

**REVISED AIR DISPERSION
MODELLING OF EMISSIONS
TO ATMOSPHERE FROM
ABBVIE,
BALLYTIVNAN,
CO. SLIGO**

Technical Report Prepared For

**AbbVie,
Ballytivnan,
Co. Sligo**

Technical Report Prepared By

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Our Reference

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EXECUTIVE SUMMARY

Air dispersion modelling was carried out using the United States Environmental Protection Agency's regulatory model AERMOD (Version 16216r). The purpose of this modelling study is to determine whether the emissions from the AbbVie facility, Ballytivnan, Co. Sligo will lead to ambient concentrations which are in compliance with the relevant ambient air quality standards for NO₂ and SO₂. There is a second AbbVie facility located approximately 1km to the east which holds a valid IED licence (Licence No. P0643-03), emissions from both facilities have been included in a cumulative assessment to ensure compliance with the ambient air quality standards for NO₂ and SO₂.

The study consists of the following components:

- Review of emission data and other relevant information needed for the modelling study;
- Summary of background NO₂ and SO₂ 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

The results indicate that the ambient ground level concentrations of nitrogen oxides (as NO₂) are below the annual mean and maximum 1-hour (measured as a 99.8th percentile) ambient air quality standards. Emissions from the facility lead to an ambient NO₂ concentration (including background) which is 24% of the maximum 1-hour limit (measured as a 99.8th percentile) and 38% of the annual mean limit at the worst-case off-site location for the worst-case years modelled (2014 and 2015).

The SO₂ modelling results indicate that the ambient ground level concentrations are below the 1-hour and 24-hour ambient air quality standards. Emissions from the facility lead to an ambient SO₂ concentration (including background) that is 21% of the maximum ambient 1-hour limit value (measured as a 99.7th percentile) and 23% of the 24-hour limit value (measured as a 99.2nd percentile) at the worst-case location off-site for the worst case years modelled (2013 and 2014).

The cumulative assessment with the neighbouring AbbVie facility also found results to be in compliance with the relevant ambient air quality limit values. Emissions from both facilities lead to an ambient NO₂ concentration (including background) which is 25% of the maximum ambient 1-hour limit value (measured as a 99.8th percentile) and 39% of the annual mean limit value at the worst-case off-site receptor for the worst-case years modelled (2014 and 2016).

Results of the cumulative assessment are also in compliance with the ambient air quality standards for SO₂. Emissions from both facilities lead to an ambient SO₂ concentration (including background) that is 25% of the maximum ambient 1-hour limit value (measured as a 99.7th percentile) and 23% of the 24-hour limit value (measured as a 99.2nd percentile) at the worst-case location off-site for the worst case years modelled (2013 and 2014).

Ambient levels of nitrogen oxides (as NO₂) and sulphur dioxide (SO₂) from the facility are well below the air quality limit values for the protection of human health and it is predicted that air emissions from the installation will not have a significant impact on the local environment

CONTENTS		Page
	Executive Summary	3
1.0	Introduction	5
2.0	Modelling Methodology	5
2.1	Background Concentrations	6
2.2	Ambient Air Quality Standards	8
2.3	Air Dispersion Modelling Methodology	8
2.4	Terrain	9
2.5	Meteorological Data	10
2.6	Process Emissions	10
3.0	Results & Discussion	13
3.1	Proposed Development	13
3.2	Cumulative Assessment	19
3.3	Assessment Summary	20
	References	21
	Appendix I – Description of the AERMOD Model	22
	Appendix II – Meteorological Data - AERMET	23
	Appendix III – Detailed Meteorological Data	25

1.0 INTRODUCTION

AWN Consulting Ltd. were commissioned to carry out an air dispersion modelling study of emissions from the AbbVie facility, Ballytivnan, Co. Sligo for their IED Licence application. 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 NO₂ and SO₂. There is a second AbbVie facility located approximately 1km to the east which holds a valid IED licence (Licence No. P0643-03), emissions from both facilities have been included in a cumulative assessment to ensure compliance with the ambient air quality standards for NO₂ and SO₂.

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 NO₂ and SO₂ 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.

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

2.0 MODELLING METHODOLOGY

Emissions from the proposed facility have been modelled using the AERMOD dispersion model (Version 16216r) which has been developed by the U.S. Environmental Protection Agency (USEPA)⁽¹⁾ and following guidance issued by the EPA⁽²⁾. 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⁽⁴⁻⁶⁾. The model has more advanced algorithms and gives better agreement with monitoring data in extensive validation studies⁽⁷⁻¹¹⁾. An overview of the AERMOD dispersion model is outlined in Appendix I.

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 full years of appropriate meteorological data. Using this input data the model predicted ambient ground level concentrations beyond the site boundary for each hour of the modelled meteorological year. The model post-processed the data to identify the location and maximum of the worst-case ground level concentration. This worst-case concentration was then added to the background concentration to give the worst-case predicted environmental concentration (PEC). The PEC was then compared with the relevant ambient air quality standard to assess the significance of the releases from the site.

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

- Maximum predicted concentrations were reported in this study, even if no residential receptors were near the location of this maximum;
- The effects of building downwash, due to on-site buildings, have been included in the model;
- All emission points were assumed to run continuously, every hour of the day, 365 days per year.

The Ozone Limiting Method (OLM) was used to model NO₂ concentrations. The OLM is a regulatory option in AERMOD which calculates ambient NO₂ concentrations by applying a background ozone concentration and an in-stack NO₂/NO_x ratio to predicted NO_x concentrations. An in-stack NO₂/NO_x ratio of 0.1 and a background ozone concentration of 60 µg/m³ were used for modelling.

2.1 Background Concentrations

Air quality monitoring programs have been undertaken in recent years by the EPA and Local Authorities^(12,13). The most recent annual report on air quality “Air Quality Monitoring Annual Report 2016”⁽¹³⁾, details the range and scope of monitoring undertaken throughout Ireland.

As part of the implementation of the Framework Directive on Air Quality (1996/62/EC), four air quality zones have been defined in Ireland for air quality management and assessment purposes⁽¹³⁾. 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, Ballytivnan is categorised as Zone C due to its proximity to Sligo town⁽¹³⁾.

NO₂

NO₂ monitoring was carried out at the Zone C monitoring stations of Kilkenny, Portlaoise and Mullingar in 2016⁽¹²⁾. The NO₂ annual average in 2016 for the locations of Kilkenny and Portlaoise were 7 and 11 µg/m³, respectively. This is significantly lower than the annual average limit value of 40 µg/m³. The average results over the last five years at a range of Zone C locations suggests an upper average of no more than 13 µg/m³ as a background concentration as shown in Table 1. Based on the above information, a conservative estimate of the current background NO₂ concentration in the region of the AbbVie facility is 13 µg/m³.

Year	Kilkenny	Portlaoise	Mullingar
2012	4	-	7
2013	4	-	6
2014	5	16	4
2015	5	10	-
2016	7	11	-
Average	5.0	12.3	5.7

Table 1 Annual Average NO₂ Concentrations – Zone C⁽¹³⁾

In relation to the annual average background, the ambient background concentration was added directly to the process concentration with the short-term peaks assumed to

have an ambient background concentration of twice the annual mean background concentration.

SO₂

Continuous SO₂ monitoring was carried out at a number of Zone C locations over the period 2012 – 2016, Mullingar, Ennis and Portlaoise. Concentrations ranged from 1 – 5 µg/m³, with no exceedances of the daily limit value of 125 µg/m³ for the protection of human health. Long term annual average results suggest an upper limit of 3.4 µg/m³ as a background concentration. Based on this EPA data a conservative estimate of the annual mean background SO₂ concentration in the region of the facility is 4 µg/m³.

SO₂ concentrations for the representative rural Zone C monitoring station at Ennis in 2017 were 14.63 µg/m³ for the 99.2nd percentile of 24-hour means. The 1-hour limit value for SO₂ (measured as a 99.7th percentile) was 31.65 µg/m³, which is significantly below the 350 µg/m³ limit value.

Year	Ennis	Portlaoise	Mullingar
2012	3	-	3
2013	3	-	3
2014	4	5	2
2015	3	1	-
2016	4	-	-
Average	3.4	2.3	2.7

Table 2 Annual Average SO₂ Concentrations – Zone C⁽¹³⁾

In relation to the annual averages, the ambient background concentration was added directly to the process concentration. However, in relation to the short-term peak concentration, concentrations due to emissions from elevated sources cannot be combined in the same way. Guidance from the UK DEFRA⁽¹³⁾ and EPA⁽²⁾ advises that for SO₂ an estimate of the maximum combined pollutant concentration can be obtained as shown below:

SO₂ - The 99.7th percentile of total 1-hour mean SO₂ is equal to the maximum of either A or B below:

- a) 99.7th percentile of hourly mean background SO₂ + (2 x annual mean process concentration SO₂)
- b) 99.7th percentile hourly mean process contribution SO₂ + (2 x annual mean background concentration SO₂)

SO₂ - The 99.2nd percentile of total 24-hour mean SO₂ is equal to the maximum of either C or D below:

- c) 99.2nd percentile of 24-hour mean background SO₂ + (2 x annual mean process concentration SO₂)
- d) 99.2nd percentile 24-hour mean process contribution SO₂ + (2 x annual mean background concentration SO₂)

2.2 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. Air quality significance criteria are assessed on the basis of compliance with the appropriate standards or limit values. The applicable standards in Ireland include the Air Quality Standards Regulations 2011, which incorporate EU Directive 2008/50/EC which combines the previous air quality framework and subsequent daughter directives (see Table 3). Although the EU Air Quality Limit Values are the basis of legislation, other thresholds outlined by the EU Directives are used which are triggers for particular actions.

The ambient air quality standards applicable for NO₂ and SO₂ are outlined in Directive 2008/50/EC (see Table 3). These standards have been used in the current assessment to determine the potential impact of NO₂ and SO₂ emissions from the facility on air quality.

Pollutant	Regulation ^{Note 1}	Limit Type	Value
Nitrogen Dioxide (NO ₂)	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 the protection of vegetation	30 µg/m ³ NO + NO ₂
Sulphur Dioxide (SO ₂)	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
		Critical limit for the protection of ecosystems	20 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 3 Air Quality Standards Regulations 2011 (Based on Directive 2008/50/EC and S.I. 180 of 2011)

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 measured 8 x 8 km with concentrations calculated at 400 m intervals. A smaller grid measured 2 x 2 km with concentrations calculated at 50 m intervals. Boundary receptor locations were also placed along the boundary of the site at 50 m intervals giving a total of 2,236 calculation points for the model.

- Hourly-sequenced meteorological information has been used in the model. The 2012 - 2016 meteorological data from Shannon Airport has been used in the assessment.
- AERMOD incorporates a meteorological pre-processor AERMET⁽¹⁴⁾. 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. 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⁽¹⁵⁾.
- The source and emissions data, including stack dimensions, gas volumes and emission temperatures have been incorporated into the model.
- Detailed terrain has been mapped into the model using SRTM (Shuttle Radar Topography Mission) data with 30 m resolution. The site is located in relatively flat terrain. All terrain features have been mapped in detail into the model using the terrain pre-processor AERMAP.

Modelling for NO_2 and SO_2 was undertaken in detail. However, emissions of carbon monoxide (CO) may also be present in the exhaust gases. In relation to CO, no detailed modelling was undertaken. Emissions of CO are significantly lower than the NO_x emissions from the boilers relative to the ambient air quality standards. The CO ambient air quality standard is $10,000 \mu\text{g}/\text{m}^3$ compared to the 1-hour NO_2 standard of $200 \mu\text{g}/\text{m}^3$. Thus ensuring compliance with the NO_2 ambient limit value will ensure compliance for any other pollutants.

2.4 Terrain

The AERMOD air dispersion model has a terrain pre-processor AERMAP which was used to map the physical environment over the receptor grid. The digital terrain input data used in the AERMAP pre-processor was SRTM data. This data was run to obtain for each receptor point the terrain height and the terrain height scale. The terrain height scale is used in AERMOD to calculate the critical dividing streamline height, H_{crit} , for each receptor. The terrain height scale is derived from the 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⁽¹⁾ a plume embedded in the flow below H_c tends to remain horizontal; it might go around the hill or impact on it. A plume above H_c will ride over the hill. Associated with this is a tendency for the plume to be depressed toward the terrain surface, for the flow to speed up, and for vertical turbulent intensities to increase.

AERMOD model formulation states that the model “captures the effect of flow above and below the dividing streamline by weighting the plume concentration associated with two possible extreme states of the boundary layer (horizontal plume and terrain-following). The relative weighting of the two states depends on: 1) the degree of atmospheric stability; 2) the wind speed; and 3) the plume height relative to terrain. In

stable conditions, the horizontal plume “dominates” and is given greater weight while in neutral and unstable conditions, the plume traveling over the terrain is more heavily weighted”⁽¹⁾.

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

2.5 Meteorological Data

The selection of the appropriate meteorological data has followed the guidance issued by the USEPA⁽³⁾ and EPA⁽²⁾. A primary requirement is that the data used should have a data capture of greater than 90% for all parameters. Shannon Airport meteorological station, which is located approximately 178 km south of the site, collects data in the correct format and has a data collection of greater than 90%. Shannon Airport is the most representative meteorological station for the region of the AbbVie facility.

Hourly observations at Shannon Airport meteorological station provide an indication of the prevailing wind conditions for the region. Results indicate that the prevailing wind direction is from south-westerly to westerly in direction (see Figure 1).

2.6 Process Emissions

The AbbVie facility will have two new boiler stacks which will have a height of 17.4 m above ground level. The two boilers will operate in a standby/duty mode, with only one boiler in operation at any one time. However, for the purposes of this modelling assessment, both boilers have been modelled as running simultaneously as a conservative approach and to allow for any potential future need to increase capacity.

There are also a number of existing LPHW boilers (3 no.) and proposed LPHW boilers (4 no.) which emit via a common flue. Separately these emission points are all less than 1 MW, however, as advised under the Medium Combustion Plant Directive, when these emission points are aggregated they are greater than 1 MW and as such have been included in the modelling assessment. These sources have been modelled as one single emission point for the existing 3 no. LPHW boilers and one single emission point for the proposed 4 no. LPHW boilers. For the purposes of this assessment it has been assumed that all 7 the LPHW boilers are operating continuously, whereas in reality these operate in a standby/duty mode with only 5 in operation at any one time.

The manufacturer could not provide maximum emissions values for SO₂, however the manufacturer confirmed that the SO₂ emissions would be negligible. Therefore, the SO₂ concentrations for the boilers have been modelled at the MCP Directive limit value of 35 µg/m³ for gaseous fuels other than natural gas (all boilers will run on LPG) as this would be the worst case emissions scenario. NO₂ concentrations have been based on maximum emissions as specified by the manufacturer.

A cumulative assessment with the neighbouring AbbVie site has also been undertaken. The relevant source parameters for the neighbouring AbbVie site (emission points A1-1, A1-2 and A2-1c) are based on actual monitoring data over the past two years and licenced details. The source information for the modelled emission points can be seen in Table 4.

There are a number of other emission points on site, however as these have an output below 1MW there were not included in the air dispersion model as their emissions were deemed insignificant.

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Stack Reference	Location (Irish Grid Coordinates)		Height Above Ground Level (m)	Exit Diameter (m)	Temp (K) ^{Note 1}	Max Volume Flow (Nm ³ /hr) Note 2	Exit Velocity (m/sec actual)	NO ₂		SO ₂	
								NO _x Concentration (mg/Nm ³)	Mass Emission (g/s) ^{Note 3}	SO _x Concentration (mg/Nm ³)	Mass Emission (g/s) ^{Note 3}
New Boiler 1	E169867	N337606	17.4	0.355	403.2	837	4.07	200	0.048	35	0.008
New Boiler 2	E169868	N337605	17.4	0.355	403.2	837	4.07	200	0.048	35	0.008
New LPHW Boilers Combined Flue	E169861	N337604	12.5	0.25	366.2	1,187	9.30	40	0.013	35	0.012
Existing LPHW Boilers Combined Flue	E169775	N337488	12.5	0.25	366.2	1,542	12.08	40	0.017	35	0.015
A1_1	E170604	N337494	26	0.75	358	1,137	0.94	166	0.052	70	0.022
A1_2	E170604	N337494	26	0.75	366	1,518	1.28	148	0.062	70	0.030
A2-1c	E170674	N337478	15	0.3	413	1,477	8.77	200	0.082	70	0.029

Note 1 Kelvin (K) SI Unit for Temperature

Note 2 (Nm³/hr) Cubic Metres per Hour measured under normal temperature and pressure conditions, 3% O₂ and 0% moisture

Note 3 (g/s) Grams per Second

Table 4 AbbVie, Ballytivnan, Co. Sligo - Process Emissions Details

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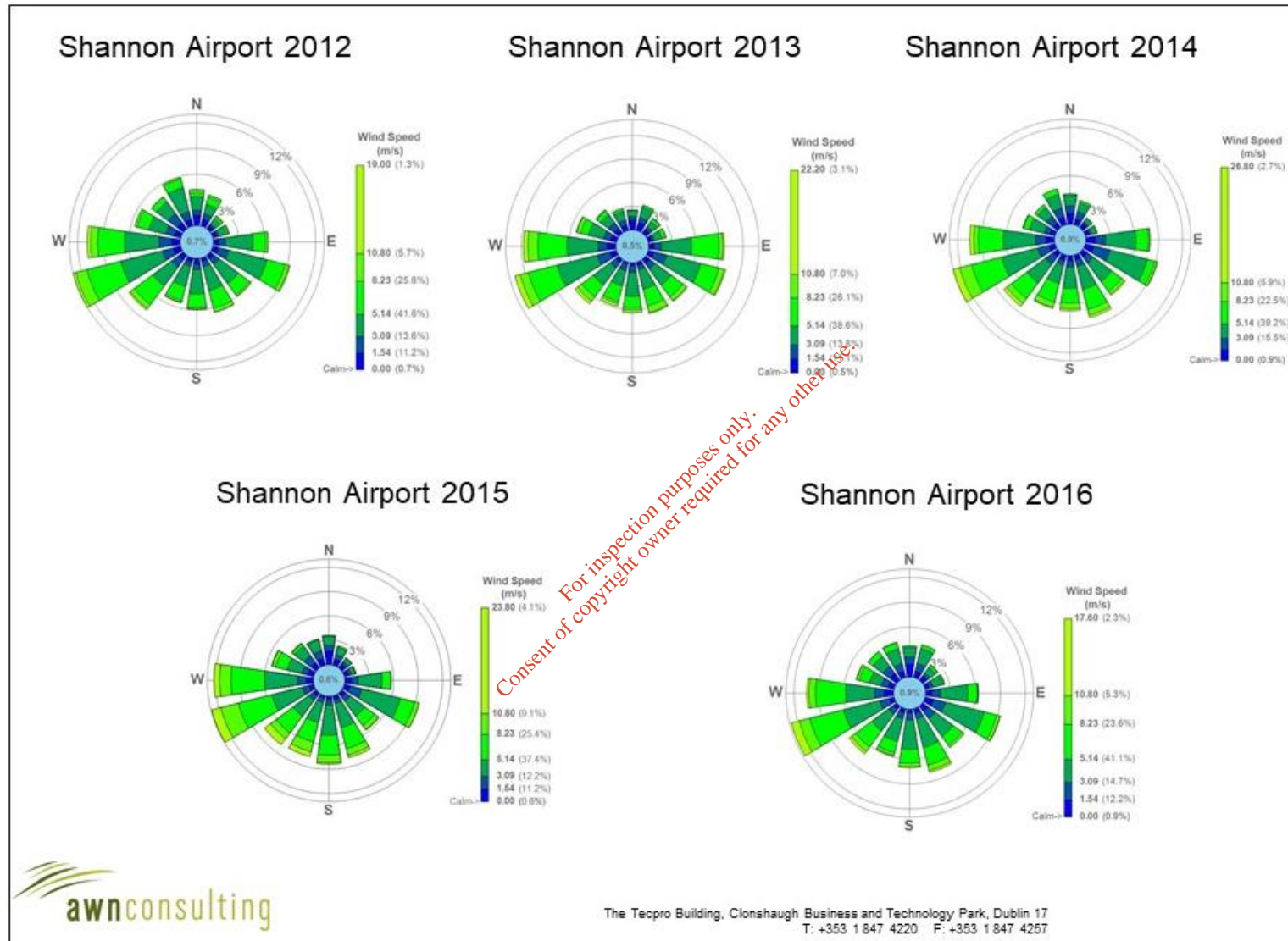


Figure 1 Shannon Airport Windrose 2012 - 2016

3.0 RESULTS & DISCUSSION

3.1 Proposed Development

NO₂

The nitrogen oxide modelling results are detailed in Table 5. The results indicate that the ambient ground level concentrations are below the annual and 1-hour ambient air quality standards. Emissions from the facility lead to an ambient NO₂ concentration (including background) which is 24% of the maximum 1-hour limit (measured as a 99.8th percentile) and 38% of the annual limit at the worst-case off-site location for the worst-case years modelled (2014 and 2015).

The geographical variations in ground level NO₂ concentrations beyond the facility boundary for the worst-case years modelled are illustrated as concentration contours in Figures 2 and 3. The locations of the maximum concentrations for NO₂ are close to the boundary of the site with concentrations decreasing with distance from the facility.

Pollutant / Meteorological Year	Background (µg/m ³)	Averaging Period	Process Contribution NO ₂ (µg/m ³)	Predicted Emission Concentration NO ₂ (µg/m ³)	Standard (µg/m ³) Note 1
NO ₂ / 2012	13	Annual Mean	2.09	15.09	40
	26	99.8 th percentile of 1-hr means	21.11	47.11	200
NO ₂ / 2013	13	Annual Mean	2.20	15.20	40
	26	99.8 th percentile of 1-hr means	22.35	48.35	200
NO ₂ / 2014	13	Annual Mean	2.31	15.31	40
	26	99.8 th percentile of 1-hr means	21.16	47.16	200
NO ₂ / 2015	13	Annual Mean	2.10	15.10	40
	26	99.8 th percentile of 1-hr means	22.39	48.39	200
NO ₂ / 2016	13	Annual Mean	2.18	15.18	40
	26	99.8 th percentile of 1-hr means	20.77	46.77	200

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

Table 5 Dispersion Model Results for Nitrogen Oxides (as NO₂) – Proposed Development

SO₂

The SO₂ modelling results are detailed in Table 6. The results indicate that the ambient ground level concentrations are below the 1-hour and 24-hour ambient air quality standards. Emissions from the facility lead to an ambient SO₂ concentration (including background) that is 21% of the maximum ambient 1-hour limit value (measured as a 99.7th percentile) and 23% of the 24-hour limit value (measured as a 99.2nd percentile) at the worst-case location off-site for the worst case years modelled (2013 and 2014).

The geographical variation in the 1-hour mean (99.7th percentile) and 24-hour mean (99.2nd percentile) SO₂ ground level concentrations are illustrated as concentration contours in Figures 4 and 5.

Pollutant/ Meteorological year	Background ($\mu\text{g}/\text{m}^3$)	Averaging Period	Process Contribution SO_2 ($\mu\text{g}/\text{m}^3$)	Predicted Environmental Concentration (PEC) SO_2 ($\mu\text{g}/\text{Nm}^3$)	Standard ($\mu\text{g}/\text{Nm}^3$) Note 1
SO_2 / 2012	14.63	24 Hour 99.2 nd %ile	18.2	26.2	125
	31.65	1-Hour 99.7 th %ile	59.0	67.0	350
SO_2 / 2013	14.63	24 Hour 99.2 nd %ile	20.8	28.8	125
	31.65	1-Hour 99.7 th %ile	57.1	65.1	350
SO_2 / 2014	14.63	24 Hour 99.2 nd %ile	19.1	27.1	125
	31.65	1-Hour 99.7 th %ile	67.0	75.0	350
SO_2 / 2015	14.63	24 Hour 99.2 nd %ile	17.5	25.5	125
	31.65	1-Hour 99.7 th %ile	56.2	64.2	350
SO_2 / 2016	14.63	24 Hour 99.2 nd %ile	19.8	27.8	125
	31.65	1-Hour 99.7 th %ile	63.2	71.2	350

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

Table 6 Dispersion Model Results for SO_2 – Proposed Development

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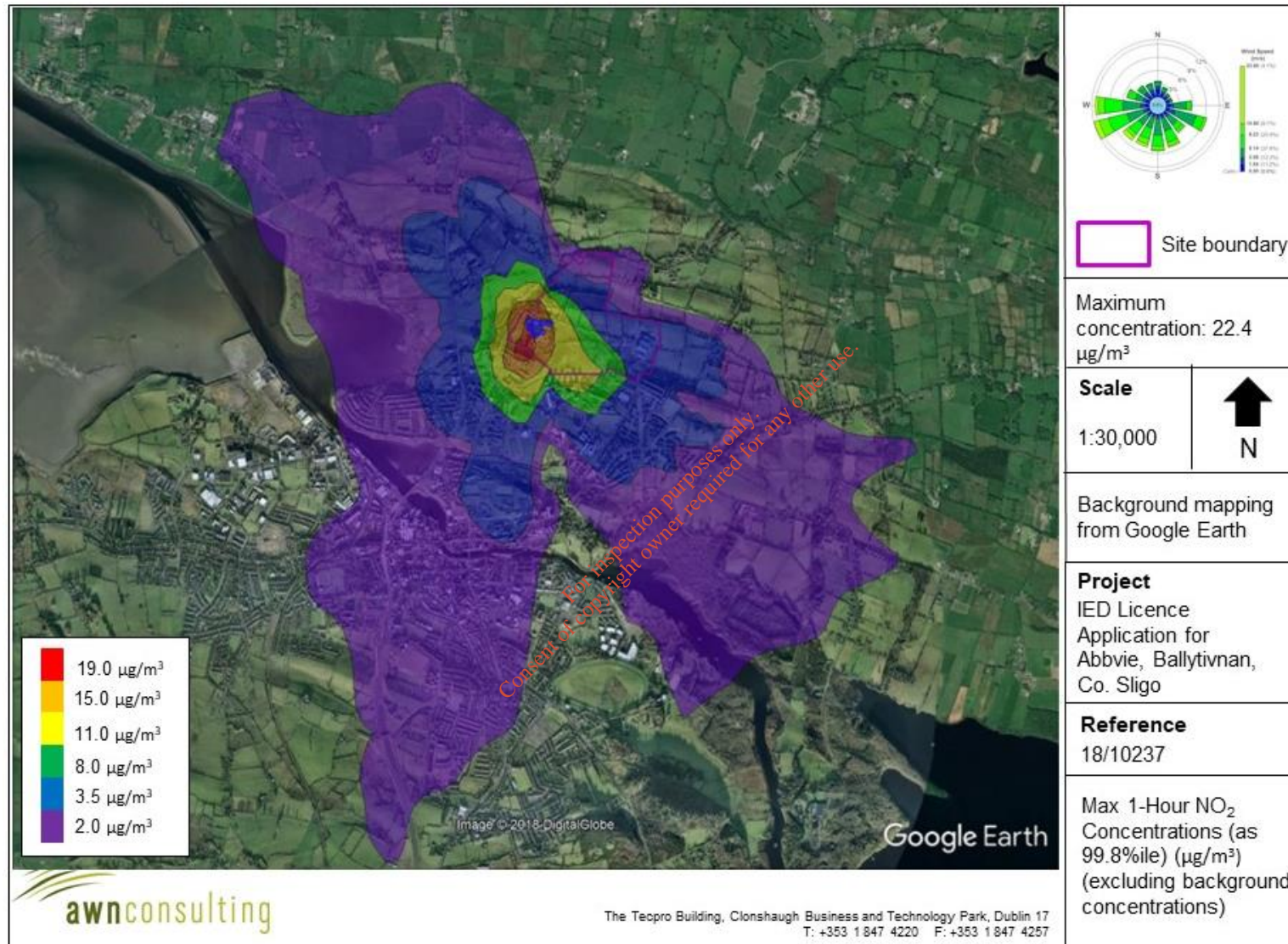


Figure 2 Maximum 1-Hour NO_2 Concentrations (as 99.8th percentile) (Year 2015)

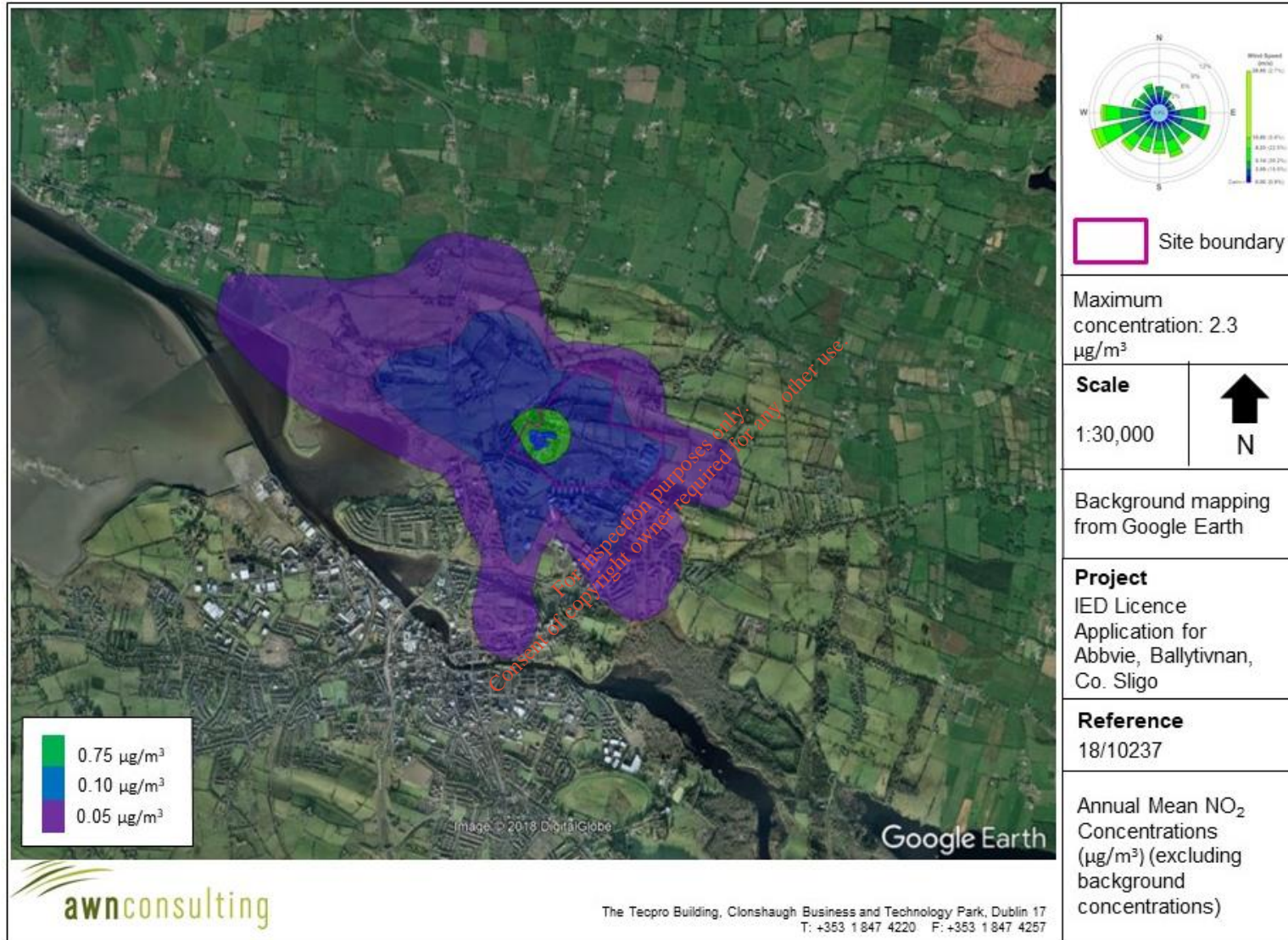


Figure 3 Annual Mean NO₂ Concentrations (Year 2014)

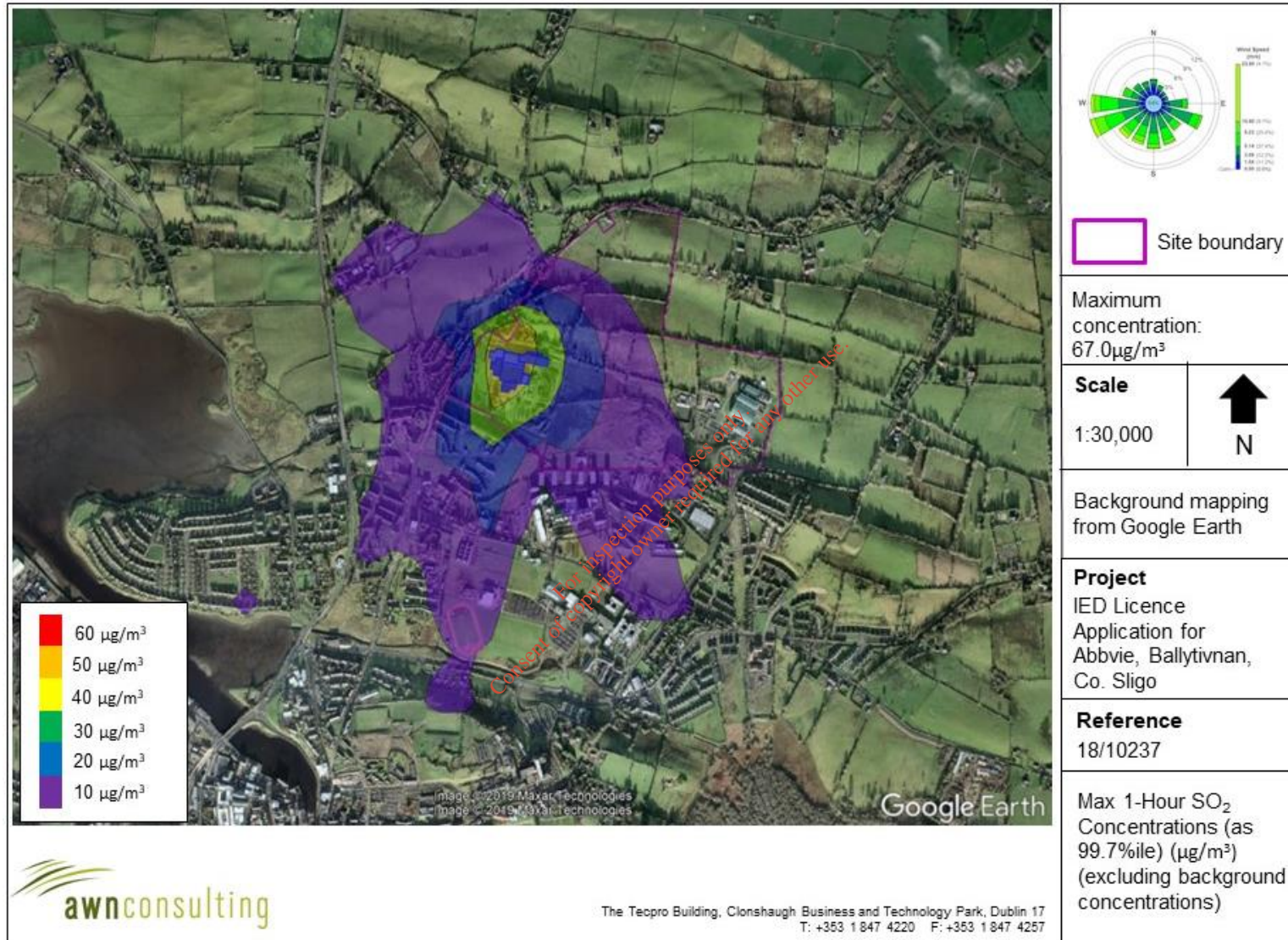


Figure 4 Maximum 1-Hour SO₂ Concentrations (as 99.7th percentile) (Year 2014)

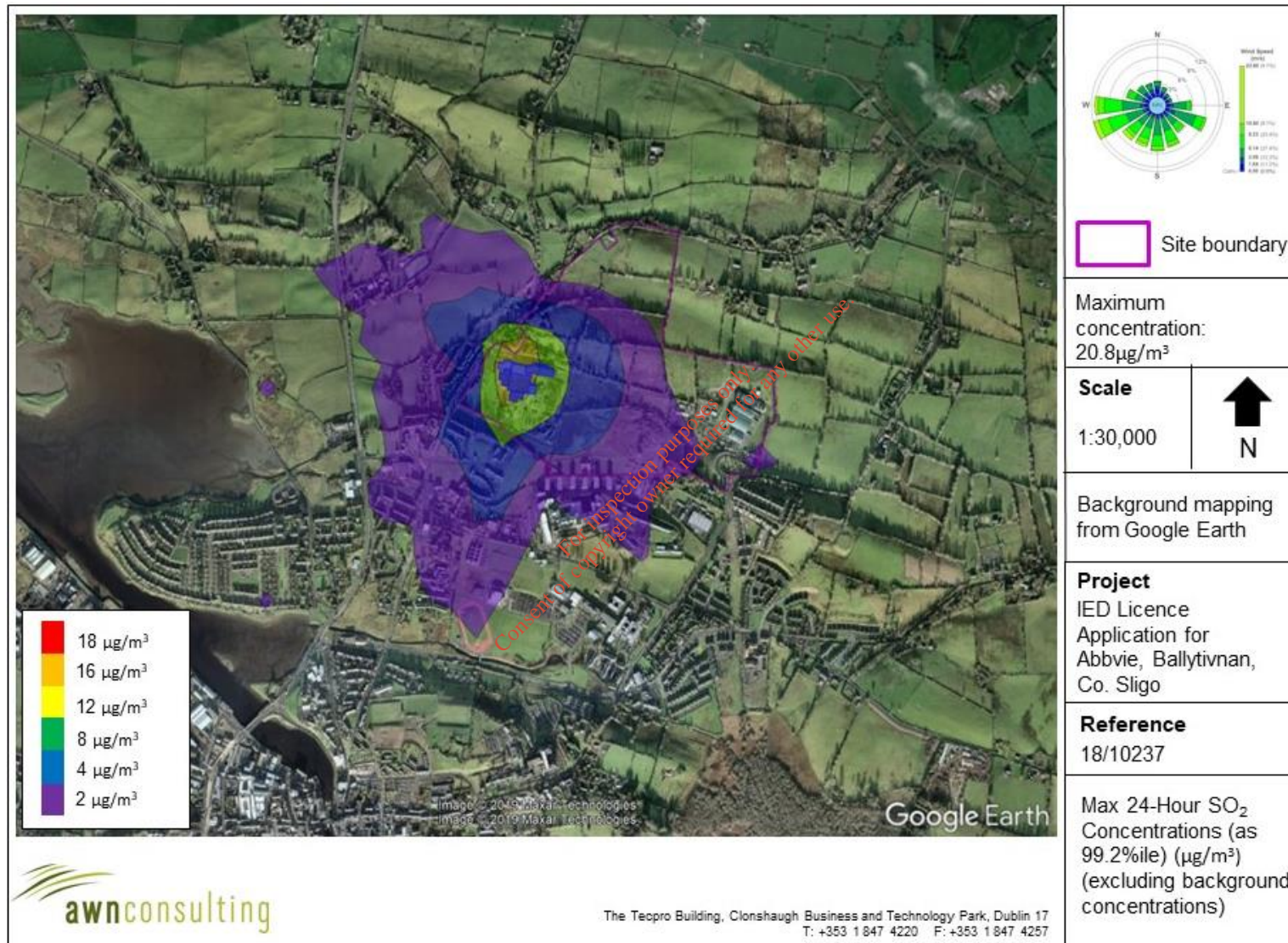


Figure 5 Maximum 24-Hour SO₂ Concentrations (as 99.2nd percentile) (Year 2013)

3.2 Cumulative Assessment

NO₂

The cumulative impact of process emissions of NO₂ from the proposed development and the neighbouring AbbVie facility are detailed in Table 7 below. The results indicate that the ambient ground level concentrations are below the relevant air quality standards for NO₂. For the worst-case year, emissions from the sites lead to an ambient NO₂ concentration (including background) which is 25% of the maximum ambient 1-hour limit value (measured as a 99.8thile) and 39% of the annual limit value at the worst-case off-site receptor for the worst-case years modelled (2014 and 2016).

Pollutant / Meteorological Year	Background (µg/m ³)	Averaging Period	Process Contribution NO ₂ (µg/m ³)	Predicted Emission Concentration NO ₂ (µg/m ³)	Standard (µg/m ³) Note 1
NO ₂ / 2012	13	Annual Mean	2.18	15.18	40
	26	99.8 th ile of 1-hr means	22.23	48.23	200
NO ₂ / 2013	13	Annual Mean	2.33	15.33	40
	26	99.8 th ile of 1-hr means	24.07	50.07	200
NO ₂ / 2014	13	Annual Mean	2.43	15.43	40
	26	99.8 th ile of 1-hr means	23.48	49.48	200
NO ₂ / 2015	13	Annual Mean	2.20	15.20	40
	26	99.8 th ile of 1-hr means	22.39	48.39	200
NO ₂ / 2016	13	Annual Mean	2.27	15.27	40
	26	99.8 th ile of 1-hr means	24.08	50.08	200

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

Table 7 Dispersion Model Results for Nitrogen Oxides (as NO₂) – Cumulative Assessment

SO₂

The SO₂ modelling results for the cumulative assessment are detailed in Table 8. The results indicate that the ambient ground level concentrations are below the 1-hour and 24-hour ambient air quality standards. Emissions from both facilities lead to an ambient SO₂ concentration (including background) that is 25% of the maximum ambient 1-hour limit value (measured as a 99.7thile) and 23% of the 24-hour limit value (measured as a 99.2ndile) at the worst-case location off-site for the worst case years modelled (2013 and 2014).

Pollutant/ Meteorological year	Background ($\mu\text{g}/\text{m}^3$)	Averaging Period	Process Contribution SO_2 ($\mu\text{g}/\text{m}^3$)	Predicted Environmental Concentration (PEC) SO_2 ($\mu\text{g}/\text{Nm}^3$)	Standard ($\mu\text{g}/\text{Nm}^3$) Note 1
SO_2 / 2012	14.63	24 Hour 99.2 nd %ile	19.1	26.3	125
	31.65	1-Hour 99.7 th %ile	75.1	82.3	350
SO_2 / 2013	14.63	24 Hour 99.2 nd %ile	21.1	28.9	125
	31.65	1-Hour 99.7 th %ile	76.9	84.7	350
SO_2 / 2014	14.63	24 Hour 99.2 nd %ile	20.0	28.5	125
	31.65	1-Hour 99.7 th %ile	80.5	89.0	350
SO_2 / 2015	14.63	24 Hour 99.2 nd %ile	18.0	25.3	125
	31.65	1-Hour 99.7 th %ile	62.1	69.4	350
SO_2 / 2016	14.63	24 Hour 99.2 nd %ile	20.3	28.3	125
	31.65	1-Hour 99.7 th %ile	77.4	85.4	350

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

Table 8 Dispersion Model Results for SO_2 – Cumulative Assessment

3.3 Assessment Summary

In conclusion, ambient levels of nitrogen oxides (as NO_2) and sulphur dioxide (SO_2) from the proposed development as well as the cumulative assessment with the neighbouring AbbVie facility are well below the air quality limit values for the protection of human health and it is predicted that air emissions from the installation will not have a significant impact on the local environment.

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APPENDIX I

Description of the AERMOD Model

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

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

In contrast to ISCST3, AERMOD is widely applicable in all types of terrain. Differentiation of the simple versus complex terrain is unnecessary with AERMOD. In complex terrain, AERMOD employs the dividing-streamline concept in a simplified simulation of the effects of plume-terrain interactions. In the dividing-streamline concept, flow below this height remains horizontal, and flow above this height tends to rise up and over terrain. Extensive validation studies have found that AERMOD (precursor to AERMOD with PRIME) performs better than ISCST3 for many applications and as well or better than CTDMPPLUS for several complex terrain data sets⁽⁷⁾.

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

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

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

APPENDIX II

Meteorological Data - AERMET

AERMOD incorporates a meteorological pre-processor AERMET (version 16216)⁽¹⁵⁾. AERMET allows AERMOD to account for changes in the plume behaviour with height. AERMET calculates hourly boundary layer parameters for use by AERMOD, including friction velocity, Monin-Obukhov length, convective velocity scale, convective (CBL) and stable boundary layer (SBL) height and surface heat flux. AERMOD uses this information to calculate concentrations in a manner that accounts for changes in dispersion rate with height, allows for a non-Gaussian plume in convective conditions, and accounts for a dispersion rate that is a continuous function of meteorology.

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

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

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

The values of albedo, Bowen Ratio and surface roughness depend on land-use type (e.g., urban, cultivated land etc) and vary with seasons and wind direction. The assessment of appropriate land-use types was carried out in line with USEPA recommendations⁽⁴⁾ and using the detailed methodology outlined by the Alaska Department of Environmental Conservation⁽¹⁷⁾. AERMET has also been updated to allow for an adjustment of the surface friction velocity (u^*) for low wind speed stable conditions based on the work of Qian and Venkatram (BLM, 2011). Previously, the model had a tendency to over-predict concentrations produced by near-ground sources in stable conditions.

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 Shannon Airport Meteorological Station is shown in Table A1.

Sector	Area Weighted Land Use Classification	Spring	Summer	Autumn	Winter ^{Note 1}
270-180	100% Grassland	0.05	0.10	0.01	0.01
180-270	100% Urban	1	1	1	1

⁽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))⁽¹⁹⁾. 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 Shannon Airport 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 Shannon Airport Meteorological Station is shown in Table A2.

Area Weighted Land Use Classification	Spring	Summer	Autumn	Winter ^{Note 1}
6% Urban, 49% Grassland, 45% Water	0.151	0.143	0.172	0.172

⁽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 x 10km grid centred on Shannon Airport 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 Shannon Airport Meteorological Station is shown in Table A3.

Area Weighted Land Use Classification	Spring	Summer	Autumn	Winter ^{Note 1}
19% Urban, 81% Grassland	0.301	0.557	0.655	0.655

⁽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 x 10km grid centred on Shannon Airport Meteorological Station.

APPENDIX III

Detailed Meteorological Data – Shannon Airport 2012 - 2016

Shannon Airport 2012

Dir \ Spd	<= 1.54	<= 3.09	<= 5.14	<= 8.23	<= 10.80	> 10.80	Total
0.0	106	51	141	40	27	4	369
22.5	70	59	100	76	21	2	328
45.0	42	22	65	29	9	0	167
67.5	40	24	79	23	8	0	174
90.0	57	68	284	130	25	2	566
112.5	60	110	404	194	40	12	820
135.0	47	71	244	141	19	1	523
157.5	34	57	253	188	39	3	574
180.0	54	58	251	138	16	5	522
202.5	38	47	214	148	20	6	473
225.0	62	89	241	237	52	17	698
247.5	79	117	440	360	118	27	1,141
270.0	86	130	357	277	72	36	958
292.5	68	91	178	126	23	1	487
315.0	76	119	150	63	1	0	409
337.5	66	85	256	92	15	0	514
Total	985	1,198	3,657	2,262	505	116	8,723
Calms							61
Missing							0
Total							8,784

Shannon Airport 2013

Dir \ Spd	<= 1.54	<= 3.09	<= 5.14	<= 8.23	<= 10.80	> 10.80	Total
0.0	106	42	65	9	0	0	222
22.5	91	57	71	27	2	0	288
45.0	57	33	74	33	9	1	207
67.5	38	30	88	48	2	0	206
90.0	56	83	339	305	42	18	843
112.5	64	148	390	209	61	14	886
135.0	58	74	223	164	50	10	579
157.5	36	52	221	193	75	12	589
180.0	32	77	265	128	27	28	557
202.5	23	77	170	179	26	32	507
225.0	42	77	237	161	60	36	613
247.5	72	146	461	330	96	59	1,164
270.0	97	99	349	324	112	47	1,028
292.5	68	79	173	91	41	10	462
315.0	69	77	112	58	5	1	322
337.5	61	58	99	27	2	0	247
Total	970	1,209	3,377	2,286	610	268	8,720
Calms							40
Missing							0
Total							8,760

Shannon Airport 2014

Dir \ Spd	<= 1.54	<= 3.09	<= 5.14	<= 8.23	<= 10.80	> 10.80	Total
0.0	118	84	112	12	2	0	328
22.5	66	80	98	25	0	0	269
45.0	56	21	44	9	0	0	130
67.5	44	23	53	14	0	1	135
90.0	102	111	332	132	18	2	697
112.5	96	181	418	81	26	5	807
135.0	65	77	250	135	34	15	576
157.5	56	71	257	222	64	27	697
180.0	58	68	229	159	62	22	598
202.5	60	52	203	207	61	10	593
225.0	62	100	250	211	64	39	726
247.5	68	126	402	335	133	74	1,138
270.0	91	113	352	271	49	45	921
292.5	58	61	166	67	6	0	358
315.0	61	92	118	35	1	0	307
337.5	87	100	153	60	0	0	400
Total	1,148	1,360	3,437	1,975	520	240	8,680
Calms							80
Missing							0
Total							8,760

Shannon Airport 2015

Dir \ Spd	<= 1.54	<= 3.09	<= 5.14	<= 8.23	<= 10.80	> 10.80	Total
0.0	146	66	93	10	0	0	315
22.5	68	49	79	19	0	0	215
45.0	52	33	45	5	0	0	135
67.5	48	29	43	8	0	0	128
90.0	70	73	256	96	4	0	499
112.5	64	130	426	159	49	2	830
135.0	48	64	198	130	49	9	498
157.5	47	40	268	233	72	29	689
180.0	36	58	327	216	79	18	734
202.5	25	51	223	216	107	55	677
225.0	39	61	212	224	77	81	694
247.5	50	77	337	372	195	102	1,133
270.0	76	94	355	361	123	59	1,068
292.5	66	67	162	127	38	6	466
315.0	71	94	129	34	4	0	332
337.5	74	85	120	13	0	0	292
Total	980	1,071	3,273	2,223	797	361	8,705
Calms							55
Missing							0
Total							8,760

Shannon Airport 2016

Dir \ Spd	<= 1.54	<= 3.09	<= 5.14	<= 8.23	<= 10.80	> 10.80	Total
0.0	137	75	100	18	0	0	330
22.5	68	86	162	42	0	0	358
45.0	57	38	76	27	4	1	203
67.5	40	43	106	17	5	1	212
90.0	65	93	288	102	6	4	558
112.5	89	131	423	138	35	5	821
135.0	70	97	236	115	27	1	546
157.5	47	64	313	191	57	23	695
180.0	38	76	308	150	35	13	620
202.5	43	68	245	126	27	11	520
225.0	43	65	219	213	57	31	628
247.5	50	104	397	371	113	87	1,122
270.0	97	102	309	319	70	22	919
292.5	64	75	128	113	27	7	414
315.0	90	93	132	61	2	0	378
337.5	70	79	164	67	4	0	384
Total	1,068	1,289	3,606	2,070	469	206	8,708
Calms							76
Missing							0
Total							8,784

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