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ATTACHMENT 7-1-3-2 AIR EMISSIONS IMPACT ASSESSMENT - TAKEDA IRELAND FACILITY, GRANGE CASTLE BUSINESS PARK, DUBLIN

Technical Report Prepared For

Takeda Ireland Ltd
Grange Castle Business Park,
Nangor Road, Dublin

Technical Report Prepared By

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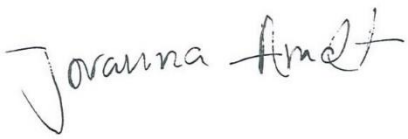
Signature		
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EXECUTIVE SUMMARY

AWN Consulting Ltd were commissioned to carry out an air dispersion modelling study of emissions from the Takeda Ireland facility in Grange Castle Business Park, Dublin 22 based on the current design details. The modelling assessment will form part of the IE Licence Review process which will be required due, in part, to the installation of a new emission point on-site (a new thermal oxidiser, EP-P1-04).

Air dispersion modelling was carried out using the United States Environmental Protection Agency's regulatory model AERMOD (Version 21112). The aim of the study was to assess the contribution of the new emission point and all existing emission points from the facility to off-site levels of release substances and to identify the location and maximum of the worst-case ground level concentrations of the VOCs of concern. The dispersion model study consisted of the following components:

- Review of new and existing emission data and other relevant information needed for the modelling study;
- Summary of background for the pollutants of concern (NO_2 / NO_X and VOCs levels);
- Dispersion modelling of released substances under a worst-case emission scenario;
- 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

For normal operational modelling scenarios, it has been assumed that all emission points are continually in operation for the full year as a worst-case.

With regard to NO_2, the scenarios modelled will lead to ambient NO_2 concentrations (including background) which are in compliance with the relevant limit values, reaching at most 50% of the 1-hour limit value (measured as a 99.8th%ile) and 28% of the annual limit value at the worst-case receptor.

The results indicate that the ambient ground level concentrations are below the relevant air quality guidelines for individual VOCs even when it is assumed that each emission point is emitting solely the VOC of concern at the IED emission limit for the full year. Under normal operations, emissions from the RTOs and other VOC emission points onsite lead to ambient individual VOC concentrations which are no more than 11% of the maximum 1-hour limit value at the worst-case receptor and no more than 17% of the annual mean limit value at the worst-case off-site location.

In relation to odour, all ambient concentrations are below the odour nuisance thresholds for each individual VOC under normal operating conditions.

In summary, all emissions from the facility under normal operations of the facility will be in compliance with the ambient air quality standards.

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1.0 INTRODUCTION

AWN Consulting Ltd were commissioned to carry out an air dispersion modelling study of emissions from the Takeda Ireland facility in Grange Castle Business Park, Dublin 22 based on the current design details. The modelling assessment will form part of the IE Licence Review process which will be required due, in part, to the installation of a new emission point on-site (a new thermal oxidiser, EP-P1-04). The current Industrial Emission Directive (IED) Licence for the facility is P0693-02.

The site, is located in Grange Castle Business Park which is approximately 12 km from Dublin city centre. Most of the land surrounding the site is occupied by industrial campuses including pharmaceutical, data centre and food manufacturing uses (see Figure 1). The Microsoft data centre campuses are located to the south of the site and the Pfizer site is located further to the east. In terms of sensitive residential receptors, one-off dwellings are located to the west with a number of large residential estates located to the north and east.

Air dispersion modelling has thus been undertaken both based on normal operations of EP-P1-03, EP-UT-01 and proposed emission point EP-P1-04 and based on bypass operations of EP-P1-02. In line with EPA publication "Agency Protocol for the Bypass of Air Emissions Abatement Equipment"(1), the environmental significance of any emission needs to be determined on a case-by-case basis for each bypass event and should be determined with consideration of the following:

a. *"Concentration or mass coupled with duration of bypass,*
b. *Maximum worst case emission on a kg/hr basis compared with relevant emission limit values and/or mass emission thresholds (e.g. TA Luft),*
c. *Results of air and/or odour dispersion modelling to assess impact,*
d. *Odour impacts and/or complaints,*
e. *Geographical location including sensitive receptors*". 1)

The purpose of this modelling study is to determine whether the emissions from the site will lead to ambient concentrations which are in compliance with the relevant ambient air quality standards for NO_2 and VOCs and to identify the location and maximum of the worst-case ground level concentrations for each compound assessed. In relation to emissions from the combustion sources onsite, CO emissions are likely to be negligible relative to the ambient air quality standard (i.e. the CO emission level is likely to be of a similar magnitude to NO_X emissions whilst the CO ambient air quality standard is 10,000 $\mu g/m^3$ compared to the NO_2 limit of 200 $\mu g/m^3$) and thus CO emissions have been screened out of the current assessment.

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

- Review of emission data and other relevant information needed for the modelling study;
- Summary of background NO_2 and VOCs levels;
- Dispersion modelling of NO_2 and VOCs under the maximum emission scenario;
- Dispersion modelling of VOCs (and associated odour) under the worst-case bypass scenarios;
- 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.

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.

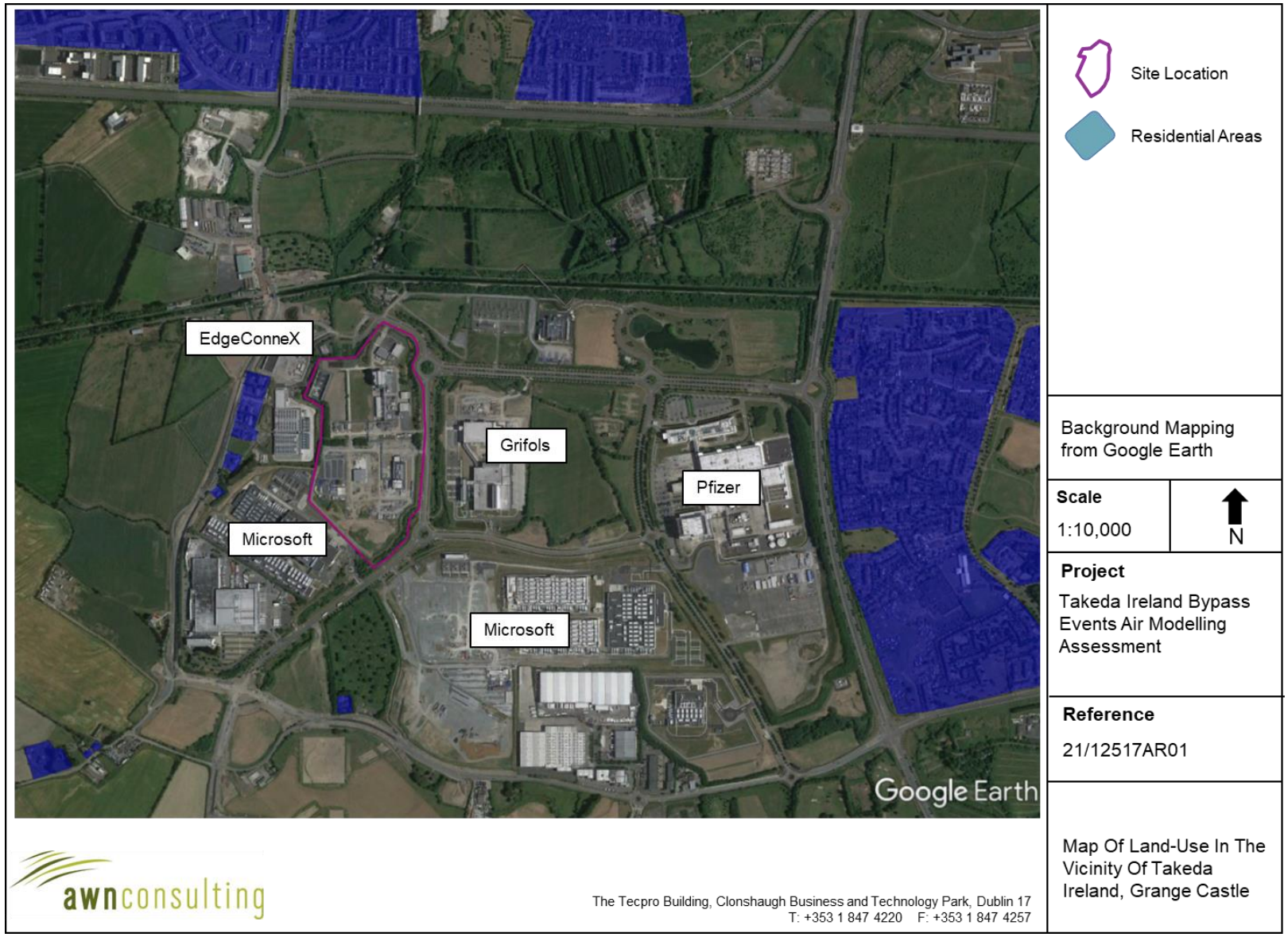

Figure 1 Map of land use in the vicinity of Takeda, Grangecastle

2.0 ASSESSMENT METHODOLOGY

Emissions from the facility have been modelled using the AERMOD dispersion model (Version 21112) which has been developed by the U.S. Environmental Protection Agency (USEPA)[2] and following guidance issued by the EPA[3]. The model is a steady-state Gaussian plume model used to assess pollutant concentrations associated with industrial sources and has replaced ISCST3[4] as the regulatory model by the USEPA for modelling emissions from industrial sources in both flat and rolling terrain[5-7]. The model has more advanced algorithms and gives better agreement with monitoring data in extensive validation studies[8-12]. 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. 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 were reported in this study, even if no residential receptors were near the location of this maximum;
- Worst-case background concentrations were used to assess the baseline levels of substances released from the site;
- The effects of building downwash, due to on-site and any nearby off-site buildings, has been included in the model;
- Worst-case operations for NO_2 and VOCs emissions assumes all emission points were running continuously for a full year;
- Modelling assumed that all emission points were running continuously at the IED emission concentration and maximum volume flow for every hour of the year;
- Under the bypass scenario, emissions of VOCs were assumed to be occurring from EP-P1-02 for a worst-case period of 4 hours for every day of the year.

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 standards in Ireland include the Air Quality Standards Regulations 2011, which incorporate EU Directive 2008/50/EC (see

Table **1**). The ambient air quality standards applicable for NO_2 are outlined in this Directive.

These standards have been used in the current assessment to determine the potential impact of NO_2 emissions from the proposed facility on air quality.

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

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
		Annual limit for protection of vegetation	30 µg/m^3 NO + NO_2

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

Emissions of Volatile Organic Compounds from Organic Solvent Regulations (2002) (SI No. 543 of 2002) and subsequently the Industrial Emission Directive (2010/75/EU) outlines appropriate mass emission limits of volatile organic compounds from a range of industries. However, no statutory air quality standards for the individual organic compounds exist in Irish legislation. In the absence of statutory standards, it is common practice to reference other suitable authorities such as the World Health Organisation (WHO) or derive an ambient air quality guideline from occupational exposure limits (OEL).

In line with the approach outlined in AG4[3], where no EU air quality standard exists, relevant statutory standards from other EU countries such as the UK, Germany or Denmark should be used. The most stringent European guideline / limit value from the sources outlined below should be referenced when determining compliance in the absence of an applicable EU ambient air quality standard. The relevant statutory guidance can be obtained from the following sources:

- Environmental Assessment Level (EAL) based on the Health & Safety Authority publication 2007 Code of Practice for the Safety, Health and Welfare at Work (Chemical Agents) Regulations 2001 (S.I. No. 619 of 2001). The EAL should be derived using the approach outlined in Appendix D of UK Environment Agency "IPPC H1 - IPPC Environmental Assessment for BAT"[13]. The guidance outlines the approach for deriving both short-term and long-term EALs. In relation to the long-term (annual) EAL, this can be derived by applying a factor of 100 to the 8-hour Occupational Exposure Level (OEL). The factor of 100 allows for both the greater period of exposure and the greater sensitivity of the general population. For short-term (1-hour) exposure, the EAL is derived by applying a factor of 10 to the short term exposure limit (STEL). In this case, only the sensitivity of the general population need be taken into account as there is no need for additional safety factors in terms of the period of exposure. Where STELs are not listed then a value of 3 times the 8-hour time weighted average occupational exposure limit may be used[13].

- EALs outlined at the UK DEFRA website https://www.gov.uk/guidance/air-emissions-risk-assessment-for-your-environmental-permit[13]

Table **2** identifies the appropriate short-term and long-term EALs, derived from the most stringent sources above, for the specific compounds which are likely to be used on-site.

Table 2 VOC Guideline Values Derived From OEL For Compounds Used Onsite

Pollutant	Regulation	Limit Type	Annual Mean Value	1-Hour Value
1-Ethyl-3-(3-dimethylaminopropyl)carbodiimide	-	-	-	-
2-butanol	2021 Code of Practice EAL	Guideline Value	30,000	4,500
Acetic acid	IPPC H1 EAL	Guideline Value	250	3,700
Acetic anhydride	IPPC H1 EAL	Guideline Value	1	40
Acetone	IPPC H1 EAL	Guideline Value	18,100	362,000
Acetonitrile	IPPC H1 EAL	Guideline Value	680	10,200
Acetyl chloride	-	-	-	-
Chlorobenzene	IPPC H1 EAL	Guideline Value	2,340	70,200
Cyclopentyl methyl ether	-	-	-	-
Dichloromethane	IPPC H1 EAL	Guideline Value	700	3,000
Difluorophenylboronic acid	-	-	-	-
Diisopropylamine	IPPC H1 EAL	Guideline Value	210	6,300
Dimethyl phosphonate	-	-	-	-
Mimethyl sulfoxide (DMSO)	-	-	-	-
Dimethylacetamide (DMAC)	IPPC H1 EAL	Guideline Value	360	7,200
Dimethylformamide (DMF)	IPPC H1 EAL	Guideline Value	300	6,100
Ethane	-	-	-	-
Ethanol	IPPC H1 EAL	Guideline Value	19,200	576,000
Ethyl acetate	IPPC H1 EAL	Guideline Value	14,600	420,000
Ethyl sulfonyl chloride	-	-	-	-
Ethylene	-	-	-	-
Formaldehyde	IPPC H1 EAL	Guideline Value	5	100
Hexane	IPPC H1 EAL	Guideline Value	720	21,600
Isopropanol	IPPC H1 EAL	Guideline Value	9,990	125,000
Isopropyl acetate	IPPC H1 EAL	Guideline Value	-	84,900
Methane	-	-	-	-
Methanol	IPPC H1 EAL	Guideline Value	2,660	33,300
Methyl tert-butyl ether	2021 Code of Practice EAL	Guideline Value	18,350	3,670

Pollutant	Regulation	Limit Type	Annual Mean Value	1-Hour Value
Methylamine	IPPC H1 EAL	Guideline Value	130	3,900
Methylcyclohexane	2021 Code of Practice EAL	Guideline Value	4,800	160,000
N,N-Diisopropylethylamine (DIPEA)	-	-	-	-
N-Acetyl-L-Cysteine	-	-	-	-
N-Heptane	Derived from OEL	Guideline Value	20,850	62,550
N-Methyl-2-pyrrolidone	IPPC H1 EAL	Guideline Value	1,030	30,900
N-Methylimidazole	-	-	-	-
Palladium triphenylphosphine	-	-	-	-
Propane	-	-	-	-
Propionyl chloride	-	-	-	-
Pyridine 4-boronic acid	-	-	-	-
Pyridine-3-sulfonyl chloride (PSC)	-	-	-	-
Pyrrolidine	-	-	-	-
THF	IPPC H1 EAL	Guideline Value	3,000	59,900
Toluene	IPPC H1 EAL	Guideline Value	19,190	8,000
Triethylamine	IPPC H1 EAL	Guideline Value	420	6,300
Triphenylphosphine	-	-	-	-

In line with EPA publication "*Agency Protocol for the Bypass of Air Emissions Abatement Equipment*" (EPA, 2008)(1), the environmental significance of odorous compounds needs to be assessment for each bypass event.

The EPA publication "*Air Dispersion Modelling from Industrial Installations Guidance Note (AG4* "(3) has outlined a range of odour criteria relating to emissions from industrial facilities from 1.5 OU_E/m^3 (most offensive) – 6.0 OU_E/m^3 (least offensive) as a 98th%ile of hourly averages. Given that emissions are mainly solvent based, and similar to paint-spraying operations, a mediumly offensive odour of criteria of 3.0 OU_E/m^3 as a 98th%ile of hourly averages would be appropriate. The odour detection threshold criteria associated with the solvents used onsite is outlined in **Table 3**. In order to compare to the odour criteria, a value of three times the odour detection threshold, which by definition is 1.0 OU_E/m^3, should be used.

Table 3 Odour Detection Thresholds & Nuisance Criteria For Compounds Used Onsite

Pollutant	Source	Odour Detection Threshold	Odour Concentration Equivalent To 3.0 OU_E/m^3
1-Ethyl-3-(3-dimethylaminopropyl)carbodiimide	-	-	-
2-butanol	IPPC H4 Threshold	3,000	9,000
Acetic acid	IPPC H4 Threshold	43	129

Pollutant	Source	Odour Detection Threshold	Odour Concentration Equivalent To 3.0 OU_E/m^3
Acetic anhydride	IPPC H4 Threshold	1.3	4
Acetone	IPPC H4 Threshold	13,900	41,700
Acetonitrile	USEPA Hazard Summary	282,000	846,000
Acetyl chloride	-	-	-
Chlorobenzene	USEPA Hazard Summary	1,000	3,000
Cyclopentyl methyl ether	-	-	-
Dichloromethane	IPPC H4 Threshold	3,420	10,260
Difluorophenylboronic acid	-	-	-
Diisopropylamine	National Institutes for Health PubChem	52	157
Dimethyl phosphonate	-	-	-
Mimethyl sulfoxide (DMSO)	-	-	-
Dimethylacetamide (DMAC)	AEA Technology	39,700	119,100
Dimethylformamide (DMF)	USEPA Hazard Summary	6,380	19,140
Ethane	-	-	-
Ethanol	IPPC H4 Threshold	280	840
Ethyl acetate	IPPC H4 Threshold	2,410	7,230
Ethyl sulfonyl chloride	-	-	-
Ethylene	-	-	-
Formaldehyde	USEPA Hazard Summary	1,021	3,063
Hexane	USEPA Hazard Summary	458,900	1,376,700
Isopropanol	Haz-Map	3,563	10,690
Isopropyl acetate	Haz-Map	1,495	4,484
Methane	-	-	-
Methanol	AEA Technology	4,000	12,000
Methyl tert-butyl ether	Haz-Map	180	541
Methylamine	Haz-Map	5	14
Methylcyclohexane	Haz-Map	573,620	1,720,859
N,N-Diisopropylethylamine (DIPEA)	-	-	-
N-Acetyl-L-Cysteine	-	-	-
N-Heptane	Haz-Map	49,130	147,391
N-Methyl-2-pyrrolidone	Haz-Map	162,176	486,528
N-Methylimidazole	-	-	-
Palladium triphenylphosphine	-	-	-
Propane	-	-	-
Propionyl chloride	-	-	-
Pyridine 4-boronic acid	-	-	-
Pyridine-3-sulfonyl chloride (PSC)	-	-	-
Pyrrolidine	-	-	-

Pollutant	Source	Odour Detection Threshold	Odour Concentration Equivalent To 3.0 OU_E/m^3
THF	Haz-Map	221	664
Toluene	IPPC H4 Threshold	644	1,932
Triethylamine	IPPC H4 Threshold	3	8
Triphenylphosphine	-	-	-

2.2 Background Concentrations Of Pollutants

Air quality monitoring programs have been undertaken in recent years by the EPA and Local Authorities[15,16]. The most recent annual report on air quality "Air Quality Monitoring Annual Report 2019"[15], 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[15]. 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, Grangecastle is categorised as Zone A[15].

NO_2

With regard to NO_2, continuous monitoring data from the EPA [13]. at suburban Zone A background locations in Rathmines, Dun Laoghaire, Swords and Ballyfermot show that current levels of NO_2 are below both the annual and 1-hour limit values, with annual average levels ranging from 13 - 22 µg/m^3 over the period 2015 - 2019 (see **Table 4**). Sufficient data is available for the station in Swords to observe long-term trends since 2015, with annual average results ranging from 13 – 16 µg/m^3, and an average of 14.8 µg/m^3. Based on these results, an estimate of the current background NO_2 concentration in the region of the facility is 15 µg/m^{3}m^3.

Table 4 Annual Mean NO_2 Background Concentrations in Zone A Locations 2015 – 2019 (µg/m^3)

Station	Averaging Period (Note 1)	Year				
		2015	2016	2017	2018	2019
Ballyfermot	Annual Mean NO_2 (µg/m^3)	16	17	17	17	20
	99.8th%ile 1-hr NO_2 (µg/m^3)	127	90	112	101	101
Dun Laoghaire	Annual Mean NO_2 (µg/m^3)	16	19	17	19	15
	99.8th%ile 1-hr NO_2 (µg/m^3)	91	105	101	91	91
Rathmines	Annual Mean NO_2 (µg/m^3)	18	20	17	20	22
	99.8th%ile 1-hr NO_2 (µg/m^3)	105	88	86	87	102
Swords	Annual Mean NO_2 (µg/m^3)	13	16	14	16	15
	99.8th%ile 1-hr NO_2 (µg/m^3)	93	96	79	85	80

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 [14,15]. 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[16,17]. 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 54 µg/m^3 based on the air monitoring stations in Zone A locations over the period 2015 – 2019[13].

In relation to the annual averages, the ambient background concentration was added directly to the process concentration with the short-term peaks calculated using the twice the annual mean concentration as an hourly background in line with guidance from the UK DEFRA[18].

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:

- Two 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 9000 m^2 with the site at the centre and with concentrations calculated at 300 m intervals. A smaller denser grid extended to 2500 m^2 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 3,681 calculation points for the model as shown in **Figure 2**. 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 90m resolution. The site is located in gentle terrain. All terrain features have been mapped in detail into the model using the terrain pre-processor AERMAP[18] ;

- Hourly-sequenced meteorological information has been used in the model covering the years 2017 – 2021 from the Met Éireann meteorological station at Casement Aerodrome (www.met.ie) flux (see Figure 4). AERMOD incorporates a meteorological pre-processor AERMET which allows AERMOD to account for changes in the plume behaviour with height using information on the surface characteristics of the site. AERMET calculates hourly boundary layer parameters for use by AERMOD, including friction velocity, Monin-Obukhov

length, convective velocity scale, temperature scale, convective boundary layer (CBL) height, stable boundary layer (SBL) height, and surface heat; and

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

2.4 Terrain

The AERMOD air dispersion model has a terrain pre-processor AERMAP[18] 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 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, 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”[2].

The terrain in the region of the facility is complex in the sense that the maximum terrain in the modelling domain peaks at 160m which is above the stack top of all emission points on site (see **Figure 3**).

2.5 Meteorological Data

The selection of the appropriate meteorological data has followed the guidance issued by the USEPA[5]. A primary requirement is that the data used should have a data capture of greater than 90% for all parameters. Casement Aerodrome meteorological station, which is located approximately 1.6 km south-east of the site, collects data in the correct format and has a data collection of greater than 90%. Long-term hourly observations at Casement Aerodrome meteorological station provide an indication of the prevailing wind conditions for the region (see Figure 4). Results indicate that the prevailing wind direction is from south to north-westerly in direction over the period 2017 - 2021. The mean wind speed is approximately 5.5 m/s over the period 1981-2010. Calm conditions account for only a small fraction of the time in any one year peaking at 70 hours in 2018 (0.8% of the time.

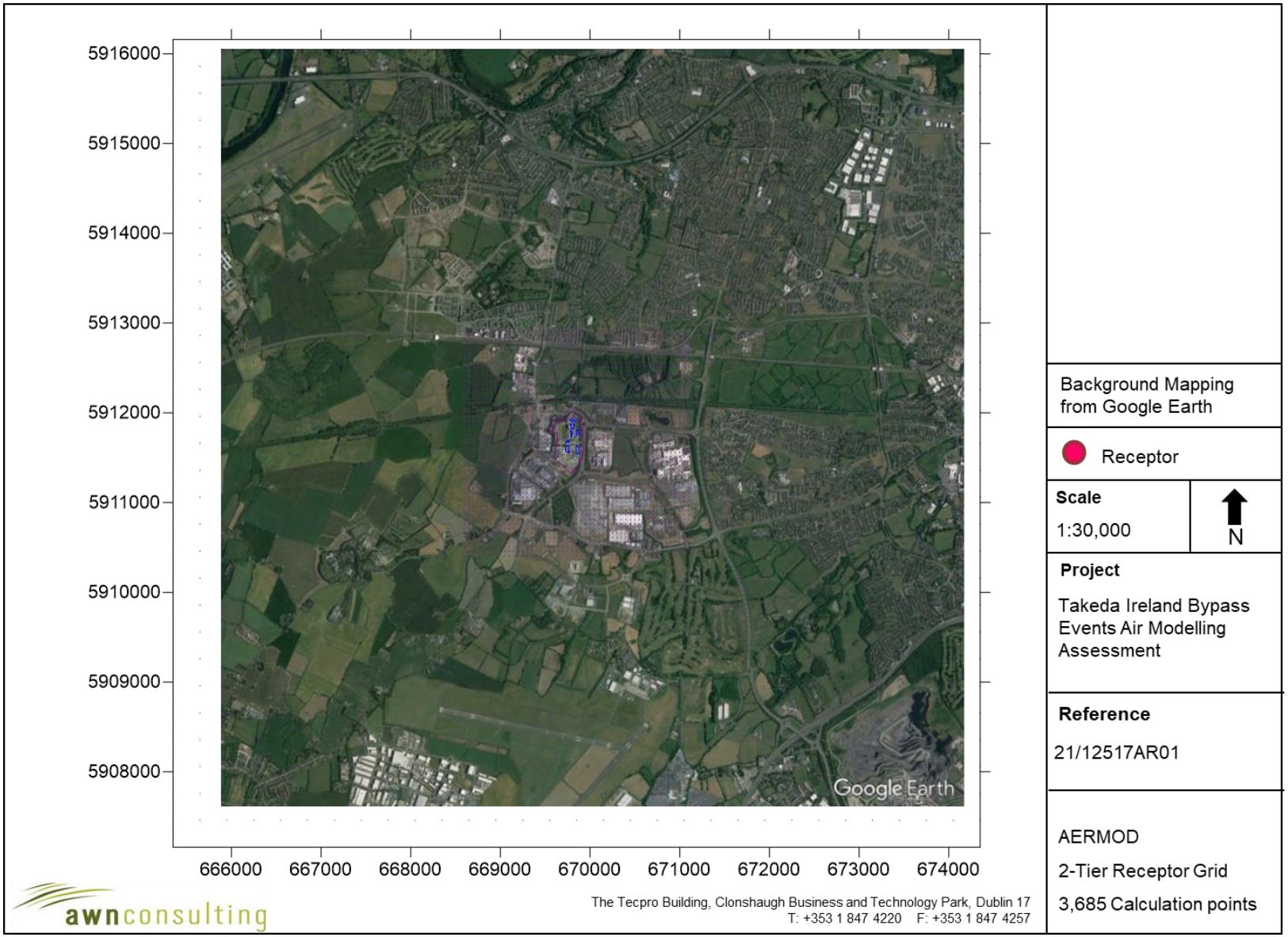

Figure 2 Modelled Grid Receptors for Takeda, Grangecastle

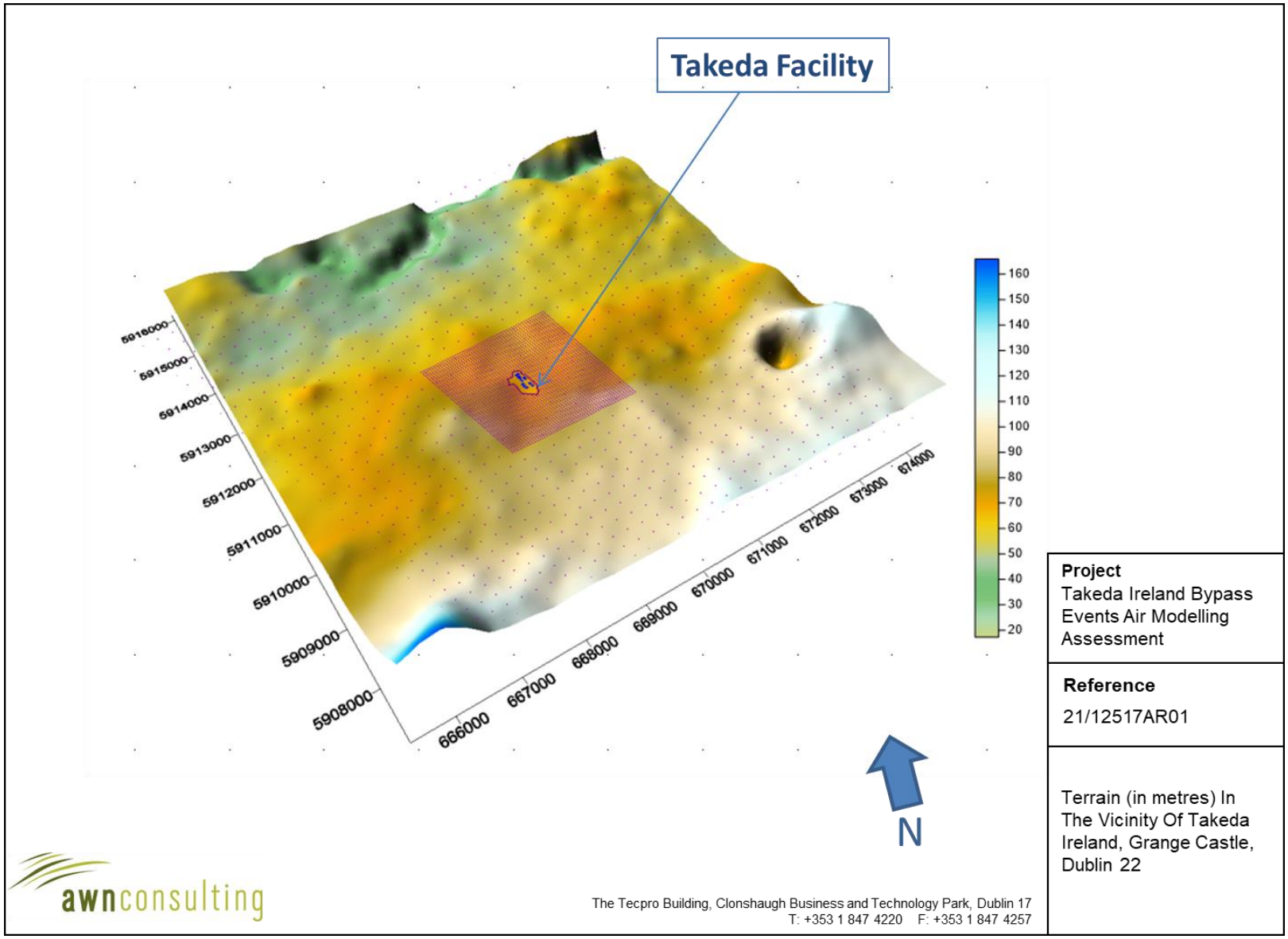

Figure 3 Terrain in the vicinity of Takeda, Grangecastle

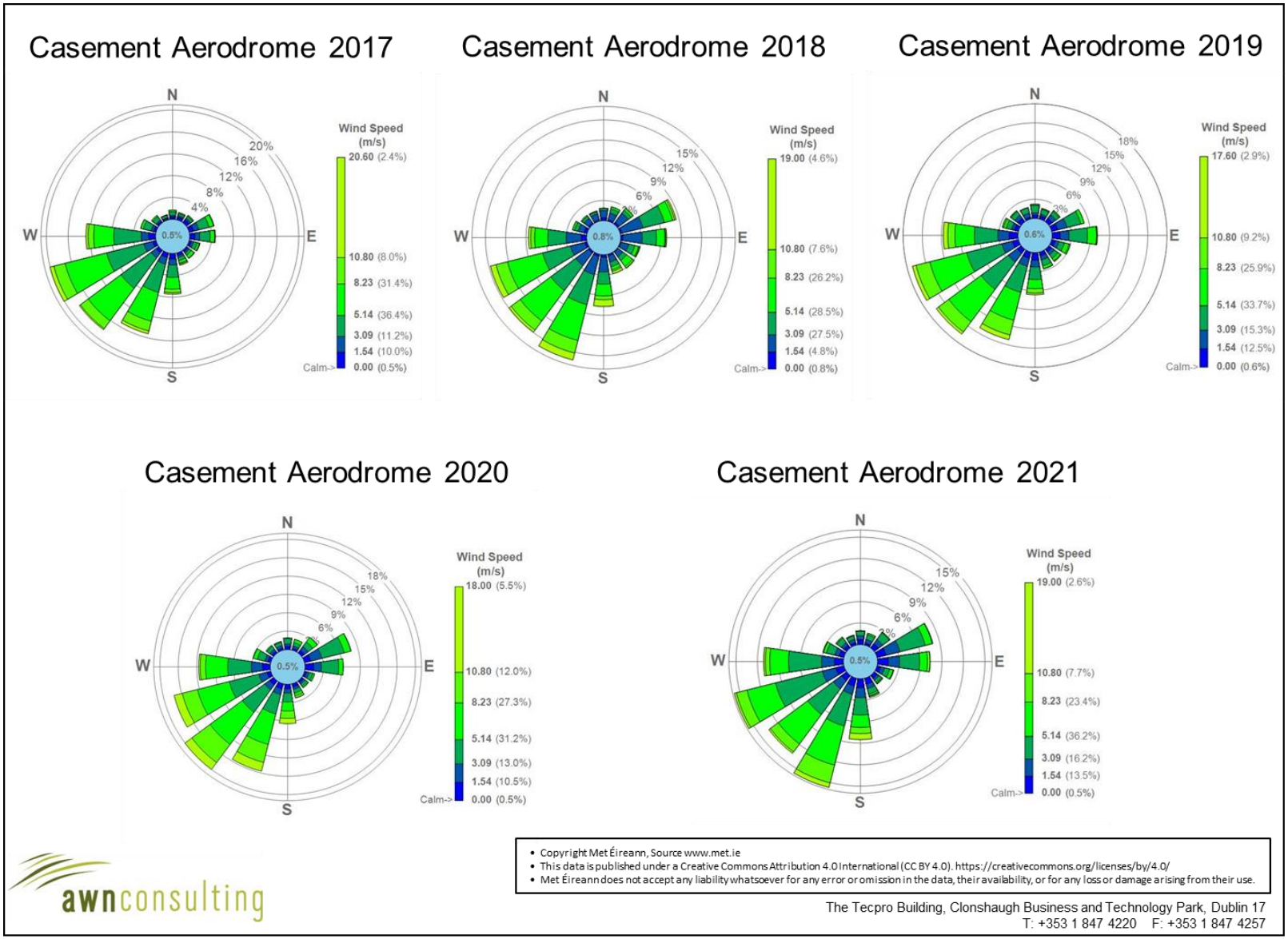

Figure 4 Casement Aerodrome Windrose (2017 – 2021)

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 PRO[19] to enable the calculation of the appropriate parameters. The AERMET PRO 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[19,20] as outlined in Appendix II.

In relation to AERMOD, detailed guidance for calculating the relevant surface parameters has been published[21]. The most pertinent features are:

- The surface characteristics should be those of the meteorological site (Cork Airport) 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[20], 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[21]. 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[22].

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 most stacks onsite are 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 may change as the wind direction changes for each of the 36 wind directions. The dominant building for each relevant stack will vary as a function of wind direction and relative building heights.

2.8 Process Emissions

Takeda are currently licensed (IED Licence number P0693-02) to operate three major emission points:

- EP-P1-02 Carbon adsorption system with steam regeneration (existing VOC abatement system)
- EP-P1-03 Carbon absorption system (hydrogenator)
- EP-UT-01 Boiler

As part of the Proposed Development, one new emission point will become operational. A new TO, EP-P1-04, will be installed. The information used in the dispersion model for the existing and proposed emission point which release either NOX and VOCs is shown in Tables 9.8 – 9.10.

All VOCs to be released have been modelled at the emission limit value of 20 mg/m3 for Organic Substances Class I given in the EPA *publication "BAT Guidance Note on Best Available Techniques for the Manufacture of Organic Chemicals"[24]*)and in line with the current IE licence. This is the maximum VOC emission concentration expected. The carbon fractions listed in Table 9.10 were then applied to the modelled ambient VOC concentrations in turn for each emitted VOC. It is assumed that where more than one compound is being emitted from any emission point, as a worst-case assumption, the Total VOC (as C) consists of only one compound (in turn) with each compound compared to the 1-hour Environment Assessment Level and annual Environment Assessment Level.

Table 5 Emission Point Characteristics Used In The Air Modelling

Stack Reference	Stack Location (UTM)	Height Above Ground Level (m)	Exit Diameter (m)	Cross-Sectional Area (m^2)	Temperature (K)	Max Volume Flow (Nm^3/hr)	Exit Velocity (m/sec actual)
EP-P1-02 (existing VOC abatement system)	669818 E, 5911738 N	11	0.1	0.08	303.15	500	17.68
EP-P1-03 (hydrogenator)	669800 E, 5911826 N	37.4	0.05	0.02	323.15	90	12.73
EP-P1-04 (proposed TO)	669666 E, 5911759 N	12	0.25	0.049	523.15	1,160	6.65
EP-UT-01 (boiler)	669799 E, 5911748 N	15	0.55	0.238	453.15	10,368	12.12

Table 6 Process Emissions Used In The Air Modelling

Stack Reference	NO_2 Concentration (mg/Nm^3)	NO_2 Mass Emission (g/s)	VOC (Class I) Concentration (mg/Nm^3) Note 1	VOC (Class I) Mass Emission (g/s) Note 1	VOC (H360D) Concentration (mg/Nm^3) Note 1,2	VOC (H360D) Mass Emission (g/s) Note 1
EP-P1-02 (existing VOC abatement system)	n/a	n/a	20	0.0025	2	0.00025
EP-P1-03 (hydro-genator)	n/a	n/a	20	0.0004	n/a	n/a
EP-P1-04 (proposed TO)	100	0.0168	20	0.0034	2	0.00034
EP-UT-01 (boiler)	150	0.2604	n/a	n/a	n/a	n/a

Note 1 Applies to both normal and bypass operations

Note 2 H360D (includes N-methyl-2-pyrrolidone and dimethylacetamide) as referred to in Article 58 (Substances or mixtures which, because of their content of volatile organic compounds classified as carcinogens, mutagens, or toxic to reproduction under Regulation (EC) No. 1272/2008, are assigned or need to carry the hazard statements H340, H350,H350i, H360D or H360F) of the Industrial Emissions Directive.

Table 7 Emissions Details for VOCs Used In The Air Modelling

Compound	Carbon Weight	Molecular Weight	Carbon Fraction
1-Ethyl-3-(3-dimethylaminopropyl)carbodiimide	96.08	155.24	0.619
2-butanol	48.04	74.12	0.648
Acetic acid	24.02	60.05	0.400
Acetic anhydride	48.04	102.09	0.471
Acetone	36.03	58.08	0.620
Acetonitrile	24.02	41.05	0.585

Compound	Carbon Weight	Molecular Weight	Carbon Fraction
Acetyl chloride	24.02	78.49	0.306
Chlorobenzene	72.06	112.56	0.640
Cyclopentyl methyl ether	72.06	100.16	0.719
Dichloromethane	12.01	84.93	0.141
Difluorophenylboronic acid	72.06	157.91	0.456
Diisopropylamine	72.06	101.19	0.712
Dimethyl phosphonate	24.02	111.06	0.216
Mimethyl sulfoxide (DMSO)	24.02	78.13	0.307
Dimethylacetamide (DMAC)	48.04	87.12	0.551
Dimethylformamide (DMF)	36.03	73.09	0.493
Ethane	24.02	30.07	0.799
Ethanol	24.02	46.07	0.521
Ethyl acetate	48.04	88.11	0.545
Ethyl sulfonyl chloride	24.02	128.58	0.187
Ethylene	24.02	28.05	0.856
Formaldehyde	12.01	30.03	0.400
Hexane	72.06	86.18	0.836
Isopropanol	36.03	60.10	0.600
Isopropyl acetate	60.05	102.10	0.588
Methane	12.01	16.04	0.749
Methanol	12.01	32.04	0.375
Methyl tert-butyl ether	60.05	88.15	0.681
Methylamine	12.01	31.05	0.387
Methylcyclohexane	84.07	98.19	0.856
N,N-Diisopropylethylamine (DIPEA)	96.08	129.05	0.745
N-Acetyl-L-Cysteine	60.05	163.19	0.368
N-Heptane	84.07	100.21	0.839
N-Methyl-2-pyrrolidone	120.10	99.13	1.212
N-Methylimidazole	48.04	82.10	0.585
Palladium triphenylphosphine	864.72	1155.56	0.748
Propane	36.03	44.10	0.817
Propionyl chloride	36.03	92.52	0.389
Pyridine 4-boronic acid	60.05	122.92	0.489
Pyridine-3-sulfonyl chloride (PSC)	60.05	177.61	0.338
Pyrrolidine	48.04	71.12	0.675
THF	48.04	72.11	0.666
Toluene	84.07	92.14	0.912
Triethylamine	24.02	101.19	0.237
Triphenylphosphine	216.18	262.29	0.824

The modelling was undertaken to assess the impact to ambient air quality from the following operations scenarios.

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Process Contributions Under Proposed Normal Operations

This is based on the normal operations of EP-P1-03, EP-UT-01 and proposed emission point EP-P1-04. All emission points were assumed to operate 24 hours per day, 7 days per week as a worst-case scenario.

Bypass Operations for Process TO

This is based on the bypass operation of the new TO, EP-P1-04. In the event of a system shutdown due to a Critical System Alarm or if Shutdown mode is activated, process emissions from EP-P1-04 will be routed to the existing VOC abatement system, EP-P1-02.

The bypass scenario has been modelled based on the following assumptions:

- It is assumed that bypass events are 4 hours in duration for every day of the year as a worst-case;
- EP-P1-02 is compliant with its licence limit values for VOCs (a test of the bypass function in September 2021 confirmed this, report reference FC/21/13112_WR02); and
- It is assumed that where more than one compound is being emitted from any emission point, as a worst-case assumption, the Total VOC (as C) consists of only one compound (in turn) with each compound compared to the 1-hour Environment Assessment Level.

3.0 RESULTS & DISCUSSION

3.1 Process Contributions Under Normal Operations

Ambient Ground Level Concentrations (GLCs) of NO_2 and VOC have been predicted below in **Table 8**, **Table 9** and **Table 10**.

NO_2 Emissions

The NO_2 modelling results are detailed in **Table 8**. The results indicate that the ambient ground level concentrations are below the relevant air quality standards for NO_2. Emissions from the existing and proposed emission points lead to an ambient NO_2 concentration (including background) which is 50% of the maximum ambient 1-hour limit value (measured as a 99.8th%ile) and 28% of the annual limit value at the worst-case receptor (see Figure 5 and Figure 6).

Table 8 NO_2 Dispersion Model Results – Process Contributions Under Normal Operations

Pollutant/ Year	Averaging Period	Process Contribution NO_2 (µg/m^3)	Background Concentration (µg/m^3)	Predicted Environmental Concentration NO_2 (µg/m^3)	Limit Value (µg/m^3)	PEC as a % of Limit Value
NO_2 / 2017	Annual Mean	3.9	16	19.9	40	50%
	99.8th%ile of 1-hr means	23.0	32	55.0	200	28%
	Annual Mean	3.0	16	19.0	40	48%

Pollutant/ Year	Averaging Period	Process Contribution NO_2 ($\mu g/m^3$)	Background Concentration ($\mu g/m^3$)	Predicted Environmental Concentration NO_2 ($\mu g/m^3$)	Limit Value ($\mu g/m^3$)	PEC as a % of Limit Value
NO_2 / 2018	99.8th%ile of 1-hr means	23.6	32	55.6	200	28%
NO_2 / 2019	Annual Mean	3.3	16	19.3	40	48%
	99.8th%ile of 1-hr means	23.7	32	55.7	200	28%
NO_2 / 2020	Annual Mean	3.4	16	19.4	40	48%
	99.8th%ile of 1-hr means	24.1	32	56.1	200	28%
NO_2 / 2021	Annual Mean	3.0	16	19.0	40	47%
	99.8th%ile of 1-hr means	23.5	32	55.5	200	28%

Note 1 Air Quality Standards 2011 (from EU Directive 2008/50/EC and S.I. 180 of 2011).

VOC Emissions

The VOC modelling results are detailed in **Table 9** and **Table 10**. The results indicate that the ambient ground level concentrations are below the relevant air quality guidelines for individual VOCs even when it is assumed that each emission point is emitting solely the VOC of concern at the IED emission limit for the full year. Emissions from the proposed TO and other VOC emission point onsite lead to ambient individual VOC concentrations which are no more than 11% of the maximum 1-hour limit value at the worst-case receptor (see **Table 9** and Figure 7) and no more than 17% of the annual mean limit value at the worst-case off-site location (**Table 10** and Figure 8).

Table 9 VOCs Dispersion Model Results – Process Contributions Under Normal Operations – Maximum 1-Hour Scenario

Pollutant	1-Hour EAL ($\mu g/Nm^3$)	2017 ($\mu g/Nm^3$)	2018 ($\mu g/Nm^3$)	2019 ($\mu g/Nm^3$)	2020 ($\mu g/Nm^3$)	2021 ($\mu g/Nm^3$)	Max PEC / EAL
1-Ethyl-3-(3-dimethylaminopropyl)carbodiimide	-	3.3	3.0	3.3	3.4	3.2	-
2-butanol	4,500	3.2	2.8	3.1	3.2	3.0	0.1%
Acetic acid	3,700	5.2	4.6	5.1	5.2	4.9	0.1%
Acetic anhydride	40	4.4	3.9	4.3	4.4	4.2	11%
Acetone	362,000	3.3	3.0	3.3	3.4	3.2	0.001%
Acetonitrile	10,200	3.5	3.1	3.5	3.6	3.3	0.03%
Acetyl chloride	-	6.8	6.0	6.7	6.8	6.4	-
Chlorobenzene	70,200	3.2	2.9	3.2	3.3	3.1	0.005%
Cyclopentyl methyl ether	-	2.9	2.5	2.8	2.9	2.7	-
Dichloromethane	3,000	14.7	13.0	14.4	14.7	13.9	0.5%
Difluorophenylboronic acid	-	4.5	4.0	4.5	4.6	4.3	-
Diisopropylamine	6,300	2.9	2.6	2.9	2.9	2.8	0.05%
Dimethyl phosphonate	-	9.6	8.5	9.4	9.6	9.1	-
Mimethyl sulfoxide (DMSO)	-	6.7	6.0	6.6	6.8	6.4	-
Dimethylacetamide (DMAC)	7,200	3.8	3.3	3.7	3.8	3.6	0.05%

Pollutant	1-Hour EAL (µg/Nm³)	2017 (µg/ Nm³)	2018 (µg/ Nm³)	2019 (µg/ Nm³)	2020 (µg/ Nm³)	2021 (µg/ Nm³)	Max PEC / EAL
Dimethylformamide (DMF)	6,100	4.2	3.7	4.1	4.2	4.0	0.1%
Ethane	-	2.6	2.3	2.5	2.6	2.5	-
Ethanol	576,000	4.0	3.5	3.9	4.0	3.8	0.001%
Ethyl acetate	420,000	3.8	3.4	3.7	3.8	3.6	0.001%
Ethyl sulfonyl chloride	-	11.1	9.8	10.9	11.1	10.5	-
Ethylene	-	2.4	2.1	2.4	2.4	2.3	-
Formaldehyde	100	5.2	4.6	5.1	5.2	4.9	5%
Hexane	21,600	2.5	2.2	2.4	2.5	2.3	0.01%
Isopropanol	125,000	3.5	3.1	3.4	3.5	3.3	0.003%
Isopropyl acetate	84,900	3.5	3.1	3.5	3.5	3.3	-
Methane	-	2.8	2.4	2.7	2.8	2.6	-
Methanol	33,300	5.5	4.9	5.4	5.6	5.2	0.02%
Methyl tert-butyl ether	3,670	3.0	2.7	3.0	3.1	2.9	0.1%
Methylamine	3,900	5.4	4.7	5.3	5.4	5.1	0.1%
Methylcyclohexane	160,000	2.4	2.1	2.4	2.4	2.3	0.002%
N,N-Diisopropylethylamine (DIPEA)	-	2.8	2.5	2.7	2.8	2.6	-
N-Acetyl-L-Cysteine	-	5.6	5.0	5.5	5.7	5.3	-
N-Heptane	62,550	2.5	2.2	2.4	2.5	2.3	0.004%
N-Methyl-2-pyrrolidone	30,900	0.3	0.3	0.3	0.3	0.3	0.001%
N-Methylimidazole	-	3.5	3.1	3.5	3.6	3.3	-
Palladium triphenylphosphine	-	2.8	2.4	2.7	2.8	2.6	-
Propane	-	2.5	2.2	2.5	2.5	2.4	-
Propionyl chloride	-	5.3	4.7	5.2	5.3	5.0	-
Pyridine 4-boronic acid	-	4.2	3.8	4.2	4.3	4.0	-
Pyridine-3-sulfonyl chloride (PSC)	-	6.1	5.4	6.0	6.2	5.8	-
Pyrrolidine	-	3.1	2.7	3.0	3.1	2.9	-
THF	59,900	3.1	2.8	3.1	3.1	2.9	0.005%
Toluene	8,000	2.3	2.0	2.2	2.3	2.1	0.03%
Triethylamine	6,300	8.7	7.7	8.6	8.8	8.3	0.1%
Triphenylphosphine	-	2.5	2.2	2.5	2.5	2.4	-

Note 1 Background levels of all VOCs are likely to be well below 1 µg/m³ in the vicinity of the facility.

Note 2 As a worst-case all VOCs released assumed to consist of each individual VOC in turn for the maximum 1-hour scenario.

Table 10 VOCs Dispersion Model Results – Process Contributions Under Normal Operations – Annual Mean Scenario

Pollutant	Annual Mean EAL (µg/Nm³)	2017 (µg/ Nm³)	2018 (µg/ Nm³)	2019 (µg/ Nm³)	2020 (µg/ Nm³)	2021 (µg/ Nm³)	Max PEC / EAL
1-Ethyl-3-(3-dimethylaminopropyl)carbodiimide	-	0.12	0.13	0.11	0.10	0.12	-

Pollutant	Annual Mean EAL (µg/Nm^3)	2017 (µg/ Nm^3)	2018 (µg/ Nm^3)	2019 (µg/ Nm^3)	2020 (µg/ Nm^3)	2021 (µg/ Nm^3)	Max PEC / EAL
2-butanol	30,000	0.12	0.12	0.11	0.10	0.12	0.0004%
Acetic acid	250	0.19	0.19	0.17	0.16	0.19	0.1%
Acetic anhydride	1	0.16	0.17	0.15	0.13	0.16	17%
Acetone	18,100	0.12	0.13	0.11	0.10	0.12	0.001%
Acetonitrile	680	0.13	0.13	0.12	0.11	0.13	0.02%
Acetyl chloride	-	0.24	0.25	0.22	0.20	0.25	-
Chlorobenzene	2,340	0.12	0.12	0.11	0.10	0.12	0.01%
Cyclopentyl methyl ether	-	0.10	0.11	0.10	0.09	0.11	-
Dichloromethane	700	0.53	0.55	0.49	0.44	0.54	0.1%
Difluorophenylboronic acid	-	0.16	0.17	0.15	0.14	0.17	-
Diisopropylamine	210	0.11	0.11	0.10	0.09	0.11	0.05%
Dimethyl phosphonate	-	0.35	0.36	0.32	0.29	0.35	-
Mimethyl sulfoxide (DMSO)	-	0.24	0.25	0.22	0.20	0.25	-
Dimethylacetamide (DMAC)	360	0.14	0.14	0.12	0.11	0.14	0.04%
Dimethylformamide (DMF)	300	0.15	0.16	0.14	0.13	0.16	0.05%
Ethane	-	0.09	0.10	0.09	0.08	0.10	-
Ethanol	19,200	0.14	0.15	0.13	0.12	0.15	0.001%
Ethyl acetate	14,600	0.14	0.14	0.13	0.11	0.14	0.001%
Ethyl sulfonyl chloride	-	0.40	0.42	0.37	0.33	0.41	-
Ethylene	-	0.09	0.09	0.08	0.07	0.09	-
Formaldehyde	5	0.19	0.19	0.17	0.16	0.19	4%
Hexane	720	0.09	0.09	0.08	0.07	0.09	0.01%
Isopropanol	9,990	0.12	0.13	0.11	0.10	0.13	0.001%
Isopropyl acetate	-	0.13	0.13	0.12	0.11	0.13	-
Methane	-	0.10	0.10	0.09	0.08	0.10	-
Methanol	2,660	0.20	0.21	0.18	0.17	0.20	0.01%
Methyl tert-butyl ether	18,350	0.11	0.11	0.10	0.09	0.11	0.001%
Methylamine	130	0.19	0.20	0.18	0.16	0.20	0.2%
Methylcyclohexane	4,800	0.09	0.09	0.08	0.07	0.09	0.002%
N,N-Diisopropylethylamine (DIPEA)	-	0.10	0.10	0.09	0.08	0.10	-
N-Acetyl-L-Cysteine	-	0.20	0.21	0.19	0.17	0.21	-
N-Heptane	20,850	0.09	0.09	0.08	0.07	0.09	0.0004%
N-Methyl-2-pyrrolidone	1,030	0.01	0.01	0.01	0.00	0.01	0.001%
N-Methylimidazole	-	0.13	0.13	0.12	0.11	0.13	-
Palladium triphenylphosphine	-	0.10	0.10	0.09	0.08	0.10	-
Propane	-	0.09	0.10	0.08	0.08	0.09	-
Propionyl chloride	-	0.19	0.20	0.18	0.16	0.20	-
Pyridine 4-boronic acid	-	0.15	0.16	0.14	0.13	0.16	-

Pollutant	Annual Mean EAL (µg/Nm^3)	2017 (µg/ Nm^3)	2018 (µg/ Nm^3)	2019 (µg/ Nm^3)	2020 (µg/ Nm^3)	2021 (µg/ Nm^3)	Max PEC / EAL
Pyridine-3-sulfonyl chloride (PSC)	-	0.22	0.23	0.20	0.18	0.23	-
Pyrrolidine	-	0.11	0.12	0.10	0.09	0.11	-
THF	3,000	0.11	0.12	0.10	0.09	0.11	0.004%
Toluene	19,190	0.08	0.09	0.08	0.07	0.08	0.0004%
Triethylamine	420	0.32	0.33	0.29	0.26	0.32	0.1%
Triphenylphosphine	-	0.09	0.09	0.08	0.08	0.09	-

Note 1 Background levels of all VOCs are likely to be well below 1 µg/m^3 in the vicinity of the facility.

Note 2 As a worst-case all VOCs released assumed to consist of each individual VOC in turn for the annual mean scenario.

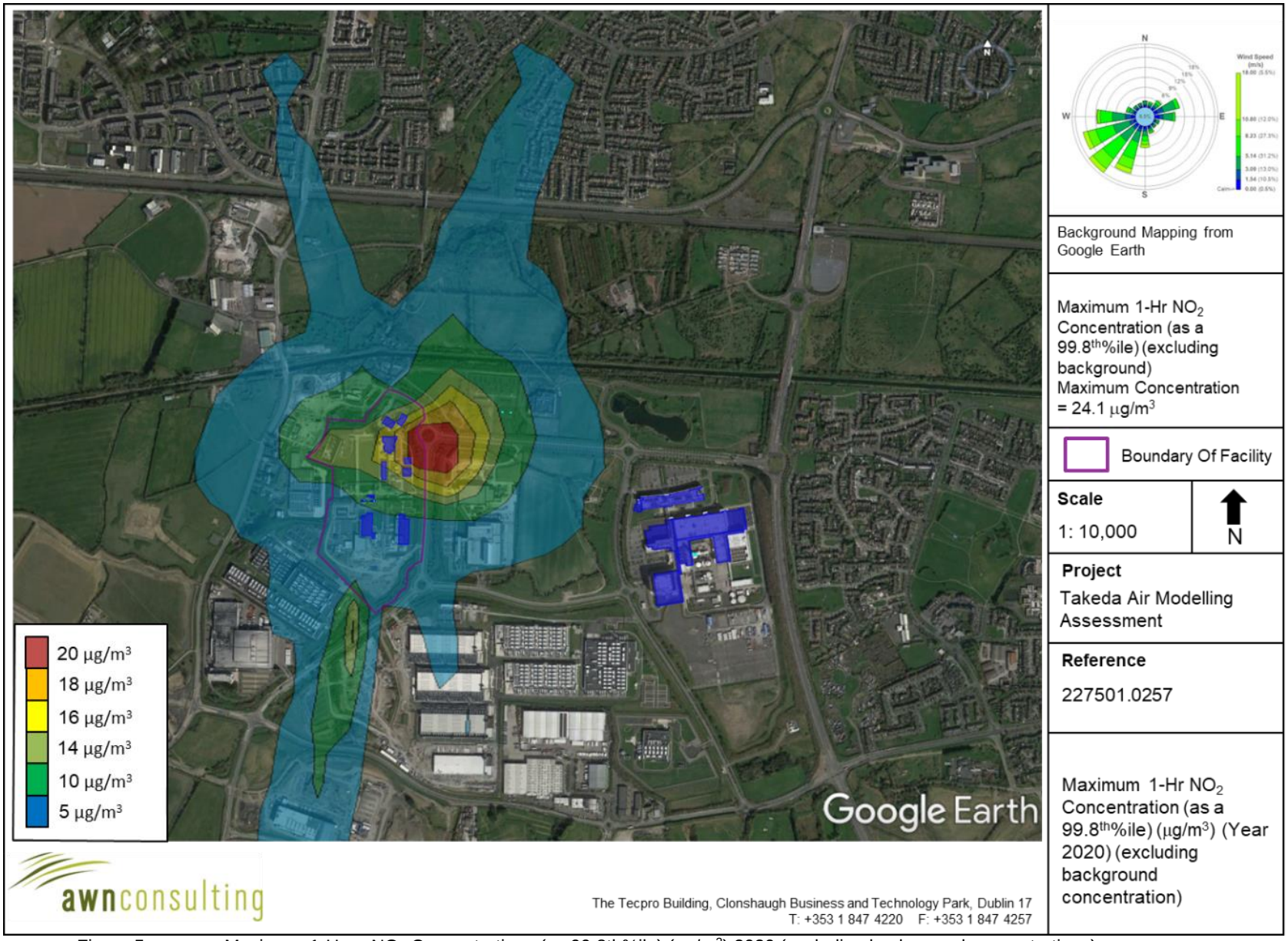

Figure 5 Maximum 1-Hour NO_2 Concentrations (as 99.8th%ile) (µg/m^3) 2020 (excluding background concentrations)

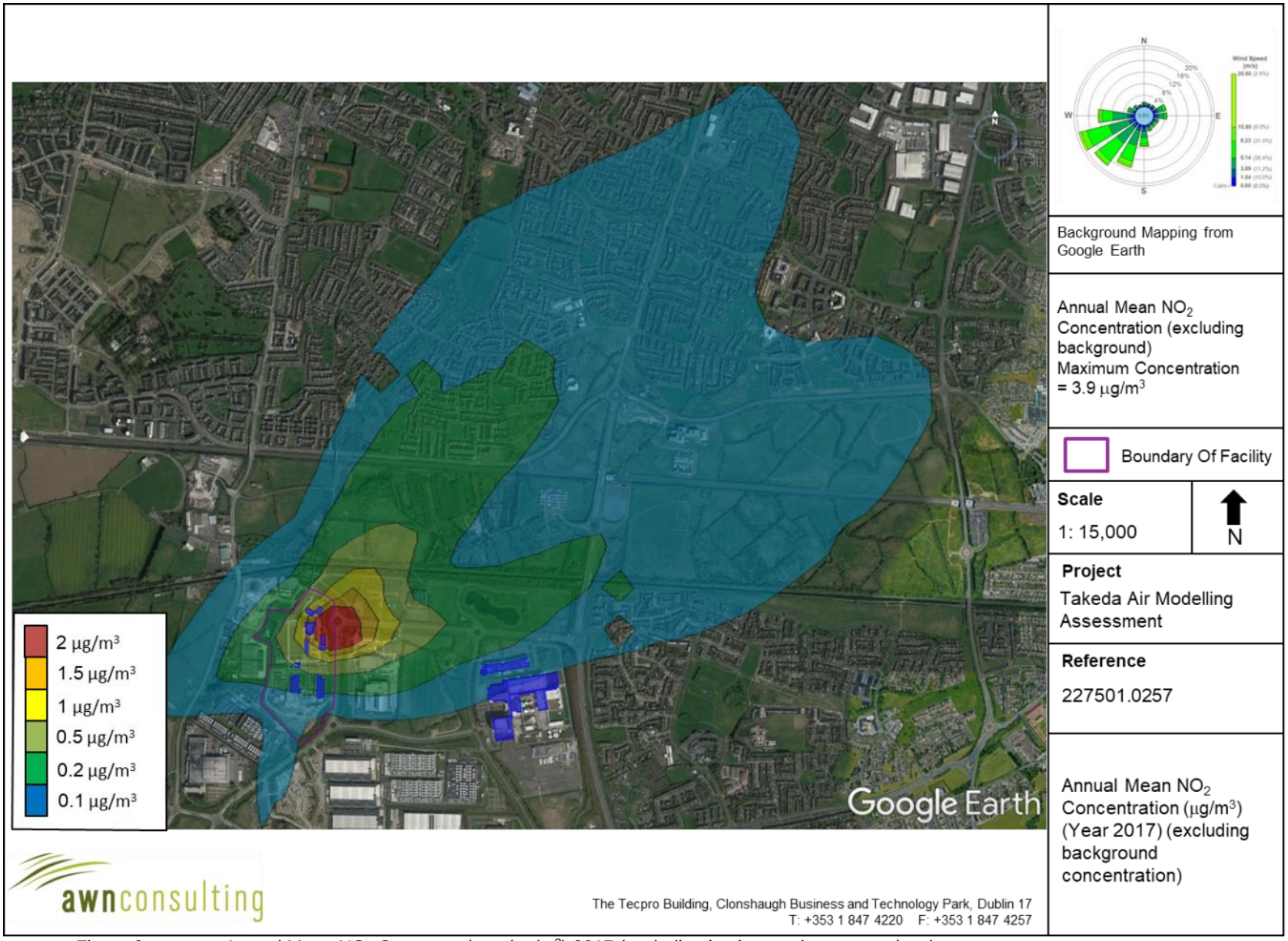

Figure 6 Annual Mean NO_2 Concentrations (µg/m^3) 2017 (excluding background concentrations)

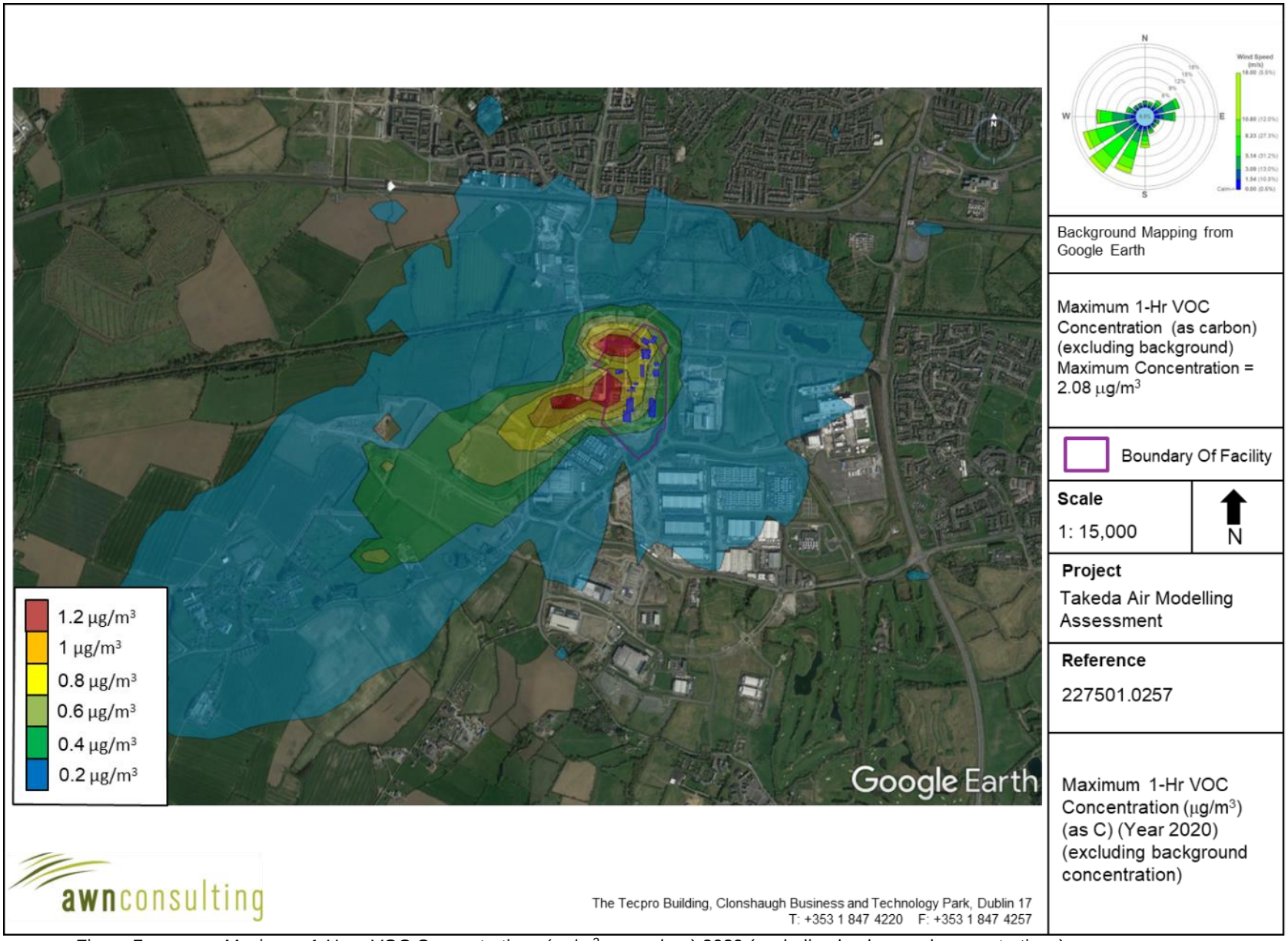

Figure 7 Maximum 1-Hour VOC Concentrations (µg/m³, as carbon) 2020 (excluding background concentrations)

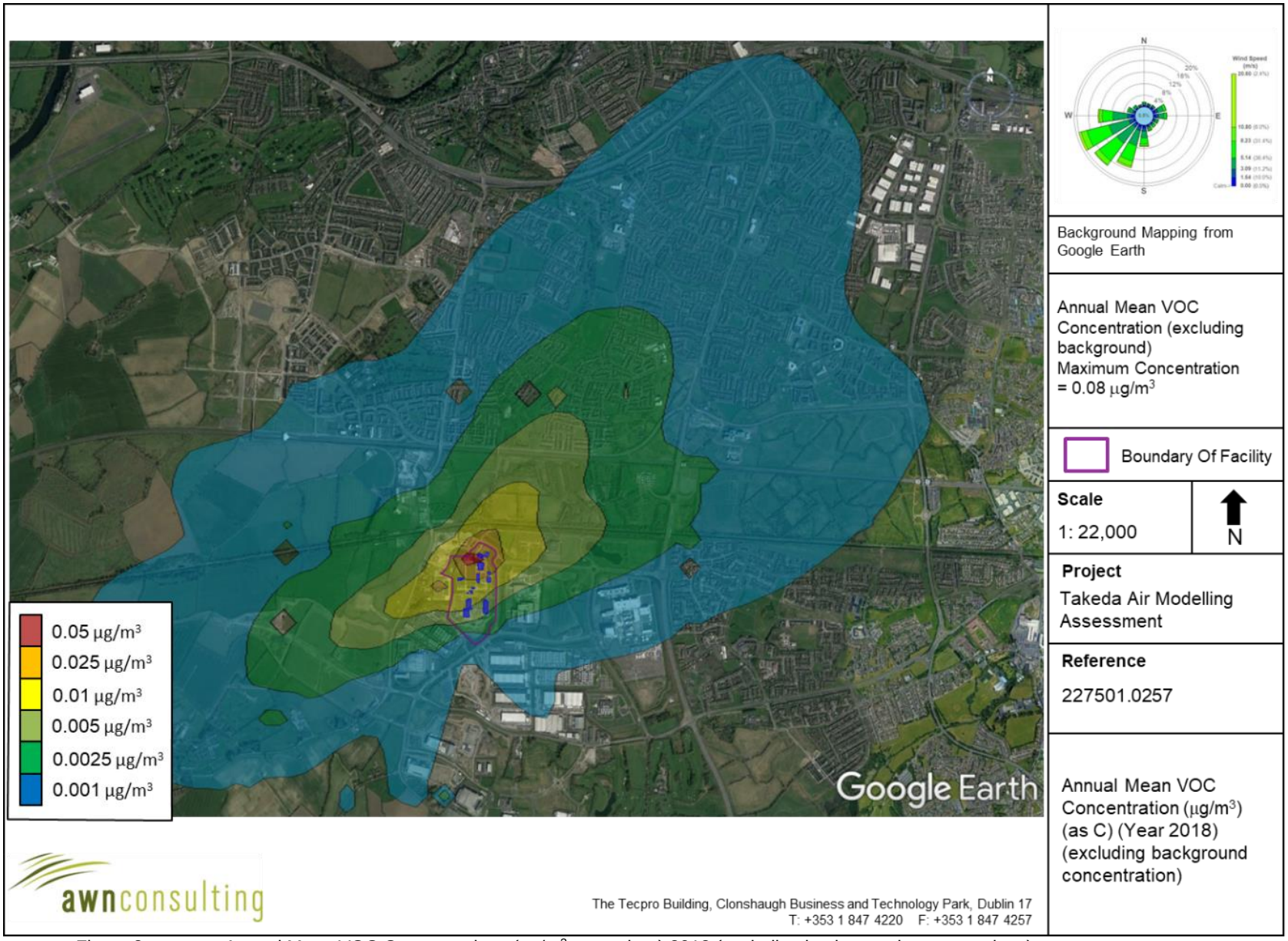

Figure 8 Annual Mean VOC Concentrations (µg/m³, as carbon) 2018 (excluding background concentrations)

3.2 Bypass Operations

VOC Emissions During Bypass Operations

The VOC modelling results during bypass operations are detailed in **Table 11**. The results indicate that under the worst-case scenario, the ambient ground level concentrations are below the relevant air quality guidelines for individual VOCs. Emissions from the existing VOC abatement system which operates during bypass of the proposed TO lead to ambient individual VOC concentrations which are no more than 4% of the maximum 1-hour limit value at the worst-case receptor.

Table 11 Dispersion Model Results – VOCs During Bypass Operations – Maximum 1-Hour Scenario

Pollutant	1-Hour EAL (µg/Nm^3)	2017 (µg/ Nm^3)	2018 (µg/ Nm^3)	2019 (µg/ Nm^3)	2020 (µg/ Nm^3)	2021 (µg/ Nm^3)	Max PEC / EAL
1-Ethyl-3-(3-dimethylaminopropyl)carbodiimide	6,301	1.1	0.7	0.7	0.9	0.9	-
2-butanol	4,500	1.0	0.7	0.7	0.8	0.9	0.02%
Acetic acid	3,700	1.7	1.1	1.1	1.4	1.4	0.04%
Acetic anhydride	40	1.4	0.9	1.0	1.2	1.2	4%
Acetone	362,000	1.1	0.7	0.7	0.9	0.9	0.0003%
Acetonitrile	10,200	1.1	0.7	0.8	0.9	0.9	0.01%
Acetyl chloride	6,302	2.2	1.4	1.5	1.8	1.8	-
Chlorobenzene	70,200	1.0	0.7	0.7	0.8	0.9	0.001%
Cyclopentyl methyl ether	6,303	0.9	0.6	0.6	0.8	0.8	-
Dichloromethane	3,000	4.7	3.0	3.2	3.8	3.9	0.2%
Difluorophenylboronic acid	6,304	1.4	0.9	1.0	1.2	1.2	-
Diisopropylamine	6,300	0.9	0.6	0.6	0.8	0.8	0.01%
Dimethyl phosphonate	6,305	3.1	2.0	2.1	2.5	2.6	-
Mimethyl sulfoxide (DMSO)	6,306	2.2	1.4	1.5	1.8	1.8	-
Dimethylacetamide (DMAC)	7,200	1.2	0.8	0.8	1.0	1.0	0.02%
Dimethylformamide (DMF)	6,100	1.3	0.9	0.9	1.1	1.1	0.02%
Ethane	6,307	0.8	0.5	0.6	0.7	0.7	-
Ethanol	576,000	1.3	0.8	0.9	1.0	1.1	0.0002%
Ethyl acetate	420,000	1.2	0.8	0.8	1.0	1.0	0.0003%
Ethyl sulfonyl chloride	6,308	3.5	2.3	2.4	2.9	3.0	-
Ethylene	6,309	0.8	0.5	0.5	0.6	0.6	-
Formaldehyde	100	1.7	1.1	1.1	1.4	1.4	2%
Hexane	21,600	0.8	0.5	0.5	0.7	0.7	0.004%
Isopropanol	125,000	1.1	0.7	0.8	0.9	0.9	0.001%
Isopropyl acetate	84,900	1.1	0.7	0.8	0.9	0.9	0.001%
Methane	6,310	0.9	0.6	0.6	0.7	0.7	-
Methanol	33,300	1.8	1.1	1.2	1.5	1.5	0.01%
Methyl tert-butyl ether	3,670	1.0	0.6	0.7	0.8	0.8	0.03%
Methylamine	3,900	1.7	1.1	1.2	1.4	1.4	0.04%

Pollutant	1-Hour EAL (µg/Nm^3)	2017 (µg/ Nm^3)	2018 (µg/ Nm^3)	2019 (µg/ Nm^3)	2020 (µg/ Nm^3)	2021 (µg/ Nm^3)	Max PEC / EAL
Methylcyclohexane	160,000	0.8	0.5	0.5	0.6	0.6	0.0005%
N,N-Diisopropylethylamine (DIPEA)	6,311	0.9	0.6	0.6	0.7	0.7	-
N-Acetyl-L-Cysteine	6,312	1.8	1.2	1.2	1.5	1.5	-
N-Heptane	62,550	0.8	0.5	0.5	0.6	0.7	0.001%
N-Methyl-2-pyrrolidone	30,900	0.1	0.04	0.04	0.04	0.05	0.0002%
N-Methylimidazole	6,313	1.1	0.7	0.8	0.9	0.9	-
Palladium triphenylphosphine	6,314	0.9	0.6	0.6	0.7	0.7	-
Propane	6,315	0.8	0.5	0.6	0.7	0.7	-
Propionyl chloride	6,316	1.7	1.1	1.2	1.4	1.4	-
Pyridine 4-boronic acid	6,317	1.4	0.9	0.9	1.1	1.1	-
Pyridine-3-sulfonyl chloride (PSC)	6,318	2.0	1.3	1.3	1.6	1.6	-
Pyrrolidine	6,319	1.0	0.6	0.7	0.8	0.8	-
THF	59,900	1.0	0.6	0.7	0.8	0.8	0.002%
Toluene	8,000	0.7	0.5	0.5	0.6	0.6	0.01%
Triethylamine	6,300	2.8	1.8	1.9	2.3	2.3	0.04%
Triphenylphosphine	6,320	0.8	0.5	0.5	0.7	0.7	-

Note 1 Background levels of all VOCs are likely to be well below 1 µg/m^3 in the vicinity of the facility.

Note 2 As a worst-case all VOCs released assumed to consist of each individual VOC in turn for the maximum 1-hour scenario.

Odour Levels During Bypass Operations

The odour modelling results during bypass operations are detailed in **Table 12** and are compared to the odour nuisance criteria. In line with previous modelling, modelling was initially undertaken using worst-case assumptions. The maximum 1-hour scenario (as a 98th%ile) at the nearest residential receptors was based on the organic compound with the largest VOC (as C) emission rate (acetone) with each compound in turn assumed to be emitted at this mass emission rate. The results indicate that under the worst-case scenario, the ambient ground level concentrations are below the odour nuisance criteria in the worst-case year for all VOCs modelled.

Table 12 Dispersion Model Results – VOCs During Bypass Operations At Maximum Theoretical Levels – Odour Nuisance Assessment at Nearest Residential Receptor

Pollutant	1-Hour EAL (µg/Nm^3)	2017 (µg/ Nm^3)	2018 (µg/ Nm^3)	2019 (µg/ Nm^3)	2020 (µg/ Nm^3)	2021 (µg/ Nm^3)	Max PEC / EAL
1-Ethyl-3-(3-dimethylaminopropyl)carbodiimide	-	1.1	0.7	0.7	0.9	0.9	-
2-butanol	9,000	1.0	0.7	0.7	0.8	0.9	0.01%
Acetic acid	129	1.7	1.1	1.1	1.4	1.4	1%
Acetic anhydride	4	1.4	0.9	1.0	1.2	1.2	36%
Acetone	41,700	1.1	0.7	0.7	0.9	0.9	0.003%
Acetonitrile	846,000	1.1	0.7	0.8	0.9	0.9	0.0001%
Acetyl chloride	-	2.2	1.4	1.5	1.8	1.8	-
Chlorobenzene	3,000	1.0	0.7	0.7	0.8	0.9	0.03%

Pollutant	1-Hour EAL (µg/Nm^3)	2017 (µg/ Nm^3)	2018 (µg/ Nm^3)	2019 (µg/ Nm^3)	2020 (µg/ Nm^3)	2021 (µg/ Nm^3)	Max PEC / EAL
Cyclopentyl methyl ether	-	0.9	0.6	0.6	0.8	0.8	-
Dichloromethane	10,260	4.7	3.0	3.2	3.8	3.9	0.05%
Difluorophenylboronic acid	-	1.4	0.9	1.0	1.2	1.2	-
Diisopropylamine	157	0.9	0.6	0.6	0.8	0.8	0.6%
Dimethyl phosphonate	-	3.1	2.0	2.1	2.5	2.6	-
Mimethyl sulfoxide (DMSO)	-	2.2	1.4	1.5	1.8	1.8	-
Dimethylacetamide (DMAC)	119,100	1.2	0.8	0.8	1.0	1.0	0.001%
Dimethylformamide (DMF)	19,140	1.3	0.9	0.9	1.1	1.1	0.01%
Ethane	-	0.8	0.5	0.6	0.7	0.7	-
Ethanol	840	1.3	0.8	0.9	1.0	1.1	0.2%
Ethyl acetate	7,230	1.2	0.8	0.8	1.0	1.0	0.02%
Ethyl sulfonyl chloride	-	3.5	2.3	2.4	2.9	3.0	-
Ethylene	-	0.8	0.5	0.5	0.6	0.6	-
Formaldehyde	3,063	1.7	1.1	1.1	1.4	1.4	0.1%
Hexane	1,376,700	0.8	0.5	0.5	0.7	0.7	0.0001%
Isopropanol	10,690	1.1	0.7	0.8	0.9	0.9	0.01%
Isopropyl acetate	4,484	1.1	0.7	0.8	0.9	0.9	0.03%
Methane	-	0.9	0.6	0.6	0.7	0.7	-
Methanol	12,000	1.8	1.1	1.2	1.5	1.5	0.01%
Methyl tert-butyl ether	541	1.0	0.6	0.7	0.8	0.8	0.2%
Methylamine	14	1.7	1.1	1.2	1.4	1.4	12%
Methylcyclohexane	1,720,859	0.8	0.5	0.5	0.6	0.6	0.00004%
N,N-Diisopropylethylamine (DIPEA)	-	0.9	0.6	0.6	0.7	0.7	-
N-Acetyl-L-Cysteine	-	1.8	1.2	1.2	1.5	1.5	-
N-Heptane	147,391	0.8	0.5	0.5	0.6	0.7	0.0005%
N-Methyl-2-pyrrolidone	486,528	0.1	0.04	0.04	0.04	0.05	0.00001%
N-Methylimidazole	-	1.1	0.7	0.8	0.9	0.9	-
Palladium triphenylphosphine	-	0.9	0.6	0.6	0.7	0.7	-
Propane	-	0.8	0.5	0.6	0.7	0.7	-
Propionyl chloride	-	1.7	1.1	1.2	1.4	1.4	-
Pyridine 4-boronic acid	-	1.4	0.9	0.9	1.1	1.1	-
Pyridine-3-sulfonyl chloride (PSC)	-	2.0	1.3	1.3	1.6	1.6	-
Pyrrolidine	-	1.0	0.6	0.7	0.8	0.8	-
THF	664	1.0	0.6	0.7	0.8	0.8	0.1%
Toluene	1,932	0.7	0.5	0.5	0.6	0.6	0.04%
Triethylamine	8	2.8	1.8	1.9	2.3	2.3	36%
Triphenylphosphine	-	0.8	0.5	0.5	0.7	0.7	-

Note 1 Background levels of all VOCs are likely to be well below 1 µg/m^3 in the vicinity of the facility.

Note 2 As a worst-case all VOCs released assumed to consist of each individual VOC in turn for the maximum 1-hour scenario.

3.3 Cumulative Impacts

The cumulative impact of NO_2 emissions from proposed normal operations and emissions from Pfizer, the Grange Castle Power Facility, the Centrica Profile Park Power Facility and Vantage Data Centre DUB11 are detailed in **Table 13** below. The results indicate that the ambient ground level concentrations are below the relevant air quality limit values for NO_2. For the worst-case year, emissions from the sites lead to an ambient NO_2 concentration (including background) which is 49% of the maximum 1 hour limit value (measured as a 99.8th%ile) and 61% of the annual limit value at the worst-case off-site receptor.

Table 13 NO_2 Dispersion Model Results – Cumulative Assessment

Pollutant/ Year	Averaging Period	Process Contribution NO_2 ($\mu g/m^3$)	Background Concentration ($\mu g/m^3$)	Predicted Environmental Concentration NO_2 ($\mu g/m^3$)	Limit Value ($\mu g/m^3$)	PEC as a % of Limit Value
NO_2 / 2017	Annual Mean	8.5	16	24.5	40	61%
	99.8th%ile of 1-hr means	50.1	32	82.1	200	41%
NO_2 / 2018	Annual Mean	8.1	16	24.1	40	60%
	99.8th%ile of 1-hr means	65.1	32	97.1	200	49%
NO_2 / 2019	Annual Mean	7.3	16	23.3	40	58%
	99.8th%ile of 1-hr means	45.8	32	77.8	200	39%
NO_2 / 2020	Annual Mean	8.2	16	24.2	40	61%
	99.8th%ile of 1-hr means	61.3	32	93.3	200	47%
NO_2 / 2021	Annual Mean	8.5	16	24.5	40	61%
	99.8th%ile of 1-hr means	50.1	32	82.1	200	41%

Note 1 Air Quality Standards 2011 (from EU Directive 2008/50/EC and S.I. 180 of 2011).

A review of licensed facilities in the surrounding area has been conducted and none have been identified with the potential for cumulative impact with VOC emissions from the Proposed Development.

3.4 Assessment Summary

For the normal operations modelling scenario, it has been assumed that all emission points are continually in operation for the full year as a worst-case.

With regard to NO_2, the scenario modelled will lead to ambient NO_2 concentrations (including background) which are in compliance with the relevant limit values, reaching at most 50% of the 1-hour limit value (measured as a 99.8th%ile) and 28% of the annual limit value at the worst-case receptor.

The results indicate that the ambient ground level concentrations are below the relevant air quality guidelines for individual VOCs even when it is assumed that each emission point is emitting solely the VOC of concern at the IED emission limit for the full year. Under normal operations, emissions from the proposed thermal oxidiser and other VOC emission points onsite lead to ambient individual VOC concentrations which are no more than 11% of the maximum 1-hour limit value at the worst-case receptor

and no more than 17% of the annual mean limit value at the worst-case off-site location.

In relation to odour, all ambient concentrations are below the odour nuisance thresholds for each individual VOC under normal operating conditions.

For the bypass operations the worst-case scenario has assumed the following:

- It is assumed that bypass events are 4 hours in duration for every day of the year as a worst-case;
- EP-P1-02 is compliant with its licence limit values for VOCs (a test of the bypass function in September 2021 confirmed this, report reference FC/21/13112_WR02); and
- It is assumed that where more than one compound is being emitted from any emission point, as a worst-case assumption, the Total VOC (as C) consists of only one compound (in turn) with each compound compared to the 1-hour Environment Assessment Level.

Emissions from the existing VOC abatement system which operates during bypass of the proposed TO lead to ambient individual VOC concentrations which are no more than 4% of the maximum 1-hour limit value at the worst-case receptor. The results indicate that under the worst-case scenario, the ambient ground level concentrations are below the relevant air quality guidelines for individual VOCs.

The odour modelling under bypass operations was initially undertaken using worst-case assumptions. The maximum 1-hour scenario (as a 98th%ile) at the nearest residential receptors was based on the organic compound with the largest VOC (as C) emission rate (acetone) with each compound in turn assumed to be emitted at this mass emission rate. The results indicate that under the worst-case scenario, the ambient ground level concentrations are below the odour nuisance criteria in the worst-case year for all VOCs modelled.

In the cumulative scenario, emissions from the sites lead to an ambient NO_2 concentration (including background) which is 49% of the maximum 1 hour limit value (measured as a 99.8th%ile) and 61% of the annual limit value at the worst-case off-site receptor. The results indicate that the ambient ground level concentrations are below the relevant air quality limit values for NO_2.

In summary, all emissions from the facility under normal operations of the facility will be in compliance with the ambient air quality standards whilst bypass conditions will not lead to a substantive risk of non-compliance or odour nuisance.

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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[8].

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[19]. 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(5) and using the detailed methodology outlined by the Alaska Department of Environmental Conservation(21).

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 Cork Airport Meteorological Station is shown in Table A1.

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

Sector	Area Weighted Land Use Classification	Spring	Summer	Autumn	Winter[Note 1]
350-50	60% Urban, 40% Grassland	0.213	0.305	0.093	0.093
50-350	100% Grassland	0.050	0.100	0.010	0.010

Note 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))[23]. Thus for the current location autumn more accurately defines "winter" conditions in Ireland.

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 Cork Airport Meteorological Station is shown in Table A2.

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

Area Weighted Land Use Classification	Spring	Summer	Autumn	Winter[Note 1]
19% Urban, 81% Grassland	0.17	0.18	0.20	0.20

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

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 Cork Airport Meteorological Station is shown in Table A3.

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

Area Weighted Land Use Classification	Spring	Summer	Autumn	Winter[Note 1]
19% Urban, 81% Grassland	0.47	0.95	1.14	1.14

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