APPENDIX 2

Determination & Air Dispersion Modelling Assessment

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STACK HEIGHT DETERMINATION AND AIR DISPERSION MODELLING ASSESSMENT OF THE BRANDON PRODUCTS FACILITY, KILCOLMAN, ASDEE, CO. KERRY

Technical Report Prepared For

Brandon Products Ltd
Kilcolman
Asdee
Co. Kerry

Technical Report Prepared By

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EXECUTIVE SUMMARY

AWN Consulting Ltd (AWN) were commissioned to assess the current odour impact of the Brandon Products facility in Kilcolman, Asdee, County Kerry. The purpose of the assessment was to determine whether the current odour emissions from the facility and in particular from the existing bioscrubber are leading to ambient odour concentrations which are in compliance with the relevant ambient guidelines for odour. AWN Consulting were further commissioned to consider additional options in order to identify the most efficient means of ensuring that no odour nuisance will occur at nearby sensitive receptors.

Dispersion modelling results show that under a pessimistic scenario of current operations of the Brandon Products facility, the 99.5^{th}%ile of mean hourly odour concentrations ranges from 0.84 – 0.90 OU_E/m^3 at the worst-case offsite residential receptor whilst the 99.5^{th}%ile of mean hourly odour concentrations ranges from 1.3 – 1.5 OU_E/m^3 anywhere offsite. The worst-case odour concentration of 1.5 OU_E/m^3 is equivalent to the relevant odour criterion. The maximum odour concentration peaks at the residential receptors located to the north-west of the boundary of the facility with ambient odour concentrations greater than 1.0 OU_E/m^3 limited to a small area near this peak.

Given that the odour dispersion modelling assessment found that current operations were leading to occasional odour detection at nearby receptors, AWN Consulting undertook an assessment of potential mitigation options in order to identify the most efficient means of ensuring that no odour nuisance will occur at nearby sensitive receptors.

The proposed abatement option recommended is a combined three-staged abatement system consisting of the following:

- Currently, all odorous processes are directed through a bioscrubber system with sufficient residence time and abatement efficiency to ensure a residual odour concentration of no more than 3000 OU_E/m^3.
- It is proposed to install an AEROX ozone abatement unit after the bioscrubber which will achieve an additional abatement efficiency of between 50 – 70%.
- This treated air from the bioscrubber and AEROX unit will be directed via a stack prior to release to atmosphere. The stack diameter of 0.60m has recently been reduced to 0.30m in order to ensure that the efflux velocity is increased to ensure that the momentum of the plume is maximized. The stack height was increased from an initial height of 15m to 17m, then 20m and thereafter 25m to determine the optimum stack height for the facility to ensure no odour nuisance beyond the site boundary.

The dispersion modelling results indicate that under the proposed conservative operational scenario of the Brandon Products facility, the 99.5^{th}%ile of mean hourly odour concentrations ranges from 0.14 – 0.44 OU_E/m^3 at the worst-case offsite residential receptor based on a stack height ranging from 15 – 25m. The worst-case odour concentration of 0.14 OU_E/m^3 at a stack height of 25m is 9% of the relevant odour criterion.

The odour impact off-site decreases as the stack height is increased from 15m, through 17m & 20m to 25m. The results indicate that no odour is likely to be detected at the nearest residential receptor at a stack height of 17m, 20m or 25m. Thus, although a stack height of 17m is likely to be sufficient to avoid odour nuisance it is recommended that a stack height of 25m be selected on the basis of an optimum solution to ensure that any risk of odour nuisance is minimised.

All levels are well below the 1.5 OU_E/m^3 at a stack height of 25m with levels at residential receptors a small fraction of this level. Thus, based on the results from the air dispersion model, ambient odour concentrations are predicted to be well below the odour limit value everywhere offsite. Compared to the existing situation, at a stack height of 15m, the 99.5th%ile of mean hourly odour concentrations will decrease from 1.37 OU_E/m^3 to 0.17 OU_E/m^3 anywhere offsite. This represents an improvement in ambient odour levels of 800%.

Compared to the ambient odour levels at the initial stack diameter of 0.60m, which represented the existing situation to the end of October 2013, and which represents the operating scenario correlating with the complaint log, predicted odour levels (as a 99.5th%ile of mean hourly odour concentrations) will be over ten times lower than this and thus it would be expected that the frequency of odour complaints will be significantly reduced at a stack height of 25m.

Under the worst-case scenario of the simultaneous failure of both the bioscrubber and AEROX abatement systems, the 99.5th%ile of mean hourly odour concentrations will be 0.84 OU_E/m^3 at the worst-case offsite residential receptor based on a stack height of 25m. The worst-case odour concentration of 0.84 OU_E/m^3 at a stack height of 25m is 56% of the relevant odour criterion. Thus, based on the results from the air dispersion model, ambient odour concentrations are predicted to be well below the odour limit value everywhere offsite even under circumstances where the odour abatement (bioscrubber & AEROX) fails.

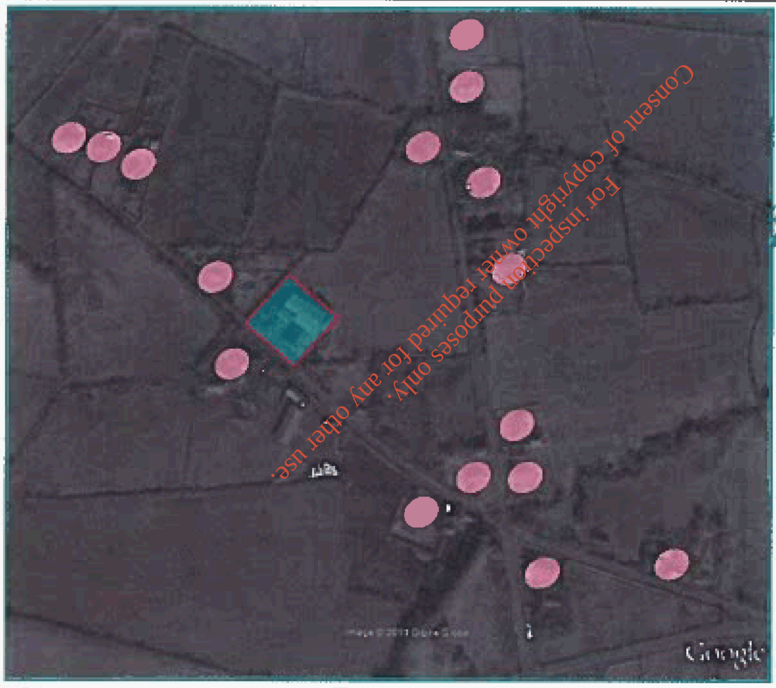
CONTENTS

1.0 INTRODUCTION

AWN Consulting Ltd (AWN) were commissioned to assess the current odour impact of the Brandon Products facility in Kilcolman, Asdee, County Kerry. The purpose of the assessment was to determine whether the current odour emissions from the facility and in particular from the existing bioscrubber are leading to ambient odour concentrations which are in compliance with the relevant ambient guidelines for odour. AWN Consulting were further commissioned to consider additional options in order to identify the most efficient means of ensuring that no odour nuisance will occur at nearby sensitive receptors.

1.1. Current Operations

Brandon Products Ltd is located on the south side of the Shannon estuary between the village of Asdee and Ballybunnion. The site is approximately 0.9 acres and is located in close proximity to several residential receptors as shown in Figure 1.

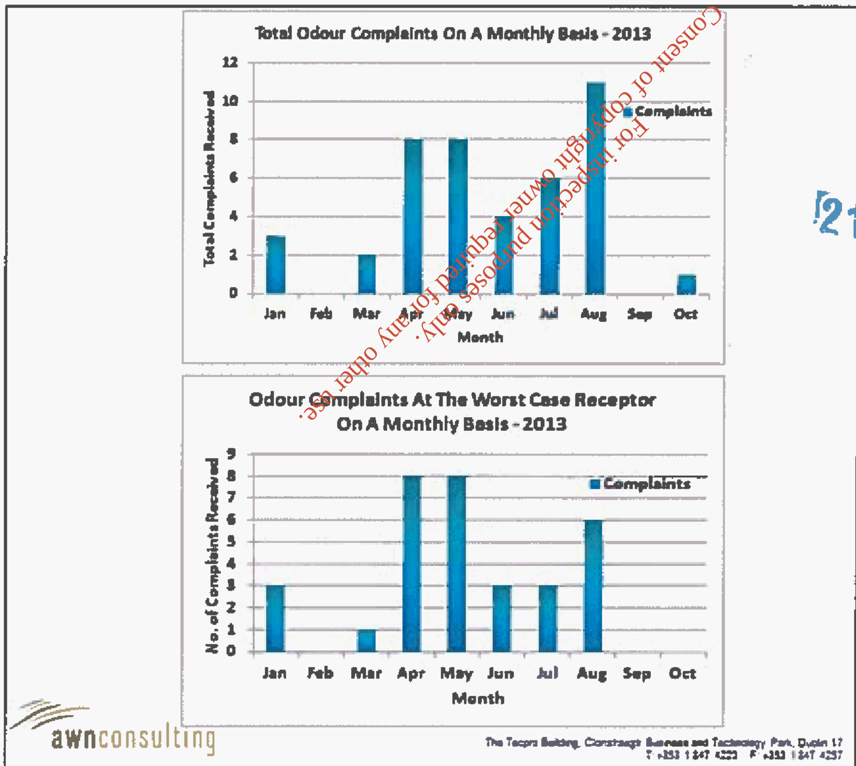


Project	Brandon Products Odour Assessment
Reference	14/7159AR01
Figure 1	Site Location And Nearby Residential Receptors

Brandon Products Ltd manufactures a liquid seaweed extract for use in horticulture and amenity grass care markets. The raw materials used in the process are seaweed, water, extracting salts and proprietary mixtures. The production process is based on a staged process. Firstly the ingredients are added to the pressure vessels to initiate the extraction process which is left overnight prior to emptying into the storage tank. The second step is the solids separation which is based on centrifuge separation. The associated vapours from the solids and centrate leaving the centrifuge are collected and treated via the bioscrubber. The next stage in the process is the evaporation of excess water in the low temperature vacuum evaporator. Finally the product is generally sent off-site in a concentrate state. In terms of odour, the facility has been designed to ensure that fugitive odour releases are minimised. All tanks and process equipment are collected and fed into the bioscrubber air treatment system whilst the condensate from the evaporation process is stored in an insulated tank and returned as boiler feed water. The operations at the facility are designed to minimise odour including the following actions:

- All processes are untaken within the process building
- All raw material and products are stored within the process building
- Seaweed sludge is enclosed in a sealed skip which is connected to the bioscrubber
- The bioscrubber is designed with a residence time of 8 seconds based on a counter current flow with a volume flow of 10,000 Nm^3/hr.

Despite the design of the facility to ensure that fugitive odour releases are minimised and that all odorous streams are diverted via the bioscrubber, occasional odour complaints have occurred over recent years. As shown in Figure 2, odour complaints have occurred on a regular basis in 2013.



Project	Brandon Products Odour Assessment
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Figure 2	Total Odour Complaints in 2013 (to end of October)

As of the end of October 2013, there have been 43 odour complaints from 4 known sensitive receptors with a peak of 32 complaints from one receptor since the start of 2013. The duration of each odour complaint has not been logged but assuming that a typical complaint lasts for a 3 hour period (variations in wind direction will generally ensure that any odour nuisance at a specific receptor will have a limited duration), the worst-case receptor would have detected odour from the facility for a period of 96 hours or 1.3% of the year up until the end of October. As the odour criterion is set as a 98th%ile, the frequency of odour detection at this residence would not strictly constitute an odour nuisance assuming this frequency is maintained for the full calendar year. However, Brandon Products are dedicated to reducing the frequency of odour occurrences and thus mitigation options have been investigated below with the aim of reducing ambient odour levels well below the guideline values at the nearest residential receptors.

Odour dispersion modelling for both the current operating scenario and the proposed operating scenario has been carried out using the United States Environmental Protection Agency's regulatory model AERMOD (Version 13350). The aim of the study was to assess the potential odour emissions associated with the current and future operations onsite and to quantify the ambient predicted odour levels relative to the ambient odour guideline values. The assessment was conducted using the methodology outlined in "*Air Dispersion Modelling from Industrial Installations Guidance Note (AG4) (EPA, 2010)*"[1].

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

- Review of onsite odour measurements and other relevant information needed for the modelling study;
- Dispersion modelling of odour emissions based on realistic operating conditions. The aim of this assessment is to determine current odour impact based on a realistic assessment of current operations;
- Dispersion modelling of odour emissions based on various proposed abatement solutions. The aim of this assessment is to determine the most efficient means to reduce ambient levels of odour;
- Presentation of predicted ground level concentrations of both current and proposed odour impact at the nearest sensitive receptors;
- Evaluation of the significance of these predicted concentrations, including consideration of whether these ground level odour concentrations are exceeding the relevant ambient odour guideline value.

Information supporting the conclusions has been detailed in the following sections. The assessment methodology and study inputs are presented in Section 2. The odour 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

Odour emissions from the facility have been modelled using the AERMOD dispersion model (Version 13350) which has been developed by the U.S. Environmental Protection Agency (USEPA)[2,3]. 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[8-11]. An overview of the AERMOD dispersion model is outlined in Appendix I.

The odour dispersion modelling input data consisted of information on the physical environment (including building dimensions and terrain features), design details from all emission sources on-site and a full year of appropriate meteorological data. Using this input data the model predicted ambient ground level odour 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 odour concentration. This worst-case concentration was then compared with the relevant ambient odour guideline values 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:

- A conservative odour emission concentration has been selected for the facility;
- A conservative odour guideline value has been selected for the facility;
- Continuous operation of the facility has been assumed (24 hours / 7 days per week) whereas in reality, operations will be limited to six days per week between the hours of 06:00 – 22:00 Monday to Saturday.
- Compliance with the odour guideline value has been determined at the boundary of the site irrespective of whether any sensitive receptors are currently present at these locations.

2.1 Characteristics of Odour

Odours are sensations resulting from the reception of a stimulus by the olfactory sensory system, which consists of two separate subsystems: the olfactory epithelium and the trigeminal nerve. The olfactory epithelium, located in the nose, is capable of detecting and discriminating between many thousands of different odours and can detect some of them in concentrations lower than those detectable by currently available analytical instruments[12]. The function of the trigeminal nerve is to trigger a reflex action that produces a painful sensation. It can initiate protective reflexes such as sneezing to interrupt inhalation. The olfactory system is extremely complex and peoples' responses to odours can be variable. This variability is the result of differences in the ability to detect odour; subjective acceptance or rejection of an odour due to past experience; circumstances under which the odour is detected and the age, health and attitudes of the human receptor.

Odour Intensity and Threshold

Odour intensity is a measure of the strength of the odour sensation and is related to the odour concentration. The odour threshold refers to the minimum concentration of an odorant that produces an olfactory response or sensation. This threshold is normally determined by an odour panel consisting of a specified number of people, and the numerical result is typically expressed as occurring when 50% of the panel correctly detect the odour. This odour threshold is given a value of one odour unit and is expressed as 1 OU_E/m^3. The odour threshold is not a precisely determined value, but depends on the sensitivity of the odour panellists and the method of presenting the odour stimulus to the panellists. An odour detection threshold relates to the minimum odorant concentration required to perceive the existence of the stimulus, whereas an odour recognition threshold relates to the minimum odorant concentration required to recognise the character of the stimulus. Typically, the recognition threshold exceeds the detection threshold by a factor of 2 to 10[12-13].

Odour Character

The character of an odour distinguishes it from another odour of equal intensity. Odours are characterised on the basis of odour descriptor terms (e.g. putrid, fishy, fruity etc.). Odour character is evaluated by comparison with other odours, either directly or through the use of descriptor words.

Hedonic Tone

The hedonic tone of an odour relates to its pleasantness or unpleasantness. When an odour is evaluated in the laboratory for its hedonic tone in the neutral context of an olfactometric presentation, the panellist is exposed to a stimulus of controlled intensity and duration. The degree of pleasantness or unpleasantness is determined by each panellist's experience and emotional associations. The responses among panellists may vary depending on odour character; an odour pleasant to many may be declared highly unpleasant by some.

Adaptation

Adaptation, or Olfactory Fatigue, is a phenomenon that occurs when people with a normal sense of smell experience a decrease in perceived intensity of an odour if the stimulus is received continually. Adaptation to a specific odorant typically does not interfere with the ability of a person to detect other odours. Another phenomenon known as habituation or occupational anosmia occurs when a worker in an industrial situation experiences a long-term exposure and develops a higher threshold tolerance to the odour.

2.2 Odour Guidelines

The exposure of the population to a particular odour consists of two factors; the concentration and the length of time that the population may perceive the odour. By definition, 1 OU_E/m^3 is the detection threshold of 50% of a qualified panel of observers working in an odour-free laboratory using odour-free air as the zero reference (the selection criteria result in the qualified panel being more sensitive to a particular odorant than the general population). The recognition threshold is generally about five times this concentration (5 OU_E/m^3) and the concentration at which the odour may be considered a nuisance is between 5 and 10 OU_E/m^3 based on hydrogen sulphide (H_2S)[14]. Clarkson and Misslebrook[15] proposed that a "faint odour" was an acceptable threshold criterion for the assessment of odour as a nuisance. Historically, it has been generally accepted that odour concentrations of between 5 and 10 ou/m^3 would give rise to a faint odour only, and that only a distinct odour (concentration of >10 OU_E/m^3) could give rise to a nuisance[16]. However, this criterion has generally been based on waste water treatment plants where the source of the odour is generally hydrogen sulphide. In 1990, a survey of the populations surrounding 200 industrial odour sources in the Netherlands showed that there were no justifiable complaints when 98%ile compliance with an odour exposure standard of a "faint odour" (5-10 OU_E/m^3) was achieved[17].

DEFRA[18,19] in the UK has published detailed guidance on appropriate odour threshold levels based in part on the offensiveness of the odour. As shown in Table 1, a seaweed manufacturing facility is not included in the list although the odour generated could be considered similar to other facilities which use a similar abatement system such as a biofilter or carbon filtration system.

DEFRA has also detailed installation-specific exposure criteria based on the "annoyance potential"[18] which is defined as "the likelihood that a specific odorous mixture will give reasonable cause for annoyance in an exposed population". Industrial sources have been ranked into three categories based on their relative offensiveness which are "low", "medium" and "high" and exposure criteria assigned to each category (as shown in Table 2). The relevant exposure criteria vary from 1.5 OU_E/m^3 for highly odorous sources to 6.0 OU_E/m^3 for the least offensive odours. The relevant exposure criteria for a seaweed manufacturing facility, in circumstances where the air is extracted and treated via a bioscrubber prior to release to atmosphere, is not included but may be assumed to be 3.0 OU_E/m^3 which should be expressed as a 98^{th}%ile and based on one hour means over a one-year period in the absence of any local factors. However, in order to ensure that a conservative approach is taken to the current assessment and in acknowledgement of the recent history of complaints, a lower odour guidance level of 1.5 OU_E/m^3 (as a 98^{th}%ile) has been selected for the current assessment.

Table 1 Ranking Table For Various Industrial Sources[18]

Environmental Odour Industrial Source	Ranking UK Median	Ranking UK Mean	Ranking Dutch Mean
Bread Factory	1	2.5	1.7
Coffee Roaster	2	3.9	4.6
Chocolate Factory	3	4.6	5.1
Beer Brewery	6	7.7	8.1
Fragrance & Flavour Factory	8	8.5	9.8
Charcoal Production	8	9.2	9.4
Green Fraction composting	9	10.3	14
Fish smoking	9	10.5	9.8
Frozen Chips production	10	11	9.6
Sugar Factory	11	11.3	9.8
Car Paint Shop	12	11.7	9.8
Livestock odours	12	12.6	12.8
Asphalt	13	12.7	11.2
Livestock Feed Factory	15	14.2	13.2
Oil Refinery	14	14.3	13.2
Car Park Bldg	15	14.4	8.3
Wastewater Treatment	17	16.1	12.9
Fat & Grease Processing	18	17.3	15.7
Creamery/milk products	10	17.7	-
Pet Food Manufacture	19	17.7	-
Brickworks (burning rubber)	18	17.8	-
Slaughter House	19	18.3	17.0
Landfill	20	18.5	14.1

Table 2 Indicative Odour Standards Based On Offensiveness Of Odour[18]

Industrial Sectors	Relative Offensiveness of Odour	Indicative Criterion
Rendering Fish Processing Oil Refining Creamery WWTP Fat & Grease Processing	High	1.5 OU_E/m^3 as a 98th%ile of hourly averages at the worst-case sensitive receptor
Intensive Livestock Rearing Food Processing (Fat Frying) Paint-spraying Operations Asphalt Manufacture	Medium	3.0 OU_E/m^3 as a 98th%ile of hourly averages at the worst-case sensitive receptor
Brewery Coffee Roasting Bakery Chocolate Manufacturing Fragrance & Flavouring	Low	6.0 OU_E/m^3 as a 98th%ile of hourly averages at the worst-case sensitive receptor

2.3 Odour Dispersion Modelling Methodology

The United States Environmental Protection Agency (USEPA) approved AERMOD dispersion model[2,3] 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:

- A receptor grid was 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 grid was based on Cartesian grids with the site at the centre. The grid extended over a distance of 1000m with concentrations calculated at 25m intervals. Boundary receptor locations were also placed along the boundary of the site, at 20m intervals, giving a total of 1701 calculation points for the model.

- All on-site and offsite buildings and significant process structures were mapped into the computer to create a three dimensional visualisation of the site and its emission sources. Buildings and process structures can influence the passage of airflow over the emission sources 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 where relevant.

- Hourly-sequenced meteorological information has been used in the model. Appropriate meteorological data for 2000 – 2002, 2004 and 2005 (Shannon Airport) was selected for use in the model (see Figure 2).

- AERMOD incorporates a meteorological pre-processor AERMET PRO[20]. 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[20].

- The source and emission 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 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.

2.4 Terrain

The AERMOD air dispersion model has a terrain pre-processor AERMAP which was used to map the physical environment in detail over the receptor grid. The digital terrain input data used in the AERMAP pre-processor was obtained from the 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.

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]. 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 48 km north-east of the site, collects data in the correct format and has a data collection of greater than 90%.

Long-term hourly observations at Shannon Airport meteorological station provide an indication of the prevailing wind conditions for the region (see Figure 2 for the wind profile in 2000 – 2002, 2004 - 2005). Results indicate that the prevailing wind direction is from south-easterly to westerly in direction. The mean wind speed is approximately 4.7 m/s over the period 1981-2010.

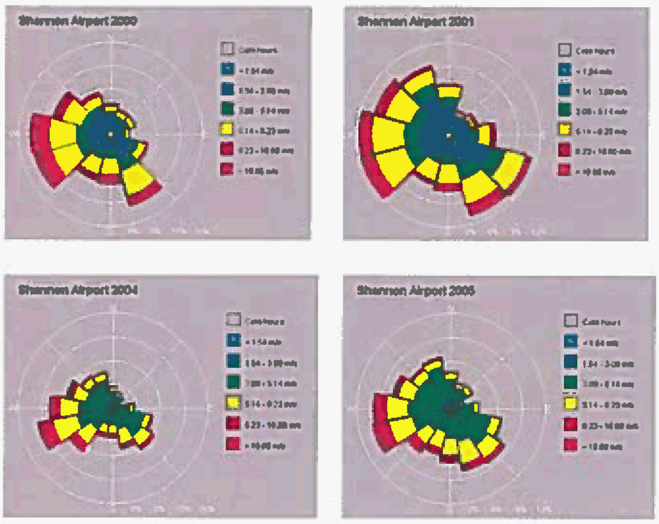

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Figure 3
Shannon Airport Windrose 2000 – 2002, 2004 and 2005

2.6 Odour Emission Rates From Brandon Products Ltd

An estimate of the current odour emission rate from the facility has been undertaken based on data available for two recent surveys of the bioscrubber. Odour Monitoring Ireland undertook an odour efficiency test of the bioscrubber in 2011 (Report Number 20125092)). The results are outlined in Table 3.

A second survey was undertaken by Catalyst Environmental in 2013. The survey was focused on testing the efficiency of an AEROX unit downstream of the bioscrubber unit. Thus, the inlet results in this assessment were actually the outlet concentration from the bioscrubbers. The results from this survey are as included in Table 3.

The data, in Table 3, indicates that the odour concentration, post-abatement of the bioscrubber, ranges from 600 – 2100 OU_E/m^3 with a reported removal efficiency of 62% based on the 2011 survey.

Table 3 Odour Emission Concentrations And Removal Efficiency From Brandon Products Ltd Bioscrubber

Survey	Samples	Odour Emission Concentration (OU_E/m^3)	Odour Emission Concentration – Average (OU_E/m^3)	Odour Removal Efficiency (%)	Odour Emission Rate (OU_E/s)
OMI Survey - 2011	Inlet	1,689	1,881	62% (bioscrubber efficiency)	N/A
		1,824			
		2,128			
	Outlet	670	712		1,003 (volume flow = 5,069 m^3/hr)
		845			
		621			
Catalyst Environmental - 2013	Outlet	2,098	1,842	60% (AEROX efficiency)	8,014 (volume flow = 15,663 m^3/hr)
		1,618			
	After AEROX Unit	906	733		3,111 (volume flow = 15,663 m^3/hr)
		594			

A review of the range of odour concentrations from two surveys (see Table 3) indicates that a worst-case odour concentration from the bioscrubber outlet at the facility is likely to be 2000 OU_E/m^3 with levels outside of production likely to be significantly lower. However, for the purposes of this modelling assessment the assumed post-abatement odour concentration was assumed to be 3,000 OU_E/m^3 (an increase of 60% above the average 2013 post-abatement odour concentration).

Table 4 outlines the odour concentration and derived odour emission rate from the facility's bioscrubber. The overall OER (odour emission rate) in odour units per sec (OU_E/s) is derived based on an odour concentration of 3000 OU_E/m^3 and a volume flow of 10,000 Nm^3/hr. The stack diameter has recently been reduced from 0.60 m to 0.30 m in order to aid dispersion of the plume.

Table 4 Worst-case Odour Emission Rates From The Bioscrubber At The Brandon Products Facility

Stack Reference	Exit Diameter (m)	Cross-Sectional Area (m^2)	Temp (K)	Max Volume Flow (Nm^3/hr)	Exit Velocity (m/sec actual)	Odour	
						Concentration (OU_E/m^3)	Mass Emission (OU_E/s)
Bioscrubber Inlet	0.30	0.071	Ambient	10,000	40.7	7,500 Note 1	20,833
Bioscrubber Outlet	0.30	0.071	Ambient	10,000	40.7	3,000 Note 1	8,333

Note 1 Based on a bioscrubber efficiency of 60%

Table 5 outlines the odour concentration and derived odour emission rate from the facility's proposed AEROX unit which will treat the odorous air downstream of the bioscrubber. The overall OER (odour emission rate) in odour units per sec (OU_E/s) is derived based on an odour inlet concentration of 3000 OU_E/m^3 and a volume flow of 10,000 Nm^3/hr.

Table 5 Worst-case Odour Emission Rates From The AEROX Abatement Unit At The Brandon Products Facility

Stack Reference	Exit Diameter (m)	Cross-Sectional Area (m^2)	Temp (K)	Max Volume Flow (Nm^3/hr)	Exit Velocity (m/sec actual)	Odour	
						Concentration (OU_E/m^3)	Mass Emission (OU_E/s)
AEROX Inlet	0.30	0.071	Ambient	10,000	40.7	3,000 Note 1	8,833
AEROX Outlet	0.30	0.071	Ambient	10,000	40.7	1,500 Note 1	4,167

Note 1 Based on an AEROX efficiency of 50%

3.0 RESULTS & DISCUSSION

3.1 Odour Dispersion Modelling Results – Current Situation

The current situation is based on the bioscrubber in operation at a stack height of 15m. The AEROX unit is not yet in operation.

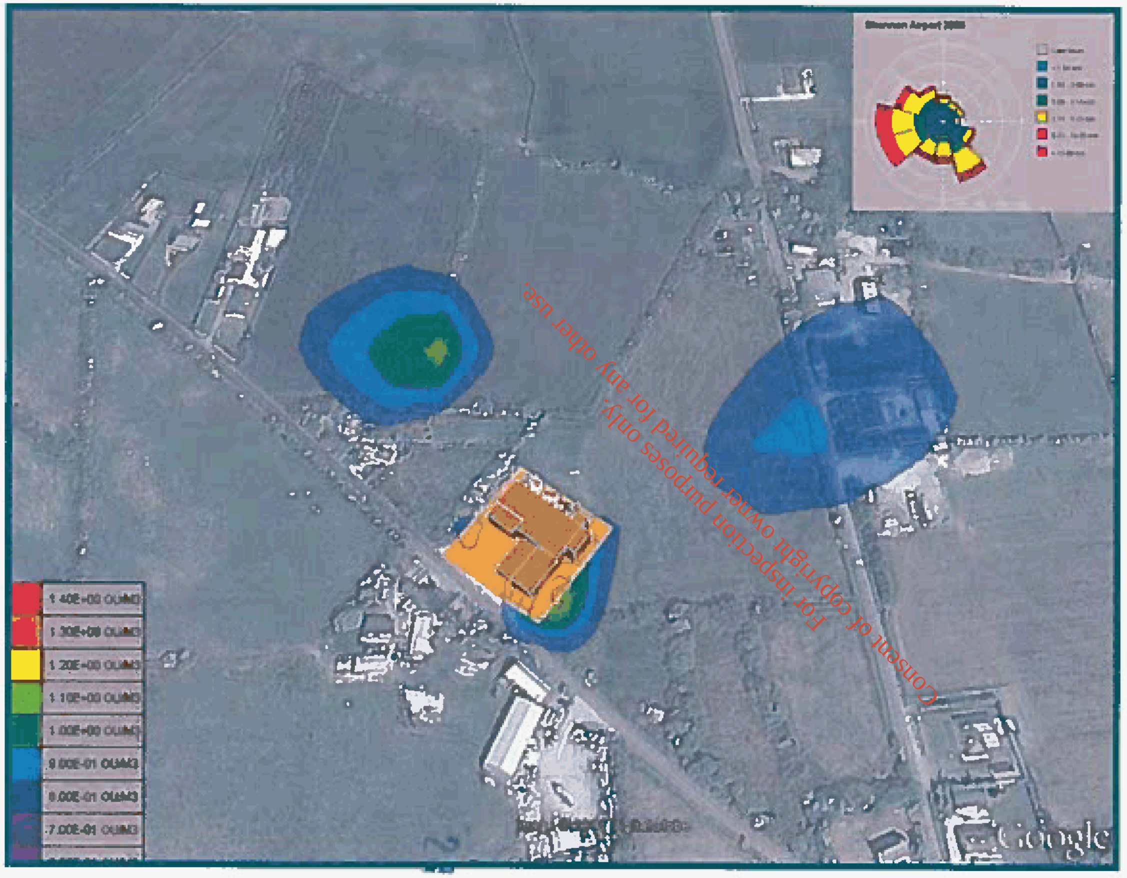
The predicted odour concentration is the maximum concentration predicted at the site boundary and beyond irrespective of whether any residential receptors are currently located at each location. This robust approach allows the assessment of odour impacts in areas which currently are not occupied by sensitive receptors.

It has been estimated that odour emissions will mainly occur from the bioscrubber (see Table 4). It is likely that other minor sources of odour may occur due to fugitive releases from the main building. However, the conservative nature of the selection of an appropriate odour concentration and worst-case approach to odour emission rates will ensure that the overall site odour emission rate of greater than 8,300 OU_E/s will be an over-estimation of reality.

Details of the maximum, 99.5th%ile and 98th%ile of 1-hour mean odour concentrations at the boundary of the site and at the nearest residential receptor are given in Table 6 over a five-year period based on the USEPA approved AERMOD model (version 12345). Figure 4 shows the ambient odour concentration contour pattern (as a 99.5th%ile of one-hour concentrations) in the vicinity of the facility for the worst-case year (in terms of the maximum impact at any receptor) of 2000.

Table 6 Current Situation (Bioscrubber Only, Stack Height 15m) - Predicted Odour Concentration At Worst-case Offsite Receptor – Brandon Products Facility (OU_E/m^3)

Model Scenario / Meteorological Year	Averaging Period	Predicted Odour Conc. (OU_E/m^3) Boundary Of Facility	Predicted Odour Conc. (OU_E/m^3) Nearest Residential Receptor	Guideline (OU_E/m^3) EPA AG4 (2010)
Ambient Odour Concentration / 2000	Maximum 1-Hour	2.8	2.6	N/A
Ambient Odour Concentration / 2001		2.9	2.6	
Ambient Odour Concentration / 2002		3.0	2.3	
Ambient Odour Concentration / 2004		1.6	1.1	
Ambient Odour Concentration / 2005		2.9	2.4	
Ambient Odour Concentration / 2000	Maximum 1-Hour (as a 99.5th%ile)	1.4	0.87	1.0 / 2.0 (New Zealand Guidance)
Ambient Odour Concentration / 2001		1.5	0.90	
Ambient Odour Concentration / 2002		1.3	0.86	
Ambient Odour Concentration / 2004		1.4	0.89	
Ambient Odour Concentration / 2005		1.4	0.84	
Ambient Odour Concentration / 2000	Maximum 1-Hour (as a 98th%ile)	0.94	0.59	1.5 (UK Guidance)
Ambient Odour Concentration / 2001		1.0	0.65	
Ambient Odour Concentration / 2002		0.79	0.64	
Ambient Odour Concentration / 2004		1.1	0.63	
Ambient Odour Concentration / 2005		1.1	0.57	



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Project	Brandon Products Odour Assessment
Reference	14/7159AR01
Figure 4	Ambient Odour Concentration (OU_E/m^3) as a 99.5th%ile (Year 2000)

The dispersion modelling results presented in Table 6 show that under a pessimistic scenario of current operations of the Brandon Products facility, the 99.5th%ile of mean hourly odour concentrations ranges from 0.84 – 0.90 OU_E/m^3 at the worst-case offsite residential receptor whilst the 99.5th%ile of mean hourly odour concentrations ranges from 1.3 – 1.5 OU_E/m^3 anywhere offsite. The worst-case odour concentration of 1.5 OU_E/m^3 is equivalent to the relevant odour criterion. As shown in Figure 4, the maximum odour concentration peaks at the residential receptors is to the north-west of the boundary of the facility with ambient odour concentrations greater than 1.0 OU_E/m^3 limited to a small area near this peak. Figure 4 also shows higher levels immediately south of the facility although no residential receptors are located at this point.

3.2 Odour Abatement Investigation

Given that the odour complaint log has found that current operations are leading to an occasional odour at nearby sensitive receptors, AWN Consulting were further commissioned to undertake an assessment of potential odour abatement options in order to identify the most efficient means of ensuring that no odour nuisance will occur at nearby receptors.

The proposed abatement option recommended is a combined three-staged abatement system consisting of the following:

- Currently, all odorous processes are directed through a bioscrubber system with sufficient residence time and abatement efficiency to ensure a residual odour concentration of no more than 3,000 OU_E/m^3.
- It is proposed to install an AEROX ozone abatement unit which will achieve an additional abatement efficiency of between 50 – 70%. Based on an odour efficiency of 50%, a residual odour concentration of no more than 1,500 OU_E/m^3 is likely to emitted downstream of the AEROX unit.
- This treated air from the bioscrubber and AEROX unit will be directed via a stack prior to release to atmosphere. The stack diameter of 0.60m has recently been reduced to 0.30m in order to ensure that the efflux velocity is increased to ensure that the momentum of the plume is maximized. The stack height was increased from an initial height of 15m to 17m, then 20m and thereafter 25m to determine the optimum stack height for the facility to ensure no odour nuisance beyond the site boundary.

3.3 Odour Abatement Results – Variation In Stack Height

It has been estimated that odour emissions will mainly occur from the odour abatement system linked to the main production building. It is likely that other minor sources of odour will occur on-site including fugitive releases. However, the conservative nature of the selection of an appropriate odour concentration and worst-case approach to odour emission rates will ensure that the overall site odour emission rate of greater than 4,167 OU_E/s during operational hours will be an over-estimation of reality.

Details of the maximum, 99.5th%ile and 98th%ile of 1-hour mean odour concentrations at the boundary of the site and at the nearest residential receptor are given in Table 7 based on the worst-case year over a five-year period (Year 2000) based on the air dispersion model using the AERMOD model (version 13350).

The dispersion modelling results presented in Table 7 indicate that under the proposed conservative operational scenario of the Brandon Products facility, the

99.5th%ile of mean hourly odour concentrations ranges from 0.14 – 0.44 OU_E/m^3 at the worst-case offsite residential receptor based on a stack height ranging from 15 – 25m. The worst-case odour concentration of 0.14 OU_E/m^3 at a stack height of 25m is 9% of the relevant odour criterion.

As shown in Figure 5, the odour impact off-site decreases as the stack height is increased from 15m, through 17m & 20m to 25m. The results indicate that no odour is likely to be detected at the nearest residential receptor at a stack height of 17m, 20m or 25m. Thus, although a stack height of 17m is likely to be sufficient to avoid odour nuisance it is recommended that a stack height of 25m be selected on the basis of an optimum solution to ensure that any risk of odour nuisance is minimised.

As shown in Table 8 and Figure 6, all levels are well below the 1.5 OU_E/m^3 at a stack height of 25m with levels at residential receptors a small fraction of this level. Thus, based on the results from the air dispersion model, ambient odour concentrations are predicted to be well below the odour limit value everywhere offsite. Compared to the existing situation, at a stack height of 15m, the 99.5th%ile of mean hourly odour concentrations will decrease from 1.37 OU_E/m^3 to 0.16 OU_E/m^3 anywhere offsite. This represents an improvement in ambient odour levels of 800%.

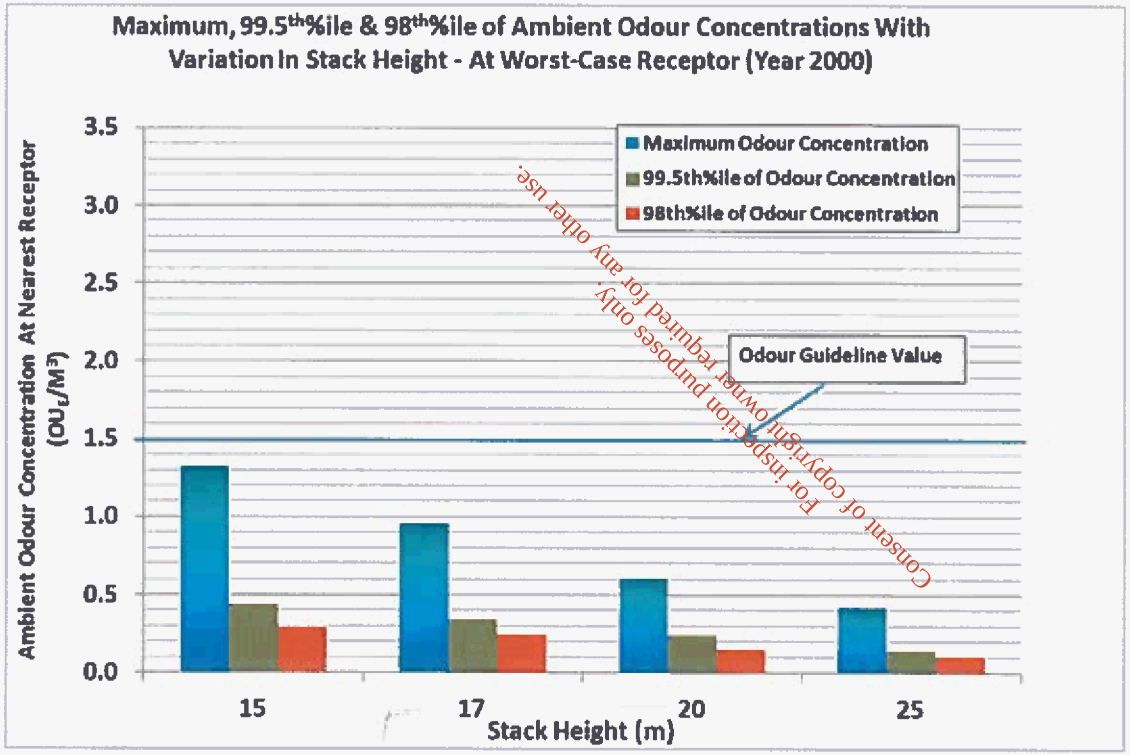
Compared to the ambient odour levels at the initial stack diameter of 0.60m, which represented the existing situation to the end of October 2013, and which represents the operating scenario correlating with the complaint log shown in Figure 2, predicted odour levels (as a 99.5th%ile of mean hourly odour concentrations) will be over ten times lower than this and thus it would be expected that the frequency of odour complaints will be significantly reduced at a stack height of 25m.

Table 7 Predicted Odour Concentration at Worst-case Offsite Receptors Based on Bioscrubber Abatement System & AEROX Unit – Brandon Products Facility (OU_E/m^3)

Model Scenario / Meteorological Year	Averaging Period	Predicted Odour Conc. (OU_E/m^3)		Guideline (OU_E/m^3)
		Boundary Of Facility	Nearest Residential Receptor	EPA AG4 (2010)
15 Metre Stack Height / Year 2000	Maximum 1-Hour	1.40	1.32	n/a
17 Metre Stack Height / Year 2000		1.08	0.96	
20 Metre Stack Height / Year 2000		0.81	0.61	
25 Metre Stack Height / Year 2000		0.53	0.42	
15 Metre Stack Height / Year 2000	Maximum 1-Hour (as a 99.5th%ile)	0.69	0.44	1.0 / 2.0 (New Zealand Guidance)
17 Metre Stack Height / Year 2000		0.42	0.34	
20 Metre Stack Height / Year 2000		0.28	0.24	
25 Metre Stack Height / Year 2000		0.16	0.14	
15 Metre Stack Height / Year 2000	Maximum 1-Hour (as a 98th%ile)	0.49	0.29	1.5 (UK Guidance)
17 Metre Stack Height / Year 2000		0.27	0.24	
20 Metre Stack Height / Year 2000		0.18	0.15	
25 Metre Stack Height / Year 2000		0.11	0.10	

Table 8 Predicted Odour Concentration Over A Five-Year Period Brandon Products Facility – 25m Stack Height (OU_E/m^3)

Model Scenario / Meteorological Year	Averaging Period	Predicted Odour Conc. (OU_E/m^3)		Guideline (OU_E/m^3)
		Boundary Of Facility	Nearest Residential Receptor	EPA AG4 (2010)
25 Metre Stack Height / Year 2000	Maximum 1-Hour	0.53	0.42	n/a
25 Metre Stack Height / Year 2001		1.22	0.92	
25 Metre Stack Height / Year 2002		1.48	0.77	
25 Metre Stack Height / Year 2004		0.34	0.23	
25 Metre Stack Height / Year 2005		0.44	0.21	
25 Metre Stack Height / Year 2000	Maximum 1-Hour (as a 99.5th%ile)	0.16	0.14	1.0 / 2.0 (New Zealand Guidance)
25 Metre Stack Height / Year 2001		0.16	0.15	
25 Metre Stack Height / Year 2002		0.17	0.15	
25 Metre Stack Height / Year 2004		0.15	0.15	
25 Metre Stack Height / Year 2005		0.15	0.14	
25 Metre Stack Height / Year 2000	Maximum 1-Hour (as a 98th%ile)	0.11	0.10	1.5 (UK Guidance)
25 Metre Stack Height / Year 2001		0.12	0.12	
25 Metre Stack Height / Year 2002		0.12	0.11	
25 Metre Stack Height / Year 2004		0.12	0.12	
25 Metre Stack Height / Year 2005		0.11	0.11	



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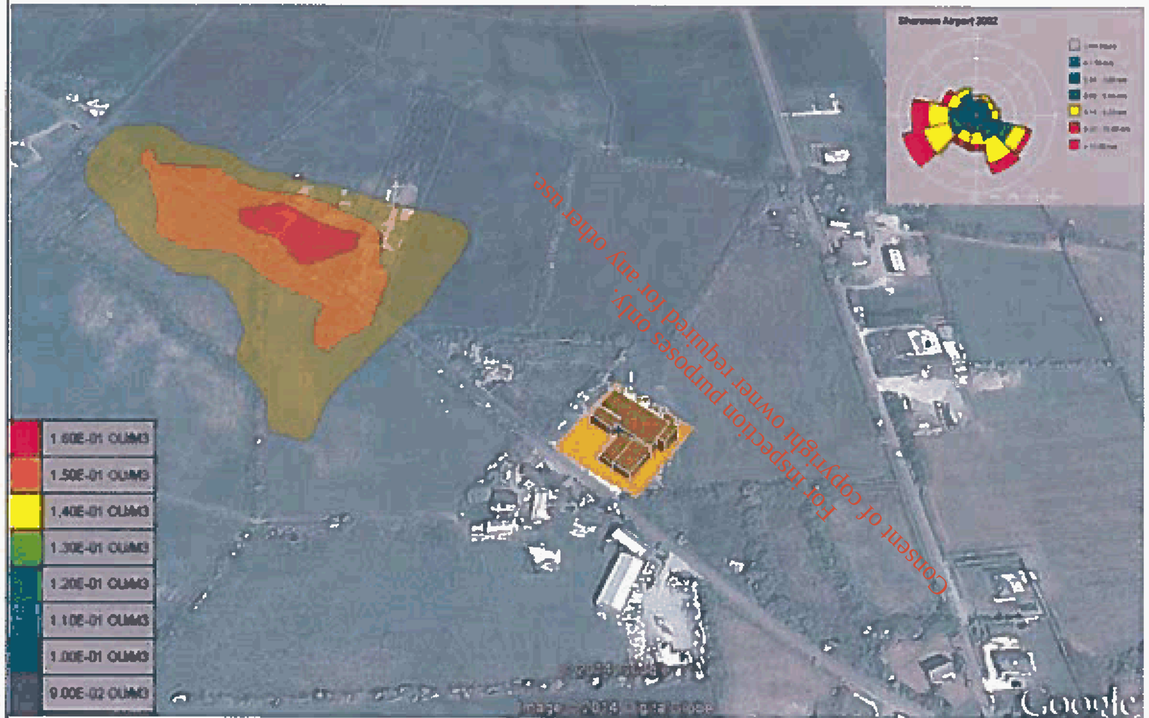
Project	Brandon Products Odour Assessment
Reference	14/7159AR01
Figure 5	Variation In Ambient Odour Concentration (OU$_E$/m^3) as a 99.5th%ile (Year 2000) At Varying Stack Heights – Worst-case Receptor



Project	Brandon Products Odour Assessment
Reference	14/7159AR01
Figure 6	Ambient Odour Concentration (OU_E/m^3) as a 99.5th%ile (Year 2002) At A Stack Height Of 25m

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3.4 Bioscrubber & AEROX Unit Failure – Ambient Odour Concentration

The bioscrubber has been measured to have an efficiency of approximately 60% (see Table 3) whilst the AEROX unit is estimated to have a minimum abatement efficiency of 50%. Thus, the odour emission rate, in the extremely unlikely event of the concurrent failure of both abatement systems, has been increased to the bioscrubber inlet odour emission rate which is given in Table 4.

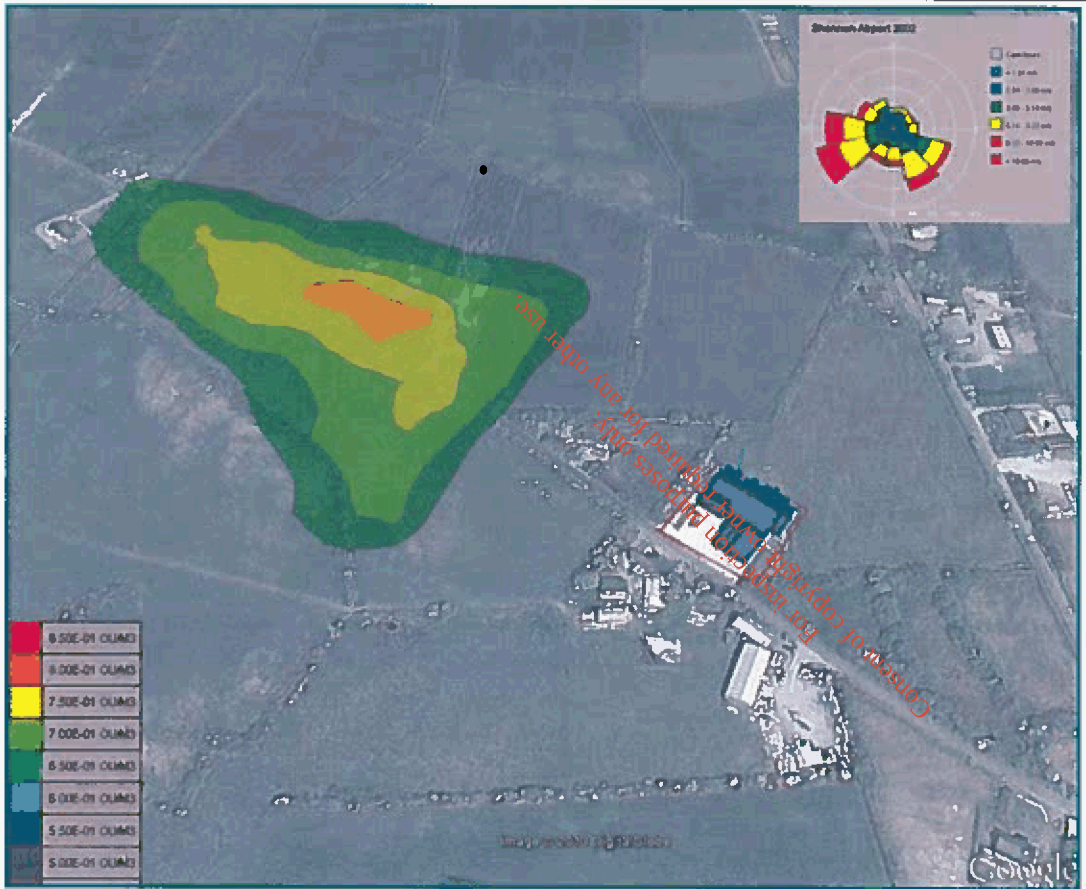
Modelling based on this pessimistic scenario where both the bioscrubber and AEROX simultaneously fails for the full year and thus no odour abatement occurs prior to release via the 25m stack is presented in Table 9. Details of the maximum, 99.5th%ile and 98th%ile of 1-hour mean odour concentrations at the boundary of the site and at the nearest residential receptor are given in Table 9 based on this worst-case scenario for the failure of both abatement systems (Year 2002) based on the air dispersion model using the AERMOD model (version 13350).

The dispersion modelling results presented in Table 9 indicate that under the worst-case scenario of the Brandon Products facility, the 99.5th%ile of mean hourly odour concentrations will be 0.84 OU_E/m^3 at the worst-case offsite residential receptor based on a stack height of 25m. The worst-case odour concentration of 0.84 OU_E/m^3 at a stack height of 25m is 56% of the relevant odour criterion.

As shown in Figure 7, ambient odour concentrations under both the bioscrubber and AEROX failure scenario are well below the 1.5 OU_E/m^3 at a stack height of 25m. Thus, based on the results from the air dispersion model, ambient odour concentrations are predicted to be well below the odour limit value everywhere offsite even under circumstances when the odour abatement (bioscrubber) fails.

Table 9 Predicted Odour Concentration Based On the Failure Of Both The Bioscrubber & AEROX Abatement System Over A Five-Year Period Brandon Products Facility – 25m Stack Height (OU_E/m^3)

Model Scenario / Meteorological Year	Averaging Period	Predicted Odour Conc. (OU_E/m^3)		Guideline (OU_E/m^3)
		Boundary Of Facility	Nearest Residential Receptor	EPA AG4 (2010)
25 Metre Stack Height / Year 2000	Maximum 1-Hour	2.7	2.1	n/a
25 Metre Stack Height / Year 2001		6.1	4.6	
25 Metre Stack Height / Year 2002		7.4	3.9	
25 Metre Stack Height / Year 2004		1.7	1.1	
25 Metre Stack Height / Year 2005		2.2	1.0	
25 Metre Stack Height / Year 2000	Maximum 1-Hour (as a 99.5th%ile)	0.82	0.71	1.0 / 2.0 (New Zealand Guidance)
25 Metre Stack Height / Year 2001		0.81	0.75	
25 Metre Stack Height / Year 2002		0.84	0.75	
25 Metre Stack Height / Year 2004		0.77	0.74	
25 Metre Stack Height / Year 2005		0.73	.71	
25 Metre Stack Height / Year 2000	Maximum 1-Hour (as a 98th%ile)	0.53	0.52	1.5 (UK Guidance)
25 Metre Stack Height / Year 2001		0.60	0.60	
25 Metre Stack Height / Year 2002		0.58	0.57	
25 Metre Stack Height / Year 2004		0.58	0.58	
25 Metre Stack Height / Year 2005		0.56	0.54	



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Project	Brandon Products Odour Assessment
Reference	14/7159AR01
Figure 7	Ambient Odour Concentration (OU_E/m^3) as a 99.5th%ile (Year 2002) At A Stack Height Of 25m Based On A Failure Of The Bioscrubber

3.5 Mitigation

Mitigation measures onsite to reduce odour impact are based on best practise.

These measures include the following:

- All processes are untaken within the process building
- All raw material and products are stored within the process building
- Seaweed sludge is enclosed in a seal skip which is connected to the bioscrubber
- The bioscrubber is designed with a residence time of 8 seconds based on a counter current flow with a volume flow of 10,000 Nm^3/hr.
- The two-stage bioscrubber and AEROX abatement system will ensure that in the event of the failure of one system that untreated odorous air will not be released from the facility.
- Vehicles delivering and removing odorous material will be enclosed or covered.
- All handling of malodorous waste is carried out in an enclosed area;
- Regular inspections, monitoring and maintenance of facility is routinely carried out;
- The bioscrubber and AEROX unit will be maintained to ensure optimum performance;
- Good housekeeping practices (internally and externally) and a closed-door management strategy is maintained at all times;
- Treated air from the bioscrubber / AEROX unit will be emitted through a 25m high stack to facilitate appropriate residual odour dispersion.

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3.6 Conclusion

Dispersion modelling results show that under a pessimistic scenario of current operations of the Brandon Products facility, the 99.5th%ile of mean hourly odour concentrations ranges from 0.84 – 0.90 OU_E/m^3 at the worst-case offsite residential receptor whilst the 99.5th%ile of mean hourly odour concentrations ranges from 1.3 – 1.5 OU_E/m^3 anywhere offsite. The worst-case odour concentration of 1.5 OU_E/m^3 is equivalent to the relevant odour criterion. The maximum odour concentration peaks at the residential receptors located to the north-west of the boundary of the facility with ambient odour concentrations greater than 1.0 OU_E/m^3 limited to a small area near this peak.

Given that the odour dispersion modelling assessment found that current operations were leading to occasional odour detection at nearby receptors, AWN Consulting undertook an assessment of potential mitigation options in order to identify the most efficient means of ensuring that no odour nuisance will occur at nearby sensitive receptors.

The proposed abatement option recommended is a combined two-staged abatement system consisting of the following:

- Currently, all odorous processes are directed through a bioscrubber system with sufficient residence time and abatement efficiency to ensure a residual odour concentration of no more than 3000 OU_E/m^3.
- It is proposed to install an AEROX ozone abatement unit after the bioscrubber which will achieve an additional abatement efficiency of between 50 – 70%. Based on an odour efficiency of 50%, a residual odour concentration of no more than 1,500 OU_E/m^3 is likely to emitted downstream of the AEROX unit.

- This treated air from the bioscrubber and AEROX unit will be directed via a stack prior to release to atmosphere. The stack diameter of 0.60m has recently been reduced to 0.30m in order to ensure that the efflux velocity is increased to ensure that the momentum of the plume is maximized. The stack height was increased from an initial height of 15m to 17m, then 20m and thereafter 25m to determine the optimum stack height for the facility to ensure no odour nuisance beyond the site boundary.

The dispersion modelling results indicate that under the proposed conservative operational scenario of the Brandon Products facility, the 99.5th%ile of mean hourly odour concentrations ranges from 0.14 – 0.44 OU_E/m^3 at the worst-case offsite residential receptor based on a stack height ranging from 15 – 25m. The worst-case odour concentration of 0.14 OU_E/m^3 at a stack height of 25m is 9% of the relevant odour criterion.

The odour impact off-site decreases as the stack height is increased from 15m, through 17m & 20m to 25m. The results indicate that no odour is likely to be detected at the nearest residential receptor at a stack height of 17m, 20m or 25m. Thus, although a stack height of 17m is likely to be sufficient to avoid odour nuisance it is recommended that a stack height of 25m be selected on the basis of an optimum solution to ensure that any risk of odour nuisance is minimised.

All levels are well below the 1.5 OU_E/m^3 at a stack height of 25m with levels at residential receptors a small fraction of this level. Thus, based on the results from the air dispersion model, ambient odour concentrations are predicted to be well below the odour limit value everywhere offsite. Compared to the existing situation, at a stack height of 15m, the 99.5th%ile of mean hourly odour concentrations will decrease from 1.37 OU_E/m^3 to 0.17 OU_E/m^3 anywhere offsite. This represents an improvement in ambient odour levels of 800%.

Compared to the ambient odour levels at the initial stack diameter of 0.60m, which represented the existing situation to the end of October 2013, and which represents the operating scenario correlating with the complaint log, predicted odour levels (as a 99.5th%ile of mean hourly odour concentrations) will be over ten times lower than this and thus it would be expected that the frequency of odour complaints will be significantly reduced at a stack height of 25m.

Under the worst-case scenario of the simultaneous failure of both the bioscrubber and AEROX abatement systems, the 99.5th%ile of mean hourly odour concentrations will be 0.84 OU_E/m^3 at the worst-case offsite residential receptor based on a stack height of 25m. The worst-case odour concentration of 0.84 OU_E/m^3 at a stack height of 25m is 56% of the relevant odour criterion. Thus, based on the results from the air dispersion model, ambient odour concentrations are predicted to be well below the odour limit value everywhere offsite even under circumstances where the odour abatement (bioscrubber & AEROX) fails.

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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)[2]. 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[7-10].

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]. 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]. 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 PRO

AERMOD incorporates a meteorological pre-processor AERMET PRO[20]. AERMET PRO allows AERMOD to account for changes in the plume behaviour with height. AERMET PRO 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 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. 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 PRO 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 PRO 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[3].

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.

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

Sector	Inverse Distance Weighted Land Use Classification	Spring	Summer	Autumn	Winter[1]
0-360	100% Grassland	0.05	0.10	0.01	0.01

(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))[21]. 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 Shannon 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 Shannon Airport Meteorological Station.

Simple Average Land Use Classification	Spring	Summer	Autumn	Winter[1]
36% Water	0.12	0.1	0.14	0.14
3% Urban	0.14	0.16	0.18	0.18
61% Grassland	0.18	0.18	0.20	0.20

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

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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.

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

Geometric Mean Land Use Classification	Spring	Summer	Autumn	Winter[1]
36% Water	0.1	0.1	0.1	0.1
3% Urban	1.0	2.0	2.0	2.0
61% Grassland	0.4	0.8	1.0	1.0

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