonly associated with the FIDOL acronym:

- Frequency of detection - the number of exposures to an odour within a given time frame.
- Intensity as perceived - the magnitude of the perception of the odour.
- Duration - the time period during which the odour exposure occurs.
- Offensiveness - this is a qualitative judgement to describe the odour.
- Location – the type of receptor will determine its sensitivity to odour, e.g. residential properties are likely to be associated with greater sensitivity than industrial locations.

2.2 Planning policy

National policies

The Air Quality Strategy for England, Scotland, Wales and Northern Ireland

The 2007 Air Quality Strategy for England, Scotland Wales and Northern Ireland (Defra *et al*., 2007) provides a framework for improving air quality at a national and local level and supersedes the previous strategy published in 2000. It imposes a number of obligations on local authorities to manage air quality. It does not directly impose obligations on developers.

Central to the Air Quality Strategy are health-based criteria for certain air pollutants; these criteria are based on medical and scientific reports on how and at what concentration each pollutant affects human health. The AQOs derived from these criteria are policy targets often expressed as a maximum ambient concentration not to be exceeded, either without exception or with a permitted number of exceedances, over a specified averaging period. At paragraph 22 of the 2007 Air Quality Strategy, the point is made that the objectives are:

> "*…a statement of policy intentions or policy targets. As such, there is no legal requirement to meet these objectives except where they mirror any equivalent legally binding limit values…*"

The AQOs, based on a selection of the objectives in the Air Quality Strategy, were incorporated into UK legislation through the Air Quality (Scotland) Regulations 2000, as amended.

Paragraph 4(2) of the Air Quality (Scotland) Regulations 2000 states:

"The achievement or likely achievement of an air quality objective prescribed by paragraph (1) above shall be determined by reference to the quality of air at locations–

(a)which are situated outside of buildings or other natural or man-made structures; and

(b)where members of the public are regularly present."

Consequently, compliance with the AQOs should focus on areas where members of the general public are regularly present over the duration of the concentration averaging period specific to the relevant AQO.

Scottish Planning Policy (SPP)

The Scottish Planning Policy (SPP) (The Scottish Government, 2020) are the national planning policies which reflect Scottish Ministers' priorities for operation of the planning system and for the development and use of land. The SPP promotes consistency in the application of policy across Scotland whilst allowing sufficient flexibility to reflect local circumstances.. It is stated in the SPP that planning policies and decisions should support sustainable development:

"avoiding over-development, protecting the amenity of new and existing development and considering the implications of development for water, air and soil quality."

Scotland's Third National Planning Framework (NPF3)

The National Planning Framework (NPF) is a long-term strategy for Scotland. It is the spatial expression of the Government Economic Strategy, and of the Scottish Government's plans for development and investment in infrastructure. NPF3 identifies national developments and other strategically important development opportunities in Scotland. It is accompanied by an Action Programme which identifies how the Scottish Government expects it to be implemented, by whom, and when.

It states:

"We are committed to reversing the decline of some habitats and species and regulating environmental pollution. Environmental quality is central to our health and well-being... Our spatial strategy identifies where development needs to be balanced with a strategic approach to environmental enhancement."

Cleaner Air for Scotland

Cleaner Air For Scotland: The Road To A Healthier Future (2015) provides a national framework which sets out how the Scottish Government and its partner organisations propose to achieve further reductions in air pollution and fulfil its legal responsibilities as soon as possible. As well as setting out a framework for local air quality management, it integrates with planning policies (especially NPF3 and SPP) to deliver "*a Scotland where air quality is not compromised by new or existing development and where places are designed to minimise air pollution and its effects*."

Local policies

Fife Local Development Plan

The Fife Local Development Plan (FIFEplan) (Fife Council, 2017) sets out the policies and proposals for the development and use of land across Fife. The policies in the Plan and supplementary guidance will be used to determine planning applications and give guidance to communities and investors on where development can and cannot take place, what type of development is allowed, how it should be laid out and designed and

how environmental and cultural assets will be protected. It is stated in the FIFEplan that air quality is relevant to planning applications:

> *"Impacts on air quality must be considered as part of the overall assessment of a development proposal. This applies particularly to impacts on Air Quality Management Areas (AQMAs). An air quality assessment may be required for developments that are within AQMAs or where the proposed development may cause or significantly contribute towards a breach in air quality management standards. Development proposals that lead to a breach of National Air Quality Standards or a significant increase in concentrations within an existing AQMA will not be supported. Supplementary guidance will provide additional information, detail and guidance on air quality assessments, including an explanation of how proposals could demonstrate that that they would not lead to an adverse impact on air quality."*

2.3 Technical guidance

IAQM/EPUK planning guidance

Although no official procedure exists for classifying the magnitude and significance of air quality effects from a new development for planning purposes, guidance issued by the Institute of Air Quality Management (IAQM) and Environmental Protection UK (EPUK) (2017) suggests ways to address the issue. In the IAQM/EPUK guidance, the magnitude of effect due to an increase/decrease in annual mean concentrations of air pollutants is described as 'negligible', 'slight', 'moderate' or 'substantial', taking into account both the change in concentration at a receptor brought about by a new development as a percentage of the assessment level, and the actual concentration at that receptor.

It must be emphasised that these descriptors are not intended to be used robotically as a measure of the significance of a proposed development. As the IAQM/EPUK guidance states:

> *"The overall significance is determined using professional judgement. For example, a 'moderate' adverse impact at one receptor may not mean that the overall impact has a significant effect. Other factors need to be considered."*

These descriptors are only designed for annual mean concentrations. For short-term concentrations, contributions from an elevated source are described as 'small', 'medium' and 'large' with their equivalent severity described as 'slight', 'moderate' and 'substantial'.

In the IAQM/EPUK guidance, the various AQS, AQOs etc are collectively referred to as Air Quality Assessment Levels (AQAL), a term which is adopted in this report.

The guidance provides indicative screening criteria to help identify when a detailed air quality assessment is required. These criteria are replicated below.

Table 2.4 Indicative development changes requiring an air quality assessment (from IAQM/EPUK)

The development would	Indicative criteria to proceed to an air quality assessment
1. Cause a significant change in Light Duty Vehicle (LDV) traffic flows on local roads with relevant receptors [A] (LDV = cars and small vans <3.5t gross vehicle weight)	A change of LDV flows of: - more than 100 Annual Average Daily Traffic (AADT) within or adjacent to an AQMA - more than 500 AADT elsewhere
2. Cause a significant change in Heavy Duty Vehicle (HDV) flows on local roads with relevant receptors (HDV = goods vehicles + buses >3.5t gross vehicle weight)	A change of HDV flows of: - more than 25 AADT within or adjacent to an AQMA - more than 100 AADT elsewhere
3. Realign roads, i.e. changing the proximity of receptors	Where the change is 5 m or more and the road is within an

The development would	Indicative criteria to proceed to an air quality assessment
to traffic lanes	AQMA
4. Introduce a new junction or remove an existing junction near to relevant receptors	Applies to junctions that cause traffic to significantly change vehicle accelerate/decelerate, e.g. traffic lights, or roundabouts
5. Introduce or change a bus station	Where bus flows will change by: - more than 25 AADT within or adjacent to an AQMA - more than 100 AADT elsewhere
6. Have an underground car park with extraction system	The ventilation extract for the car park will be within 20 m of a relevant receptor coupled with the car park having more than 100 movements per day (total in and out)
7. Have one or more substantial combustion processes, where there is a risk of impacts at relevant receptors. NB. this includes combustion plant associated with standby emergency generators (typically associated with centralised energy centres) and shipping	Typically, any combustion plant where the single or combined NOx emission rate is less than 5 mg/sec is unlikely to give rise to impacts, provided that the emissions are released from a vent or stack in a location and at a height that provides adequate dispersion. In situations where the emissions are released close to buildings with relevant receptors, or where the dispersion of the plume may be adversely affected by the size and/or height of adjacent buildings (including situations where the stack height is lower than the receptor) then consideration will need to be given to potential impacts at much lower emission rates. Conversely, where existing nitrogen dioxide concentrations are low, and where the dispersion conditions are favourable, a much higher emission rate may be acceptable.

[A] Relevant in this context relates to a location where there is exposure over the full duration of the AQO averaging period. Table 6.6 provides details of locations which are relevant in the context of different averaging periods.
Source: Directly extracted from IAQM/EPUK (2017).

SEPA Horizontal Guidance Note H1

SEPA's Horizontal Guidance Note H1 (2003) provides methods for quantifying the environmental impacts of emissions to all media to support permit applications made under the PPC Regulations (2012). The H1 guidance contains long and short-term Environmental Assessment Levels (EALs) for releases to air derived from a number of published UK and international sources. For some of the pollutants considered in this study, these EALs are equivalent to the AQS and AQOs.

Although intended for use in evaluating permit applications, H1 is often used for planning applications where no better guidance is available (particularly for ecological receptors).

This guidance also introduces the terms 'process contribution' (PC), meaning the concentration or deposition rate resulting from the installation activities only, excluding other sources, and 'predicted environmental contribution' (PEC), meaning the total modelled concentration, equal to the PC plus the background contribution. These terms are commonly used in air quality assessments, even where the term 'process' is not strictly accurate, and so are used in this assessment with 'process' referring to the Proposed Development.

The guidance also provides appropriate screening distances for biodiversity sites, requiring Special Protection Areas (SPA) and Special Conservation Areas to be considered within 10 km. For Sites of Special Scientific Interest (SSSI) and local wildlife sites (LWS), it is more common to assess these sites within 2 km.

Local Air Quality Management Technical Guidance LAQM.TG16

LAQM.TG16 (Defra, 2018) provides guidance for technical officers and local authorities to discharge their obligations under the LAQM regime. It contains guidance on numerous areas including, for example:

- Screening tools and methodologies;
- Air quality monitoring;
- Estimating emissions; and
- Dispersion modelling.

Guidance in LAQM.TG16 makes it clear that exceedances of the human health based objectives should only be assessed at outdoor locations where members of the general public are regularly present over the averaging time of the objective. Table 2.5 provides an indication of those locations that may be relevant for different averaging periods, as extracted from LAQM.TG16.

Table 2.5 Typical examples of relevant exposure for different averaging periods

Averaging period	Objectives should apply	Objectives should not apply
Annual mean	All locations where members of the public might be regularly exposed. Building facades of residential properties, schools, hospitals, care homes etc.	Building facades of offices or other places of work where members of the public do not have regular access. Hotels, unless people live there as their permanent residence. 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.
24-hour mean and 8-hour mean	All locations where the annual mean objectives 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 objectives would apply. Kerbside sites (e.g. pavements of busy shopping streets). Those parts of car parks, bus stations and railway stations etc. which are not fully enclosed, where the public might reasonably be expected to spend one hour or more. Any outdoor locations at which the public may be expected to spend one hour or longer.	Kerbside sites where the public would not be expected to have regular access.
15-min mean	All locations where members of the public might reasonably be expected to spend a period of 15 minutes or longer.	

Source: directly extracted from LAQM.TG16

IAQM dust guidance

The IAQM dust guidance (2014) provides a four-step process for evaluating the risk associated with dust emissions from construction and demolition sites on different types of receptor to dust soiling, health effects and ecological effects.

The first step of this process is to screen the requirement for a detailed assessment. No further assessment is required if there are no:

- Human receptors within:
  - 350 m of the boundary of the site; or
  - 50 m of the route(s) used by construction vehicles on the public highway, up to 500 m from the site entrance(s).
- Ecological receptors within:
  - 50 m of the boundary of the site; or
  - 50 m of the route(s) used by construction vehicles on the public highway, up to 500 m from the site entrance(s).

Should the requirement for a detailed assessment be identified, Step 2 of this process is to assess the risk of dust impacts. This is done separately for each of four defined activities (demolition; earthworks; construction; and trackout) and takes account of:

- the scale and nature of the works, which determines the potential dust emission magnitude; and
- the sensitivity of the area.

These factors are combined to give the risk of dust impacts. Step 3 is to determine the site-specific mitigation for each of the four potential activities based on the risk of dust impacts identified in Step 2. Step 4 is to examine the residual effects and to determine whether or not these are significant. In Step 4, the guidance states:

"For almost all construction activity, the aim should be to prevent significant effects on receptors through the use of effective mitigation. Experience shows that this is normally possible. Hence the residual effect will normally be 'not significant'.

There may be cases where, for example, there is inadequate access to water for dust suppression to be effective, and even with other mitigation measures in place there may be a significant effect. Therefore, it is important to consider the specific characteristics of the site and the surrounding area to ensure that the conclusion of no significant effect is robust."

IAQM guidance on assessment of nature conservation sites

IAQM offers guidance[4] to assist in the assessment of the air quality impacts of development on designated nature conservation sites. It focuses on air quality assessments in support of Habitats Regulations Assessments (HRA), but is also useful when assessing the air quality impact on national or local designated nature conservation sites. A companion document has been published by the Chartered Institute of Ecology

[4] IAQM (2020) A guide to the assessment of air quality impacts on designated nature conservation sites. Version 1.1, May 2020.

and Environmental Management (CIEEM)[5], which is aimed more at ecologists for use where air quality impacts cannot be screened out as insignificant.

The IAQM guidance summarises current legislation, much of which consists of case law. It then sets out a procedure for air quality specialists to follow when evaluating the impacts of airborne pollution at designated sites, and provides a basis for when an assessment might reach the conclusion that there is no likely significant effect because the air quality impact is too small.

The guidance establishes that a change in the long-term process contribution of a pollutant of 1% of a critical level or critical load, when assessed in-combination with other projects, can generally be used as a screening criterion. However, importantly, the guidance also establishes that the criterion should not be used as a threshold for harm and that the overall assessment of significance of effects should be made by a suitably qualified ecologist, not an air quality practitioner.

Other guideline values

In the absence of statutory standards for the other prescribed substances that may be found in the emissions, there are several sources of applicable air quality guidelines.

Air Quality Guidelines for Europe, the World Health Organisation (WHO)

The aim of the WHO Air Quality Guidelines for Europe (WHO, 2000) is to provide a basis for protecting public health from adverse effects of air pollutants and to eliminate or reduce exposure to those pollutants that are known or likely to be hazardous to human health or well-being. These guidelines are intended to provide guidance and information to international, national and local authorities making risk management decisions, particularly in setting air quality standards.

Environmental Assessment Levels (EALs)

SEPA's H1 Horizontal Guidance Note "*Environmental Assessment and Appraisal of BAT*" contains long-term and short-term Environmental Assessment Levels (EALs) for releases to air derived from a number of published UK and international sources. For the pollutants considered in this study, the majority of these EALs are equivalent to the AQS and AQOs set in force by the Air Quality Standards Regulations (Scotland) 2010 and the Air Quality (Scotland) Regulations 2000 as amended. Other EALs relevant for this assessment are given in Table 2.6.

Table 2.6 Environmental assessment levels

Pollutant	Status	Averaging Period	Value (µg m^{-3})
	Human receptors		
CO	EAL	Annual mean	350
UHCs (as butane)	EAL	Annual mean	14,500
	EAL	1-hour mean	181,000
BTEX (as benzene)	EAL	1-hour mean	208
	Ecological receptors		
NO_x	WHO critical level	Daily mean	75

[5] CIEEM (2021) Advisory note: Ecological assessment of air quality impacts. January 2021.

3. Data gathering methodology

3.1 Study area

The spatial extent of the study area has been informed by the guidance detailed in Section 2. The study area encompasses a region within 10 km of FEP with the assessment made at relevant human and ecological receptor locations within that distance.

3.2 Desk study

The information used in this assessment includes:

- Process and emissions data for the point (non-flare) emission sources at FEP provided by EMCL;
- Flare mass flow rate and composition during base-load and event flaring provided by EMCL;
- Information obtained as part of the previous modelling studies in 2009 and 2019;
- Information from SEPA including the PPC permits for the FEP and FNGL plant and annual flare quantities;
- Background air quality data from Fife Council, SEPA, Ineos and the Mossmorran and Braefoot Bay Independent Air Quality Monitoring (IAQM) Review Group. This includes, amongst others, continuous and passive monitoring undertaken by Fife Council throughout 2019 (the latest year where ratified data was available when this assessment was undertaken), continuous and passive monitoring undertaken by SEPA between August 2019 and March 2020, and passive monitoring undertaken of volatile organic compounds (VOCs) by Ineos, as reported by the IAQMRG;
- Forecast concentrations of pollutants at background locations from Department for Environment, Food and Rural Affairs (Defra), Air Quality in Scotland, and Air Pollution Information System (APIS) background maps;
- Type and specification of wind turbines from the Fife Council Planning Portal;
- OS Maps of the local area; and
- Meteorological data supplied by Atmospheric Dispersion Modelling Ltd from World Meteorological Organisation (WMO) affiliated weather stations.

3.3 Survey work

No additional survey or monitoring work was undertaken specifically for this assessment, as considerable data from other routine and campaign monitoring is available (see Section 4).

4. Overall baseline

4.1 Current baseline

Local air quality management

Under Part IV of the Environment Act 1995, Fife Council is required to periodically review and assess air quality within its area of jurisdiction. This process of Local Air Quality Management (LAQM) is an integral process for achieving national air quality objectives (AQOs).

Review and assessments of local air quality aim to identify areas where national policies to reduce vehicle and industrial emissions are unlikely to result in air quality meeting the Government's air quality objectives by the required dates.

Where the assessment indicates that some or all of the objectives may be potentially exceeded, the Local Authority has a duty to declare an Air Quality Management Area (AQMA). The declaration of an AQMA requires the Local Authority to implement an Air Quality Action Plan (AQAP) to reduce air pollution concentrations so that the required AQOs are met.

Fife Council has declared two AQMAs for annual mean NO_2 and PM_{10} within its jurisdictional area:

- Bonnygate, Cupar, declared in October 2008; and
- Appin Crescent, Dunfermline, declared in November 2011 for NO_2 and August 2012 for PM_{10}.

The AQAP for the Bonnygate, Cupar AQMA was last updated in 2015 and has been successful in reducing both NO_2 and PM_{10} concentrations within the Bonnygate area. During 2017 annual mean concentrations of NO_2 and PM_{10} within the AQMA were below their respective objective.

Following a review of the 2019 Annual Progress Report, SEPA and the Scottish Government both recommended that Fife Council strongly consider revoking both AQMA's. Concentrations of NO_2 and PM_{10} recorded within both AQMAs have improved significantly and now meet the Scottish air quality objectives for both pollutants, However, in their latest Annual Progress report for 2020, Fife Council say that due to the current uncertainty regarding PM_{10} concentrations reported by different analysers and the Particular Matter concentrations indicated by the Bonnygate AQMesh monitoring in 2019, they do not propose to implement the revocation procedure for either AQMA at this time.

The Bonnygate and Appin Crescent AQMAs are approximately 29 km to the north-east, and approximately 9 km to the west-south-west of FEP. Due to the distance or prevailing south-westerly wind direction, it is highly unlikely that emissions from the FEP will contribute significantly to concentrations within the AQMAs.

Outside the AQMAs, air quality in Fife is generally good, with Fife Council's 2020 Progress Report[6] noting that the principal emission source contributing to specific 'hot-spots' of pollution in town centres is road vehicle emissions.

Ambient monitoring data

Fife Council operates four continuous monitoring locations for NO_2, PM_{10} and $PM_{2.5}$. The monitoring site located closest to FEP is the Appin Crescent roadside monitoring site in Dunfermline. Table 4.1 summarises recent data from this monitoring site.

[6] Fife Council, 2020. 'Fife Air Quality Annual Progress Report 2020' [online] https://www.fife.gov.uk/__data/assets/pdf_file/0017/160163/Fife-Air-Quality-Annual-Progress-Report-2020.pdf

Table 4.1 Monitored data from the Appin Crescent monitoring site

Year	Annual mean NO_2 (µg m^{-3})	Annual mean PM_{10} (µg m^{-3})	Annual mean $PM_{2.5}$ (µg m^{-3})	Number of hours where NO_2 > 200 µg m^{-3}	Number of days where PM_{10} > 50 µg m^{-3}
2015	25	16	Not recorded	0	2
2016	24	13	6	0	1
2017	23	10	6	0	0
2018	22	11	6	0	0
2019	21	11	6	0	0

In addition to continuous monitoring, Fife Council operates a network of passive diffusion tubes for monitoring NO_2. The 2019 diffusion tube results indicate that there were no exceedances of the annual mean NO_2 objective at all monitoring locations, including locations within Dunfermline and Cupar which have exceeded in previous years.

The highest annual mean concentration measured in Appin Crescent, Dunfermline during 2019 was 34 µg m^{-3} at Appin Crescent 6(A, B, C). The highest annual mean concentration measured in Bonnygate, Cupar during 2019 was 32 µg m^{-3} at Bonnygate B4. The nearest diffusion tube monitoring site to FEP is the kerbside monitoring location in High Street, Cowdenbeath. The monitored annual mean NO_2 concentration at this location in 2019 was 19 µg m^{-3}.

INEOS FPS Ltd. commissioned NPL to monitor the ambient air hydrocarbon levels at 12 locations on the Forth Estuary coastline during 2018 (5 January 2018 to 3 January 2019). Nine locations on the Estuary North shore between North Queensferry and West Wemyss (including four locations between Dalgety Bay and Burntisland) were used, and three locations on the Estuary South shore between South Queensferry and Whitehouse Point were used. The ambient air samples were collected over two-week periods using passive diffusive tubes. These samples were analysed for iso-butane, n-butane, iso-pentane, n-pentane, n-hexane, n-heptane, benzene, toluene, xylene and total hydrocarbons (C_4–C_{10}).

The results from these monitoring surveys are summarised in the 2018 Annual Report of the Mossmorran & Braefoot Bay Independent Air Quality Monitoring Review Group[7]. The Review Group notes that concentrations of n-butane ranged from 1.9–14.5 ppb (4.6–35.0 µg m^{-3}) and the average concentrations of benzene over the 12-month period at each location ranged from 0.1–0.4 ppb (~0.3–1.3 µg m^{-3}).

SEPA carried out a monitoring campaign in the vicinity of the Mossmorran Complex during the plant shutdown and subsequent start up, running between August 2019 and March 2020[8]. Pollutants monitored were PM_{10}, $PM_{2.5}$, benzene, toluene, ethylbenzene, xylene, 1,3-butadiene, nitrogen dioxide, total hydrocarbons (C_4 to C_{10}), sulphur dioxide and carbon monoxide. The report concludes that there were no breaches of any of the air quality objectives, and the data produced during the study would indicate no measurable impact on airborne pollutant levels as a result of the shutdown and start up activities, including flaring. Although the monitoring did not take place for a full calendar year, the analysis in the report suggests that the monitored values are representative of annual mean results and so may be compared with annual mean objectives.

[7] Mossmorran & Braefoot Bay Independent Air Quality Monitoring Review Group, 2019. '2018 Annual Report' [online] https://www.fife.gov.uk/__data/assets/pdf_file/0032/72968/MMBBIAQRG-2018-Report-16_10_19.pdf
[8] SEPA, 2020. 'Air Quality Monitoring Mossmorran August 2019 – March 2020' [online] https://www.sepa.org.uk/media/558658/air-quality-monitoring-mossmorran-pdf.pdf

Mapped background concentrations and deposition rates

Defra provides results from a nationwide model (the Pollution Climate Mapping (PCM) model) of existing and future background air quality concentrations of NOx, NO_2, PM_{10}, $PM_{2.5}$, SO_2, CO and benzene at a 1 km grid square resolution. The PCM model is semi-empirical in nature; it uses data from the national atmospheric emissions inventory (NAEI) to model the concentrations of pollutants at the centroid of each 1 km grid square but then calibrates these concentrations in relation to actual monitoring data.

In addition to the UK-wide version of PCM, a Scotland-specific version is now available for NO_x, NO_2 and PM_{10}. The Scotland-specific version of PCM uses meteorology from RAF Leuchars and measurements from Scottish air quality monitoring sites only to calibrate and verify the model.

PCM contains contributions from all existing Part A(1) installations using data available at the time the base year datasets were compiled. For NO_x, NO_2 and PM_{10} this base year is 2018 and projections are available out to 2030. For SO_2, CO and benzene, this base year is 2001, and projections are available to 2010 for benzene only. The model also considers contributions from other non-industrial line, area and volume sources e.g., road traffic, shipping emissions and airports etc.

Similarly, the Air Pollution Information System (APIS) database provides estimated background concentrations of NO_x and SO_2, as well as background deposition rates of nitrogen and sulphur, using the Concentration Based Estimated Deposition (CBED) model but on a more coarse 5 km grid square resolution.

As an existing Part A(1) installation, contributions from the FEP and FNGL plant emission sources are already reflected in the UK and Scotland-specific PCM and CBED background estimates.

Table 4.2 provides the mapped background estimates of NO_2 and PM_{10} from the Scotland-specific version of PCM, and mapped background estimates of $PM_{2.5}$, SO_2, CO and benzene from the UK-wide version of PCM for the human receptors considered in this study. The model years are 2021 for NO_2, PM_{10} and $PM_{2.5}$, 2001 for SO_2 and CO, and 2010 for benzene. Table 4.3 provides the mapped background concentrations and deposition rates for the ecological receptors.

Table 4.2 Annual mean mapped background concentrations at human receptors

Receptor ID	NO_2 (µg m^{-3})	PM_{10} (µg m^{-3})	$PM_{2.5}$ (µg m^{-3})	SO_2 (µg m^{-3})	CO (µg m^{-3})	Benzene (µg m^{-3})
H1	6.9	10.0	5.5	2.1	197.0	0.2
H2	6.8	10.4	5.6	2.3	191.0	0.2
H3	8.9	9.3	5.4	2.2	200.0	0.2
H4	9.2	10.5	5.6	2.2	199.0	0.2
H5	6.8	10.4	5.6	2.3	191.0	0.2
H6	8.1	10.3	5.5	2.4	189.0	0.2
H7	9.7	10.3	5.6	2.2	211.0	0.2
H8	6.9	10.0	5.5	2.1	197.0	0.2
H9	8.5	9.8	5.4	2.2	212.0	0.2
H10	8.3	9.6	5.5	4.8	211.0	0.3
H11	8.4	9.8	5.6	7.5	199.0	0.2

Receptor ID	NO_2 (µg m^{-3})	PM_{10} (µg m^{-3})	$PM_{2.5}$ (µg m^{-3})	SO_2 (µg m^{-3})	CO (µg m^{-3})	Benzene (µg m^{-3})
H12	10.1	10.1	5.7	6.8	215.0	0.3
H13	8.6	10.3	5.5	2.7	216.0	0.3
H14	10.1	10.1	5.7	6.8	215.0	0.3
H15	9.7	10.9	5.9	3.6	204.0	0.2
H16	6.8	10.4	5.6	2.3	191.0	0.2
H17	8.5	10.6	5.5	2.2	212.0	0.2

Table 4.3 Annual mean mapped background concentrations and deposition rates at ecological receptors

Receptor ID	Receptor name	NO_x (µg m^{-3})	SO_2 (µg m^{-3})	Nitrogen deposition (kgN/ha/yr)	Nitrogen deposition (keq/ha/yr)	Sulphur deposition (keq/ha/yr)
E1	Firth of Forth SPA/Ramsar	12.3	2.3	13.70	1.00	0.10
E2	Outer Firth of Forth and St Andrews Bay Complex SPA	12.1	2.3	13.70	1.00	0.10
E3	Forth Islands SPA	12.0	2.3	13.40	1.00	0.20

4.2 Future baseline

Concentrations of pollutants of national concern, notably NO_2, NO_x, PM_{10}, $PM_{2.5}$, are generally decreasing steadily in response to measures to control and reduce emissions. Other pollutants, which are at low levels already, are not expected to reduce significantly in future.

Annual mean background concentrations for NO_2, $PM_{10,}$ $PM_{2.5}$, SO_2, CO and benzene have been taken from the PCM modelled estimates for each receptor as detailed in Table 4.2. With respect to UHCs, a uniform annual mean concentration of 35.0 µg m^{-3}, corresponding to the highest monitored n-butane concentration from the INEOS monitoring on the Fife coast, has been conservatively applied to all receptors. For ecological receptors, the data in Table 4.3 have been used. Background concentration estimates already include contributions from the FEP and FNGL plant, so there is some double-counting of impacts.

The annual average process contribution (PC) is added to the annual average background concentration, to give a total predicted environmental concentration (PEC) at each receptor location. This total concentration can then be compared against the relevant air quality objective and the likelihood of an exceedence determined.

It is not technically rigorous to add predicted short term or percentile concentrations to ambient background concentrations not measured over the same averaging period, since peak contributions from different sources would not necessarily coincide in time or location. For the purposes of estimating short-term background concentrations, a factor of two has been applied to the annual mean background concentration as per the procedure in SEPA's H1 Horizontal Guidance note.

5. Scope of the assessment

5.1 Spatial scope

The spatial scope of the assessment of air quality covers the area of the Proposed Development that has formed the basis of the study area described in Section 3.

5.2 Temporal scope

This assessment assumes a worst-case scenario once the Proposed Development has been commissioned and put into operation, including worst-case emissions from the site (Section 7) and worst-case background concentrations (Section 4.2). The temporal scope of the assessment may therefore be taken as the operational lifetime of the Proposed Development.

5.3 Potential receptors

Human receptors

The human receptors considered in this assessment were chosen based the guidance in LAQM.TG16 by identifying places where people may be located, judged in terms of the likely duration of their exposure to pollutants and proximity to the site.

Workplace locations where there is no access for the general public (i.e., those members of the public other than the workforce) have been excluded from the assessment in accordance with Schedule 1, Part 1, Paragraph 2 of the Air Quality Standards Regulations 2010. It is important to note that these Regulations do not differentiate between whether this is a workplace location under the control of the operator or an off-site workplace location.

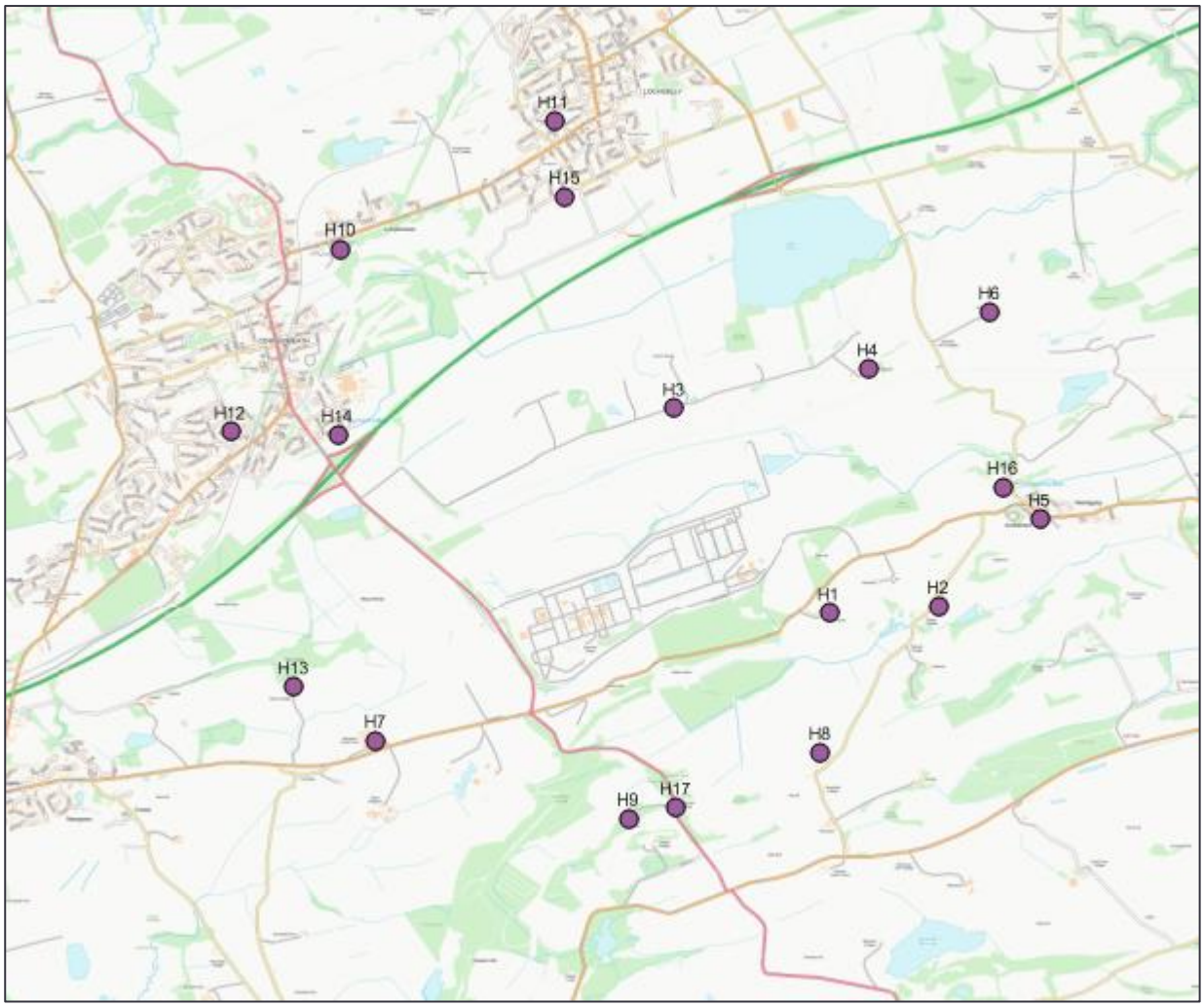
Details of the receptors considered are provided in Table 5.1 and Figure 5.1. It should be noted that this list of receptors is by no means exhaustive, with certain receptors grouped together to represent exposure over a wider area, rather than at specific residential properties, for example.

Table 5.1 Location of modelled human receptors

ID	Receptor Name	Easting (m)	Northing (m)
H1	Newton Farm	320320	689970
H2	Kirkton Cottages	321076	690016
H3	Easter Lochead	319252	691385
H4	Little Raith Farm	320590	691656
H5	Auchtertool School	321775	690621
H6	Glenniston	321432	692051
H7	Moss Bank Farm	317193	689090
H8	Bankhead	320262	689008

ID	Receptor Name	Easting (m)	Northing (m)
H9	Cullaloe	318936	688554
H10	Cowdenbeath School	316948	692487
H11	Lochgelly School	318421	693367
H12	Cowdenbeath School 2	316189	691223
H13	Heath/Ivy/Beech Cottages	316626	689463
H14	Cowdenbeath Properties	316928	691202
H15	Lochgelly Properties	318501	692848
H16	Camilla Properties	321523	690842
H17	Beechwood Cottage	319263	688627

Figure 5.1 Modelled human receptors



Ecological receptors

SEPA's Horizontal Guidance Note H1 requires detailed dispersion modelling to be carried out to assess effects upon local ecological receptors. Using this guidance, Natura 2000 sites (i.e., SPAs, SACs, Ramsar sites within 10 km of FEP, and other designated ecological sites within 2 km of FEP (e.g., SSSIs, LNRs, ancient woodland etc.,) have been assessed. However, where receptors are designated solely based on geological features of interest, these receptors have been excluded from the assessment since critical levels and loads are only prescribed for vegetation and ecosystems.

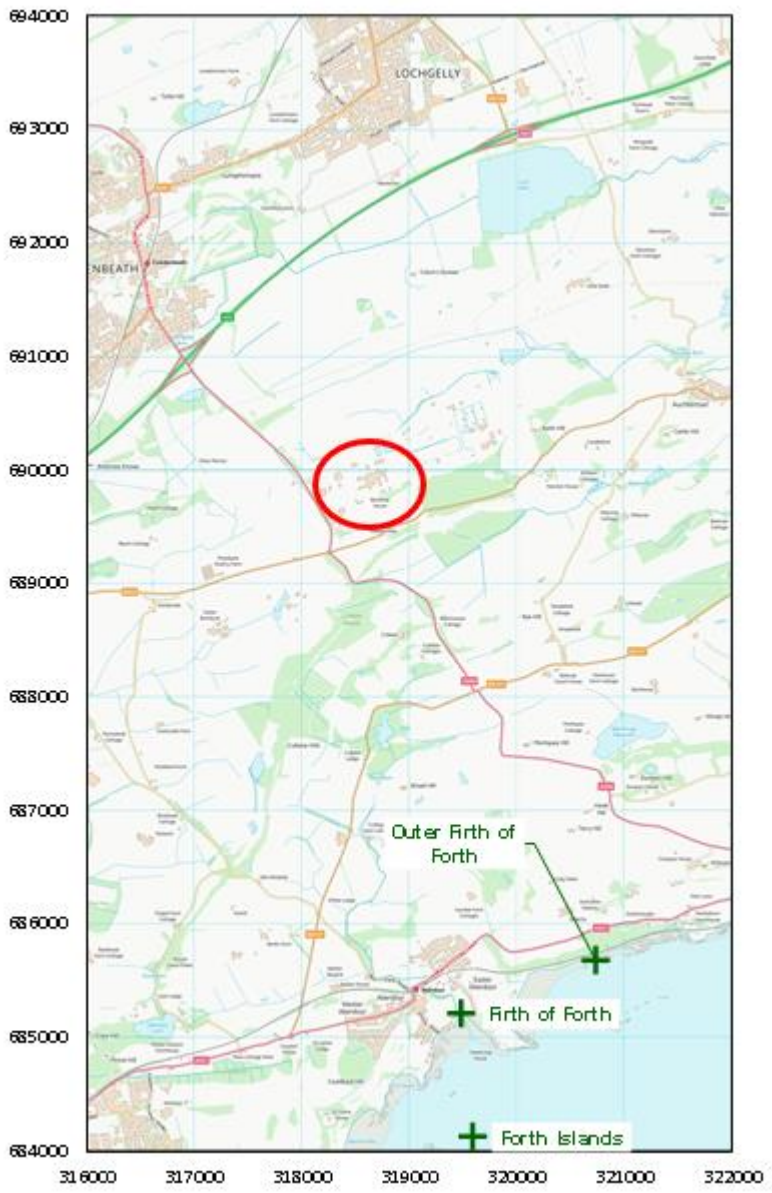
Where designated sites cover a large area but are situated a large enough distance from the installation (generally >2 km), a single receptor point corresponding to the closest point of any part of the designated area to the installation has been input to the model.

Table 5.2 and Figure 5.2 detail the ecological receptors assessed in this study.

Table 5.2 Location of modelled ecological receptors

ID	Receptor name	Easting (m)	Northing (m)	Approx. distance from FEP (km)
E1	Firth of Forth SPA/Ramsar	319486	685208	4.7
E2	Outer Firth of Forth and St Andrews Bay Complex SPA	320742	685672	4.7
E3	Forth Islands SPA	319590	319590	7.6

Figure 5.2 Modelled ecological receptors



5.4 Potential effects subject to further assessment

The air quality receptors and potential effects that have been taken forward for assessment are summarised in Table 5.3.

Table 5.3 Air quality receptors and potential effects scoped in for further assessment

Receptor	Relevant assessment criteria	Potential effects requiring further assessment
Human Receptors	AQS, AQOs and EALs	Effects of increases in annual and short-term process contributions from FEP emissions associated with new EGF and other emission sources.
Ecological Receptors	AQS, EALs and Critical Levels	Effects of increases in concentrations of NOx and SO_2 in air are associated with adverse effects on

Receptor	Relevant assessment criteria	Potential effects requiring further assessment
		plant growth associated with new point source (stack) emissions to air
Ecological Receptors	Critical loads	Deposition of nitrogen and sulphur onto nature conservation sites, which may be sensitive to both nutrifying nitrogen and acid deposition, due to new point source (stack) emissions to air of NOx and SO_2

The following receptors and potential effects have been scoped out from further detailed assessment because the potential effects are not considered likely to be significant:

- *Dust effects during construction:* There are no human or ecological receptors within 350 m of any construction activity which could result in fugitive emissions of dust during construction causing significant effects to receptors. Additionally, there are no human or ecological receptors within 50 m of the route to be used by construction vehicles to travel from the main development area towards the public highway, up to 500 m. As a result, in accordance with the IAQM's guidance on the assessment of dust from demolition and construction, such effects can be scoped out from further assessment. Dust suppression techniques will, however, still be employed during the construction phase and implemented by a Construction Environmental Management Plan (CEMP);
- *Potential effects of emissions from non-road mobile machinery (NRMM) during construction*: Emissions from NRMM are regulated by the Non-Road Mobile Machinery (Type-Approval and Emission of Gaseous and Particulate Pollutants) Regulations 2018 and with the nearest relevant receptor being more than 1 km from construction activity, it is unlikely that these emissions would cause significant effects.
- *Potential effects of emissions from development related on-road traffic emissions during construction and operation:* FEP is not located within an AQMA and it is unlikely construction traffic will travel through the AQMAs in more distant areas within Fife. Construction HDVs will total less than 100 two-way movements per day and construction LDVs less than 500 two-way movements per day. There would be no to negligible change in the number of operational employees at FEP with the new EGF operational. Consequently, potential effects from changes in construction and operational traffic on the local road network can be screened from further assessment.
- *Potential effects of fugitive emissions during operation*: Fugitive emissions from e.g., leaks from flanges, compressor seals etc., have not been considered in this assessment. The assessment aims to identify the potential air quality impacts resulting from the change in operation of the flare system at FEP. Fugitive emissions are unlikely to change by any meaningful extent as a result of the flare system changes. Furthermore, the 'type' of emissions discharged from the flares, i.e., products of combustion, are materially different than fugitive emissions, which primarily comprise different hydrocarbon products or other raw materials.

  Furthermore, due to the inherent uncertainty of fugitive emissions modelling, requiring the use of a volume source approach (at in installation typical of that such as FEP, there can be well over 100,000 individual potential sources of fugitive emissions), the predictions from fugitive emission models are associated with a significant level of uncertainty. For example, when Wood compared modelled fugitive emission data and monitored ambient data at an UK refinery, there was an order of magnitude difference between the over-estimated modelled result and the actual monitored value.

- *Potential effects of odour during construction and operation*: FEP currently has an Odour Management Plan in place and odour is regulated by SEPA using conditions in FEP's PPC Permit. Installation and operation of the new EGF will not materially change odour emissions from FEP.
- *Potential effects from formation of secondary pollutants*: The modelling assessment only considers the emissions of primary pollutants from FEP. Primary pollutants are those species which are present in the discharges from the flares and other stacks. Upon their discharge to the atmosphere, certain primary pollutants may undergo subsequent chemical reactions with other chemicals in the atmosphere to form different compounds which themselves can be considered a pollutant. These additional pollutants are known as secondary pollutants and include ozone (O_3) and secondary particulate matter, also known as secondary inorganic aerosol (SIA).

  NO_X emissions from combustion processes consist of nitrogen monoxide (NO) and nitrogen dioxide (NO_2), with more than 95% of NO_x being in the form of NO. Near to an emission source, NO has a scavenging effect on O_3, i.e., it reduces local O_3 concentrations. Much further downwind (typically greater than several kilometres) and the influence of other pollutants, such as NO_2, CO and VOCs becomes important, O_3 concentrations begin to increase. However, as the emissions from FEP would be considerably diluted by this point, any increase in O_3 concentrations above background levels as a direct result of FEP emissions would be negligible.

  Previous studies of emissions from large industrial emission sources, such as those by Preiss et al (2013)[9], found that the overall health risks associated with changes to O_3 concentrations as a result of primary emissions of NO_x were negative, i.e., producing an overall health *benefit* with respect to O_3. Whilst such an outcome would be influenced by site-specific variables, this study demonstrated the scavenging effect of NO on O_3 close to the emission source which was sufficient to off-set the subsequent formation of low concentrations of O_3 from photolysis of NO_2 at distances further downwind.

  With respect to SIA, these are typically nitrate and sulphate particles formed because of further reaction of the primary NO_2 and SO_2 released from an emission source with other pollutants in the atmosphere including ozone and ammonia. The aerosols formed are typically within the $PM_{2.5}$ fraction. SIA formation takes time (hours to days) and, as such, occurs at distances much further downwind from an emission source where the plume has been sufficiently diluted. Consequently, impacts of secondary pollutants are typically negligible when considering a single emission source/site in isolation.

[9] Preiss, P., Roos, J. and Friedrich, R., 2013. 'Estimating Health Risks caused by Emissions of Air Pollutants from Coal Fired Power Plants in Europe - Documentation of Methods and Results'

6. Environmental measures embedded into the development proposals

The aim of the Proposed Development is to reduce the environmental impact of flaring events. EMCL completed a BAT assessment in 2019 which identified installation of a new, enclosed ground flare (EGF) would represent BAT for reducing noise and visual impacts, allowing operation of the elevated flare to be substantially reduced. However, due to the lower release height of the EGF compared to the elevated flare, the potential for small increases in ground level concentrations of certain combustion products with the EGF operating needed to be considered.

Embedded measures which tend to reduce air quality impacts include:

- Due to their enclosed nature, it is easier to control and optimise combustion conditions in ground flares, resulting in an increase in the combustion efficiency whilst the fraction of heat radiated reduces considerably. The combined effect of these factors is to increase the plume buoyancy, which increases buoyancy-driven plume rise above that which occurs from the elevated flare.
- The improved combustion efficiency significantly reduces the formation of particulate matter and reduces unburnt hydrocarbon emissions. Thus, for PM_{10}, $PM_{2.5}$ and UHCs, there is a dual effect of increasing plume buoyancy and reduced emission rate which drives the reduction in ground level impacts.
- Consolidation of the ground flares (from two to one) also acts to reduce the maximum impact of some pollutants.

7. Assessment methodology

Full details of the methodology for calculating concentrations of pollutants are given in Annex 1. A summary of key points is given below.

The assessment uses detailed dispersion modelling to predict contributions from FEP and other emission sources. The modelling considers two emission scenarios for the current and proposed operation of the flare system at FEP:

- Assessment of impacts during normal operation of FEP; and
- Assessment of a more conservative flaring event emissions scenario, considering the impacts on air quality during a process gas compressor (PGC) trip.

For the first five minutes of a PGC trip, peak instantaneous flaring rates can increase to 200 T h^{-1}, although a more typical rate until the plant can be re-configured in 'safepark' mode is 130 T h^{-1}. For the purposes of this assessment, two sub-scenarios are considered for the flaring event scenario:

- An assessment of impact during a PGC trip assuming flaring occurs at the instantaneous peak rate of 200 T h^{-1} continuously over the course of the year; and
- An assessment of impact during a PGC trip assuming flaring occurs at the more typical peak rate of 130 T h^{-1} continuously over the course of the year.

It should be strongly emphasised that, in actual operation, flaring would not occur at this rate continuously throughout the year. This is a conservative assumption introduced to the modelling to address potential model uncertainty, ensuring that the model prediction is robust, if not overly pessimistic, particularly for long-term, annual mean impacts.

Owing to the interlinked nature of the FEP and FNGL plant, and to allow a more accurate prediction of the total predicted environmental concentration (PEC), in addition to FEP emission sources, the FNGL plant furnace stacks and flares have also been included within the model with their emissions modelled under a normal operational scenario.

The assessment considers emissions of the following pollutants:

- Oxides of nitrogen as nitrogen dioxide (NO_x as NO_2);
- Sulphur dioxide (SO_2);
- Carbon monoxide (CO);
- Particulate matter with an aerodynamic diameter < 10 µm (PM_{10})[10];
- Particulate matter with an aerodynamic diameter < 2.5 µm ($PM_{2.5}$)[10];
- Unburnt hydrocarbons (UHCs)[11]; and
- Benzene, toluene, ethyl benzene and xylene (BTEX)[12].

Other aspects of the modelling methodology are presented in Annex 1. This presents details of:

[10] As a conservative approach, it is assumed all particulate matter is emitted in the $PM_{2.5}$ fraction
[11] UHCs have been modelled as n-butane in order to allow comparison against the n-butane environmental assessment level (EAL); this likely being the most significant hydrocarbon in the various process streams for which an EAL is available
[12] As benzene has the lowest air quality standard of any pollutant within this group, BTEX is assumed to be emitted as benzene and compared against the benzene air quality standards

- Dispersion model selection;
- Emission parameters for point (non-flare) and flare sources;
- Fugitive emissions;
- Meteorology;
- Buildings;
- Terrain;
- Surface roughness;
- Surface energy budget;
- Conversion of NO to NO_2;
- Wind turbines; and
- Deposition.

Section 2 of Annex 1 also presents a model uncertainty and sensitivity analysis, covering:

- Meteorology;
- Buildings;
- Terrain;
- Coastal effects; and
- Wind turbines.

7.1 Significance evaluation methodology

Air Quality Assessment Levels

There are a number of sources of legislation and guidance, which use a wide range of terms for assessment level - AQS, AQO, limit value, EAL, target, critical level, critical load and more. There are differences of meaning between terms, but often different authors refer to effectively the same assessment level under different names. This report follows the IAQM/EPUK planning guidance in using the term "Air Quality Assessment Level (AQAL)" (or just "assessment level") as a generic term for any of these things. A more specific term is used where it is helpful to do so (e.g., to clarify its legal status or to distinguish concentrations from deposition rates). As the AQOs and AQS, from which many of the AQALs in this assessment are obtained, are set to protect the most vulnerable members of the population, all human air quality receptors are considered to be "high sensitivity" receptors.

Table 7.1 summarises the applicable air quality standards (AQS), objectives (AQOs), environmental assessment levels (EALs) and critical levels appropriate for assessing concentrations in air and resultant impacts on human health, vegetation and ecosystems.

Table 7.1 Air quality standards, objectives and environmental assessment levels

Pollutant	Status	Averaging Period	Value (µg m^{-3})
		Human receptors	
NO_2	AQS	Annual mean	40
	AQS	1-hour mean, not to be exceeded more than 18 times a year (equivalent of 99.79 Percentile)	200
CO	AQS	Rolling 8-hour mean	10,000
	EAL	Annual mean	350
SO_2	AQS	1-hour mean not to be exceeded more than 24 times a year (equivalent to 99.73 percentile)	350
	AQS	24-hour mean, not to be exceeded more than 3 times a year (equivalent to 99.18 percentile)	125
	AQO	15-min mean, not to be exceeded more than 35 times a year (equivalent to 99.9 percentile)	266
PM_{10}	AQS	Annual mean	18
	AQS	24-hour mean, not to be exceeded more than 7 times a year (equivalent to 98.08 percentile)	50
$PM_{2.5}$	AQO	Annual mean	10
UHCs (as butane)	EAL	Annual mean	14,500
	EAL	1-hour mean	181,000
BTEX (as benzene)	AQO	Annual mean	3.25
	EAL	1-hour mean	208
		Ecological receptors	
NOx	AQS	Annual mean	30
	EAL	Daily mean	75
SO_2	AQS	Annual mean	20

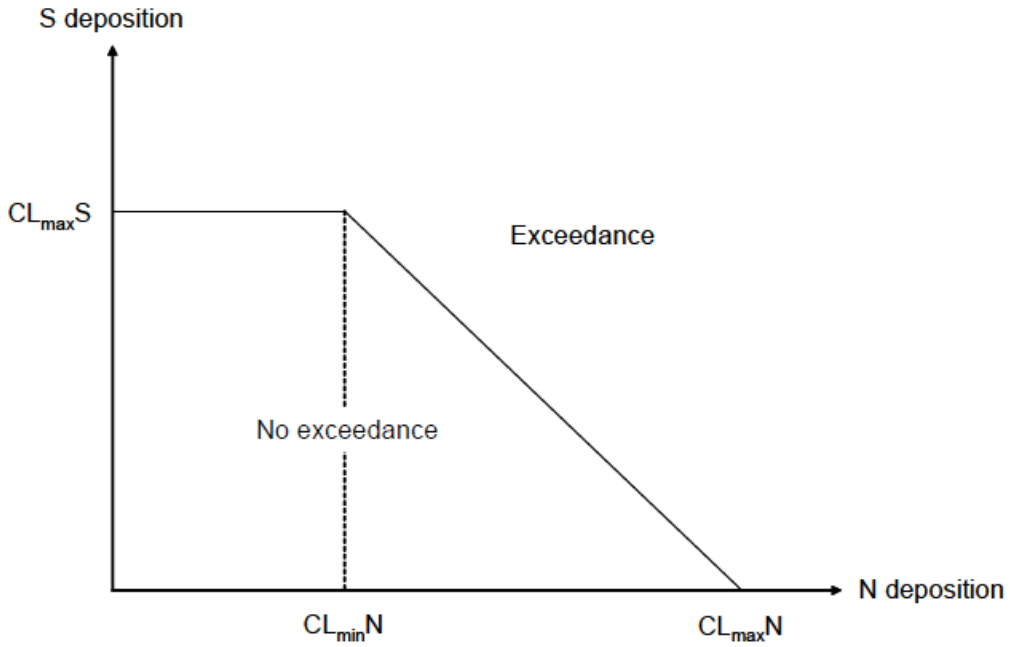
Critical loads

Eutrophication critical loads are given as a range and have units of kgN/ha/y. Generally, the lower end of the range should be used as a conservative assessment. The critical loads for acidification are more complicated, in that both the nitrogen and sulphur deposition fluxes must be considered at the same time. Therefore, a critical load function is specified for acidification, via the use of three critical load parameters:

- $CL_{max}S$ – the maximum critical load of sulphur, above which the deposition of sulphur alone would be considered to lead to an exceedence;
- $CL_{min}N$ – a measure of the ability of a system to "consume" deposited nitrogen (e.g. via immobilisation and uptake of the deposited nitrogen); and
- $CL_{max}N$ – the maximum critical load of acidifying nitrogen, above which the deposition of nitrogen alone would be considered to lead to an exceedance.

These three quantities define the critical load function shown in Figure 7.1.

Figure 7.1 Acid deposition critical load function



Source: AQTAG06 (2014)

APIS contains information on applicable critical loads for various habitats and species. Critical load data extracted from APIS for the ecological receptors considered in this assessment is provided in Table 7.2 below. The critical loads reported are for the most sensitive qualifying habitat/species for that particular site and location as reported by the APIS Site Relevant Critical Load (SRCL) tool and have been used in this assessment as a conservative approach. At the time of writing, APIS does not have data for the Outer Firth of Forth and St Andrews Bay Complex SPA, which was designated in December 2020, so data for the Firth of Forth SPA have been used instead.

Table 7.2 Site Specific Critical Loads

Receptor ID	Receptor Name	MinCLN (kgN/ha/y)	CLminN (keq/ha/y)	CLmaxN (keq/ha/y)	CLmaxS (keq/ha/y)
E1	Firth of Forth SPA/Ramsar	10	0.300	0.500	0.200
E2	Outer Firth of Forth and St Andrews Bay Complex SPA	10	0.300	0.500	0.200
E3	Forth Islands SPA	10	0.438	4.263	4.040

7.2 Significance criteria

For assessing the significance of long-term effects on human receptors, this assessment follows the IAQM/EPUK guidance, using the impact descriptors defined in Table 7.3. The significance of the effects arising from changes in the impact magnitudes are assessed based upon the impact descriptors in the IAQM/EPUK matrix, combined with professional judgement.

Table 7.3 Impact descriptors for increases in annual mean concentrations at human receptors

Absolute concentration with proposed development relative to assessment level	Increase in concentration relative to assessment level				
	<1%	1%	2–5%	6-10%	>10%
75% or less	Negligible	Negligible	Negligible	Slight	Moderate
76–94%	Negligible	Negligible	Slight	Moderate	Moderate
95–102%	Negligible	Slight	Moderate	Moderate	Substantial
103–109%	Negligible	Moderate	Moderate	Substantial	Substantial
110% or more	Negligible	Moderate	Substantial	Substantial	Substantial

Source: Directly extracted from IAQM/EPUK (2017)

For assessing the significance of short-term effects on human receptors, this assessment follows the IAQM/EPUK guidance by describing the magnitude and severity of the short-term PCs in the following terms:

- PCs between 11-20% of the AQAL are described as 'small' in magnitude with their severity described as 'slight';
- PCs between 21-50% of the AQAL are described as 'medium' in magnitude with their severity described as 'moderate'; and
- PCs greater than 51% of the AQAL are described as 'large' in magnitude with their severity described as 'substantial'.

The IAQM/EPUK guidance does not explicitly provide descriptors for short-term effects when the PC is less than 10% of the AQAL. PCs less than 10% of the AQAL are therefore described as 'very small' in magnitude with their severity described as 'negligible' in this Chapter.

For ecological receptors, whilst the predicted concentrations and deposition rates are enumerated by this chapter of the ES, the evaluation of significance is made in the Biodiversity chapter of the ES (Chapter 9) as per the IAQM's Position Paper referenced in Section 6.3.

8. Assessment of air quality effects

Full results tables providing the process contribution (PC) from FEP and the predicted environmental concentration (PEC = PC + background concentration + FNGL plant contribution) for each receptor are presented in Appendix D of Annex 1. These results are the highest concentrations predicted for individual receptors obtained from any year of meteorological data.

Summary results for the proposed flare system, i.e., after introduction of the new EGF, are presented in Section 8.1, with a comparison of impact against the existing site scenario in Section 8.2. Note that the PC in this instance is the total contribution from FEP, not that just related to the contribution from the new EGF.

Results are presented to several decimal places to assist comparison between receptors, scenarios and AQALs. The number of decimal places should not be taken as an indication of the accuracy of the modelling.

8.1 Proposed flare system

Effects on human receptors

Table 8.1 to Table 8.3 summarise the receptors results for the human receptor experiencing the highest predicted impact from the model. Results are shown for the receptors with the highest PC and the highest PEC; in general these are different receptors due to having different background concentrations. Full results at all receptors are given in Appendix D of Annex 1.

Table 8.1 Summary of impact at human receptor experiencing maximum PC and/or PEC: normal operation

Pollutant	Selection	AQAL ($\mu g\ m^{-3}$)	PC ($\mu g\ m^{-3}$)	PEC ($\mu g\ m^{-3}$)	PC (% of AQAL)	PEC (% of AQAL)	Receptor
NO_2 annual mean	Max PC	40	3.02	10.46	7.6%	26.1%	Camilla Props
NO_2 annual mean	Max PEC	40	2.60	12.63	6.5%	31.6%	Moss Bank Farm
NO_2 99.79 percentile 1-hour mean	Max PC	200	18.00	35.73	9.0%	17.9%	Easter Lochead
NO_2 99.79 percentile 1-hour mean	Max PEC	200	17.19	39.24	8.6%	19.6%	Moss Bank Farm
PM_{10} annual mean	Max PC	18	0.08	10.44	0.4%	58.0%	Camilla Props
PM_{10} annual mean	Max PEC	18	0.01	10.92	0.0%	60.7%	Lochgelly Props
PM_{10} 98.08 percentile 24-hour mean	Max PC	50	0.36	20.95	0.7%	41.9%	Moss Bank Farm
PM_{10} 98.08 percentile 24-hour mean	Max PEC	50	0.08	21.90	0.2%	43.8%	Lochgelly Props
$PM_{2.5}$ annual mean	Max PC	10	0.08	5.65	0.8%	56.5%	Camilla Props
$PM_{2.5}$ annual mean	Max PEC	10	0.01	5.91	0.1%	59.1%	Lochgelly Props
CO annual mean	Max PC	350	0.74	192.38	0.2%	55.0%	Camilla Props

Pollutant	Selection	AQAL (µg m^{-3})	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)	Receptor
CO annual mean	Max PEC	350	0.31	216.56	0.1%	61.9%	Heath/Ivy/Beech Cott
CO 100 percentile rolling 8-hour mean	Max PC	10,000	8.96	441.21	0.1%	4.4%	Moss Bank Farm
CO 100 percentile rolling 8-hour mean	Max PEC	10,000	8.96	441.21	0.1%	4.4%	Moss Bank Farm
SO_2 99.9 percentile 15-minute mean	Max PC	266	4.64	9.12	1.7%	3.4%	Moss Bank Farm
SO_2 99.9 percentile 15-minute mean	Max PEC	266	1.45	16.43	0.5%	6.2%	Lochgelly School
SO_2 99.73 percentile 1-hour mean	Max PC	350	2.71	7.21	0.8%	2.1%	Moss Bank Farm
SO_2 99.73 percentile 1-hour mean	Max PEC	350	0.75	15.73	0.2%	4.5%	Lochgelly School
SO_2 99.18 percentile 24-hour mean	Max PC	125	0.72	5.20	0.6%	4.2%	Moss Bank Farm
SO_2 99.18 percentile 24-hour mean	Max PEC	125	0.12	15.10	0.1%	12.1%	Lochgelly School
UHCs (as n-butane) annual mean	Max PC	14,500	0.04	35.14	0.0%	0.2%	Camilla Props
UHCs (as n-butane) annual mean	Max PEC	14,500	0.03	35.15	0.0%	0.2%	Little Raith
UHCs (as n-butane) 1 hour mean	Max PC	181,000	1.13	73.92	0.0%	0.0%	Moss Bank Farm
UHCs (as n-butane) 1 hour mean	Max PEC	181,000	1.02	74.60	0.0%	0.0%	Newton Farm
BTEX (as benzene) annual mean	Max PC	3	0.17	0.36	5.3%	11.2%	Camilla Props
BTEX (as benzene) annual mean	Max PEC	3	0.14	0.38	4.3%	11.7%	Moss Bank Farm
BTEX (as benzene) 1 hour mean	Max PC	208	18.27	18.65	8.8%	9.0%	Auchtertool School
BTEX (as benzene) 1 hour mean	Max PEC	208	18.27	18.65	8.8%	9.0%	Auchtertool School

Table 8.2 Summary of impact at human receptor experiencing maximum PC and/or PEC: PGC trip typical peak flaring rate – 130 T h^{-1}

Pollutant	Selection	AQAL (µg m^{-3})	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)	Receptor
NO_2 annual mean	Max PC	40	3.27	10.70	8.2%	26.8%	Camilla Props
NO_2 annual mean	Max PEC	40	2.78	12.81	7.0%	32.0%	Moss Bank Farm
NO_2 99.79 percentile 1-hour mean	Max PC	200	20.44	38.16	10.2%	19.1%	Easter Lochead
NO_2 99.79 percentile 1-hour mean	Max PEC	200	19.96	41.69	10.0%	20.8%	Moss Bank Farm
PM_{10} annual mean	Max PC	18	0.10	10.46	0.6%	58.1%	Camilla Props
PM_{10} annual mean	Max PEC	18	0.01	10.92	0.0%	60.7%	Lochgelly Props
PM_{10} 98.08 percentile 24-hour mean	Max PC	50	0.48	21.07	1.0%	42.1%	Moss Bank Farm
PM_{10} 98.08 percentile 24-hour mean	Max PEC	50	0.12	21.95	0.2%	43.9%	Lochgelly Props
$PM_{2.5}$ annual mean	Max PC	10	0.10	5.67	1.0%	56.7%	Camilla Props
$PM_{2.5}$ annual mean	Max PEC	10	0.01	5.92	0.1%	59.2%	Lochgelly Props
CO annual mean	Max PC	350	1.49	201.16	0.4%	57.5%	Little Raith
CO annual mean	Max PEC	350	0.25	216.46	0.1%	61.8%	Heath/Ivy/Beech Cott
CO 100 percentile rolling 8-hour mean	Max PC	10,000	28.55	428.78	0.3%	4.3%	Little Raith
CO 100 percentile rolling 8-hour mean	Max PEC	10,000	11.06	443.99	0.1%	4.4%	Heath/Ivy/Beech Cott
SO_2 99.9 percentile 15-minute mean	Max PC	266	5.46	9.96	2.1%	3.7%	Moss Bank Farm
SO_2 99.9 percentile 15-minute mean	Max PEC	266	2.88	17.87	1.1%	6.7%	Lochgelly School
SO_2 99.73 percentile 1-hour mean	Max PC	350	3.44	7.86	1.0%	2.2%	Easter Lochead
SO_2 99.73 percentile 1-hour mean	Max PEC	350	1.33	16.31	0.4%	4.7%	Lochgelly School
SO_2 99.18 percentile 24-hour mean	Max PC	125	1.55	5.97	1.2%	4.8%	Easter Lochead
SO_2 99.18 percentile 24-hour mean	Max PEC	125	0.30	15.29	0.2%	12.2%	Lochgelly School
UHCs (as n-butane) annual mean	Max PC	14,500	0.18	35.28	0.0%	0.2%	Little Raith

Pollutant	Selection	AQAL (µg m^{-3})	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)	Receptor
UHCs (as n-butane) annual mean	Max PEC	14,500	0.18	35.28	0.0%	0.2%	Little Raith
UHCs (as n-butane) 1 hour mean	Max PC	181,000	7.15	77.69	0.0%	0.0%	Easter Lochead
UHCs (as n-butane) 1 hour mean	Max PEC	181,000	7.15	77.69	0.0%	0.0%	Easter Lochead
BTEX (as benzene) annual mean	Max PC	3	0.18	0.37	5.4%	11.3%	Camilla Props
BTEX (as benzene) annual mean	Max PEC	3	0.14	0.38	4.3%	11.7%	Moss Bank Farm
BTEX (as benzene) 1 hour mean	Max PC	208	18.26	18.64	8.8%	9.0%	Auchtertool School
BTEX (as benzene) 1 hour mean	Max PEC	208	18.26	18.64	8.8%	9.0%	Auchtertool School

Table 8.3 Summary of impact at human receptor experiencing maximum PC and/or PEC: PGC trip instantaneous peak flaring rate – 200 T h^{-1}

Pollutant	Selection	AQAL (µg m^{-3})	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)	Receptor
NO_2 annual mean	Max PC	40	3.31	10.75	8.3%	26.9%	Camilla Props
NO_2 annual mean	Max PEC	40	2.79	12.81	7.0%	32.0%	Moss Bank Farm
NO_2 99.79 percentile 1-hour mean	Max PC	200	20.44	38.16	10.2%	19.1%	Easter Lochead
NO_2 99.79 percentile 1-hour mean	Max PEC	200	19.96	41.69	10.0%	20.8%	Moss Bank Farm
PM_{10} annual mean	Max PC	18	0.10	10.46	0.6%	58.1%	Camilla Props
PM_{10} annual mean	Max PEC	18	0.01	10.92	0.0%	60.7%	Lochgelly Props
PM_{10} 98.08 percentile 24-hour mean	Max PC	50	0.48	21.07	1.0%	42.1%	Moss Bank Farm
PM_{10} 98.08 percentile 24-hour mean	Max PEC	50	0.12	21.95	0.2%	43.9%	Lochgelly Props
$PM_{2.5}$ annual mean	Max PC	10	0.10	5.67	1.0%	56.7%	Camilla Props
$PM_{2.5}$ annual mean	Max PEC	10	0.01	5.92	0.1%	59.2%	Lochgelly Props
CO annual mean	Max PC	350	1.91	201.59	0.5%	57.6%	Little Raith
CO annual mean	Max PEC	350	0.30	216.50	0.1%	61.9%	Heath/Ivy/Beech Cott

Pollutant	Selection	AQAL (µg m^{-3})	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)	Receptor
CO 100 percentile rolling 8-hour mean	Max PC	10,000	39.09	439.32	0.4%	4.4%	Little Raith
CO 100 percentile rolling 8-hour mean	Max PEC	10,000	13.64	446.57	0.1%	4.5%	Heath/Ivy/Beech Cott
SO_2 99.9 percentile 15-minute mean	Max PC	266	5.46	9.96	2.1%	3.7%	Moss Bank Farm
SO_2 99.9 percentile 15-minute mean	Max PEC	266	2.88	17.87	1.1%	6.7%	Lochgelly School
SO_2 99.73 percentile 1-hour mean	Max PC	350	3.70	8.12	1.1%	2.3%	Easter Lochead
SO_2 99.73 percentile 1-hour mean	Max PEC	350	1.45	16.43	0.4%	4.7%	Lochgelly School
SO_2 99.18 percentile 24-hour mean	Max PC	125	1.64	5.99	1.3%	4.8%	Little Raith
SO_2 99.18 percentile 24-hour mean	Max PEC	125	0.31	15.29	0.2%	12.2%	Lochgelly School
UHCs (as n-butane) annual mean	Max PC	14,500	1.10	36.19	0.0%	0.2%	Little Raith
UHCs (as n-butane) annual mean	Max PEC	14,500	1.10	36.19	0.0%	0.2%	Little Raith
UHCs (as n-butane) 1 hour mean	Max PC	181,000	32.66	103.01	0.0%	0.1%	Little Raith
UHCs (as n-butane) 1 hour mean	Max PEC	181,000	32.47	103.23	0.0%	0.1%	Easter Lochead
BTEX (as benzene) annual mean	Max PC	3	0.20	0.39	6.3%	12.1%	Camilla Props
BTEX (as benzene) annual mean	Max PEC	3	0.20	0.39	6.3%	12.1%	Camilla Props
BTEX (as benzene) 1 hour mean	Max PC	208	18.26	18.64	8.8%	9.0%	Auchtertool School
BTEX (as benzene) 1 hour mean	Max PEC	208	18.26	18.64	8.8%	9.0%	Auchtertool School

Table 8.1 to Table 8.3 indicate that there are no predicted exceedances of any AQS, AQO or EAL during normal operation of FEP and during both PGC trip scenarios with the proposed changes to the flare system. On this basis, the risk of adverse impacts on human health would appear to be negligible. The largest PEC as a percentage of the AQS, AQO or EAL is annual mean CO, where a PEC of up to 61.9% of the AQS is predicted at Heath/Ivy/Beech Cottages during the normal operation scenario. However, the background concentration is the largest contributor to the PEC at this location, with the background concentration alone accounting for 61.7% of the AQS and with FEP contributing less than 0.1% of the AQS at this location in each scenario. It should be noted that the background concentrations for CO are for the year 2001 and have not been updated since then.

The results from the PGC trip scenarios are obtained using the ultimate worst-case assumption that such a scenario would occur continuously throughout the year. This would significantly overestimate annual mean impacts as such scenarios, if they did occur, would occur over a matter of hours or days, rather than being a continuous event.

Effects on ecological receptors

Table 8.4 to Table 8.6 summarise the results for the ecological receptor experiencing the highest predicted impact from the model. Results are shown for the receptors with the highest PC and the highest PEC; in general these are different receptors due to having different background concentrations. Full results at all receptors are given in Appendix E of Annex 1.

Table 8.4 Summary of impact at ecological receptor experiencing maximum PC and/or PEC: normal operation

Pollutant	Selection	AQAL ($\mu g\ m^{-3}$)	PC ($\mu g\ m^{-3}$)	PEC ($\mu g\ m^{-3}$)	PC (% of AQAL)	PEC (% of AQAL)	Receptor
NO_x annual mean	Max PC	30	0.19	12.29	0.6%	41.0%	Outer Firth of Forth
NO_x annual mean	Max PEC	30	0.15	12.54	0.5%	41.8%	Firth of Forth
NO_x daily mean	Max PC	75	12.45	38.22	16.6%	51.0%	Outer Firth of Forth
NO_x daily mean	Max PEC	75	12.45	38.22	16.6%	51.0%	Outer Firth of Forth
SO_2 annual mean	Max PC	20	0.01	2.34	<0.1%	11.7%	Outer Firth of Forth
SO_2 annual mean	Max PEC	20	0.01	2.34	<0.1%	11.7%	Outer Firth of Forth
Pollutant	**Selection**	**AQAL (kgN/ha/y)**	**PC (kgN/ha/y)**	**PEC (kgN/ha/y)**	**PC (% of AQAL)**	**PEC (% of AQAL)**	**Receptor**
Nitrogen deposition	Max PC	10	0.02	13.72	0.2%	137%	Outer Firth of Forth
Nitrogen deposition	Max PEC	10	0.02	13.72	0.2%	137%	Outer Firth of Forth
Pollutant	**Selection**	**AQAL (% of CL function)**	**PC (% of CL function)**	**PEC (% of CL function)**	**PC (% of AQAL)**	**PEC (% of AQAL)**	**Receptor**
Acid Deposition*	Max PC	100%	0.47%	220%	0.47%	220%	Outer Firth of Forth
Acid Deposition*	Max PEC	100%	0.47%	220%	0.47%	220%	Outer Firth of Forth

* Acid deposition results expressed as percentage of the site-specific critical load function

Table 8.5 Summary of impact at ecological receptor experiencing maximum PC and/or PEC: PGC trip typical peak flaring rate – 130 T h^{-1}

Pollutant	Selection	AQAL ($\mu g\ m^{-3}$)	PC ($\mu g\ m^{-3}$)	PEC ($\mu g\ m^{-3}$)	PC (% of AQAL)	PEC (% of AQAL)	Receptor
NO_x annual mean	Max PC	30	0.21	12.31	0.7%	41.0%	Outer Firth of Forth
NO_x annual mean	Max PEC	30	0.17	12.56	0.6%	41.9%	Firth of Forth

Pollutant	Selection	AQAL (µg m^{-3})	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)	Receptor
NO_x daily mean	Max PC	75	14.29	40.07	19.1%	53.4%	Outer Firth of Forth
NO_x daily mean	Max PEC	75	14.29	40.07	19.1%	53.4%	Outer Firth of Forth
SO_2 annual mean	Max PC	20	0.01	2.34	0.1%	11.7%	Outer Firth of Forth
SO_2 annual mean	Max PEC	20	0.01	2.34	0.1%	11.7%	Outer Firth of Forth
Pollutant	**Selection**	**AQAL (kgN/ha/y)**	**PC (kgN/ha/y)**	**PEC (kgN/ha/y)**	**PC (% of AQAL)**	**PEC (% of AQAL)**	**Receptor**
Nitrogen deposition	Max PC	10	0.02	13.72	0.2%	137.2%	Outer Firth of Forth
Nitrogen deposition	Max PEC	10	0.02	13.72	0.2%	137.2%	Outer Firth of Forth
Pollutant	**Selection**	**AQAL (% of CL function)**	**PC (% of CL function)**	**PEC (% of CL function)**	**PC (% of AQAL)**	**PEC (% of AQAL)**	**Receptor**
Acid Deposition*	Max PC	100%	0.59%	221%	0.59%	220.59%	Outer Firth of Forth
Acid Deposition*	Max PEC	100%	0.59%	221%	0.59%	220.59%	Outer Firth of Forth

* Acid deposition results expressed as percentage of the site-specific critical load function

Table 8.6 Summary of impact at ecological receptor experiencing maximum PC and/or PEC: PGC trip instantaneous peak flaring rate – 200 T h^{-1}

Pollutant	Selection	AQAL (µg m^{-3})	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)	Receptor
NO_x annual mean	Max PC	30	0.21	12.31	0.7%	41.0%	Outer Firth of Forth
NO_x annual mean	Max PEC	30	0.17	12.56	0.6%	41.9%	Firth of Forth
NO_x daily mean	Max PC	75	14.32	40.09	19.1%	53.5%	Outer Firth of Forth
NO_x daily mean	Max PEC	75	14.32	40.09	19.1%	53.5%	Outer Firth of Forth
SO_2 annual mean	Max PC	20	0.01	2.34	0.1%	11.7%	Outer Firth of Forth
SO_2 annual mean	Max PEC	20	0.01	2.34	0.1%	11.7%	Outer Firth of Forth
Pollutant	**Selection**	**AQAL (kN/ha/y)**	**PC (kgN/ha/y)**	**PEC (kN/ha/y)**	**PC (% of AQAL)**	**PEC (% of AQAL)**	**Receptor**
Nitrogen deposition	Max PC	10	0.02	13.72	0.2%	137.2%	Outer Firth of Forth
Nitrogen deposition	Max PEC	10	0.02	13.72	0.2%	137.2%	Outer Firth of Forth
Pollutant	**Selection**	**AQAL (% of CL function)**	**PC (% of CL function)**	**PEC (% of CL function)**	**PC (% of AQAL)**	**PEC (% of AQAL)**	**Receptor**
Acid Deposition*	Max PC	100%	0.60%	221%	0.60%	220.60%	Outer Firth of Forth
Acid Deposition*	Max PEC	100%	0.60%	221%	0.60%	220.60%	Outer Firth of Forth

* Acid deposition results expressed as percentage of the site-specific critical load function

Table 8.4 to Table 8.6 indicate that there are no predicted exceedances of any AQS, AQO or EAL during normal operation of FEP and during both PGC trip scenarios with the proposed changes to the flare system. On this basis, the risk of adverse impacts on human health would appear to be negligible.

The PCs for all long-term effects are less than 1% of the relevant assessment level at all receptors in all scenarios. The PCs for shorter-term effects, namely daily mean NO_x, are less than 20% of the critical level at all receptors in all scenarios, with the PEC less than 54% of the critical level. The largest PEC as a percentage of the AQS, AQO or EAL is nitrogen deposition, where there are exceedances of the minimum critical load at all ecological receptors. However, this is almost entirely due to the existing background, with the PC being at most 0.2% of the critical load.

The results from the PGC trip scenarios are obtained using the ultimate worst-case assumption that such a scenario would occur continuously throughout the year. This would significantly overestimate annual mean impacts as such scenarios, if they did occur, would occur over a matter of hours or days, rather than being a continuous event. The modelling also assumes that the flaring events would occur when the worst-case meteorology was occurring in terms of contributions to daily mean NO_x concentrations, which is unlikely.

8.2 Comparison of impacts with the existing flare system

Table 8.7 compares the change in the ground level concentration at the human receptor experiencing the maximum process contribution between the existing site scenario and with the proposed new EGF operating (this may be a different receptor in the two scenarios). The comparison is made for each of the three flare emission scenarios and pollutant averaging period. Cells are shaded green where the concentration in the proposed scenario is lower than in the existing scenario, orange where it is higher, and white where the change, as a percentage of the relevant AQAL, is smaller than 0.1% in absolute value.

Model predictions for each receptor for the existing site scenario are provided in Appendix E of Annex 1.

Table 8.7 Change in maximum impact at any receptor between the existing and proposed operation of FEP with the new EGF operational

Pollutant	Normal operation (µg m^{-3})	PGC trip – typical peak rate (µg m^{-3})	PGC trip – instantaneous peak rate (µg m^{-3})
NO_2 annual mean	0.00	-0.15	-0.10
NO_2 99.79 percentile 1-hour mean	-0.07	0.00	0.00
PM_{10} annual mean	0.00	-0.22	-0.17
PM_{10} 98.08 percentile 24-hour mean	0.00	-1.56	-1.51
$PM_{2.5}$ annual mean	0.00	-0.22	-0.17
CO annual mean	0.00	-1.45	-1.04
CO 100 percentile rolling 8-hour mean	-0.61	-24.52	-13.95
SO_2 99.9 percentile 15-minute mean	0.00	-0.01	-0.02
SO_2 99.73 percentile 1-hour mean	0.00	-1.18	-0.87
SO_2 99.18 percentile 24-hour mean	0.00	-0.72	-0.63
UHCs (as n-butane) annual mean	-0.01	-1.02	-1.33

Pollutant	Normal operation (µg m^{-3})	PGC trip – typical peak rate (µg m^{-3})	PGC trip – instantaneous peak rate (µg m^{-3})
UHCs (as n-butane) 1 hour mean	-0.42	-27.21	-20.55
BTEX (as benzene) annual mean	0.00	-0.03	-0.03
BTEX (as benzene) 1 hour mean	0.00	0.00	0.00
NO_x annual mean	0.00	-0.01	-0.01
NO_x daily mean	-0.01	0.03	0.04
SO_2 annual mean	0.00	0.00	0.00
Pollutant	**Normal operation (kgN/ha/y)**	**PGC trip – typical peak rate (kgN/ha/y)**	**PGC trip – instantaneous peak rate (kgN/ha/y)**
Nitrogen deposition	0.00	0.00	0.00
Pollutant	**Normal operation (% of CL function)**	**PGC trip – typical peak rate (% of CL function)**	**PGC trip – instantaneous peak rate (% of CL function)**
Acid Deposition	0.00	-0.08	-0.08

Normal operation scenario

In the normal operation scenario, there is negligible difference in the predictions between the proposed flare system and the existing flare system for most pollutants. This is because flare emissions are not the dominant emission source during normal operation of FEP, with emissions from the furnaces, boilers and gas turbine dominating.

For the one pollutant to which the flare system is the dominant/only emitter in this scenario, i.e., UHCs, it is evident the proposed flare system reduces the impact from the current site scenario. This is due to combining the base load flare stream to a single EGF whose combined buoyancy and momentum is greater than the sum of such effects from the separate Shell ground flares, whilst the release height of the new EGF is greater than that of the two Shell ground flares.

For all pollutants with long-term averaging periods (i.e. annual means), the absolute value of the change in PC is less than 1% of the AQAL at all human receptors, so under the IAQM/EPUK criteria, the impact is classified as **negligible**. For all pollutants with hourly or shorter averaging periods, the absolute value of the change in PC is less than 10% of the AQAL at all human receptors, so under the IAQM/EPUK criteria, the impact is classified as **negligible**. For daily mean PM_{10}, the absolute value of the change in PC is less than 10% of the AQAL at all human receptors, so under the IAQM/EPUK criteria, the impact is classified as **negligible**.

PGC trip – typical peak rate

In this scenario, the primary difference between the proposed flare system and existing flare system is as follows:

- Use of elevated flare – with the existing flare system, 85 T h^{-1} of gas is routed to the elevated flare whereas, with the proposed flare system, the elevated flare is not operational in this scenario, with all gas routed to the new EGF.

- Consolidation of ground flares – with the existing flare system, 45 T h^{-1} of gas is routed to the two Shell ground flares (22.5 T h^{-1} each), whereas, with the proposed flare system, all 130 T h^{-1} of gas is routed to the new, single ground flare.

There is either a reduction in the maximum predicted impact with the proposed flare system, or no significant change, for each pollutant. The maximum daily mean NO_x PC is very slightly higher with the proposed flare system, but this increase is just 0.03 µg m^{-3} or 0.04% of the AQAL. Although 85 T h^{-1} of gas has been diverted from the elevated flare to the ground flare, there are several competing factors which mitigate the effects of reducing the release height, with an individual receptor experiencing either a decrease or negligible increase in impact dependent on its location and how these competing factors influence the dispersion of emissions from FEP at that specific distance/orientation from the emission source. These mitigating factors include:

- Due to their enclosed nature, it is easier to control and optimise combustion conditions in ground flares, resulting in an increase in the combustion efficiency whilst the fraction of heat radiated reduces considerably. The combined effect of these factors is to increase the plume buoyancy, which increases buoyancy-driven plume rise above that which occurs from the elevated flare.
- The improved combustion efficiency significantly reduces the formation of particulate matter and reduces unburnt hydrocarbon emissions. Thus, for PM_{10}, $PM_{2.5}$ and UHCs, there is a dual effect of increasing plume buoyancy and reduced emission rate which drives the reduction in ground level impacts.
- Consolidation of the ground flares (from two to one) also acts to reduce the maximum impact of some pollutants, as discussed in the normal operation scenario.

There are no, or more minor reductions, in maximum NO_2 and BTEX impacts between the existing and proposed flare system scenarios. This is a consequence of other non-flare emission sources having a more dominant impact on ground level concentrations (the furnaces, boilers and gas turbine for NO_2, and the caustic oxidiser vent for BTEX).

For all pollutants with long-term averaging periods (i.e. annual means) except $PM_{2.5}$, the absolute value of the change in PC is less than 1% of the AQAL at all human receptors (to the nearest percentage point), so under the IAQM/EPUK criteria, the impact is classified as **negligible**. For annual mean $PM_{2.5}$, there are some receptors where the absolute change is larger than 1%, but the background is less than 75% of the AQAL, so the impact at all receptors is **negligible**. For all pollutants with hourly or shorter averaging periods, the absolute value of the change in PC is less than 10% of the AQAL at all human receptors, so under the IAQM/EPUK criteria, the impact is classified as **negligible**. For daily mean PM_{10}, the absolute value of the change in PC is less than 10% of the AQAL at all human receptors, so under the IAQM/EPUK criteria, the impact is classified as **negligible**.

PGC trip – peak instantaneous rate

In this scenario, the primary difference between the proposed flare system and existing flare system is as follows:

- Use of elevated flare – with the existing flare system, 155 T h^{-1} of gas is routed to the elevated flare whereas, with the proposed flare system, 70 T h^{-1} of gas is routed to the elevated flare.
- Consolidation of ground flares – with the existing flare system, 45 T h^{-1} of gas is routed to the two Shell ground flares (22.5 T h^{-1} each), whereas, with the proposed flare system, 130 T h^{-1} of gas routed to the new, single ground flare.

Like the typical peak rate PGC trip scenario, for each pollutant there is predicted to be either a reduction in the maximum predicted ground level impact of the instantaneous peak rate during a PGC trip scenario, or no

significant change compared to the existing configuration. The maximum daily mean NO_x PC is slightly higher with the proposed flare system, but as with the typical peak flaring rate, this increase is negligible, representing an increase of less than 0.1% of the critical level.

For all pollutants with long-term averaging periods (i.e. annual means) except $PM_{2.5}$, the absolute value of the change in PC is less than 1% of the AQAL at all human receptors (to the nearest percentage point), so under the IAQM/EPUK criteria, the impact is classified as **negligible**. For annual mean $PM_{2.5}$, there are some receptors where the absolute change is larger than 1%, but the background is less than 75% of the AQAL, so the impact at all receptors is **negligible**. For all pollutants with hourly or shorter averaging periods, the absolute value of the change in PC is less than 10% of the AQAL at all human receptors, so under the IAQM/EPUK criteria, the impact is classified as **negligible**. For daily mean PM_{10}, the absolute value of the change in PC is less than 10% of the AQAL at all human receptors, so under the IAQM/EPUK criteria, the impact is classified as **negligible**.

Summary of significance of air quality effects

A summary of the results of the air quality assessment is provided in Table 8.8. The significance of effects on habitat sites, including the Firth of Forth Special Protection Area (SPA)/Ramsar site, Outer Firth of Forth and St Andrews Bay Complex SPA and Forth Islands SPA, are not assessed in this assessment in line with the IAQM's guidance but are considered in the biodiversity assessment that accompanies the application.

Table 8.8 Summary of significance of adverse air quality effects

Receptor and summary of predicted effects	Sensitivity/ importance/ value of receptor[1]	Magnitude of change[2]	Significance	Summary rationale
Long-term effects of emissions from FEP on all human receptors	High	Negligible for all receptors	Not significant	The change in long-term concentrations of relevant pollutants with the new EGF in operation are classed as 'negligible' under IAQM/EPUK guidance and, in many cases, result in an improvement in local air quality. The effects, therefore, are Not Significant.
Short-term effects of emissions from FEP on all human receptors	High	Negligible for all receptors	Not significant	The change in short-term process contributions of emissions associated with the Proposed Development are be classed as 'negligible' under IAQM/EPUK guidance and, in many cases, result in an improvement in local air quality. On this basis, the effects are Not Significant.

9. Assessment of cumulative effects

The impacts of the Proposed Development are negligible but generally beneficial. In view of this no cumulative effects assessment has been carried out.

10. Consideration of additional mitigation or compensation

The purpose of the Proposed Development is to reduce environmental impacts from noise and visual impact, and secondarily air quality. The air quality impacts of the Proposed Development are negligible but generally beneficial. In view of this no additional mitigation or compensation is considered necessary.

11. Conclusions of significance evaluation

Changes in concentrations of relevant air quality pollutants with the Proposed Development in operation can be considered 'negligible' under IAQM/EPUK planning guidance. Any such adverse effects are, therefore, considered not significant at all receptors.

The assessment has incorporated several worst-case assumptions, which will likely result in an overestimation of the predicted ground level concentrations. As a result of these worst-case assumptions, the predicted results should be considered the upper limit of model uncertainty for a scenario where the actual site impact is determined. These worst-case assumptions include, amongst others:

- Assuming emissions from the flares occur continuously throughout the year at instantaneous and typical peak rates for the flare event scenarios;
- Assuming emissions from the adjacent FNGL plant occur at permit emission limit values, as opposed to report (lower) actual emissions;
- Using background concentration estimates that already include contributions from the FEP and FNGL plant (i.e., attempts have not been made to prevent 'double-counting' of impacts); and
- Reporting results from the year(s) producing the highest predicted impacts at receptors from 5 years of meteorological data.

Annex 1
Assessment of Air Quality Impacts from the Operation of a New Enclosed Ground Flare at Fife Ethylene Plant: Technical Report

ExxonMobil Chemical Limited

Assessment of Air Quality Impacts from the Operation of a New Enclosed Ground Flare at Fife Ethylene Plant

TECHNICAL REPORT

Wood Group UK Limited – April 2021

Report for

ExxonMobil Chemical Limited

Main contributors

[redacted]

Issued by

.....

[redacted]

Approved by

.....

[redacted]

Wood

Block 3, Level 2
Booths Park
Chelford Road
Knutsford WA16 8QZ
United Kingdom
Tel +44 (0)1565 652100

Doc Ref. Final Report 190711-WOOD-XX-XX-RP-OA-00001_A_C1.0_2021 update.docx

n:\projects\40787 aq fife ethylene plant flaring study\d - design\2021 modelling\reports\190711-wood-xx-xx-rp-oa-00001_a_c1.0_2021 update.docx

Copyright and non-disclosure notice

Third party disclaimer

Management systems

This document has been produced by Wood Group UK Limited in full compliance with our management systems, which have been certified to ISO 9001, ISO 14001 and ISO 45001 by Lloyd's Register.

Document revisions

No.	Details	Date
1	Draft Report	April 2021
2	Final Report	April 2021

Executive summary

Purpose of this report

In 2019, Wood Group UK Limited ('Wood'), then operating as Wood Environment & Infrastructure Solutions Limited, undertook an assessment to quantify the potential impacts on local air quality associated with emissions to air from the Fife Ethylene Plant (FEP), operated by ExxonMobil Chemical Limited ('EMCL'), and the Fife Natural Gas Liquids (FNGL) Mossmorran Fractionation Plant, operated by Shell UK Limited ('Shell'). The assessments had a particular emphasis on flare emissions, but also included an assessment of the other process and combustion plant emitting to atmosphere at the two installations.

The assessment was undertaken to update a previous assessment by Entec UK Limited in 2009 and in response to complaints from members of the public concerning the potential human health effects during non-routine flaring from the elevated flare at FEP. These complaints also cited noise and vibration, and visual impact concerns.

EMCL completed a Best Available Technique (BAT) assessment in 2019 which identified the installation of a new, enclosed ground flare (EGF) would represent BAT for reducing noise and visual impacts, allowing operation of the elevated flare to be substantially reduced. However, due to the lower release height of the EGF compared to the elevated flare, the potential for small increases in ground level concentrations of certain combustion products with the EGF operating needed to be considered.

Consequently, this assessment investigates the potential changes in ground level concentrations of key pollutants, including oxides of nitrogen (NO_x), carbon monoxide (CO), sulphur dioxide (SO_2), particulate matter (PM_{10} and $PM_{2.5}$), unburnt hydrocarbons (UHCs) and benzene with the EGF operational.

Methodology

The assessment uses detailed dispersion modelling to predict the process contribution of emissions from FEP, and the total predicted environmental concentration taking in to account other emission sources, at local human receptors near FEP. It then compares these to statutory and non-statutory air quality standards (AQS), air quality objectives (AQO) and Environmental Assessment Levels (EAL) set for the protection of human health.

This latest study considers two scenarios for both the current site operation and proposed operation with the EGF operational:

- Assessment of impacts during normal operation of FEP;
- Assessment of a more conservative flaring event emissions scenario, considering the impacts on air quality during a process gas compressor (PGC) trip under the following assumptions:
  - An assessment of impact during a PGC trip assuming flaring occurs at the instantaneous peak rate of 200 T h^{-1} continuously over the course of the year; and
  - An assessment of impact during a PGC trip assuming flaring occurs at the more typical peak rate of 130 T h^{-1} continuously over the course of the year.

Conclusions

The principal conclusion of this assessment is that, as there are no predicted exceedances of any air quality AQS, AQO or EAL during normal operation of FEP and during both PGC trip flare event scenarios for the current and proposed site operation, the risk of adverse impacts on human health or ecological sites due to emissions to air from FEP would appear to be negligible. Due to the improved combustion efficiency and

lower radiative loss associated with the EGF compared to the elevated flare, maximum ground level impacts are generally found to **reduce** in the proposed site scenario. These effects compete against, and mitigate, the reduction in release height.

Impacts on habitat sites, including the Firth of Forth Special Protection Area (SPA)/Ramsar site, Outer Firth of Forth and St Andrews Bay Complex SPA and Forth Islands SPA, are assessed as insignificant under SEPA's H1 Horizontal Guidance[1].

[1] Environment Agency (2002) Integrated Pollution Prevention and Control (IPPC) Environmental Assessment and Appraisal of BAT. Horizontal Guidance Note IPPC H1. https://www.sepa.org.uk/media/61377/ippc-h1-environmental-assessment-and-appraisal-of-bat-updated-july-2003.pdf

Model checklist

Item	✓/✗	Reason for Omission
Location map	✓	
Site plan	✓	
List of pollutants modelled and relevant air quality guidelines	✓	
Details of modelled scenarios	✓	
Details of relevant ambient concentrations used	✓	
Model description and justification	✓	
Special model treatments used	✓	
Table of emission parameters used	✓	
Details of modelled domain and receptors	✓	
Details of meteorological data used, including origin, and justification	✓	
Details of terrain treatment	✓	
Details of buildings treatment	✓	
Details of modelling wet/dry deposition	✓	
Sensitivity analysis	✓	
Assessment of impacts	✓	
Model input files	✗	Provided by email to EMCL

Contents

1. Introduction

1.1 Background, aims and objectives

In 2019, Wood Group UK Limited ('Wood') undertook assessments to quantify the potential impacts on local air quality associated with emissions to air from the Fife Ethylene Plant (FEP)[2], operated by ExxonMobil Chemical Limited ('EMCL'), and the Fife Natural Gas Liquids (FNGL) Mossmorran Fractionation Plant, operated by Shell UK Limited ('Shell'). The assessments had a particular emphasis on flare emissions, but also included the other process and combustion plant emitting to atmosphere at the two installations.

The assessments concluded that emissions from FEP and FNGL plants, in isolation and in combination, would not result in an exceedance of any statutory air quality standard or non-statutory guideline value, with background emission sources (e.g., roads, domestic combustion etc.) being the largest contributor to modelled ground level concentrations of key air quality pollutants. These pollutants included nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO), fine particulate matter (PM_{10} and $PM_{2.5}$) and certain speciated volatile organic compounds (VOCs) such as benzene.

The assessment was undertaken to update a previous assessment by Entec UK Limited in 2009[3] and in response to complaints from members of the public concerning the potential human health effects during non-routine flaring from the elevated flare at FEP. These complaints also cited noise and vibration, and visual impact concerns.

EMCL completed a Best Available Technique (BAT) assessment in 2019 which identified installation of a new, enclosed ground flare (EGF) would represent BAT for reducing noise and visual impacts, allowing operation of the elevated flare to be substantially reduced. However, due to the lower release height of the EGF compared to the elevated flare, the potential for small increases in ground level concentrations of certain combustion products with the EGF operating needed to be considered.

Consequently, this assessment investigates the potential changes in ground level concentrations and deposition rates of key pollutants at human receptors and habitat sites with the EGF operational.

1.2 Site location and description

FEP is located approximately 3 km south-east of the town of Cowdenbeath in Fife. The site produces ethylene using ethane as its primary feedstock. The major source of ethane arrives at the installation from the adjacent FNGL plant, having first been pumped from offshore oil and gas fields via the Shell/Exxon gas processing plant at St Fergus as a mixture of Natural Gas Liquids (NGL). The ethane is heated in a steam mix which cracks the ethane into ethylene, hydrogen and other various by-products. Uncracked ethane is recycled and all other by-product gases are used as fuel in the plant's furnaces and turbines.

Ethylene is transported by pipeline to the Braefoot Bay marine terminal, where it is shipped to other markets, with some of the ethylene distributed via the UK ethylene pipeline to other manufacturing plants in the UK.

[2] Wood, 2019. 'Assessment of Air Quality Impacts from Flaring at Fife Ethylene Plant' Report 40787-WOOD-XX-XX-RP-OA-0001_A_C01

[3] Entec, 2009. 'Local Air Quality Modelling Study for the Fife Ethylene Plant and Mossmorran Fractionation Plant – Impact Assessment of Flare and Process Stack Emissions from the Mossmorran Fractionation Plant'

The current FEP flare system consists of two different types of flare:

- An elevated flare, 100 m in height above ground level; and
- Two ground flares. These are operated by Shell but can be used by both sites as required.

Flaring occurs at low rates during normal operation of FEP ('base-load flaring'), with the Shell ground flares being preferentially used when available. Flaring can, however, increase significantly for short periods of time during unplanned process upsets (e.g., compressor or turbine trips) or before and/or following planned maintenance ('flaring event'). In all instances, flaring is an essential safety mechanism to allow excess gas, or out of specification gas, that cannot be processed at the installation to be combusted in a safe and controlled manner.

EMCL are proposing to replace the use of the existing shared ground flares with a new, larger enclosed ground flare (EGF) intended for sole use by EMCL. With the new EGF operational, the use of the elevated flare would be reduced considerably, with the EGF being the primary flare in operation during normal operation and most non-routine operations.

Figure 1.1 provides a site location map.

Figure 1.1 Site location map

1.3 Sources of Information

The information used in this assessment includes:

- Process and emissions data for the point (non-flare) emission sources at FEP provided by EMCL;
- Flare mass flow rate and composition during base-load and event flaring provided by EMCL;
- Information obtained as part of the previous modelling studies in 2009 and 2019;
- Information from SEPA including the PPC permits for the FEP and FNGL plant and annual flare quantities;
- Background air quality data from Fife Council, SEPA, Ineos and the Mossmorran and Braefoot Bay Independent Air Quality Monitoring (IAQM) Review Group; This includes, amongst others, continuous and passive monitoring undertaken by Fife Council throughout 2019 (the latest year where ratified data was available when this assessment was undertaken), continuous and passive monitoring undertaken by SEPA between August 2019 and March 2020, and passive monitoring undertaken of volatile organic compounds (VOCs) by Ineos, as reported by the IAQMRG. Type and specification of wind turbines from the Fife Council Planning Portal;
- OS Maps of the local area; and
- Meteorological data supplied by Atmospheric Dispersion Modelling Ltd from World Meteorological Organisation (WMO) affiliated weather stations.

2. Methodology

2.1 Dispersion model selection

There are two primary dispersion models which have been used extensively for developments of this nature and accepted as appropriate air quality modelling tools by SEPA:

- The ADMS model, developed in the UK by Cambridge Environmental Research Consultants (CERC) in collaboration with the Met Office, National Power and the University of Surrey; and
- The AERMOD model, developed in the United States by the American Meteorological Society (AMS) / United States Environmental Protection Agency (USEPA) Regulatory Model Improvement Committee (AERMIC).

Both models are termed 'new generation' models, parameterising stability and turbulence in the planetary boundary layer (PBL) by the Monin-Obukhov length and the boundary layer depth. This approach allows the vertical structure of the PBL to be more accurately defined than by the stability classification methods of earlier dispersion models. Like these earlier models, ADMS and AERMOD adopt a symmetrical Gaussian profile of the concentration distribution in the vertical and crosswind directions in neutral and stable conditions. However, unlike the earlier models, the ADMS and AERMOD vertical concentration profile in convective conditions adopts a skewed Gaussian distribution to take account of the heterogeneous nature of the vertical velocity distribution in the Convective Boundary Layer (CBL).

Numerous model inter-comparison studies have demonstrated little difference between the output of ADMS and AERMOD, except in certain complex terrain scenarios (Carruthers et al., 2011)[4]. For the purposes of this study, emissions have been assessed using the ADMS model only for the reasons set out below.

ADMS can calculate sub-hourly averaged concentrations based on site-specific meteorological and surface conditions, whereas AERMOD can only produce output down to hourly-averaged values. Therefore, to enable an assessment of impact against the sub-hourly assessment metrics e.g. 10-minute and 15-minute means, standard conversion factors must be applied to the hourly output. These factors are generally taken from Turner (1994)[5] who published estimated ratios of calculated peak and mean concentrations at 3 minutes, 15 minutes, 1 hour, 3 hours and 24 hours from published data on lateral and vertical diffusion co-efficients in steady winds as reported by Nonhebel (1960)[6]. What is important to note here is that these estimates were based upon calculated dispersion coefficients, rather than monitoring results. Furthermore, Turner (1994) cautions that:

"...ratios of peak to mean data depend also on the stability of the atmosphere and the type of terrain that the plume is passing over."

Therefore, application of a standard, non-site-specific conversion factor that does not have its basis in monitored data would significantly increase the uncertainty in modelled sub-hourly mean values obtained from AERMOD. This limitation is not present in ADMS, which uses site-specific meteorological and surface conditions to directly calculate sub-hourly averaged concentrations. This is pertinent for the assessment of SO_2 emissions against the 15-minute mean SO_2 AQO.

[4] Carruthers et al., 2011. 'Comparison of the complex terrain algorithms incorporated into two commonly used local-scale air pollution dispersion models (ADMS and AERMOD) using a hybrid model.' J. Air Waste Manag. Assoc., 61, 1227-35

[5] Turner, B., 1994. 'Workbook of Atmospheric Dispersion Estimates.'

[6] Nonhebel, G., 1960. 'Recommendations on Heights for Industrial Chimneys.' J. Inst. Fuel 33, 479-513

AERMOD also adopts a basic treatment of topographical effects on pollutant dispersion, using a dividing streamline approach, with the receptor concentration being a weighted average of the contribution from a horizontal plume and terrain following-plume. ADMS, however, through its FLOWSTAR sub-routine, explicitly calculates the 3-dimensional flow field over terrain, allowing more advanced treatment of dispersion in areas of complex terrain. The overly-pessimistic approach of AERMOD in areas of complex terrain has been discussed by Carruthers et al (2011) who concluded:

"...where there is plume impaction AERMOD has a tendency to overestimate concentrations and, therefore, may act as a screening model in this case, whereas ADMS may predict more realistic concentrations"

Although Carruthers et al (2011) acknowledge both models appeared to perform reasonably when compared to measurements at the six specific monitoring sites in one of the case studies reviewed (the Clifty Creek case), they also state that:

"...although both models appear to perform reasonably, the comparisons provide relatively little insight into how well the two models are taking account of the impacts of the complex terrain because other factors such as differences in input meteorology arising from the two meteorological pre-processors may cause the model differences between the data and model predictions."

Furthermore, as stated in Carruthers et al (2011), only ADMS was able to replicate the higher predicted concentrations because of the reduction in speed and streamline divergence across the valley, with associated increase in speed and streamline convergence towards the downwind edge of the valley, demonstrated in field studies of air flow by Wiggs et al (2002)[7] and Mason (1987)[8].

In the Clifty Creek case, the discharge occurs some 60 m above the valley. The specific concern with the AERMOD terrain module demonstrated in Carruthers et al (2011) is the direct impaction of the plume on windward sides of the terrain when the release height is lower than the terrain height, particularly since, as discussed in Carruthers et al (2011), the AERMOD treatment effectively assumes 50% of the plume, as a minimum, impacts the surface without any consideration of the specific nature of boundary layer stability or the terrain features. Terrain within certain areas of the model domain considered in this assessment is higher than the release elevation of some emission points. In this set up, the treatment of terrain within AERMOD is considered to provide a less realistic simulation of the impacts associated with plume impaction.

With specific reference to flare emissions, only the ADMS model allows direct user input of the plume buoyancy flux (Fb) and momentum flux (Fm) parameters. These provide more accurate parameterisation and treatment of flare emissions, whereas AERMOD is constrained to the use of pseudo-point source approaches, making arbitrary assumptions regarding discharge temperature and velocity. The limitations of imposing the arbitrary assumptions made in the latter approach have been highlighted in Boger et al (2013)[9].

Finally, ADMS is the only model capable of taking into account the potential effects of wind turbines on plume dispersion. Concerns have previously been expressed of the impact of Little Raith Wind Farm on emissions from FEP.

[7] Wiggs, G.F.S.; Bullard, J.E.; Garvey, B. and Castro, I., 2002. 'Interactions between Airflow and Valley Topography with Implications for Aeolian Sediment Transport' Phys. Geogr. 23, 366-380.

[8] Mason, P.J., 1987. 'Diurnal Variations in Flow over a Succession of Ridges and Valleys' Q. J. R. Meteorol. Soc. 113, 1117-1140

[9] Boger, W. et al., 2013 'Comparison of Flare Dispersion Modeling Methodologies and Current Flare Technologies' presented at the 2013 Air & Waste Management Association Speciality Conference Guideline on Air Quality Models: The Path Forward, 19-21 March 2013, Raleigh.

2.2 Emission scenarios

The assessment considers two emission scenarios for the current and proposed operation of the flare system at FEP:

- Assessment of impacts during normal operation of FEP; and
- Assessment of a more conservative flaring event emissions scenario, considering the impacts on air quality during a process gas compressor (PGC) trip.

During normal operation of FEP, based on actual flaring data during the period 2013-2020, base-load flaring rates averaged 0.11 T h^{-1} for the elevated flare and 0.67 T h^{-1} for the ground flares.

For the first five minutes of a PGC trip, peak instantaneous flaring rates can increase to 200 T h^{-1}, although a more typical rate until the plant can be re-configured in 'safepark' mode is 130 T h^{-1}. For the purposes of this assessment, two sub-scenarios are considered for the flaring event scenario:

- An assessment of impact during a PGC trip assuming flaring occurs at the instantaneous peak rate of 200 T h^{-1} continuously over the course of the year; and
- An assessment of impact during a PGC trip assuming flaring occurs at the more typical peak rate of 130 T h^{-1} continuously over the course of the year.

It should be strongly emphasised that, in actual operation, flaring would not occur at this rate continuously throughout the year. This is a conservative assumption introduced to the modelling to address potential model uncertainty, ensuring that the model prediction is robust, if not overly pessimistic, particularly for long-term, annual mean impacts.

Owing to the interlinked nature of the FEP and FNGL plant, and to allow a more accurate prediction of the total predicted environmental concentration (PEC), in addition to FEP emission sources, the FNGL plant furnace stacks and flares have also been included within the model with their emissions modelled under a normal operational scenario.

The assessment considers emissions of the following pollutants:

- Oxides of nitrogen as nitrogen dioxide (NO_x as NO_2);
- Sulphur dioxide (SO_2);
- Carbon monoxide (CO);
- Particulate matter with an aerodynamic diameter < 10 µm (PM_{10})[10];
- Particulate matter with an aerodynamic diameter < 2.5 µm ($PM_{2.5}$)[10];
- Unburnt hydrocarbons (UHCs)[11]; and
- Benzene, toluene, ethyl benzene and xylene (BTEX)[12].

[10] As a conservative approach, it is assumed all particulate matter is emitted in the $PM_{2.5}$ fraction
[11] UHCs have been modelled as n-butane in order to allow comparison against the n-butane environmental assessment level (EAL); this likely being the most significant hydrocarbon in the various process streams for which an EAL is available
[12] As benzene has the lowest air quality standard of any pollutant within this group, BTEX is assumed to be emitted as benzene and compared against the benzene air quality standards

2.3 Emission parameters

Emissions during normal operation of FEP have been modelled based on the average 2013-2020 base-load flaring rate and the average 2014-2020 reported emissions from the non-flare release points as supplied by EMCL. Base-load flaring composition and other process parameters for the non-flare release points (e.g., discharge temperatures, flows etc) have been taken from the 2019 study, based on actual operational data. Base-load flare emission parameters for input to the model have been calculated from the flaring rate and gas composition using the methodology described in Appendix A.

Emissions from the FEP elevated flare and ground flares during a PGC trip have been modelled based on the flaring rate and gas composition provided by EMCL, with emissions from the other non-flare release points modified from their normal operating parameters to reflect any change in operation during a PGC trip, e.g., loads increased or reduced etc.

In the existing flare system, gas to flare preferentially goes to the Shell ground flares by design but, during a large flux, such as a PGC trip scenario, the seal height at the elevated seal drum would be exceeded, back pressure would increase and any flow beyond the capacity of the ground flares would go to elevated flare. Using a conservative combined ground flare capacity of ~ 45 T h^{-1} (design basis is ~55T h^{-1}), this would result in 155 T h^{-1} of gas being routed to the elevated flare in the instantaneous peak scenario, and 85 T h^{-1} of gas being routed to the elevated flare in the typical peak scenario.

With the proposed flare system, and following introduction of the new EGF, the ground flare capacity will increase to 130 T h^{-1}. As such, in the instantaneous peak scenario, the volume of gas routed to the elevated flare will reduce to 70 T h^{-1}, whilst no gas would be routed to the elevated flare in the typical peak scenario.

Emissions from the FNGL plant furnaces have been modelled on the assumption that they are discharging to air at the respective emission limit value in the FNGL plant PPC Permit, whilst the quantities of gas flared have been obtained from the summary provided by SEPA of FNGL flaring events during the period 2008-2017[13]. These have been converted to an equivalent base-load flaring rate by distributing the annual mass of gas flared uniformly over the year.

Point (non-flare) sources

Normal operation

Table 2.1 provides the model input data for the point source releases from the FEP and FNGL plant during normal operation.

[13] SEPA (2018) 'Shell UK Natural Gas Liquids (NGL) Plant, Mossmorran Flaring Events – Summary 2008 to 2017' [online] https://www.sepa.org.uk/media/368364/shell-flaring-events-summary-2008-2017.pdf

Table 2.1 Model input data for point source emissions to air (normal operation)

Source	X/Y	Stack Height (m)	Stack Diam. (m)	Efflux Temp. (°C)	Efflux Velocity (m/s)	SO_2 (g s^{-1})	NO_x (g s^{-1})	PM (g s^{-1})	CO (g s^{-1})	BTEX (g s^{-1})
FEP Emission Sources										
Furnace No. 1	318585, 689849	61	2.0	150	13.3	---	3.37	0.05	0.42	---
Furnace No. 2	318565, 689928	61	2.0	150	13.3	---	3.37	0.05	0.42	---
Furnace No. 3	318573, 689844	61	2.0	150	13.3	---	3.37	0.05	0.42	---
Furnace No. 4	318549, 689924	61	2.0	150	13.3	---	3.37	0.05	0.42	---
Furnace No. 5	318558, 689839	61	2.0	150	13.3	---	3.37	0.05	0.42	---
Furnace No. 6	318533, 689916	61	2.0	150	13.3	---	3.37	0.05	0.42	---
Furnace No.7	318539, 689834	61	2.0	135	10.6	---	3.37	0.05	0.42	---
Boiler Z-SG-01 A	318567, 690050	25	1.6	170	10.5	0.21	2.28	0.07	0.03	---
Boiler Z-SG-01 B	318563, 690062	25	1.6	170	10.5	0.21	2.28	0.07	0.03	---
Boiler Z-SG-01 C	318562, 690072	25	1.6	170	10.5	0.21	2.28	0.07	0.03	---
Caustic Oxidiser Vent	318644, 690110	12	0.1	80	47.0	---	---	---	---	0.41
Gas Turbine Dump Stack	318596, 689948	30	3.0	345	7.0	---	3.78	0.05	1.33	---
FNGL Plant Emission Sources										
Furnace 1	319438, 690506	48	2.4	130	6.1	0.02	2.48	---	1.65	---
Furnace 2	319529, 690537	48	2.4	130	6.3	0.02	2.48	---	1.65	---
Furnace 3	319617, 690567	48	2.4	130	6.3	0.02	2.48	---	1.65	---

Operation during PGC trip

During a PGC trip, two of the seven FEP furnaces will immediately reduce from 100% load to 15% load with the load on the other five furnaces ramping down from 100% load to 80% load. All three boilers will increase from 30% maximum continuous rating (MCR) to 100% MCR as the loss of steam from the furnaces takes effect. The gas turbine will reduce from 100% to 70% load.

EMCL has confirmed that normal operations at the FNGL plant would continue during a PGC trip.

Table 2.2 provides the model input data for the point source releases from the FEP and FNGL plant during a PGC trip.

Table 2.2 Model input data for point source emissions to air (PGC trip scenario)

Source	X/Y	Stack Height (m)	Stack Diam. (m)	Efflux Temp. (°C)	Efflux Velocity (m/s)	SO_2 (g s^{-1})	NO_x (g s^{-1})	PM (g s^{-1})	CO (g s^{-1})	BTEX (g s^{-1})
FEP Emission Sources										
Furnace No. 1	318585, 689849	61	2.0	150	2.0	---	0.51	0.01	0.06	---
Furnace No. 2	318565, 689928	61	2.0	150	2.0	---	0.51	0.01	0.06	---
Furnace No. 3	318573, 689844	61	2.0	150	10.7	---	2.70	0.04	0.33	---
Furnace No. 4	318549, 689924	61	2.0	150	10.7	---	2.70	0.04	0.33	---
Furnace No. 5	318558, 689839	61	2.0	150	10.7	---	2.70	0.04	0.33	---
Furnace No. 6	318533, 689916	61	2.0	150	10.7	---	2.70	0.04	0.33	---
Furnace No.7	318539, 689834	61	2.0	135	8.5	---	2.70	0.04	0.33	---
Boiler Z-SG-01 A	318567, 690050	25	1.6	170	35.1	0.71	7.60	0.22	0.11	---
Boiler Z-SG-01 B	318563, 690062	25	1.6	170	35.1	0.71	7.60	0.22	0.11	---
Boiler Z-SG-01 C	318562, 690072	25	1.6	170	35.1	0.71	7.60	0.22	0.11	---
Caustic Oxidiser Vent	318644, 690110	12	0.1	80	47.0	---	---	---	---	0.41
Gas Turbine Dump Stack	318596, 689948	30	3.0	345	5.0	---	2.65	0.03	0.93	---

Source	X/Y	Stack Height (m)	Stack Diam. (m)	Efflux Temp. (°C)	Efflux Velocity (m/s)	SO_2 (g s^{-1})	NO_x (g s^{-1})	PM (g s^{-1})	CO (g s^{-1})	BTEX (g s^{-1})
FNGL Plant Emission Sources										
Furnace 1	319438, 690506	48	2.4	130	6.1	0.02	2.48	---	1.65	---
Furnace 2	319529, 690537	48	2.4	130	6.3	0.02	2.48	---	1.65	---
Furnace 3	319617, 690567	48	2.4	130	6.3	0.02	2.48	---	1.65	---

Flare sources

Elevated flares

The FEP and FNGL elevated flares are open, candle-type flares and, as such, certain modifications need to be made to a conventional point source modelling approach to account for the presence and behaviour of the open flame. Importantly, dispersion models cannot be applied to the flaming region, only to the buoyant plume above the flame.

Consequently, methods are required to estimate the length of the flame, which is affected by several variables including, flare gas mass flow and composition, combustion efficiency and wind speed. Furthermore, unlike a conventional point source, heat from a flare is released in two forms – sensible heat and radiative heat. Only the sensible heat component has an influence on plume buoyancy and, consequently, the fraction of heat radiated must be accounted for. Additionally, varying wind speed and direction will affect flame tilt which influences the height above ground level and downwind distance at which the start of the buoyant plume region (and, hence, dispersion of emissions) occurs.

None of these factors can be replicated using a conventional point source approach, where the initial release conditions are parameterised solely through the physical stack height and location, and discharge temperature and velocity. As a result, various methods have been proposed, primarily by state regulatory bodies in the United States and Canada, to define equivalent source parameters that allow flares to be included in regulatory approved dispersion models (e.g. Ohio EPA, 2003[14]; Iowa DNR, 2013[15]).

Despite the wide use of these methods, formal evaluation of their predictions in the context of actual observed data has rarely been undertaken. Most studies to date, such as Boger and Kanchan (2012)[16], have performed simple comparative analysis of predictions from the various methods without reference to observed data. Furthermore, many of these methods make arbitrary assumptions with regard to discharge velocity and temperature or make assumptions that can no longer be considered relevant for modern flare technology (Boger et al., 2013).

[14] Ohio EPA, 2003. 'Engineering Guide # 63 Air Dispersion Modelling Guidance' [Online] Available: http://books5.net/o/ohio-epa-division-of-air-pollution-control-engineering-guide-69-w4865-book.html

[15] Iowa DNR. (2012) 'Modeling Flares' [Online] Available: http://www.iowadnr.gov/portals/idnr/uploads/air/insidednr/dispmodel/flares.pdf

[16] Boger, W. and Kanchan, A., 2012. 'Comparative Study of Flare Dispersion Modeling Methodologies' presented at the 2012 Annual Conference of the Air & Waste Management Association, 19-22 June 2012, San Antonio.

Consequently, Wood has developed a method which aims to overcome the limitations of these methods and evaluated the predictions from this method and other alternative methods against monitored ambient data collected around a UK refinery (Clegg, 2017)[17]. The detailed Wood flare modelling methodology and results of the evaluation study are presented in Appendix A, with a summary of the method provided below:

- Key release parameters primarily determined by the net heat release;
- Combustion efficiency and fraction of heat radiated determined by the composition of gas being flared and process conditions;
- Uses the plume buoyancy flux (F_b) and momentum flux (F_m) parameters as model input parameters instead of discharge temperature and velocity;
- Calculates crosswind effects on flame tilt and, hence, effective release height and downwind position of the flame;
- Effective release co-ordinates determined by the shift in downwind position of the flame and the wind direction;
- Flare input parameters varied hour-by-hour to take account of changes in meteorology and process conditions:
  - Wood commissioned Cambridge Environmental Research Consultants, the developers of ADMS, to produce a branch version of ADMS which expands the number of input parameters that can be entered in a time-varying emissions file; and
  - These expanded capabilities are now included in the general release version of ADMS 5.2.

The flare mass flow rate and composition used in the calculation of the effective flare emission parameters for the normal operational scenario and PGC trip scenarios are provided in Appendix B. The physical stack parameters for the elevated flares are provided in Table 2.3.

Table 2.3 Physical stack parameters for FEP and FNGL elevated flares

Source	X/Y	Stack Height (m)	Stack Diameter (m)
FEP elevated flare	318760, 690190	100	1.98
FNGL elevated flares	318565, 689928	80	0.76

Ground flares

Unlike the elevated flares, the ground flares are surrounded by a flame radiation shroud which allows greater protection from cross winds and more control over combustion conditions. Emission parameters from the ground flares are calculated using a similar approach to the elevated flares but with the following conditions imposed:

- The combustion efficiency is increased from 98% to 99.9% (based on experience with other EGFs) to reflect the improved control over combustion conditions;
- The fraction of heat radiated is reduced to 5% to take in to account the enclosed nature and presence of the flame radiation shroud;

[17] Clegg, A., 2017. 'An Alternative Method for Modelling Flare Emissions' Presentation at the IAQM Dispersion Modellers User Group meeting, London, 6th April 2017

- The release height and diameter are set to the physical height and diameter of the flare enclosure; and
- The buoyant plume momentum flux is calculated at the height of the top of the flare enclosure.

The physical stack parameters for the ground flares are provided in Table 2.4.

Table 2.4 Physical stack parameters for ground flares

Source	X/Y	Stack Height (m)	Stack Diameter (m)
7005-A (existing ground flare)	319000, 690360	8.4	12.7[A]
7005-B (existing ground flare)	318960, 690320	8.4	12.7[A]
New EMCL enclosed ground flare	318854, 690106	31	18.3

[A] Effective diameter (polygonal source)

Derivation of flare emission rates

As it is not possible to monitor emissions from flares using conventional stack emissions monitoring techniques for safety reasons, emission rates of pollutants from the flares are calculated using emission factors provided by CONCAWE (2017)[18] and US EPA (2015)[19]. These emission factors express the mass of pollutant emitted per unit energy of fuel input. The emission factors used are summarised in Table 2.5.

Table 2.5 Flare emission factors

Pollutant	Emission factor (g MJ^{-1})	Source
NO_x	0.029	CONCAWE (2017)
CO	0.133	CONCAWE (2017)
PM (non-smoking flame)	0	US EPA (2015)
PM (lightly smoking flame)	0.012	US EPA (2015)
PM (average smoking flame)	0.052	US EPA (2015)
PM (heavily smoking flame)	0.082	US EPA (2015)

As noted in Table 2.5, US EPA (2015) provides different PM emission factors dependent upon how smoky the flare is. The level of smoke generated by a flare is dependent upon several factors but is strongly influenced by the mass flow rate to the flare and the degree of steam injection.

Smokeless combustion of the FEP flares is available up to a flaring rate of 190 T h^{-1}. However, if steam header pressure is compromised, steam availability to the flare can be reduced causing the flare to be smoky. For the purposes of this assessment, it is assumed that base-load flaring from the elevated flare, and operation of the ground flares for all cases, results in a non-smoking flame. However, as a worst-case assumption for both

[18] CONCAWE, 2017. 'Air pollutant emission estimation methods for E-PRTR reporting by refineries' Report no. 4/17

[19] US EPA, 2015. 'Emission Estimation Protocol for Petroleum Refineries' Version 3, April 2015.

PGC trip scenarios, it is assumed a heavily smoking flame occurs for the FEP elevated flare with the current flare system, but a non-smoking flare for the proposed flare system due to the reduced volume of gas sent to the elevated flare.

VOC emission rates from the flares are predominantly in the form of unburnt hydrocarbons (UHCs) remaining after combustion. UHC emission rates are calculated on a mass balance approach based on the hydrocarbon content of the gas to flare and the combustion efficiency.

$$E_{UHC} = (1 - \varepsilon)\dot{m}_{HC}$$

Where:

E_{UHC} = flare emission rate of UHCs (g s^{-1})

ε = fractional combustion efficiency (dimensionless)

$\dot{m}_{HC}$ = mass flow of hydrocarbons to the flare (g s^{-1})

Emission rates of individual UHC components, e.g., benzene, are calculated using a similar approach based on the mass fraction of the individual component in the flare feed.

Summary of flare emission parameters

Table 2.6 and 2.7 provides a summary of the modelled flare emission parameters for the various emission scenarios for the current flare system and proposed flare system.

Table 2.6 Summary model input data for the flares (current flare system)

Source	X/Y	Eff. Release Height (m)	Eff Stack Diam. (m)	F_b (MW)	F_m (m^4 s^{-2})	NO_x (g s^{-1})	PM (g s^{-1})	CO (g s^{-1})	UHC (g s^{-1})	BTEX (g s^{-1})
Normal operation										
FEP elevated flare	Variable	Variable	Variable	1.0	Variable	0.05	---	0.21	0.37	---
FNGL elevated flares	Variable	Variable	Variable	1.9	Variable	0.11	---	0.50	1.24	---
7005-A [a]	319000, 690360	8.4	12.7	4.4	10	0.13	---	0.61	0.07	---
7005-B [a]	318960, 690320	8.4	12.7	4.4	10	0.13	---	0.61	0.07	---
PGC trip (typical peak flaring rate)										
FEP elevated flare	Variable	Variable	Variable	795	Variable	34.3	96.0	156.3	334.7	15.6
FNGL elevated flares	Variable	Variable	Variable	1.9	Variable	0.11	---	0.50	1.24	---

Source	X/Y	Eff. Release Height (m)	Eff Stack Diam. (m)	F_b (MW)	F_m (m^4 s^{-2})	NO_x (g s^{-1})	PM (g s^{-1})	CO (g s^{-1})	UHC (g s^{-1})	BTEX (g s^{-1})
7005-A	319000, 690360	8.4	12.7	295	1851	9.1	---	41.4	5.9	0.3
7005-B	318960, 690320	8.4	12.7	295	1851	9.1	---	41.4	5.9	0.3
PGC trip (instantaneous peak flaring rate)										
FEP elevated flare	Variable	Variable	Variable	1,462	Variable	62.6	175.0	285.0	610	28.4
FNGL elevated flares	Variable	Variable	Variable	1.9	Variable	0.11	---	0.50	1.24	---
7005-A	319000, 690360	8.4	12.7	295	1851	9.1	---	41.4	5.9	0.3
7005-B	318960, 690320	8.4	12.7	295	1851	9.1	---	41.4	5.9	0.3

Table 2.7 Summary model input data for the flares (proposed flare system)

Source	X/Y	Eff. Release Height (m)	Eff Stack Diam. (m)	F_b (MW)	F_m (m^4 s^{-2})	NO_x (g s^{-1})	PM (g s^{-1})	CO (g s^{-1})	UHC (g s^{-1})	BTEX (g s^{-1})
Normal operation										
FEP elevated flare	Variable	Variable	Variable	1.0	Variable	0.05	---	0.21	0.37	---
FNGL elevated flares	Variable	Variable	Variable	1.9	Variable	0.11	---	0.50	1.24	---
New EGF	318854, 690106	31	18.3	8.7	16	0.27	---	1.22	0.14	
PGC trip (typical peak flaring rate)										
FNGL elevated flares	Variable	Variable	Variable	1.9	Variable	0.11	---	0.50	1.24	---
New EGF	319000, 690360	31	18.3	1,705	38,997	52.5	---	239.0	34.1	1.6

Source	X/Y	Eff. Release Height (m)	Eff Stack Diam. (m)	F_b (MW)	F_m (m^4 s^{-2})	NO_x (g s^{-1})	PM (g s^{-1})	CO (g s^{-1})	UHC (g s^{-1})	BTEX (g s^{-1})
PGC trip (instantaneous peak flaring rate)										
FEP elevated flare	Variable	Variable	Variable	653	Variable	28.3	---	128.7	275.6	12.8
FNGL elevated flares	Variable	Variable	Variable	1.9	Variable	0.11	---	0.50	1.24	---
New EGF	319000, 690360	31	18.3	1,705	38,997	52.5	---	239.0	34.1	1.6

2.4 Fugitive emissions

Fugitive emissions from e.g., leaks from flanges, compressor seals etc., have not been considered in this assessment. The assessment aims to identify the potential air quality impacts resulting from the **change** in operation of the flare system at FEP. Fugitive emissions are unlikely to change by any meaningful extent as a result of the flare system changes. Furthermore, the 'type' of emissions discharged from the flares, i.e., products of combustion, are materially different than fugitive emissions, which primarily comprise different hydrocarbon products or other raw materials.

Furthermore, due to the inherent uncertainty of fugitive emissions modelling, requiring the use of a volume source approach (at in installation typical of that such as FEP, there can be well over 100,000 individual potential sources of fugitive emissions), the predictions from fugitive emission models are associated with a significant level of uncertainty. For example, when Wood compared modelled fugitive emission data and monitored ambient data at an UK refinery, there was an order of magnitude difference between the over-estimated modelled result and the actual monitored value.

2.5 Meteorology

For meteorological data to be suitable for dispersion modelling purposes, several meteorological parameters need to be measured on an hourly basis. These parameters include wind speed, wind direction, cloud cover and temperature. There are only a limited number of sites where the required meteorological measurements are made. The year of meteorological data that is used for a modelling assessment can also have a significant effect on ground level concentrations.

The nearest and most suitable meteorological station to the site is located at Edinburgh airport, approximately 15 km to the south west of the site. Data from this station between 2014 and 2018 inclusive have been used in this assessment to take account of inter-year variations in prevailing meteorological conditions and, hence, ground level concentrations. The composite wind rose for the 2014-2018 period is provided as Figure 2.1. The meteorological data show a predominantly south-westerly wind direction.

Gaussian plume models, such as ADMS, cannot, as standard, model calm weather conditions, since this results in a discontinuity produced by a 'divide by zero' calculation. Most Gaussian plume models simply skip lines of meteorological data where calm conditions occur (defined where the wind speed at 10 m is less than 0.75 m s^{-1}). Met lines will also be skipped where any of the required meteorological input parameters are missing. If there are a significant number of calm conditions or missing data, this can result in an equally

significant number of met lines being discounted and an unrepresentative prediction of modelled impact, particularly for annual mean or percentile-based concentrations.

Table 2.8 details the number of hours of meteorological data used for each year and expresses these as a percentage of the total hours in the dataset.

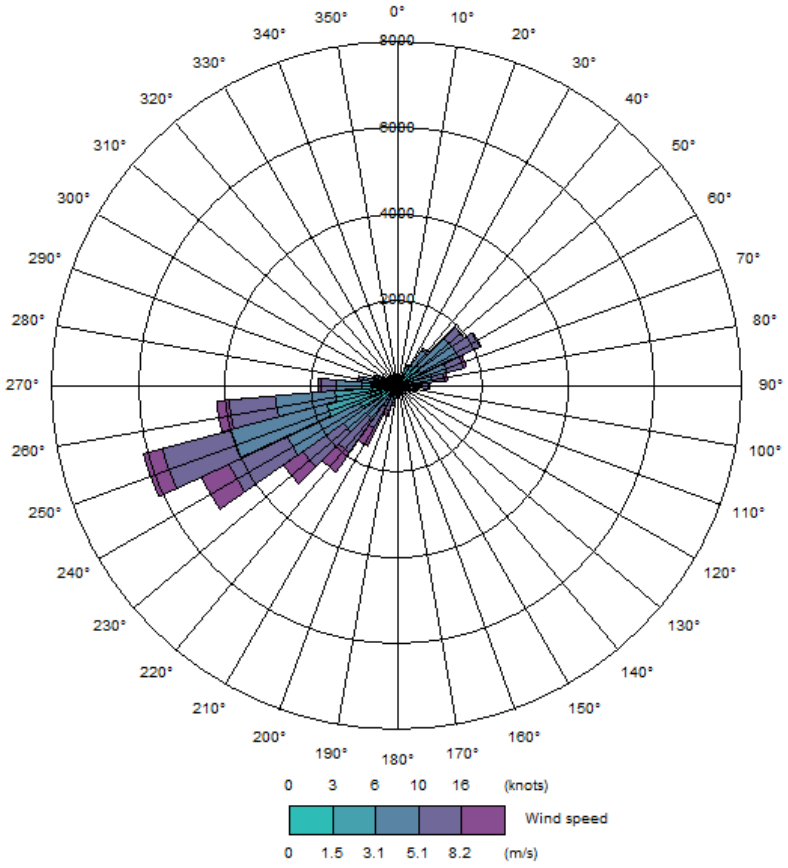
Table 2.8 Number of met lines with calm conditions, inadequate data and total number of hours used

Met Station/Year	Total Number of Hours Used	Number of Hours used as Percentage of Total Hours
Edinburgh 2014	8,104	93%
Edinburgh 2015	8,147	93%
Edinburgh 2016	8,105	92%
Edinburgh 2017	8,320	95%
Edinburgh 2018	8,106	93%

Table 2.8 indicates data capture from both datasets is within the generally accepted best practice guideline of ensuring no more than 10% of met lines are excluded from the assessment.

ADMS does possess an additional sub-routine, allowing estimates of modelled contributions during calm conditions to be made. However, validation of this method of calculating concentrations has never been carried out and, consequently, this sub-routine was not used as part of the model runs.

Figure 2.1 Edinburgh 2014-2018 composite wind rose



2.6 Model domain and receptors

Model domain

In addition to specific human receptor locations, a 10 km x 10 km Cartesian grid, centred on the centre of the site, with a receptor resolution of 100 m, was modelled to assess the impact of emissions on local air quality. This resolution is considered suitable for capturing the maximum process contribution from site emissions and is within the generally accepted best practice guideline of adopting a model domain with a receptor resolution less than 1.5 times the stack height, with the FEP elevated flare (100 m in height) being the primary stack of interest in this assessment.

Human receptors

Guidance from the UK Government and Devolved Administrations in LAQM.TG16[20] makes it clear that exceedances of the human health-based objectives should only be assessed at outdoor locations where members of the general public are regularly present over the averaging time of the objective. Table 2.9 provides an indication of those locations that may be relevant for different averaging periods.

[20] Defra and the Devolved Administrations, 2016. 'Local Air Quality Technical Guidance LAQM.TG16'

Table 2.9 Typical examples of relevant exposure for different averaging periods

Averaging period	Objectives should apply	Objectives should not apply
Annual mean	All locations where members of the public might be regularly exposed. Building facades of residential properties, schools, hospitals, care homes etc.	Building facades of offices or other places of work where members of the public do not have regular access. Hotels, unless people live there as their permanent residence. 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
24-hour mean and 8-hour mean	All locations where the annual mean objectives 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 objectives would apply. Kerbside sites (e.g. pavements of busy shopping streets). Those parts of car parks, bus stations and railway stations etc. which are not fully enclosed, where the public might reasonably be expected to spend one hour or more. Any outdoor locations at which the public may be expected to spend one hour or longer.	Kerbside sites where the public would not be expected to have regular access
15-min mean	All locations where members of the public might reasonably be expected to spend a period of 15 minutes or longer	

The human receptors considered in this assessment were chosen based on the above guidance by identifying places where people may be located, judged in terms of the likely duration of their exposure to pollutants and proximity to the site.

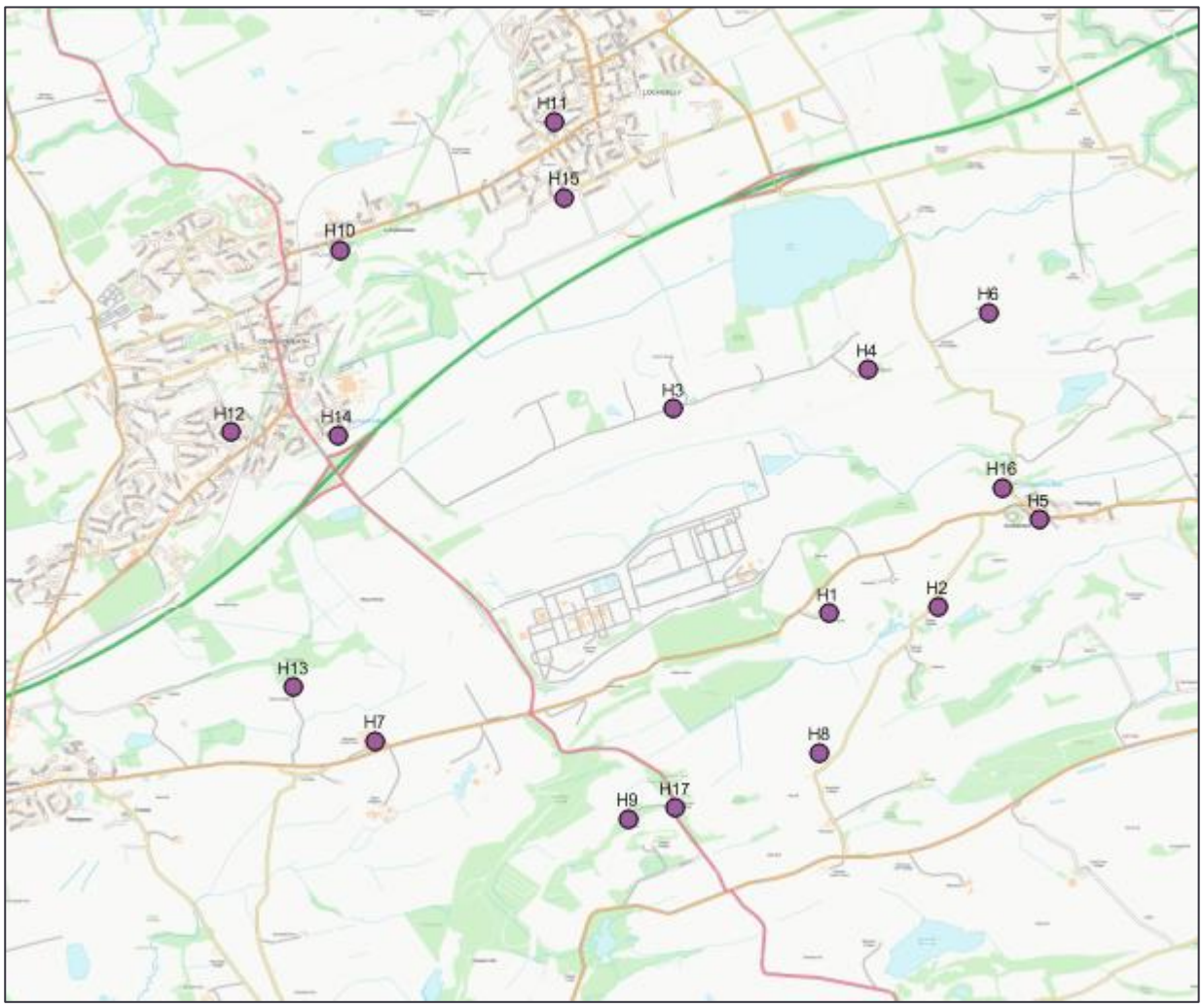
Workplace locations where there is no access for the general public (i.e., those members of the public other than the workforce) have been excluded from the assessment in accordance with Schedule 1, Part 1, Paragraph 2 of the Air Quality Standards Regulations 2010. It is important to note that these Regulations do not differentiate between whether this is a workplace location under the control of the operator or an off-site workplace location.

Details of the receptors considered are provided in Table 2.10 and Figure 2.2. It should be noted that this list of receptors is by no means exhaustive, with certain receptors grouped together to represent exposure over a wider area, rather than at specific residential properties, for example.

Table 2.10 Location of modelled human receptors

ID	Receptor Name	Easting (m)	Northing (m)
H1	Newton Farm	320320	689970
H2	Kirkton Cottages	321076	690016
H3	Easter Lochead	319252	691385
H4	Little Raith Farm	320590	691656
H5	Auchertool School	321775	690621
H6	Glenniston	321432	692051
H7	Moss Bank Farm	317193	689090
H8	Bankhead	320262	689008
H9	Cullaloe	318936	688554
H10	Cowdenbeath School	316948	692487
H11	Lochgelly School	318421	693367
H12	Cowdenbeath School 2	316189	691223
H13	Heath/Ivy/Beech Cottages	316626	689463
H14	Cowdenbeath Properties	316928	691202
H15	Lochgelly Properties	318501	692848
H16	Camilla Properties	321523	690842
H17	Beechwood Cottage	319263	688627

Figure 2.2 Modelled human receptors



Ecological receptors

SEPA's Horizontal Guidance Note H1 requires detailed dispersion modelling to be carried out to assess effects upon local ecological receptors. Using this guidance, Natura 2000 sites (i.e., SPAs, SACs, Ramsar sites within 10 km of FEP, and other designated ecological sites within 2 km of FEP (e.g., SSSIs, LNRs, ancient woodland etc.,) have been assessed. However, where receptors are designated solely based on geological features of interest, these receptors have been excluded from the assessment since critical levels and loads are only prescribed for vegetation and ecosystems.

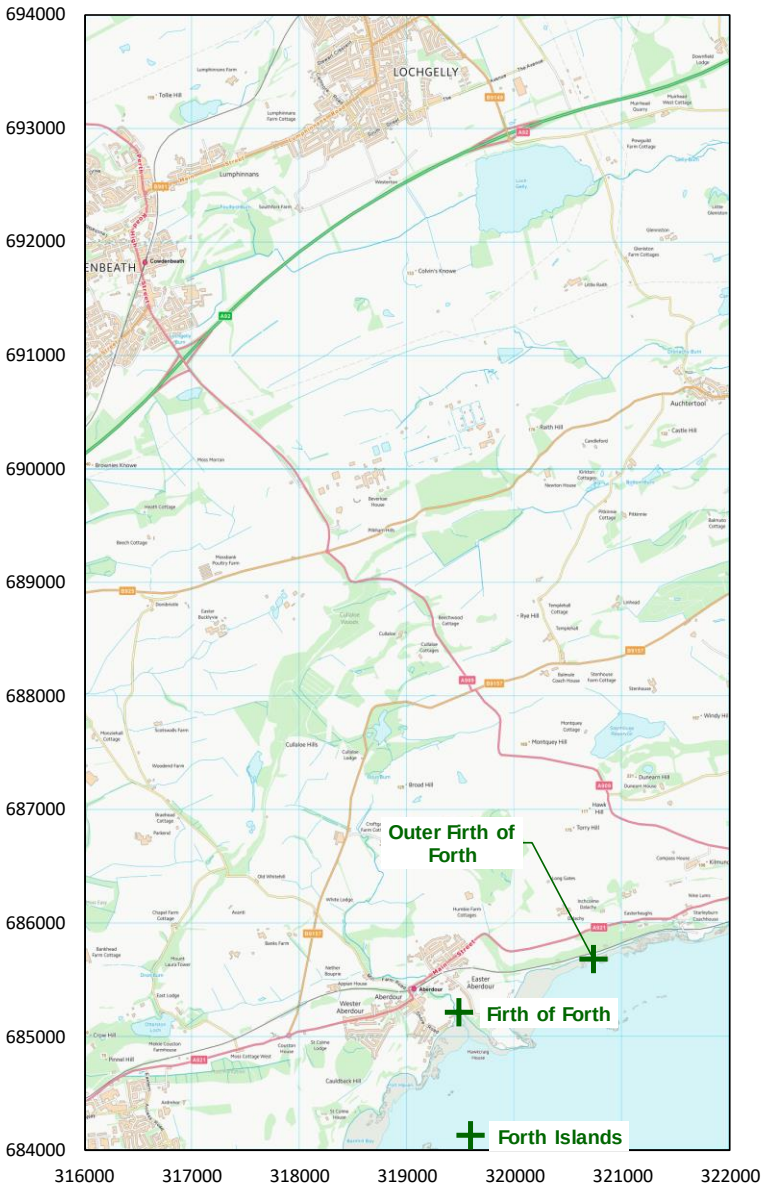
Where designated sites cover a large area but are situated a large enough distance from the installation (generally >2 km), a single receptor point corresponding to the closest point of any part of the designated area to the installation has been input to the model.

Table 2.11 and Figure 2.3 detail the ecological receptors assessed in this study.

Table 2.11 Location of modelled ecological receptors

ID	Receptor name	Easting (m)	Northing (m)	Approx. distance from FEP (km)
E1	Firth of Forth SPA/Ramsar	319486	685208	4.7
E2	Outer Firth of Forth and St Andrews Bay Complex SPA	320742	685672	4.7
E3	Forth Islands SPA	319590	319590	7.6

Figure 2.3 Modelled ecological receptors



2.7 Buildings

Atmospheric flow is disrupted by aerodynamic forces in the immediate vicinity of structures. These disruptions generate an area of stagnation behind the structure known as the cavity region. The flow within this region is highly turbulent and can be visualised as circulating eddies of air. The area beyond the cavity region is known as the building wake, where turbulence generated by the structure gradually decays to background levels. The entire area covered by the cavity region and turbulent wake is known as the 'building envelope'.

The above phenomena can cause a plume to be drawn downwards towards the ground in the building envelope, resulting in elevated ground level concentrations; this effect is known as building induced downwash. The building envelope is generally regarded as extending to a height of three times the height of the structure in the vertical plane, and a distance of 5L (where L is the lesser of the building width or height) from the foot of the building in the horizontal plane. Thus, stacks within these extents should be identified and the corresponding building included in the dispersion model.

Using these criteria, relevant buildings or large lattice steel structures/pipework have been included in the assessment as necessary. However, as ADMS agglomerates individual buildings into a single, effective building, on large, complex sites, including many buildings in the model can result in an artificially large effective building with resultant consequential effects on plume dispersion. This phenomenon is discussed in LAQM.TG16 and the guidance at paragraph 7.468 is followed with respect to treatment of buildings on large industrial sites:

"Where there are a large number of buildings in the vicinity of stack source, those closest (and often tallest) should be included and the surface roughness assumed in the model may be increased."

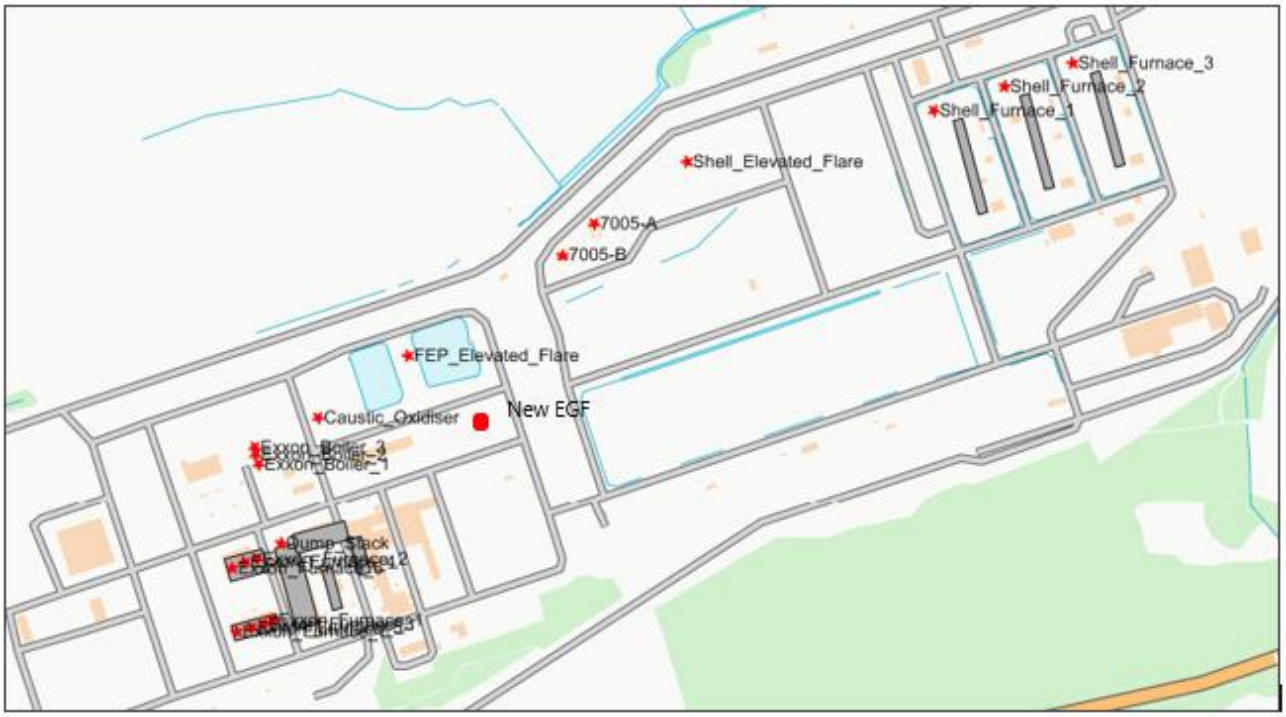
The buildings included in the model are provided in Table 2.12. Other on-site structures that have not been explicitly modelled have been indirectly represented through an increased surface roughness length of 1.5 m for all areas within the installation boundary (see section 2.8 for further discussion of surface characteristics).

The sensitivity analysis in Section 2.12 explores the model sensitivity to building-induced effects.

Table 2.12 Modelled buildings

Building/Module	X (m)	Y (m)	Height (m)	Length/Diameter (m)	Width (m)	Angle (°N)
FEP Furnace Structure 1	318616	689893	20	108	30	345
FEP Furnace Structure 2	318647	689956	15	70	25	75
FEP Refrigeration Compressor House	318698	689932	24	48	15	345
FEP Charge Gas Compressor House	318662	689889	25	53	13	345
FEP Furnace Housing A	318551	689920	40	50	30	75
FEP Furnace Housing B	318563	689840	40	60	20	75
FNGL Module 1	319485	690434	20	125	13	345
FNGL Module 2	319571	690466	20	125	13	345
FNGL Module 3	319662	690495	20	125	13	345

Figure 2.4 Visualisation of modelled buildings (grey) and emission points (red)

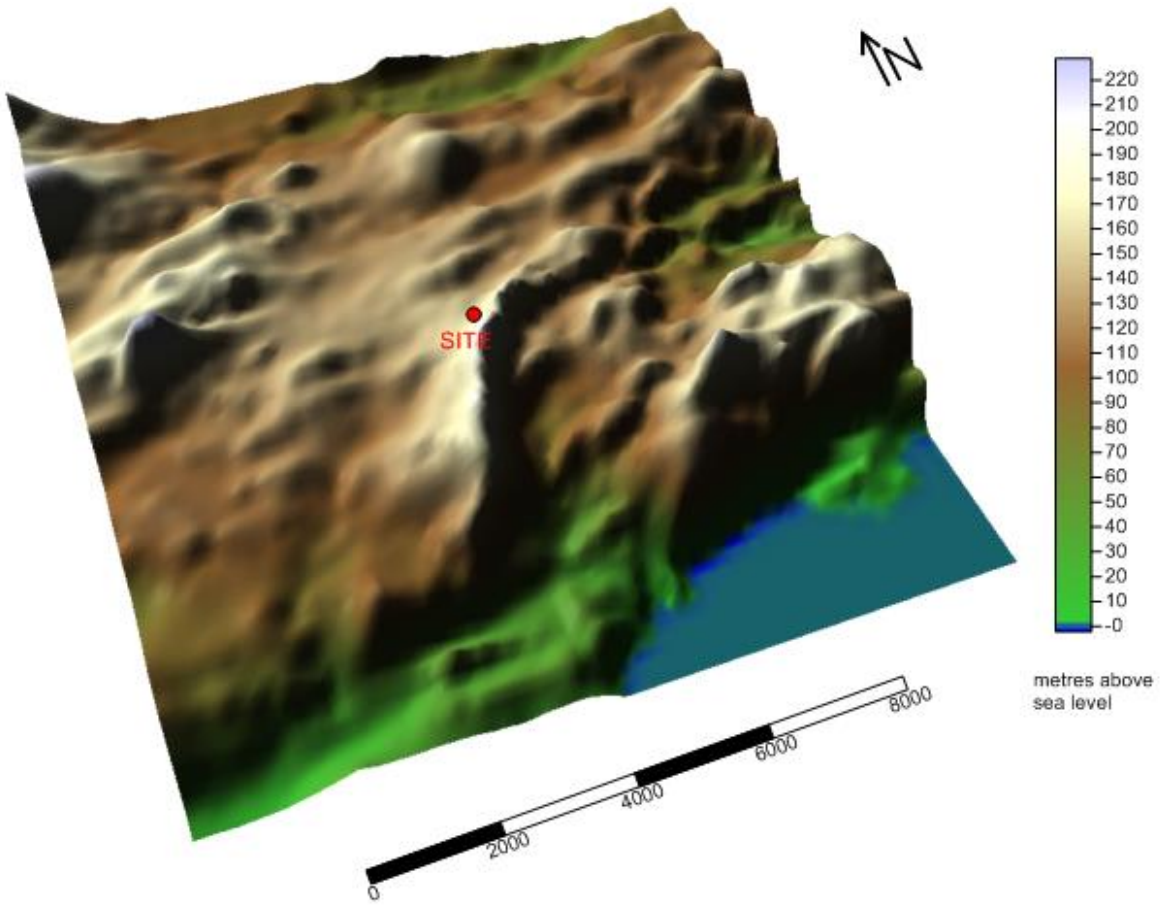


2.8 Terrain

The ground level concentrations of pollutants arising from emissions in areas of complex terrain differ from those found in simple, level terrain due to several topographical-induced effects on the three-dimensional flow and turbulent fields over the terrain. These effects are most pronounced when terrain gradients exceed 1 in 10. The terrain in the immediate vicinity of FEP (Figure 2.5) approaches or exceeds this criterion and, consequently, digitally mapped terrain data has been included in the model set up. OS Landform Panorama DTM NTF data, which has a resolution of 50 m, has been used to create the terrain file.

The sensitivity analysis in Section 2.12 explores the model sensitivity to topographical-induced effects.

Figure 2.5 Terrain within the model domain



2.9 Surface characteristics

The predominant surface characteristics and land use in a model domain have an important influence in determining turbulent fluxes and, hence, the stability of the boundary layer and subsequent dispersion. The principal parameters of interest are the surface roughness length, albedo and the modified Priestly-Taylor parameter/Bowen ratio.

Surface roughness

The surface roughness length is related to the height of surface elements; typically, the surface roughness length is approximately 10% of the height of the main surface features. Thus, it follows that surface roughness is greater in urban and congested areas than in rural and open areas. Oke (1987)[21] and CERC (2014)[22] suggest typical roughness lengths for various land use categories (Table 2.13).

[21] Oke, 1987. 'Boundary Layer Climates'.

[22] CERC, 2014. 'The Met Input Module'

Table 2.13 Typical surface roughness lengths for various land use categories

Type of Surface	Typical surface roughness length (m)
Ice	0.00001
Smooth snow	0.00005
Smooth sea	0.0001 - 0.0002
Lawn grass	0.01
Pasture	0.2
Isolated settlement (farms, trees, hedges)	0.4
Parkland, woodlands, villages, open suburbia	0.5-1.0
Forests/cities/industrialised areas	1.0-1.5
Heavily industrialised areas	1.5-2.0

Increasing surface roughness increases turbulent mixing in the lower boundary layer. With respect to elevated sources under neutral and stable conditions, conflicting impacts in terms of ground level concentrations often occur due to:

- The increased mixing can bring portions of an elevated plume down towards ground level, resulting in increased ground level concentrations closer to the emission source; however; and
- The increased mixing increases entrainment of ambient air into the plume and dilutes plume concentrations, resulting in reduced ground level concentrations further downwind from an emission source.

The overall impact on ground level concentration is, therefore, strongly correlated with the distance of a receptor from the emission source.

Surface energy budget

One of the key factors governing the generation of convective turbulence is the magnitude of the surface sensible heat flux. This, in turn, is a factor of the incoming solar radiation. However, not all solar radiation arriving at the Earth's surface is available to be emitted back to atmosphere in the form of sensible heat. By adopting a surface energy budget approach, it can be identified that, for fixed values of incoming short and long wave solar radiation, the surface sensible heat flux is inversely proportional to the surface albedo and latent heat flux.

The surface albedo is a measure of the fraction of incoming short-wave solar radiation reflected by the Earth's surface. This parameter is dependent upon surface characteristics and varies throughout the year. Oke (1987) recommends average surface albedo values of 0.6 for snow covered ground and 0.23 for non-snow covered ground, respectively.

The latent heat flux is dependent upon the amount of moisture present at the surface. The modified Priestly-Taylor parameter can be used to represent the amount of moisture available for evaporation. Areas where moisture availability is greater will experience a greater proportion of incoming solar radiation released back to atmosphere in the form of latent heat, leaving less available in the form of sensible heat and, thus,

decreasing convective turbulence. Holstag and van Ulden (1983)[23] suggest modified Priestly-Taylor parameter values of 0.45 and 1.0 for dry grassland and moist grassland respectively, whilst completely arid soil would have a modified Priestly-Taylor parameter value of 0.

Selection of appropriate surface characteristic parameters for the installation

A detailed analysis of the effects of surface characteristics on ground level concentrations by Auld *et al.* (2002)[24] led them to conclude that, with respect to uncertainty in model predictions:

"…the energy budget calculations had relatively little impact on the overall uncertainty"

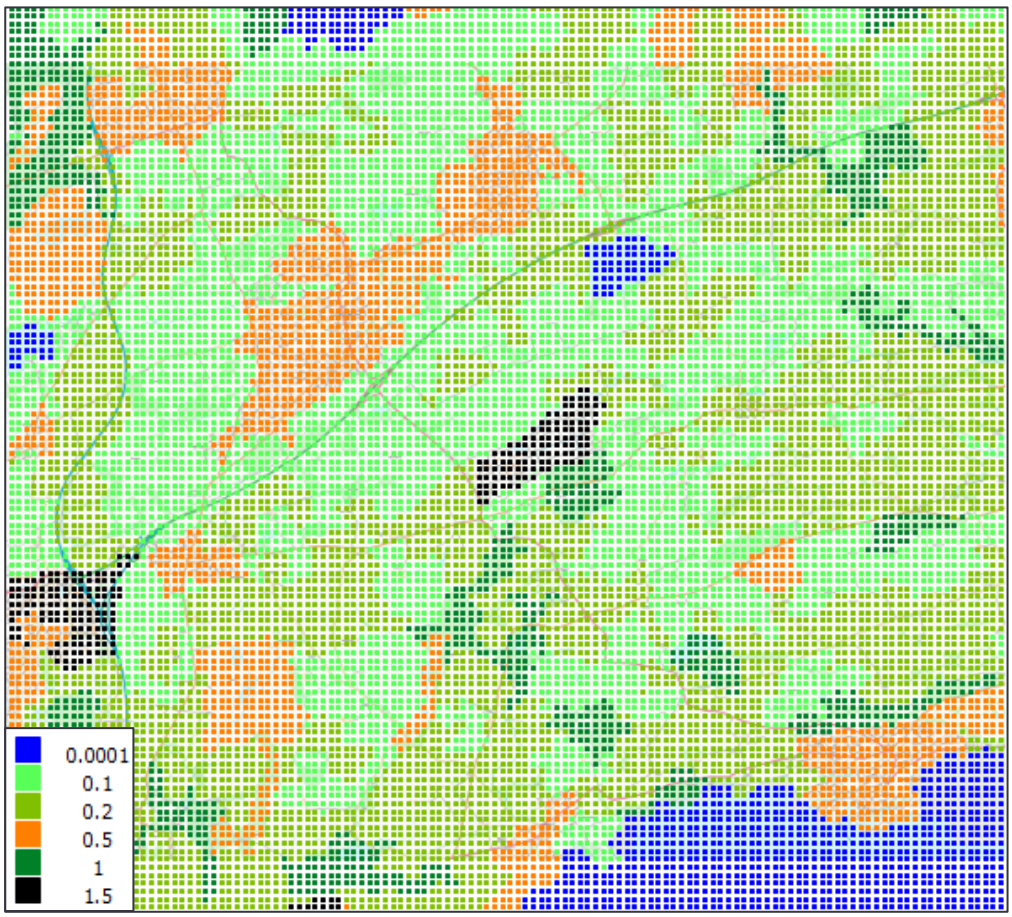
In this regard, it is not considered necessary to vary the surface energy budget parameters spatially or temporally and annual averaged values have been adopted throughout the model domain for this assessment. As snow covered ground is only likely to be present for a small fraction of the year, the surface albedo of 0.23 for non-snow-covered ground advocated by Oke (1987) has been used, whilst a value of 1 has been selected for the modified Priestly-Taylor parameter. These assumptions are consistent with the 2009 study.

The 2009 study adopted a uniform surface roughness length across the entire model domain. Since the 2009 study, ADMS has been updated to allow the use of a spatially varying surface roughness length in the model. The spatially varying surface roughness length file in this study has been developed using CORINE Land Cover (CLC) raster data published by the European Environment Agency under the Copernicus programme. The CLC dataset expresses the land use across EU countries in 44 classes at a 100 m x 100 m resolution. The CLC land use categories have been converted to an equivalent surface roughness length using Table 2.13 with Figure 2.6 providing a visualisation of the spatially varying surface roughness length used in the model.

[23] van Ulden and Holstag, 1983. 'The Stability of the Atmospheric Surface Layer during Nighttime'. American Met. Soc., 6th Symposium on Turbulence and Diffusion.

[24] Auld et al., 2002. 'Uncertainty in Deriving Dispersion Parameters from Meteorological Data'. Atmospheric Dispersion Modelling Liaison Committee (ADMLC). Annual Report 2002-2003.

Figure 2.6 Visualisation of spatially varying surface roughness length



Notes: Surface roughness length measured in metres.

2.10 Conversion of NO to NO_2

Emissions of NO_x from combustion processes are predominantly in the form of nitrogen monoxide (NO). Excess oxygen in the combustion gases and further atmospheric reactions cause the oxidation of NO to nitrogen dioxide (NO_2). NO_x chemistry in the lower troposphere is strongly interlinked in a complex chain of reactions involving volatile organic compounds (VOCs) and ozone (O_3). Two of the key reactions interlinking NO and NO_2 are detailed below:

$$NO_2 + h\nu \xrightarrow{O_2} NO + O_3 \quad \text{(R1)}$$

$$NO + O_3 \rightarrow NO_2 + O_2 \quad \text{(R2)}$$

where $h\nu$ is used to represent a photon of light energy (i.e., sunlight)

Taken together, reactions R1 and R2 produce no net change in O_3 concentrations, and NO and NO_2 adjust to establish a near steady state reaction (photo-equilibrium). However, the presence of VOCs and CO in the atmosphere offer an alternative production route of NO_2 for photolysis, allowing O_3 concentrations to increase during the day with a subsequent decrease in the NO_2:NO_x ratio.

However, at night, the photolysis of NO_2 ceases, allowing reaction R2 to promote the production of NO_2, at the expense of O_3, with a corresponding increase in the NO_2:NO_x ratio.

Near to an emission source of NO, the result is a net increase in the rate of reaction R2, suppressing O_3 concentrations immediately downwind of the source, and increasing further downwind as the concentrations of NO begin to stabilise to typical background levels.

Given the complex nature of NO_x chemistry, the Environment Agency's Air Quality Modelling and Assessment Unit (AQMAU) have adopted a pragmatic, risk-based approach in determining the conversion rate of NO to NO_2 which dispersion model practitioners can use in their detailed assessments. AQMAU guidance advises that the source term should be modelled as NO_x (as NO_2) and then suggests a tiered approach when considering ambient NO_2:NO_x ratios:

- **Screening Scenario:** 50% and 100% of the modelled NO_x process contributions should be used for short-term and long-term average concentration, respectively. That is, 50% of the predicted NO_x concentrations should be assumed to be NO_2 for short-term assessments and 100% of the predicted NO_x concentrations should be assumed to be NO_2 for long-term assessments;
- **Worst Case Scenario:** 35% and 70% of the modelled NO_x process contributions should be used for short-term and long-term average concentration, respectively. That is, 35% of the predicted NO_x concentrations should be assumed to be NO_2 for short-term assessments and 70% of the predicted NO_x concentrations should be assumed to be NO_2 for long-term assessments; and
- **Case Specific Scenario:** Operators are asked to justify their use of percentages lower than 35% for short-term and 70% for long-term assessments in their application reports.

In line with the AQMAU guidance, this assessment uses the 'Worst Case Scenario' approach in determining the conversion rate of NO to NO_2 as a robust assumption. The 'Screening Scenario' factors are only applicable for screening assessments using the H1 software tool, not once a decision has been made to progress to detailed modelling. Use of the screening scenario approach in detailed assessments, particularly the assumption of 100% conversion to NO_2 would, effectively, require perpetual darkness and a non-limiting ozone concentration, to ensure that photolysis of NO_2 does not take place (i.e. reaction R1 ceases) and that the equilibrium shifts reaction R2 to completion. These conditions, quite obviously, could not occur and their use in anything other than a basic, screening assessment, is unrealistic and overly pessimistic.

2.11 Wind turbines

Since the 2009 study, several wind farms or isolated turbines near FEP have commenced operation. The flow downwind of an operating wind turbine is reduced due to the action of the wind turbine on the flow field. This creates a turbulent wake downwind of the turbine that gradually decays to background levels with increasing downwind distance. Plumes from elevated industrial sources may interact with this wake, affecting the concentration at ground level.

ADMS contains a wind turbine module that can be activated using an additional ADMS input file (.aai) to predict the effects of plumes interacting with the turbulent wake from a single, or groups of wind turbines. ADMS is the only regulatory-approved dispersion model with this capability.

The wind turbine module considers the turbulent wake effects from individual turbines in downstream order, so that the turbulent wake from upstream wind turbines affect the flow field predicted at downstream turbines. The wake model has been validated against measured data from Tjærborg Enge, Nysted wind farm and Noordzee wind farm.

Table 2.14 provides the model input data for the wind turbines included in this study with the turbines' co-efficient of thrust (C_T) as a function of wind speed provided in Appendix C. These data have been obtained from turbine specification documents submitted with the planning applications for the wind turbines through

Fife Council's planning portal[25] and wind turbines map[26]. Where thrust co-efficient data has not been made available for a specific turbine type, generic data from a similar capacity turbine has been used.

Figure 2.7 provides a location map for the turbines in relation to FEP. Sensitivity analysis to understand the potential effects of the wind turbines on emissions from FEP is included in Section 2.12.

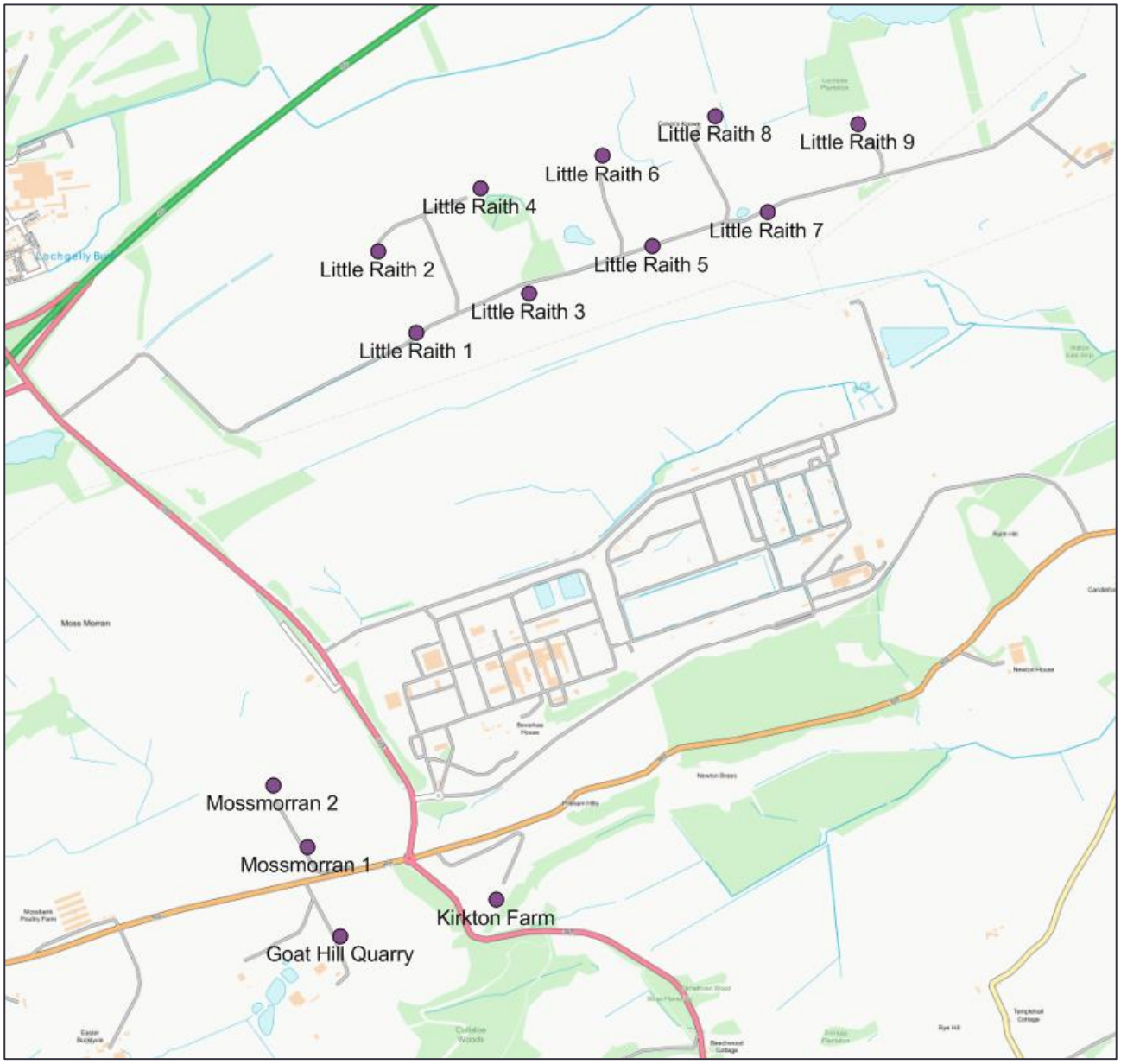
Table 2.14 Wind turbine model input data

Turbine ID	X (m)	Y (m)	Hub Height (m)	Diameter (m)
Little Raith 1	318290	691043	75	103
Little Raith 2	318159	691317	75	103
Little Raith 3	318666	691176	75	103
Little Raith 4	318503	691528	75	103
Little Raith 5	319080	691333	75	103
Little Raith 6	318916	691638	75	103
Little Raith 7	319468	691448	75	103
Little Raith 8	319294	691773	75	103
Little Raith 9	319773	691746	75	103
Mossmorran 1	317920	689317	59	82
Mossmorran 2	317806	689524	59	82
Goat Hill Quarry	318033	689017	60	77
Kirkton Farm	318557	689138	40	54

[25] https://planning.fife.gov.uk/online/

[26]https://www.fifedirect.org.uk/topics/index.cfm?fuseaction=page.display&p2sid=500C3CB2-D5E6-F216-50BAD63DFA0C1E8F&themeid=2B482E89-1CC4-E06A-52FBA69F838F4D24

Figure 2.7 Location of wind turbines near FEP



2.12 Deposition

The predominant route by which emissions will affect land in the vicinity of a process is by deposition of atmospheric pollutants. Ecological receptors can potentially be sensitive to the deposition of pollutants, particularly nitrogen and sulphur compounds, which can affect the character of the habitat through eutrophication and acidification.

Deposition processes in the form of dry and wet deposition remove material from a plume and alter the plume concentration. Dry deposition occurs when particles are brought to the surface by gravitational settling and turbulence. They are then removed from the atmosphere by deposition on the land surface. Wet deposition occurs due to rainout scavenging (within clouds) and washout scavenging (below clouds) of the material in the plume. These processes lead to a variation with downwind distance of the plume strength, and may alter the shape of the vertical concentration profile as dry deposition only occurs at the surface.

Near to sources of pollutants (<2 km), dry deposition is generally the predominant removal mechanism for pollutants such as NO_x, SO_2 and NH_3 (Fangmeier *et al.* 1994; Environment Agency, 2011). Dry deposition may be quantified from the near-surface plume concentration and the deposition velocity (Chamberlin and Chadwick, 1953);

$$F_d = v_d C(x, y, 0)$$

Where:

F_d= dry deposition flux (µg/m^2/s)

v_d= deposition velocity (m/s)

$C(x, y, 0)$ = ground level concentration (µg/m3)

Guidance from the Environment Agency, SEPA and NRW Technical Advisory Group AQTAG06 (AQTAG, 2014) recommends deposition velocities for various pollutants dependent upon the habitat type (Table 2.15).

Table 2.15 AQTAG06 recommended deposition velocities

Pollutant	Deposition Velocity (m/s)	
	Grassland	Forest
NO_2	0.0015	0.003
SO_2	0.012	0.024

Source: AQTAG06

In order to assess the impacts of deposition, habitat-specific critical loads and critical levels have been created. These are generally defined as (e.g. Nilsson and Grennfelt, 1988);

> "*...a quantitative estimate of exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge.*"

It is important to distinguish between a critical load and a critical level. The critical load relates to the quantity of a material deposited from air to the ground, whilst critical levels refer to the concentration of a material in air. The UK Air Pollution Information System (APIS) provides critical load data for the UK.

The critical loads used to assess the impact of compounds deposited to land which result in eutrophication and acidification are expressed in terms of kilograms of nitrogen deposited per hectare per year (kg N/ha/y) and kilo-equivalents deposited per hectare per year (keq/ha/y). The unit of 'equivalents' (eq) is used for the purposes of assessing acidification, rather than a unit of mass. The unit eq (1 keq ≡ 1,000 eq) refers to molar equivalent of potential acidity resulting from e.g. sulphur, oxidised and reduced nitrogen, as well as base cations. Essentially, it means 'moles of charge' and is a measure of how acidifying a particular chemical species can be.

To convert the predicted concentration in air, the following algorithm is used.

$$DR_i = C_i v_{d_i} f_i$$

Where:

DR_i = annual deposition of the *i*th species (kg/ha/y or kg/ha/y)

C_i = annual mean concentration of the *i*th species (µg/m^3)

v_{d_i} = deposition velocity of *i*th species

f_i = factor to convert from µg/m^2/s to kg/ha/y for the *i*th species

Table 2.16 provides the relevant conversion factors as extracted from AQTAG06.

Table 2.16 Factors for converting modelled deposition rates

Pollutant	Conversion factor (µg/m^2/s to kg/ha/y)	
	Of	f_i
NO_2	N	96
SO_2	S	157.7

Source: AQTAG06

In order to convert deposition of N or S to acid equivalents, the following relationships can be used:

- 1 keq/ha/y = 14 kgN/ha/y; and
- 1 keq/ha/y = 16 kgS/ha/y.

With respect to wet deposition, AQTAG06 states:

> "*It is considered that wet deposition of SO_2, NO_2 and NH_3 is not significant within a short range.*"

Therefore, the assessment only considers dry deposition of nitrifying and acidifying compounds. Dry deposition has been modelled assuming no depletion of the plume and using the deposition velocities provided in Table 2.17.

Table 2.17 Modelled deposition velocities for ecological receptors

Receptor ID	Receptor Name	NO_2 Deposition Velocity (m/s)	SO_2 Deposition Velocity (m/s)
E1	Firth of Forth SPA/Ramsar	0.0015	0.012
E2	Outer Firth of Forth and St Andrews Bay Complex SPA	0.0015	0.012
E3	Forth Islands SPA	0.0015	0.012

2.13 Model uncertainty and sensitivity

Process emissions have been modelled under various expected normal and abnormal operational scenarios using the standard steady state algorithms in ADMS to determine the impact on local human and ecological receptors. In order to model atmospheric dispersion using standard Gaussian methods, the following assumptions and limitations have to be made:

- Conservation of mass – the entire mass of emitted pollutant remains in the atmosphere and no allowance is made for loss due to chemical reactions or deposition processes (although the

standard Gaussian model can be modified to include such processes). Portions of the plume reaching the ground are assumed to be dispersed back away from the ground by turbulent eddies (eddy reflection);

- Steady state emissions – emission rates are assumed to be constant and continuous over the time averaging period of interest; and
- Steady state meteorology – no variations in wind speed, direction or turbulent profiles occur during transport from the source to the receptor. This assumption is reasonable within a few kilometres of a source but may not be valid for receptor distances in the order of tens of kilometres. For example, for a receptor 50 km from a source and with a wind speed of 5 m s^{-1} it will take nearly three hours for the plume to travel this distance during which time many different processes may change (e.g., the sun may rise or set, and clouds may form or dissipate affecting the turbulent profiles). For this reason, Gaussian models are practically limited to predicting concentrations within ~20 km of a source.

As a result of the above, and in combination with other factors, not least attempting to replicate stochastic processes (e.g., turbulence) by deterministic methods, dispersion modelling is inherently uncertain, but is nonetheless a useful tool in plume footprint visualisation and prediction of ground level concentrations. The use of dispersion models has been widely used in the UK for both regulatory and compliance purposes for many years and is an accepted approach for this type of assessment. The model used has also undergone extensive validation.

The assessment has incorporated several worst-case assumptions, which will likely result in an overestimation of the predicted ground level concentrations. As a result of these worst-case assumptions, the predicted results should be considered the upper limit of model uncertainty for a scenario where the actual site impact is determined. These worst-case assumptions include, amongst others:

- Assuming emissions from the flares occur continuously throughout the year at instantaneous and typical peak rates for the flare event scenarios;
- Assuming emissions from the adjacent FNGL plant occur at permit emission limit values, as opposed to reported (lower) actual emissions;
- Using background concentration estimates that already include contributions from the FEP and FNGL plant (i.e., attempts have not been made to prevent 'double-counting' of impacts); and
- Reporting results from the year(s) producing the highest predicted impacts at receptors from 5 years of meteorological data.

However, sensitivity analysis is an important component of any model assessment, since it helps to identify the magnitude of potential uncertainty in model predictions. Various sensitivity analyses have been undertaken to identify the uncertainty in model predictions in relation to the following inputs:

- Meteorology;
- Buildings;
- Terrain;
- Coastal effects; and
- Wind turbines.

Meteorological data

Results are presented in this assessment for the meteorological year(s) resulting in the highest ground level concentrations for **each individual receptor** using data recorded at Edinburgh airport meteorological station between 2014 to 2018.

However, sensitivity analysis has been undertaken to identify how model predictions may change if an alternative year of meteorological data was selected. Maximum long-term and short-term PM_{10} process contributions at any receptor location have been compared for each year of modelled meteorological data for the peak, instantaneous PGC trip scenario.

The results of the sensitivity analysis are provided in Table 2.17. Results have been normalised by the value obtained from the year of meteorological data resulting in the highest ground level concentration. For example, a value of 0.85 would indicate the prediction from that dataset is 15% lower than the maximum prediction from any dataset

Table 2.18 Model sensitivity to meteorological data

Year	Normalised Annual Mean PM_{10} Process Contribution	Normalised 98.08 Percentile 24-hour Mean PM_{10} Process Contribution
2014	0.74	0.86
2015	**1.00**	**1.00**
2016	0.71	0.78
2017	0.73	0.66
2018	0.76	0.89

Table 2.17 demonstrates predicted ground level concentrations outwith the 'worst-case' meteorological year could be up to one-third lower than the values reported in this assessment.

Buildings

Sensitivity analysis has been undertaken to identify whether including buildings within the model produces worst-case results. Models have been run with and without the inclusion of buildings for each year of meteorological data and maximum long-term and short-term PM_{10} process contributions at any receptor location have been compared for each year of modelled meteorological data for the peak, instantaneous PGC trip scenario. The results of the sensitivity analysis are provided in Table 2.19. Results have been normalised by the value obtained from the model run resulting in the highest ground level concentration.

Table 2.19 Model sensitivity to buildings

	Normalised Annual Mean PM_{10} Process Contribution	Normalised 98.08 Percentile 24-hour Mean PM_{10} Process Contribution
With buildings	**1.00**	1.00
Without buildings	0.97	1.00

The results in Table 2.19 demonstrates the model is relatively insensitive to buildings in this particular instance, with inclusion of buildings resulting in marginally higher long-term process contributions but negligible difference in short-term process contributions. The low sensitivity to buildings is likely a consequence of the main emission source in this scenario (FEP elevated flare) being of sufficient height that it is not affected by building effects.

Terrain

Sensitivity analysis has been undertaken to identify whether including digitally mapped terrain data within the model would significantly affect the model predictions. Models have been run with and without the inclusion of terrain data for each year of meteorological data and maximum long-term and short-term PM_{10} process contributions at any receptor location have been compared for each year of modelled meteorological data for the peak, instantaneous PGC trip scenario. The results of the sensitivity analysis are provided in Table 2.20. Results have been normalised by the value obtained from the model run resulting in the highest ground level concentration.

Table 2.20 Model sensitivity to terrain

	Normalised Annual Mean PM_{10} Process Contribution	**Normalised 98.08 Percentile 24-hour Mean PM_{10} Process Contribution**
With terrain	**1.00**	**1.00**
Without terrain	0.78	0.70

Table 2.20 demonstrates the model is sensitive to terrain data, reflecting the complex nature of terrain within the model domain, with process contributions up to 30% lower if terrain data was not included in the model set up. Model results presented in this assessment are those obtained with runs from models with terrain data included as a conservative approach.

Coastal effects

Localised flow patterns can arise near to coastal areas due to the atmospheric pressure differential established between land and sea areas as a consequence of their different heat capacities (the heat capacity of the sea being much greater than that of the land). The land surface can exhibit a significant diurnal temperature variation whilst the sea temperature remains near constant throughout the day, changing only on a monthly/seasonal basis.

When the land is warmer than the sea, an onshore breeze is established as the warm air above the land surface is heated and rises, forming a localised low-pressure area above the land towards which the cooler, denser air over the sea flows. Due to the high heat capacity of liquid water, the boundary layer over the sea is most frequently neutral. However, as the air over the sea begins to flow inland, an internal convective boundary layer begins to grow as a function of distance inland. When this internal boundary layer reaches the height of a discharged plume, a coastal fumigation event can occur, whereby portions of the plume are rapidly mixed towards ground level due to the strong vertical motion in the internal boundary layer. This can cause transient, elevated ground level concentrations which may persist for 10-15 minutes.

ADMS does have the capability of modelling coastal effects. However, the coastal module cannot be applied at the same time as the buildings and/or terrain modules and has never been subject to formal validation. Sensitivity analysis has, however, been undertaken to identify whether including coastal effects would significantly affect the conclusions of the assessment.

Models have been with and without coastal effects and maximum 15-minute short-term SO_2 process contributions at modelled receptor locations compared (long-term process contributions have not been compared due to the short-term, transient nature of coastal effects on the discharged plume). Table 2.21 presents this sensitivity analysis. Results have been normalised by the value obtained from the model run resulting in the highest ground level concentration.

Table 2.21 Model sensitivity to coastal effects

Scenario	Normalised 99.9 Percentile 15-minute Mean SO_2 Process Contribution
With coastal effects	**1.00**
Without coastal effects	**1.00**

Table 2.21 demonstrates that the model is insensitive to potential coastal fumigation events and such events are unlikely to have any material effect on the conclusions of the assessment. This is likely due to the distance of FEP from the coast (~4.5 km) and the fact that the prevailing synoptic wind direction is parallel to the coastline.

Wind turbines

Sensitivity analysis has been undertaken to identify whether including wind turbine effects within the model significantly affects the model predictions. Models have been run with and without the inclusion of wind turbines for each year of meteorological data and maximum long-term and short-term PM_{10} process contributions at any receptor location have been compared for each year of modelled meteorological data for the peak, instantaneous PGC trip scenario. The results of the sensitivity analysis are provided in Table 2.22. Results have been normalised by the value obtained from the model run resulting in the highest ground level concentration.

Table 2.22 Model sensitivity to wind turbine effects

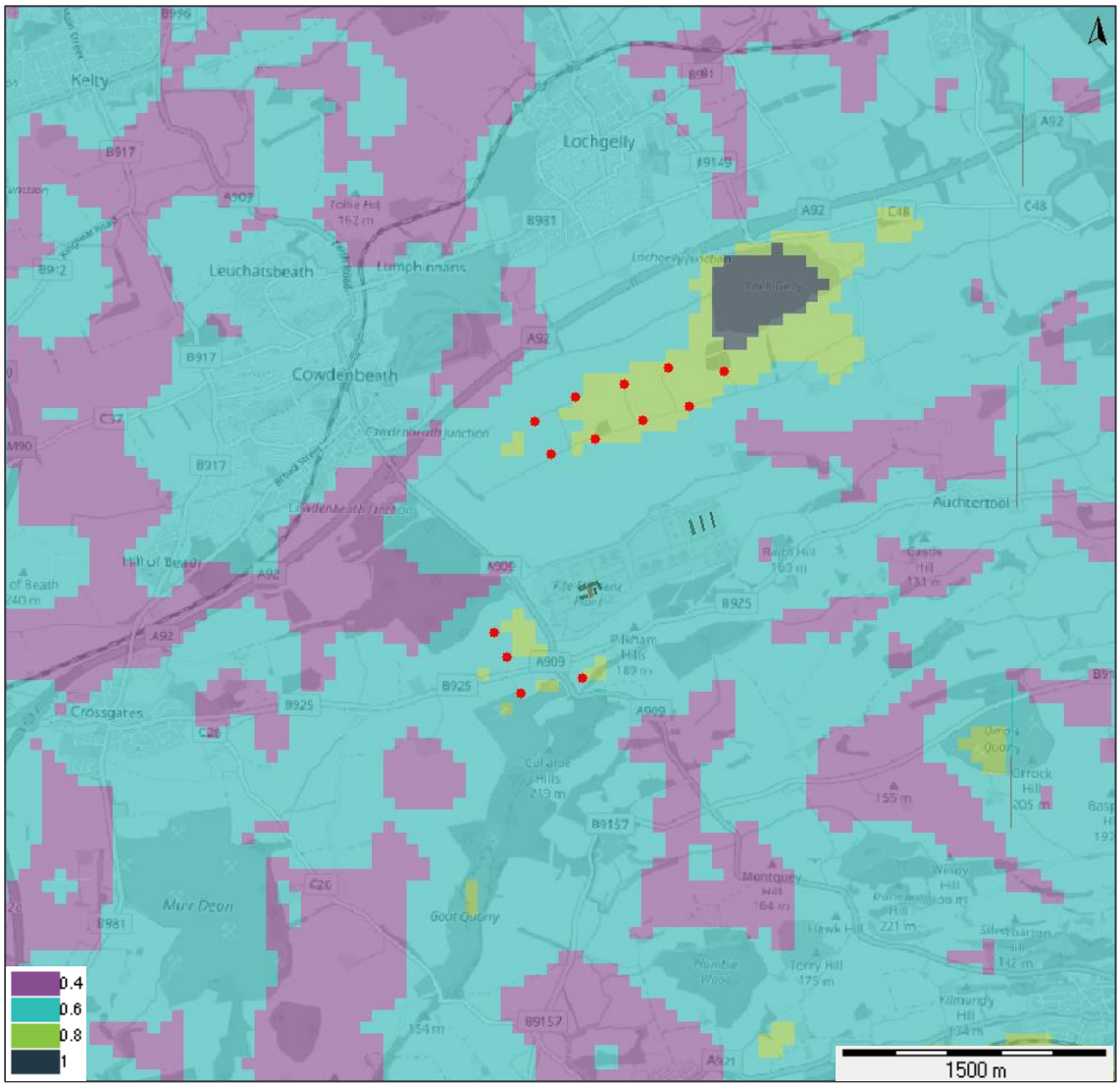
	Normalised Annual Mean PM_{10} Process Contribution	Normalised 98.08 Percentile 24-hour Mean PM_{10} Process Contribution
With wind turbines	**1.00**	**1.00**
Without wind turbines	0.94	1.00

Table 2.22 demonstrates the model is relatively insensitive to wind turbines with maximum predicted long-term process contributions 6% higher when wind turbines are included but with negligible difference in the maximum predicted short-term process contribution. These findings are largely consistent with the conclusion of an ambient monitoring survey undertaken pre and post commencement of operations at Little Raith Wind Farm by Kennedy Renewables, which identified measured concentrations of benzene following commissioning of the wind farm in September 2013 were no higher than the concentrations measured prior to installation and were consistent with typical rural background levels.[27]

[27] https://www.sepa.org.uk/media/162890/impact_of_little_raith_windfarm_on_air_emissions_from_mossmorran.pdf

To further investigate the potential impact of the wind turbines on the flow field and turbulent parameters, the spatial variance in the predicted standard deviation of the vertical turbulence parameter across the model domain has been plotted in Figure 2.8. The figure demonstrates the increased turbulence downstream of the turbines but the magnitude and spatial extent of this is quite limited, particularly for the isolated turbines to the south-west of FEP. The elevated level of vertical turbulence to the north-east of Little Raith Wind Farm exceeding 1 m s^{-1} is not a turbine-induced effect; rather, it is caused as the flow velocity increases over the surface of Loch Gelly associated the change in surface roughness. This further demonstrates terrain-induced effects have a greater influence on model predictions than wind turbine effects.

Figure 2.8 Standard deviation of the vertical turbulence parameter (m s^{-1})



2.14 Special model treatments

Specialised model treatments for short-term (puff) releases, fluctuations or photochemistry have not been used in this assessment.

2.15 Data gaps and assumptions

Table 2.23 details the data gaps identified during the course of the assessment and the corresponding assumption made in order to allow an assessment to proceed.

Table 2.23 Data gaps and assumptions

Data Gap	Limitation and Assumption
Flare emission rates	It is not possible to monitor emissions from the flares using conventional stack emissions monitoring techniques for safety reasons. Emission rates from the flares have been estimated using emission factors provided by CONCAWE and the US EPA as industry best-practice.
FNGL plant emission parameters	Updated actual emissions from the FNGL plant emission sources were not available for this updated study. Consequently, it has conservatively been assumed that the furnaces are operating at their respective emission limit values whilst furnace volume flows and temperatures, and base-load flaring rates and gas composition have been taken from the 2009 study.
Goat Hill Quarry and Kirkton Farm wind turbines	Published thrust co-efficients are not available for the specific type of turbines installed at Goat Hill Quarry and Kirkton Farm. Consequently, generic data from similar capacity turbines have been used.
Particle size distribution	Profiles of size distribution of particulates emitted from the FEP and FNGL plant are not available. Consequently, as a conservative approach, it is assumed that all particulate matter is emitted in the $PM_{2.5}$ fraction
Speciation of UHCs and BTEX	Information is not available on the speciation of UHCs and BTEX. UHCs have conservatively been modelled as n-butane in order to allow comparison against the n-butane environmental assessment level (EAL); this likely being the most significant hydrocarbon in the various process streams for which an EAL is available. As benzene has the lowest air quality standard of any pollutant within this group, BTEX is conservatively assumed to be emitted as benzene and compared against the benzene air quality standards.

3. Existing ambient air quality

3.1 Local air quality management

Under Part IV of the Environment Act 1995, Fife Council is required to periodically review and assess air quality within its area of jurisdiction. This process of Local Air Quality Management (LAQM) is an integral process for achieving national air quality objectives (AQOs).

Review and assessments of local air quality aim to identify areas where national policies to reduce vehicle and industrial emissions are unlikely to result in air quality meeting the Government's air quality objectives by the required dates.

Where the assessment indicates that some or all of the objectives may be potentially exceeded, the Local Authority has a duty to declare an Air Quality Management Area (AQMA). The declaration of an AQMA requires the Local Authority to implement an Air Quality Action Plan (AQAP) to reduce air pollution concentrations so that the required AQOs are met.

Fife Council has declared two AQMAs for annual mean NO_2 and PM_{10} within its jurisdictional area:

- Bonnygate, Cupar, declared in October 2008; and
- Appin Crescent, Dunfermline, declared in November 2011 for NO_2 and August 2012 for PM_{10}.

The AQAP for the Bonnygate, Cupar AQMA was last updated in 2015 and has been successful in reducing both NO_2 and PM_{10} concentrations within the Bonnygate area. During 2017 annual mean concentrations of NO_2 and PM_{10} within the AQMA were below their respective objective.

Following a review of the 2019 Annual Progress Report, SEPA and the Scottish Government both recommended that Fife Council strongly consider revoking both AQMA's. Concentrations of NO_2 and PM_{10} recorded within both AQMAs have improved significantly and now meet the Scottish air quality objectives for both pollutants, However, in their latest Annual Progress report for 2020, Fife Council say that due to the current uncertainty regarding PM_{10} concentrations reported by different analysers and the Particular Matter concentrations indicated by the Bonnygate AQMesh monitoring in 2019, they do not propose to implement the revocation procedure for either AQMA at this time.

The Bonnygate and Appin Crescent AQMAs are approximately 29 km to the north-east, and approximately 9 km to the west-south-west of FEP. Due to the distance or prevailing south-westerly wind direction, it is highly unlikely that emissions from the FEP will contribute significantly to concentrations within the AQMAs.

Outside the AQMAs, air quality in Fife is generally good, with Fife Council's 2020 Progress Report[28] noting that the principal emission source contributing to specific 'hot-spots' of pollution in town centres is road vehicle emissions.

3.2 Ambient monitoring data

Fife Council operates four continuous monitoring locations for NO_2, PM_{10} and $PM_{2.5}$. The monitoring site located closest to FEP is the Appin Crescent roadside monitoring site in Dunfermline. Table 3.1 summarises recent data from this monitoring site.

[28] Fife Council, 2020. 'Fife Air Quality Annual Progress Report 2020' [online] https://www.fife.gov.uk/__data/assets/pdf_file/0017/160163/Fife-Air-Quality-Annual-Progress-Report-2020.pdf

Table 3.1 Monitored data from the Appin Crescent monitoring site

Year	Annual mean NO_2 (µg m^{-3})	Annual mean PM_{10} (µg m^{-3})	Annual mean $PM_{2.5}$ (µg m^{-3})	Number of hours where NO_2 > 200 µg m^{-3}	Number of days where PM_{10} > 50 µg m^{-3}
2015	25	16	Not recorded	0	2
2016	24	13	6	0	1
2017	23	10	6	0	0
2018	22	11	6	0	0
2019	21	11	6	0	0

In addition to continuous monitoring, Fife Council operates a network of passive diffusion tubes for monitoring NO_2. The 2019 diffusion tube results indicate that there were no exceedances of the annual mean NO_2 objective at all monitoring locations, including locations within Dunfermline and Cupar which have exceeded in previous years.

The highest annual mean concentration measured in Appin Crescent, Dunfermline during 2019 was 34 µg m^{-3} at Appin Crescent 6(A, B, C). The highest annual mean concentration measured in Bonnygate, Cupar during 2019 was 32 µg m^{-3} at Bonnygate B4. The nearest diffusion tube monitoring site to FEP is the kerbside monitoring location in High Street, Cowdenbeath. The monitored annual mean NO_2 concentration at this location in 2019 was 19 µg m^{-3}.

INEOS FPS Ltd. commissioned NPL to monitor the ambient air hydrocarbon levels at 12 locations on the Forth Estuary coastline during 2018 (5 January 2018 to 3 January 2019). Nine locations on the Estuary North shore between North Queensferry and West Wemyss (including four locations between Dalgety Bay and Burntisland) were used, and three locations on the Estuary South shore between South Queensferry and Whitehouse Point were used. The ambient air samples were collected over two-week periods using passive diffusive tubes. These samples were analysed for iso-butane, n-butane, iso-pentane, n-pentane, n-hexane, n-heptane, benzene, toluene, xylene and total hydrocarbons (C_4–C_{10}).

The results from these monitoring surveys are summarised in the 2018 Annual Report of the Mossmorran & Braefoot Bay Independent Air Quality Monitoring Review Group[29]. The Review Group notes that concentrations of n-butane ranged from 1.9–14.5 ppb (4.6–35.0 µg m^{-3}) and the average concentrations of benzene over the 12-month period at each location ranged from 0.1–0.4 ppb (~0.3–1.3 µg m^{-3}).

SEPA carried out a monitoring campaign in the vicinity of the Mossmorran Complex during the plant shutdown and subsequent start up, running between August 2019 and March 2020[30]. Pollutants monitored were PM_{10}, $PM_{2.5}$, benzene, toluene, ethylbenzene, xylene, 1,3-butadiene, nitrogen dioxide, total hydrocarbons (C_4 to C_{10}), sulphur dioxide and carbon monoxide. The report concludes that there were no breaches of any of the air quality objectives, and the data produced during the study would indicate no measurable impact on airborne pollutant levels as a result of the shutdown and start up activities, including flaring. Although the monitoring did not take place for a full calendar year, the analysis in the report suggests

[29] Mossmorran & Braefoot Bay Independent Air Quality Monitoring Review Group, 2019. '2018 Annual Report' [online] https://www.fife.gov.uk/__data/assets/pdf_file/0032/72968/MMBBIAQRG-2018-Report-16_10_19.pdf

[30] SEPA, 2020. 'Air Quality Monitoring Mossmorran August 2019 – March 2020' [online] https://www.sepa.org.uk/media/558658/air-quality-monitoring-mossmorran-pdf.pdf

that the monitored values are representative of annual mean results and so may be compared with annual mean objectives.

Results from the SEPA monitoring are summarised in Table 3.2. This presents the mean concentrations of each pollutant over the monitoring period, at the monitoring location that gave the highest average value where there was more than one monitoring location for a pollutant.

Table 3.2 SEPA monitored data

Pollutant	Mean concentration (µg m^{-3})	Location
PM_{10}	7.0	Lochgelly
$PM_{2.5}$	5.1	Donibristle
NO_2	23.2	Cowdenbeath
SO_2	1.2	Little Raith
CO	< limit of detection	Little Raith
1,3-butadiene	<0.2	All
Benzene	0.9	Cowdenbeath
Toluene	1.9	Cowdenbeath
Ethylbenzene	<1.3	All
Xylene	2.0	Donibristle
Total C_4-C_{10}	9.0	Donibristle, Cowdenbeath

3.3 Mapped background concentrations and deposition rates

Defra provides results from a nationwide model (the Pollution Climate Mapping (PCM) model) of existing and future background air quality concentrations of NOx, NO_2, PM_{10}, $PM_{2.5}$, SO_2, CO and benzene at a 1 km grid square resolution. The PCM model is semi-empirical in nature; it uses data from the national atmospheric emissions inventory (NAEI) to model the concentrations of pollutants at the centroid of each 1 km grid square but then calibrates these concentrations in relation to actual monitoring data.

In addition to the UK-wide version of PCM, a Scotland-specific version is now available for NO_x, NO_2 and PM_{10}. The Scotland-specific version of PCM uses meteorology from RAF Leuchars and measurements from Scottish air quality monitoring sites only to calibrate and verify the model.

PCM contains contributions from all existing Part A(1) installations using data available at the time the base year datasets were compiled. For NO_x, NO_2 and PM_{10} this base year is 2018 and projections are available out to 2030. For SO_2, CO and benzene, this base year is 2001, and projections are available to 2010 for benzene only. The model also considers contributions from other non-industrial line, area and volume sources e.g., road traffic, shipping emissions and airports etc.

Similarly, the Air Pollution Information System (APIS) database provides estimated background concentrations of NO_x and SO_2, as well as background deposition rates of nitrogen and sulphur, using the Concentration Based Estimated Deposition (CBED) model but on a more coarse 5 km grid square resolution.

As an existing Part A(1) installation, contributions from the FEP and FNGL plant emission sources are already reflected in the UK and Scotland-specific PCM and CBED background estimates.

Table 3.2 provides the mapped background estimates of NO_2 and PM_{10} from the Scotland-specific version of PCM, and mapped background estimates of $PM_{2.5}$, SO_2, CO and benzene from the UK-wide version of PCM for the human receptors considered in this study. The model years are 2021 for NO_2, PM_{10} and $PM_{2.5}$, 2001 for SO_2 and CO, and 2010 for benzene. Table 3.3 provides the mapped background concentrations and deposition rates for the ecological receptors.

Table 3.3 Annual mean mapped background concentrations at human receptors

Receptor ID	NO_2 (µg m^{-3})	PM_{10} (µg m^{-3})	$PM_{2.5}$ (µg m^{-3})	SO_2 (µg m^{-3})	CO (µg m^{-3})	Benzene (µg m^{-3})
H1	6.9	10.0	5.5	2.1	197.0	0.2
H2	6.8	10.4	5.6	2.3	191.0	0.2
H3	8.9	9.3	5.4	2.2	200.0	0.2
H4	9.2	10.5	5.6	2.2	199.0	0.2
H5	6.8	10.4	5.6	2.3	191.0	0.2
H6	8.1	10.3	5.5	2.4	189.0	0.2
H7	9.7	10.3	5.6	2.2	211.0	0.2
H8	6.9	10.0	5.5	2.1	197.0	0.2
H9	8.5	9.8	5.4	2.2	212.0	0.2
H10	8.3	9.6	5.5	4.8	211.0	0.3
H11	8.4	9.8	5.6	7.5	199.0	0.2
H12	10.1	10.1	5.7	6.8	215.0	0.3
H13	8.6	10.3	5.5	2.7	216.0	0.3
H14	10.1	10.1	5.7	6.8	215.0	0.3
H15	9.7	10.9	5.9	3.6	204.0	0.2
H16	6.8	10.4	5.6	2.3	191.0	0.2
H17	8.5	10.6	5.5	2.2	212.0	0.2

Table 3.4 Annual mean mapped background concentrations and deposition rates at ecological receptors

Receptor ID	Receptor name	NO_x (µg m^{-3})	SO_2 (µg m^{-3})	Nitrogen deposition (kgN/ha/yr)	Nitrogen deposition (keq/ha/yr)	Sulphur deposition (keq/ha/yr)
E1	Firth of Forth SPA/Ramsar	12.3	2.3	13.70	1.00	0.10
E2	Outer Firth of Forth and St Andrews Bay Complex SPA	12.1	2.3	13.70	1.00	0.10
E3	Forth Islands SPA	12.0	2.3	13.40	1.00	0.20

3.4 Background concentrations used in the assessment

Annual mean background concentrations for NO_2, $PM_{10,}$ $PM_{2.5}$, SO_2, CO and benzene have been taken from the PCM modelled estimates for each receptor as detailed in Table 3.2. With respect to UHCs, a uniform annual mean concentration of 35.0 µg m^{-3}, corresponding to the highest monitored n-butane concentration from the INEOS monitoring on the Fife coast, has been conservatively applied to all receptors. For ecological receptors, the data in Table 3.4 have been used. Background concentration estimates already include contributions from the FEP and FNGL plant, so there is some double-counting of impacts.

The annual average process contribution (PC) is added to the annual average background concentration, to give a total predicted environmental concentration (PEC) at each receptor location. This total concentration can then be compared against the relevant air quality objective and the likelihood of an exceedence determined.

It is not technically rigorous to add predicted short term or percentile concentrations to ambient background concentrations not measured over the same averaging period, since peak contributions from different sources would not necessarily coincide in time or location. For the purposes of estimating short-term background concentrations, a factor of two has been applied to the annual mean background concentration as per the procedure in SEPA's H1 Horizontal Guidance[1] note.

4. Assessment criteria

4.1 Relevant legislation and guidance

EU Legislation

Directive 2008/50/EC on Ambient Air Quality and Cleaner Air for Europe

Directive 2008/50/EC (the 'Directive'), which came into force in June 2008, consolidates existing EU-wide air quality legislation (with the exception of Directive 2004/107/EC) and provides a new regulatory framework for $PM_{2.5}$.

The Directive sets limit values, or target levels, for selected pollutants that are to be achieved by specific dates and details procedures EU Member States should take in assessing ambient air quality. The limit values and target levels relate to concentrations in ambient air. At Article 2(1), the Directive defines ambient air as:

> *"…outdoor air in the troposphere, excluding workplaces as defined by Directive 89/654/EEC where provisions concerning health and safety at work apply and to which members of the public do not have regular access."*

In accordance with Article 2(1), Annex III, Part A, paragraph 2 details locations where compliance with the limit values does not need to be assessed:

> *"Compliance with the limit values directed at the protection of human health shall not be assessed at the following locations:*
>
> *a) any locations situated within areas where members of the public do not have access and there is no fixed habitation;*
>
> *b) in accordance with Article 2(1), on factory premises or at industrial installations to which all relevant provisions concerning health and safety at work apply; and*
>
> *c) on the carriageway of roads; and on the central reservation of roads except where there is normally pedestrian access to the central reservation.*

UK Legislation

The Air Quality Standards (Scotland) Regulations 2010

The Air Quality Standards (Scotland) Regulations 2010 (the 'Regulations') came into force on the 11th June 2010 and transpose Directive 2008/50/EC into UK legislation. The Directive's limit values are transposed into the Regulations as 'Air Quality Standards' (AQS) with attainment dates in line with the Directive.

These standards are legally binding concentrations of pollutants in the atmosphere which can broadly be taken to achieve a certain level of environmental quality. The standards are based on the assessment of the effects of each pollutant on human health including the effects of sensitive groups or on ecosystems.

Similar to Directive 2008/50/EC, the Regulations define ambient air as;

> *"…outdoor air in the troposphere, excluding workplaces where members of the public do not have regular access."*

with direction provided in Schedule 1, Part 1, Paragraph 2 as to where compliance with the AQS does not need to be assessed:

> *"Compliance with the limit values directed at the protection of human health does not need to be assessed at the following locations:*
>
> *a) any location situated within areas where members of the public do not have access and there is no fixed habitation;*
>
> *b) on factory premises or at industrial locations to which all relevant provisions concerning health and safety at work apply; and*
>
> *c) on the carriageway of roads and on the central reservation of roads except where there is normally pedestrian access to the central reservation."*

The Air Quality (Scotland) Regulations 2000, as amended and the Air Quality (Scotland) Amendment Regulations 2016

The Air Quality (Scotland) Regulations 2000, as amended provide health-based criteria for certain air pollutants; these criteria are based on medical and scientific reports on how and at what concentration each pollutant affects human health. The air quality objectives (AQOs) derived from these criteria are policy targets often expressed as a maximum ambient concentration not to be exceeded, without exception or with a permitted number of exceedances, within a specified timescale. The AQOs are central to the 2007 Air Quality Strategy, which clarifies that the objectives are:

> *"…a statement of policy intentions or policy targets. As such, there is no legal requirement to meet these objectives except where they mirror any equivalent legally binding limit values…"*

Paragraph 4(2) of The Air Quality (Scotland) Regulations 2000 states:

> *"The achievement or likely achievement of an air quality objective prescribed by paragraph (1) shall be determined by reference to the quality of air at locations – which are situated outside of buildings or other natural or man-made structures above or below ground; and where members of the public are regularly present"*

Consequently, compliance with the AQOs should focus on areas where members of the general public are present over the entire duration of the concentration averaging period specific to the relevant objective.

The Air Quality (Scotland) Regulations 2000 were last amended in 2016 by the Air Quality (Scotland) Amendment Regulations 2016. These amended regulations introduce an AQO for $PM_{2.5}$ which is consistent with the World Health Organisation (WHO) guideline level. The new AQO is to be complied at all locations within Scotland outside of buildings or other natural or man-made structures above or below ground, and where members of the public are regularly present, by the 31st December 2020.

The Environment Act

Part IV of the Environment Act 1995 requires that Local Authorities periodically review air quality within their individual areas. This process of Local Air Quality Management (LAQM) is an integral part of delivering the Government's AQOs.

To carry out an air quality Review and Assessment under the LAQM process, the Government recommends a three-stage approach. This phased review process uses initial simple screening methods and progresses through to more detailed assessment methods of modelling and monitoring in areas identified to be at potential risk of exceeding the objectives in the Regulations.

Review and assessments of local air quality aim to identify areas where national policies to reduce vehicle and industrial emissions are unlikely to result in air quality meeting the Government's air quality objectives by the required dates.

For the purposes of determining the focus of Review and Assessment, Local Authorities should have regard to those locations where members of the public are likely to be regularly present and are likely to be exposed over the averaging period of the objective.

Where the assessment indicates that some or all of the objectives may be potentially exceeded, the Local Authority has a duty to declare an Air Quality Management Area (AQMA). The declaration of an AQMA requires the Local Authority to implement an Air Quality Action Plan (AQAP), to reduce air pollution concentrations so that the required AQOs are met.

Other Guideline Values

In the absence of statutory standards for the other prescribed substances that may be found in the emissions, there are several sources of applicable air quality guidelines.

Air Quality Guidelines for Europe, the World Health Organisation (WHO)

The aim of the WHO Air Quality Guidelines for Europe (WHO, 2000) is to provide a basis for protecting public health from adverse effects of air pollutants and to eliminate or reduce exposure to those pollutants that are known or likely to be hazardous to human health or well-being. These guidelines are intended to provide guidance and information to international, national and local authorities making risk management decisions, particularly in setting air quality standards.

Environmental Assessment Levels (EALs)

SEPA's H1 Horizontal Guidance Note "*Environmental Assessment and Appraisal of BAT*" contains long and short-term Environmental Assessment Levels (EALs) for releases to air derived from a number of published UK and international sources. For the pollutants considered in this study, the majority of these EALs are equivalent to the AQS and AQOs set in force by the Air Quality Standards Regulations 2010 and the Air Quality Regulations 2000 as amended.

4.2 Pollutant descriptions

Table 4.1 provides a brief description of the potential effects on human health and the environment for the pollutants considered in this assessment, as reported by WHO (2000) together with their principal emission sources in the UK.

Table 4.1 Summary of the pollutants assessed

Pollutant	Description and effect on human health and the environment	Principal sources
Carbon monoxide	The toxicity of CO results in it binding avidly to haemoglobin and thus reducing the oxygen-carrying capacity of the blood. In very high doses, the restriction of oxygen to the brain and heart can be fatal. At lower concentrations, CO can affect higher cerebral function, heart function and exercise capacity.	The principal sources of UK CO emissions are from domestic combustion of wood and industrial off-road machinery
Sulphur dioxide	At high concentrations SO_2 is a potent bronchoconstrictor, and asthmatic individuals are more susceptible. It is likely that SO_2 contributes to respiratory symptoms, reduced lung function and rises in hospital admissions. Exposure to high levels of SO_2 over a long period can result in structural changes in the lungs and may enhance sensitisation to allergens.	The principal source of SO_2 is the combustion of fossil fuels containing sulphur and, in the UK, this is primarily through the combustion of fuel oil in ships, combustion of coal in power stations and oil refining

Pollutant	Description and effect on human health and the environment	Principal sources
Particulate matter (PM_{10} and $PM_{2.5}$)	Particulate matter is the term used to describe all suspended solid matter. Particulate matter with an aerodynamic diameter of less than 10 µm (PM_{10}) is the subject of health concerns because of its ability to penetrate and remain deep within the lungs. The health effects of particles are difficult to assess, and evidence is mainly based on epidemiological studies. Evidence suggests that there may be associations between increased PM_{10} concentrations and increased mortality and morbidity rates, changes in symptoms or lung function, episodes of hospitalisation or doctors' consultations. Recent reviews by the World Health Organisation (WHO) and Committee on the Medical Effects of Air Pollutants (COMEAP) have suggested exposure to a finer fraction of particles ($PM_{2.5}$) give a stronger association with the observed health effects. $PM_{2.5}$ typically makes up around two-thirds of ambient PM_{10} concentrations.	Domestic combustion, road transport, industrial processes. Other pollutants, including NO_2 and SO_2, have the potential to form secondary particulates which are often smaller than PM_{10}.
Oxides of nitrogen	Nitrogen dioxide (NO_2) and Nitric oxide (NO) are both collectively referred to as oxides of Nitrogen (NO_X). It is NO_2 that is associated with adverse effects on human health. Most atmospheric emissions are in the form of NO which is converted to NO_2 in the atmosphere through reactions with Ozone. The oxidising properties of NO_2 theoretically could damage lung tissue, and exposure to very high concentrations of NO_2 can lead to inflammation of lung tissue, affect the ability to fight infection. The greatest impact of NO_2 is on individuals with asthma or other respiratory conditions, but consistent impacts on these individuals is at levels of greater than 564 µg m^{-3}, much higher than typical UK ambient concentrations.	All combustion processes produce NO_X emissions, and the principal source of NO_X is road transport
Volatile organic compounds (including butane and benzene)	VOCs represent a wide group of organic (i.e., carbon containing) compounds that are volatile (i.e., evaporate or volatilise easily in normal conditions). Many VOCs are odorous, even in very low concentrations. Certain VOCs, e.g., benzene, are known carcinogens.	Wide variety of sources, both natural and anthropogenic. VOC emissions from domestic solvent use in e.g. cleaning products was the largest source of non-methane VOC emissions in the UK in 2017

4.3 Criteria appropriate to the assessment

Assessment criteria arise from several sources and have different statuses. There are therefore a number of terms for these criteria, including AQO, AQS, EAL, critical level and critical load. This report therefore follows the Institute of Air Quality Management (IAQM)[31] in using the term "air quality assessment level (AQAL)" to refer to any of these.

Concentrations in air

Table 4.2 summarises the applicable air quality standards (AQS), objectives (AQOs), environmental assessment levels (EALs) and critical levels appropriate for assessing concentrations in air and resultant impacts on human health, vegetation and ecosystems.

[31] Environmental Protection UK and the Institute of Air Quality Management (2017) Land-Use Planning & Development Control: Planning For Air Quality. v1.2.

Table 4.2 Air quality standards, objectives and environmental assessment levels

Pollutant	Status	Averaging Period	Value (µg m^{-3})
Human receptors			
NO_2	AQS	Annual mean	40
	AQS	1-hour mean, not to be exceeded more than 18 times a year (equivalent of 99.79 Percentile)	200
CO	AQS	Rolling 8-hour mean	10,000
	EAL	Annual mean	350
SO_2	AQS	1-hour mean not to be exceeded more than 24 times a year (equivalent to 99.73 percentile)	350
	AQS	24-hour mean, not to be exceeded more than 3 times a year (equivalent to 99.18 percentile)	125
	AQO	15-min mean, not to be exceeded more than 35 times a year (equivalent to 99.9 percentile)	266
PM_{10}	AQS	Annual mean	18
	AQS	24-hour mean, not to be exceeded more than 7 times a year (equivalent to 98.08 percentile)	50
$PM_{2.5}$	AQO	Annual mean	10
UHCs (as butane)	EAL	Annual mean	14,500
	EAL	1-hour mean	181,000
BTEX (as benzene)	AQO	Annual mean	3.25
	EAL	1-hour mean	208
Ecological receptors			
NOx	AQS	Annual mean	30
	EAL	Daily mean	75
SO_2	AQS	Annual mean	20

Critical Loads

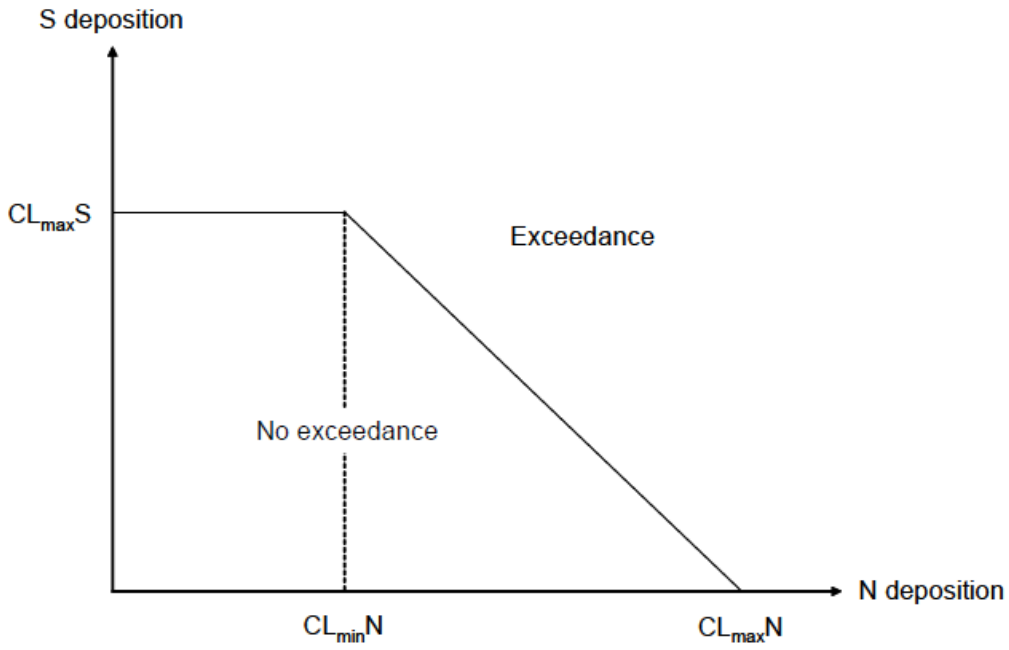
Eutrophication critical loads are given as a range and have units of kgN/ha/y. Generally, the lower end of the range should be used as a conservative assessment. The critical loads for acidification are more complicated, in that both the nitrogen and sulphur deposition fluxes must be considered at the same time. Therefore, a critical load function is specified for acidification, via the use of three critical load parameters:

- $CL_{max}S$ – the maximum critical load of sulphur, above which the deposition of sulphur alone would be considered to lead to an exceedence;

- $CL_{min}N$ – a measure of the ability of a system to "consume" deposited nitrogen (e.g. via immobilisation and uptake of the deposited nitrogen); and
- $CL_{max}N$ – the maximum critical load of acidifying nitrogen, above which the deposition of nitrogen alone would be considered to lead to an exceedance.

These three quantities define the critical load function shown in Figure 4.1.

Figure 4.1 Acid deposition critical load function



Source: AQTAG06 (2014)

APIS contains information on applicable critical loads for various habitats and species. Critical load data extracted from APIS for the ecological receptors considered in this assessment is provided in Table 4.3 below. The critical loads reported are for the most sensitive qualifying habitat/species for that particular site and location as reported by the APIS Site Relevant Critical Load (SRCL) tool and have been used in this assessment as a conservative approach. At the time of writing, APIS does not have data for the Outer Firth of Forth and St Andrews Bay Complex SPA, which was designated in December 2020, so data for the Firth of Forth SPA have been used instead.

Table 4.3 Site Specific Critical Loads

Receptor ID	Receptor Name	MinCLN (kgN/ha/y)	CLminN (keq/ha/y)	CLmaxN (keq/ha/y)	CLmaxS (keq/ha/y)
E1	Firth of Forth SPA/Ramsar	10	0.300	0.500	0.200
E2	Outer Firth of Forth and St Andrews Bay Complex SPA	10	0.300	0.500	0.200
E3	Forth Islands SPA	10	0.438	4.263	4.040

5. Results

Results tables providing the process contribution (PC) from FEP and the predicted environmental concentration (PEC = PC + background concentration + FNGL plant contribution) for each receptor are presented in Appendix D. These results are the highest concentrations predicted for individual receptors obtained from any year of meteorological data.

Results for the proposed flare system, i.e., after introduction of the new EGF, are presented in Section 5.1, with a comparison of impact against the existing flare system in Section 5.2.

Results are presented to several decimal places to assist comparison between receptors, scenarios and AQALs. The number of decimal places should not be taken as an indication of the accuracy of the modelling.

5.1 Impacts of proposed flare system

Human receptors

Tables 5.1 through 5.3 summarise the receptors results in Appendix D for the human receptor experiencing the highest predicted impact from the model. Results are shown for the receptors with the highest PC and the highest PEC; in general these are different receptors due to having different background concentrations.

Table 5.1 Summary of impact at human receptor experiencing maximum PC and/or PEC: normal operation

Pollutant	Selection	AQAL (µg m^{-3})	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)	Receptor
NO_2 annual mean	Max PC	40	3.02	10.46	7.6%	26.1%	Camilla Props
NO_2 annual mean	Max PEC	40	2.60	12.63	6.5%	31.6%	Moss Bank Farm
NO_2 99.79 percentile 1-hour mean	Max PC	200	18.00	35.73	9.0%	17.9%	Easter Lochead
NO_2 99.79 percentile 1-hour mean	Max PEC	200	17.19	39.24	8.6%	19.6%	Moss Bank Farm
PM_{10} annual mean	Max PC	18	0.08	10.44	0.4%	58.0%	Camilla Props
PM_{10} annual mean	Max PEC	18	0.01	10.92	0.0%	60.7%	Lochgelly Props
PM_{10} 98.08 percentile 24-hour mean	Max PC	50	0.36	20.95	0.7%	41.9%	Moss Bank Farm
PM_{10} 98.08 percentile 24-hour mean	Max PEC	50	0.08	21.90	0.2%	43.8%	Lochgelly Props
$PM_{2.5}$ annual mean	Max PC	10	0.08	5.65	0.8%	56.5%	Camilla Props
$PM_{2.5}$ annual mean	Max PEC	10	0.01	5.91	0.1%	59.1%	Lochgelly Props
CO annual mean	Max PC	350	0.74	192	0.2%	55.0%	Camilla Props
CO annual mean	Max PEC	350	0.31	217	0.1%	61.9%	Heath/Ivy/Beech Cott

Pollutant	Selection	AQAL (µg m^{-3})	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)	Receptor
CO 100 percentile rolling 8-hour mean	Max PC	10,000	8.96	441	0.1%	4.4%	Moss Bank Farm
CO 100 percentile rolling 8-hour mean	Max PEC	10,000	8.96	441	0.1%	4.4%	Moss Bank Farm
SO_2 99.9 percentile 15-minute mean	Max PC	266	4.64	9.12	1.7%	3.4%	Moss Bank Farm
SO_2 99.9 percentile 15-minute mean	Max PEC	266	1.45	16.43	0.5%	6.2%	Lochgelly School
SO_2 99.73 percentile 1-hour mean	Max PC	350	2.71	7.21	0.8%	2.1%	Moss Bank Farm
SO_2 99.73 percentile 1-hour mean	Max PEC	350	0.75	15.73	0.2%	4.5%	Lochgelly School
SO_2 99.18 percentile 24-hour mean	Max PC	125	0.72	5.20	0.6%	4.2%	Moss Bank Farm
SO_2 99.18 percentile 24-hour mean	Max PEC	125	0.12	15.10	0.1%	12.1%	Lochgelly School
UHCs (as n-butane) annual mean	Max PC	14,500	0.04	35.14	<0.1%	0.2%	Camilla Props
UHCs (as n-butane) annual mean	Max PEC	14,500	0.03	35.15	<0.1%	0.2%	Little Raith
UHCs (as n-butane) 1 hour mean	Max PC	181,000	1.13	73.92	<0.1%	<0.1%	Moss Bank Farm
UHCs (as n-butane) 1 hour mean	Max PEC	181,000	1.02	74.60	<0.1%	<0.1%	Newton Farm
BTEX (as benzene) annual mean	Max PC	3	0.17	0.36	5.3%	11.2%	Camilla Props
BTEX (as benzene) annual mean	Max PEC	3	0.14	0.38	4.3%	11.7%	Moss Bank Farm
BTEX (as benzene) 1 hour mean	Max PC	208	18.27	18.65	8.8%	9.0%	Auchtertool School
BTEX (as benzene) 1 hour mean	Max PEC	208	18.27	18.65	8.8%	9.0%	Auchtertool School

Table 5.2 Summary of impact at human receptor experiencing maximum PC and/or PEC: PGC trip typical peak flaring rate – 130 T h^{-1}

Pollutant	Selection	AQAL (µg m^{-3})	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)	Receptor
NO_2 annual mean	Max PC	40	3.27	10.70	8.2%	26.8%	Camilla Props
NO_2 annual mean	Max PEC	40	2.78	12.81	7.0%	32.0%	Moss Bank Farm

Pollutant	Selection	AQAL (µg m^{-3})	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)	Receptor
NO_2 99.79 percentile 1-hour mean	Max PC	200	20.44	38.16	10.2%	19.1%	Easter Lochead
NO_2 99.79 percentile 1-hour mean	Max PEC	200	19.96	41.69	10.0%	20.8%	Moss Bank Farm
PM_{10} annual mean	Max PC	18	0.10	10.46	0.6%	58.1%	Camilla Props
PM_{10} annual mean	Max PEC	18	0.01	10.92	0.0%	60.7%	Lochgelly Props
PM_{10} 98.08 percentile 24-hour mean	Max PC	50	0.48	21.07	1.0%	42.1%	Moss Bank Farm
PM_{10} 98.08 percentile 24-hour mean	Max PEC	50	0.12	21.95	0.2%	43.9%	Lochgelly Props
$PM_{2.5}$ annual mean	Max PC	10	0.10	5.67	1.0%	56.7%	Camilla Props
$PM_{2.5}$ annual mean	Max PEC	10	0.01	5.92	0.1%	59.2%	Lochgelly Props
CO annual mean	Max PC	350	1.49	201	0.4%	57.5%	Little Raith
CO annual mean	Max PEC	350	0.25	216	0.1%	61.8%	Heath/Ivy/Beech Cott
CO 100 percentile rolling 8-hour mean	Max PC	10,000	28.55	429	0.3%	4.3%	Little Raith
CO 100 percentile rolling 8-hour mean	Max PEC	10,000	11.06	444	0.1%	4.4%	Heath/Ivy/Beech Cott
SO_2 99.9 percentile 15-minute mean	Max PC	266	5.46	9.96	2.1%	3.7%	Moss Bank Farm
SO_2 99.9 percentile 15-minute mean	Max PEC	266	2.88	17.87	1.1%	6.7%	Lochgelly School
SO_2 99.73 percentile 1-hour mean	Max PC	350	3.44	7.86	1.0%	2.2%	Easter Lochead
SO_2 99.73 percentile 1-hour mean	Max PEC	350	1.33	16.31	0.4%	4.7%	Lochgelly School
SO_2 99.18 percentile 24-hour mean	Max PC	125	1.55	5.97	1.2%	4.8%	Easter Lochead
SO2 99.18 percentile 24-hour mean	Max PEC	125	0.30	15.29	0.2%	12.2%	Lochgelly School
UHCs (as n-butane) annual mean	Max PC	14,500	0.18	35.28	<0.1%	0.2%	Little Raith
UHCs (as n-butane) annual mean	Max PEC	14,500	0.18	35.28	<0.1%	0.2%	Little Raith
UHCs (as n-butane) 1 hour mean	Max PC	181,000	7.15	77.69	<0.1%	<0.1%	Easter Lochead
UHCs (as n-butane) 1 hour mean	Max PEC	181,000	7.15	77.69	<0.1%	<0.1%	Easter Lochead

Pollutant	Selection	AQAL (µg m^{-3})	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)	Receptor
BTEX (as benzene) annual mean	Max PC	3	0.18	0.37	5.4%	11.3%	Camilla Props
BTEX (as benzene) annual mean	Max PEC	3	0.14	0.38	4.3%	11.7%	Moss Bank Farm
BTEX (as benzene) 1 hour mean	Max PC	208	18.26	18.64	8.8%	9.0%	Auchtertool School
BTEX (as benzene) 1 hour mean	Max PEC	208	18.26	18.64	8.8%	9.0%	Auchtertool School

Table 5.3 Summary of impact at human receptor experiencing maximum PC and/or PEC: PGC trip instantaneous peak flaring rate – 200 T h^{-1}

Pollutant	Selection	AQAL (µg m^{-3})	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)	Receptor
NO_2 annual mean	Max PC	40	3.31	10.75	8.3%	26.9%	Camilla Props
NO_2 annual mean	Max PEC	40	2.79	12.81	7.0%	32.0%	Moss Bank Farm
NO_2 99.79 percentile 1-hour mean	Max PC	200	20.44	38.16	10.2%	19.1%	Easter Lochead
NO_2 99.79 percentile 1-hour mean	Max PEC	200	19.96	41.69	10.0%	20.8%	Moss Bank Farm
PM_{10} annual mean	Max PC	18	0.10	10.46	0.6%	58.1%	Camilla Props
PM_{10} annual mean	Max PEC	18	0.01	10.92	0.0%	60.7%	Lochgelly Props
PM_{10} 98.08 percentile 24-hour mean	Max PC	50	0.48	21.07	1.0%	42.1%	Moss Bank Farm
PM_{10} 98.08 percentile 24-hour mean	Max PEC	50	0.12	21.95	0.2%	43.9%	Lochgelly Props
$PM_{2.5}$ annual mean	Max PC	10	0.10	5.67	1.0%	56.7%	Camilla Props
$PM_{2.5}$ annual mean	Max PEC	10	0.01	5.92	0.1%	59.2%	Lochgelly Props
CO annual mean	Max PC	350	1.91	202	0.5%	57.6%	Little Raith
CO annual mean	Max PEC	350	0.30	217	0.1%	61.9%	Heath/Ivy/Beech Cott
CO 100 percentile rolling 8-hour mean	Max PC	10,000	39.09	439	0.4%	4.4%	Little Raith
CO 100 percentile rolling 8-hour mean	Max PEC	10,000	13.64	447	0.1%	4.5%	Heath/Ivy/Beech Cott
SO_2 99.9 percentile 15-minute mean	Max PC	266	5.46	9.96	2.1%	3.7%	Moss Bank Farm
SO_2 99.9 percentile 15-minute mean	Max PEC	266	2.88	17.87	1.1%	6.7%	Lochgelly School

Pollutant	Selection	AQAL (µg m^{-3})	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)	Receptor
SO_2 99.73 percentile 1-hour mean	Max PC	350	3.70	8.12	1.1%	2.3%	Easter Lochead
SO_2 99.73 percentile 1-hour mean	Max PEC	350	1.45	16.43	0.4%	4.7%	Lochgelly School
SO_2 99.18 percentile 24-hour mean	Max PC	125	1.64	5.99	1.3%	4.8%	Little Raith
SO_2 99.18 percentile 24-hour mean	Max PEC	125	0.31	15.29	0.2%	12.2%	Lochgelly School
UHCs (as n-butane) annual mean	Max PC	14,500	1.10	36.19	<0.1%	0.2%	Little Raith
UHCs (as n-butane) annual mean	Max PEC	14,500	1.10	36.19	<0.1%	0.2%	Little Raith
UHCs (as n-butane) 1 hour mean	Max PC	181,000	32.66	103	<0.1%	0.1%	Little Raith
UHCs (as n-butane) 1 hour mean	Max PEC	181,000	32.47	103	<0.1%	0.1%	Easter Lochead
BTEX (as benzene) annual mean	Max PC	3	0.20	0.39	6.3%	12.1%	Camilla Props
BTEX (as benzene) annual mean	Max PEC	3	0.20	0.39	6.3%	12.1%	Camilla Props
BTEX (as benzene) 1 hour mean	Max PC	208	18.26	18.64	8.8%	9.0%	Auchtertool School
BTEX (as benzene) 1 hour mean	Max PEC	208	18.26	18.64	8.8%	9.0%	Auchtertool School

Tables 5.1 through 5.3 indicate that there are no predicted exceedances of any AQS, AQO or EAL during normal operation of FEP and during both PGC trip scenarios with the proposed changes to the flare system. On this basis, the risk of adverse impacts on human health would appear to be negligible. The largest PEC as a percentage of the AQS, AQO or EAL is annual mean CO, where a PEC of up to 61.9% of the AQS is predicted at Heath/Ivy/Beech Cottages during the normal operation scenario. However, the background concentration is the largest contributor to the PEC at this location, with the background concentration alone accounting for 61.7% of the AQS and with FEP contributing less than 0.1% of the AQS at this location in each scenario. It should be noted that the background concentrations for CO are for the year 2001 and have not been updated since then.

The results from the PGC trip scenarios are obtained using the ultimate worst-case assumption that such a scenario would occur continuously throughout the year. This would significantly overestimate annual mean impacts as such scenarios, if they did occur, would occur over a matter of hours or days, rather than being a continuous event.

Ecological receptors

Tables 5.4 through 5.6 summarise the receptors results in Appendix E for the ecological receptor experiencing the highest predicted impact from the model. Results are shown for the receptors with the highest PC and the highest PEC; in general these are different receptors due to having different background concentrations.

Table 5.4 Summary of impact at ecological receptor experiencing maximum PC and/or PEC: normal operation

Pollutant	Selection	AQAL (µg m^{-3})	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)	Receptor
NO_x annual mean	Max PC	30	0.19	12.29	0.6%	41.0%	Outer Firth of Forth
NO_x annual mean	Max PEC	30	0.15	12.54	0.5%	41.8%	Firth of Forth
NO_x daily mean	Max PC	75	12.45	38.22	16.6%	51.0%	Outer Firth of Forth
NO_x daily mean	Max PEC	75	12.45	38.22	16.6%	51.0%	Outer Firth of Forth
SO_2 annual mean	Max PC	20	0.01	2.34	<0.1%	11.7%	Outer Firth of Forth
SO_2 annual mean	Max PEC	20	0.01	2.34	<0.1%	11.7%	Outer Firth of Forth
Pollutant	**Selection**	**AQAL (kgN/ha/y)**	**PC (kgN/ha/y)**	**PEC (kgN/ha/y)**	**PC (% of AQAL)**	**PEC (% of AQAL)**	**Receptor**
Nitrogen deposition	Max PC	10	0.02	13.72	0.2%	137%	Outer Firth of Forth
Nitrogen deposition	Max PEC	10	0.02	13.72	0.2%	137%	Outer Firth of Forth
Pollutant	**Selection**	**AQAL (% of CL function)**	**PC (% of CL function)**	**PEC (% of CL function)**	**PC (% of AQAL)**	**PEC (% of AQAL)**	**Receptor**
Acid Deposition*	Max PC	100%	0.47%	220%	0.47%	220%	Outer Firth of Forth
Acid Deposition*	Max PEC	100%	0.47%	220%	0.47%	220%	Outer Firth of Forth

* Acid deposition results expressed as percentage of the site-specific critical load function

Table 5.5 Summary of impact at ecological receptor experiencing maximum PC and/or PEC: PGC trip typical peak flaring rate – 130 T h^{-1}

Pollutant	Selection	AQAL (µg m^{-3})	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)	Receptor
NO_x annual mean	Max PC	30	0.21	12.31	0.7%	41.0%	Outer Firth of Forth
NO_x annual mean	Max PEC	30	0.17	12.56	0.6%	41.9%	Firth of Forth
NO_x daily mean	Max PC	75	14.29	40.07	19.1%	53.4%	Outer Firth of Forth
NO_x daily mean	Max PEC	75	14.29	40.07	19.1%	53.4%	Outer Firth of Forth
SO_2 annual mean	Max PC	20	0.01	2.34	0.1%	11.7%	Outer Firth of Forth

Pollutant	Selection	AQAL ($\mu g\ m^{-3}$)	PC ($\mu g\ m^{-3}$)	PEC ($\mu g\ m^{-3}$)	PC (% of AQAL)	PEC (% of AQAL)	Receptor
SO_2 annual mean	Max PEC	20	0.01	2.34	0.1%	11.7%	Outer Firth of Forth
Pollutant	**Selection**	**AQAL (kgN/ha/y)**	**PC (kgN/ha/y)**	**PEC (kgN/ha/y)**	**PC (% of AQAL)**	**PEC (% of AQAL)**	**Receptor**
Nitrogen deposition	Max PC	10	0.02	13.72	0.2%	137.2%	Outer Firth of Forth
Nitrogen deposition	Max PEC	10	0.02	13.72	0.2%	137.2%	Outer Firth of Forth
Pollutant	**Selection**	**AQAL (% of CL function)**	**PC (% of CL function)**	**PEC (% of CL function)**	**PC (% of AQAL)**	**PEC (% of AQAL)**	**Receptor**
Acid Deposition*	Max PC	100%	0.59%	221%	0.59%	220.59%	Outer Firth of Forth
Acid Deposition*	Max PEC	100%	0.59%	221%	0.59%	220.59%	Outer Firth of Forth

* Acid deposition results expressed as percentage of the site-specific critical load function

Table 5.6 Summary of impact at ecological receptor experiencing maximum PC and/or PEC: PGC trip instantaneous peak flaring rate – 200 T h^{-1}

Pollutant	Selection	AQAL ($\mu g\ m^{-3}$)	PC ($\mu g\ m^{-3}$)	PEC ($\mu g\ m^{-3}$)	PC (% of AQAL)	PEC (% of AQAL)	Receptor
NO_x annual mean	Max PC	30	0.21	12.31	0.7%	41.0%	Outer Firth of Forth
NO_x annual mean	Max PEC	30	0.17	12.56	0.6%	41.9%	Firth of Forth
NO_x daily mean	Max PC	75	14.32	40.09	19.1%	53.5%	Outer Firth of Forth
NO_x daily mean	Max PEC	75	14.32	40.09	19.1%	53.5%	Outer Firth of Forth
SO_2 annual mean	Max PC	20	0.01	2.34	0.1%	11.7%	Outer Firth of Forth
SO_2 annual mean	Max PEC	20	0.01	2.34	0.1%	11.7%	Outer Firth of Forth
Pollutant	**Selection**	**AQAL (kN/ha/y)**	**PC (kgN/ha/y)**	**PEC (kN/ha/y)**	**PC (% of AQAL)**	**PEC (% of AQAL)**	**Receptor**
Nitrogen deposition	Max PC	10	0.02	13.72	0.2%	137.2%	Outer Firth of Forth
Nitrogen deposition	Max PEC	10	0.02	13.72	0.2%	137.2%	Outer Firth of Forth
Pollutant	**Selection**	**AQAL (% of CL function)**	**PC (% of CL function)**	**PEC (% of CL function)**	**PC (% of AQAL)**	**PEC (% of AQAL)**	**Receptor**
Acid Deposition*	Max PC	100%	0.60%	221%	0.60%	220.60%	Outer Firth of Forth
Acid Deposition*	Max PEC	100%	0.60%	221%	0.60%	220.60%	Outer Firth of Forth

* Acid deposition results expressed as percentage of the site-specific critical load function

Tables 5.4 through 5.6 indicate that there are no predicted exceedances of any AQS, AQO or EAL during normal operation of FEP and during both PGC trip scenarios with the proposed changes to the flare system. On this basis, the risk of adverse impacts on human health would appear to be negligible. The largest PEC as a percentage of the AQS, AQO or EAL is nitrogen deposition, where there are exceedances of the minimum critical load at all ecological receptors. However, this is almost entirely due to the existing background, with the PC being at most 0.2% of the critical load.

The PCs for all long-term effects are less than 1% of the relevant assessment level at all receptors in all scenarios. The PCs for shorter-term effects, namely daily mean NO_x, are less than 20% of the critical level at all receptors in all scenarios, with the PEC less than 54% of the critical level. Impacts on habitat sites, including the Firth of Forth Special Protection Area (SPA)/Ramsar site, Outer Firth of Forth and St Andrews Bay Complex SPA and Forth Islands SPA, are therefore assessed as insignificant under SEPA's H1 Horizontal Guidance.

The results from the PGC trip scenarios are obtained using the ultimate worst-case assumption that such a scenario would occur continuously throughout the year. This would significantly overestimate annual mean impacts as such scenarios, if they did occur, would occur over a matter of hours or days, rather than being a continuous event. The modelling also assumes that the flaring events would occur when the worst-case meteorology was occurring in terms of contributions to daily mean NO_x concentrations, which is unlikely.

5.2 Comparison of impacts with the existing flare system

Table 5.7 compares the change in the ground level concentration at the human receptor experiencing the maximum process contribution between the existing site scenario and with the proposed new EGF operating (this may be a different receptor in the two scenarios). The comparison is made for each of the three flare emission scenarios and pollutant averaging period. Cells are shaded green where the concentration in the proposed scenario is lower than in the existing scenario, orange where it is higher, and white where the change, as a percentage of the relevant AQAL, is smaller than 0.1% in absolute value.

Model predictions for each receptor for the existing site scenario are provided in Appendix E.

Table 5.7 Change in maximum impact at any receptor between the existing and proposed operation of FEP with the new EGF operational

Pollutant	Normal operation (µg m^{-3})	PGC trip – typical peak rate (µg m^{-3})	PGC trip – instantaneous peak rate (µg m^{-3})
NO2 annual mean	0.00	-0.15	-0.10
NO2 99.79 percentile 1-hour mean	-0.07	0.00	0.00
PM10 annual mean	0.00	-0.22	-0.17
PM10 98.08 percentile 24-hour mean	0.00	-1.56	-1.51
PM2.5 annual mean	0.00	-0.22	-0.17
CO annual mean	0.00	-1.45	-1.04
CO 100 percentile rolling 8-hour mean	-0.61	-24.52	-13.95
SO2 99.9 percentile 15-minute mean	0.00	-0.01	-0.02
SO2 99.73 percentile 1-hour mean	0.00	-1.18	-0.87

Pollutant	Normal operation (µg m^{-3})	PGC trip – typical peak rate (µg m^{-3})	PGC trip – instantaneous peak rate (µg m^{-3})
SO2 99.18 percentile 24-hour mean	0.00	-0.72	-0.63
UHCs (as n-butane) annual mean	-0.01	-1.02	-1.33
UHCs (as n-butane) 1 hour mean	-0.42	-27.21	-20.55
BTEX (as benzene) annual mean	0.00	-0.03	-0.03
BTEX (as benzene) 1 hour mean	0.00	0.00	0.00
NOx annual mean	0.00	-0.01	-0.01
NOx daily mean	-0.01	0.03	0.04
SO2 annual mean	0.00	0.00	0.00
Pollutant	**Normal operation (kgN/ha/y)**	**PGC trip – typical peak rate (kgN/ha/y)**	**PGC trip – instantaneous peak rate (kgN/ha/y)**
Nitrogen deposition	0.00	0.00	0.00
Pollutant	**Normal operation (% of CL function)**	**PGC trip – typical peak rate (% of CL function)**	**PGC trip – instantaneous peak rate (% of CL function)**
Acid Deposition	0.00	-0.08	-0.08

Normal operation scenario

In the normal operation scenario, there is negligible difference in the predictions between the proposed flare system and the existing flare system for most pollutants. This is because flare emissions are not the dominant emission source during normal operation of FEP, with emissions from the furnaces, boilers and gas turbine dominating.

For the one pollutant to which the flare system is the dominant/only emitter in this scenario, i.e., UHCs, it is evident the proposed flare system reduces the impact from the current site scenario. This is due to combining the base load flare stream to a single EGF whose combined buoyancy and momentum is greater than the sum of such effects from the separate Shell ground flares, whilst the release height of the new EGF is greater than that of the two Shell ground flares.

PGC trip – typical peak rate

In this scenario, the primary difference between the proposed flare system and existing flare system is as follows:

- Use of elevated flare – with the existing flare system, 85 T h^{-1} of gas is routed to the elevated flare whereas, with the proposed flare system, the elevated flare is not operational in this scenario, with all gas routed to the new EGF.
- Consolidation of ground flares – with the existing flare system, 45 T h^{-1} of gas is routed to the two Shell ground flares (22.5 T h^{-1} each), whereas, with the proposed flare system, all 130 T h^{-1} of gas is routed to the new, single ground flare.

There is either a reduction in the maximum predicted impact with the proposed flare system, or no significant change, for each pollutant. The maximum daily mean NO_x PC is very slightly higher with the

proposed flare system, but this increase is just 0.03 µg m^{-3} or 0.04% of the AQAL, and considered to be insignificant. Although 85 T h^{-1} of gas has been diverted from the elevated flare to the ground flare, there are several competing factors which mitigate the effects of reducing the release height, with an individual receptor experiencing either a decrease or negligible increase in impact dependent on its location and how these competing factors influence the dispersion of emissions from FEP at that specific distance/orientation from the emission source. These mitigating factors include:

- Due to their enclosed nature, it is easier to control and optimise combustion conditions in ground flares, resulting in an increase in the combustion efficiency whilst the fraction of heat radiated reduces considerably. The combined effect of these factors is to increase the plume buoyancy, which increases buoyancy-driven plume rise above that which occurs from the elevated flare.
- The improved combustion efficiency significantly reduces the formation of particulate matter and reduces unburnt hydrocarbon emissions. Thus, for PM_{10}, $PM_{2.5}$ and UHCs, there is a dual effect of increasing plume buoyancy and reduced emission rate which drives the reduction in ground level impacts.
- Consolidation of the ground flares also acts to reduce the maximum impact of some pollutants, as discussed in the normal operation scenario.

There are no, or more minor reductions, in maximum NO_2 and BTEX impacts between the existing and proposed flare system scenarios. This is a consequence of other non-flare emission sources having a more dominant impact on ground level concentrations (the furnaces, boilers and gas turbine for NO_2, and the caustic oxidiser vent for BTEX).

PGC trip – peak instantaneous rate

In this scenario, the primary difference between the proposed flare system and existing flare system is as follows:

- Use of elevated flare – with the existing flare system, 155 T h^{-1} of gas is routed to the elevated flare whereas, with the proposed flare system, 70 T h^{-1} of gas is routed to the elevated flare.
- Consolidation of ground flares – with the existing flare system, 45 T h^{-1} of gas is routed to the two Shell ground flares (22.5 T h^{-1} each), whereas, with the proposed flare system, 130 T h^{-1} of gas routed to the new, single ground flare.

Like the typical peak rate PGC trip scenario, for each pollutant there is predicted to be either a reduction in the maximum predicted ground level impact of the instantaneous peak rate during a PGC trip scenario, or no significant change compared to the existing configuration. The maximum daily mean NO_x PC is slightly higher with the proposed flare system, but as with the typical peak flaring rate, this increase is negligible, representing an increase of less than 0.1% of the critical level.

5.3 Formation of secondary pollutants

The modelling assessment only considers the emissions of primary pollutants from FEP. Primary pollutants are those species which are present in the discharges from the flares and other stacks. Upon their discharge to the atmosphere, certain primary pollutants may undergo subsequent chemical reactions with other chemicals in the atmosphere to form different compounds which themselves can be considered a pollutant. These additional pollutants are known as secondary pollutants and include ozone (O_3) and secondary particulate matter, also known as secondary inorganic aerosol (SIA).

In the stratosphere[32], ozone is beneficial to human health, since it reduces the levels of harmful UV radiation from the sun reaching the surface of the Earth. However, at low altitudes in the troposphere[33], ozone can be considered an air pollutant where it can affect respiratory and pulmonary function. Hence, it is important to distinguish between the beneficial ozone, known as stratospheric ozone, and the potentially detrimental ozone, known as tropospheric ozone.

Tropospheric ozone is formed from a multitude of complex chemical reactions that take place in the atmosphere in the presence of sunlight. However, as discussed in Section 2.9, the most important reactions linking ozone formation are those involving NO_x. Emissions of NO_x from combustion processes are predominantly in the form of nitrogen monoxide (NO). Excess oxygen in the combustion gases and further atmospheric reactions cause the oxidation of NO to nitrogen dioxide (NO_2). Two of the key reactions interlinking NO and NO_2 are detailed below:

$$NO_2 + h\nu \overset{O_2}{\rightarrow} NO + O_3 \quad \text{(R1)}$$

$$NO + O_3 \rightarrow NO_2 + O_2 \quad \text{(R2)}$$

where $h\nu$ is used to represent a photon of light energy (i.e., sunlight) and O_2 represents a molecule of oxygen.

Taken together, reactions R1 and R2 produce no net change in tropospheric O_3 concentrations, and NO and NO_2 adjust to establish a near steady state reaction (photo-equilibrium). However, this equilibrium can be disturbed. For instance, near to a significant emission source of NO, the equilibrium can be perturbed, resulting in the promotion of reaction R2 and a corresponding reduction in local O_3 concentrations. Further away from local sources of NO, the equilibrium is re-established and, during daylight, O_3 concentrations can increase due to the interaction of other atmospheric pollutants, including carbon monoxide, and the subsequent photolysis of NO_2 via reaction R1.

The NO_x emitted from most combustion processes, including those at FEP, is generally in the form of NO with only a limited amount of primary NO_2 emitted – as much as 95% of the NO_x emitted during combustion is in the form of NO. As such, in the area local to FEP, emissions of NO_x from FEP would most likely contribute to a reduction in local O_3 concentrations due to the promotion of reaction R2. Much further downwind (typically greater than several kilometres) after the equilibrium has re-established and the influence of other pollutants becomes important, O_3 concentrations would begin to increase. However, as the emissions from FEP would be considerably diluted by this point, any increase in O_3 concentrations above background levels as a direct result of FEP emissions would be negligible.

Previous studies of emissions from large industrial emission sources, such as those by Preiss et al (2013)[34], found that the overall health risks associated with changes to O_3 concentrations as a result of primary emissions of NO_x were negative, i.e., producing an overall health *benefit* with respect to O_3. Whilst such an outcome would be influenced by site-specific variables, this study demonstrated the scavenging effect of NO on O_3 close to the emission source which was sufficient to off-set the subsequent formation of low concentrations of O_3 from photolysis of NO_2 at distances further downwind.

With respect to SIA, these are typically nitrate and sulphate particles formed because of further reaction of the primary NO_2 and SO_2 released from an emission source with other pollutants in the atmosphere including ozone and ammonia. The aerosols formed are typically within the $PM_{2.5}$ fraction. SIA formation takes time (hours to days) and, as such, occurs at distances much further downwind from an emission source where the plume has been sufficiently diluted. Consequently, impacts of secondary pollutants are typically negligible when considering a single emission source/site in isolation.

[32] A layer of the atmosphere above the troposphere from ~ 10 – 50 km above ground

[33] The lowest layer of the atmosphere, present from ground to ~ 10 km above ground

[34] Preiss, P., Roos, J. and Friedrich, R., 2013. 'Estimating Health Risks caused by Emissions of Air Pollutants from Coal Fired Power Plants in Europe - Documentation of Methods and Results'

6. Conclusions

This report provides an assessment of the impact on local air quality following the introduction of a new EGF at FEP. Once commissioned, the EGF will reduce both the frequency and volume of gas sent to the existing elevated flare which will have benefits from both a noise and vibration, and visual impact perspective. However, as the EGF has a lower release height, there is the potential that increases in ground level concentrations may occur.

The principal conclusion of this assessment is that that there are no predicted exceedances of any AQS, AQO or EAL during normal operation of FEP and during non-routine flaring representing a PGC trip flare event and, on this basis, the risk of adverse impacts on human health or on ecological sites due to flaring activities at FEP would appear to be negligible. This conclusion is entirely consistent with the conclusions of previous studies which identified that, for most pollutants, background concentrations dominate the model prediction.

The assessment also concludes that, despite diverting the flare gas streams from the elevated flare to the EGF, for the majority of pollutants there would be a reduction in maximum ground level impacts at human receptor locations with the EGF in operation. Although the EGF has a lower release height than the elevated flare, due to its enclosed nature, it is easier to control and optimise combustion conditions, resulting in an increase in the combustion efficiency, whilst the fraction of heat radiated also reduces considerably. The combined effect of these factors is to increase the plume buoyancy, which increases buoyancy-driven plume rise above that which occurs from the elevated flare.

Additionally, the improved combustion efficiency significantly reduces the formation of particulate matter and reduces unburnt hydrocarbon emissions. Thus, for PM_{10}, $PM_{2.5}$ and UHCs, there is a dual effect of increasing plume buoyancy and reduced emission rate which drives the reduction in ground level impacts.

Impacts on habitat sites, including the Firth of Forth Special Protection Area (SPA)/Ramsar site, Outer Firth of Forth and St Andrews Bay Complex SPA and Forth Islands SPA, are assessed as insignificant under SEPA's H1 Horizontal Guidance.

Appendix A
Flare emissions modelling methodology

Derivation of flare emission parameters

The methodology considers the dispersion of pollutants emitted by the flare from the start of the buoyant region above the flame, rather than the flare stack tip. Due to this approach, effective parameters are needed to define the release height, location and diameter for input to the model.

The still air flame length is estimated using the American Petroleum Institute R521 correlation (API, 2014) [35]:

$$L_0 = 2.76Q^{0.452}$$

where;

L_0 = flame length in still air (m)

Q = heat release rate (MW)

In a crosswind, the still air flame length is significantly reduced due to increased entrainment of air along the flame. In order to account for the effects of a crosswind on the flame length, the relationship in Chamberlain (1987)[36] is used:

$$L = L_0(0.51e^{-0.4u_w} + 0.49)\left[1 - 6.07 \times 10^{-3}(\theta_j - 90)\right]$$

Where:

L = wind corrected flame length (m)

u_w = wind speed (m s^{-1})

θ_j = angle of the release from horizontal (degrees)

For most onshore flare stacks, the release is vertical ($\theta_j = 90$) and the value in the square brackets resolves to unity.

The heat release rate is calculated from the flare feed gas flow rate and composition:

$$Q = \varepsilon \dot{m} \sum_{i=1}^{N} f_{m_i} \Delta H_{LV}$$

Where:

ε = combustion efficiency

$\dot{m}$ = mass flow rate to flare (kg s^{-1})

f_{m_i} = mass fraction of ith component in the gas mixture

[35] API, 2014. 'Pressure-relieving and Depressuring Systems' ANSI/API Standard 521 Sixth Edition, American Petroleum Institute, Washington D.C.

[36] Chamberlain, G., 1987. 'Developments in Design Methods in Predicting Thermal Radiation from Flares' Chemical Engineering Research and Design, 65(4), 299-309

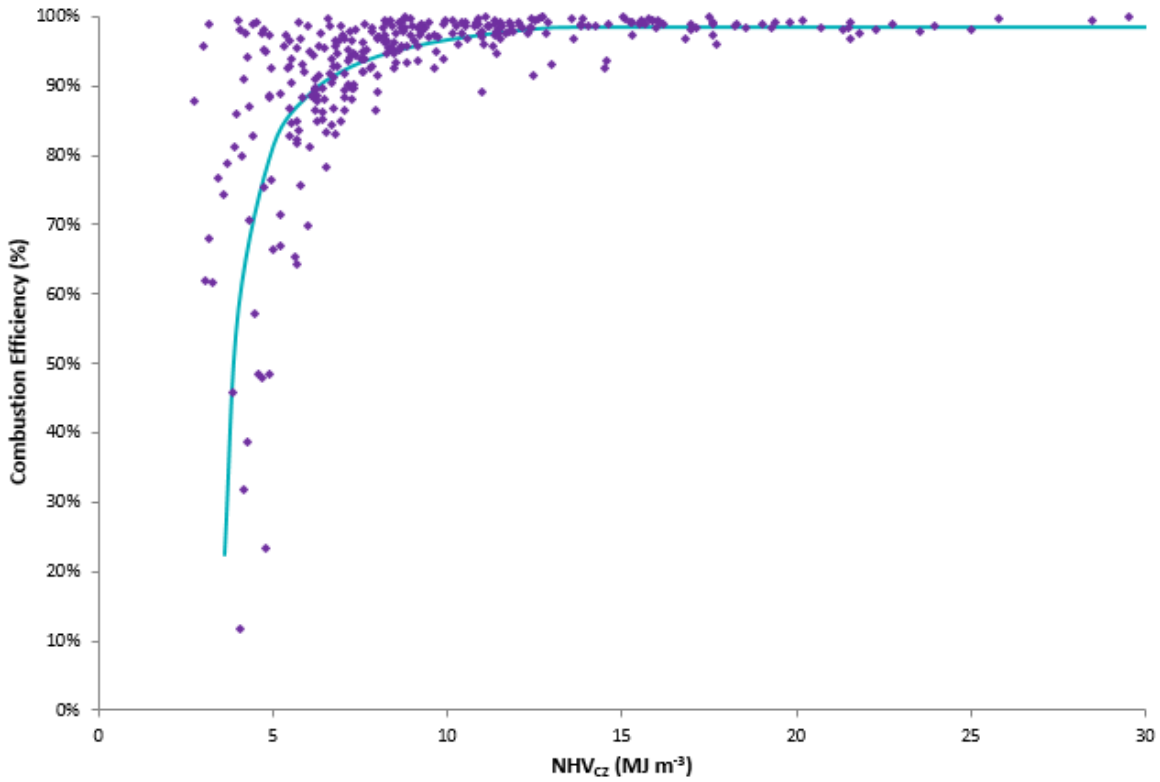
ΔH_{LV} = lower heating value of *i*th component in the gas mixture (MJ kg^{-1})

The United States Environmental Protection Agency (USEPA) undertook studies to ascertain the impact of several variables on flare combustion efficiency (USEPA, 1983[37], 1986[38]). These extensive studies led them to conclude:

> *"When flares are operated under conditions which are representative of industrial practices, the combustion efficiencies in the flare plume are greater than 98%."*

However, more recent field studies in USEPA (2012)[39] reveal that significant departures from this level of efficiency can occur when flaring low calorific feeds or in high wind speed conditions. Indeed, the USEPA (2012) study concludes that a combustion efficiency of 98% is generally only achievable where the net calorific value of the gas mixture in the flare combustion zone (including support fuel and injection of inerts e.g., steam or air) exceeds ~13-15 MJ m^{-3}. Figure A.1 plots the combustion efficiency as a function of the net heating value of the mixture in the combustion zone based on the raw data reported by US EPA (2012).

Figure A.1 Flare combustion efficiency as a function of net heating value in the combustion zone



Using the US EPA (2012) data, Wood has developed a relationship linking the combustion efficiency to the net heating value of the mixture in the combustion zone. The relationship is provided below and plotted graphically on Figure A.1 as the solid light blue line.

[37] US EPA, 1983. 'Flare Efficiency Study' United States Environmental Protection Agency, Washington, D.C., Report EPA600/2-83-052.

[38] US EPA, 1986. 'Evaluation of the Efficiency of Industrial Flares: H_2S Mixtures and Pilot Assisted Flares' United States Environmental Protection Agency, Washington, D.C., Report EPA600/2-86-080

[39] US EPA, 2012. 'Parameters for Properly Designed and Operated Flares'

$$\varepsilon = min\left(\frac{1}{1+\frac{0.4}{NHV_{cz}-3.5}}+0.025, \varepsilon_{max}\right)$$

Where:

ε_{max} = 0.985

NHV_{cz} = net heating value of gas mixture in the combustion zone (MJ m^{-3}).

The net heating value of the mixture in the combustion zone is calculated as follows:

$$NHV_{cz} = NHV_{vg}\frac{V_{vg}}{V_{vg}+V_{inerts}}$$

Where:

NHV_{vg} = net heating value of the vent gas/feed to flare (MJ m^{-3})

V_{vg} = volumetric flow rate of vent gas to the flare (Sm^3 s^{-1})

V_{inerts} = volumetric flow rate of assist steam or air (Sm^3 s^{-1})

For NHV_{cz} values less than 3.5 MJ m^{-3}, ε is set to take a value of 0.2 (20%).

Leahey and Davis (1984)[40] conducted field tests to validate a model used to calculate the fraction of heat radiated from flares. As part of these experiments, the flame length and expanded diameter were recorded. The average length/diameter ratio from these field tests is used to calculate the expanded flame diameter/effective flare release diameter, d_{eff}, from the calculated flame length:

$$d_{eff} = 0.24L$$

Crosswinds cause deflection of the flame from the vertical, reducing the height above ground level at which the flame terminates. The degree of deflection is dependent upon the wind speed, u_w, and velocity of the expanded jet, u_j. The velocity of the expanded jet is calculated as:

$$u_j = M_j\sqrt{\frac{\gamma R T_j}{MW_k}}$$

Where:

u_j = velocity of expanded jet (m s^{-1})

M_j = Mach number of the expanded jet (dimensionless)

γ = Ratio of specific heats (dimensionless)

R = Universal gas constant (=8.314 J mol^{-1} k^{-1})

T_j = Temperature of expanded jet (K)

MW_k = Molecular mass of the flare gas (kg mol^{-1})

The temperature of the expanded jet is calculated as:

[40] Leahey, D. and Davies, M., 1984. 'Observations of Plume Rise from Sour Gas Flares' Atmospheric Environment, 18, 917-922

$$T_j = T_0 \left(\frac{p_a}{p_0}\right)^{\frac{\gamma-1}{\gamma}}$$

Where:

T_0 = Initial temperature at the exit point (K)

p_a = Atmospheric pressure (Pa)

p_0 = Initial pressure at exit point (Pa)

The Mach number of the expanded jet is calculated as per API (2014):

$$M_j = 116.28 \frac{\dot{m}}{p_a d_0^2} \sqrt{\frac{ZT_j}{MW}}$$

Where:

d_0 = flare tip diameter (m)

Z = compressibility factor (dimensionless)

MW = relative molecular weight (dimensionless)

The deflection of the flame can then be modelled by splitting the flame into a series of circular segments of length, $L_{segment}$, and with $L_{segment}$ defined by the ratio L/N, where N represents the number of circular segments. In this case, N is set to a value of 10.

For each circular segment, the vertical gradient dz/dx can be calculated from Cook et al. (1990)[41]:

$$\frac{dz}{dx} = 1.6\pi \frac{d_{eff} u_j}{u_w} \left(\frac{1}{S_i} - \frac{1}{L}\right)$$

Where S_i represents the distance along the flame centreline for the ith circle, given by:

$$S_i = \frac{i}{N} L$$

By setting z_0 to the height of the flare stack, h_s, the height above ground level of subsequent circular segments can be found from:

$$z_i = z_{i-1} + z_{increment}$$

With $z_{increment}$ evaluated for each segment as:

$$z_{increment} = \frac{L_{segment}}{\sqrt{1 + \left(\frac{dz}{dx}\right)^{-2}}}$$

The effective release height for the flare source then becomes z_N. For scenarios with wind speeds less than 0.5 m s^{-1}, it is assumed that flame deflection is negligible and z_N is simply set to take the value of $L + h_s$.

In order to account for thermal buoyancy effects produced by the flare, the heat released during combustion is used to define the buoyancy flux parameter which is then used as a direct input parameter in the model. However, not all the heat released during combustion will be available to produce buoyancy-driven plume

[41] Cook, J., Bahrami, Z. and Whitehouse, R.J., 1990. 'A Comprehensive Program for Calculation of Flame Radiation Levels' Journal of Loss Prevention in the Process Industries, 3, 150-155.

rise. A fraction of the total heat release will be lost as thermal radiation and this fraction must be subtracted before the buoyancy flux parameter can be defined, as follows:

$$F_b = (1 - F_r)Q$$

Where:

F_b = buoyancy flux parameter (MW)

F_r = fraction of heat radiated

The fraction of heat radiated from a flare is dependent upon several factors, including the gas composition, flame type, soot/smoke formation, jet velocity and flare burner design. The fraction of heat radiated is less for hydrogen and methane than it is for longer chain hydrocarbons. For a pure hydrogen flame, values in the literature for the fraction of heat radiated range from 15% whilst methane is typically quoted as 20%. For hydrocarbon mixtures, F_r is typically of the order of 0.4 (i.e., 40% of the total heat release is lost as radiation).

In order to calculate F_r, the relationship derived by Cook et al. (1990) is used, with a limit of 0.5 set for the maximum amount of heat radiated:

$$F_r = min\left(0.5, f_{MW}\left[0.11 + exp\left(-0.00323u_j\right)\right]\right)$$

Where:

$MW < 21$: $f_{MW} = 1$

$21 < MW \leq 60$: $f_{MW} = \sqrt{\frac{MW}{21}}$

$MW > 60$: $f_{MW} = 1.69$

When defining the momentum flux parameter, consideration needs to be given to the fact that this method assumes dispersion begins at the start of the buoyant region above the flame, and not at the flare stack tip. Consequently, the relationships in McCaffrey (1979)[42] are used to calculate the effective temperature rise above ambient and the plume centreline velocity at the termination point of the flame.

The effective temperature rise above ambient at the start of the buoyant plume is calculated as:

$$\Delta T_p = 1.49 \frac{T_a}{2g}\left(\frac{L}{1 \times 10^3 Q^{2/5}}\right)^{-5/3}$$

Where:

ΔT_p = effective temperature rise above ambient at the start of the buoyant plume (K)

T_a = ambient temperature (K)

g = acceleration due to gravity (9.81 m s^{-2})

The effective temperature rise above ambient is then used to calculate the effective plume density:

$$\rho_p = \frac{p_a}{R^*\left(T_a + \Delta T_p\right)}$$

[42] McCaffrey, B.J., 1979. 'Purely Buoyant Diffusion Flames: Some Experimental Results' NBSIR 79-1910

Where:

ρ_p = effective plume density (kg m^{-3})

R^* = specific gas constant for the buoyant plume (J kg^{-1} K^{-1})

The plume centreline velocity at the start of the buoyant plume region is also calculated using McCaffrey (1979):

$$u_p = 1.1 \times 10^3 Q^{1/5} \left(\frac{L}{1 \times 10^3 Q^{2/5}} \right)^{-1/3}$$

Where:

u_p = plume centerline velocity (m s^{-1})

Finally, the plume centreline velocity and effective plume density are used to calculate the momentum flux:

$$F_m = \frac{\pi d_{eff}^2 u_p^2 \rho_p}{4 \rho_a}$$

Where:

F_m = momentum flux (m^4 s^{-2})

Another modification to the physical stack parameters that needs to be made when assuming dispersion originates from the buoyant region above the flame is to amend the release co-ordinates to reflect the shift in downwind position of the flame tip in a crosswind. The Cook et al. (1990) approach of splitting the flame in to a number of circular segments can also be used to calculate the horizontal displacement of the flame tip, with the incremental downwind shift in each segment calculated as:

$$x_{increment} = \frac{L_{segment}}{\sqrt{1 + \left(\frac{dz}{dx}\right)^2}}$$

The shift in the X and Y release co-ordinates, ΔX and ΔY respectively, due to flame deflection can be determined from the wind direction, ϕ_w, and the downwind displacement of the flame tip, x_N. The (increasing) positive X axis is defined as North and the increasing positive Y axis is defined as East. The wind direction, ϕ_w, is defined in degrees (clockwise from North) and represents the wind blowing from this direction.

The calculation of ΔX and ΔY is.

$$\Delta X = -x_N \sin \phi_w$$
$$\Delta Y = -x_N \cos \phi_w$$

The effective release co-ordinates, X_{eff} and Y_{eff}, can then be determined from the physical co-ordinates of the flare stack, X_s and Y_s, as follows:

$$X_{eff} = X_s + \Delta X$$
$$Y_{eff} = Y_s + \Delta Y$$

Method validation

Validation of the Wood flare modelling methodology has been undertaken with reference to monitored ambient concentrations of SO_2 recorded by an air quality monitoring station (AQMS) near an operational UK refinery.

The AQMS was commissioned for a 12-month period to continuously monitor concentrations of SO_2 for regulatory compliance purposes. Although the AQMS was not specifically commissioned for the purposes of this study, data recorded by the station does present the opportunity to validate the flare modelling method.

Ambient concentrations of SO_2 were monitored continuously using a UV fluorescent real-time SO_2 analyser in accordance with the procedural requirements of BS EN 14212:2012. To ensure that the data recorded were accurate and reliable, a high standard of maintenance, calibration, operational and QA/QC procedures in line with the UK Automatic Urban Rural Network Site Operator's Manual was maintained for the duration of the operation of the monitoring survey. The QA/QC programme included an established schedule of regular site calibrations and subsequent validation and ratification of the raw data.

In addition to continuously monitoring ambient concentrations of SO_2, the AQMS was also equipped with a meteorological station recording wind speed, wind direction and temperature data. These data were subsequently used as inputs to the model with missing cloud cover data obtained from a local synoptic weather station operated by the UK Met Office.

Predictions of SO_2 concentrations using the Wood flare method were compared with equivalent methods proposed by the Alabama Department of Environmental Management (ADEM), the Ohio Environmental Protection Agency (Ohio EPA) and the Iowa Department of Natural Resources (Iowa DNR).

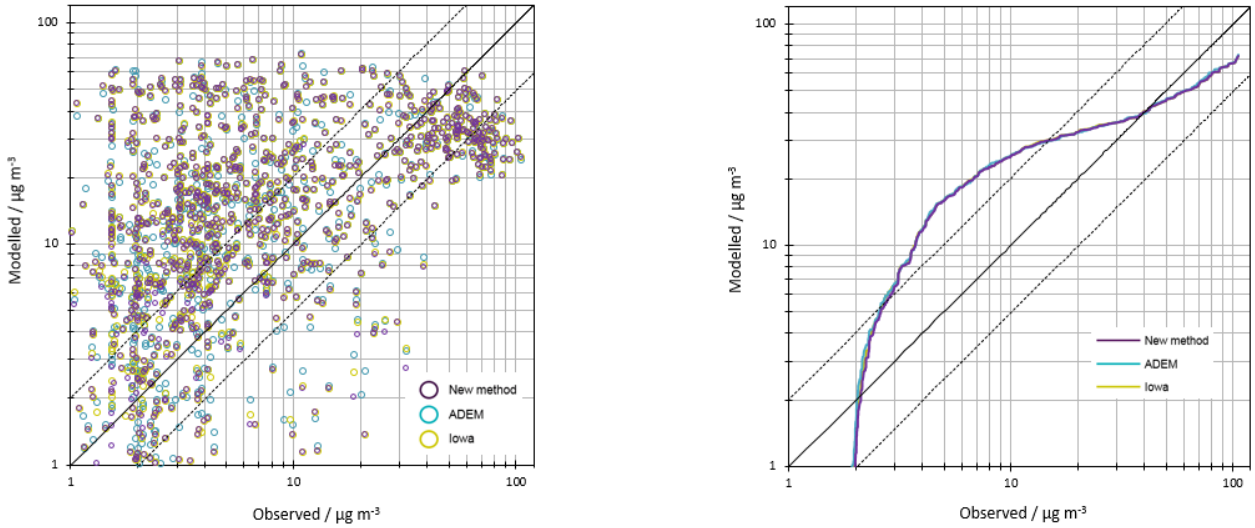
Evaluation of model predictions against observed concentration data from the four individual flare emission methodologies was made using a combination of statistical tests prescribed by the Model Validation Kit (Olesen and Chang, 2010) and openair software (Carslaw and Ropkins, 2012). These include calculation of the correlation co-efficient, r, fraction of modelled values within a factor of two of the observed values, FA2, mean gross error, MGE and fractional bias, FB

Results of the validation exercise are presented in Clegg (2017) and summarised below.

Table A.1 Evaluation of the Wood flare method compared to other commonly used flare modelling methods

Case	n	Mean	r	FA2	MGE	FB
Observations	1,231	12.7	1	1	0	0
Wood method	1,231	16.2	0.423	0.329	12.7	-0.242
ADEM method	1,231	16.6	0.418	0.322	13.0	-0.266
Ohio EPA method	1,231	16.6	0.418	0.322	13.0	-0.266
Iowa DNR method	1,231	16.5	0.419	0.324	13.0	-0.260

Figure A.2 Scatter and quantile-quantile plots from the validation exercise



The validation exercise demonstrated little difference between each method, primarily due to combustion and process plant emissions being the dominant contributor to predicted impacts at the monitoring station. The Wood method, however, did produce mean predictions closer to those observed, with the highest correlation co-efficient and FA2 value, and lowest mean gross error and fractional bias values.

Appendix B
Modelled flare gas flow rates and compositions

Table B.1 Flare gas flow rates and composition for the normal operation scenario (current flare system)

Case	FEP Elevated Flare	FNGL Elevated Flare	7005-B	7005-B
Mass flow rate to flare (kg h^{-1})	114	297	334	334
Composition (%w/w)				
Hydrogen	10.07	0.00	10.07	10.07
Nitrogen	12.15	0.00	12.15	12.15
Methane	22.22	0.00	22.22	22.22
Ethane	26.09	0.00	26.09	26.09
Ethylene	19.47	0.00	19.47	19.47
Acetylene	0.00	0.00	0.00	0.00
Propylene	3.65	0.00	3.65	3.65
Propane	3.83	43.00	3.83	3.83
Butylene	2.52	0.00	2.52	2.52
Butane	0.00	57.00	0.00	0.00

Table B.2 Flare gas flow rates and composition for the PGC trip scenario with typical peak flaring rate (current flare system)

Case	FEP Elevated Flare	FNGL Elevated Flare	7005-B	7005-B
Mass flow rate to flare (kg h^{-1})	85,000	297	22,500	22,500
Composition (%w/w)				
Hydrogen	4.30	0.00	4.30	4.30
Methane	8.40	0.00	8.40	8.40
Ethane	21.50	0.00	21.50	21.50
Ethylene	54.50	0.00	54.50	54.50
Acetylene	1.20	0.00	1.20	1.20
Propylene	1.70	0.00	1.70	1.70
Propane	0.20	43.00	0.20	0.20

Case	FEP Elevated Flare	FNGL Elevated Flare	7005-B	7005-B
Butylene	2.60	0.00	2.60	2.60
Butane	0.00	57.00	0.00	0.00
Benzene	4.40	0.00	4.40	4.40
Water	1.40	0.00	1.40	1.40
Carbon monoxide	0.17	0.00	0.17	0.17
Hydrogen sulphide	0.0265	0.00	0.0265	0.0265

Table B.3 Flare gas flow rates and composition for the PGC trip scenario with instantaneous peak flaring rate

Case	FEP Elevated Flare	FNGL Elevated Flare	7005-B	7005-B
Mass flow rate to flare (kg h^{-1})	145,000	297	22,500	22,500
		Composition (%w/w)		
Hydrogen	4.30	0.00	4.30	4.30
Methane	8.40	0.00	8.40	8.40
Ethane	21.50	0.00	21.50	21.50
Ethylene	54.50	0.00	54.50	54.50
Acetylene	1.20	0.00	1.20	1.20
Propylene	1.70	0.00	1.70	1.70
Propane	0.20	43.00	0.20	0.20
Butylene	2.60	0.00	2.60	2.60
Butane	0.00	57.00	0.00	0.00
Benzene	4.40	0.00	4.40	4.40
Water	1.40	0.00	1.40	1.40
Carbon monoxide	0.17	0.00	0.17	0.17
Hydrogen sulphide	0.0265	0.00	0.0265	0.0265

Table B.4 Flare gas flow rates and composition for the normal operation scenario (proposed flare system)

Case	FEP Elevated Flare	FNGL Elevated Flare	New EGF
Mass flow rate to flare (kg h^{-1})	114	297	668
	Composition (%w/w)		
Hydrogen	10.07	0.00	10.07
Nitrogen	12.15	0.00	12.15
Methane	22.22	0.00	22.22
Ethane	26.09	0.00	26.09
Ethylene	19.47	0.00	19.47
Acetylene	0.00	0.00	0.00
Propylene	3.65	0.00	3.65
Propane	3.83	43.00	3.83
Butylene	2.52	0.00	2.52
Butane	0.00	57.00	0.00

Table B.5 Flare gas flow rates and composition for the PGC trip scenario with typical peak flaring rate (proposed flare system)

Case	FEP Elevated Flare	FNGL Elevated Flare	New EGF
Mass flow rate to flare (kg h^{-1})	0	297	130,000
	Composition (%w/w)		
Hydrogen	4.30	0.00	4.30
Methane	8.40	0.00	8.40
Ethane	21.50	0.00	21.50
Ethylene	54.50	0.00	54.50
Acetylene	1.20	0.00	1.20
Propylene	1.70	0.00	1.70
Propane	0.20	0.00	0.20
Butylene	2.60	43.00	2.60
Butane	0.00	0.00	0.00
Benzene	4.40	57.00	4.40
Water	1.40	0.00	1.40
Carbon monoxide	0.17	0.00	0.17

Case	FEP Elevated Flare	FNGL Elevated Flare	New EGF
Hydrogen sulphide	0.0265	0.00	0.0265

Table B.6 Flare gas flow rates and composition for the PGC trip scenario with instantaneous peak flaring rate (proposed flare system)

Case	FEP Elevated Flare	FNGL Elevated Flare	New EGF
Mass flow rate to flare (kg h^{-1})	70,000	297	130,000
	Composition (%w/w)		
Hydrogen	4.30	0.00	4.30
Methane	8.40	0.00	8.40
Ethane	21.50	0.00	21.50
Ethylene	54.50	0.00	54.50
Acetylene	1.20	0.00	1.20
Propylene	1.70	0.00	1.70
Propane	0.20	0.00	0.20
Butylene	2.60	43.00	2.60
Butane	0.00	0.00	0.00
Benzene	4.40	57.00	4.40
Water	1.40	0.00	1.40
Carbon monoxide	0.17	0.00	0.17
Hydrogen sulphide	0.0265	0.00	0.0265

Appendix C
Wind turbine thrust coefficients

Table C.1 Thrust co-efficients as a function of wind speed

Wind speed (ms^{-1})	Little Raith C_T	Mossmorran C_T	Goat Hill Quarry C_T	Kirkton Farm C_T
3	1.05	0.97	0.97	0.97
4	0.85	0.85	0.87	0.87
5	0.8	0.88	0.85	0.85
6	0.8	0.9	0.84	0.84
7	0.8	0.91	0.84	0.84
8	0.8	0.9	0.83	0.83
9	0.72	0.84	0.8	0.8
10	0.64	0.79	0.74	0.74
11	0.57	0.75	0.64	0.64
12	0.4	0.63	0.54	0.54
13	0.3	0.44	0.44	0.44
14	0.24	0.34	0.42	0.42
15	0.19	0.27	0.26	0.26
16	0.16	0.22	0.21	0.21
17	0.13	0.18	0.18	0.18
18	0.11	0.15	0.15	0.15
19	0.1	0.13	0.13	0.13
20	0.08	0.11	0.11	0.11
21	0.07	0.1	0.11	0.11
22	0.06	0.09	0.11	0.11

Appendix D
Receptor results tables (proposed flare system)

Normal operation

Table D.1 Modelled annual mean NO_2 at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	2.32	9.46	5.8%	23.6%
H2	1.60	8.57	4.0%	21.4%
H3	1.36	10.33	3.4%	25.8%
H4	2.05	11.96	5.1%	29.9%
H5	2.29	9.49	5.7%	23.7%
H6	1.67	10.33	4.2%	25.8%
H7	2.60	12.63	6.5%	31.6%
H8	0.38	7.41	1.0%	18.5%
H9	0.41	9.02	1.0%	22.6%
H10	0.20	8.50	0.5%	21.2%
H11	0.17	8.58	0.4%	21.4%
H12	0.19	10.39	0.5%	26.0%
H13	1.41	10.20	3.5%	25.5%
H14	0.27	10.49	0.7%	26.2%
H15	0.21	9.95	0.5%	24.9%
H16	3.02	10.46	7.6%	26.1%
H17	0.40	8.93	1.0%	22.3%

Table D.2 Modelled 99.79 percentile 1-hour mean NO_2 at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	12.96	26.85	6.5%	13.4%
H2	10.18	24.17	5.1%	12.1%
H3	18.00	35.73	9.0%	17.9%
H4	15.39	36.58	7.7%	18.3%
H5	13.16	28.11	6.6%	14.1%
H6	13.44	33.30	6.7%	16.6%
H7	17.19	39.24	8.6%	19.6%
H8	10.20	24.09	5.1%	12.0%
H9	14.70	31.84	7.4%	15.9%
H10	8.03	24.56	4.0%	12.3%
H11	7.89	25.01	3.9%	12.5%
H12	8.57	29.05	4.3%	14.5%
H13	11.47	29.53	5.7%	14.8%
H14	11.49	31.87	5.7%	15.9%
H15	8.76	28.38	4.4%	14.2%
H16	13.20	27.74	6.6%	13.9%
H17	14.49	31.45	7.2%	15.7%

Table D.3 Modelled annual mean PM_{10} at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.06	10.04	0.3%	55.8%
H2	0.04	10.40	0.2%	57.8%
H3	0.04	9.30	0.2%	51.7%
H4	0.06	10.58	0.3%	58.8%
H5	0.06	10.42	0.3%	57.9%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H6	0.05	10.30	0.3%	57.2%
H7	0.07	10.37	0.4%	57.6%
H8	0.01	9.99	0.1%	55.5%
H9	0.01	9.78	0.1%	54.3%
H10	0.01	9.61	0.0%	53.4%
H11	0.00	9.84	0.0%	54.7%
H12	0.01	10.10	0.0%	56.1%
H13	0.04	10.38	0.2%	57.7%
H14	0.01	10.10	0.0%	56.1%
H15	0.01	10.92	0.0%	60.7%
H16	0.08	10.44	0.4%	58.0%
H17	0.01	10.61	0.1%	58.9%

Table D.4 Modelled 98.08 percentile 24-hour mean PM_{10} at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.22	20.18	0.4%	40.4%
H2	0.14	20.86	0.3%	41.7%
H3	0.25	18.77	0.5%	37.5%
H4	0.16	21.20	0.3%	42.4%
H5	0.19	20.91	0.4%	41.8%
H6	0.14	20.66	0.3%	41.3%
H7	0.36	20.95	0.7%	41.9%
H8	0.09	20.05	0.2%	40.1%
H9	0.14	19.67	0.3%	39.3%
H10	0.08	19.28	0.2%	38.6%
H11	0.07	19.74	0.1%	39.5%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H12	0.07	20.26	0.1%	40.5%
H13	0.28	20.96	0.6%	41.9%
H14	0.13	20.31	0.3%	40.6%
H15	0.08	21.90	0.2%	43.8%
H16	0.22	20.94	0.4%	41.9%
H17	0.14	21.34	0.3%	42.7%

Table D.5 Modelled annual mean $PM_{2.5}$ at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.06	5.52	0.6%	55.2%
H2	0.04	5.61	0.4%	56.1%
H3	0.04	5.40	0.4%	54.0%
H4	0.06	5.63	0.6%	56.3%
H5	0.06	5.63	0.6%	56.3%
H6	0.05	5.50	0.5%	55.0%
H7	0.07	5.64	0.7%	56.4%
H8	0.01	5.47	0.1%	54.7%
H9	0.01	5.39	0.1%	53.9%
H10	0.01	5.51	0.1%	55.1%
H11	0.00	5.62	0.0%	56.2%
H12	0.01	5.71	0.1%	57.1%
H13	0.04	5.58	0.4%	55.8%
H14	0.01	5.71	0.1%	57.1%
H15	0.01	5.91	0.1%	59.1%
H16	0.08	5.65	0.8%	56.5%
H17	0.01	5.54	0.1%	55.4%

Table D.6 Modelled annual mean CO at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.54	197.74	0.2%	56.5%
H2	0.37	191.55	0.1%	54.7%
H3	0.29	200.43	0.1%	57.3%
H4	0.46	200.15	0.1%	57.2%
H5	0.56	191.97	0.2%	54.8%
H6	0.38	189.96	0.1%	54.3%
H7	0.58	211.91	0.2%	60.5%
H8	0.09	197.17	0.0%	56.3%
H9	0.10	212.18	0.0%	60.6%
H10	0.05	211.09	0.0%	60.3%
H11	0.04	199.09	0.0%	56.9%
H12	0.04	215.11	0.0%	61.5%
H13	0.31	216.56	0.1%	61.9%
H14	0.06	215.13	0.0%	61.5%
H15	0.05	204.11	0.0%	58.3%
H16	0.74	192.38	0.2%	55.0%
H17	0.09	212.16	0.0%	60.6%

Table D.7 Modelled rolling 8-hour mean CO at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	7.49	404.15	0.1%	4.0%
H2	6.42	393.66	0.1%	3.9%
H3	5.27	409.11	0.1%	4.1%
H4	5.93	408.62	0.1%	4.1%
H5	4.91	390.98	0.0%	3.9%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H6	6.92	392.42	0.1%	3.9%
H7	8.96	441.21	0.1%	4.4%
H8	4.37	403.81	0.0%	4.0%
H9	7.37	434.07	0.1%	4.3%
H10	2.95	429.27	0.0%	4.3%
H11	2.93	404.14	0.0%	4.0%
H12	2.33	433.83	0.0%	4.3%
H13	4.29	439.67	0.0%	4.4%
H14	3.45	434.02	0.0%	4.3%
H15	3.44	412.57	0.0%	4.1%
H16	5.49	391.31	0.1%	3.9%
H17	6.85	432.21	0.1%	4.3%

Table D.8 Modelled 99.9 percentile 15-minute mean SO_2 at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	2.52	6.75	0.9%	2.5%
H2	1.95	6.55	0.7%	2.5%
H3	3.89	8.31	1.5%	3.1%
H4	2.10	6.43	0.8%	2.4%
H5	2.54	7.14	1.0%	2.7%
H6	1.94	6.76	0.7%	2.5%
H7	4.64	9.12	1.7%	3.4%
H8	1.76	5.98	0.7%	2.2%
H9	2.69	7.05	1.0%	2.7%
H10	1.87	11.40	0.7%	4.3%
H11	1.45	16.43	0.5%	6.2%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H12	1.62	15.22	0.6%	5.7%
H13	2.94	8.44	1.1%	3.2%
H14	1.98	15.58	0.7%	5.9%
H15	1.82	9.08	0.7%	3.4%
H16	2.08	6.69	0.8%	2.5%
H17	2.84	7.14	1.1%	2.7%

Table D.9 Modelled 99.73 percentile 1-hour mean SO_2 at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	1.50	5.72	0.4%	1.6%
H2	1.11	5.71	0.3%	1.6%
H3	2.12	6.54	0.6%	1.9%
H4	1.48	5.82	0.4%	1.7%
H5	1.32	5.94	0.4%	1.7%
H6	1.32	6.13	0.4%	1.8%
H7	2.71	7.21	0.8%	2.1%
H8	0.80	5.02	0.2%	1.4%
H9	1.48	5.85	0.4%	1.7%
H10	1.01	10.54	0.3%	3.0%
H11	0.75	15.73	0.2%	4.5%
H12	0.78	14.39	0.2%	4.1%
H13	1.74	7.19	0.5%	2.1%
H14	1.16	14.76	0.3%	4.2%
H15	0.93	8.20	0.3%	2.3%
H16	1.17	5.80	0.3%	1.7%
H17	1.53	5.83	0.4%	1.7%

Table D.10 Modelled 99.18 percentile 24-hour mean SO_2 at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.38	4.61	0.3%	3.7%
H2	0.26	4.87	0.2%	3.9%
H3	0.53	4.95	0.4%	4.0%
H4	0.37	4.71	0.3%	3.8%
H5	0.39	5.00	0.3%	4.0%
H6	0.29	5.05	0.2%	4.0%
H7	0.72	5.20	0.6%	4.2%
H8	0.20	4.42	0.2%	3.5%
H9	0.36	4.73	0.3%	3.8%
H10	0.22	9.75	0.2%	7.8%
H11	0.12	15.10	0.1%	12.1%
H12	0.19	13.79	0.2%	11.0%
H13	0.53	5.97	0.4%	4.8%
H14	0.24	13.85	0.2%	11.1%
H15	0.15	7.42	0.1%	5.9%
H16	0.49	5.10	0.4%	4.1%
H17	0.46	4.76	0.4%	3.8%

Table D.11 Modelled annual mean BTEX at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.14	0.34	4.3%	10.4%
H2	0.10	0.29	3.1%	8.9%
H3	0.06	0.27	1.8%	8.3%
H4	0.11	0.31	3.4%	9.7%
H5	0.13	0.32	4.0%	9.9%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H6	0.08	0.27	2.3%	8.2%
H7	0.14	0.38	4.3%	11.7%
H8	0.04	0.24	1.3%	7.5%
H9	0.04	0.26	1.1%	8.0%
H10	0.02	0.30	0.6%	9.1%
H11	0.01	0.24	0.3%	7.3%
H12	0.02	0.29	0.6%	8.8%
H13	0.10	0.35	2.9%	10.8%
H14	0.03	0.29	0.8%	9.1%
H15	0.01	0.25	0.3%	7.7%
H16	0.17	0.36	5.3%	11.2%
H17	0.04	0.26	1.2%	8.1%

Table D.12 Modelled 1-hour mean BTEX at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	6.51	6.91	3.1%	3.3%
H2	4.20	4.58	2.0%	2.2%
H3	11.24	11.66	5.4%	5.6%
H4	4.38	4.79	2.1%	2.3%
H5	18.27	18.65	8.8%	9.0%
H6	2.91	3.29	1.4%	1.6%
H7	5.90	6.38	2.8%	3.1%
H8	5.84	6.24	2.8%	3.0%
H9	6.92	7.37	3.3%	3.5%
H10	4.74	5.29	2.3%	2.5%
H11	1.93	2.39	0.9%	1.2%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H12	4.04	4.58	1.9%	2.2%
H13	5.63	6.14	2.7%	3.0%
H14	6.68	7.22	3.2%	3.5%
H15	14.34	14.82	6.9%	7.1%
H16	15.09	15.47	7.3%	7.4%
H17	6.06	6.51	2.9%	3.1%

Table D.13 Modelled annual mean UHCs at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.02	35.08	0.0%	0.2%
H2	0.02	35.06	0.0%	0.2%
H3	0.02	35.08	0.0%	0.2%
H4	0.03	35.15	0.0%	0.2%
H5	0.03	35.10	0.0%	0.2%
H6	0.03	35.12	0.0%	0.2%
H7	0.03	35.11	0.0%	0.2%
H8	0.00	35.02	0.0%	0.2%
H9	0.01	35.02	0.0%	0.2%
H10	0.00	35.01	0.0%	0.2%
H11	0.00	35.01	0.0%	0.2%
H12	0.00	35.01	0.0%	0.2%
H13	0.02	35.07	0.0%	0.2%
H14	0.00	35.01	0.0%	0.2%
H15	0.00	35.01	0.0%	0.2%
H16	0.04	35.14	0.0%	0.2%
H17	0.01	35.02	0.0%	0.2%

Table D.14 Modelled 1-hour mean UHCs at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	1.02	74.60	0.0%	0.0%
H2	0.78	73.54	0.0%	0.0%
H3	1.07	73.02	0.0%	0.0%
H4	0.62	73.21	0.0%	0.0%
H5	0.55	72.50	0.0%	0.0%
H6	0.50	72.59	0.0%	0.0%
H7	1.13	73.92	0.0%	0.0%
H8	0.97	74.38	0.0%	0.0%
H9	0.86	73.53	0.0%	0.0%
H10	0.59	72.67	0.0%	0.0%
H11	0.54	72.09	0.0%	0.0%
H12	0.66	73.18	0.0%	0.0%
H13	0.96	73.19	0.0%	0.0%
H14	0.66	73.23	0.0%	0.0%
H15	0.67	72.47	0.0%	0.0%
H16	0.56	72.89	0.0%	0.0%
H17	0.65	73.94	0.0%	0.0%

Table D.15 Modelled annual mean NO_x at ecological receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.15	12.54	0.5%	41.8%
H2	0.19	12.29	0.6%	41.0%
H3	0.12	12.18	0.4%	40.6%

Table D.16 Modelled daily mean NO_x at ecological receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	8.07	33.82	10.8%	45.1%
H2	12.45	38.22	16.6%	51.0%
H3	7.07	32.18	9.4%	42.9%

Table D.17 Modelled annual mean SO_2 at ecological receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.01	2.34	0%	12%
H2	0.01	2.34	0%	12%
H3	0.00	2.33	0%	12%

Table D.18 Modelled annual mean nitrogen deposition at ecological receptors

Receptor ID	PC (kg/ha/y)	PEC (kg/ha/y)	PC (% of AQAL)	PEC (% of AQAL)
H1	0.02	13.72	0.2%	137.2%
H2	0.02	13.72	0.2%	137.2%
H3	0.01	13.41	0.1%	134.1%

Table D.19 Modelled annual mean acid deposition at ecological receptors

Receptor ID	Sulphur PC (keq/ha/y)	Nitrogen PC (keq/ha/y)	Sulphur PEC (keq/ha/y)	Nitrogen PEC (keq/ha/y)	PC (% of critical load function)	PEC (% of critical load function)
H1	0.000634	0.0011	0.10	1.00	0.3%	220.3%
H2	0.000947	0.0014	0.10	1.00	0.5%	220.5%
H3	0.000513	0.0009	0.20	1.00	0.0%	28.2%

PGC trip – typical peak flaring rate (130 T h^{-1})

Table D.20 Modelled annual mean NO_2 at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	2.34	9.48	5.9%	23.7%
H2	1.66	8.63	4.1%	21.6%
H3	1.78	10.74	4.5%	26.8%
H4	2.66	12.57	6.6%	31.4%
H5	2.44	9.65	6.1%	24.1%
H6	2.15	10.82	5.4%	27.0%
H7	2.78	12.81	7.0%	32.0%
H8	0.39	7.42	1.0%	18.5%
H9	0.47	9.08	1.2%	22.7%
H10	0.22	8.52	0.5%	21.3%
H11	0.20	8.61	0.5%	21.5%
H12	0.20	10.41	0.5%	26.0%
H13	1.62	10.41	4.0%	26.0%
H14	0.29	10.50	0.7%	26.3%
H15	0.25	9.99	0.6%	25.0%
H16	3.27	10.70	8.2%	26.8%
H17	0.42	8.95	1.1%	22.4%

Table D.21 Modelled 99.79 percentile 1-hour mean NO_2 at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	13.35	27.31	6.7%	13.7%
H2	11.32	25.47	5.7%	12.7%
H3	20.44	38.16	10.2%	19.1%
H4	16.96	37.24	8.5%	18.6%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H5	11.82	26.84	5.9%	13.4%
H6	16.28	35.92	8.1%	18.0%
H7	19.96	41.69	10.0%	20.8%
H8	10.68	24.60	5.3%	12.3%
H9	16.78	33.85	8.4%	16.9%
H10	9.39	25.92	4.7%	13.0%
H11	10.46	27.20	5.2%	13.6%
H12	9.78	30.22	4.9%	15.1%
H13	13.74	33.28	6.9%	16.6%
H14	11.66	31.95	5.8%	16.0%
H15	10.51	29.96	5.3%	15.0%
H16	11.80	26.26	5.9%	13.1%
H17	15.36	32.31	7.7%	16.2%

Table D.22 Modelled annual mean PM_{10} at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.07	10.05	0.4%	55.8%
H2	0.05	10.41	0.3%	57.8%
H3	0.06	9.32	0.3%	51.8%
H4	0.09	10.61	0.5%	58.9%
H5	0.07	10.43	0.4%	58.0%
H6	0.07	10.33	0.4%	57.4%
H7	0.09	10.38	0.5%	57.7%
H8	0.01	10.00	0.1%	55.5%
H9	0.02	9.78	0.1%	54.3%
H10	0.01	9.61	0.0%	53.4%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H11	0.01	9.84	0.0%	54.7%
H12	0.01	10.10	0.0%	56.1%
H13	0.05	10.39	0.3%	57.7%
H14	0.01	10.10	0.1%	56.1%
H15	0.01	10.92	0.0%	60.7%
H16	0.10	10.46	0.6%	58.1%
H17	0.01	10.61	0.1%	59.0%

Table D.23 Modelled 98.08 percentile 24-hour mean PM_{10} at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.28	20.25	0.6%	40.5%
H2	0.19	20.91	0.4%	41.8%
H3	0.37	18.89	0.7%	37.8%
H4	0.23	21.27	0.5%	42.5%
H5	0.22	20.94	0.4%	41.9%
H6	0.21	20.72	0.4%	41.4%
H7	0.48	21.07	1.0%	42.1%
H8	0.12	20.09	0.2%	40.2%
H9	0.19	19.72	0.4%	39.4%
H10	0.11	19.31	0.2%	38.6%
H11	0.10	19.77	0.2%	39.5%
H12	0.09	20.28	0.2%	40.6%
H13	0.38	21.06	0.8%	42.1%
H14	0.15	20.33	0.3%	40.7%
H15	0.12	21.95	0.2%	43.9%
H16	0.26	20.98	0.5%	42.0%
H17	0.18	21.38	0.4%	42.8%

Table D.24 Modelled annual mean $PM_{2.5}$ at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.07	5.53	0.7%	55.3%
H2	0.05	5.62	0.5%	56.2%
H3	0.06	5.42	0.6%	54.2%
H4	0.09	5.66	0.9%	56.6%
H5	0.07	5.65	0.7%	56.5%
H6	0.07	5.52	0.7%	55.2%
H7	0.09	5.66	0.9%	56.6%
H8	0.01	5.47	0.1%	54.7%
H9	0.02	5.39	0.2%	53.9%
H10	0.01	5.51	0.1%	55.1%
H11	0.01	5.62	0.1%	56.2%
H12	0.01	5.71	0.1%	57.1%
H13	0.05	5.59	0.5%	55.9%
H14	0.01	5.72	0.1%	57.2%
H15	0.01	5.92	0.1%	59.2%
H16	0.10	5.67	1.0%	56.7%
H17	0.01	5.54	0.1%	55.4%

Table D.25 Modelled annual mean CO at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.65	197.85	0.2%	56.5%
H2	0.48	191.66	0.1%	54.8%
H3	0.48	200.59	0.1%	57.3%
H4	1.49	201.16	0.4%	57.5%
H5	0.77	192.19	0.2%	54.9%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H6	1.06	190.55	0.3%	54.4%
H7	0.40	211.74	0.1%	60.5%
H8	0.06	197.14	0.0%	56.3%
H9	0.06	212.14	0.0%	60.6%
H10	0.03	211.07	0.0%	60.3%
H11	0.03	199.08	0.0%	56.9%
H12	0.03	215.10	0.0%	61.5%
H13	0.25	216.46	0.1%	61.8%
H14	0.05	215.11	0.0%	61.5%
H15	0.04	204.09	0.0%	58.3%
H16	1.00	192.66	0.3%	55.0%
H17	0.05	212.13	0.0%	60.6%

Table D.26 Modelled rolling 8-hour mean CO at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	18.24	412.35	0.2%	4.1%
H2	13.02	395.32	0.1%	4.0%
H3	28.10	428.34	0.3%	4.3%
H4	28.55	428.78	0.3%	4.3%
H5	15.08	398.34	0.2%	4.0%
H6	16.92	396.27	0.2%	4.0%
H7	8.84	437.50	0.1%	4.4%
H8	3.12	403.68	0.0%	4.0%
H9	4.65	433.41	0.0%	4.3%
H10	2.89	428.95	0.0%	4.3%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H11	3.22	403.26	0.0%	4.0%
H12	6.46	437.01	0.1%	4.4%
H13	11.06	443.99	0.1%	4.4%
H14	7.14	438.18	0.1%	4.4%
H15	4.34	412.75	0.0%	4.1%
H16	15.42	398.71	0.2%	4.0%
H17	6.01	431.68	0.1%	4.3%

Table D.27 Modelled 99.9 percentile 15-minute mean SO_2 at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	3.34	7.56	1.3%	2.8%
H2	2.96	7.56	1.1%	2.8%
H3	5.12	9.54	1.9%	3.6%
H4	4.11	8.45	1.5%	3.2%
H5	3.36	8.02	1.3%	3.0%
H6	3.72	8.54	1.4%	3.2%
H7	5.46	9.96	2.1%	3.7%
H8	2.39	6.61	0.9%	2.5%
H9	3.99	8.35	1.5%	3.1%
H10	2.48	12.00	0.9%	4.5%
H11	2.88	17.87	1.1%	6.7%
H12	2.20	15.80	0.8%	5.9%
H13	4.36	9.88	1.6%	3.7%
H14	2.74	16.34	1.0%	6.1%
H15	3.68	10.94	1.4%	4.1%
H16	3.39	8.00	1.3%	3.0%
H17	3.32	7.62	1.2%	2.9%

Table D.28 Modelled 99.73 percentile 1-hour mean SO_2 at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	2.63	6.85	0.8%	2.0%
H2	1.83	6.44	0.5%	1.8%
H3	3.44	7.86	1.0%	2.2%
H4	2.87	7.21	0.8%	2.1%
H5	1.96	6.60	0.6%	1.9%
H6	2.66	7.48	0.8%	2.1%
H7	3.20	7.70	0.9%	2.2%
H8	1.52	5.74	0.4%	1.6%
H9	2.53	6.89	0.7%	2.0%
H10	1.44	10.97	0.4%	3.1%
H11	1.33	16.31	0.4%	4.7%
H12	1.46	15.06	0.4%	4.3%
H13	2.64	8.12	0.8%	2.3%
H14	1.75	15.35	0.5%	4.4%
H15	1.51	8.79	0.4%	2.5%
H16	1.89	6.52	0.5%	1.9%
H17	2.15	6.45	0.6%	1.8%

Table D.29 Modelled 99.18 percentile 24-hour mean SO_2 at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	1.01	5.23	0.8%	4.2%
H2	0.68	5.28	0.5%	4.2%
H3	1.55	5.97	1.2%	4.8%
H4	1.33	5.68	1.1%	4.5%
H5	0.70	5.31	0.6%	4.2%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H6	0.83	5.59	0.7%	4.5%
H7	1.31	5.80	1.1%	4.6%
H8	0.36	4.58	0.3%	3.7%
H9	0.70	5.06	0.6%	4.1%
H10	0.38	9.91	0.3%	7.9%
H11	0.30	15.29	0.2%	12.2%
H12	0.38	13.99	0.3%	11.2%
H13	1.15	6.57	0.9%	5.3%
H14	0.44	14.05	0.4%	11.2%
H15	0.40	7.66	0.3%	6.1%
H16	0.82	5.43	0.7%	4.3%
H17	0.66	4.96	0.5%	4.0%

Table D.30 Modelled annual mean BTEX at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.14	0.34	4.3%	10.5%
H2	0.10	0.29	3.1%	9.0%
H3	0.06	0.27	1.8%	8.4%
H4	0.11	0.32	3.5%	9.8%
H5	0.13	0.33	4.1%	10.0%
H6	0.08	0.27	2.5%	8.3%
H7	0.14	0.38	4.3%	11.7%
H8	0.04	0.24	1.3%	7.5%
H9	0.04	0.26	1.1%	8.0%
H10	0.02	0.30	0.6%	9.1%
H11	0.01	0.24	0.3%	7.3%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H12	0.02	0.29	0.6%	8.8%
H13	0.10	0.35	2.9%	10.8%
H14	0.03	0.29	0.8%	9.1%
H15	0.01	0.25	0.3%	7.7%
H16	0.18	0.37	5.4%	11.3%
H17	0.04	0.26	1.2%	8.1%

Table D.31 Modelled 1-hour mean BTEX at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	6.52	6.92	3.1%	3.3%
H2	4.20	4.58	2.0%	2.2%
H3	15.13	15.56	7.3%	7.5%
H4	4.41	4.82	2.1%	2.3%
H5	18.26	18.64	8.8%	9.0%
H6	2.91	3.29	1.4%	1.6%
H7	6.24	6.72	3.0%	3.2%
H8	5.84	6.24	2.8%	3.0%
H9	6.91	7.36	3.3%	3.5%
H10	4.75	5.30	2.3%	2.5%
H11	1.92	2.38	0.9%	1.1%
H12	4.06	4.60	2.0%	2.2%
H13	5.64	6.15	2.7%	3.0%
H14	6.68	7.22	3.2%	3.5%
H15	14.39	14.87	6.9%	7.1%
H16	15.13	15.51	7.3%	7.5%
H17	6.07	6.51	2.9%	3.1%

Table D.32 Modelled annual mean UHCs at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.05	35.11	0.0%	0.2%
H2	0.04	35.08	0.0%	0.2%
H3	0.05	35.11	0.0%	0.2%
H4	0.18	35.28	0.0%	0.2%
H5	0.07	35.14	0.0%	0.2%
H6	0.13	35.21	0.0%	0.2%
H7	0.01	35.10	0.0%	0.2%
H8	0.00	35.01	0.0%	0.2%
H9	0.00	35.02	0.0%	0.2%
H10	0.00	35.01	0.0%	0.2%
H11	0.00	35.01	0.0%	0.2%
H12	0.00	35.01	0.0%	0.2%
H13	0.02	35.06	0.0%	0.2%
H14	0.00	35.01	0.0%	0.2%
H15	0.00	35.01	0.0%	0.2%
H16	0.09	35.19	0.0%	0.2%
H17	0.00	35.02	0.0%	0.2%

Table D.33 Modelled 1-hour mean UHCs at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	5.69	76.17	0.0%	0.0%
H2	3.46	73.78	0.0%	0.0%
H3	7.15	77.69	0.0%	0.0%
H4	4.42	74.80	0.0%	0.0%
H5	2.83	73.05	0.0%	0.0%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H6	2.99	73.22	0.0%	0.0%
H7	2.33	73.13	0.0%	0.0%
H8	2.37	73.41	0.0%	0.0%
H9	1.46	72.86	0.0%	0.0%
H10	1.52	72.15	0.0%	0.0%
H11	1.87	72.12	0.0%	0.0%
H12	1.78	72.54	0.0%	0.0%
H13	2.86	73.25	0.0%	0.0%
H14	1.87	72.62	0.0%	0.0%
H15	2.38	72.72	0.0%	0.0%
H16	3.16	73.39	0.0%	0.0%
H17	1.36	73.30	0.0%	0.0%

Table D.34 Modelled annual mean NO_x at ecological receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.17	12.56	0.6%	41.9%
H2	0.21	12.31	0.7%	41.0%
H3	0.14	12.20	0.5%	40.7%

Table D.35 Modelled daily mean NO_x at ecological receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	10.74	36.49	14.3%	48.6%
H2	14.29	40.07	19.1%	53.4%
H3	9.45	34.55	12.6%	46.1%

Table D.36 Modelled annual mean SO_2 at ecological receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.01	2.34	0%	12%
H2	0.01	2.34	0%	12%
H3	0.01	2.34	0%	12%

Table D.37 Modelled annual mean nitrogen deposition at ecological receptors

Receptor ID	PC (kg/ha/y)	PEC (kg/ha/y)	PC (% of AQAL)	PEC (% of AQAL)
H1	0.02	13.72	0.2%	137.2%
H2	0.02	13.72	0.2%	137.2%
H3	0.01	13.41	0.1%	134.1%

Table D.38 Modelled annual mean acid deposition at ecological receptors

Receptor ID	Sulphur PC (keq/ha/y)	Nitrogen PC (keq/ha/y)	Sulphur PEC (keq/ha/y)	Nitrogen PEC (keq/ha/y)	PC (% of critical load function)	PEC (% of critical load function)
H1	0.001153	0.0013	0.10	1.00	0.5%	220.5%
H2	0.001409	0.0015	0.10	1.00	0.6%	220.6%
H3	0.000904	0.0010	0.20	1.00	0.0%	28.2%

PGC trip – instantaneous peak flaring rate (200 T h^{-1})

Table D.39 Modelled annual mean NO_2 at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	2.36	9.49	5.9%	23.7%
H2	1.68	8.65	4.2%	21.6%
H3	1.80	10.75	4.5%	26.9%
H4	2.70	12.61	6.7%	31.5%
H5	2.49	9.69	6.2%	24.2%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H6	2.20	10.86	5.5%	27.2%
H7	2.79	12.81	7.0%	32.0%
H8	0.40	7.42	1.0%	18.5%
H9	0.47	9.08	1.2%	22.7%
H10	0.22	8.52	0.5%	21.3%
H11	0.21	8.61	0.5%	21.5%
H12	0.20	10.41	0.5%	26.0%
H13	1.62	10.42	4.1%	26.0%
H14	0.29	10.50	0.7%	26.3%
H15	0.25	9.99	0.6%	25.0%
H16	3.31	10.75	8.3%	26.9%
H17	0.42	8.95	1.1%	22.4%

Table D.40 Modelled 99.79 percentile 1-hour mean NO_2 at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	13.35	27.31	6.7%	13.7%
H2	11.32	25.47	5.7%	12.7%
H3	20.44	38.16	10.2%	19.1%
H4	16.96	37.25	8.5%	18.6%
H5	11.82	26.84	5.9%	13.4%
H6	16.29	35.93	8.1%	18.0%
H7	19.96	41.69	10.0%	20.8%
H8	10.68	24.60	5.3%	12.3%
H9	16.78	33.85	8.4%	16.9%
H10	9.39	25.92	4.7%	13.0%
H11	10.46	27.20	5.2%	13.6%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H12	9.78	30.22	4.9%	15.1%
H13	13.74	33.28	6.9%	16.6%
H14	11.66	31.95	5.8%	16.0%
H15	10.51	29.96	5.3%	15.0%
H16	11.80	26.26	5.9%	13.1%
H17	15.36	32.31	7.7%	16.2%

Table D.41 Modelled annual mean PM_{10} at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.07	10.05	0.4%	55.8%
H2	0.05	10.41	0.3%	57.8%
H3	0.06	9.32	0.3%	51.8%
H4	0.09	10.61	0.5%	58.9%
H5	0.07	10.43	0.4%	58.0%
H6	0.07	10.33	0.4%	57.4%
H7	0.09	10.38	0.5%	57.7%
H8	0.01	10.00	0.1%	55.5%
H9	0.02	9.78	0.1%	54.3%
H10	0.01	9.61	0.0%	53.4%
H11	0.01	9.84	0.0%	54.7%
H12	0.01	10.10	0.0%	56.1%
H13	0.05	10.39	0.3%	57.7%
H14	0.01	10.10	0.1%	56.1%
H15	0.01	10.92	0.0%	60.7%
H16	0.10	10.46	0.6%	58.1%
H17	0.01	10.61	0.1%	59.0%

Table D.42 Modelled 98.08 percentile 24-hour mean PM_{10} at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.28	20.25	0.6%	40.5%
H2	0.19	20.91	0.4%	41.8%
H3	0.37	18.89	0.7%	37.8%
H4	0.23	21.27	0.5%	42.5%
H5	0.22	20.94	0.4%	41.9%
H6	0.21	20.72	0.4%	41.4%
H7	0.48	21.07	1.0%	42.1%
H8	0.12	20.09	0.2%	40.2%
H9	0.19	19.72	0.4%	39.4%
H10	0.11	19.31	0.2%	38.6%
H11	0.10	19.77	0.2%	39.5%
H12	0.09	20.28	0.2%	40.6%
H13	0.38	21.06	0.8%	42.1%
H14	0.15	20.33	0.3%	40.7%
H15	0.12	21.95	0.2%	43.9%
H16	0.26	20.98	0.5%	42.0%
H17	0.18	21.38	0.4%	42.8%

Table D.43 Modelled annual mean $PM_{2.5}$ at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.07	5.53	0.7%	55.3%
H2	0.05	5.62	0.5%	56.2%
H3	0.06	5.42	0.6%	54.2%
H4	0.09	5.66	0.9%	56.6%
H5	0.07	5.65	0.7%	56.5%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H6	0.07	5.52	0.7%	55.2%
H7	0.09	5.66	0.9%	56.6%
H8	0.01	5.47	0.1%	54.7%
H9	0.02	5.39	0.2%	53.9%
H10	0.01	5.51	0.1%	55.1%
H11	0.01	5.62	0.1%	56.2%
H12	0.01	5.71	0.1%	57.1%
H13	0.05	5.59	0.5%	55.9%
H14	0.01	5.72	0.1%	57.2%
H15	0.01	5.92	0.1%	59.2%
H16	0.10	5.67	1.0%	56.7%
H17	0.01	5.54	0.1%	55.4%

Table D.44 Modelled annual mean CO at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.74	197.94	0.2%	56.6%
H2	0.60	191.78	0.2%	54.8%
H3	0.56	200.68	0.2%	57.3%
H4	1.91	201.59	0.5%	57.6%
H5	1.04	192.46	0.3%	55.0%
H6	1.45	190.94	0.4%	54.6%
H7	0.45	211.79	0.1%	60.5%
H8	0.06	197.14	0.0%	56.3%
H9	0.06	212.14	0.0%	60.6%
H10	0.03	211.07	0.0%	60.3%
H11	0.04	199.09	0.0%	56.9%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H12	0.04	215.10	0.0%	61.5%
H13	0.30	216.50	0.1%	61.9%
H14	0.05	215.12	0.0%	61.5%
H15	0.05	204.10	0.0%	58.3%
H16	1.33	193.00	0.4%	55.1%
H17	0.06	212.13	0.0%	60.6%

Table D.45 Modelled rolling 8-hour mean CO at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	21.95	416.06	0.2%	4.2%
H2	17.80	400.11	0.2%	4.0%
H3	32.92	433.21	0.3%	4.3%
H4	39.09	439.32	0.4%	4.4%
H5	22.39	405.70	0.2%	4.1%
H6	23.44	402.80	0.2%	4.0%
H7	11.09	437.50	0.1%	4.4%
H8	3.94	403.68	0.0%	4.0%
H9	5.96	433.41	0.1%	4.3%
H10	4.36	428.95	0.0%	4.3%
H11	5.15	403.53	0.1%	4.0%
H12	9.93	440.49	0.1%	4.4%
H13	13.64	446.57	0.1%	4.5%
H14	10.62	441.66	0.1%	4.4%
H15	6.71	415.11	0.1%	4.2%
H16	22.32	406.08	0.2%	4.1%
H17	7.68	432.06	0.1%	4.3%

Table D.46 Modelled 99.9 percentile 15-minute mean SO_2 at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	3.79	8.01	1.4%	3.0%
H2	3.03	7.63	1.1%	2.9%
H3	5.12	9.54	1.9%	3.6%
H4	4.11	8.45	1.5%	3.2%
H5	3.36	8.02	1.3%	3.0%
H6	3.74	8.56	1.4%	3.2%
H7	5.46	9.96	2.1%	3.7%
H8	2.39	6.61	0.9%	2.5%
H9	4.00	8.36	1.5%	3.1%
H10	2.48	12.00	0.9%	4.5%
H11	2.88	17.87	1.1%	6.7%
H12	2.20	15.80	0.8%	5.9%
H13	4.36	9.88	1.6%	3.7%
H14	2.74	16.34	1.0%	6.1%
H15	3.69	10.95	1.4%	4.1%
H16	3.39	8.00	1.3%	3.0%
H17	3.32	7.62	1.2%	2.9%

Table D.47 Modelled 99.73 percentile 1-hour mean SO_2 at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	2.93	7.15	0.8%	2.0%
H2	2.22	6.83	0.6%	2.0%
H3	3.70	8.12	1.1%	2.3%
H4	3.50	7.85	1.0%	2.2%
H5	2.14	6.75	0.6%	1.9%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H6	2.67	7.49	0.8%	2.1%
H7	3.20	7.70	0.9%	2.2%
H8	1.57	5.79	0.4%	1.7%
H9	2.53	6.89	0.7%	2.0%
H10	1.44	10.97	0.4%	3.1%
H11	1.45	16.43	0.4%	4.7%
H12	1.46	15.06	0.4%	4.3%
H13	2.64	8.12	0.8%	2.3%
H14	1.77	15.37	0.5%	4.4%
H15	1.65	8.92	0.5%	2.5%
H16	2.39	7.03	0.7%	2.0%
H17	2.15	6.45	0.6%	1.8%

Table D.48 Modelled 99.18 percentile 24-hour mean SO_2 at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	1.09	5.31	0.9%	4.2%
H2	0.79	5.40	0.6%	4.3%
H3	1.58	6.00	1.3%	4.8%
H4	1.64	5.99	1.3%	4.8%
H5	0.86	5.47	0.7%	4.4%
H6	1.09	5.84	0.9%	4.7%
H7	1.37	5.85	1.1%	4.7%
H8	0.37	4.59	0.3%	3.7%
H9	0.71	5.08	0.6%	4.1%
H10	0.39	9.91	0.3%	7.9%
H11	0.31	15.29	0.2%	12.2%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H12	0.38	13.99	0.3%	11.2%
H13	1.28	6.71	1.0%	5.4%
H14	0.45	14.05	0.4%	11.2%
H15	0.40	7.66	0.3%	6.1%
H16	1.03	5.65	0.8%	4.5%
H17	0.70	5.00	0.6%	4.0%

Table D.49 Modelled annual mean BTEX at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.15	0.35	4.6%	10.8%
H2	0.11	0.30	3.5%	9.4%
H3	0.07	0.28	2.0%	8.6%
H4	0.14	0.35	4.3%	10.6%
H5	0.16	0.35	5.0%	10.9%
H6	0.11	0.30	3.4%	9.2%
H7	0.14	0.38	4.4%	11.8%
H8	0.04	0.24	1.3%	7.5%
H9	0.04	0.26	1.1%	8.0%
H10	0.02	0.30	0.6%	9.1%
H11	0.01	0.24	0.3%	7.3%
H12	0.02	0.29	0.6%	8.8%
H13	0.10	0.36	3.1%	10.9%
H14	0.03	0.30	0.8%	9.1%
H15	0.01	0.25	0.4%	7.7%
H16	0.20	0.39	6.3%	12.1%
H17	0.04	0.26	1.2%	8.1%

Table D.50 Modelled 1-hour mean BTEX at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	6.54	6.94	3.1%	3.3%
H2	4.22	4.60	2.0%	2.2%
H3	15.13	15.56	7.3%	7.5%
H4	4.41	4.82	2.1%	2.3%
H5	18.26	18.64	8.8%	9.0%
H6	2.91	3.29	1.4%	1.6%
H7	6.25	6.73	3.0%	3.2%
H8	5.85	6.25	2.8%	3.0%
H9	6.92	7.37	3.3%	3.5%
H10	4.76	5.31	2.3%	2.6%
H11	1.92	2.38	0.9%	1.1%
H12	4.08	4.62	2.0%	2.2%
H13	5.67	6.18	2.7%	3.0%
H14	6.69	7.23	3.2%	3.5%
H15	14.39	14.87	6.9%	7.1%
H16	15.13	15.51	7.3%	7.5%
H17	6.07	6.52	2.9%	3.1%

Table D.51 Modelled annual mean UHCs at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.24	35.29	0.0%	0.2%
H2	0.29	35.34	0.0%	0.2%
H3	0.23	35.29	0.0%	0.2%
H4	1.10	36.19	0.0%	0.2%
H5	0.65	35.72	0.0%	0.2%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H6	0.97	36.05	0.0%	0.2%
H7	0.11	35.19	0.0%	0.2%
H8	0.01	35.03	0.0%	0.2%
H9	0.01	35.03	0.0%	0.2%
H10	0.01	35.02	0.0%	0.2%
H11	0.02	35.02	0.0%	0.2%
H12	0.01	35.02	0.0%	0.2%
H13	0.11	35.15	0.0%	0.2%
H14	0.01	35.02	0.0%	0.2%
H15	0.02	35.03	0.0%	0.2%
H16	0.81	35.91	0.0%	0.2%
H17	0.01	35.03	0.0%	0.2%

Table D.52 Modelled 1-hour mean UHCs at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	27.81	98.29	0.0%	0.1%
H2	25.76	96.09	0.0%	0.1%
H3	32.47	103.23	0.0%	0.1%
H4	32.66	103.01	0.0%	0.1%
H5	22.58	92.80	0.0%	0.1%
H6	24.55	94.78	0.0%	0.1%
H7	16.31	86.90	0.0%	0.0%
H8	13.42	84.09	0.0%	0.0%
H9	11.90	82.50	0.0%	0.0%
H10	15.30	85.67	0.0%	0.0%
H11	20.40	90.66	0.0%	0.1%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H12	18.73	89.09	0.0%	0.0%
H13	21.87	92.32	0.0%	0.1%
H14	17.17	87.70	0.0%	0.0%
H15	23.97	94.31	0.0%	0.1%
H16	26.01	96.29	0.0%	0.1%
H17	9.30	79.92	0.0%	0.0%

Table D.53 Modelled annual mean NO_x at ecological receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.17	12.56	0.6%	41.9%
H2	0.21	12.31	0.7%	41.0%
H3	0.14	12.20	0.5%	40.7%

Table D.54 Modelled daily mean NO_x at ecological receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	10.74	36.49	14.3%	48.7%
H2	14.32	40.09	19.1%	53.5%
H3	9.45	34.55	12.6%	46.1%

Table D.55 Modelled annual mean SO_2 at ecological receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.01	2.34	0%	12%
H2	0.01	2.34	0%	12%
H3	0.01	2.34	0%	12%

Table D.56 Modelled annual mean nitrogen deposition at ecological receptors

Receptor ID	PC (kg/ha/y)	PEC (kg/ha/y)	PC (% of AQAL)	PEC (% of AQAL)
H1	0.02	13.72	0.2%	137.2%
H2	0.02	13.72	0.2%	137.2%
H3	0.01	13.41	0.1%	134.1%

Table D.57 Modelled annual mean acid deposition at ecological receptors

Receptor ID	Sulphur PC (keq/ha/y)	Nitrogen PC (keq/ha/y)	Sulphur PEC (keq/ha/y)	Nitrogen PEC (keq/ha/y)	PC (% of critical load function)	PEC (% of critical load function)
H1	0.001181	0.0013	0.10	1.00	0.5%	220.5%
H2	0.001444	0.0015	0.10	1.00	0.6%	220.6%
H3	0.000937	0.0010	0.20	1.00	0.0%	28.2%

Appendix E
Receptor results tables (existing flare system)

Normal operation

Table E.1 Modelled annual mean NO_2 at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	2.31	9.45	5.8%	23.6%
H2	1.59	8.57	4.0%	21.4%
H3	1.37	10.34	3.4%	25.8%
H4	2.07	11.98	5.2%	29.9%
H5	2.29	9.49	5.7%	23.7%
H6	1.68	10.34	4.2%	25.9%
H7	2.61	12.63	6.5%	31.6%
H8	0.38	7.41	1.0%	18.5%
H9	0.41	9.02	1.0%	22.6%
H10	0.20	8.50	0.5%	21.2%
H11	0.17	8.58	0.4%	21.4%
H12	0.19	10.40	0.5%	26.0%
H13	1.41	10.21	3.5%	25.5%
H14	0.27	10.49	0.7%	26.2%
H15	0.21	9.95	0.5%	24.9%
H16	3.02	10.46	7.6%	26.1%
H17	0.40	8.93	1.0%	22.3%

Table E.2 Modelled 99.79 percentile 1-hour mean NO_2 at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	12.94	26.83	6.5%	13.4%
H2	10.11	24.23	5.1%	12.1%
H3	18.07	35.81	9.0%	17.9%
H4	15.43	36.62	7.7%	18.3%
H5	13.12	28.09	6.6%	14.0%
H6	13.51	33.36	6.8%	16.7%
H7	17.20	39.26	8.6%	19.6%
H8	10.18	24.07	5.1%	12.0%
H9	14.66	31.82	7.3%	15.9%
H10	8.02	24.55	4.0%	12.3%
H11	8.01	25.12	4.0%	12.6%
H12	8.53	29.03	4.3%	14.5%
H13	11.43	29.47	5.7%	14.7%
H14	11.43	31.81	5.7%	15.9%
H15	8.73	28.42	4.4%	14.2%
H16	13.17	27.54	6.6%	13.8%
H17	14.46	31.42	7.2%	15.7%

Table E.3 Modelled annual mean PM_{10} at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.06	10.04	0.3%	55.8%
H2	0.04	10.40	0.2%	57.8%
H3	0.04	9.30	0.2%	51.7%
H4	0.06	10.58	0.3%	58.8%
H5	0.06	10.42	0.3%	57.9%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H6	0.05	10.30	0.3%	57.2%
H7	0.07	10.37	0.4%	57.6%
H8	0.01	9.99	0.1%	55.5%
H9	0.01	9.78	0.1%	54.3%
H10	0.01	9.61	0.0%	53.4%
H11	0.00	9.84	0.0%	54.7%
H12	0.01	10.10	0.0%	56.1%
H13	0.04	10.38	0.2%	57.7%
H14	0.01	10.10	0.0%	56.1%
H15	0.01	10.92	0.0%	60.7%
H16	0.08	10.44	0.4%	58.0%
H17	0.01	10.61	0.1%	58.9%

Table E.4 Modelled 98.08 percentile 24-hour mean PM_{10} at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.22	20.18	0.4%	40.4%
H2	0.14	20.86	0.3%	41.7%
H3	0.25	18.77	0.5%	37.5%
H4	0.16	21.20	0.3%	42.4%
H5	0.19	20.91	0.4%	41.8%
H6	0.14	20.66	0.3%	41.3%
H7	0.36	20.95	0.7%	41.9%
H8	0.09	20.05	0.2%	40.1%
H9	0.14	19.67	0.3%	39.3%
H10	0.08	19.28	0.2%	38.6%
H11	0.07	19.74	0.1%	39.5%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H12	0.07	20.26	0.1%	40.5%
H13	0.28	20.96	0.6%	41.9%
H14	0.13	20.31	0.3%	40.6%
H15	0.08	21.90	0.2%	43.8%
H16	0.22	20.94	0.4%	41.9%
H17	0.14	21.34	0.3%	42.7%

Table E.5 Modelled annual mean $PM_{2.5}$ at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.06	5.52	0.6%	55.2%
H2	0.04	5.61	0.4%	56.1%
H3	0.04	5.40	0.4%	54.0%
H4	0.06	5.63	0.6%	56.3%
H5	0.06	5.63	0.6%	56.3%
H6	0.05	5.50	0.5%	55.0%
H7	0.07	5.64	0.7%	56.4%
H8	0.01	5.47	0.1%	54.7%
H9	0.01	5.39	0.1%	53.9%
H10	0.01	5.51	0.1%	55.1%
H11	0.00	5.62	0.0%	56.2%
H12	0.01	5.71	0.1%	57.1%
H13	0.04	5.58	0.4%	55.8%
H14	0.01	5.71	0.1%	57.1%
H15	0.01	5.91	0.1%	59.1%
H16	0.08	5.65	0.8%	56.5%
H17	0.01	5.54	0.1%	55.4%

Table E.6 Modelled annual mean CO at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.50	197.71	0.1%	56.5%
H2	0.36	191.54	0.1%	54.7%
H3	0.35	200.48	0.1%	57.3%
H4	0.59	200.29	0.2%	57.2%
H5	0.56	191.97	0.2%	54.8%
H6	0.46	190.05	0.1%	54.3%
H7	0.59	211.93	0.2%	60.6%
H8	0.09	197.18	0.0%	56.3%
H9	0.10	212.18	0.0%	60.6%
H10	0.05	211.09	0.0%	60.3%
H11	0.05	199.10	0.0%	56.9%
H12	0.06	215.12	0.0%	61.5%
H13	0.34	216.58	0.1%	61.9%
H14	0.07	215.14	0.0%	61.5%
H15	0.06	204.12	0.0%	58.3%
H16	0.75	192.39	0.2%	55.0%
H17	0.09	212.17	0.0%	60.6%

Table E.7 Modelled rolling 8-hour mean CO at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	7.32	403.98	0.1%	4.0%
H2	6.83	394.73	0.1%	3.9%
H3	5.89	409.30	0.1%	4.1%
H4	6.85	409.62	0.1%	4.1%
H5	4.58	392.17	0.0%	3.9%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H6	6.83	392.33	0.1%	3.9%
H7	9.57	441.83	0.1%	4.4%
H8	5.02	404.27	0.1%	4.0%
H9	6.40	435.13	0.1%	4.4%
H10	3.81	430.31	0.0%	4.3%
H11	5.11	405.55	0.1%	4.1%
H12	2.46	434.02	0.0%	4.3%
H13	4.55	439.93	0.0%	4.4%
H14	3.33	434.57	0.0%	4.3%
H15	5.98	415.30	0.1%	4.2%
H16	5.04	391.45	0.1%	3.9%
H17	6.67	432.03	0.1%	4.3%

Table E.8 Modelled 99.9 percentile 15-minute mean SO_2 at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	2.52	6.75	0.9%	2.5%
H2	1.95	6.55	0.7%	2.5%
H3	3.89	8.31	1.5%	3.1%
H4	2.10	6.43	0.8%	2.4%
H5	2.54	7.14	1.0%	2.7%
H6	1.94	6.76	0.7%	2.5%
H7	4.64	9.12	1.7%	3.4%
H8	1.76	5.98	0.7%	2.2%
H9	2.69	7.05	1.0%	2.7%
H10	1.87	11.40	0.7%	4.3%
H11	1.45	16.43	0.5%	6.2%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H12	1.62	15.22	0.6%	5.7%
H13	2.94	8.44	1.1%	3.2%
H14	1.98	15.58	0.7%	5.9%
H15	1.82	9.08	0.7%	3.4%
H16	2.08	6.69	0.8%	2.5%
H17	2.84	7.14	1.1%	2.7%

Table E.9 Modelled 99.73 percentile 1-hour mean SO_2 at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	1.50	5.72	0.4%	1.6%
H2	1.11	5.71	0.3%	1.6%
H3	2.12	6.54	0.6%	1.9%
H4	1.48	5.82	0.4%	1.7%
H5	1.32	5.94	0.4%	1.7%
H6	1.32	6.13	0.4%	1.8%
H7	2.71	7.21	0.8%	2.1%
H8	0.80	5.02	0.2%	1.4%
H9	1.48	5.85	0.4%	1.7%
H10	1.01	10.54	0.3%	3.0%
H11	0.75	15.73	0.2%	4.5%
H12	0.78	14.39	0.2%	4.1%
H13	1.74	7.19	0.5%	2.1%
H14	1.16	14.76	0.3%	4.2%
H15	0.93	8.20	0.3%	2.3%
H16	1.17	5.80	0.3%	1.7%
H17	1.53	5.83	0.4%	1.7%

Table E.10 Modelled 99.18 percentile 24-hour mean SO_2 at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.38	4.61	0.3%	3.7%
H2	0.26	4.87	0.2%	3.9%
H3	0.53	4.95	0.4%	4.0%
H4	0.37	4.71	0.3%	3.8%
H5	0.39	5.00	0.3%	4.0%
H6	0.29	5.05	0.2%	4.0%
H7	0.72	5.20	0.6%	4.2%
H8	0.20	4.42	0.2%	3.5%
H9	0.36	4.73	0.3%	3.8%
H10	0.22	9.75	0.2%	7.8%
H11	0.12	15.10	0.1%	12.1%
H12	0.19	13.79	0.2%	11.0%
H13	0.53	5.97	0.4%	4.8%
H14	0.24	13.85	0.2%	11.1%
H15	0.15	7.42	0.1%	5.9%
H16	0.49	5.10	0.4%	4.1%
H17	0.46	4.76	0.4%	3.8%

Table E.11 Modelled annual mean BTEX at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.14	0.34	4.3%	10.4%
H2	0.10	0.29	3.1%	8.9%
H3	0.06	0.27	1.8%	8.3%
H4	0.11	0.31	3.4%	9.7%
H5	0.13	0.32	4.0%	9.9%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H6	0.08	0.27	2.3%	8.2%
H7	0.14	0.38	4.3%	11.7%
H8	0.04	0.24	1.3%	7.5%
H9	0.04	0.26	1.1%	8.0%
H10	0.02	0.30	0.6%	9.1%
H11	0.01	0.24	0.3%	7.3%
H12	0.02	0.29	0.6%	8.8%
H13	0.10	0.35	2.9%	10.8%
H14	0.03	0.29	0.8%	9.1%
H15	0.01	0.25	0.3%	7.7%
H16	0.17	0.36	5.3%	11.2%
H17	0.04	0.26	1.2%	8.1%

Table E.12 Modelled 1-hour mean BTEX at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	6.51	6.91	3.1%	3.3%
H2	4.20	4.58	2.0%	2.2%
H3	11.24	11.66	5.4%	5.6%
H4	4.38	4.79	2.1%	2.3%
H5	18.27	18.65	8.8%	9.0%
H6	2.91	3.29	1.4%	1.6%
H7	5.90	6.38	2.8%	3.1%
H8	5.84	6.24	2.8%	3.0%
H9	6.92	7.37	3.3%	3.5%
H10	4.74	5.29	2.3%	2.5%
H11	1.93	2.39	0.9%	1.2%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H12	4.04	4.58	1.9%	2.2%
H13	5.63	6.14	2.7%	3.0%
H14	6.68	7.22	3.2%	3.5%
H15	14.34	14.82	6.9%	7.1%
H16	15.09	15.47	7.3%	7.4%
H17	6.06	6.51	2.9%	3.1%

Table E.13 Modelled annual mean UHCs at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.02	35.07	0.0%	0.2%
H2	0.02	35.06	0.0%	0.2%
H3	0.02	35.08	0.0%	0.2%
H4	0.05	35.16	0.0%	0.2%
H5	0.03	35.10	0.0%	0.2%
H6	0.04	35.13	0.0%	0.2%
H7	0.03	35.12	0.0%	0.2%
H8	0.01	35.02	0.0%	0.2%
H9	0.01	35.02	0.0%	0.2%
H10	0.00	35.01	0.0%	0.2%
H11	0.00	35.01	0.0%	0.2%
H12	0.00	35.01	0.0%	0.2%
H13	0.02	35.07	0.0%	0.2%
H14	0.00	35.01	0.0%	0.2%
H15	0.00	35.02	0.0%	0.2%
H16	0.04	35.14	0.0%	0.2%
H17	0.01	35.02	0.0%	0.2%

Table E.14 Modelled 1-hour mean UHCs at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	1.10	74.62	0.0%	0.0%
H2	0.91	73.58	0.0%	0.0%
H3	1.55	73.09	0.0%	0.0%
H4	0.88	73.34	0.0%	0.0%
H5	0.72	72.59	0.0%	0.0%
H6	0.77	72.70	0.0%	0.0%
H7	0.93	73.98	0.0%	0.0%
H8	1.03	74.44	0.0%	0.0%
H9	0.98	73.53	0.0%	0.0%
H10	0.63	72.76	0.0%	0.0%
H11	0.82	72.11	0.0%	0.0%
H12	0.72	73.20	0.0%	0.0%
H13	0.80	73.29	0.0%	0.0%
H14	0.77	73.26	0.0%	0.0%
H15	0.99	72.50	0.0%	0.0%
H16	0.77	73.21	0.0%	0.0%
H17	1.04	74.22	0.0%	0.0%

Table E.15 Modelled annual mean NO_x at ecological receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.15	12.54	0.5%	41.8%
H2	0.19	12.29	0.6%	41.0%
H3	0.12	12.19	0.4%	40.6%

Table E.16 Modelled daily mean NO_x at ecological receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	8.11	33.86	10.8%	45.1%
H2	12.46	38.23	16.6%	51.0%
H3	7.12	32.22	9.5%	43.0%

Table E.17 Modelled annual mean SO_2 at ecological receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.01	2.34	0%	12%
H2	0.01	2.34	0%	12%
H3	0.00	2.33	0%	12%

Table E.18 Modelled annual mean nitrogen deposition at ecological receptors

Receptor ID	PC (kg/ha/y)	PEC (kg/ha/y)	PC (% of AQAL)	PEC (% of AQAL)
H1	0.02	13.72	0.2%	137.2%
H2	0.02	13.72	0.2%	137.2%
H3	0.01	13.41	0.1%	134.1%

Table E.19 Modelled annual mean acid deposition at ecological receptors

Receptor ID	Sulphur PC (keq/ha/y)	Nitrogen PC (keq/ha/y)	Sulphur PEC (keq/ha/y)	Nitrogen PEC (keq/ha/y)	PC (% of critical load function)	PEC (% of critical load function)
H1	0.000634	0.0011	0.10	1.00	0.3%	220.3%
H2	0.000947	0.0014	0.10	1.00	0.5%	220.5%
H3	0.000513	0.0009	0.20	1.00	0.0%	28.2%

PGC trip – typical peak flaring rate (130 T h^{-1})

Table E.20 Modelled annual mean NO_2 at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	2.38	9.51	5.9%	23.8%
H2	1.70	8.67	4.3%	21.7%
H3	1.88	10.84	4.7%	27.1%
H4	2.88	12.80	7.2%	32.0%
H5	2.56	9.76	6.4%	24.4%
H6	2.33	10.99	5.8%	27.5%
H7	2.85	12.88	7.1%	32.2%
H8	0.40	7.42	1.0%	18.6%
H9	0.47	9.08	1.2%	22.7%
H10	0.22	8.52	0.6%	21.3%
H11	0.21	8.62	0.5%	21.5%
H12	0.21	10.42	0.5%	26.0%
H13	1.66	10.45	4.1%	26.1%
H14	0.30	10.51	0.7%	26.3%
H15	0.26	10.00	0.6%	25.0%
H16	3.42	10.85	8.5%	27.1%
H17	0.43	8.96	1.1%	22.4%

Table E.21 Modelled 99.79 percentile 1-hour mean NO_2 at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	13.34	27.31	6.7%	13.7%
H2	11.33	25.47	5.7%	12.7%
H3	20.44	38.16	10.2%	19.1%
H4	16.98	37.24	8.5%	18.6%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H5	11.83	26.87	5.9%	13.4%
H6	16.30	35.94	8.2%	18.0%
H7	20.00	41.70	10.0%	20.9%
H8	10.70	24.60	5.4%	12.3%
H9	16.78	33.85	8.4%	16.9%
H10	9.39	25.92	4.7%	13.0%
H11	10.44	27.18	5.2%	13.6%
H12	9.82	30.32	4.9%	15.2%
H13	13.80	33.30	6.9%	16.6%
H14	11.66	31.95	5.8%	16.0%
H15	10.50	29.95	5.3%	15.0%
H16	11.81	26.29	5.9%	13.1%
H17	15.36	32.31	7.7%	16.2%

Table E.22 Modelled annual mean PM_{10} at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.12	10.10	0.6%	56.1%
H2	0.12	10.47	0.6%	58.2%
H3	0.11	9.37	0.6%	52.1%
H4	0.32	10.84	1.8%	60.2%
H5	0.23	10.59	1.3%	58.8%
H6	0.29	10.55	1.6%	58.6%
H7	0.11	10.41	0.6%	57.8%
H8	0.02	10.00	0.1%	55.5%
H9	0.02	9.78	0.1%	54.3%
H10	0.01	9.61	0.0%	53.4%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H11	0.01	9.85	0.1%	54.7%
H12	0.01	10.10	0.0%	56.1%
H13	0.07	10.41	0.4%	57.8%
H14	0.01	10.10	0.1%	56.1%
H15	0.01	10.92	0.1%	60.7%
H16	0.29	10.65	1.6%	59.2%
H17	0.01	10.61	0.1%	59.0%

Table E.23 Modelled 98.08 percentile 24-hour mean PM_{10} at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.69	20.66	1.4%	41.3%
H2	0.77	21.49	1.5%	43.0%
H3	0.90	19.42	1.8%	38.8%
H4	2.05	23.08	4.1%	46.2%
H5	1.31	22.03	2.6%	44.1%
H6	1.65	22.16	3.3%	44.3%
H7	0.73	21.32	1.5%	42.6%
H8	0.13	20.10	0.3%	40.2%
H9	0.24	19.77	0.5%	39.5%
H10	0.12	19.32	0.2%	38.6%
H11	0.12	19.80	0.2%	39.6%
H12	0.10	20.29	0.2%	40.6%
H13	0.60	21.28	1.2%	42.6%
H14	0.19	20.37	0.4%	40.7%
H15	0.14	21.96	0.3%	43.9%
H16	1.60	22.32	3.2%	44.6%
H17	0.18	21.38	0.4%	42.8%

Table E.24 Modelled annual mean $PM_{2.5}$ at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.12	5.58	1.2%	55.8%
H2	0.12	5.69	1.2%	56.9%
H3	0.11	5.47	1.1%	54.7%
H4	0.32	5.89	3.2%	58.9%
H5	0.23	5.80	2.3%	58.0%
H6	0.29	5.74	2.9%	57.4%
H7	0.11	5.68	1.1%	56.8%
H8	0.02	5.48	0.2%	54.8%
H9	0.02	5.40	0.2%	54.0%
H10	0.01	5.51	0.1%	55.1%
H11	0.01	5.63	0.1%	56.3%
H12	0.01	5.72	0.1%	57.2%
H13	0.07	5.61	0.7%	56.1%
H14	0.01	5.72	0.1%	57.2%
H15	0.01	5.92	0.1%	59.2%
H16	0.29	5.86	2.9%	58.6%
H17	0.01	5.54	0.1%	55.4%

Table E.25 Modelled annual mean CO at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.86	198.06	0.2%	56.6%
H2	0.77	191.95	0.2%	54.8%
H3	1.14	201.26	0.3%	57.5%
H4	2.93	202.61	0.8%	57.9%
H5	1.50	192.92	0.4%	55.1%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H6	2.05	191.55	0.6%	54.7%
H7	0.87	212.21	0.2%	60.6%
H8	0.11	197.19	0.0%	56.3%
H9	0.11	212.19	0.0%	60.6%
H10	0.07	211.11	0.0%	60.3%
H11	0.08	199.12	0.0%	56.9%
H12	0.07	215.14	0.0%	61.5%
H13	0.53	216.77	0.2%	61.9%
H14	0.09	215.16	0.0%	61.5%
H15	0.09	204.15	0.0%	58.3%
H16	2.05	193.72	0.6%	55.3%
H17	0.11	212.19	0.0%	60.6%

Table E.26 Modelled rolling 8-hour mean CO at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	27.21	421.97	0.3%	4.2%
H2	17.67	401.78	0.2%	4.0%
H3	53.06	453.30	0.5%	4.5%
H4	32.81	432.88	0.3%	4.3%
H5	19.68	403.00	0.2%	4.0%
H6	18.46	397.52	0.2%	4.0%
H7	18.90	442.49	0.2%	4.4%
H8	8.57	403.68	0.1%	4.0%
H9	9.05	433.80	0.1%	4.3%
H10	7.18	429.85	0.1%	4.3%
H11	8.51	407.33	0.1%	4.1%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H12	11.59	442.14	0.1%	4.4%
H13	17.85	451.37	0.2%	4.5%
H14	16.60	447.65	0.2%	4.5%
H15	10.65	419.63	0.1%	4.2%
H16	21.75	405.73	0.2%	4.1%
H17	14.30	438.89	0.1%	4.4%

Table E.27 Modelled 99.9 percentile 15-minute mean SO_2 at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	3.57	7.79	1.3%	2.9%
H2	2.96	7.56	1.1%	2.8%
H3	5.21	9.63	2.0%	3.6%
H4	4.15	8.48	1.6%	3.2%
H5	3.37	8.02	1.3%	3.0%
H6	3.83	8.64	1.4%	3.2%
H7	5.47	9.97	2.1%	3.7%
H8	2.38	6.60	0.9%	2.5%
H9	4.00	8.36	1.5%	3.1%
H10	2.48	12.00	0.9%	4.5%
H11	2.88	17.87	1.1%	6.7%
H12	2.26	15.86	0.8%	6.0%
H13	4.41	9.92	1.7%	3.7%
H14	2.73	16.33	1.0%	6.1%
H15	3.65	10.91	1.4%	4.1%
H16	3.39	8.01	1.3%	3.0%
H17	3.32	7.62	1.2%	2.9%

Table E.28 Modelled 99.73 percentile 1-hour mean SO_2 at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	3.01	7.23	0.9%	2.1%
H2	2.29	6.90	0.7%	2.0%
H3	4.62	9.04	1.3%	2.6%
H4	3.06	7.41	0.9%	2.1%
H5	2.03	6.66	0.6%	1.9%
H6	2.71	7.53	0.8%	2.2%
H7	3.26	7.76	0.9%	2.2%
H8	1.65	5.87	0.5%	1.7%
H9	2.55	6.91	0.7%	2.0%
H10	1.47	11.00	0.4%	3.1%
H11	1.50	16.50	0.4%	4.7%
H12	1.52	15.12	0.4%	4.3%
H13	2.71	8.19	0.8%	2.3%
H14	2.01	15.62	0.6%	4.5%
H15	1.66	8.92	0.5%	2.5%
H16	2.21	6.84	0.6%	2.0%
H17	2.23	6.53	0.6%	1.9%

Table E.29 Modelled 99.18 percentile 24-hour mean SO_2 at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	1.18	5.41	0.9%	4.3%
H2	0.89	5.49	0.7%	4.4%
H3	2.27	6.69	1.8%	5.4%
H4	1.57	5.92	1.3%	4.7%
H5	1.01	5.62	0.8%	4.5%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H6	1.17	5.92	0.9%	4.7%
H7	1.66	6.13	1.3%	4.9%
H8	0.47	4.69	0.4%	3.8%
H9	0.90	5.28	0.7%	4.2%
H10	0.43	9.96	0.3%	8.0%
H11	0.33	15.32	0.3%	12.3%
H12	0.42	14.03	0.3%	11.2%
H13	1.45	6.90	1.2%	5.5%
H14	0.60	14.21	0.5%	11.4%
H15	0.43	7.69	0.3%	6.2%
H16	1.23	5.84	1.0%	4.7%
H17	0.87	5.18	0.7%	4.1%

Table E.30 Modelled annual mean BTEX at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.15	0.35	4.6%	10.8%
H2	0.11	0.30	3.5%	9.3%
H3	0.07	0.28	2.1%	8.7%
H4	0.15	0.35	4.5%	10.8%
H5	0.16	0.35	5.0%	10.9%
H6	0.11	0.30	3.5%	9.3%
H7	0.15	0.39	4.5%	11.9%
H8	0.04	0.24	1.3%	7.5%
H9	0.04	0.26	1.1%	8.0%
H10	0.02	0.30	0.6%	9.1%
H11	0.01	0.24	0.3%	7.4%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H12	0.02	0.29	0.6%	8.9%
H13	0.10	0.36	3.1%	11.0%
H14	0.03	0.30	0.8%	9.1%
H15	0.01	0.25	0.4%	7.7%
H16	0.21	0.40	6.3%	12.2%
H17	0.04	0.26	1.2%	8.1%

Table E.31 Modelled 1-hour mean BTEX at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	6.55	6.95	3.1%	3.3%
H2	4.23	4.61	2.0%	2.2%
H3	15.13	15.56	7.3%	7.5%
H4	4.41	4.82	2.1%	2.3%
H5	18.26	18.64	8.8%	9.0%
H6	2.91	3.29	1.4%	1.6%
H7	6.26	6.74	3.0%	3.2%
H8	5.85	6.25	2.8%	3.0%
H9	6.93	7.38	3.3%	3.5%
H10	4.76	5.31	2.3%	2.6%
H11	1.92	2.38	0.9%	1.1%
H12	4.08	4.62	2.0%	2.2%
H13	5.69	6.21	2.7%	3.0%
H14	6.70	7.24	3.2%	3.5%
H15	14.39	14.87	6.9%	7.1%
H16	15.13	15.51	7.3%	7.5%
H17	6.07	6.52	2.9%	3.1%

Table E.32 Modelled annual mean UHCs at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.23	35.29	0.0%	0.2%
H2	0.29	35.34	0.0%	0.2%
H3	0.30	35.36	0.0%	0.2%
H4	1.20	36.30	0.0%	0.3%
H5	0.68	35.75	0.0%	0.2%
H6	1.04	36.12	0.0%	0.2%
H7	0.16	35.24	0.0%	0.2%
H8	0.02	35.03	0.0%	0.2%
H9	0.01	35.03	0.0%	0.2%
H10	0.01	35.02	0.0%	0.2%
H11	0.02	35.03	0.0%	0.2%
H12	0.01	35.02	0.0%	0.2%
H13	0.13	35.17	0.0%	0.2%
H14	0.02	35.02	0.0%	0.2%
H15	0.02	35.03	0.0%	0.2%
H16	0.87	35.97	0.0%	0.2%
H17	0.02	35.03	0.0%	0.2%

Table E.33 Modelled 1-hour mean UHCs at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	24.97	95.45	0.0%	0.1%
H2	26.29	96.61	0.0%	0.1%
H3	32.12	102.89	0.0%	0.1%
H4	34.36	104.69	0.0%	0.1%
H5	23.94	94.18	0.0%	0.1%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H6	25.51	95.75	0.0%	0.1%
H7	16.31	86.90	0.0%	0.0%
H8	11.14	81.81	0.0%	0.0%
H9	10.95	81.54	0.0%	0.0%
H10	14.40	84.76	0.0%	0.0%
H11	20.59	90.84	0.0%	0.1%
H12	18.16	88.51	0.0%	0.0%
H13	21.31	91.77	0.0%	0.1%
H14	16.73	87.26	0.0%	0.0%
H15	23.61	93.95	0.0%	0.1%
H16	26.37	96.65	0.0%	0.1%
H17	14.25	84.80	0.0%	0.0%

Table E.34 Modelled annual mean NO_x at ecological receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.18	12.57	0.6%	41.9%
H2	0.22	12.32	0.7%	41.1%
H3	0.14	12.21	0.5%	40.7%

Table E.35 Modelled daily mean NO_x at ecological receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	10.91	36.66	14.5%	48.9%
H2	14.27	40.04	19.0%	53.4%
H3	9.49	34.60	12.7%	46.1%

Table E.36 Modelled annual mean SO_2 at ecological receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.01	2.34	0%	12%
H2	0.01	2.35	0%	12%
H3	0.01	2.34	0%	12%

Table E.37 Modelled annual mean nitrogen deposition at ecological receptors

Receptor ID	PC (kg/ha/y)	PEC (kg/ha/y)	PC (% of AQAL)	PEC (% of AQAL)
H1	0.02	13.72	0.2%	137.2%
H2	0.02	13.72	0.2%	137.2%
H3	0.01	13.41	0.1%	134.1%

Table E.38 Modelled annual mean acid deposition at ecological receptors

Receptor ID	Sulphur PC (keq/ha/y)	Nitrogen PC (keq/ha/y)	Sulphur PEC (keq/ha/y)	Nitrogen PEC (keq/ha/y)	PC (% of critical load function)	PEC (% of critical load function)
H1	0.001453	0.0013	0.10	1.00	0.6%	220.6%
H2	0.001765	0.0016	0.10	1.00	0.7%	220.7%
H3	0.001186	0.0010	0.20	1.00	0.1%	28.2%

PGC trip – instantaneous peak flaring rate (200 T h^{-1})

Table E.39 Modelled annual mean NO_2 at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	2.38	9.51	5.9%	23.8%
H2	1.70	8.67	4.2%	21.7%
H3	1.89	10.84	4.7%	27.1%
H4	2.89	12.80	7.2%	32.0%
H5	2.55	9.76	6.4%	24.4%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H6	2.33	10.99	5.8%	27.5%
H7	2.86	12.88	7.1%	32.2%
H8	0.40	7.42	1.0%	18.6%
H9	0.47	9.08	1.2%	22.7%
H10	0.22	8.52	0.6%	21.3%
H11	0.21	8.62	0.5%	21.5%
H12	0.21	10.42	0.5%	26.0%
H13	1.66	10.46	4.2%	26.1%
H14	0.30	10.51	0.7%	26.3%
H15	0.26	10.00	0.6%	25.0%
H16	3.42	10.85	8.5%	27.1%
H17	0.43	8.96	1.1%	22.4%

Table E.40 Modelled 99.79 percentile 1-hour mean NO_2 at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	13.34	27.31	6.7%	13.7%
H2	11.33	25.47	5.7%	12.7%
H3	20.44	38.16	10.2%	19.1%
H4	17.01	37.25	8.5%	18.6%
H5	11.83	26.88	5.9%	13.4%
H6	16.32	35.95	8.2%	18.0%
H7	20.01	41.71	10.0%	20.9%
H8	10.70	24.60	5.4%	12.3%
H9	16.78	33.85	8.4%	16.9%
H10	9.39	25.92	4.7%	13.0%
H11	10.45	27.19	5.2%	13.6%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H12	9.82	30.32	4.9%	15.2%
H13	13.82	33.30	6.9%	16.7%
H14	11.66	31.95	5.8%	16.0%
H15	10.55	29.95	5.3%	15.0%
H16	11.81	26.30	5.9%	13.1%
H17	15.36	32.31	7.7%	16.2%

Table E.41 Modelled annual mean PM_{10} at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.10	10.08	0.5%	56.0%
H2	0.09	10.45	0.5%	58.1%
H3	0.09	9.35	0.5%	52.0%
H4	0.27	10.79	1.5%	59.9%
H5	0.19	10.55	1.0%	58.6%
H6	0.26	10.52	1.4%	58.4%
H7	0.10	10.40	0.6%	57.8%
H8	0.01	10.00	0.1%	55.5%
H9	0.02	9.78	0.1%	54.3%
H10	0.01	9.61	0.0%	53.4%
H11	0.01	9.84	0.0%	54.7%
H12	0.01	10.10	0.0%	56.1%
H13	0.06	10.40	0.3%	57.8%
H14	0.01	10.10	0.1%	56.1%
H15	0.01	10.92	0.1%	60.7%
H16	0.24	10.60	1.3%	58.9%
H17	0.01	10.61	0.1%	59.0%

Table E.42 Modelled 98.08 percentile 24-hour mean PM_{10} at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.55	20.52	1.1%	41.0%
H2	0.57	21.29	1.1%	42.6%
H3	0.68	19.21	1.4%	38.4%
H4	1.99	23.03	4.0%	46.1%
H5	1.03	21.75	2.1%	43.5%
H6	1.70	22.21	3.4%	44.4%
H7	0.60	21.19	1.2%	42.4%
H8	0.13	20.09	0.3%	40.2%
H9	0.24	19.77	0.5%	39.5%
H10	0.11	19.32	0.2%	38.6%
H11	0.12	19.79	0.2%	39.6%
H12	0.10	20.28	0.2%	40.6%
H13	0.47	21.14	0.9%	42.3%
H14	0.17	20.35	0.3%	40.7%
H15	0.14	21.96	0.3%	43.9%
H16	1.43	22.15	2.9%	44.3%
H17	0.18	21.38	0.4%	42.8%

Table E.43 Modelled annual mean $PM_{2.5}$ at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.10	5.56	1.0%	55.6%
H2	0.09	5.66	0.9%	56.6%
H3	0.09	5.45	0.9%	54.5%
H4	0.27	5.84	2.7%	58.4%
H5	0.19	5.76	1.9%	57.6%
H6	0.26	5.71	2.6%	57.1%
H7	0.10	5.67	1.0%	56.7%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H8	0.01	5.47	0.1%	54.7%
H9	0.02	5.39	0.2%	53.9%
H10	0.01	5.51	0.1%	55.1%
H11	0.01	5.62	0.1%	56.2%
H12	0.01	5.71	0.1%	57.1%
H13	0.06	5.60	0.6%	56.0%
H14	0.01	5.72	0.1%	57.2%
H15	0.01	5.92	0.1%	59.2%
H16	0.24	5.81	2.4%	58.1%
H17	0.01	5.54	0.1%	55.4%

Table E.44 Modelled annual mean CO at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.86	198.07	0.2%	56.6%
H2	0.76	191.94	0.2%	54.8%
H3	1.16	201.28	0.3%	57.5%
H4	2.95	202.63	0.8%	57.9%
H5	1.49	192.90	0.4%	55.1%
H6	2.07	191.57	0.6%	54.7%
H7	0.90	212.24	0.3%	60.6%
H8	0.11	197.19	0.0%	56.3%
H9	0.12	212.20	0.0%	60.6%
H10	0.07	211.11	0.0%	60.3%
H11	0.08	199.12	0.0%	56.9%
H12	0.08	215.15	0.0%	61.5%
H13	0.55	216.80	0.2%	61.9%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H14	0.10	215.16	0.0%	61.5%
H15	0.09	204.15	0.0%	58.3%
H16	2.04	193.71	0.6%	55.3%
H17	0.11	212.19	0.0%	60.6%

Table E.45 Modelled rolling 8-hour mean CO at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	26.92	421.68	0.3%	4.2%
H2	16.58	401.33	0.2%	4.0%
H3	53.04	453.28	0.5%	4.5%
H4	33.80	433.87	0.3%	4.3%
H5	21.21	404.53	0.2%	4.0%
H6	20.61	399.45	0.2%	4.0%
H7	18.79	442.38	0.2%	4.4%
H8	8.73	403.68	0.1%	4.0%
H9	8.96	433.70	0.1%	4.3%
H10	7.08	429.74	0.1%	4.3%
H11	8.22	407.04	0.1%	4.1%
H12	10.59	441.14	0.1%	4.4%
H13	17.35	451.37	0.2%	4.5%
H14	15.58	446.62	0.2%	4.5%
H15	10.45	419.43	0.1%	4.2%
H16	22.99	406.97	0.2%	4.1%
H17	13.61	438.20	0.1%	4.4%

Table E.46 Modelled 99.9 percentile 15-minute mean SO_2 at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	3.57	7.79	1.3%	2.9%
H2	2.96	7.56	1.1%	2.8%
H3	5.14	9.56	1.9%	3.6%
H4	4.16	8.49	1.6%	3.2%
H5	3.37	8.03	1.3%	3.0%
H6	3.90	8.72	1.5%	3.3%
H7	5.47	9.98	2.1%	3.8%
H8	2.39	6.61	0.9%	2.5%
H9	4.00	8.36	1.5%	3.1%
H10	2.48	12.00	0.9%	4.5%
H11	2.88	17.87	1.1%	6.7%
H12	2.27	15.88	0.9%	6.0%
H13	4.42	9.93	1.7%	3.7%
H14	2.73	16.33	1.0%	6.1%
H15	3.66	10.92	1.4%	4.1%
H16	3.40	8.01	1.3%	3.0%
H17	3.32	7.62	1.2%	2.9%

Table E.47 Modelled 99.73 percentile 1-hour mean SO_2 at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	2.99	7.23	0.9%	2.1%
H2	2.18	6.81	0.6%	1.9%
H3	4.57	8.99	1.3%	2.6%
H4	3.16	7.51	0.9%	2.1%
H5	2.04	6.67	0.6%	1.9%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H6	2.73	7.55	0.8%	2.2%
H7	3.26	7.76	0.9%	2.2%
H8	1.65	5.87	0.5%	1.7%
H9	2.54	6.91	0.7%	2.0%
H10	1.46	10.99	0.4%	3.1%
H11	1.50	16.48	0.4%	4.7%
H12	1.52	15.12	0.4%	4.3%
H13	2.73	8.20	0.8%	2.3%
H14	1.98	15.59	0.6%	4.5%
H15	1.60	8.86	0.5%	2.5%
H16	2.24	6.86	0.6%	2.0%
H17	2.21	6.51	0.6%	1.9%

Table E.48 Modelled 99.18 percentile 24-hour mean SO_2 at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	1.17	5.39	0.9%	4.3%
H2	0.85	5.46	0.7%	4.4%
H3	2.27	6.71	1.8%	5.4%
H4	1.57	5.91	1.3%	4.7%
H5	1.04	5.65	0.8%	4.5%
H6	1.19	5.94	1.0%	4.8%
H7	1.66	6.13	1.3%	4.9%
H8	0.46	4.68	0.4%	3.7%
H9	0.92	5.29	0.7%	4.2%
H10	0.44	9.97	0.4%	8.0%
H11	0.33	15.32	0.3%	12.3%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H12	0.43	14.03	0.3%	11.2%
H13	1.45	6.90	1.2%	5.5%
H14	0.60	14.22	0.5%	11.4%
H15	0.43	7.70	0.3%	6.2%
H16	1.20	5.81	1.0%	4.7%
H17	0.88	5.19	0.7%	4.2%

Table E.49 Modelled annual mean BTEX at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.16	0.36	4.9%	11.1%
H2	0.12	0.31	3.7%	9.6%
H3	0.09	0.30	2.7%	9.3%
H4	0.20	0.40	6.1%	12.4%
H5	0.18	0.37	5.6%	11.5%
H6	0.15	0.34	4.5%	10.4%
H7	0.16	0.40	4.9%	12.3%
H8	0.04	0.24	1.3%	7.5%
H9	0.04	0.26	1.1%	8.1%
H10	0.02	0.30	0.7%	9.1%
H11	0.01	0.24	0.3%	7.4%
H12	0.02	0.29	0.6%	8.9%
H13	0.11	0.36	3.3%	11.2%
H14	0.03	0.30	0.9%	9.1%
H15	0.01	0.25	0.4%	7.7%
H16	0.23	0.43	7.2%	13.1%
H17	0.04	0.26	1.3%	8.1%

Table E.50 Modelled 1-hour mean BTEX at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	6.60	7.00	3.2%	3.4%
H2	4.29	4.67	2.1%	2.2%
H3	15.13	15.56	7.3%	7.5%
H4	4.41	4.82	2.1%	2.3%
H5	18.26	18.64	8.8%	9.0%
H6	2.91	3.29	1.4%	1.6%
H7	6.32	6.80	3.0%	3.3%
H8	5.86	6.26	2.8%	3.0%
H9	6.95	7.40	3.3%	3.6%
H10	4.81	5.36	2.3%	2.6%
H11	1.93	2.39	0.9%	1.1%
H12	4.15	4.69	2.0%	2.3%
H13	5.85	6.36	2.8%	3.1%
H14	6.76	7.30	3.3%	3.5%
H15	14.39	14.87	6.9%	7.1%
H16	15.13	15.51	7.3%	7.5%
H17	6.09	6.53	2.9%	3.1%

Table E.51 Modelled annual mean UHCs at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.47	35.53	0.0%	0.2%
H2	0.50	35.54	0.0%	0.2%
H3	0.79	35.85	0.0%	0.2%
H4	2.42	37.52	0.0%	0.3%
H5	1.12	36.19	0.0%	0.2%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H6	1.83	36.91	0.0%	0.3%
H7	0.45	35.54	0.0%	0.2%
H8	0.05	35.06	0.0%	0.2%
H9	0.05	35.07	0.0%	0.2%
H10	0.04	35.05	0.0%	0.2%
H11	0.05	35.06	0.0%	0.2%
H12	0.04	35.05	0.0%	0.2%
H13	0.31	35.36	0.0%	0.2%
H14	0.05	35.06	0.0%	0.2%
H15	0.05	35.07	0.0%	0.2%
H16	1.55	36.65	0.0%	0.3%
H17	0.05	35.07	0.0%	0.2%

Table E.52 Modelled 1-hour mean UHCs at human receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	36.75	107.40	0.0%	0.1%
H2	39.08	109.41	0.0%	0.1%
H3	50.07	120.83	0.0%	0.1%
H4	53.21	123.50	0.0%	0.1%
H5	38.89	109.07	0.0%	0.1%
H6	42.97	113.15	0.0%	0.1%
H7	27.35	97.93	0.0%	0.1%
H8	19.32	89.61	0.0%	0.0%
H9	21.23	91.83	0.0%	0.1%
H10	15.89	86.25	0.0%	0.0%
H11	24.57	94.83	0.0%	0.1%

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H12	20.12	90.47	0.0%	0.0%
H13	26.02	96.47	0.0%	0.1%
H14	21.58	92.12	0.0%	0.1%
H15	27.08	97.41	0.0%	0.1%
H16	42.69	112.88	0.0%	0.1%
H17	17.89	88.42	0.0%	0.0%

Table E.53 Modelled annual mean NO_x at ecological receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.18	12.57	0.6%	41.9%
H2	0.22	12.32	0.7%	41.1%
H3	0.14	12.21	0.5%	40.7%

Table E.54 Modelled daily mean NO_x at ecological receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	10.92	36.67	14.6%	48.9%
H2	14.28	40.05	19.0%	53.4%
H3	9.50	34.61	12.7%	46.1%

Table E.55 Modelled annual mean SO_2 at ecological receptors

Receptor ID	PC (µg m^{-3})	PEC (µg m^{-3})	PC (% of AQAL)	PEC (% of AQAL)
H1	0.01	2.34	0%	12%
H2	0.02	2.35	0%	12%
H3	0.01	2.34	0%	12%

Table E.56 Modelled annual mean nitrogen deposition at ecological receptors

Receptor ID	PC (kg/ha/y)	PEC (kg/ha/y)	PC (% of AQAL)	PEC (% of AQAL)
H1	0.02	13.72	0.2%	137.2%
H2	0.02	13.72	0.2%	137.2%
H3	0.01	13.41	0.1%	134.1%

Table E.57 Modelled annual mean acid deposition at ecological receptors

Receptor ID	Sulphur PC (keq/ha/y)	Nitrogen PC (keq/ha/y)	Sulphur PEC (keq/ha/y)	Nitrogen PEC (keq/ha/y)	PC (% of critical load function)	PEC (% of critical load function)
H1	0.001470	0.0013	0.10	1.00	0.6%	220.6%
H2	0.001799	0.0016	0.10	1.00	0.7%	220.7%
H3	0.001205	0.0010	0.20	1.00	0.1%	28.2%

Appendix F
Concentration Isopleths

Normal operation

Figure F1 Modelled annual mean NO_2

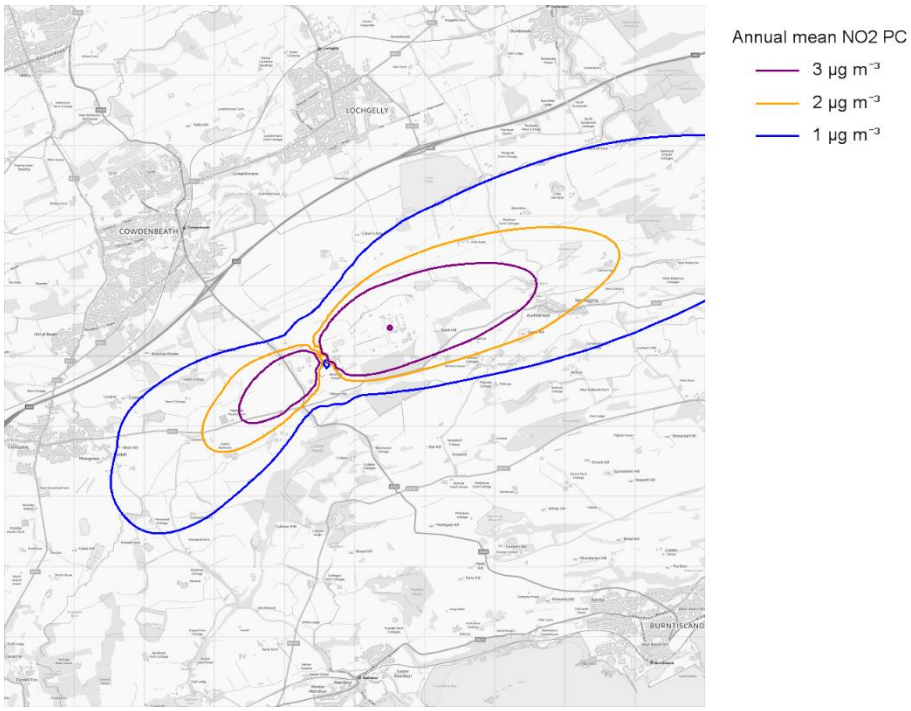


Figure F.2 Modelled 99.79 percentile 1-hour mean NO_2

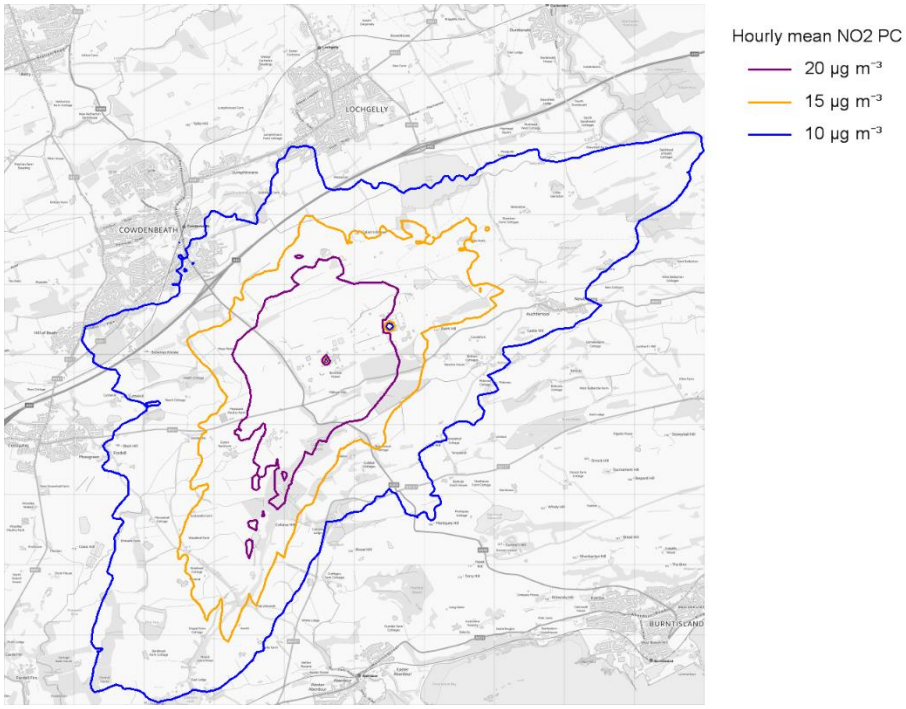


Figure F.3 Modelled annual mean PM_{10}

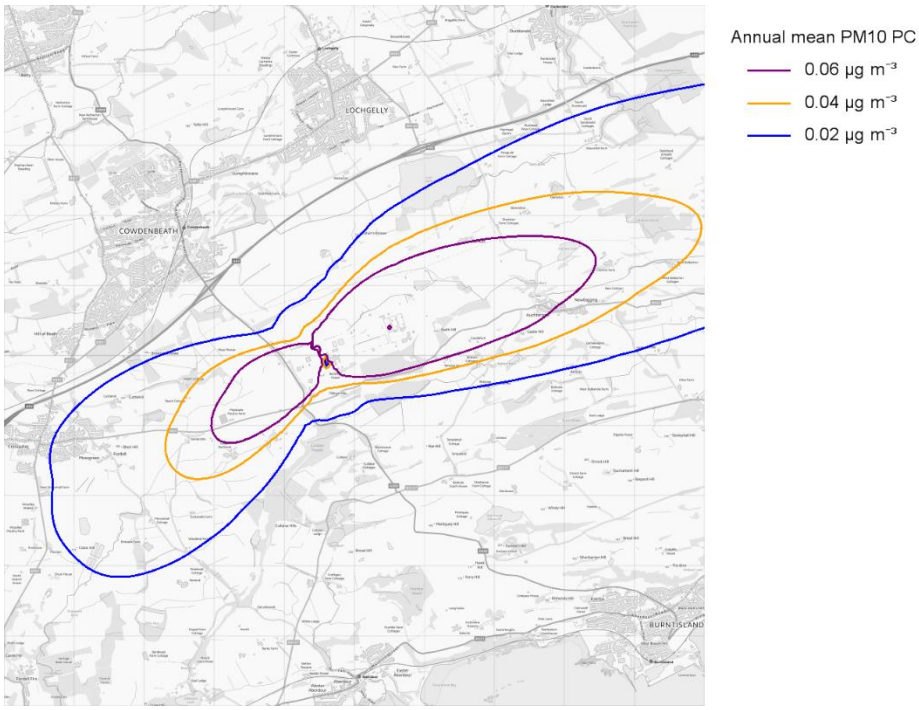


Figure F.4 Modelled 98.08 percentile 24-hour mean PM_{10}

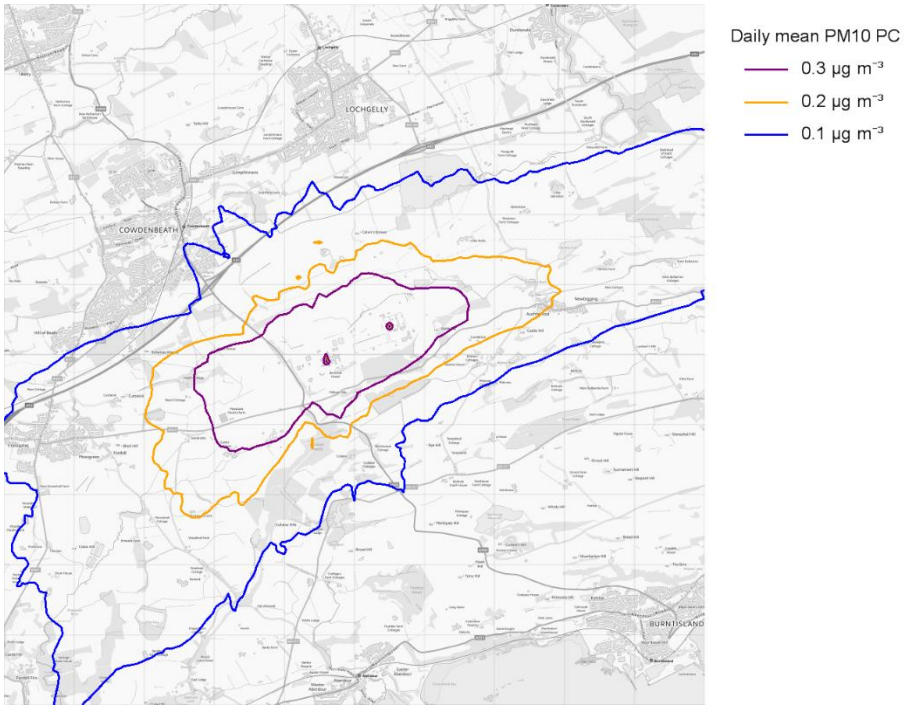


Figure F.5 Modelled annual mean $PM_{2.5}$

Figure F.6 Modelled annual mean CO

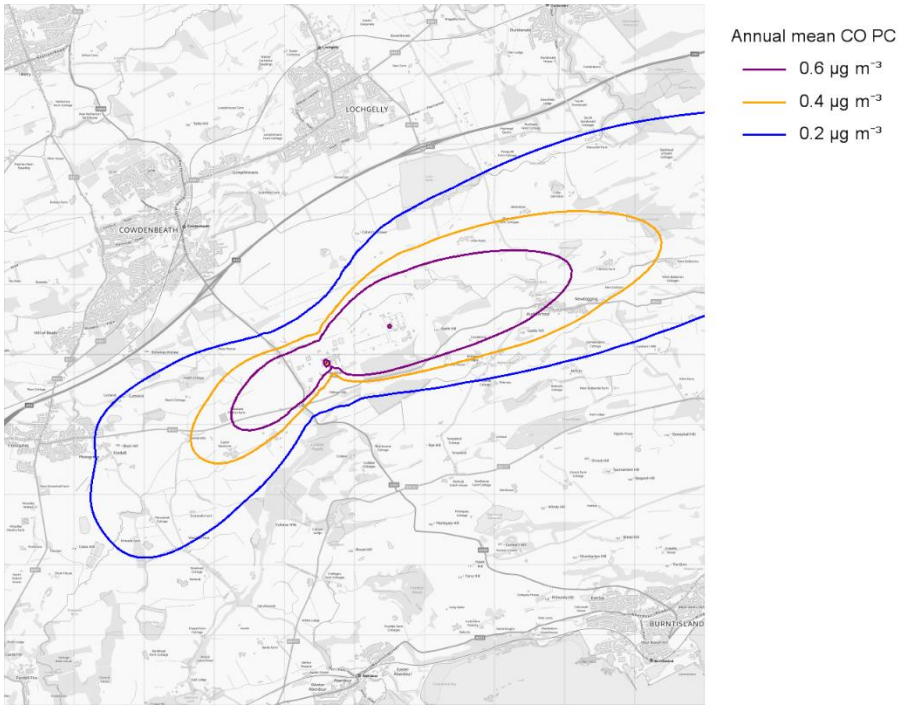


Figure F7 Modelled rolling 8-hour mean CO

Figure F.8 Modelled 99.9 percentile 15-minute mean SO_2

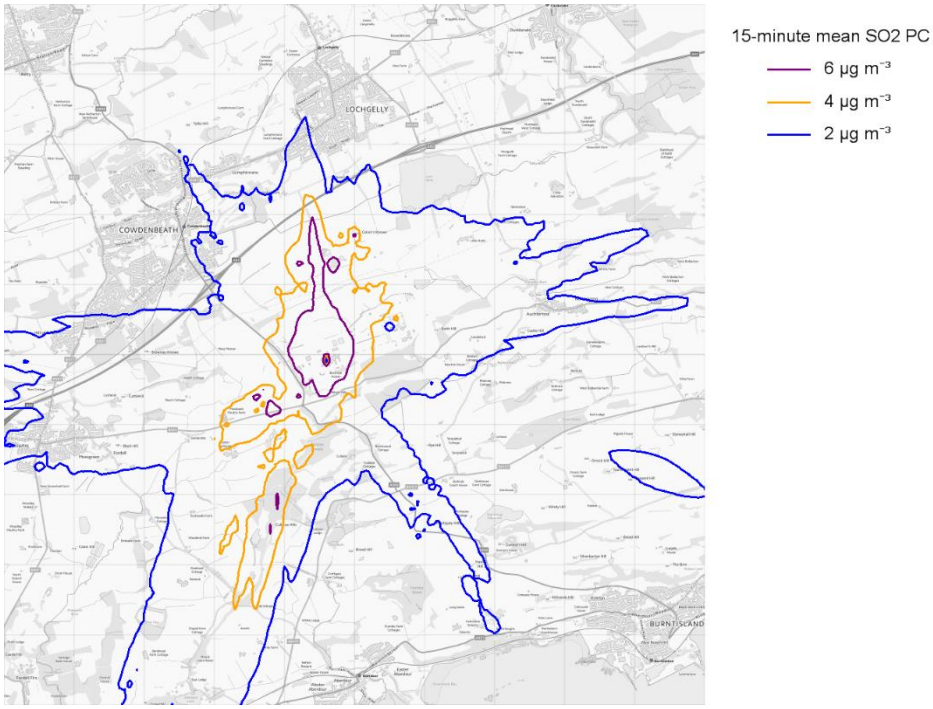


Figure F9 Modelled 99.73 percentile 1-hour mean SO_2

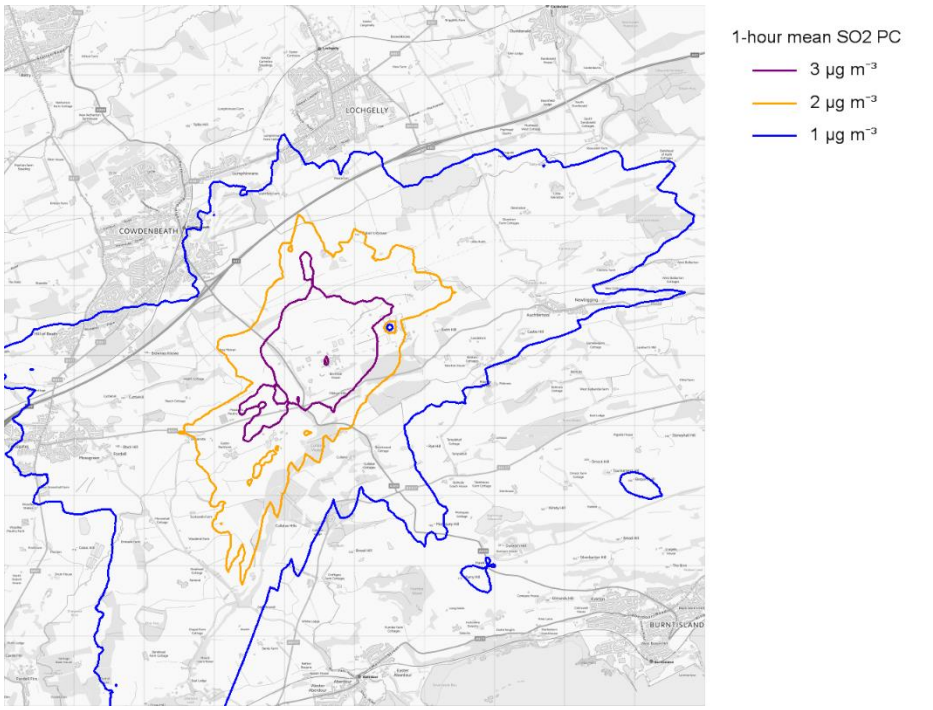


Figure F.10 Modelled 99.18 percentile 24-hour mean SO_2

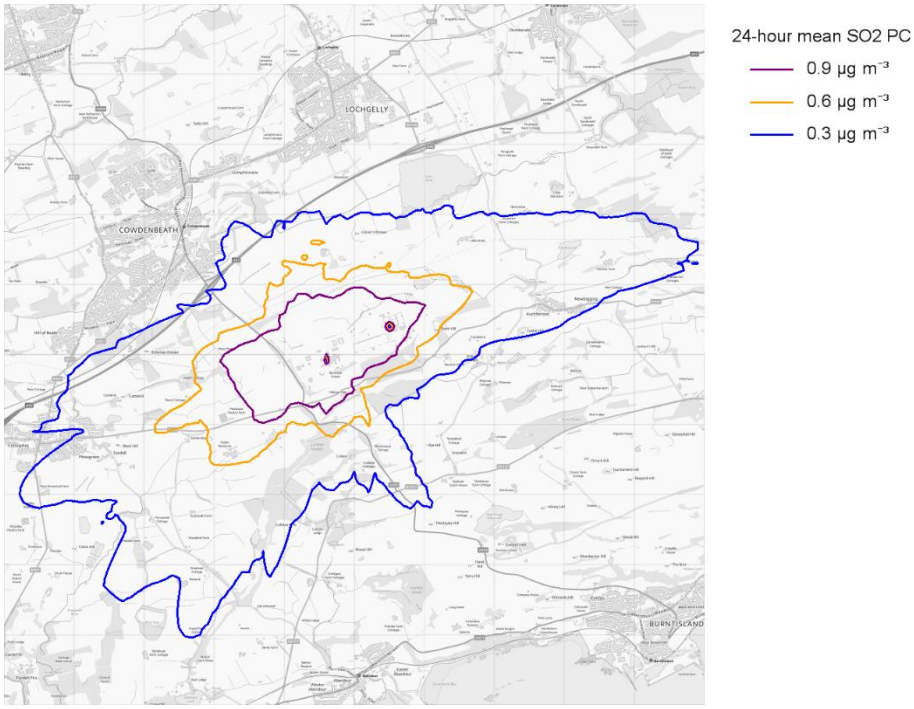


Figure F11 Modelled annual mean BTEX

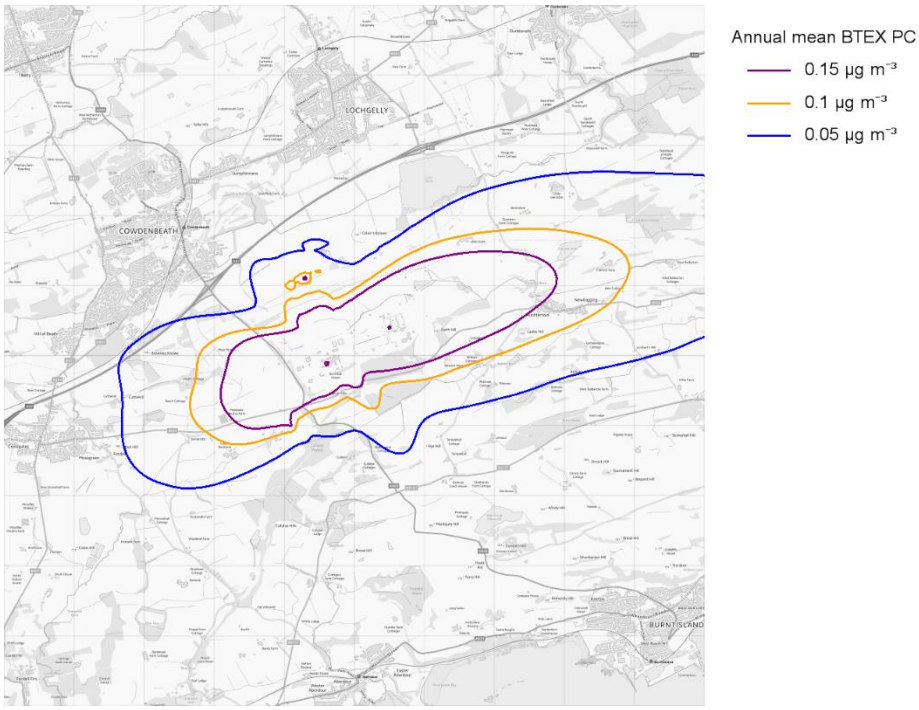


Figure F.12 Modelled 1-hour mean BTEX

Figure F.13 Modelled annual mean UHCs

Figure F.14 Modelled 1-hour mean UHCs

Figure F.15 Modelled annual mean NO_x

Figure F.16 Modelled daily mean NO_x

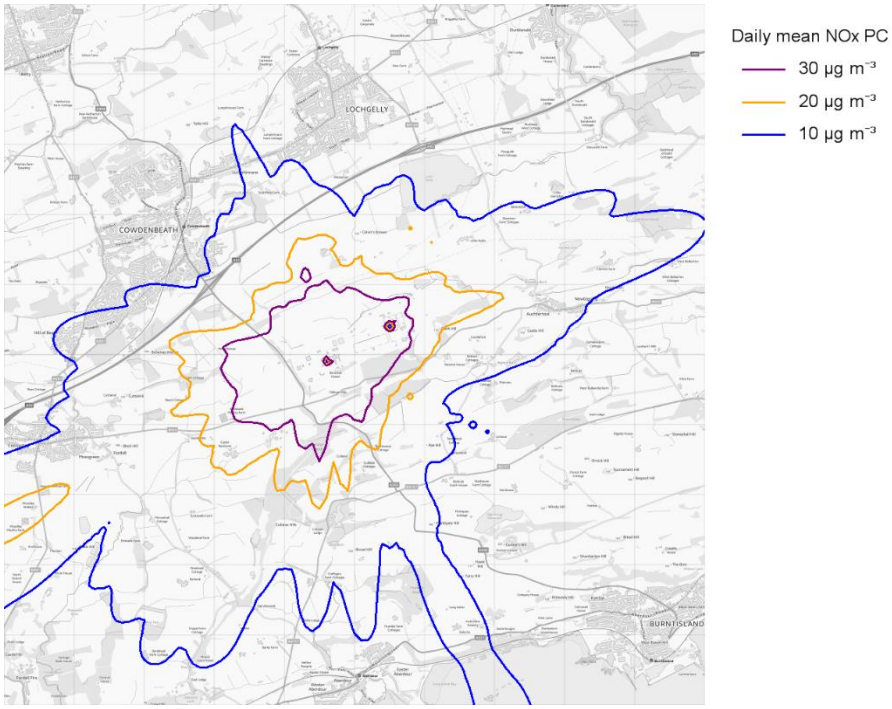


Figure F.17 Modelled annual mean SO_2

PGC trip – typical peak flaring rate (130 T h^{-1})

Figure F.18 Modelled annual mean NO_2

Figure F.19 Modelled 99.79 percentile 1-hour mean NO_2

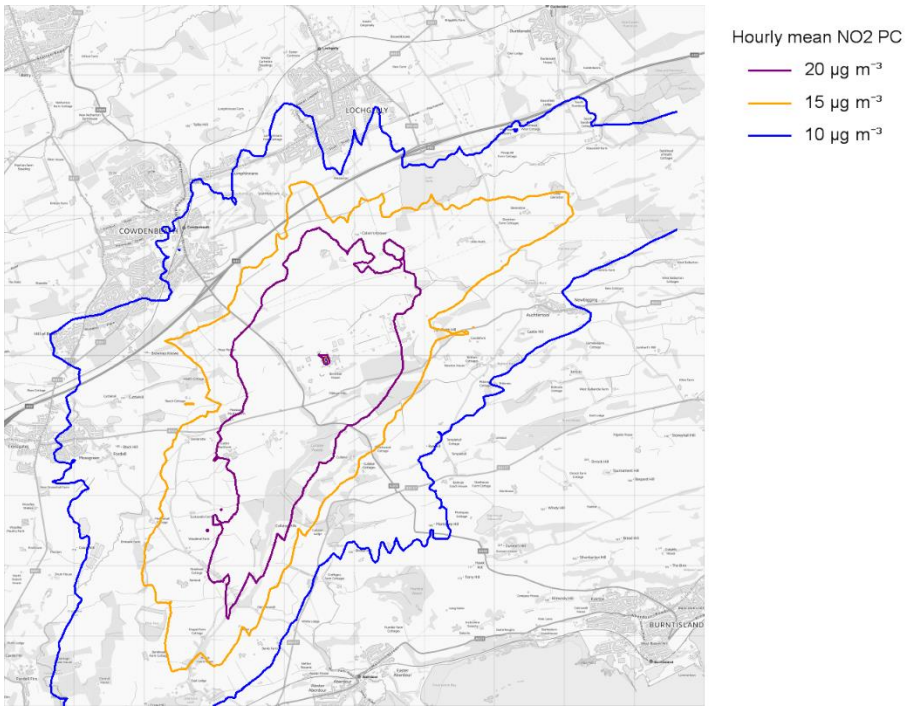


Figure F.20 Modelled annual mean PM_{10}

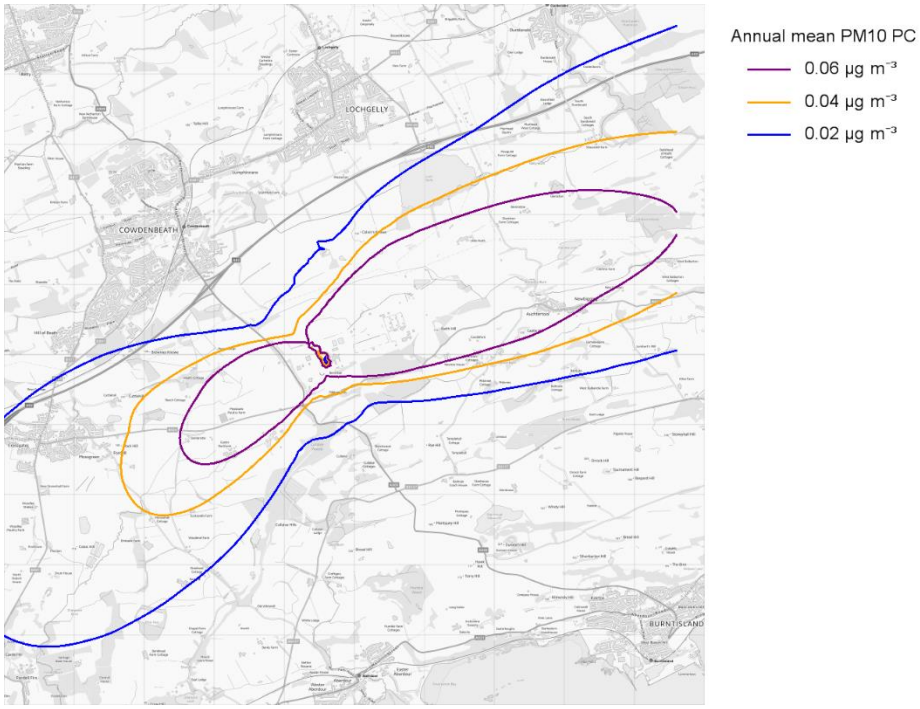


Figure F.21 Modelled 98.08 percentile 24-hour mean PM_{10}

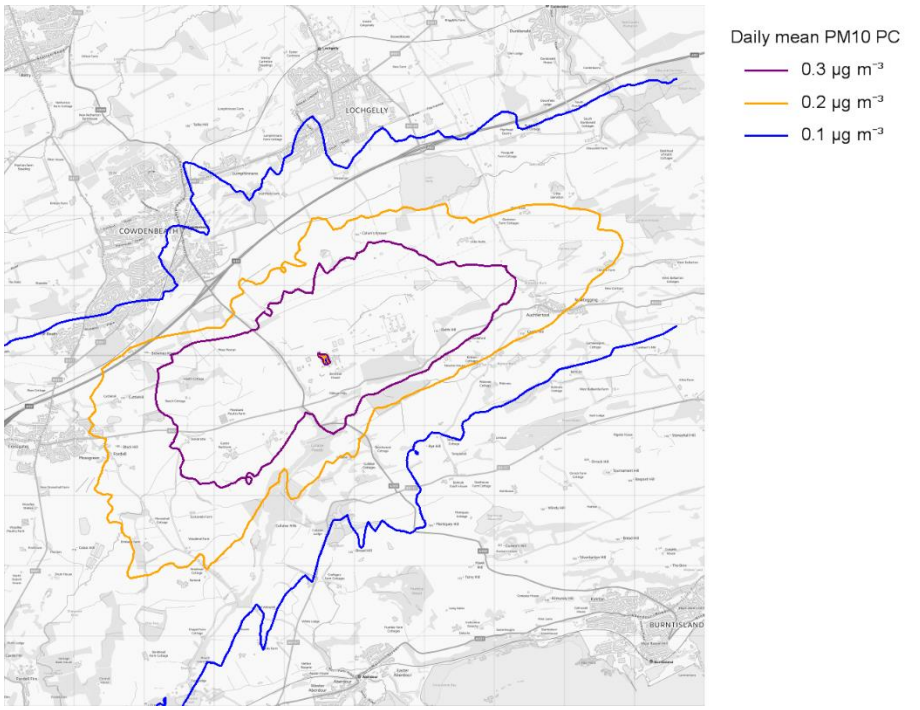


Figure F.22 Modelled annual mean $PM_{2.5}$

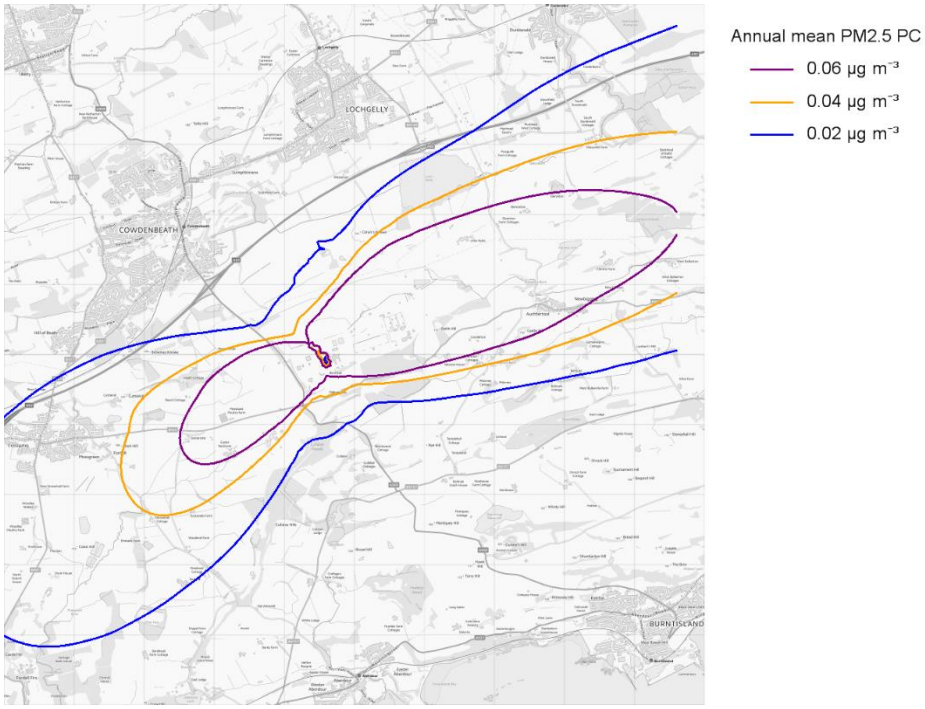


Figure F.23 Modelled annual mean CO

Figure F.24 Modelled rolling 8-hour mean CO

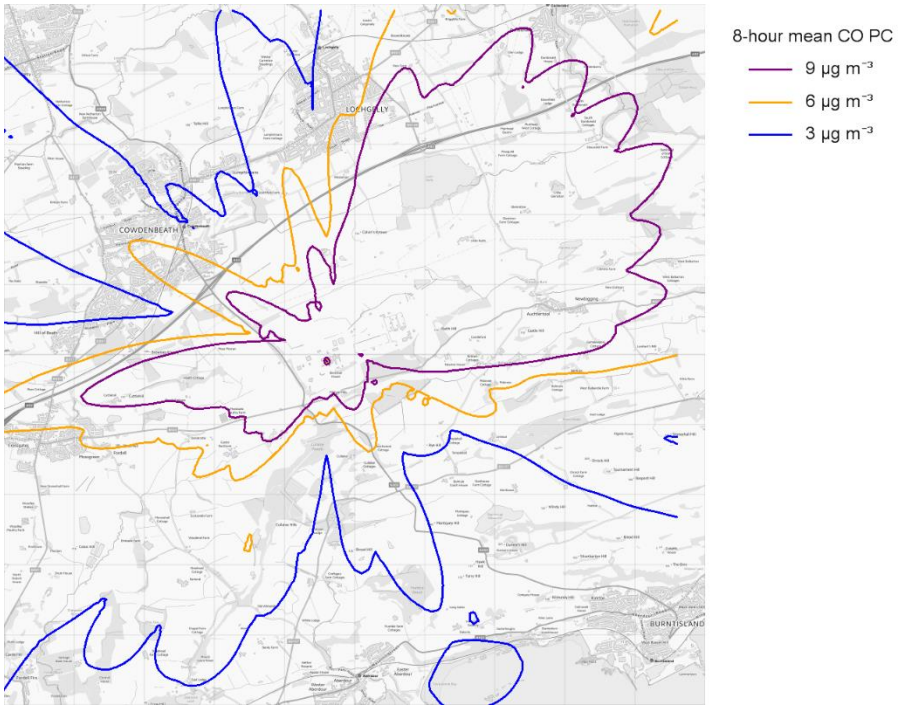


Figure F.25 Modelled 99.9 percentile 15-minute mean SO_2

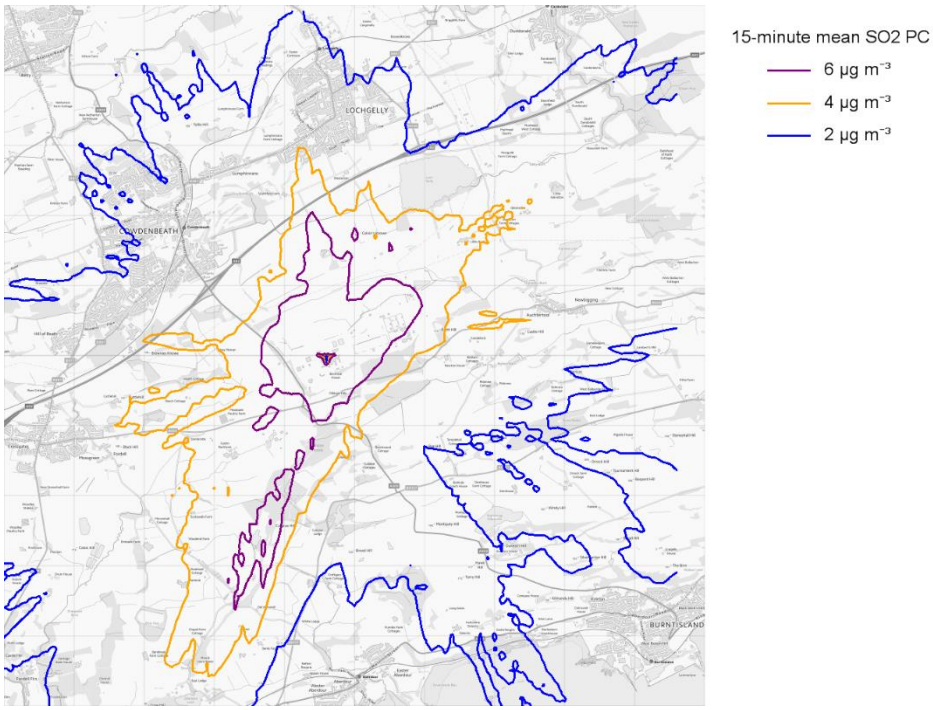


Figure F.26 Modelled 99.73 percentile 1-hour mean SO_2

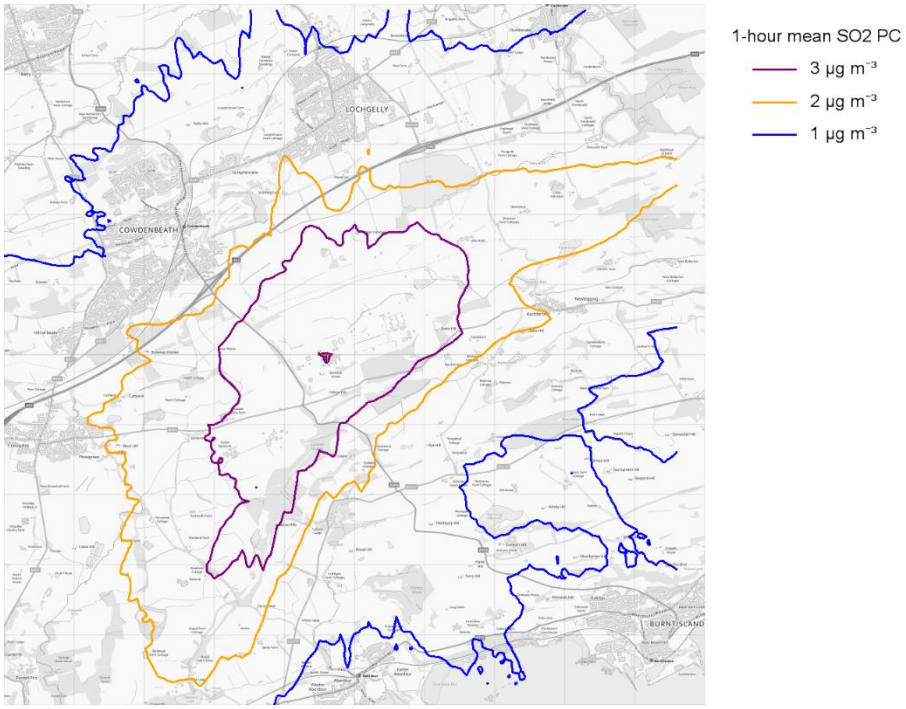


Figure F.27 Modelled 99.18 percentile 24-hour mean SO_2

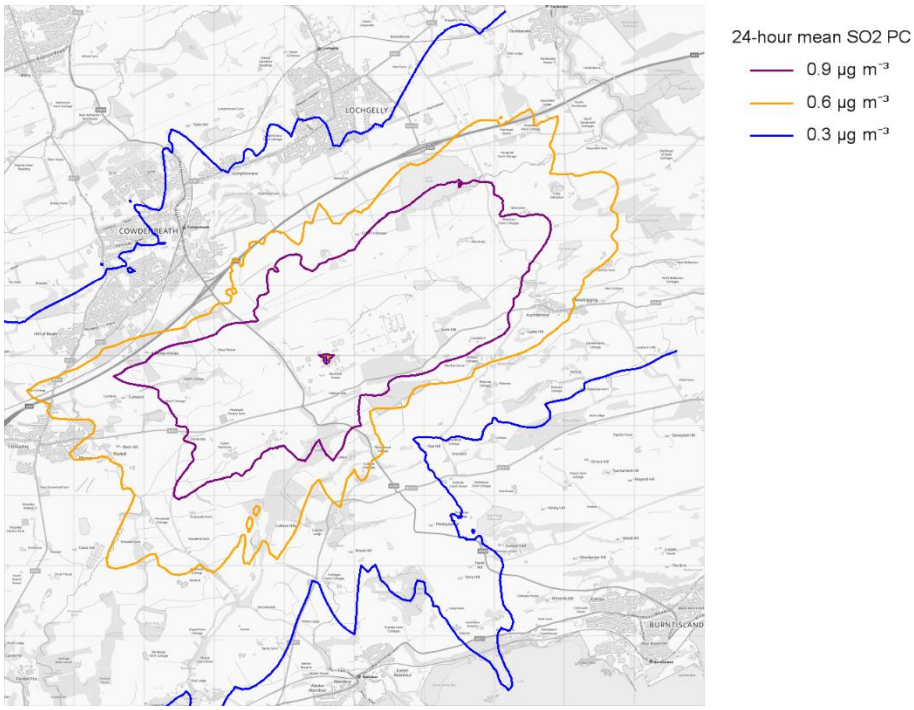


Figure F.28 Modelled annual mean BTEX

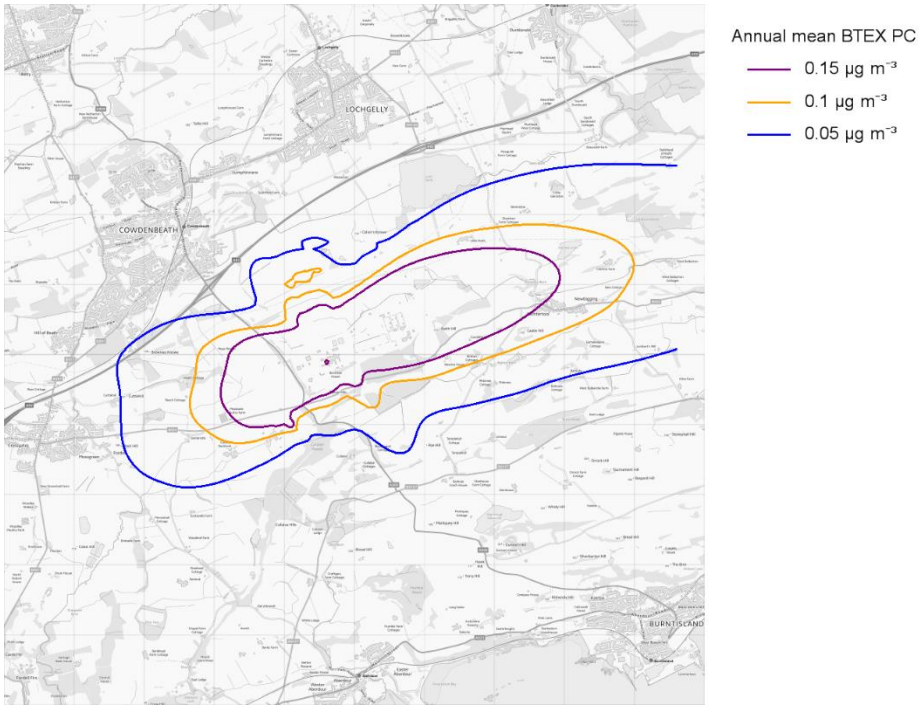


Figure F.29 Modelled 1-hour mean BTEX

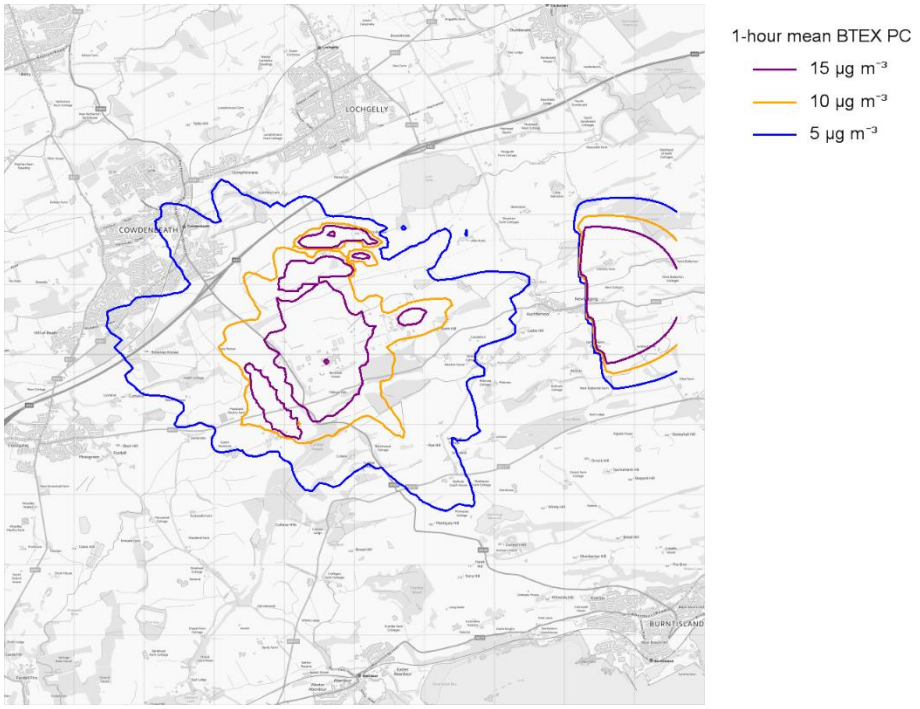


Figure F.30 Modelled annual mean UHCs

Figure F.31 Modelled 1-hour mean UHCs

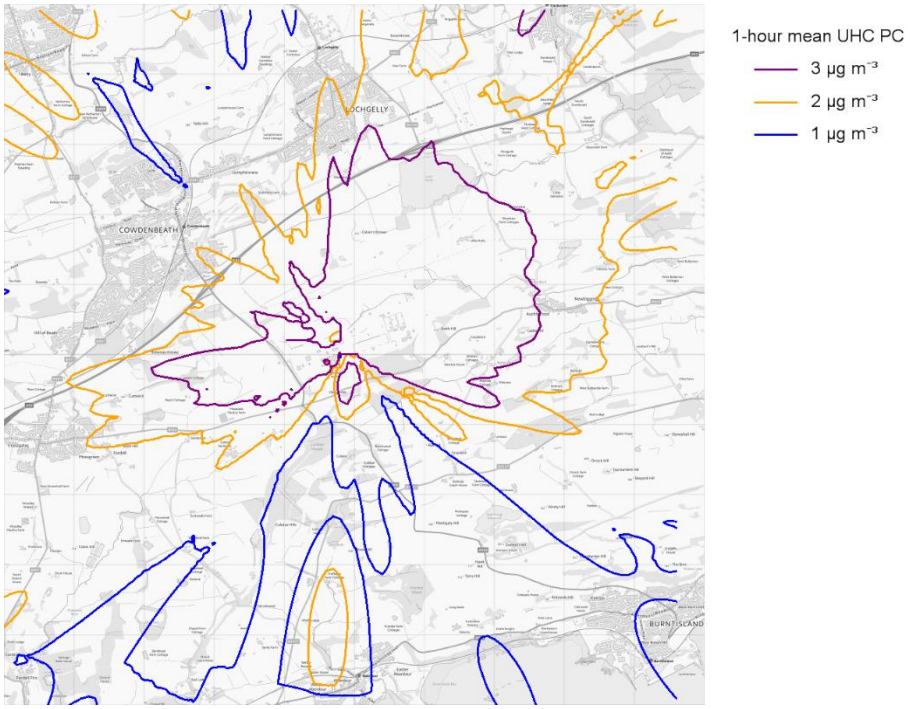


Figure F.32 Modelled annual mean NO_x

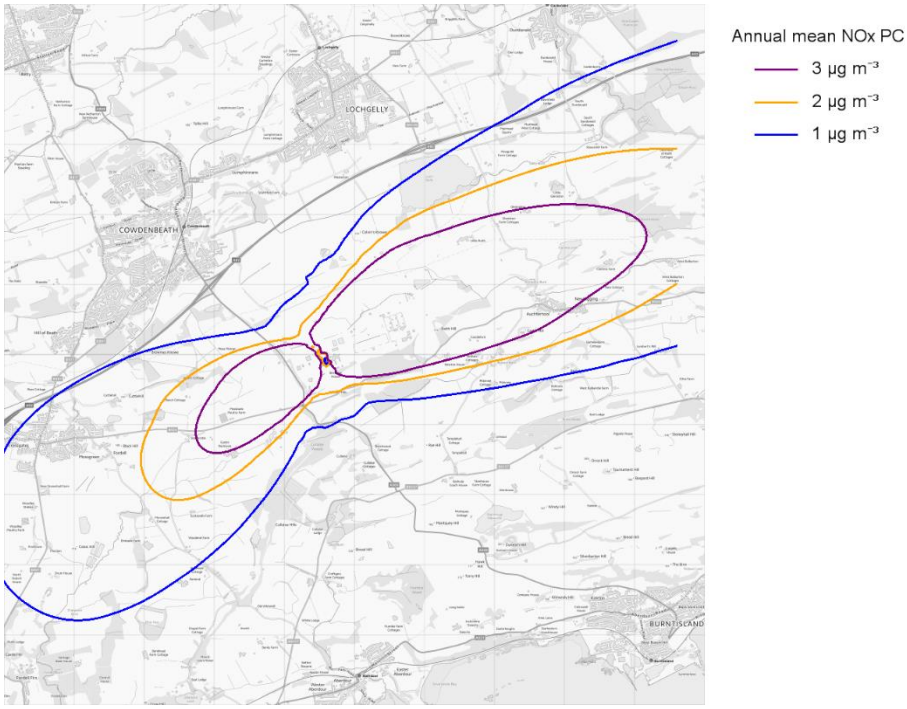


Figure F.33 Modelled daily mean NO_x

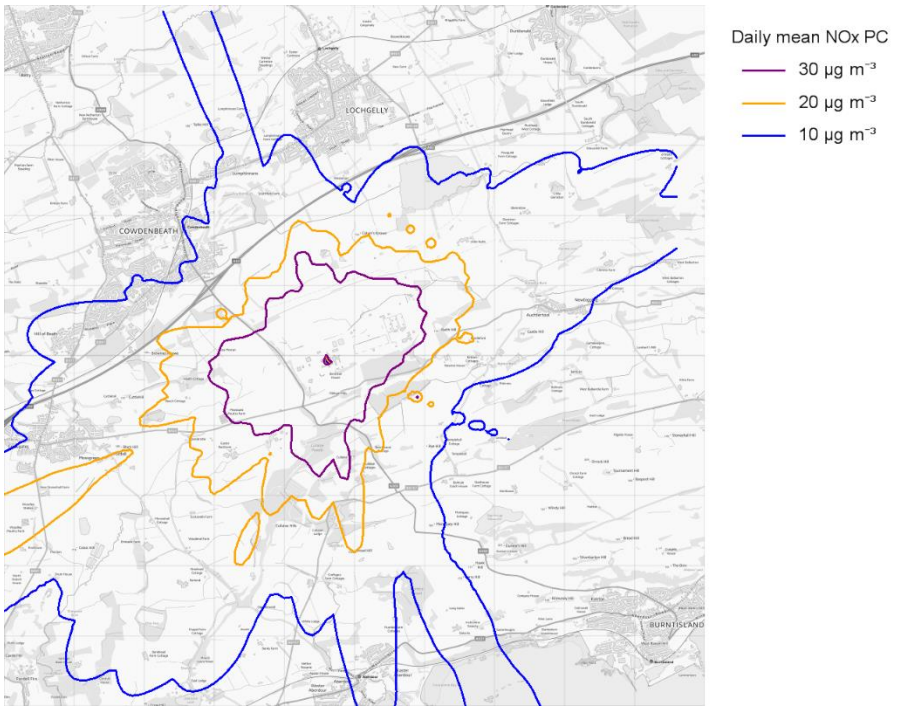


Figure F.34 Modelled annual mean SO_2

PGC trip – instantaneous peak flaring rate (200 T h^{-1})

Figure F.35 Modelled annual mean NO_2

Figure F.36 Modelled 99.79 percentile 1-hour mean NO_2

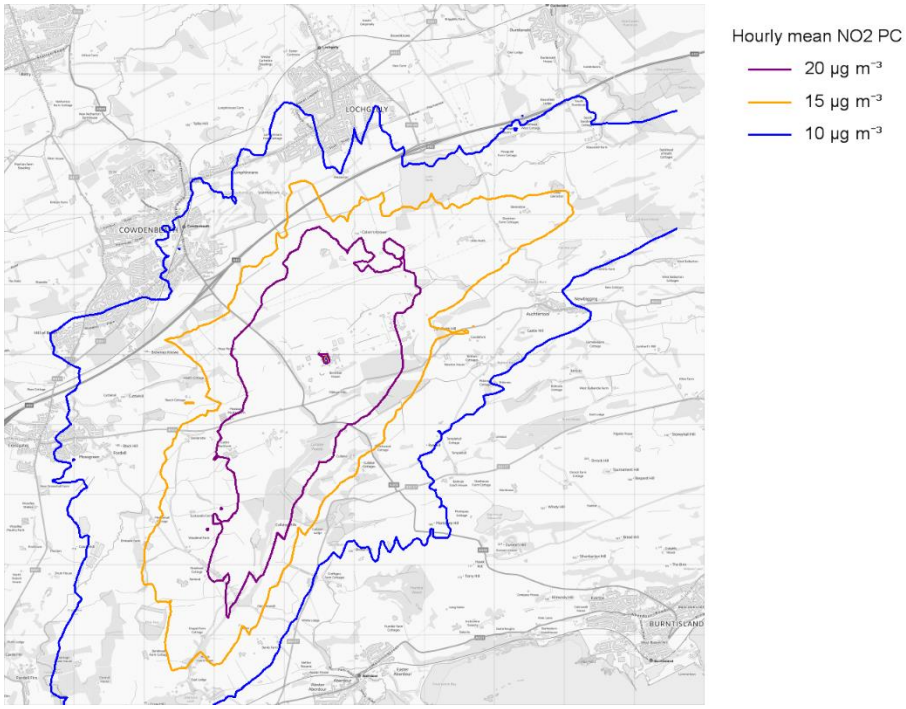


Figure F.37 Modelled annual mean PM_{10}

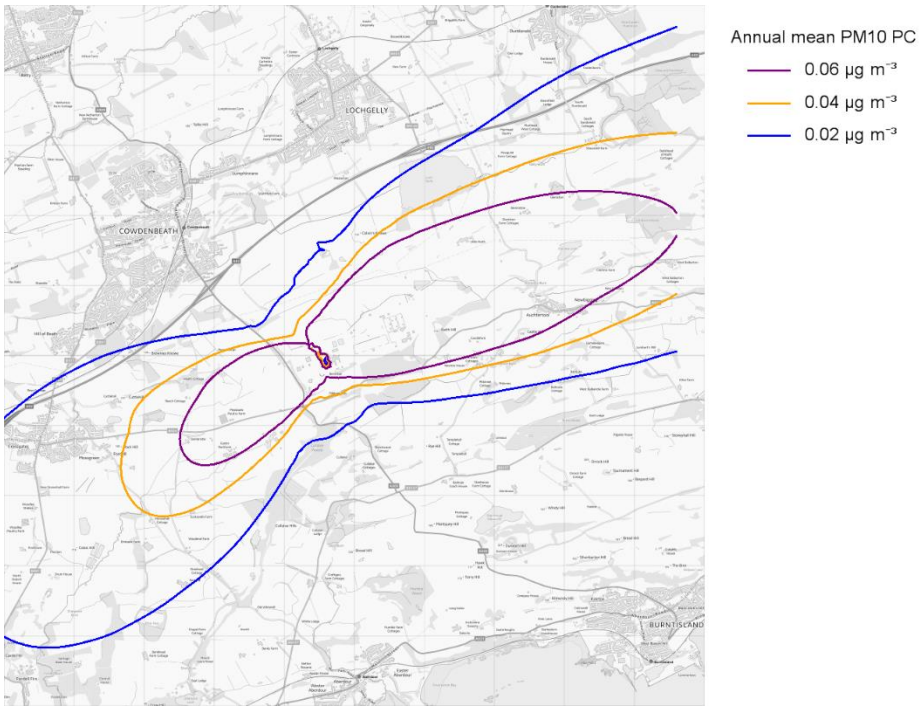


Figure F.38 Modelled 98.08 percentile 24-hour mean PM_{10}

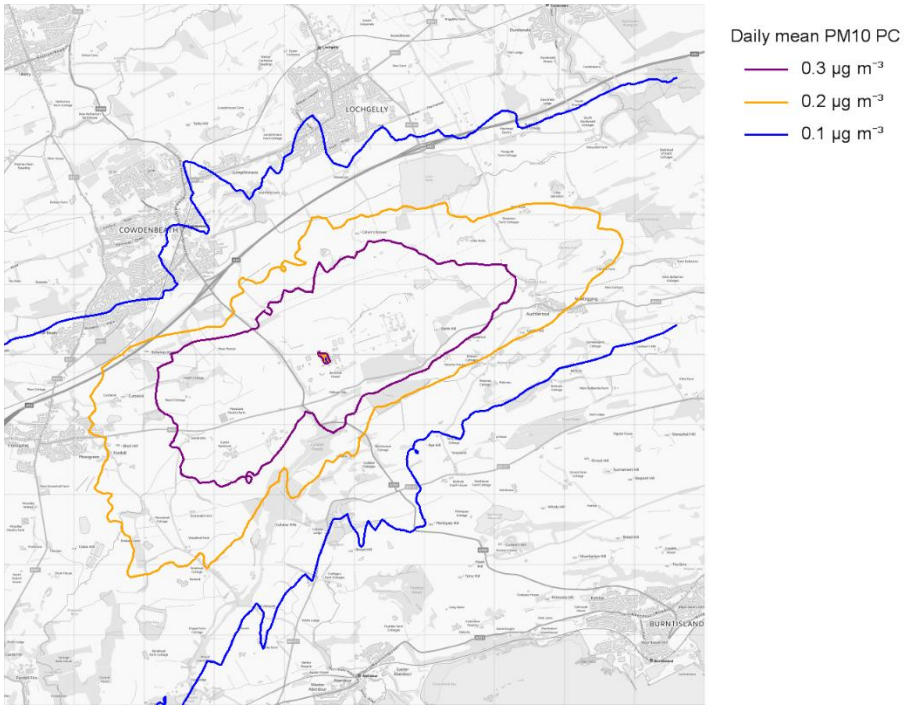


Figure F.39 Modelled annual mean $PM_{2.5}$

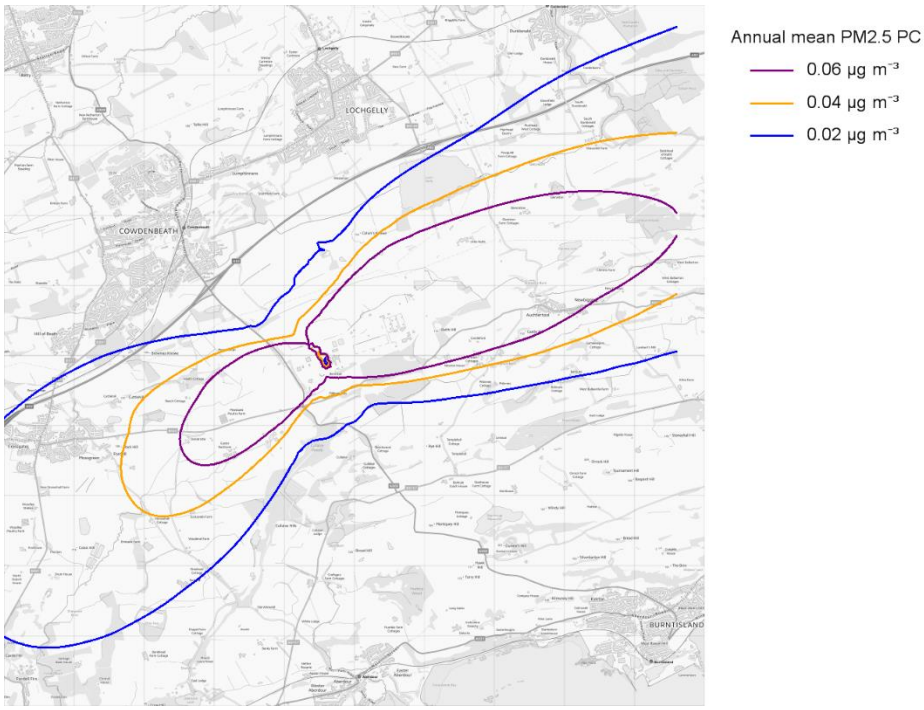


Figure F.40 Modelled annual mean CO

Figure F.41 Modelled rolling 8-hour mean CO

Figure F.42 Modelled 99.9 percentile 15-minute mean SO_2

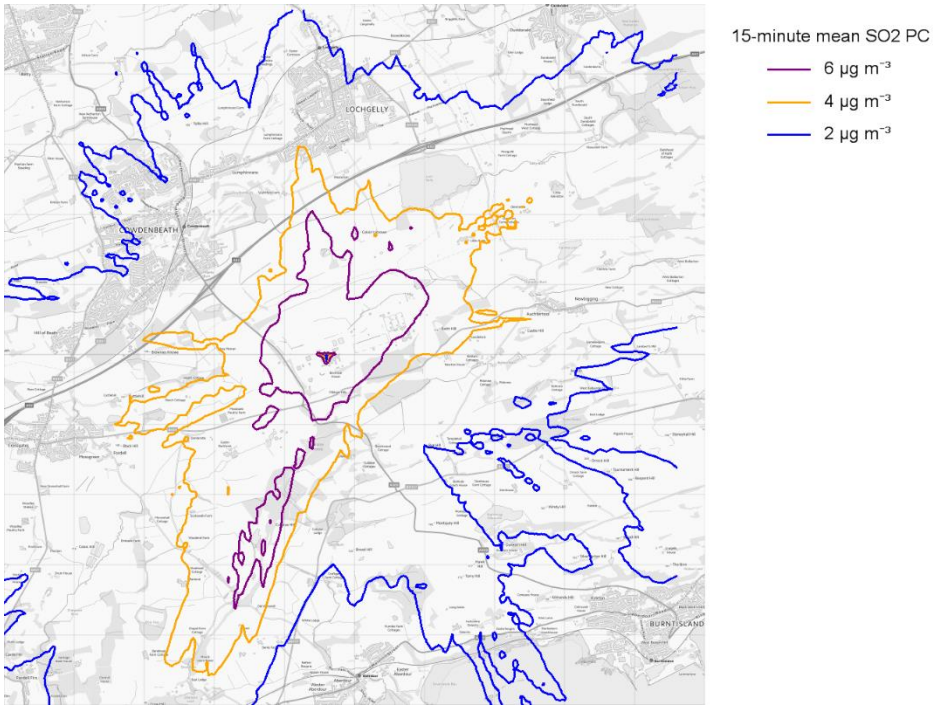


Figure F.43 Modelled 99.73 percentile 1-hour mean SO_2

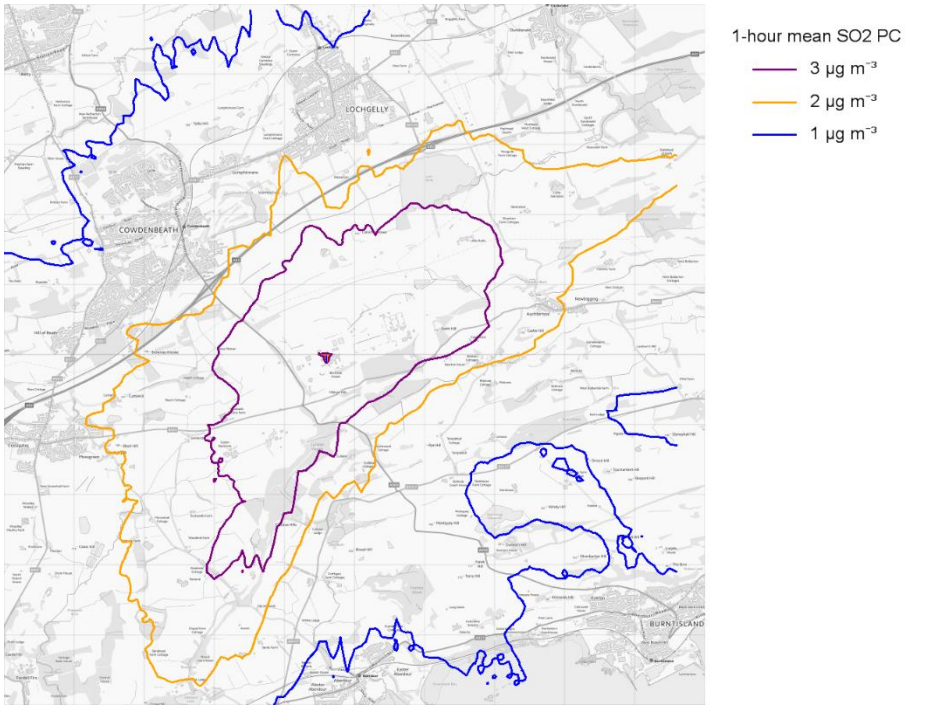


Figure F.44 Modelled 99.18 percentile 24-hour mean SO_2

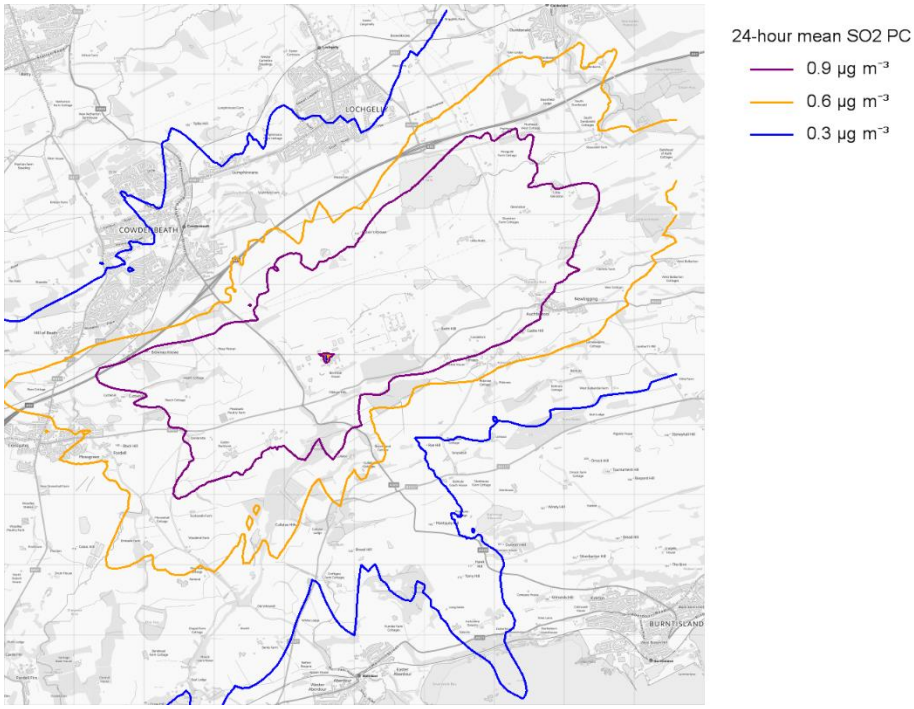


Figure F.45 Modelled annual mean BTEX

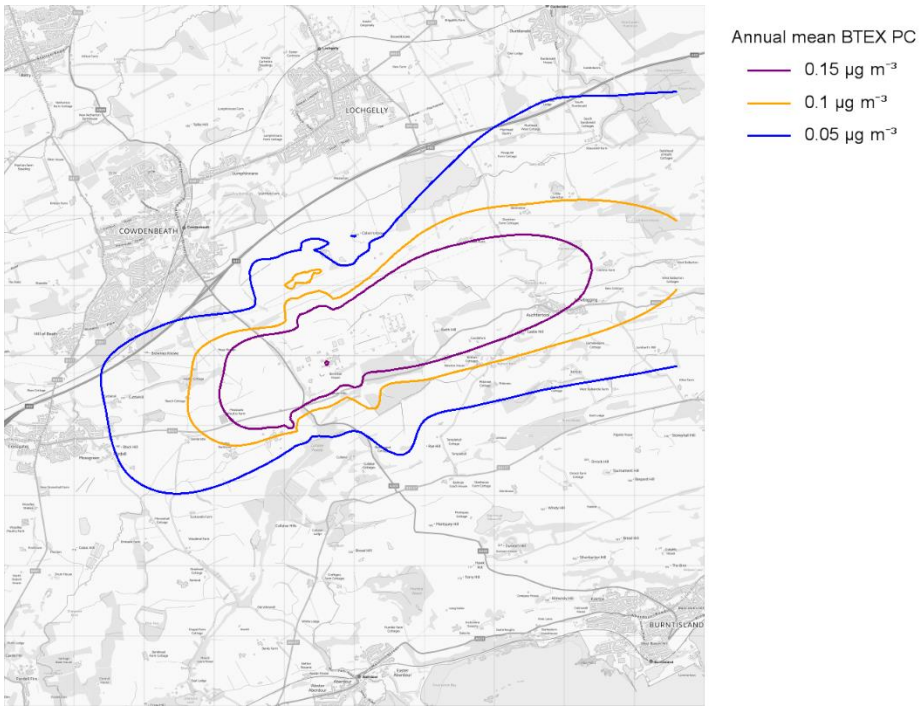


Figure F.46 Modelled 1-hour mean BTEX

Figure F.47 Modelled annual mean UHCs

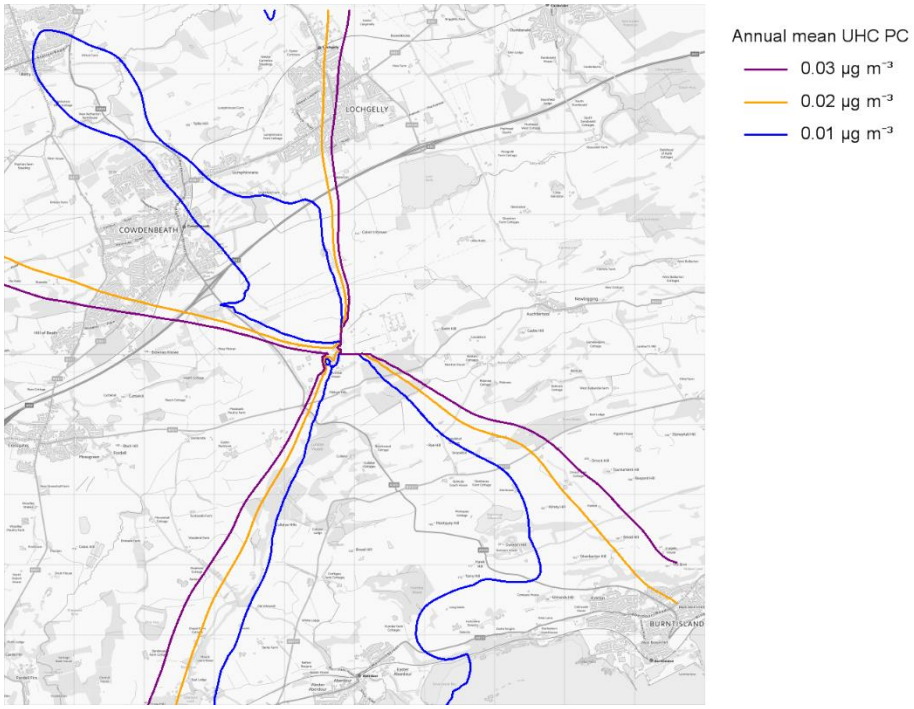


Figure F.48 Modelled 1-hour mean UHCs

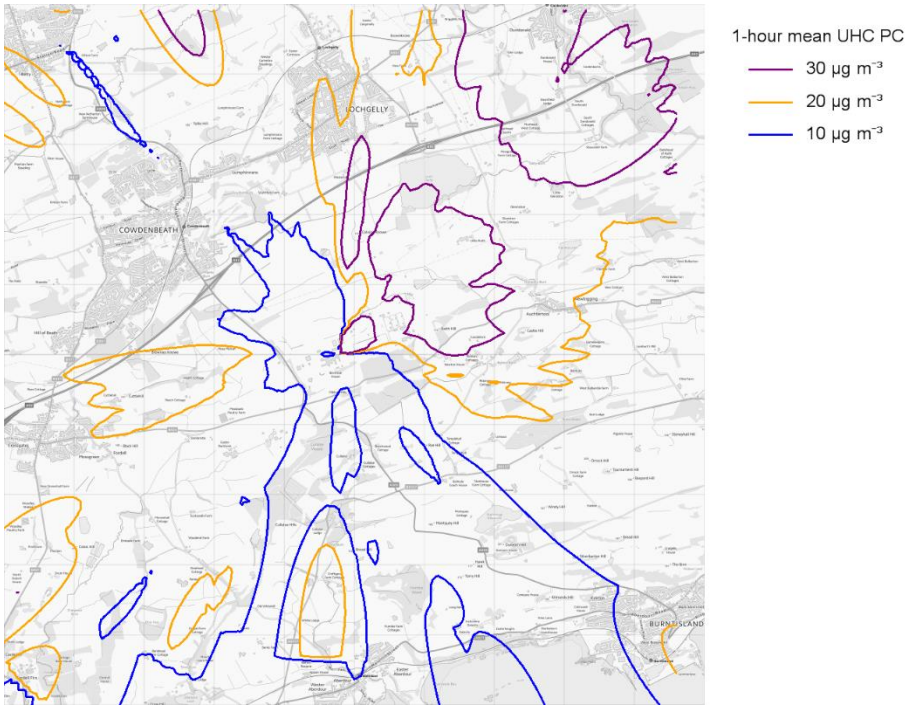


Figure F.49 Modelled annual mean NO_x

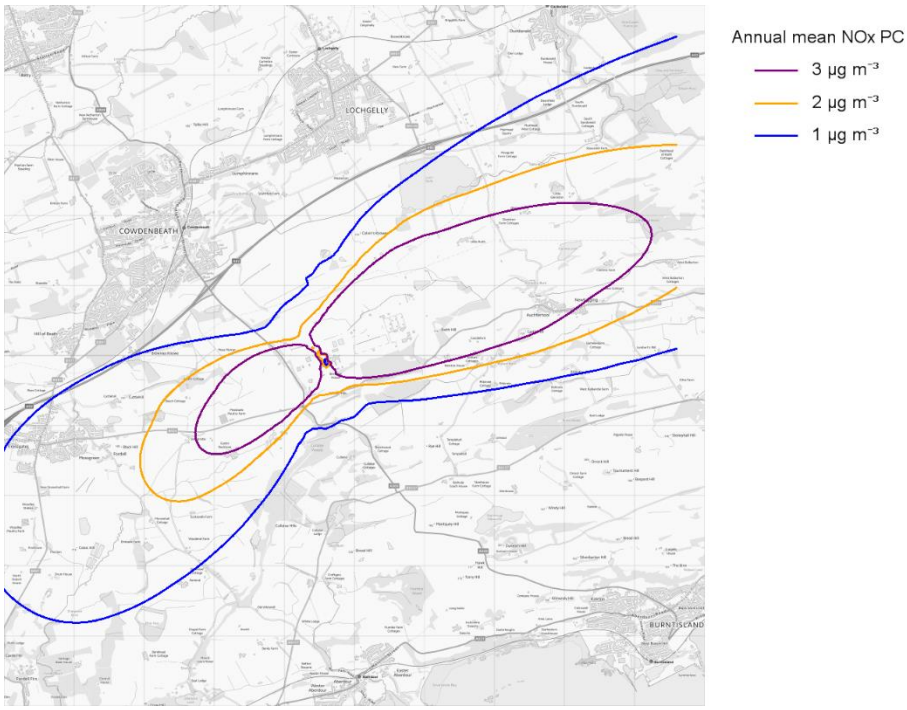


Figure F.50 Modelled daily mean NO_x

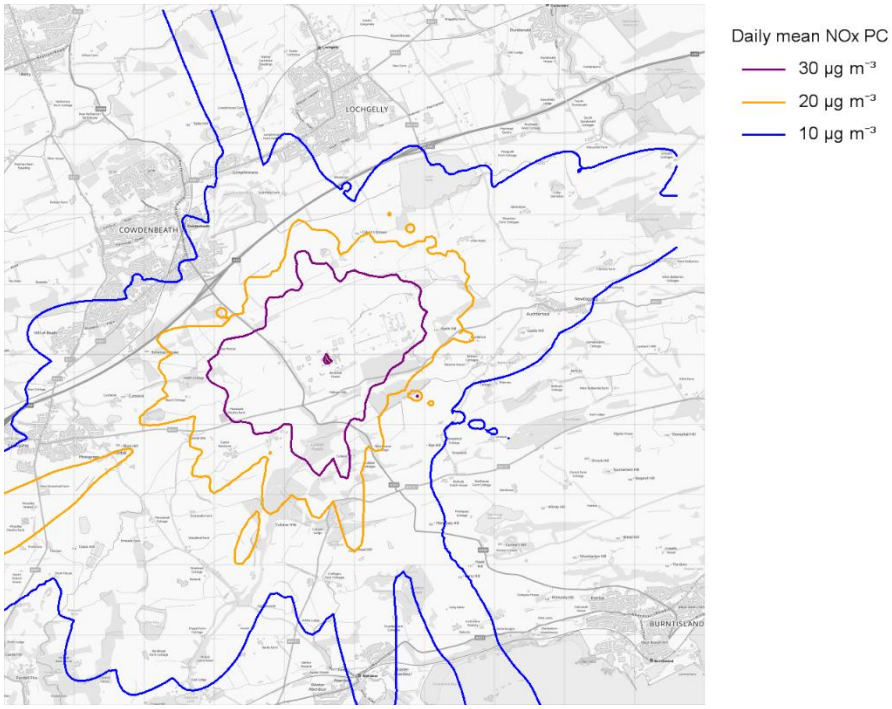


Figure F.51 Modelled annual mean SO_2