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

DETERMINATION OF AIR EMISSIONS TO ATMOSPHERE FROM THE WATERFORD PROTEINS FACILITY, COUNTY KILKENNY

Technical Report Prepared For

Anglo Beef Processors Unlimited Company (T/A Waterford Proteins)
Christendom,
Ferrybank,
Co. Kilkenny

Technical Report Prepared By

Dr. Edward Porter C Chem MRSC MIAQM

Our Reference

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

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Name	Dr. Edward Porter	Ciara Nolan
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EXECUTIVE SUMMARY

AWN Consulting Ltd were commissioned by Environet Ltd to carry out an air dispersion modelling study of emissions from the thermal oxidiser at Anglo Beef Processors Unlimited Company (T/A Waterford Proteins), Christendom, Ferrybank, Co. Kilkenny. Inputs to the model included design details provided by Waterford Proteins. The assessment has determined, through dispersion modelling of emissions from the facility, whether the predicted ambient air concentration are in compliance with the relevant ambient air quality standards.

Air dispersion modelling was carried out using the United States Environmental Protection Agency's regulatory model AERMOD (Version 19191). The aim of the study was to assess the contribution of air emission from the thermal oxidiser to off-site levels of air pollutants and to identify the location and maximum of the worst-case ground level air concentrations.

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

- Review of air emissions from the thermal oxidiser based on the current operations at the facility;
- Dispersion modelling of air under the maximum emission scenario to determine the likely level of air pollutants in the ambient environment;
- Presentation of predicted ground level concentrations of released pollutants;
- 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 Standards.

Modelling and a subsequent impact assessment were undertaken for the following substances released from the facility:

- Nitrogen dioxide (NO_2) and Nitrogen Oxides (NO_X);
- Sulphur Dioxide (SO_2);
- Total Dust (as PM_{10} (particulate matter less than 10 microns) and $PM_{2.5}$ (particulate matter less than 2.5 microns)); and
- Gaseous and vaporous organic substances expressed as total organic carbon (TOC).

Assessment Summary

Modelling results indicate that the ambient ground level concentrations will be below the relevant air quality standards or guidelines for the protection of human health for all parameters under maximum operation of the facility. The modelling results indicate that the long-term maximum concentrations occur near the northern and north-eastern boundaries of the facility.

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1.0 INTRODUCTION

AWN Consulting Ltd were commissioned by Environet Ltd to carry out an air dispersion modelling study of emissions from the thermal oxidiser at Waterford Proteins facility, Christendom, Ferrybank, Co. Kilkenny. Inputs to the model included design details provided by Waterford Proteins. The assessment has determined, through dispersion modelling of emissions from the facility, whether the predicted ambient air concentration are in compliance with the relevant ambient air quality standards.

The site is located at Christendom, Ferrybank, Co. Kilkenny. The site is approximately 1.5 km east of Waterford city. The facility is a rendering facility. In the immediate region of the facility, the land use is predominantly agricultural with several other industrial / logistical facilities also located nearby. There are a number of residential properties within 200 m of the site and several housing developments within 500m of the site as shown in Figure 1.

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- Gaseous and vaporous organic substances expressed as total organic carbon (TOC).

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, a review of the meteorological data used is detailed in Appendix II, Appendix III details the comprehensive meteorological data is presented in Appendix III.

Site Location

Closest Residences

Commercial / Industrial

Scale
1:15,000

N

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Waterford Proteins Air Modelling Assessment

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21/12180AR02

Figure 1
Map of land use in the vicinity of Waterford Proteins, Christendom, Co. Kilkenny

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

2.0 ASSESSMENT METHODOLOGY

Emissions from the facility have been modelled using the AERMOD dispersion model (Version 19191) which has been developed by the U.S. Environmental Protection Agency (USEPA)(2) and following guidance issued by the EPA(1). The model 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(2). The model has more advanced algorithms and gives better agreement with monitoring data in extensive validation studies(5,6). An overview of the AERMOD dispersion model is outlined in Appendix I.

The air dispersion modelling input data consisted of information on the physical environment (including building dimensions and terrain features), design details from all emission points on-site and five years of appropriate hourly meteorological data. Using this input data the model predicted ambient ground level concentrations beyond the site boundary for each hour of the modelled meteorological years. The model post-processed the data to identify the location and maximum of the worst-case ground level concentration.

2.1 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 limit values in Ireland include the Air Quality Standards Regulations 2011, which incorporate EU Directive 2008/50/EC (see Table 1).

These limit values have been used in the current assessment to determine the potential impact of NO_X, PM_{10}/$PM_{2.5}$, benzene and SO_2 emissions from the facility on air quality.

Pollutant	Regulation Note 1	Limit Type	Value
Nitrogen Dioxide	2008/50/EC	Hourly limit for protection of human health - not to be exceeded more than 18 times/year	200 μg/m^3 NO_2
		Annual limit for protection of human health	40 μg/m^3 NO_2
		Critical level for protection of vegetation	30 μg/m^3 NO + NO_2
Sulphur Dioxide	2008/50/EC	Hourly limit for protection of human health - not to be exceeded more than 24 times/year	350 μg/m^3
		Daily limit for protection of human health - not to be exceeded more than 3 times/year	125 μg/m^3
		Annual & Winter critical level for the protection of ecosystems	20 μg/m^3
Particulate Matter (as PM_{10})	2008/50/E	Daily limit for protection of human health - not to be exceeded more than 35 times/year	50μg/m^3
		Annual limit for protection of human health	40 μg/m^3
Particulate Matter (as $PM_{2.5}$)	2008/50/E	Annual limit for protection of human health	25 μg/m^3
Benzene	2008/50/E	Annual limit for protection of human health	5 μg/m^3

Note 1 EU 2008/50/EC – Clean Air For Europe (CAFÉ) Directive replaces the previous Air Framework Directive (1996/30/EC) and daughter directives 1999/30/EC and 2000/69/EC

Table 1 Air Quality Standards 2011 (Based on Directive 2008/50/EC)

2.2 Background Concentrations Of Pollutants

Air quality monitoring programs have been undertaken in recent years by the EPA and Local Authorities[7,8]. The most recent annual report on air quality "Air Quality Monitoring Annual Report 2019"[7], 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[7]. 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, Waterford is categorised as Zone C[7].

NO_2

With regard to NO_2, continuous monitoring data from the EPA[7] at the Zone C locations of Dundalk, Kilkenny and Portlaoise in 2019 show that levels of NO_2 are below both the annual and 1-hour limit values (see Table 2). Average long-term concentrations at Kilkenny and Portlaoise range from 5 - 14 µg/m^3 for the period 2015 – 2019; suggesting an upper average over the five year period of no more than 15 µg/m^3. There were no exceedances of the maximum 1-hour limit of 200 µg/m^3 in any year (18 exceedances are allowed per year). Results are also available for Brownes Road, Waterford in 2019 showing an average of 8 µg/m^3. Based on these results a conservative estimate of the background NO_2 concentration in the region of the development in 2021 is 12 µg/m^3. In summary, existing baseline levels of NO_2 based on extensive long-term data from the EPA are expected to be below ambient air quality limit values in the vicinity of the facility.

Station	Averaging Period	Year				
		2015	2016	2017	2018	2019
Kilkenny	Annual Mean NO_2 (µg/m^3)	5	7	5	6	5
	99.8th%ile 1-hr NO_2 (µg/m^3)	70	51	58	45	42
Dundalk	Annual Mean NO_2 (µg/m^3)	-	-	-	14	12
	99.8th%ile 1-hr NO_2 (µg/m^3)	-	-	-	67	69
Portlaoise	Annual Mean NO_2 (µg/m^3)	10	11	11	11	11
	99.8th%ile 1-hr NO_2 (µg/m^3)	84	86	80	68	60

Table 2 Trends in Zone C Air Quality Locations 2015 – 2019 – Nitrogen Dioxide (µg/m^3)

The Plume Volume Molar Ratio Method (PVMRM) was used to model NO_2 concentrations. The PVMRM is a regulatory option in AERMOD which assumes that the amount of NO converted to NO_2 is proportional to the ambient ozone (O_3) concentration. The PVMRM uses both plume size and O_3 concentration to derive the amount of O_3 available for the reaction between NO and O_3. NO_X moles are determined by emission rate and travel time through the plume segment. The concentration is usually limited by the amount of ambient O_3 that is entrained in the plume. Thus, the ratio of the moles of O_3 to the moles of NO_X gives the ratio of NO_2/NO_X that is formed after the NO_X leaves the stack. In addition, it has been assumed that 5% of the NO_X in the stack gas is already in the form of NO_2 before the gas leaves the stack[9,10]. The equation used in the algorithm to derive the ratio of NO_2/NO_X is:

$$NO_2/NO_X = (\text{moles } O_3/ \text{ moles } NO_X) + 0.10$$

The ozone concentration used in the PVMRM model runs was 60 µg/m^3 based on data from the air monitoring stations in Zone C locations over the period 2015 – 2019[7].

SO_2

Long-term SO_2 monitoring was carried out at the Zone C locations of Ennis, Portlaoise and Dundalk in 2019. The SO_2 annual average measured no more than 4 µg/m^3 in 2019[7]. Previous monitoring from 2015 – 2018 at three locations indicated annual averages ranging from 1 – 4 µg/m^3 (see Table 3). Based on the above information a conservative estimate of the background SO_2 concentration in the region of the facility is 4 µg/m^3. The 99.7th%ile of 1-hour means for Ennis in 2019 was 52.7 µg/m^3 whilst the 99.2th%ile of 24-hour means for Ennis in 2019 was 21.1 µg/m^3.

Year	Ennis (µg/m^3)	Portlaoise(µg/m^3)	Dundalk (µg/m^3)
2015	3	1	-
2016	4	1	-
2017	3	2	-
2018	3	3	4
2019	4	1	2
Average	**3**	**2**	**3**

Table 3 Annual Mean SO_2 Background Concentrations in Zone C Locations 2015 – 2019 (µg/m^3)

PM_{10}

Continuous PM_{10} monitoring carried out at the locations of Galway, Ennis and Portlaoise in 2019 showed annual mean concentrations of 13, 18 and 15 µg/m^3, respectively (see Table 4), with at most 12 exceedances (in Ennis) of the 24-hour limit value of 50 µg/m^3 (35 exceedances are permitted per year)[7]. Long-term data for the period 2015 – 2019 for these three locations shows that concentrations range from 10 - 18 µg/m^3, suggesting an upper average concentration over the five year period of no more than 17 µg/m^3. Also recorded was a level of 15 µg/m^3 for Waterford Brownes Rd in 2019. Based on this EPA data (Table 4), a conservative estimate of the background PM_{10} concentration in the region of the development is 15 µg/m^3.

Station	Averaging Period Notes 1,2	Year				
		2015	2016	2017	2018	2019
Galway	Annual Mean PM_{10} (µg/m^3)	15	15	-	15	13
	24-hr Mean > 50 µg/m^3 (days)	2	3	-	0	0
Ennis	Annual Mean PM_{10} (µg/m^3)	18	17	16	16	18
	24-hr Mean > 50 µg/m^3 (days)	10	12	9	4	12
Portlaoise	Annual Mean PM_{10} (µg/m^3)	12	12	10	11	15
	24-hr Mean > 50 µg/m^3 (days)	1	1	0	1	0

Note 1 Annual average limit value - 40 µg/m^3 (EU Council Directive 2008/50/EC & S.I. No. 180 of 2011).

Note 2 24-hour limit value - 50 µg/m^3 as a 90.4th%ile, i.e. not to be exceeded >35 times per year (EU Council Directive 1999/30/EC & S.I. No. 180 of 2011).

Table 4 Trends In Zone C Air Quality - PM_{10}

$PM_{2.5}$

Continuous $PM_{2.5}$ monitoring carried out at the Zone C locations of Ennis and Bray showed average levels of 5 - 14 µg/m^3 over the period 2015 - 2019, with a $PM_{2.5}/PM_{10}$ ratio in Ennis ranging from 0.63 – 0.78. Based on this information, a ratio of 0.7 was used to generate a background $PM_{2.5}$ concentration in the region of the development of 10.5 µg/m^3.

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 EPA[(1)] advises that for SO_2 and PM_{10} an estimate of the maximum combined pollutant concentration can be obtained as shown on the following page:

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)

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).

PM_{10} - The 90.4th%ile of total 24-hour mean PM_{10} is equal to the maximum of either A or B below:

a) 90.4th%ile of 24-hour mean background PM_{10} + annual mean process contribution PM_{10}

b) 90.4th%ile 24-hour mean process contribution PM_{10} + annual mean background PM_{10}

2.3 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 extended to 10 km with the site at the centre and with concentrations calculated at 500 m intervals. A middle grid extended to 5 km from the site with concentrations calculated at 250 m intervals whilst an inner grid extended to 1 km from the site with concentrations calculated at 50 m intervals. Boundary receptor locations were also placed along the boundary of the site, at 25 m intervals, giving a total of 5,086 calculation points for the model. All receptors have been modelled at 1.5 m to represent breathing height.

- All on-site buildings and significant process structures were mapped into the computer 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). The stacks themselves can influence airflow in the same way as buildings by causing low pressure regions behind them (termed stack tip downwash). Both building and stack tip downwash were incorporated into the modelling.

- Detailed terrain has been mapped into the model using SRTM data with 30m resolution. The site is located in rolling terrain. This takes account of all significant features of the terrain. All terrain features have been mapped in detail into the model using the terrain pre-processor AERMAP(11) as shown in Figure 2.

- Hourly-sequenced meteorological information has been used in the model. Meteorological data over a five year period (Johnstown Castle 2016 - 2020) was used in the model (see Figure 3 and Appendix III).

- The source and emission data, including stack dimensions, volume flows and emission temperatures have been incorporated into the model.

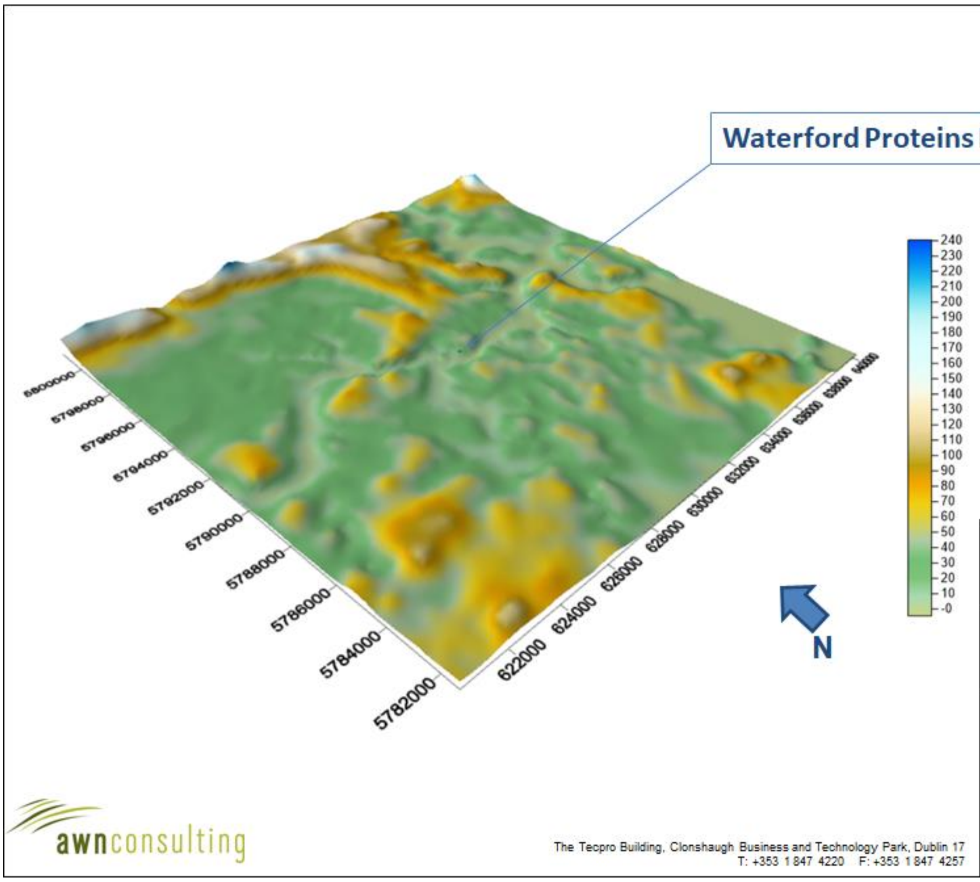
2.4 Terrain

The AERMOD air dispersion model has a terrain pre-processor AERMAP(11) 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 obtained from SRTM. 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 Digital 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, AERMOD models the impact of terrain using the concept of the dividing streamline (H_c). As outlined in the AERMOD model formulation(2) 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"(2).

The terrain in the region of the facility is complex in the sense that the maximum terrain in the modelling domain peaks at 246 m which is above the stack top of all emission points onsite. However, as shown in Figure 2, the region of the site has sloping terrain in the immediate vicinity of the facility.



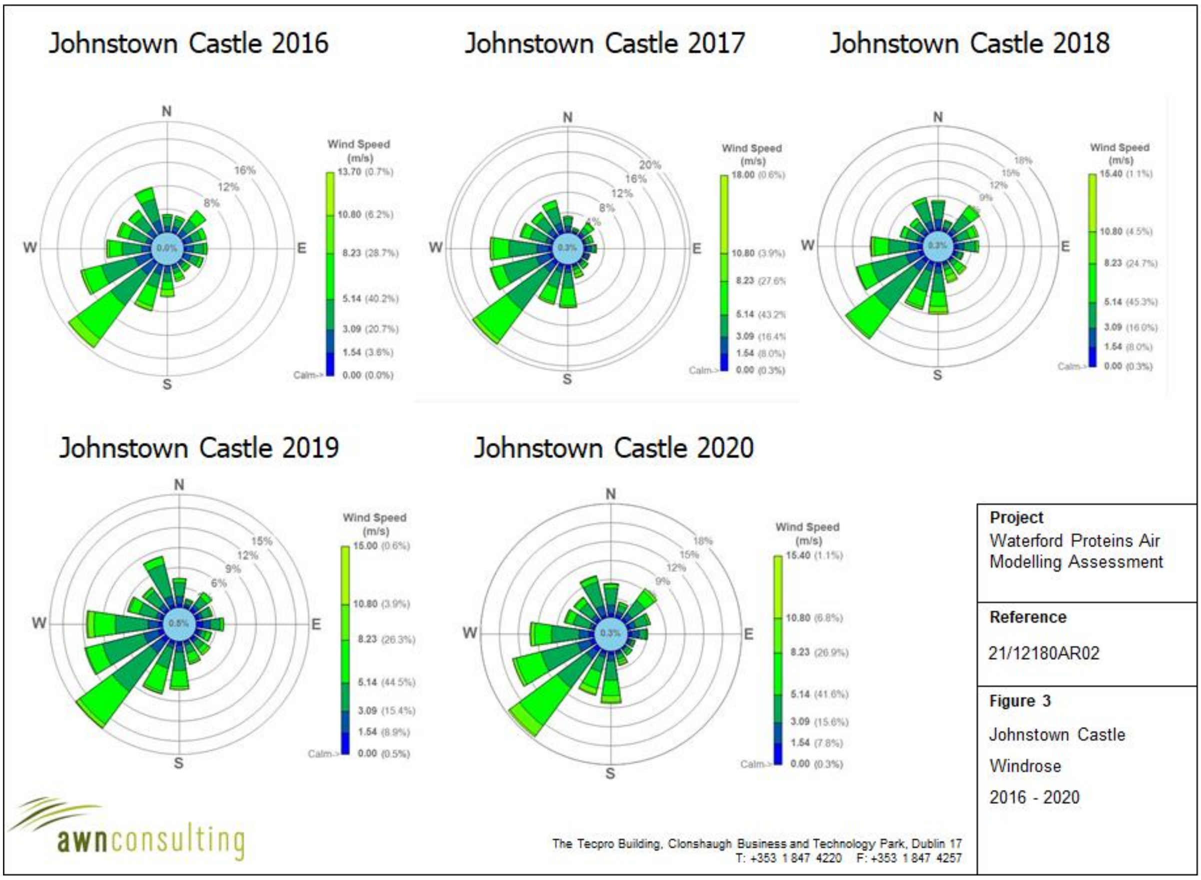
Project Waterford Proteins Air Modelling Assessment

Reference 21/12180AR02

Figure 2 Terrain In The Vicinity Of Waterford Proteins, Christendom, Co. Kilkenny (UTM Coordinates)

2.5 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 40 km east of the site, collects data in the correct format and has a data collection of greater than 90%. Long-term hourly observations at Johnstown Castle meteorological station provide an indication of the prevailing wind conditions for the region (see Figure 3 and Appendix III). Results indicate that the prevailing wind direction is south-westerly in direction over the period 2016 - 2020. Calm conditions account for only a small fraction of the time in any one year peaking at 40 hours in 2019 (0.46% of the time). There are no missing hours over the period 2016 – 2020.



2.6 Geophysical Considerations

AERMOD simulates the dispersion process using planetary boundary layer (PBL) scaling theory[2]. PBL depth and the dispersion of pollutants within this layer are influenced by specific surface characteristics such as surface roughness, albedo and the availability of surface moisture. Surface roughness is a measure of the aerodynamic roughness of the surface and is related to the height of the roughness element. Albedo is a measure of the reflectivity of the surface whilst the Bowen ratio is a measure of the availability of surface moisture.

AERMOD incorporates a meteorological pre-processor AERMET[12] to enable the calculation of the appropriate parameters. 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[12,13] as outlined in Appendix II.

In relation to AERMOD, detailed guidance for calculating the relevant surface parameters has been published[13]. The most pertinent features are:

- The surface characteristics should be those of the meteorological site (Johnstown Castle) rather than the installation;
- Surface roughness should use a default 1km radius upwind of the meteorological tower and should be based on an inverse-distance weighted

geometric mean. If land use varies around the site, the land use should be sub-divided by sectors with a minimum sector size of 30º;

- Bowen ratio and albedo should be based on a 10km grid. The Bowen ratio should be based on an un-weighted geometric mean. The albedo should be based on a simple un-weighted arithmetic mean.

AERMOD has an associated pre-processor, AERSURFACE(13) which has representative values for these parameters depending on land use type. The AERSURFACE pre-processor currently only accepts NLCD92 land use data which covers the USA. Thus, manual input of surface parameters is necessary when modelling in Ireland. Ordnance survey discovery maps (1:50,000) and digital maps such as those provided by the EPA, National Parks and Wildlife Service (NPWS) and Google Earth® are useful in determining the relevant land use in the region of the meteorological station. The Alaska Department of Environmental Conservation has issued a guidance note for the manual calculation of geometric mean for surface roughness and Bowen ratio for use in AERMET(14). This approach has been applied to the current site with full details provided in Appendix II.

2.7 Building Downwash

When modelling emissions from an industrial installation, stacks which are relatively short can be subjected to additional turbulence due to the presence of nearby buildings. Buildings are considered nearby if they are within five times the lesser of the building height or maximum projected building width (but not greater than 800m).

The USEPA has defined the “Good Engineering Practice” (GEP) stack height as the building height plus 1.5 times the lesser of the building height or maximum projected building width. It is generally considered unlikely that building downwash will occur when stacks are at or greater than GEP(15).

When stacks are less than this height, building downwash will tend to occur. As the wind approaches a building it is forced upwards and around the building leading to the formation of turbulent eddies. In the lee of the building these eddies will lead to downward mixing (reduced plume centreline and reduced plume rise) and the creation of a cavity zone (near wake) where re-circulation of the air can occur. Plumes released from short stacks may be entrained in this airflow leading to higher ground level concentrations than in the absence of the building.

The Plume Rise Model Enhancements (PRIME)(9,10) plume rise and building downwash algorithms, which calculates the impact of buildings on plume rise and dispersion, have been incorporated into AERMOD. The building input processor BPIP-PRIME produces the parameters which are required in order to run PRIME. The model takes into account the position of each stack relative to each relevant building and the projected shape of each building for 36 wind directions (at 10º intervals). The model determines the change in plume centreline location with downwind distance based on the slope of the mean streamlines and coupled to a numerical plume rise model(10).

Given that the stack is less than 2.5 times the lesser of the building height or maximum projected building width, building downwash will need to be taken into account and the PRIME algorithm run prior to modelling with AERMOD. The dominant building for each relevant stack will vary as a function of wind direction and relative building heights as shown in Figure 4.

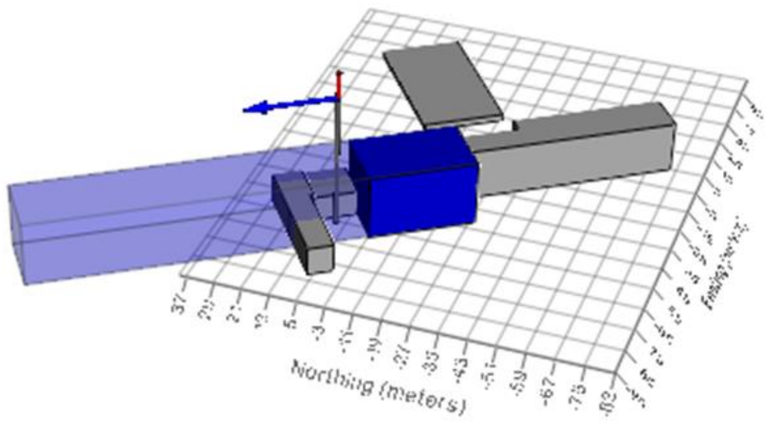


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Figure 4
Example Of Building Downwash Calculations (Example Shown For TO)

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

2.8 Air Emission Rates From Waterford Proteins

The Waterford Proteins site is located at Christendom, Ferrybank, Co. Kilkenny.

In consultation with Waterford Proteins, the main air sources at the facility were identified. Emission point AEP1-2 is the thermal oxidiser and is the main air emission source onsite. A summary of the emission parameters for AEP1-2 is outlined in Table 5.

Stack Reference	Exit Diameter (m)	Stack Height (m)	Temp (K)	Volume Flow Rate (Nm^3/hr)	Exist Velocity (m/sec actual)	NO_X Conc. (mg/Nm^3)	NO_X Mass Emission (g/s)	SO_2 Conc. (mg/Nm^3)	SO_2 Mass Emission (g/s)	PM_{10} Conc. (mg/Nm^3)	PM_{10} Mass Emission (g/s)	TOC Conc. (mg/Nm^3)	TOC Mass Emission (g/s)
AEP1-2	1.5	40	573.15	150,000	22.8	650	27.1	400	16.7	30	1.25	10	0.42

Note 1 For the purposes of this assessment normalised conditions are 273.15 K, 101.3 Pa, dry gas and 17% O_2

Table 5 Air Emission Details For AEP1-2 (Thermal Oxidiser) At Waterford Proteins, Christendom, Ferrybank, County Kilkenny

3.0 RESULTS & DISCUSSION

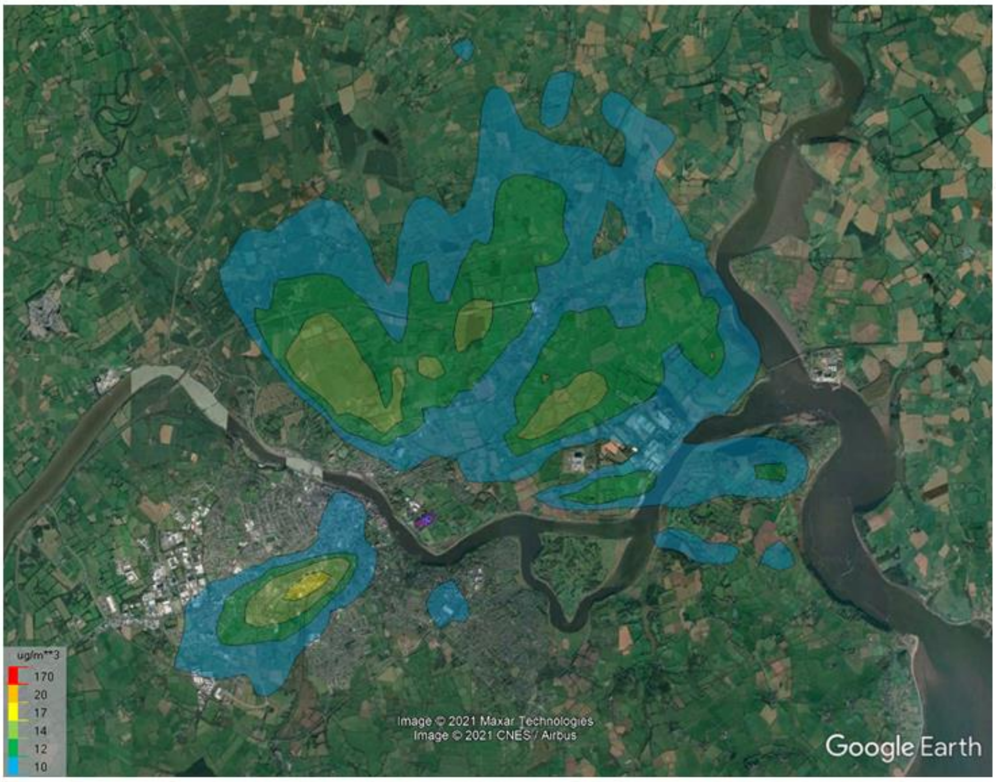
3.1 Air Emissions

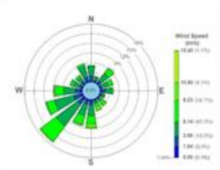
NO_2 Emissions

The NO_2 modelling results at the worst-case location at and beyond the site boundary are detailed in Table 6. The results indicate that the ambient ground level concentrations are in compliance with the relevant air quality standards for NO_2. For the worst-case year modelled, emissions from the site lead to an ambient NO_2 concentration (including background) which is 25% of the maximum ambient 1-hour limit value (measured as a 98.8th percentile) (as shown in Table 6 and Figure 5) and 40% of the annual limit value at the worst-case off-site receptor (as shown in Table 6 and Figure 6). Concentrations decrease with distance from the site boundary.

Pollutant / Year	Background Concentration (μg/m^3)	Averaging Period	Process Contribution NO_2 (μg/m^3)	Predicted Environmental Concentration NO_2 (μg/m^3)	Limit Value (μg/m^3) Note 1
NO_2 / 2016	24	98.8th%ile of 1-Hr Means	18.8	32.8	200
	12	Annual mean	0.78	12.78	40
NO_2 / 2017	24	98.8th%ile of 1-Hr Means	17.8	31.8	200
	12	Annual mean	0.92	12.92	40
NO_2 / 2018	24	98.8th%ile of 1-Hr Means	19.8	33.8	200
	12	Annual mean	0.73	12.73	40
NO_2 / 2019	24	98.8th%ile of 1-Hr Means	17.1	31.1	200
	12	Annual mean	0..81	12..81	40
NO_2 / 2020	24	98.8th%ile of 1-Hr Means	19.1	33.1	200
	12	Annual mean	0.81	12.81	40

Table 6 NO_2 Dispersion Model Results





Background Mapping from Google Earth

99.8th%ile of 1-Hour Mean NO_2 Concentrations Maximum Concentration = 19.8 µg/m^3 (not including background concentration)

Boundary Of Facility

Scale 1:150,000 N

Project Waterford Proteins Air Modelling Assessment

Reference 21/12180AR02

Figure 5

99.8th%ile of 1-Hour NO_2 Concentrations (µg/m^3) (Year 2018)

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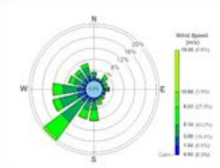

Background Mapping from Google Earth

Annual Mean NO_2 Concentrations Maximum Concentration = 0.92 µg/m^3 (not including background concentration)

Boundary Of Facility

Scale 1:100,000 N

Project Waterford Proteins Air Modelling Assessment

Reference 21/12180AR02

Figure 2

Annual Mean NO_2 Concentrations (µg/m^3) (Year 2017)

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

SO_2 Emissions

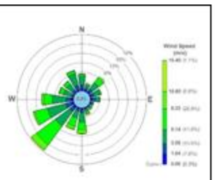
The SO_2 modelling results are detailed in Table 7. The results indicate that the ambient ground level concentration is below the relevant air quality standard for SO_2. Emissions from the facility lead to an ambient SO_2 concentration (including background) which is 19% of the maximum ambient 1-hour limit value (as a 99.7th%ile) at the worst-case receptor (see Table 7 and Figure 7). Emissions from the facility lead to an ambient SO_2 concentration (including background) which is 25% of the maximum ambient 24-hour limit value (as a 99.2th%ile) at the worst-case receptor (see Table 7 and Figure 8).

Pollutant / Year	Background ($\mu g/m^3$)	Averaging Period	Process Contribution ($\mu g/m^3$)	Predicted Environmental Concentration ($\mu g/Nm^3$)	Standard ($\mu g/Nm^3$) Note 1
SO_2 / 2016	50	Maximum 1-hr mean (as a 99.7th%ile) Note 2	48.2	58.2	350
	20	Maximum 24-hr mean (as a 99.2th%ile) Note 2	18.0	28.0	125
	5	Annual Mean	2.9	7.9	n/a
SO_2 / 2017	50	Maximum 1-hr mean (as a 99.7th%ile) Note 2	44.8	54.8	350
	20	Maximum 24-hr mean (as a 99.2th%ile) Note 2	13.4	23.4	125
	5	Annual Mean	3.5	8.5	n/a
SO_2 / 2018	50	Maximum 1-hr mean (as a 99.7th%ile) Note 2	47.7	57.7	350
	20	Maximum 24-hr mean (as a 99.2th%ile) Note 2	15.5	25.5	125
	5	Annual Mean	2.7	7.7	n/a
SO_2 / 2019	50	Maximum 1-hr mean (as a 99.7th%ile) Note 2	55.8	65.8	350
	20	Maximum 24-hr mean (as a 99.2th%ile) Note 2	17.7	27.7	125
	5	Annual Mean	2.9	7.9	n/a
SO_2 / 2020	50	Maximum 1-hr mean (as a 99.7th%ile) Note 2	56.2	66.2	350
	20	Maximum 24-hr mean (as a 99.2th%ile) Note 2	21.7	31.7	125
	5	Annual Mean	3.0	8.0	n/a

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

Note 2 Short-term Environmental Concentrations calculated according to EPA guidance[(1)] based on the maximum background 1-hr mean (as a 99.7th%ile) of 50 $\mu g/m^3$, the maximum background 24-hr mean (as a 99.2th%ile) of 20 $\mu g/m^3$ and an annual mean of 5 $\mu g/m^3$

Table 7 Dispersion Model Results – SO_2



Background Mapping from Google Earth

99.7th%ile of 1-Hour Mean SO_2 Concentrations Maximum Concentration = 56.2 $\mu g/m^3$ (not including background concentration)

Boundary Of Facility

Scale 1:120,000 N

Project
Waterford Proteins Air Modelling Assessment

Reference
21/12180AR02

Figure 7

99.7th%ile of 1-Hour SO_2 Concentrations ($\mu g/m^3$) (Year 2020)

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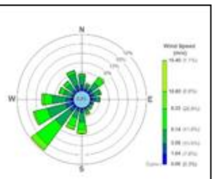

Background Mapping from Google Earth

99.2th%ile of 24-Hour Mean SO_2 Concentrations Maximum Concentration = 21.7 $\mu g/m^3$ (not including background concentration)

Boundary Of Facility

Scale 1:70,000 N

Project
Waterford Proteins Air Modelling Assessment

Reference
21/12180AR02

Figure 8

99.2nd%ile of 24-Hour SO_2 Concentrations ($\mu g/m^3$) (Year 2020)

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PM_{10} Emissions

The PM_{10} modelling results are detailed in Table 8. The results indicate that the ambient ground level concentration is below the relevant air quality standard for PM_{10}. Emissions from the facility lead to an ambient PM_{10} concentration (including background) which is 55% of the maximum ambient 24-hour limit value (as a 90.4^{th}%ile) at the worst-case receptor (see Table 8 and Figure 9). Emissions from the facility lead to an ambient PM_{10} concentration (including background) which is 38% of the annual mean limit value at the worst-case receptor (see Table 8).

Pollutant / Year	Background ($\mu g/m^3$)	Averaging Period	Process Contribution ($\mu g/m^3$)	Predicted Environmental Concentration ($\mu g/Nm^3$)	Standard ($\mu g/Nm^3$) Note 1
PM_{10} / 2016	27.0	Maximum 24-hr mean (as a 90^{th}%ile) Note 2	0.76	27.2	50
	15.0	Annual mean	0.21	15.21	40
PM_{10} / 2017	27.0	Maximum 24-hr mean (as a 90^{th}%ile) Note 2	0.89	27.3	50
	15.0	Annual mean	0.26	15.26	40
PM_{10} / 2018	27.0	Maximum 24-hr mean (as a 90^{th}%ile) Note 2	0.71	27.2	50
	15.0	Annual mean	0.20	15.20	40
PM_{10} / 2019	27.0	Maximum 24-hr mean (as a 90^{th}%ile) Note 2	0.76	27.2	50
	15.0	Annual mean	0.22	15.22	40
PM_{10} / 2020	27.0	Maximum 24-hr mean (as a 90^{th}%ile) Note 2	0.74	27.2	50
	15.0	Annual mean	0.23	15.23	40

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

Note 2 Short-term Environmental Concentrations calculated according to EPA guidance(1) based on the maximum background 24-hr mean (as a 90^{th}%ile) of 27 $\mu g/m^3$ based on Portlaoise in 2019

Table 8 Dispersion Model Results – PM_{10}

$PM_{2.5}$ Emissions

The $PM_{2.5}$ modelling results are detailed in Table 9. As a worst-case, it is assumed that $PM_{2.5}$ emissions comprise 100% of PM_{10} emissions, in reality this is not the case as particles greater than 2.5 microns will also be present and thus the mass of $PM_{2.5}$ released from the facility has been overestimated. For the worst-case year (2017), ambient concentrations will be 43% of the annual mean $PM_{2.5}$ limit value of 25 µg/m^3.

Pollutant / Year	Annual Mean Background (µg/m^3)	Averaging Period	Process Contribution (µg/m^3)	Predicted Environmental Concentration (µg/Nm^3)	Standard (µg/Nm^3)Note 1
$PM_{2.5}$ / 2016	10.5	Annual mean	0.21	10.71	25
$PM_{2.5}$ / 2017	10.5	Annual mean	0.26	10.76	25
$PM_{2.5}$ / 2018	10.5	Annual mean	0.20	10.70	25
$PM_{2.5}$ / 2019	10.5	Annual mean	0.22	10.72	25
$PM_{2.5}$ / 2020	10.5	Annual mean	0.23	10.73	25

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

Table 9 Dispersion Model Results – $PM_{2.5}$

TOC Emissions

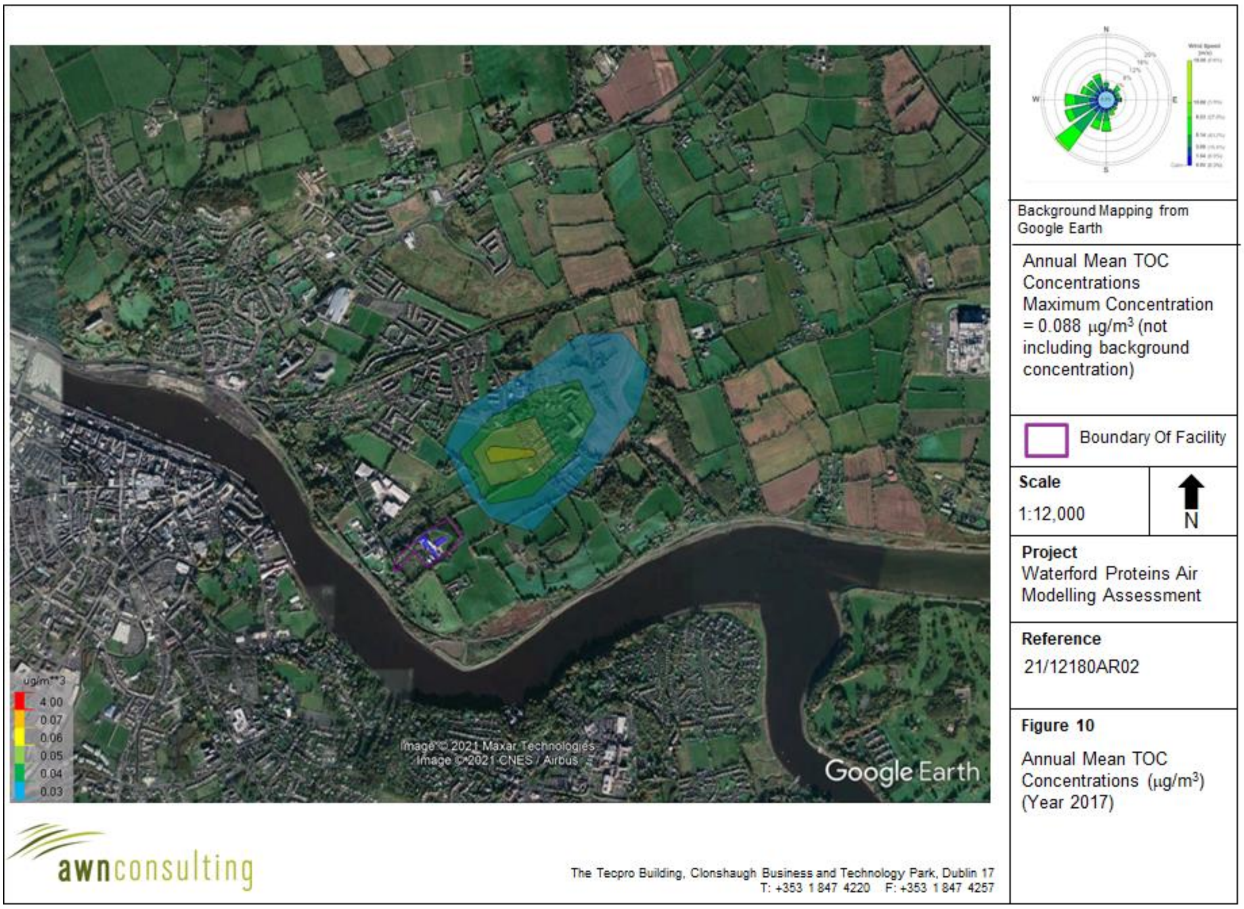
The TOC modelling results are detailed in Table 10. As a worst-case, it is assumed that TOC emissions comprise 100% of benzene emissions, in reality this is not the case as the emissions will consist of a range of organic compounds and thus the mass of benzene released from the facility has been overestimated. For the worst-case year (2017), ambient concentrations will be 11% of the annual mean benzene limit value of 5 μg/m^3 as shown in Figure 10.

Pollutant / Year	**Annual Mean Background (μg/m^3)$^{Note 1}$**	**Averaging Period**	**Process Contribution (μg/m^3)**	**Predicted Environmental Concentration (μg/Nm^3)**	**Standard (μg/Nm^3)$^{Note 2}$**
TOC / 2016	0.3	Annual mean	0.21	0.51	5
TOC / 2017	0.3	Annual mean	0.26	0.56	5
TOC / 2018	0.3	Annual mean	0.20	0.50	5
TOC / 2019	0.3	Annual mean	0.22	0.52	5
TOC / 2020	0.3	Annual mean	0.23	0.53	5

Note 1 Worst-case benzene level in Ireland in 2019

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

Table 10 Dispersion Model Results – Benzene



3.2 Assessment Summary

Modelling results indicate that the ambient ground level concentrations will be below the relevant air quality standards or guidelines for the protection of human health for all parameters under maximum operation of the facility. The modelling results indicate that the long-term maximum concentrations occur near the northern and north-eastern boundaries of the facility.

References

(1) EPA (2020) Air Dispersion Modelling from Industrial Installations Guidance Note (AG4)
(2) USEPA (2018) AERMOD Description of Model Formulation
(3) USEPA (1995) User's Guide for the Industrial Source Complex (ISC3) Dispersion Model Vol I & II
(4) USEPA (2017) Guidelines on Air Quality Models, Appendix W to Part 51, 40 CFR Ch.1
(5) USEPA (1999) Comparison of Regulatory Design Concentrations: AERMOD vs. ISCST3 vs. CTDM PLUS
(6) Schulman, L.L; Strimaitis, D.G.; Scire, J.S. (2000) Development and evaluation of the PRIME plume rise and building downwash model. Journal of the Air & Waste Management Association, 50, 378-390.
(7) Environmental Protection Agency (2020) Air Quality in Ireland 2019 (& earlier reports)
(8) EPA (2021) http://www.epa.ie/whatwedo/monitoring/air/
(9) Hanrahan, P (1999a) The Plume Volume Molar Ratio Method for Determining NO_2/NO_X Ratios in Modeling – Part 1: Methodology J. Air & Waste Management Assoc. 49 1324-1331
(10) Hanrahan, P (1999b).The Plume Volume Molar Ratio Method for Determining NO_2/NO_X Ratios in Modeling – Part 21: Evaluation Studies J. Air & Waste Management Assoc. 49 1332-1338
(11) USEPA (2019) AERMAP Users Guide
(12) USEPA (2019) User's Guide to the AERMOD Meteorological Preprocessor (AERMET)
(13) USEPA (2008) AERSURFACE User's Guide
(14) Alaska Department of Environmental Conservation (2008) ADEC Guidance re AERMET Geometric Means (http://dec.alaska.gov/air/ap/modeling.htm)
(15) USEPA (1985) Good Engineering Practice Stack Height (Technical Support Document For The Stack Height Regulations) (Revised)

APPENDIX I

Description of the AERMOD Model

The AERMOD dispersion model has been developed in part by the U.S. Environmental Protection Agency (USEPA)[2,4]. 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[5-6].

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[(2,4)]. 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[(2,4)]. 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 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.

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(12). 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 pre-processor 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).

Surface roughness

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 Meteorological Data – Johnstown Castle 2016 - 2020

Johnstown Castle 2016

Dir \ Spd	<= 1.54	<= 3.09	<= 5.14	<= 8.23	<= 10.80	> 10.80	Total
0.0	41	82	207	35	4	0	369
22.5	45	37	115	37	2	0	236
45.0	46	52	192	130	1	0	421
67.5	53	71	165	55	0	0	344
90.0	79	115	218	31	5	0	448
112.5	37	60	134	31	5	0	267
135.0	20	29	59	39	17	2	166
157.5	24	28	81	63	18	2	216
180.0	43	101	192	203	86	3	628
202.5	51	100	241	255	56	7	710
225.0	74	129	652	484	93	7	1439
247.5	58	187	588	208	32	6	1079
270.0	45	128	448	219	30	6	876
292.5	17	62	291	87	21	9	487
315.0	37	65	209	56	13	0	380
337.5	48	139	377	116	9	0	689
Total	718	1385	4169	2049	392	42	8755
Calms							29
Missing							0
Total							8784

Johnstown Castle 2017

Dir \ Spd	<= 1.54	<= 3.09	<= 5.14	<= 8.23	<= 10.80	> 10.80	Total
0.0	31	84	136	33	0	0	284
22.5	24	19	30	26	0	0	99
45.0	38	44	98	93	15	0	288
67.5	27	22	73	55	2	0	179
90.0	53	77	69	21	0	0	220
112.5	29	51	23	14	0	0	117
135.0	28	23	48	50	12	0	161
157.5	28	25	51	78	58	14	254
180.0	65	73	268	302	32	9	749
202.5	46	97	287	251	38	4	723
225.0	71	164	814	646	82	11	1788
247.5	58	231	591	215	20	0	1115
270.0	61	201	485	274	47	7	1075
292.5	39	86	280	148	26	5	584
315.0	41	116	251	96	9	0	513
337.5	59	127	281	118	3	0	588
Total	698	1440	3785	2420	344	50	8737
Calms							23
Missing							0
Total							8760

Johnstown Castle 2018

Dir \ Spd	<= 1.54	<= 3.09	<= 5.14	<= 8.23	<= 10.80	> 10.80	Total
0.0	42	128	255	29	0	0	454
22.5	24	37	92	20	0	0	173
45.0	44	64	260	150	22	0	540
67.5	26	36	189	100	35	0	386
90.0	55	97	176	43	0	0	371
112.5	38	36	66	18	0	0	158
135.0	29	25	72	112	35	23	296
157.5	31	28	71	92	87	25	334
180.0	62	101	284	218	87	30	782
202.5	48	103	317	236	34	7	745
225.0	65	164	730	508	30	5	1502
247.5	64	197	541	220	12	0	1034
270.0	73	130	308	216	45	7	779
292.5	31	67	172	79	6	2	357
315.0	30	69	127	67	4	0	297
337.5	40	116	306	60	1	0	523
Total	702	1398	3966	2168	398	99	8731
Calms							29
Missing							0
Total							8760

Johnstown Castle 2019

Dir \ Spd	<= 1.54	<= 3.09	<= 5.14	<= 8.23	<= 10.80	> 10.80	Total
0.0	47	100	183	51	2	0	383
22.5	31	26	48	19	2	0	126
45.0	48	52	132	74	0	0	306
67.5	46	48	110	24	0	0	228
90.0	86	100	131	45	0	0	362
112.5	47	34	65	65	5	0	216
135.0	40	34	109	66	34	2	285
157.5	23	39	110	117	27	6	322
180.0	52	93	240	213	38	2	638
202.5	41	61	270	315	29	9	725
225.0	77	172	634	534	58	9	1,484
247.5	69	191	564	223	18	1	1,066
270.0	51	139	433	281	85	16	1,005
292.5	41	56	231	129	22	5	484
315.0	37	79	210	45	15	2	388
337.5	42	121	428	106	4	1	702
Total	778	1,345	3,898	2,307	339	53	8,720
Calms							40
Missing							0
Total							8,760

Johnstown Castle 2020

Dir \ Spd	<= 1.54	<= 3.09	<= 5.14	<= 8.23	<= 10.80	> 10.80	Total
0.0	53	119	231	57	11	0	471
22.5	38	50	91	43	3	0	225
45.0	43	89	224	158	42	0	556
67.5	39	83	172	33	3	0	330
90.0	49	105	99	19	0	0	272
112.5	26	37	48	1	0	0	112
135.0	17	20	52	40	3	0	132
157.5	29	27	67	45	36	13	217
180.0	46	90	268	216	90	20	730
202.5	43	58	206	235	86	16	644
225.0	68	127	503	653	171	26	1,548
247.5	61	179	527	360	47	4	1,178
270.0	68	140	386	235	55	7	891
292.5	26	47	236	101	21	6	437
315.0	41	65	202	87	16	2	413
337.5	40	135	340	76	14	0	605
Total	687	1,371	3,652	2,359	598	94	8,761
Calms							23
Missing							0
Total							8,784