awnconsulting

The Tecpro Building,
Clonshaugh Business & Technology Park,
Dublin 17, Ireland.

T: + 353 1 847 4220
F: + 353 1 847 4257
E: info@awnconsulting.com
W: www.awnconsulting.com

AIR DISPERSION MODELLING ASSESSMENT FOR GREAT ISLAND CCGT POWER STATION, COUNTY WEXFORD

Technical Report Prepared For

SSE Generation Ireland Ltd.

Technical Report Prepared By

Claire Flynn BA (Science), MSc, MIAQM

Our Reference

CF/17/9488AR01

Date Of Issue

18 May 2017

Cork Office
Unit 5, ATS Building,
Carrigaline Industrial Estate,
Carrigaline, Co. Cork.
T: +353 21 438 7400
F: +353 21 483 4606

AWN Consulting Limited
Registered in Ireland No. 319812
Directors: F Callaghan, C Dilworth,
T Donnelly, E Porter
Associate Director: D Kelly

Document History

Document Reference		Original Issue Date	
CF/17/9488AR01		18/05/17	
Revision Level	Revision Date	Description	Sections Affected

Record of Approval

Details	Written by	Checked by
Signature		
Name	Claire Flynn	Dr. Edward Porter
Title	Senior Environmental Consultant	Director – Air Quality
Date	18/05/17	18/05/17

EXECUTIVE SUMMARY

AWN Consulting was instructed by SSE Generation Ireland Ltd. to conduct an air modelling study to assess the impact to ambient air quality from the Combined Cycle Gas Turbine (CCGT) emission point (A2-1) at the Great Island Power Station in County Wexford. The contribution of both worst-case actual emissions from 2016 and average actual emissions for April 2016 to April 2017 from the facility to off-site levels of release substances was assessed and the location and maximum of the worst-case ground level concentrations for each compound identified. Air dispersion modelling was carried out using the United States Environmental Protection Agency's regulatory model AERMOD (Version 16216r). The dispersion modelling study consisted of the following components:

- Review of emissions data and other relevant information needed for the modelling study;
- Summary of background NO_2, SO_2 and CO concentrations;
- Dispersion modelling of released substances under the following scenarios:
    - Worst-case actual emission concentrations of pollutants based on emissions data recorded by the Continuous Emission Monitoring System (CEMS) during December 2016 when the plant was operating below 70% load (hereafter *Worst Case Actual Scenario*). The facility is bound to comply with the emission limit values (ELVs) stipulated in IED licence P0606-03 only when they are operating at greater than 70% load.
    - Actual average emissions from the facility from April 2016 to April 2017 based on averaging data from the CEMS (hereafter *Average Actual Scenario*). Actual emissions from the facility vary over time depending on the load factor of the generating units, planned maintenance to be undertaken for abatement systems and operational performance of the abatement systems. Data from April 2016 to April 2017 has been selected as an example year of actual emissions from the facility for the purpose of this assessment.
- Presentation of predicted ground level concentrations of released substances;
- Evaluation of the significance of these predicted concentrations, including consideration of whether these ground level concentrations are likely to exceed the relevant ambient air quality limit values.

Assessment Summary

The modelling results demonstrate that ambient pollutant concentrations (including background) are well below the applicable air quality limit values at all off-site receptors.

Worst Case Actual Scenario

All predicted ambient pollutant concentrations (including background) are in compliance with the relevant limit values. The results indicate that the ambient ground level NO_2 concentrations (including background) reach 50% of the maximum 1-hour limit value (measured as a 99.8^{th}%ile) and 31% of the annual limit value at the worst-case off-site receptor. Ambient ground level SO_2 concentrations (including background) reach 6% of the maximum 1-hour limit value (measured as a 99.7^{th}%ile) and 7% of the maximum 24-hour limit value (measured as a 99.2^{nd}%ile) at the worst-case off-site receptor. Ambient ground level CO concentrations (including background) reach 7% of the maximum 8-hour limit value at the worst-case off-site receptor.

Average Actual Scenario

All predicted ambient pollutant concentrations (including background) are in compliance with the relevant limit values. The results indicate that the ambient ground level NO_2

concentrations (including background) reach 32% of the maximum 1-hour limit value (measured as a 99.8th%ile) and 30% of the annual limit value at the worst-case off-site receptor. Ambient ground level SO_2 concentrations (including background) reach 6% of the maximum 1-hour limit value (measured as a 99.7th%ile) and 7% of the maximum 24-hour limit value (measured as a 99.2nd%ile) at the worst-case off-site receptor. Ambient ground level CO concentrations (including background) reach 7% of the maximum 8-hour limit value at the worst-case off-site receptor.

Impact on Ecology

The NO_x modelling results indicate that the ambient ground level concentrations are below the relevant air quality standard for NO_x for the protection of ecosystems. Emissions from the facility lead to ambient NO_x concentrations (including background) for the *Worst Case Actual Scenario* and the *Average Actual Scenario* which are 38% and 37% of the annual NO_x limit value at the worst-case locations within the SAC / pNHA, respectively.

The SO_2 modelling results indicate that the ambient ground level concentrations including background are below the relevant air quality standard for SO_2 for the protection of ecosystems for the *Worst Case Actual Scenario* and the *Average Actual Scenario* reaching 15% of the annual limit value at the worst-case locations within the SAC / pNHA for both scenarios.

CONTENTS Page

1.0 INTRODUCTION

AWN Consulting was instructed by SSE Generation Ireland Ltd. to conduct an air modelling study to assess the impact to ambient air quality from the Combined Cycle Gas Turbine (CCGT) emission point (A2-1) at the Great Island Power Station in County Wexford. The contribution of both worst case actual and average actual emissions from the facility to off-site levels of release substances was assessed and the location and maximum of the worst-case ground level concentrations for each compound identified. Air dispersion modelling was carried out using the United States Environmental Protection Agency's regulatory model AERMOD (Version 16216r).

This report describes the outcome of this study. The study consists of the following components:

- Review of emissions data and other relevant information needed for the modelling study;
- Summary of background NO_2, SO_2 and CO concentrations;
- Dispersion modelling of released substances under the following scenarios:
    - Worst-case actual emission concentrations of pollutants based on emissions data recorded by the Continuous Emission Monitoring System (CEMS) over three days during December 2016 when the plant was operating below 70% load (hereafter *Worst Case Actual Scenario*). The facility is bound to comply with the emission limit values (ELVs) stipulated in IED licence P0606-03 only when they are operating at greater than 70% load.
    - Actual average emissions from the facility from April 2016 to April 2017 based on averaging data from the CEMS (hereafter *Average Actual Scenario*). Actual emissions from the facility vary over time depending on the load factor of the generating units, planned maintenance to be undertaken for abatement systems and operational performance of the abatement systems. Data from April 2016 to April 2017 has been selected as an example year of actual emissions from the facility for the purpose of this assessment.
- Presentation of predicted ground level concentrations of released substances;
- Evaluation of the significance of these predicted concentrations, including consideration of whether these ground level concentrations are likely to exceed the relevant ambient air quality limit values.

Process emission information as well as stack heights and locations for the various scenarios modelled are provided in Table 10 of Section 2.8.

Information supporting the conclusions has been detailed in the following sections. The assessment methodology and study inputs are presented in Section 2. The dispersion modelling results and assessment summaries are presented in Section 3. The model formulation is detailed in Appendix I and a review of the meteorological data used is detailed in Appendix II.

2.0 MODELLING METHODOLOGY

The air dispersion modelling input data consisted of information on the physical environment (including building dimensions and terrain features), design details from the CCGT emission point on-site and a full year of appropriate meteorological data. Using this input data the model predicted ambient ground level concentrations beyond the site boundary for each hour of the modelled meteorological year. The model post-processed the data to identify the location and maximum of the worst-case ground level concentration. This worst-case concentration was then added to the background concentration to give the worst-case predicted environmental concentration (PEC). The PEC was then compared with the relevant ambient air quality standard to assess the significance of the releases from the site.

Throughout this study a worst-case approach was taken. This will most likely lead to an over-estimation of the levels that will arise in practice. The worst-case assumptions are outlined below:

- Maximum predicted concentrations are reported in this study, even if no residential receptors are near the location of this maximum;
- Conservative background concentrations were added to the modelled concentrations released from the site before comparing the total predicted concentrations with the applicable limit values;
- The effect of building downwash, due to nearby buildings, has been included in the model.

2.1 Air Dispersion Modelling Software

Emissions from the CCGT have been modelled using the AERMOD dispersion model (Version 16216r) which has been developed by the U.S. Environmental Protection Agency (USEPA)(1) and following guidance issued by the EPA(2). AERMOD is a steady-state Gaussian plume model used to assess pollutant concentrations associated with industrial sources and has replaced ISCST3(3) as the regulatory model by the USEPA for modelling emissions from industrial sources in both flat and rolling terrain(4-6). The model has more advanced algorithms and gives better agreement with monitoring data in extensive validation studies(7-11). An overview of the AERMOD dispersion model is outlined in Appendix I.

2.2 Background Concentrations

Air quality monitoring programs have been undertaken in recent years by the EPA and Local Authorities(12,13). The most recent annual report on air quality "Air Quality Monitoring Annual Report 2015"(13), details the range and scope of monitoring undertaken throughout Ireland.

As part of the implementation of the Framework Directive on Air Quality (1996/62/EC), four air quality zones have been defined in Ireland for air quality management and assessment purposes(12). Dublin is defined as Zone A and Cork as Zone B. Zone C is composed of 23 towns with a population of greater than 15,000. The remainder of the country, which represents rural Ireland but also includes all towns with a population of less than 15,000 is defined as Zone D. In terms of air monitoring, the area surrounding Great Island Power Station is categorised as Zone D(12).

NO_2

NO_2 monitoring was carried out at two rural Zone D locations in 2015, Emo and Kilkitt and in two urban areas, Enniscorthy and Castlebar(13). The NO_2 annual average in 2015 for both rural sites was 2.5 µg/m^3 with the results for urban stations averaging 8.5 µg/m^3. Hence long-term average concentrations measured at all locations were significantly lower than the annual average limit value of 40 µg/m^3. The average results over the last five years at a range of urban Zone D locations suggest an upper average of no more than 11 µg/m^3 as a background concentration as shown in Table 1. Based on the above information a conservative estimate of the background NO_2 concentration in the region of the facility is 11 µg/m^3.

Year	Enniscorthy (µg/m³)	Kilkitt (µg/m³)	Emo Court (µg/m³)	Castlebar (µg/m³)
2011	-	3	-	8
2012	-	4	-	8
2013	-	4	4	11
2014	13	3	3	8
2015	9	2	3	8
Average	**11**	**3.2**	**3.3**	**8.6**

Table 1 Annual Mean NO_2 Background Concentrations in Zone D Locations 2011 – 2015 (µg/m³)

In relation to the annual averages, the ambient background concentration was added directly to the process concentration. However, in relation to the short-term peak concentration, concentrations due to emissions from elevated sources cannot be combined in the same way. Guidance from the UK DEFRA(14) and EPA(2) advises that for NO_2 an estimate of the maximum combined pollutant concentration can be obtained as shown below:

NO_2 - The 99.8th%ile of total 1-hour NO_2 is equal to the minimum of either A or B below:

a) 99.8th%ile hourly background total oxidant (O_3 & NO_2) + 0.05 x (99.8th%ile process contribution NO_x)

b) The maximum of either:

99.8th% process contribution NO_x + 2 x (annual mean background NO_2)

or

99.8th% hourly background NO_2 + 2 x (annual mean process contribution NO_x)

The ozone and NO_2 monitoring data from the EPA monitoring station at Emo Court in 2013 was used to calculate the background values required for the equations above. 2013 was selected as the NO_2 data for Emo Court in 2015 is not yet publicly available and the data for 2014 has a high proportion of missing data.

SO_2

Long-term SO_2 monitoring was carried out at the Zone D locations of Enniscorthy, Kilkitt and the Shannon Estuary in 2015. The SO_2 annual average measured 2 µg/m^3 at all three locations in 2015[13]. Previous monitoring from 2011 – 2015 at the three locations indicated annual averages ranging from 2 – 4 µg/m^3 (see Table 2). Based on the above information a conservative estimate of the background SO_2 concentration in the region of the facility is 3 µg/m^3.

Year	Enniscorthy (µg/m^3)	Kilkitt (µg/m^3)	Shannon Estuary (µg/m^3)
2011	-	3	3
2012	-	3	2
2013	-	3	2
2014	4	2	3
2015	2	2	2
Average	**3.0**	**2.6**	**2.4**

Table 2 Annual Mean SO_2 Background Concentrations in Zone D Locations 2011 – 2015 (µg/m^3)

When calculating the short-term peak results, guidance from the UK DEFRA[14] and EPA[2] advises that for SO_2 an estimate of the maximum combined pollutant concentrations can be obtained as shown below:

SO_2 - The 99.2th%ile of total 24-hour SO_2 is equal to the maximum of either A or B below:

a) 99.2th%ile of 24-hour mean background SO_2 + (2 x annual mean process contribution SO_2)

b) 99.2th%ile 24-hour mean process contribution SO_2 + (2 x annual mean background contribution SO_2)

SO_2 - The 99.7th%ile of total 1-hour SO_2 is equal to the maximum of either A or B below:

a) 99.7th%ile hourly background SO_2 + (2 x annual mean process contribution SO_2)

b) 99.7th%ile hourly process contribution SO_2 + (2 x annual mean background contribution SO_2)

The background data used to calculate the results in line with the equations above were taken from the EPA hourly SO_2 monitoring data for Enniscorthy for the year 2015.

CO

With regard to CO, annual averages at the Zone C and D locations of Mullingar, Portlaoise, Shannon Town and Enniscorthy have been low over the past five years reaching a maximum annual average of 0.5 mg/m^3 in Enniscorthy and Portlaoise (see Table 3). Based on this EPA data, a conservative estimate of the background CO concentration in the region of the facility is 0.5 mg/m^3. When calculating the 8-hour mean modelling results, a value of twice the annual mean background value is added to the process contributions from the facility.

Year	Mullingar (mg/m^3)	Portlaoise (mg/m^3)	Shannon Town (mg/m^3)	Enniscorthy (mg/m^3)
2011	-	-	0.2	-
2012	0.3	-	0.2	-
2013	0.3	-	-	-
2014	-	0.5	-	0.4
2015	-	0.4	-	0.5
Average	**0.3**	**0.5**	**0.2**	**0.5**

Table 3 Annual Mean CO Background Concentrations in Zone C & D Locations 2011 – 2015 (mg/m^3)

2.3 Air Quality Standards

Ambient Air Quality Standards

In order to reduce the risk to health from poor air quality, national and European statutory bodies have set limit values in ambient air for a range of air pollutants. These limit values or "Air Quality Standards" are health- or environmental-based levels for which additional factors may be considered. The applicable standards in Ireland include the Air Quality Standards Regulations 2011, which incorporate EU Directive 2008/50/EC (see Table 4).

Ambient air quality legislation designed to protect human health and the environment is generally based on assessing ambient air quality at locations where the exposure of the population is significant relevant to the averaging time of the pollutant. However, in the current assessment, ambient air quality legislation has been applied to all locations within 10km of the facility regardless of whether any sensitive receptors (such as residential locations) are present. This represents a worst-case approach and an examination of the corresponding concentrations at the nearest sensitive receptors relative to the actual quoted maximum concentration indicates that these receptors generally experience ambient concentrations significantly lower than that reported for the worst-case location.

Pollutant	Averaging Period	Limit Value ($\mu g/m^3$)
NO_2	99.8th percentile of 1- Hourly Averages	200
	Annual Average (for the protection of human health)	40
NO_x	Annual Average (for the protection of vegetation)	30
SO_2	99.7th percentile of 1- Hourly Averages	350
	99.2th percentile of 24- Hourly Averages	125
	Annual Average (for the protection of ecosystems)	20
CO	8-hour limit (on a rolling basis) for protection of human health	10 mg/m^3

Table 4 EU Ambient Air Quality Standards (Based on Directive 2008/50/EC and SI No. 180 of 2011)

2.4 Air Dispersion Modelling Methodology

The United States Environmental Protection Agency (USEPA) approved AERMOD dispersion model has been used to predict the ground level concentrations (GLC) of compounds emitted from the principal emission sources on-site.

The modelling incorporated the following features:

- Three receptor grids were created at which concentrations would be modelled. Receptors were mapped with sufficient resolution to ensure all localised "hot-spots" were identified without adding unduly to processing time. The receptor grids were based on Cartesian grids with the site at the centre. An outer grid measuring 20 x 20 km, extended to 10km from the site with concentrations calculated at 500m intervals. A second grid measuring 10 x 10 km extended to 5km from the site with concentrations calculated at 250m intervals. An inner grid measuring 5 x 5 km, extended to 2.5 km from the site with concentrations calculated at 50m intervals. Boundary receptor locations were also placed along the boundary of the site, at 100m intervals, giving a total of 13,469 calculation points for the models.

- All on-site buildings and significant process structures were mapped into the models to create a three-dimensional visualisation of the site and its emission points. Buildings and process structures can influence the passage of airflow over the emission stacks and draw plumes down towards the ground (termed building downwash). Building downwash was incorporated into the modelling.

- Hourly-sequenced meteorological information has been used in the model. Meteorological data over a five year period (Johnstown Castle, 2012 – 2016) was used in the models. As there was no cloud cover data available for Johnstown Castle, the cloud cover data from Casement Aerodrome over the period 2012 – 2016 was added to the meteorological data files.

- AERMOD incorporates a meteorological pre-processor AERMET[17]. The AERMET meteorological preprocessor requires the input of surface characteristics, including surface roughness (z_0), Bowen Ratio and albedo by sector and season, as well as hourly observations of wind speed, wind direction, cloud cover, and temperature. The values of albedo, Bowen Ratio and surface roughness depend on land-use type (e.g., urban, cultivated land etc) and vary with seasons and wind direction. The assessment of appropriate land-use type was carried out to a distance of 10km from the meteorological station for Bowen Ratio and albedo and to a distance of 1km for surface roughness in line with USEPA recommendations.

- The source and emission data, including stack dimension, gas velocities, emission temperatures and pollutant emission rates have been incorporated into the model for both emission scenarios (*Worst Case Actual Scenario* and *Average Actual Scenario)*.

- Detailed terrain has been mapped into the model using SRTM (Shuttle Radar Topography Mission) data with 30m resolution. The site is located in low level terrain next to the River Barrow Estuary. The terrain elevation increases to the north of the CCGT plant where the tank farm is located. The terrain beyond the site boundary can be described as gently rolling. All terrain features have been mapped in detail into the model using the terrain pre-processor AERMAP.

Site Boundary

CCGT Emission Point

N

Project

Great Island CCGT Power Station– Air Dispersion Model

Reference

17/9488AR01

Figure 1

Approximate Location of CCGT Emission Point and Site Boundary

awnconsulting

The Tecpro Building, Clonshaugh Business and Technology Park, Dublin 17
T: +353 1 847 4220 F: +353 1 847 4257

2.5 Terrain

The terrain across the 20 x 20 km domain modelled has been illustrated as contours in Figure 2.

The AERMOD air dispersion model has a terrain pre-processor AERMAP which was used to map the physical environment in detail over the receptor grid. The digital terrain input data used in the AERMAP pre-processor was SRTM data. This data was run to obtain for each receptor point the terrain height and the terrain height scale. The terrain height scale is used in AERMOD to calculate the critical dividing streamline height, H_{crit}, for each receptor. The terrain height scale is derived from the Digitial Elevation Model (DEM) files in AERMAP by computing the relief height of the DEM point relative to the height of the receptor and determining the slope. If the slope is less than 10%, the program goes to the next DEM point. If the slope is 10% or greater, the controlling hill height is updated if it is higher than the stored hill height.

In areas of complex terrain, such as the current region, AERMOD models the impact of terrain using the concept of the dividing streamline (H_c). As outlined in the AERMOD model formulation[(1)] a plume embedded in the flow below H_c tends to remain horizontal; it might go around the hill or impact on it. A plume above H_c will ride over the hill. Associated with this is a tendency for the plume to be depressed toward the terrain surface, for the flow to speed up, and for vertical turbulent intensities to increase.

AERMOD model formulation states that the model "captures the effect of flow above and below the dividing streamline by weighting the plume concentration associated with two possible extreme states of the boundary layer (horizontal plume and terrain-following). The relative weighting of the two states depends on: 1) the degree of atmospheric stability; 2) the wind speed; and 3) the plume height relative to terrain. In stable conditions, the horizontal plume "dominates" and is given greater weight while in neutral and unstable conditions, the plume traveling over the terrain is more heavily weighted"[(1)].

AERMOD also has the capability of modelling both unstable (convective) conditions and stable (inversion) conditions. The stability of the atmosphere is defined by the sign of the sensible heat flux. Where the sensible heat flux is positive, the atmosphere is unstable whereas when the sensible heat flux is negative the atmosphere is defined as stable. The sensible heat flux is dependent on the net radiation and the available surface moisture (Bowen Ratio). Under stable (inversion) conditions, AERMOD has specific algorithms to account for plume rise under stable conditions, mechanical mixing heights under stable conditions and vertical and lateral dispersion in the stable boundary layer.

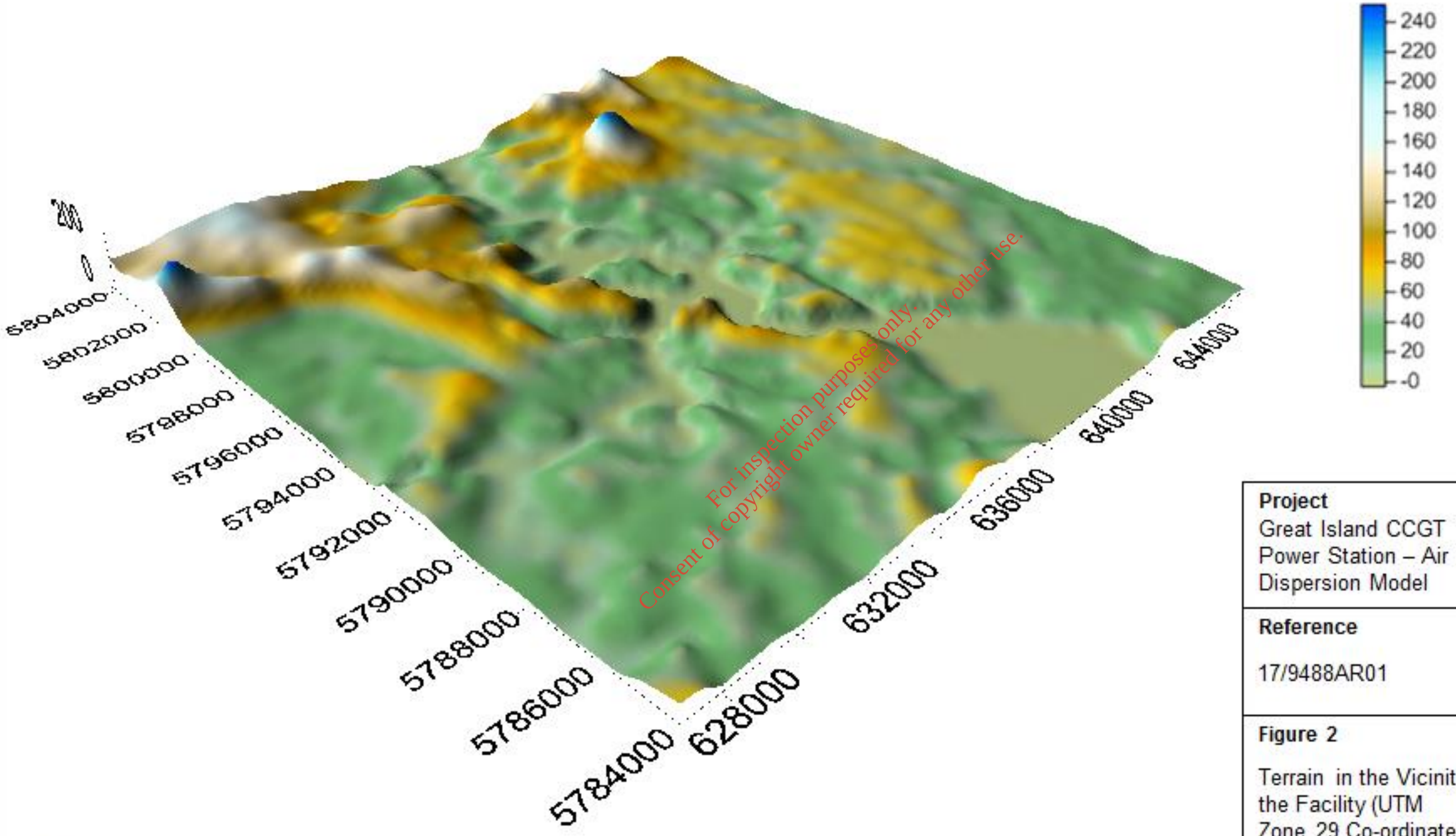
2.6 Meteorological Data

The selection of the appropriate meteorological data has followed the guidance issued by the USEPA[(4)]. A primary requirement is that the data used should have a data capture of greater than 90% for all parameters. Johnstown Castle meteorological station, which is located approximately 35 km east of the site, collects data in the correct format and has a data collection rate of greater than 90% with the exception of cloud cover. Meteorological data over a five year period (Johnstown Castle, 2012 – 2016) was used in the model (see Figure 3) and cloud cover data for the same period from Casement Aerodrome was added to complete the meteorological data files.

Long-term hourly observations at Johnstown Castle meteorological station provide an indication of the prevailing wind conditions for the region (see Figure 3). Results indicate that the prevailing wind direction is south-westerly in direction.

2.7 Process Emissions

The information used in the dispersion model for the CCGT emission point is shown in Table 5.

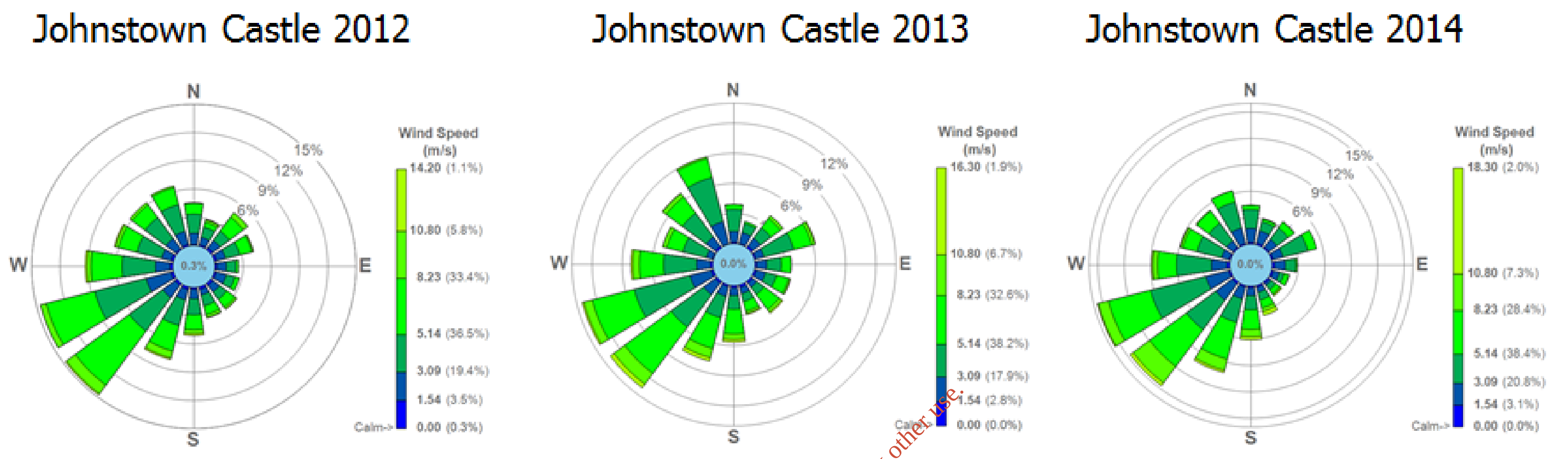


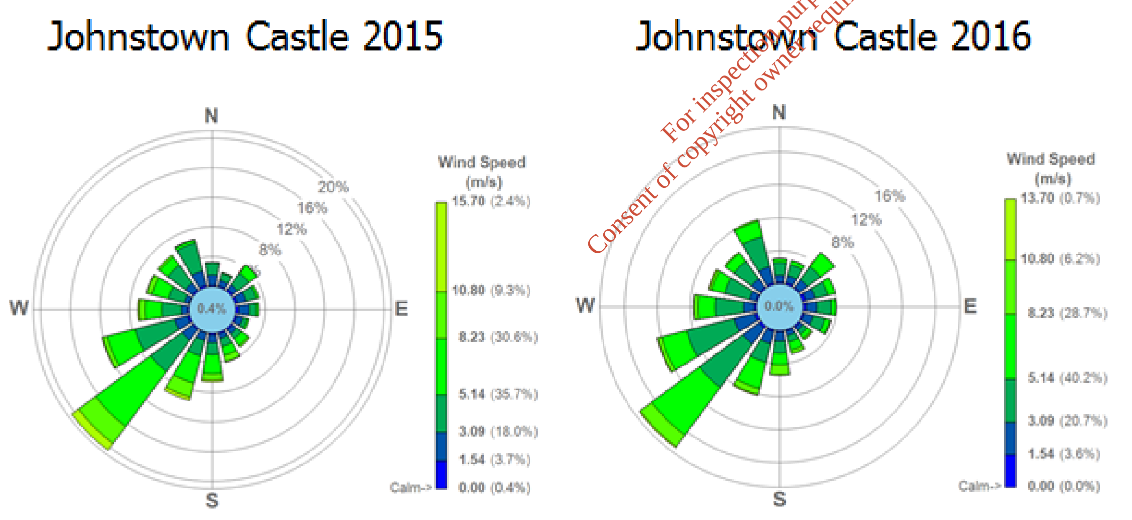
Project
Great Island CCGT Power Station – Air Dispersion Model

Reference
17/9488AR01

Figure 2
Terrain in the Vicinity of the Facility (UTM Zone 29 Co-ordinates)

awnconsulting
The Tecpro Building, Clonshaugh Business and Technology Park, Dublin 17
T: +353 1 847 4220 F: +353 1 847 4257





Project
Great Island CCGT Power Station– Air Dispersion Model

Reference
17/9488AR01

Figure 3
Johnstown Castle
Windrose
2012 - 2016

awnconsulting
The Tecpro Building, Clonshaugh Business and Technology Park, Dublin 17
T: +353 1 847 4220 F: +353 1 847 4257

Parameter	Worst Case Actual Scenario		Actual Average 2016 Scenario	
Stack Name	A2-1		A2-1	
Stack Location Note 1	637067 E 5793955 N		637067 E 5793955 N	
Height above Ground (m)	60		60	
Exit Diameter (m)	6		6	
Cross-sectional Area (m^2)	33.8		33.8	
Temperature (K)	339.05		350.95	
Max Volume Flow (Nm^3/hr)	1,677,691		1,604,927	
Exit Velocity (m/sec actual)	17.11		16.95	
Process Emissions	**Conc. (mg/Nm^3)**	**Mass Emission (g/s)**	**Conc. (mg/Nm^3)**	**Mass Emission (g/s)**
NO_x	55	25.63	38	16.99
SO_2	5	2.33	5	2.27
CO	200	93.21	40	18.01

Note 1 Stack location is in UTM Zone 29 and is approximate

Table 5 Stack Emission Details for the Two Scenarios Modelled

3.0 RESULTS & DISCUSSION

3.1 NO_2

Worst Case Actual Scenario

The NO_2 modelling results for *Worst Case Actual Scenario* are detailed in Table 6. The results indicate that the ambient ground level concentrations are below the relevant air quality standards for NO_2. Emissions from the facility including background lead to an ambient NO_2 concentration which is 50% of the maximum 1-hour limit value (measured as a 99.8^{th}%ile) and 31% of the annual limit value at the worst-case off-site receptor for the worst-case years modelled (2014 and 2015).). Further details of the calculation of the PEC for the 99.8^{th}%ile of 1-hour mean NO_2 is outlined in Appendix III.

The geographical variations in ground level NO_x (as NO_2) concentrations (without background) beyond the facility boundary for the worst-case years modelled are illustrated as concentration contours in Figures 4 and 5. The contents of each figure are described below:

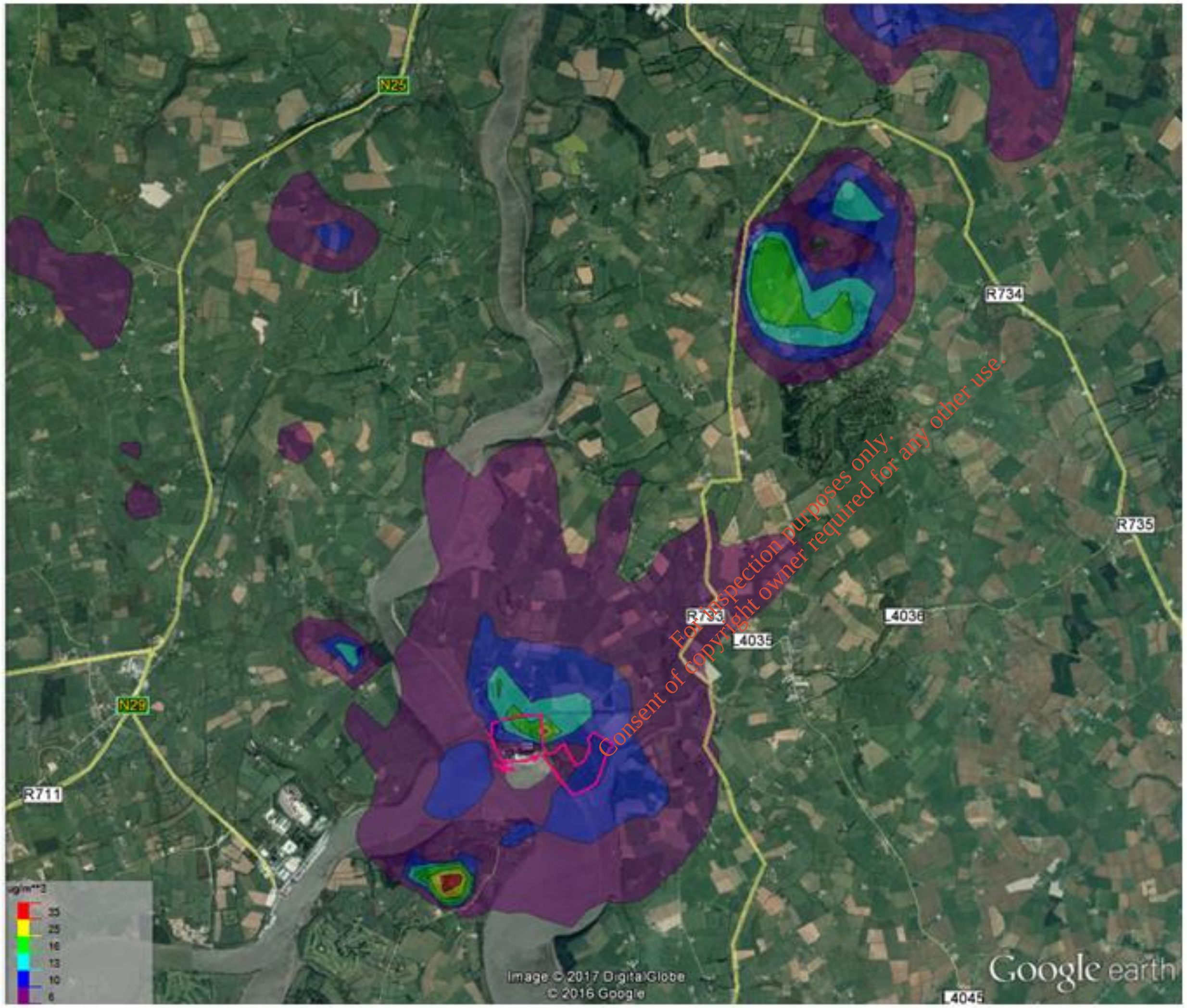
Figure 4 *Worst Case Actual Scenario*: Predicted NO_x (as NO_2) 99.8^{th} Percentile of Hourly Concentrations (2014)

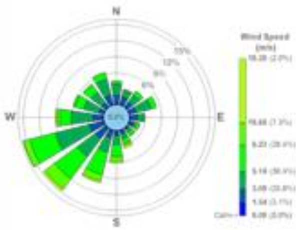
Figure 5 *Worst Case Actual Scenario*: Predicted Annual Mean NO_x (as NO_2) Concentrations (2015)

Pollutant/ Scenario / Year	Averaging Period	Process Contribution NO_x ($\mu g/m^3$)	Background Concentration ($\mu g/m^3$)	Predicted Emission Concentration - PEC NO_2 ($\mu g/Nm^3$)	Standard ($\mu g/Nm^3$)Note 2	PEC as a % of Standard
NO_2 / WC / 2012	Annual Mean	0.70	11	11.7	40	29%
	99.8^{th}%ile of 1-hr means	54.6	Note 1	76.6	200	38%
NO_2 / WC / 2013	Annual Mean	0.72	11	11.7	40	29%
	99.8^{th}%ile of 1-hr means	39.0	Note 1	61.0	200	31%
NO_2 / WC / 2014	Annual Mean	0.93	11	11.9	40	30%
	99.8^{th}%ile of 1-hr means	78.3	Note 1	100.3	200	50%
NO_2 / WC / 2015	Annual Mean	1.51	11	12.5	40	31%
	99.8^{th}%ile of 1-hr means	47.9	Note 1	69.9	200	35%
NO_2 / WC / 2016	Annual Mean	0.9	11	11.9	40	30%
	99.8^{th}%ile of 1-hr means	70.9	Note 1	92.9	200	46%

Note 1 Short-term Immission Concentrations calculated according to UK DEFRA guidance[14]
Note 2 Air Quality Standards 2011 (from EU Directive 2008/50/EC)

Table 6 Modelled NO_2 Concentrations for *Worst Case Actual Scenario* ($\mu g/m^3$)





Background Mapping from Google Earth

Worst Case Actual Scenario
99.8th%ile of 1-Hour Mean NO_2 Concentrations (excluding background)

Maximum Concentration = 78.3 µg/m^3

Boundary Of Facility
Emission Point

N

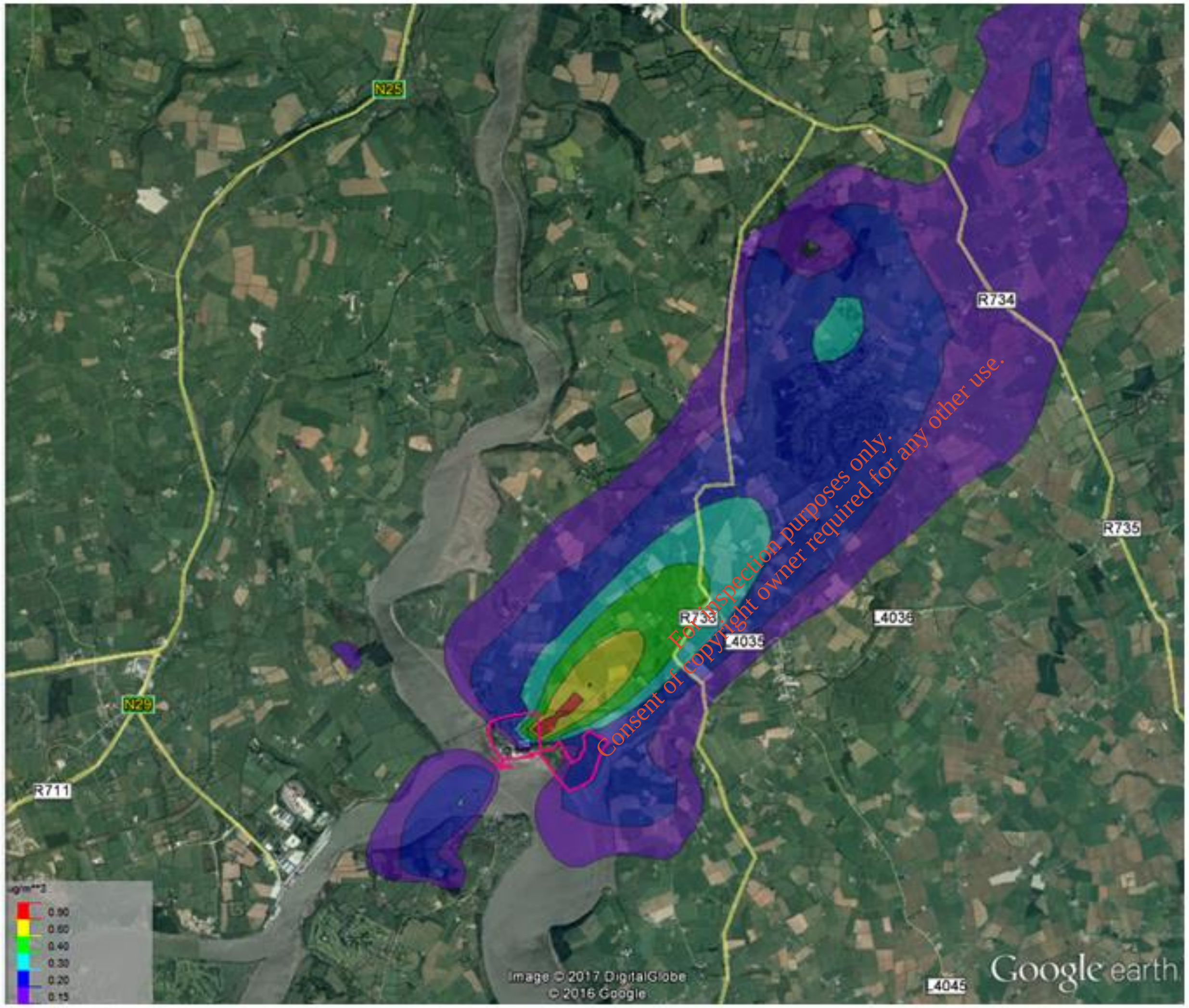
Project
Great Island CCGT Power Station – Air Dispersion Model

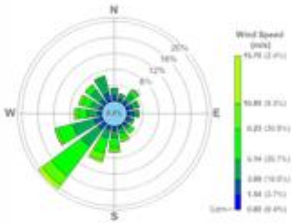
Reference
17/9488AR01

Figure 4
Worst Case Actual Scenario: Predicted NO_2 99.8th Percentile of Hourly Concentrations (2014) (µg/m^3)

awnconsulting

The Tecpro Building, Clonshaugh Business and Technology Park, Dublin 17
T: +353 1 847 4220 F: +353 1 847 4257





Background Mapping from Google Earth

Worst Case Actual Scenario Annual Mean NO_2 Concentrations (excluding background)

Maximum Concentration = 1.51 µg/m^3

Boundary Of Facility

Emission Point

N

Project

Great Island CCGT Power Station– Air Dispersion Model

Reference

17/9488AR01

Figure 5

Worst Case Actual Scenario: Predicted NO_2 Annual Mean Concentrations (2015) (µg/m^3)

awnconsulting

The Tecpro Building, Clonshaugh Business and Technology Park, Dublin 17
T: +353 1 847 4220 F: +353 1 847 4257

Average Actual Scenario

The NO_2 modelling results for the *Average Actual Scenario* are detailed in Table 7. The results indicate that the ambient ground level concentrations are below the relevant air quality standards for NO_2. Emissions from the facility lead to an ambient NO_2 concentration including background which is 32% of the maximum 1-hour limit value (measured as a 99.8th%ile) and 30% of the annual limit value at the worst-case off-site receptor for the worst-case years modelled (2014 and 2015). Further details of the calculation of the PEC for the 99.8th%ile of 1-hour mean NO_2 is outlined in Appendix III.

The geographical variations in ground level NO_x (as NO_2) concentrations (without background) beyond the facility boundary for the worst-case years modelled are illustrated as concentration contours in Figures 8 and 9. The contents of each figure are described below:

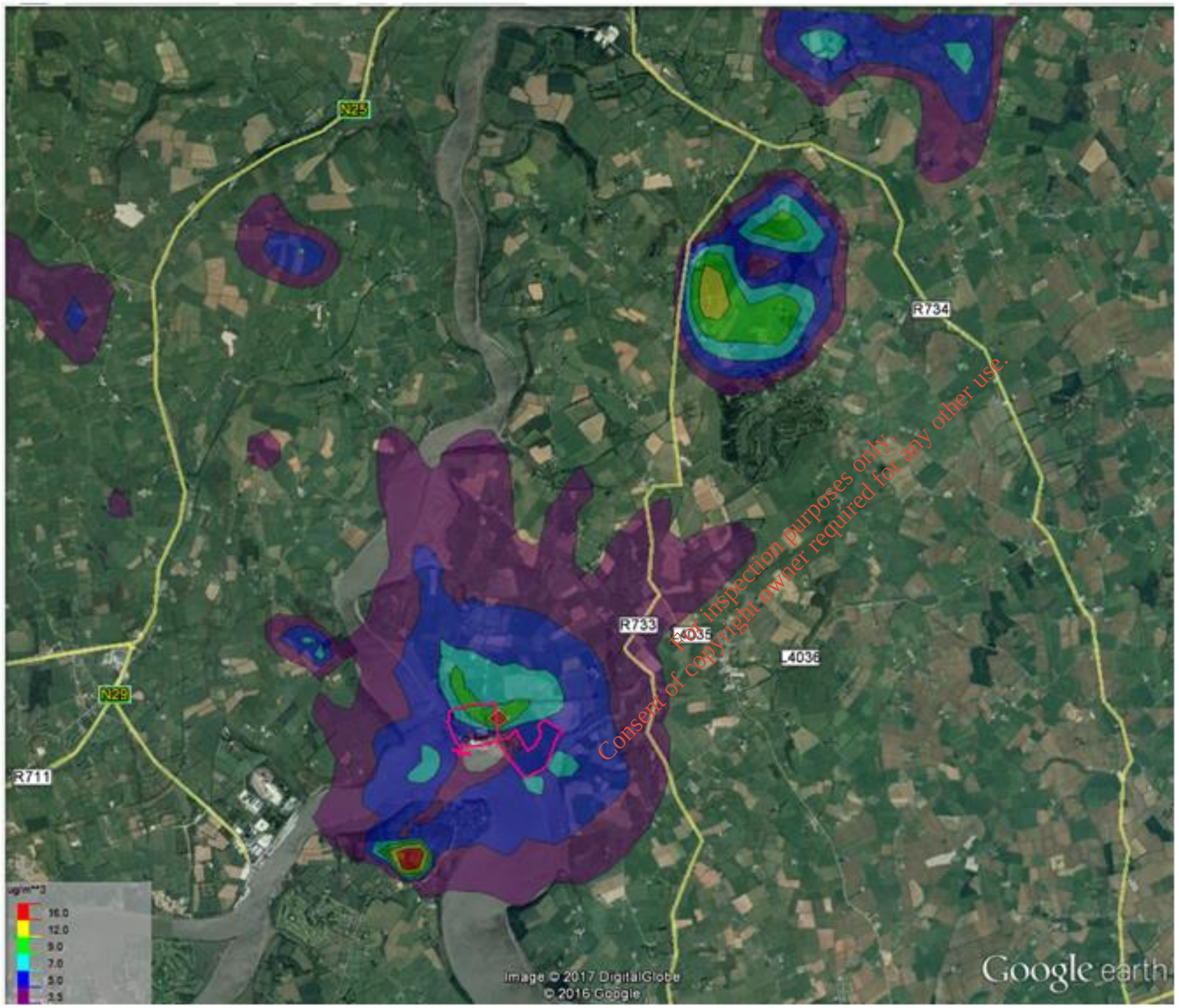
Figure 6 *Average Actual Scenario*: Predicted NO_x (as NO_2) 99.8th Percentile of Hourly Concentrations (2014)

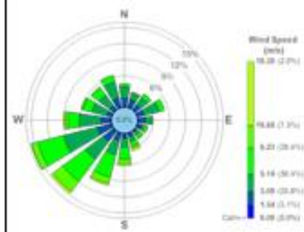
Figure 7 *Average Actual Scenario*: Predicted Annual Mean NO_x (as NO_2) Concentrations (2015)

Pollutant/ Scenario / Year	Averaging Period	Process Contribution (μg/m³)	Background Concentration (μg/m³)	Predicted Emission Concentration - PEC (μg/Nm³)	Standard (μg/Nm³)Note 2	PEC as a % of Standard
NO_2 / Avg / 2012	Annual Mean	0.4	11	11.4	40	29%
	99.8th%ile of 1-hr means	30.5	Note 1	52.5	200	26%
NO_2 / Avg / 2013	Annual Mean	0.42	11	11.4	40	29%
	99.8th%ile of 1-hr means	23.4	Note 1	45.4	200	23%
NO_2 / Avg / 2014	Annual Mean	0.54	11	11.5	40	29%
	99.8th%ile of 1-hr means	42.6	Note 1	64.6	200	32%
NO_2 / Avg / 2015	Annual Mean	0.88	11	11.9	40	30%
	99.8th%ile of 1-hr means	29.5	Note 1	51.5	200	26%
NO_2 / Avg / 2016	Annual Mean	0.52	11	11.5	40	29%
	99.8th%ile of 1-hr means	34.5	Note 1	56.5	200	28%

Note 1 Short-term Immission Concentrations calculated according to UK DEFRA guidance[14]
Note 2 Air Quality Standards 2011 (from EU Directive 2008/50/EC)

Table 7 Modelled NO_2 Concentrations for the *Average Actual Scenario* (μg/m³)





Background Mapping from Google Earth

Average Actual Scenario
99.8th%ile of 1-Hour Mean NO_2 Concentrations (excluding background)

Maximum Concentration = 42.6 µg/m³

Boundary Of Facility
Emission Point

N

Project
Great Island CCGT Power Station – Air Dispersion Model

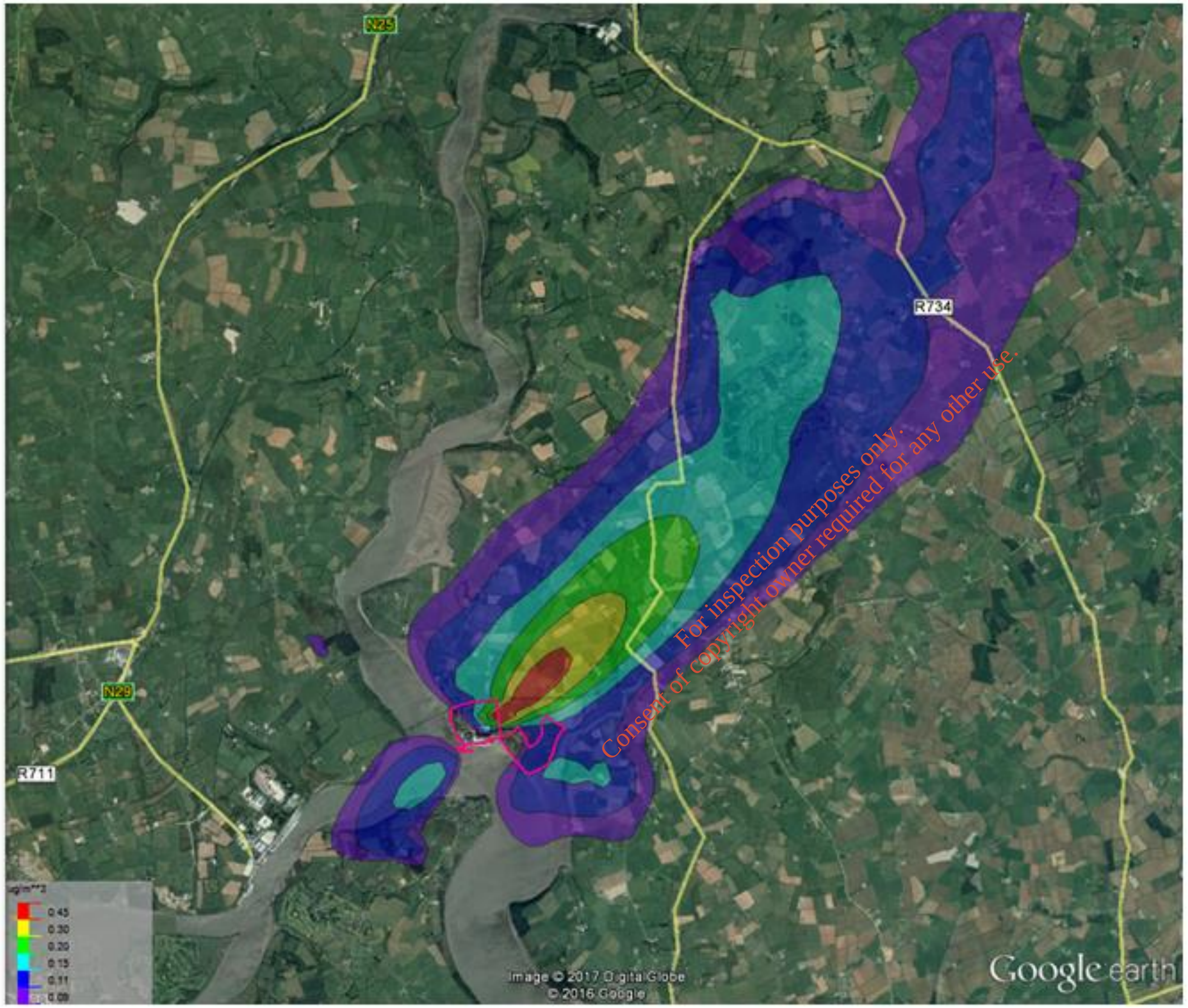
Reference
17/9488AR01

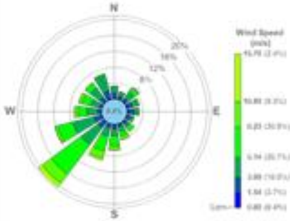
Figure 6

Average Actual Scenario: Predicted NO_2 99.8th Percentile of Hourly Concentrations (2014) (µg/m³)

awnconsulting

The Tecpro Building, Clonshaugh Business and Technology Park, Dublin 17
T: +353 1 847 4220 F: +353 1 847 4257





Background Mapping from Google Earth

Average Actual Scenario
Annual Mean NO_2 Concentrations (excluding background)

Maximum Concentration = 0.88 µg/m³

Boundary Of Facility
Emission Point

N

Project
Great Island CCGT Power Station– Air Dispersion Model

Reference
17/9488AR01

Figure 7

Average Actual Scenario: Predicted NO_2 Annual Mean Concentrations (2015) (µg/m³)

awnconsulting

The Tecpro Building, Clonshaugh Business and Technology Park, Dublin 17
T: +353 1 847 4220 F: +353 1 847 4257

3.2 SO_2

Worst Case Actual Scenario

The SO_2 modelling results for *Worst Case Actual Scenario* are detailed in Table 8. The results indicate that the ambient ground level concentrations are below the relevant air quality standards for SO_2. Emissions from the facility lead to an ambient SO_2 concentration including background which is 6% of the maximum 1-hour limit value (measured as a 99.7th%ile) and 7% of the maximum 24-hour limit value (measured as a 99.2nd%ile) at the worst-case off-site receptor for the worst-case years modelled (2014 and 2015).

The geographical variations in ground level SO_2 concentrations (without background) beyond the facility boundary for the worst-case years modelled are illustrated as concentration contours in Figures 8 and 9. The contents of each figure are described below:

Figure 8 *Worst Case Actual Scenario*: Predicted SO_2 99.7th Percentile of Hourly Mean Concentrations (2014)

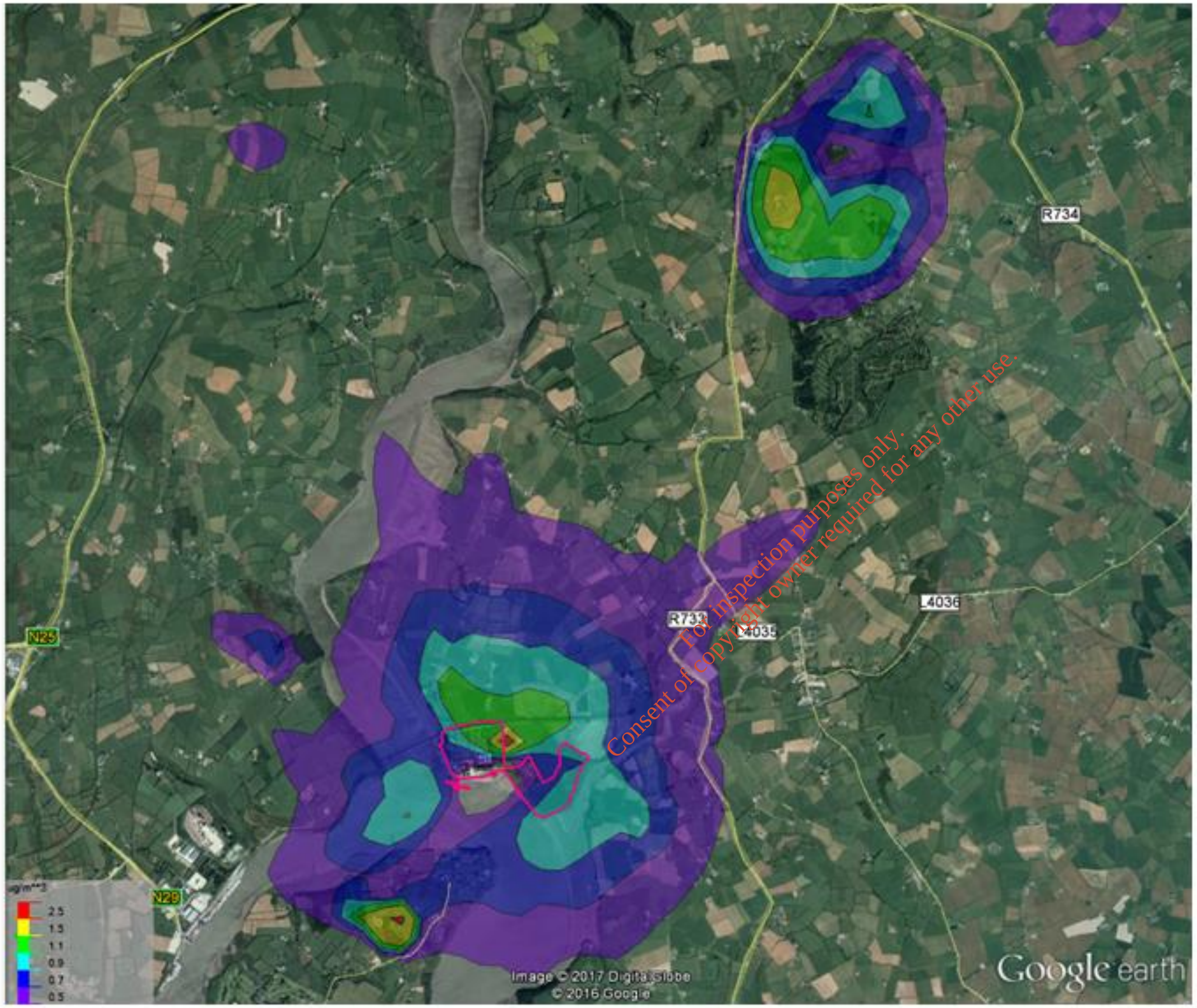
Figure 9 *Worst Case Actual Scenario*: Predicted SO_2 99.2nd Percentile of 24-Hour Mean Concentrations (2015)

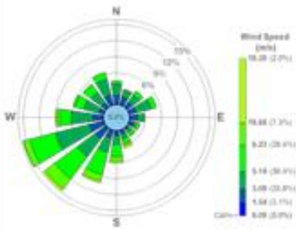
Pollutant/ Scenario / Year	Averaging Period	Process Contribution (µg/m³)	Background Concentration (µg/m³)	Predicted Emission Concentration - PEC (µg/Nm³)	Standard (µg/Nm³)Note 2	PEC as a % of Standard
SO_2 / WC / 2012	99.2nd%ile of 24-hr means	0.75	Note 1	9.03	125	7%
	99.7th%ile of 1-hr means	3.96	Note 1	22.23	350	6%
SO_2 / WC / 2013	99.2nd%ile of 24-hr means	1.02	Note 1	9.03	125	7%
	99.7th%ile of 1-hr means	3.22	Note 1	22.23	350	6%
SO_2 / WC / 2014	99.2nd%ile of 24-hr means	1.33	Note 1	9.07	125	7%
	99.7th%ile of 1-hr means	5.09	Note 1	22.27	350	6%
SO_2 / WC / 2015	99.2nd%ile of 24-hr means	1.83	Note 1	9.17	125	7%
	99.7th%ile of 1-hr means	4.14	Note 1	22.37	350	6%
SO_2 / WC / 2016	99.2nd%ile of 24-hr means	0.83	Note 1	9.06	125	7%
	99.7th%ile of 1-hr means	4.67	Note 1	22.26	350	6%

Note 1 Short-term Immission Concentrations calculated according to UK DEFRA guidance(14)

Note 2 Air Quality Standards 2011 (from EU Directive 2008/50/EC)

Table 8 Modelled SO_2 Concentrations for *Worst Case Actual Scenario* (µg/m³)





Background Mapping from Google Earth

Worst Case Actual Scenario
99.7th%ile of 1-Hour Mean SO_2 Concentrations (excluding background)

Maximum Concentration = 5.1 µg/m^3

Boundary Of Facility
Emission Point

N

Project
Great Island CCGT Power Station– Air Dispersion Model

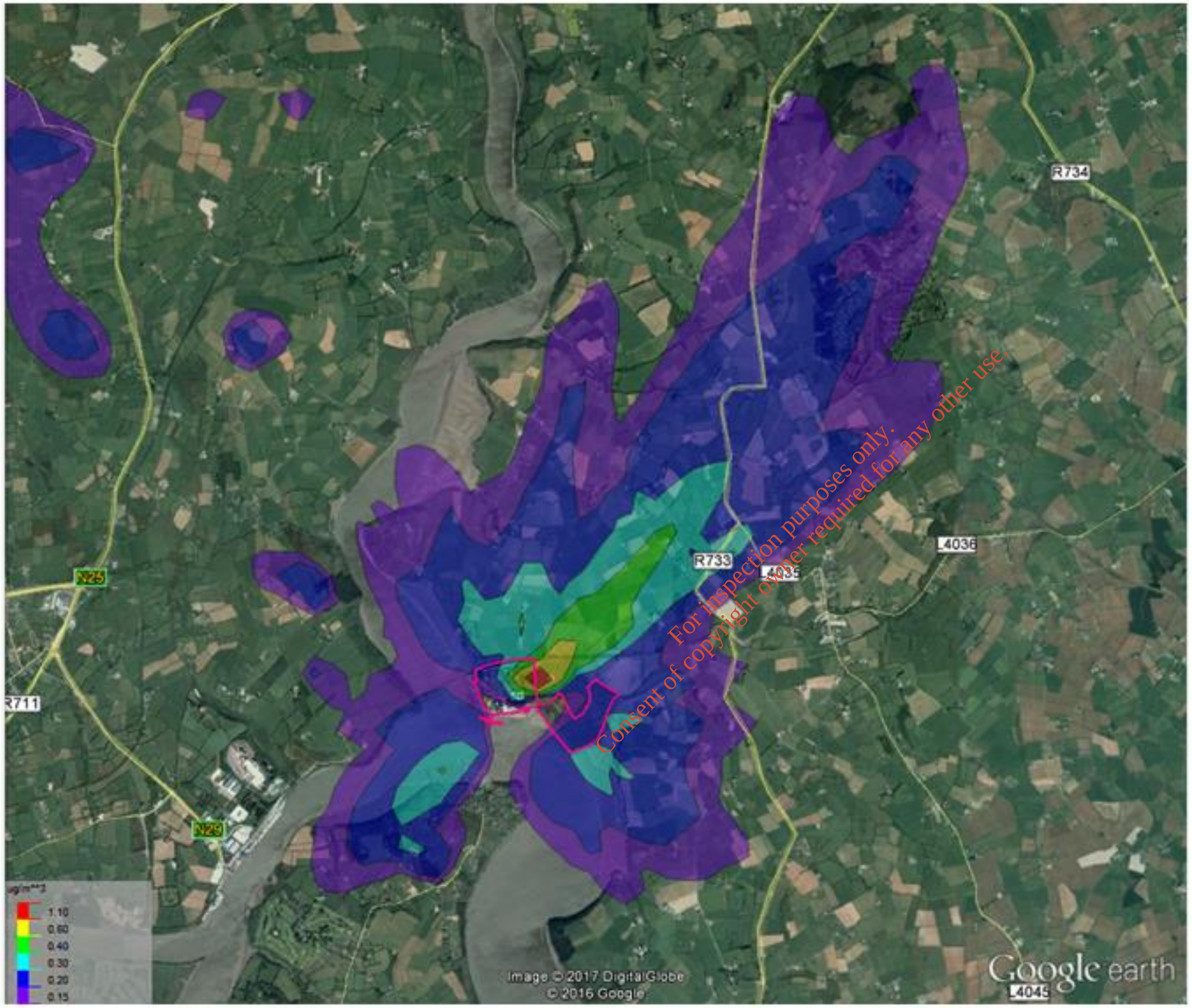
Reference
17/9488AR01

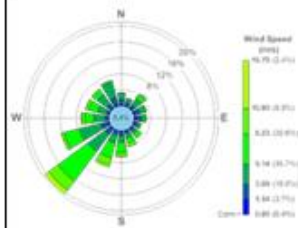
Figure 8

Worst Case Actual Scenario: Predicted SO_2 99.7th Percentile of Hourly Concentrations (2014) (µg/m^3)

awnconsulting

The Tecpro Building, Clonshaugh Business and Technology Park, Dublin 17
T: +353 1 847 4220 F: +353 1 847 4257





Background Mapping from Google Earth

Worst Case Actual Scenario
99.2nd%ile of 24-Hour Mean SO_2 Concentrations (excluding background)

Maximum Concentration = 1.83 µg/m^3

Boundary Of Facility
Emission Point

N

Project
Great Island CCGT Power Station– Air Dispersion Model

Reference
17/9488AR01

Figure 9

Worst Case Actual Scenario: Predicted SO_2 99.2nd Percentile of 24-Hourly Concentrations (2015) (µg/m^3)

awnconsulting

The Tecpro Building, Clonshaugh Business and Technology Park, Dublin 17
T: +353 1 847 4220 F: +353 1 847 4257

Average Actual Scenario

The SO_2 modelling results for the *Average Actual Scenario* are detailed in Table 9. The results indicate that the ambient ground level concentrations are below the relevant air quality standards for SO_2. Emissions from the facility lead to an ambient SO_2 concentration including background which is 6% of the maximum 1-hour limit value (measured as a 99.7th%ile) and 7% of the maximum 24-hour limit value (measured as a 99.2nd%ile) at the worst-case off-site receptor for the worst-case year modelled (2014 and 2015).

The geographical variations in ground level SO_2 concentrations (without background) beyond the facility boundary for the worst-case years modelled are illustrated as concentration contours in Figures 10 and 11. The contents of each figure are described below:

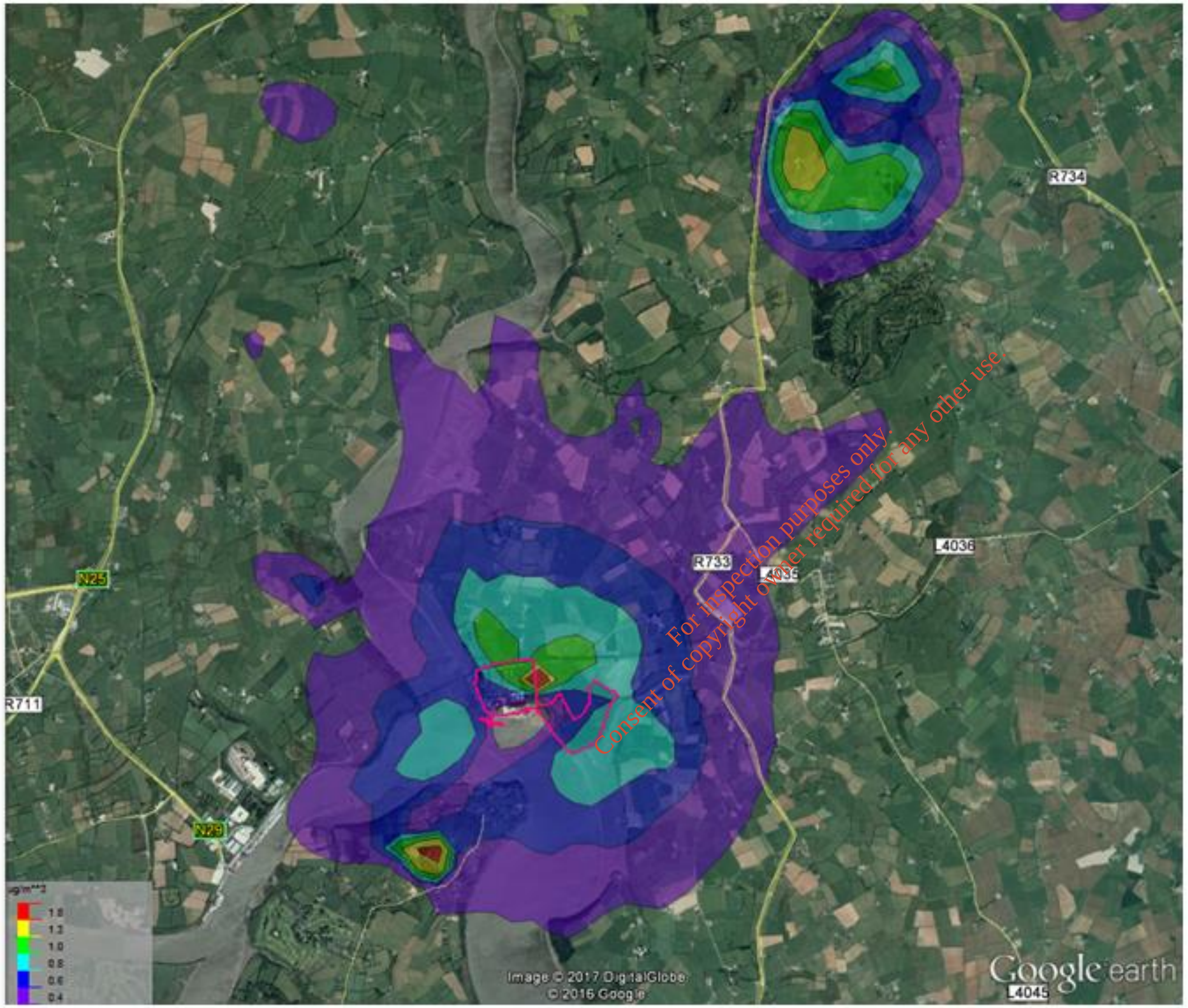
Figure 10 *Average Actual Scenario*: Predicted SO_2 99.7th Percentile of Hourly Mean Concentrations (2014)

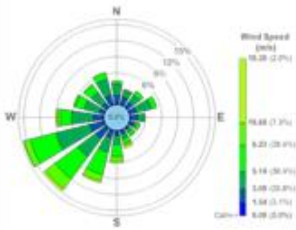
Figure 11 *Average Actual Scenario:* Predicted SO_2 99.2nd Percentile of 24-Hour Mean Concentrations (2015)

Pollutant/ Scenario / Year	Averaging Period	Process Contribution (μg/m³)	Background Concentration (μg/m³)¹	Predicted Emission Concentration - PEC (μg/Nm³)	Standard (μg/Nm³) Note 2	PEC as a % of Standard
SO_2 / Avg / 2012	99.2nd%ile of 24-hr means	0.63	Note 1	9.01	125	7%
	99.7th%ile of 1-hr means	3.21	Note 1	22.21	350	6%
SO2 / Avg / 2013	99.2nd%ile of 24-hr means	0.93	Note 1	9.01	125	7%
	99.7th%ile of 1-hr means	2.86	Note 1	22.21	350	6%
SO2 / Avg / 2014	99.2nd%ile of 24-hr means	1.12	Note 1	9.05	125	7%
	99.7th%ile of 1-hr means	4.13	Note 1	22.25	350	6%
SO2 / Avg / 2015	99.2nd%ile of 24-hr means	1.62	Note 1	9.14	125	7%
	99.7th%ile of 1-hr means	3.84	Note 1	22.34	350	6%
SO_2 / Avg / 2016	99.2nd%ile of 24-hr means	0.7	Note 1	9.04	125	7%
	99.7th%ile of 1-hr means	3.63	Note 1	22.24	350	6%

Note 1 Short-term Immission Concentrations calculated according to UK DEFRA guidance[14]
Note 2 Air Quality Standards 2011 (from EU Directive 2008/50/EC)

Table 9 Modelled SO_2 Concentrations for *Average Actual Scenario* (μg/m³)





Background Mapping from Google Earth

Average Actual Scenario
99.7th%ile of 1-Hour Mean SO_2 Concentrations (excluding background)

Maximum Concentration = 4.1 µg/m^3

Boundary Of Facility
Emission Point

N

Project
Great Island CCGT Power Station– Air Dispersion Model

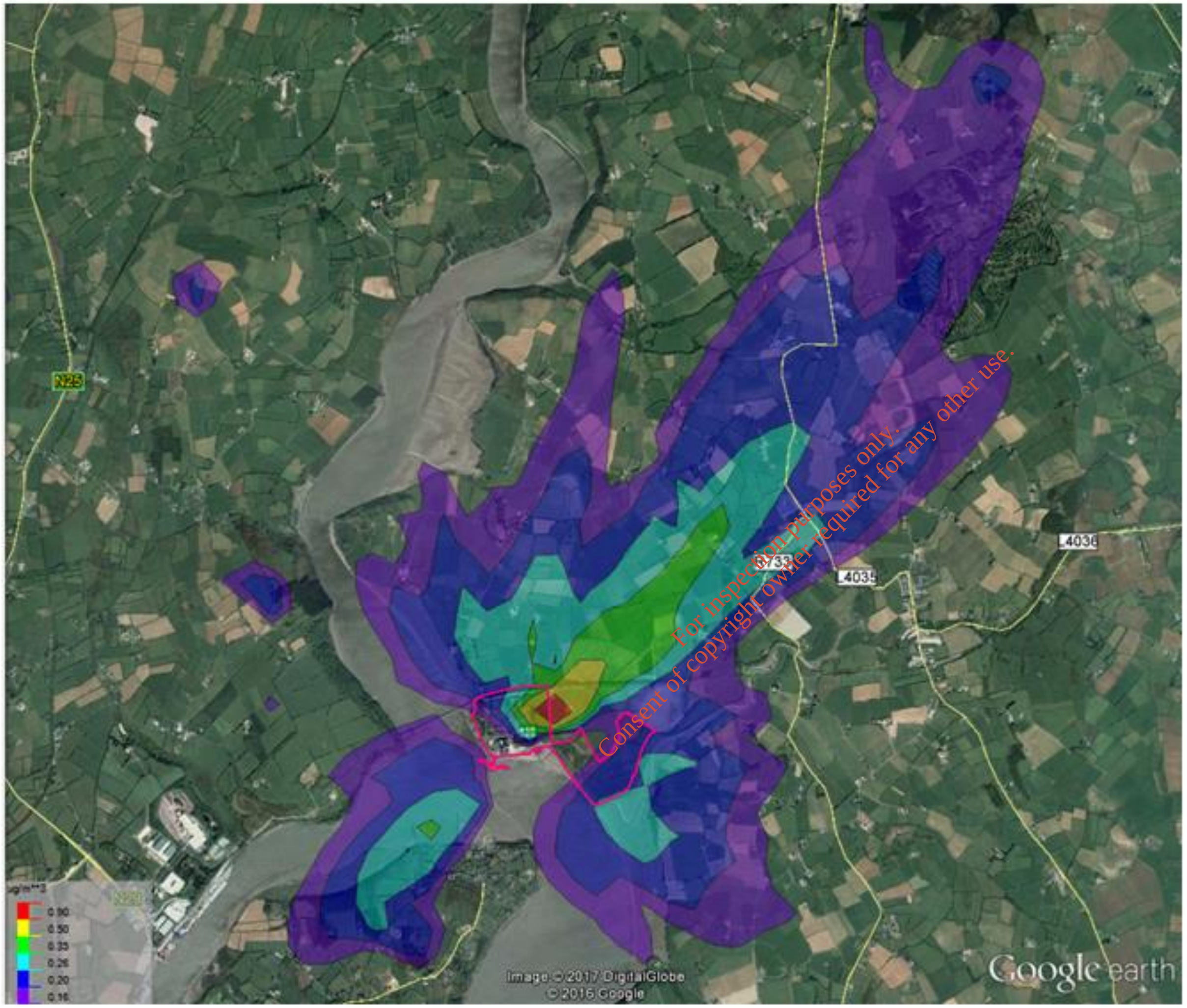
Reference
17/9488AR01

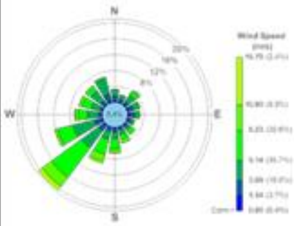
Figure 10

Average Actual Scenario: Predicted SO_2 99.7th Percentile of Hourly Concentrations (2014) (µg/m^3)

awnconsulting

The Tecpro Building, Clonshaugh Business and Technology Park, Dublin 17
T: +353 1 847 4220 F: +353 1 847 4257





Background Mapping from Google Earth

Average Actual Scenario
99.2nd%ile of 24-Hour Mean SO_2 Concentrations (excluding background)

Maximum Concentration = 1.62 µg/m³

Boundary Of Facility
Emission Point

N

Project
Great Island CCGT Power Station– Air Dispersion Model

Reference
17/9488AR01

Figure 11

Average Actual Scenario: Predicted SO_2 99.2nd Percentile of 24-Hourly Concentrations (2015) (µg/m³)

awnconsulting

The Tecpro Building, Clonshaugh Business and Technology Park, Dublin 17
T: +353 1 847 4220 F: +353 1 847 4257

3.3 CO

Worst Case Actual Scenario

The CO modelling results for *Worst Case Actual Scenario* are detailed in Table 10. The results indicate that the ambient ground level concentrations are below the relevant air quality standard for CO. Emissions from the facility lead to an ambient CO concentration which is 2% of the maximum 8-hour limit value at the worst-case off-site receptor for the worst-case year modelled (2016). When the background concentration is included this rises to 12% of the maximum 8-hour limit value at the worst-case off-site receptor.

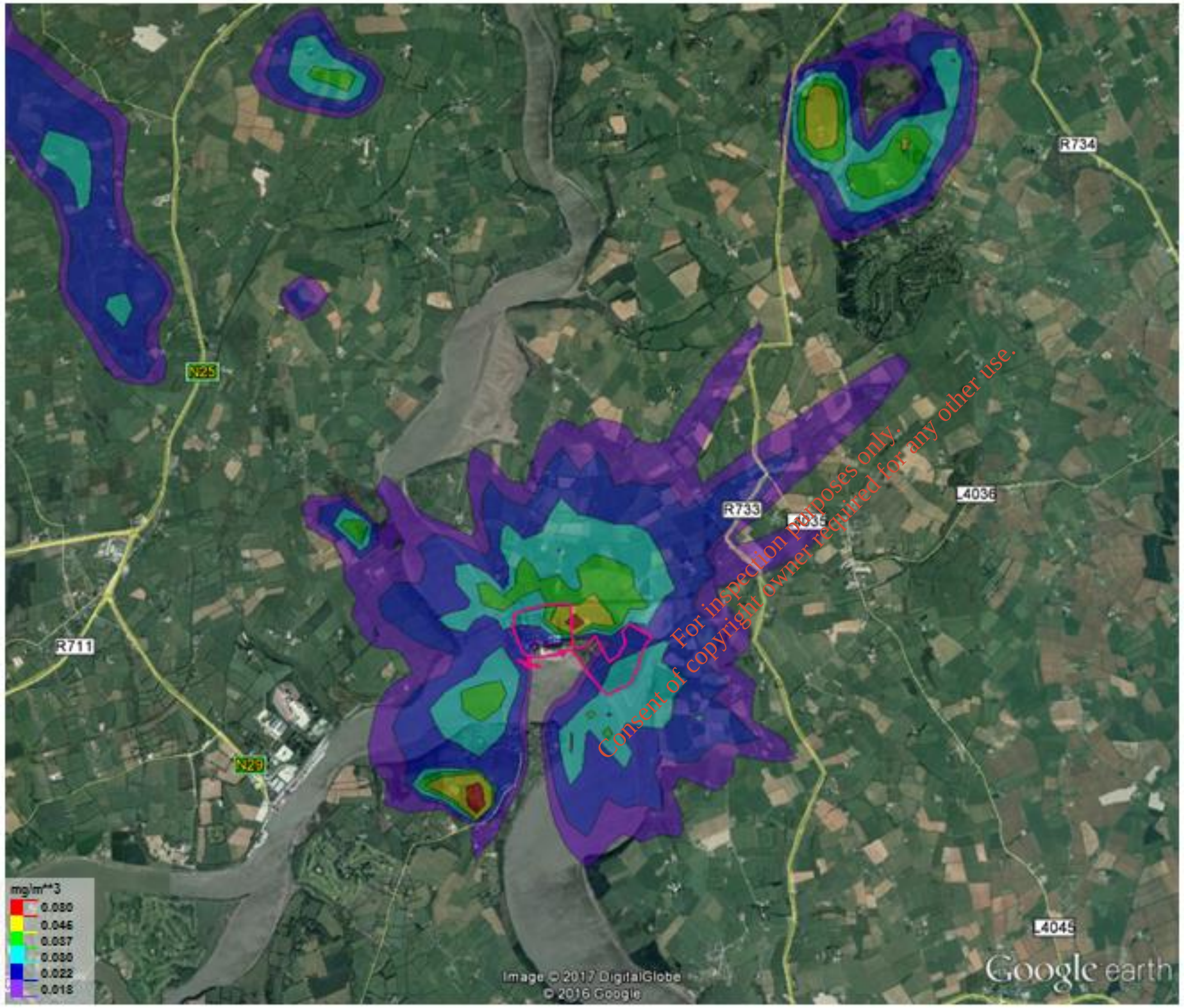
The geographical variations in ground level CO concentrations (without background) beyond the facility boundary for the worst-case year modelled are illustrated as concentration contours in Figure 12. The contents of the figure is described below:

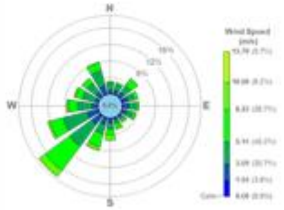
Figure 12 *Worst Case Actual Scenario*: Predicted CO Maximum 8-Hour Concentrations (2016)

Pollutant/ Scenario / Year	Averaging Period	Process Contribution (mg/m³)	Background Concentration (mg/m³)	Predicted Emission Concentration - PEC (mg/Nm³)	Standard (mg/Nm³) Note 1	PEC as a % of Standard
CO / WC / 2012	Maximum 8-Hour Mean	0.15	1.00	1.15	10	11%
CO / WC / 2013	Maximum 8-Hour Mean	0.12	1.00	1.12	10	11%
CO / WC / 2014	Maximum 8-Hour Mean	0.13	1.00	1.13	10	11%
CO / WC / 2015	Maximum 8-Hour Mean	0.16	1.00	1.16	10	12%
CO / WC / 2016	Maximum 8-Hour Mean	0.18	1.00	1.18	10	12%

Note 1 Air Quality Standards 2011 (from EU Directive 2008/50/EC)

Table 10 Modelled CO Concentrations for the *Worst Case Actual Scenario* (mg/m³)





Background Mapping from Google Earth

Worst Case Actual Scenario Maximum 8-Hour Mean CO Concentrations (excluding background)

Maximum Concentration = 0.177 mg/m^3

Boundary Of Facility
Emission Point

N

Project

Great Island CCGT Power Station– Air Dispersion Model

Reference

17/9488AR01

Figure 12

Worst Case Actual Scenario: Predicted CO Maximum 8-Hour Mean Concentrations (2016) (mg/m^3)

awnconsulting

The Tecpro Building, Clonshaugh Business and Technology Park, Dublin 17
T: +353 1 847 4220 F: +353 1 847 4257

Average Actual Scenario

The CO modelling results for *Average Actual Scenario* are detailed in Table 11. The results indicate that the ambient ground level concentrations are below the relevant air quality standard for CO. Emissions from the facility lead to an ambient CO concentration which is 0.3% of the maximum 8-hour limit value at the worst-case off-site receptor for the worst-case year modelled (2015). When the background concentration is included this rises to 10% of the maximum 8-hour limit value at the worst-case off-site receptor.

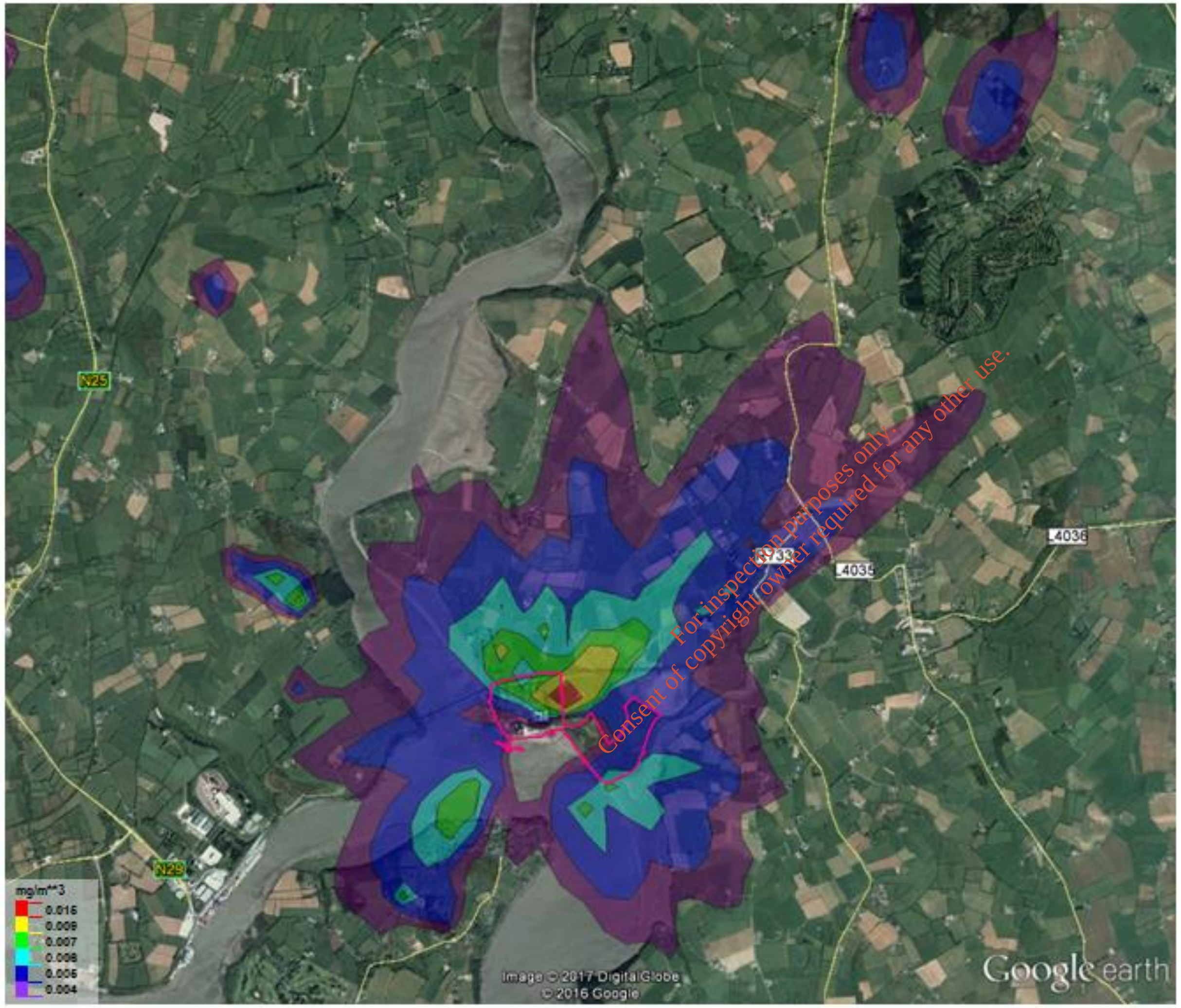
The geographical variations in ground level CO concentrations (without background) beyond the facility boundary for the worst-case year modelled are illustrated as concentration contours in Figure 13. The contents of the figure is described below:

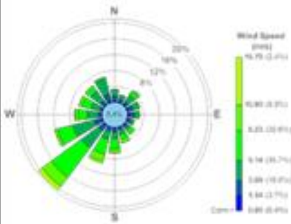
Figure 13 *Average Actual Scenario*: Predicted CO Maximum 8-Hour Concentrations (2015)

Pollutant/ Scenario / Year	Averaging Period	Process Contribution (mg/m^3)	Background Concentration (mg/m^3)	Predicted Emission Concentration - PEC (mg/Nm^3)	Standard (mg/Nm^3)$^{Note\ 1}$	PEC as a % of Standard
CO / Avg / 2012	Maximum 8-Hour Mean	0.022	1.00	1.02	10	10%
CO / Avg / 2013	Maximum 8-Hour Mean	0.020	1.00	1.02	10	10%
CO / Avg / 2014	Maximum 8-Hour Mean	0.021	1.00	1.02	10	10%
CO / Avg / 2015	Maximum 8-Hour Mean	0.029	1.00	1.03	10	10%
CO / Avg / 2016	Maximum 8-Hour Mean	0.027	1.00	1.03	10	10%

Note 1 Air Quality Standards 2011 (from EU Directive 2008/50/EC)

Table 11 Modelled CO Concentrations for the *Average Actual Scenario* (mg/m^3)





Background Mapping from Google Earth

Average Actual Scenario
Maximum 8-Hour Mean CO Concentrations (excluding background)

Maximum Concentration = 0.029 mg/m^3

Boundary Of Facility
Emission Point

N

Project
Great Island CCGT Power Station– Air Dispersion Model

Reference
17/9488AR01

Figure 13

Average Actual Scenario: Predicted CO Maximum 8-Hour Mean Concentrations (2016) (mg/m^3)

awnconsulting
The Tecpro Building, Clonshaugh Business and Technology Park, Dublin 17
T: +353 1 847 4220 F: +353 1 847 4257

3.4 Impact of NO_x and SO_2 Emissions on Sensitive Ecosystems

The impact of the emissions of NO_x and SO_2 from Great Island CCGT Power Station on ambient ground level concentrations of those concentrations within the River Barrow and River Nore SAC & the Barrow River Estuary pNHA was assessed using AERMOD. Annual limit values for both pollutants are specified within EU Directive 2008/50/EC for the protection of ecosystems and vegetation. Annual average concentrations for both pollutants were predicted at receptors within the SAC / pNHA boundary up to a distance of 10km from the emission points for the worst-case year for annual average concentrations (2015). The receptor spacing was the same as that used for the receptor grids (every 50m within 2.5km of the facility, every 250m within 5km of the facility and every 500m within 10km of the facility).

The NO_x modelling results for the two scenarios are detailed in Table 12. The results indicate that the ambient ground level concentrations are below the relevant air quality standard for NO_x for the protection of ecosystems. Emissions from the facility for the *Worst Case Actual Scenario* lead to an ambient NO_x concentration which is 1% of the annual limit value at the worst-case location within the SAC / SPA. When background concentrations are included this rises to 38% of the annual limit value at the worst-case location. Emissions for the *Average Actual Scenario* lead to lower annual NO_x concentrations within the SAC. Ambient NO_x concentrations including background reach 37% of the annual limit value at the worst-case location within the SAC / pNHA for the *Average Actual Scenario.*

Pollutant/ Scenario / Year	Averaging Period	Process Contribution (µg/m^3)	Annual Mean Background (µg/m^3)	Predicted Emission Concentration - PEC (µg/Nm^3)	Standard (µg/Nm^3) Note 1	PEC as a % of Standard
NO_x/ WC / 2015	Annual Mean	0.36	11	11.36	30	38%
NO_x/ Avg / 2015	Annual Mean	0.22	11	11.22	30	37%

Note 1 Air Quality Standards 2011 (from EU Directive 2008/50/EC)

Table 12 Modelled NO_x Concentrations within the River Barrow and River Nore SAC & the Barrow River Estuary pNHA (µg/m^3) for Both Emission Scenarios

The SO_2 modelling results for the two scenarios are detailed in Table 13. The results indicate that the ambient ground level concentrations are below the relevant air quality standard for SO_2 for the protection of vegetation for the *Worst Case Actual Scenario* and the *Average Actual Scenario*. Emissions from the facility for the *Worst Case Actual Scenario* lead to an ambient SO_2 concentration which is 0.2% of the annual limit value at the worst-case location within the SAC / pNHA. When background concentrations are included this rises to 15% of the annual limit value at the worst-case location. The emissions for the *Average Actual Scenario* lead to lower annual SO_2 concentrations within the SAC / pNHA. Ambient SO_2 concentrations including background reach 15% of the annual limit value at the worst-case location within the SAC / pNHA for the *Average Actual Scenario.*

Pollutant/ Scenario / Year	Averaging Period	Process Contribution (µg/m^3)	Annual Mean Background (µg/m^3)	Predicted Emission Concentration - PEC (µg/Nm^3)	Standard (µg/Nm^3) Note 1	PEC as a % of Standard
SO_2 / WC / 2015	Annual Mean	0.033	3	3.033	20	15%
SO_2/ Avg / 2015	Annual Mean	0.029	3	3.029	20	15%

Note 1 Air Quality Standards 2011 (from EU Directive 2008/50/EC)

Table 13 Modelled SO_2 Concentrations within the River Barrow and River Nore SAC & the Barrow River Estuary pNHA (µg/m^3) for Both Emission Scenarios

3.5 Summary of Modelling Results

The modelling results demonstrate that ambient pollutant concentrations (including background) are well below the applicable air quality limit values at all off-site receptors modelled.

References

(1) USEPA (1998) AERMOD Description of Model Formulation
(2) EPA (2010) Air Dispersion Modelling from Industrial Installations Guidance Note (AG4)
(3) USEPA (1995) User's Guide for the Industrial Source Complex (ISC3) Dispersion Model Vol I & II
(4) USEPA (2005) Guidelines on Air Quality Models, Appendix W to Part 51, 40 CFR Ch.1
(5) USEPA (2000) Seventh Conference on Air Quality Modelling (June 2000) Vol I & II
(6) USEPA (1998) Human Health Risk Assessment Protocol, Chapter 3: Air Dispersion and Deposition Modelling, Region 6 Centre for Combustion Science and Engineering
(7) USEPA (1999) Comparison of Regulatory Design Concentrations: AERMOD vs. ISCST3 vs. CTDM PLUS
(8) Schulman et al "Development and evaluation of the PRIME Plume Rise and Building Downwash Model" Air & Waste Management Association, 1998.
(9) Paine, R & Lew, F. "Consequence Analysis for Adoption of PRIME: an Advanced Building Downwash Model" Prepared for the EPRI, ENSR Document No. 2460-026-450 (1997).
(10) Paine, R & Lew, F. "Results of the Independent Evaluation of ISCST3 and ISC-PRIME" Prepared for the EPRI, ENSR Document No. 2460-026-3527-02 (1997).
(11) USEPA (2000) Estimating Exposure to Dioxin-Like Compounds Volume IV, Chapter 3 Evaluating Atmospheric Releases of Dioxin-Like Compounds from Combustion Sources (Draft)
(12) EPA (2017) http://www.epa.ie/whatwedo/monitoring/air/data/
(13) Environmental Protection Agency (2016) Air Quality Monitoring Report 2015
(14) UK DEFRA (2016) Part IV of the Environment Act 1995: Local Air Quality Management, LAQM. TG(16)
(15) UK DEFRA and UK Environment Agency (2016) Guidance Air Emissions Risk Assessment for your Environmental Permit
(16) UK Environment Agency (2003) IPPC Environmental Assessment and Appraisal of BAT
(17) USEPA (1998) User's Guide to the AERMOD Meteorological Preprocessor (AERMET)

APPENDIX I

Description of the AERMOD Model

The AERMOD dispersion model has been recently developed in part by the U.S. Environmental Protection Agency (USEPA)[(1)]. The model is a steady-state Gaussian model used to assess pollutant concentrations associated with industrial sources. The model is an enhancement on the Industrial Source Complex-Short Term 3 (ISCST3) model which has been widely used for emissions from industrial sources.

Improvements over the ISCST3 model include the treatment of the vertical distribution of concentration within the plume. ISCST3 assumes a Gaussian distribution in both the horizontal and vertical direction under all weather conditions. AERMOD with PRIME, however, treats the vertical distribution as non-Gaussian under convective (unstable) conditions while maintaining a Gaussian distribution in both the horizontal and vertical direction during stable conditions. This treatment reflects the fact that the plume is skewed upwards under convective conditions due to the greater intensity of turbulence above the plume than below. The result is a more accurate portrayal of actual conditions using the AERMOD model. AERMOD also enhances the turbulence of night-time urban boundary layers thus simulating the influence of the urban heat island.

In contrast to ISCST3, AERMOD is widely applicable in all types of terrain. Differentiation of the simple versus complex terrain is unnecessary with AERMOD. In complex terrain, AERMOD employs the dividing-streamline concept in a simplified simulation of the effects of plume-terrain interactions. In the dividing-streamline concept, flow below this height remains horizontal, and flow above this height tends to rise up and over terrain. Extensive validation studies have found that AERMOD (precursor to AERMOD with PRIME) performs better than ISCST3 for many applications and as well or better than CTDMPLUS for several complex terrain data sets[(6)].

Due to the proximity to surrounding buildings, the PRIME (Plume Rise Model Enhancements) building downwash algorithm has been incorporated into the model to determine the influence (wake effects) of these buildings on dispersion in each direction considered. The PRIME algorithm takes into account the position of the stack relative to the building in calculating building downwash. In the absence of the building, the plume from the stack will rise due to momentum and/or buoyancy forces. Wind streamlines act on the plume leads to the bending over of the plume as it disperses. However, due to the presence of the building, wind streamlines are disrupted leading to a lowering of the plume centreline.

When there are multiple buildings, the building tier leading to the largest cavity height is used to determine building downwash. The cavity height calculation is an empirical formula based on building height, the length scale (which is a factor of building height & width) and the cavity length (which is based on building width, length and height). As the direction of the wind will lead to the identification of differing dominant tiers, calculations are carried out in intervals of 10 degrees.

In PRIME, the nature of the wind streamline disruption as it passes over the dominant building tier is a function of the exact dimensions of the building and the angle at which the wind approaches the building. Once the streamline encounters the zone of influence of the building, two forces act on the plume. Firstly, the disruption caused by the building leads to increased turbulence and enhances horizontal and vertical dispersion. Secondly, the streamline descends in the lee of the building due to the reduced pressure and drags the plume (or part of) nearer to the ground, leading to higher ground level concentrations. The model calculates the descent of the plume as a function of the building shape and, using a numerical plume rise model, calculates the change in the plume centreline location with distance downwind.

The immediate zone in the lee of the building is termed the cavity or near wake and is characterised by high intensity turbulence and an area of uniform low pressure. Plume mass captured by the cavity region is re-emitted to the far wake as a ground-level volume source. The volume source is located at the base of the lee wall of the building, but is only evaluated near the end of the near wake and beyond. In this region, the disruption caused by the building downwash gradually fades with distance to ambient values downwind of the building.

AERMOD has made substantial improvements in the area of plume growth rates in comparison to ISCST3(1). ISCST3 approximates turbulence using six Pasquill-Gifford-Turner Stability Classes and bases the resulting dispersion curves upon surface release experiments. This treatment, however, cannot explicitly account for turbulence in the formulation. AERMOD is based on the more realistic modern planetary boundary layer (PBL) theory which allows turbulence to vary with height. This use of turbulence-based plume growth with height leads to a substantial advancement over the ISCST3 treatment.

Improvements have also been made in relation to mixing height(1). The treatment of mixing height by ISCST3 is based on a single morning upper air sounding each day. AERMOD, however, calculates mixing height on an hourly basis based on the morning upper air sounding and the surface energy balance, accounting for the solar radiation, cloud cover, reflectivity of the ground and the latent heat due to evaporation from the ground cover. This more advanced formulation provides a more realistic sequence of the diurnal mixing height changes.

AERMOD also contains improved algorithms for dealing with low wind speed (near calm) conditions. As a result, AERMOD can produce model estimates for conditions when the wind speed may be less than 1 m/s, but still greater than the instrument threshold.

APPENDIX II

Meteorological Data - AERMET

AERMOD incorporates a meteorological pre-processor AERMET[17]. AERMET allows AERMOD to account for changes in the plume behaviour with height. AERMET calculates hourly boundary layer parameters for use by AERMOD, including friction velocity, Monin-Obukhov length, convective velocity scale, convective (CBL) and stable boundary layer (SBL) height and surface heat flux. AERMOD uses this information to calculate concentrations in a manner that accounts for changes in dispersion rate with height, allows for a non-Gaussian plume in convective conditions, and accounts for a dispersion rate that is a continuous function of meteorology.

The AERMET meteorological preprocessor requires the input of surface characteristics, including surface roughness (z_0), Bowen Ratio and albedo by sector and season, as well as hourly observations of wind speed, wind direction, cloud cover, and temperature. A morning sounding from a representative upper air station, latitude, longitude, time zone, and wind speed threshold are also required.

Two files are produced by AERMET for input to the AERMOD dispersion model. The surface file contains observed and calculated surface variables, one record per hour. The profile file contains the observations made at each level of a meteorological tower, if available, or the one-level observations taken from other representative data, one record level per hour.

From the surface characteristics (i.e. surface roughness, albedo and amount of moisture available (Bowen Ratio)) AERMET calculates several boundary layer parameters that are important in the evolution of the boundary layer, which, in turn, influences the dispersion of pollutants. These parameters include the surface friction velocity, which is a measure of the vertical transport of horizontal momentum; the sensible heat flux, which is the vertical transport of heat to/from the surface; the Monin-Obukhov length which is a stability parameter relating the surface friction velocity to the sensible heat flux; the daytime mixed layer height; the nocturnal surface layer height and the convective velocity scale which combines the daytime mixed layer height and the sensible heat flux. These parameters all depend on the underlying surface.

The values of albedo, Bowen Ratio and surface roughness depend on land-use type (e.g., urban, cultivated land etc) and vary with seasons and wind direction. The assessment of appropriate land-use types was carried out in line with USEPA recommendations[4].

<u>Surface roughness</u>

Surface roughness length is the height above the ground at which the wind speed goes to zero. Surface roughness length is defined by the individual elements on the landscape such as trees and buildings. In order to determine surface roughness length, the USEPA recommends that a representative length be defined for each sector, based on an upwind area-weighted average of the land use within the sector, by using the eight land use categories outlined by the USEPA. The inverse-distance weighted surface roughness length derived from the land use classification within a radius of 1km from Johnstown Castle Meteorological Station is shown in Table A1.

Sector	Inverse Distance Weighted Land Use Classification	Spring	Summer	Autumn	Winter[1]
0-360	100% Grassland	0.050	0.100	0.010	0.010

(1) Winter defined as periods when surfaces covered permanently by snow whereas autumn is defined as periods when freezing conditions are common, deciduous trees are leafless and no snow is present (Iqbal (1983)). Thus for the current location autumn more accurately defines "winter" conditions in Ireland.

Table A1 Surface Roughness based on an inverse distance weighted average of the land use within a 1km radius of Johnstown Castle Meteorological Station.

Albedo

Noon-time albedo is the fraction of the incoming solar radiation that is reflected from the ground when the sun is directly overhead. Albedo is used in calculating the hourly net heat balance at the surface for calculating hourly values of Monin-Obuklov length. A 10km x 10km square area is drawn around the meteorological station to determine the albedo based on a simple average for the land use types within the area independent of both distance from the station and the near-field sector. The classification within 10km from Johnstown Castle Meteorological Station is shown in Table A2.

Simple Average Land Use Classification	Spring	Summer	Autumn	Winter[1]
10% Water	0.012	0.010	0.014	0.014
5% Urban	0.007	0.008	0.009	0.009
75% Grassland	0.135	0.135	0.150	0.150
10% Cultivated Land	0.014	0.020	0.018	0.018

(1) For the current location autumn more accurately defines "winter" conditions in Ireland.

Table A2 Albedo based on a simple average of the land use within a 10km × 10km grid centred on Johnstown Castle Meteorological Station.

Bowen Ratio

The Bowen ratio is a measure of the amount of moisture at the surface of the earth. The presence of moisture affects the heat balance resulting from evaporative cooling which, in turn, affects the Monin-Obukhov length which is used in the formulation of the boundary layer. A 10km x 10km square area is drawn around the meteorological station to determine the Bowen Ratio based on geometric mean of the land use types within the area independent of both distance from the station and the near-field sector. The classification within 10km from Johnstown Castle Meteorological Station is shown in Table A3.

Geometric Mean Land Use Classification	Spring	Summer	Autumn	Winter[1]
10% Water	0.1	0.1	0.1	0.1
5% Urban	1.0	2.0	2.0	2.0
75% Grassland	0.4	0.8	1.0	1.0
10% Cultivated Land	0.3	0.5	0.7	0.7

(1) For the current location autumn more accurately defines "winter" conditions in Ireland.

Table A3 Bowen Ratio based on a geometric mean of the land use within a 10km × 10km grid centred on Johnstown Castle Meteorological Station.

APPENDIX III

Detailed NO_X Process Calculations – *Worst Case Actual Scenario*

A) 99.8th%ile hourly background total oxidant (O_3 & NO_2) + 0.05 x (99.8th%ile process contribution NO_X)

Year	99.8th%ile hourly background total oxidant (O_3 & NO_2)	99.8th%ile process contribution NO_X	NO_2 PEC
2012	103.6	54.6	**106.3**
2013	103.6	39.0	**105.6**
2014	103.6	78.3	**107.5**
2015	103.6	47.9	**106.0**
2016	103.6	70.9	**107.1**

Minimum
76.6
61.0
100.3
69.9
92.9

B) 1 99.8th%ile process contribution NO_X + 2 x (annual mean background NO_2)

Year	99.8th%ile process contribution NO_X	Annual Mean Background NO_2	NO_2 PEC
2012	54.6	11	**76.6**
2013	39.0	11	**61.0**
2014	78.3	11	**100.3**
2015	47.9	11	**69.9**
2016	70.9	11	**92.9**

Maximum
76.6
61.0
100.3
69.9
92.9

B) 2 99.8th%ile hourly background NO_2 + 2 x (annual mean process contribution NO_X).

Year	99.8th%ile hourly background NO_2	Annual Mean Process NO_X	NO_2 PEC
2012	26.9	0.7	**28.3**
2013	26.9	0.7	**28.3**
2014	26.9	0.9	**28.7**
2015	26.9	1.5	**29.9**
2016	26.9	0.9	**28.7**

Detailed NO_X Process Calculations – *Average Actual Scenario*

A) 99.8th%ile hourly background total oxidant (O_3 & NO_2) + 0.05 x (99.8th%ile process contribution NO_X)

Year	99.8th%ile hourly background total oxidant (O_3 & NO_2)	99.8th%ile process contribution NO_X	NO_2 PEC
2012	103.6	30.5	**105.1**
2013	103.6	23.4	**104.8**
2014	103.6	42.6	**105.7**
2015	103.6	29.5	**105.1**
2016	103.6	34.5	**105.3**

Minimum
52.5
45.4
64.6
51.5
56.5

B) 1 99.8th%ile process contribution NO_X + 2 x (annual mean background NO_2)

Year	99.8th%ile process contribution NO_x	Annual Mean Background NO_2	NO_2 PEC
2012	30.5	11	**52.5**
2013	23.4	11	**45.4**
2014	42.6	11	**64.6**
2015	29.5	11	**51.5**
2016	34.5	11	**56.5**

Maximum
52.5
45.4
64.6
51.5
56.5

B) 2 99.8th%ile hourly background NO_2 + 2 x (annual mean process contribution NO_X).

Year	99.8th%ile hourly background NO_2	Annual Mean Process NO_X	NO_2 PEC
2012	26.9	0.4	**27.7**
2013	26.9	0.4	**27.7**
2014	26.9	0.5	**28.0**
2015	26.9	0.9	**28.7**
2016	26.9	0.5	**27.9**