aurora LNG

COMMUNITY COMMITMENT CONNECTION

Aurora LNG Facility
Plume Rise Impact Assessment Report

Document No: **CO-BC1100-PM31RPT-0086**

Document Owner: Dale D'Arcy					
Security Classification: [1, 2, 3]		*(1 – All, 2 – Author Team Only, 3 – Confidential)*			
ISSUE RECORD SUMMARY					
0	17-Feb-2017	Issued For Use	D. D'Arcy	D.D'Arcy	A.Hamilton
Rev	**Date**	**Revision Description**	**Prepared**	**Checked**	**Approved**

Aurora LNG Facility

Plume Rise Impact Assessment

9 February 2017

Level 4, 600 Murray St
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Australia

407071-00097-EN-REP-0002

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Project No: 407071-00097-EN-REP-0002 – Aurora LNG Facility: Plume Rise Impact Assessment

Rev	Description	Author	Review	Advisian Approval	Date
0	Issued for Client Use	G Hickson	A Campbell	J Gibson	

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Glossary of Acronyms and Abbreviations

Abbreviation	Definition
3D	Three-dimensional
AC	Advisory Circular
AD INSP	Aerodrome Inspector
AD OPR	Aerodrome Operator
AGL	Above Ground Level
APM	All Particulate Matter
ASL	Above Sea Level
AWS	Automated Weather Station
BOG	Boil Off Gas
CASA	Civil Aviation Safety Authority
CASR	Civil Aviation Safety Regulations
CH_4	Methane
C_2H_6	Ethane
C_3H_8	Propane
C_4H_{10}	i-Butane / n-Butane
C_5H_{12}	i-Pentane / n-Pentane
C_6H_{14}	Hexane
C_7H_{16}	Heptane
CO_2	Carbon Dioxide
CPH	Critical Plume Height
CPV	Critical Plume Velocity
CSIRO	The Commonwealth Scientific and Industrial Research Organisation (Australia)
CSV	Comma Separated Variable
DFP	Diesel Firewater Pump
EDG	Emergency Diesel Generator
FH	Fired Heater
FPM	Fine Particulate Matter
GC	Government of Canada
GT	Gas Turbine
H_2	Hydrogen
H_2S	Hydrogen Sulfide
He	Helium
LHV	Lower Heating Value
LNG	Liquefied Natural Gas
LSALT	Lowest Safe Altitude
N_2	Nitrogen
Nexen	Nexen Energy
NO	Nitric Oxide

Abbreviation	Definition
NO_X	Oxides of Nitrogen
OAR	Office of Airspace Regulation
OLS	Obstacle Limitation Surface
$PM_{2.5}$	Particulate Matter < 2.5 µm in Aerodynamic Diameter
PM_{10}	Particulate Matter < 10 µm in Aerodynamic Diameter
TAPM	The Air Pollution Model
TIFP	Terminal Instrument Flight Procedure
TO	Thermal Oxidiser
UTM	Universal Transverse Mercator
VFR	Visual Flight Rules

Units

Unit	Definition
°C	degree Celsius
cal	Calorie
g	gram
hr	hour
K	Kelvin
kg	kilogram
km	kilometre
kPa	kiloPascal
m	metre
MJ	megaJoule
mole	mole
μm	micrometre
%	percent
Pa	Pascal
s	second

Executive Summary

Nexen Energy (Nexen), a wholly owned subsidiary of CNOOC Ltd. conducted an options analysis for the potential location of the proposed Aurora Liquefied Natural Gas (LNG) Facility in 2014. The buoyant plumes emanating from various process operations within the LNG Facility may pose a potential safety hazard to low-flying aircraft at Prince Rupert Airport, located on Digby Island, north-western British Columbia, Canada. Aircraft involved in take-off and landing manoeuvres were considered at particular risk due to the turbulence created from buoyant plumes and the proximity of the proposed facility to the southern approach / take-off vector for the airport.

Advisian (then known as WorleyParsons Consulting) was commissioned to conduct a Plume Rise Impact Assessment focussing on the Digby Island option in accordance with the Australian Civil Aviation Safety Authority (CASA) *Advisory Circular AC 139-5(1)* (WorleyParsons 2015) in lieu of specific guidance in Canada on how to conduct a plume rise impact assessment.

Nexen has in 2016 redefined the design of the proposed LNG Facility, which includes adjusting various buoyant plume emission sources across the facility. Advisian has been commissioned to re-evaluate the plume rise assessment based on the new information provided in the document: *LNG Facility Basis of Environment Assessment Air Emission* (Document No: CO-BC1100-RG25DBM-0001, revision B. Dated: 28 April 2016).

The proposed Aurora LNG Facility, at full plant build, incorporates the following operations, relevant to a plume rise impact assessment:

- Four (4) natural gas liquefaction trains, each comprising:
  - Pre-treatment Train:
    - One (1) Thermal Oxidiser; and
    - One (1) Fired Heater.
  - Liquefaction Train:
    - Two (2) Propane/HP Mixed Refrigerant Compressor Gas Turbines; and
    - Two (2) MR Compressor Gas Turbines.
  - All Gas Turbines (GTs) are Siemens Trent 60 models.
- A power generation plant, comprising:
  - Six (6) Simple Cycle Gas Turbines (GE LM6000 PF [DLE] models).
- One (1) Wet Gas, one (1) Dry Gas and one (1) BOG flare, all elevated flare designs.
- Two (2) Emergency Diesel Generators, supplying Trains 1-2 and 3-4 respectively.
- Two (2) Diesel Firewater Pump engines, supplying Trains 1-2 and 3-4 respectively.

In total, 37 individual plume sources were identified, assessed, spatially modelled and simulated in this assessment:

- Four (4) Thermal Oxidisers;
- Four (4) Fired Heaters;
- 22 Gas Turbines: 16 Gas Compression and 6 Power Generation;
- Two (2) Emergency Diesel Generators;
- Two (2) Diesel Firewater Pump engines; and
- Three (3) Flares.

The simulations for the assessment were conducted utilising the three-dimensional (3D) prognostic dispersion model TAPM (The Air Pollution Model) version 4.0.5 developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), being the CASA preferred model for plume rise impact assessments in Australia. A site-specific meteorological dataset was generated and adjusted to reflect local observed meteorological data at three nearby locations and then validated against the observed data to ensure it was representative of five calendar years for the site.

Analysis of the wind directions and speeds at varying altitudes indicated a drop in frequency of low wind speeds at 300 m above ground level (mAGL), corresponding with a shift in prevailing wind direction from a slower but predominant south-easterly wind near ground level, to a faster but more directionally variable south-westerly wind at higher elevations.

It was found that the Wet Gas Flare produced both the tallest (3,395 m above sea level, mASL) and widest (1,718 m) plume profile. It was also identified that, when considering the 4.3 m/s critical plume vertical velocity, this plume overlapped the southern approach / take-off vector for the Prince Rupert Airport by 318 m laterally an altitude of 2,368 mAGL (2,398 mASL).

Additionally, several plume sources are located within the outer limits of the Obstacle Limitation Surface (OLS) for the Prince Rupert Airport, namely:

- All Power Plant Gas Turbines (6 sources);
- Utility sources for Trains 3 and 4 (Emergency Diesel Generator and Diesel Firewater Pump, 2 sources); and
- ME Gas Turbines 1 and 3 for Train 3 (2 sources).

Only the Utility sources did not produce plumes greater than the OLS height of 73.65 mASL.

It was concluded that the potential obstacle presented by the Wet Gas Flare may present a level of risk that Transport Canada is unwilling to accept. A potential risk mitigation measure is to relocate the Wet Gas Flare a minimum of approximately 350 m to the east. This would move the plume obstacle out of the southern approach / take-off vector of the airport. However, this may then impinge upon the Visual Flight Rules (VFR) "South Corridor Route" along the eastern coast of Digby Island.

Therefore it was recommended that:

- A quantitative risk analysis is conducted for the plumes defined in this study to accurately determine the level of risk presented by the buoyant plumes; and
- Nexen review the results of the study and discuss the issue with the Canadian aviation regulators (Transport Canada).

1 Introduction

Nexen Energy (Nexen), a wholly owned subsidiary of CNOOC Ltd. conducted an options analysis for the potential location of the proposed Aurora Liquefied Natural Gas (LNG) Facility in 2014. Nexen identified two primary locations for the facility at the time: Digby Island and Grassy Point, both located on the western coast of British Columbia, Canada, near the Canadian border with Alaska. As the Digby Island location option for the proposed LNG facility, located approximately 6 km southwest of the city of Prince Rupert, was within 15 km of an existing aerodrome, namely the Prince Rupert Airport also located on Digby Island, a potential safety concern was identified. The buoyant plumes emanating from various process operations within the LNG Facility may pose a potential safety hazard to low-flying aircraft. Aircraft involved in take-off and landing manoeuvres were considered at particular risk due to the turbulence created from buoyant plumes and the proximity of the proposed facility to the southern approach / take-off vector for the airport.

Advisian (then known as WorleyParsons Consulting) was commissioned to conduct a Plume Rise Impact Assessment focussing on the Digby Island option (WorleyParsons 2015). In lieu of specific guidance in Canada on how to conduct a plume rise impact assessment, the Aurora Project chose to conduct the assessment in accordance with the method defined in the Australian Civil Aviation Safety Authority (CASA) Advisory Circular *AC 139-5(1): Plume Rise Assessments* (CASA 2012).

Nexen has in 2016 redefined the design of the proposed LNG Facility, which includes adjusting various buoyant plume emission sources across the facility. Therefore, Advisian has been commissioned to re-evaluate the plume rise assessment based on the new information provided in the document: *LNG Facility Basis of Environment Assessment Air Emission* (Document No: CO-BC1100-RG25DBM-0001, revision B. Dated: 28 April 2016).

1.1 Assessment Objectives

The primary objectives of the impact assessment are:

> *To identify, quantify and assess the buoyant plumes associated with the proposed Aurora LNG Facility Digby Island location and report on the potential safety hazard it may present to aircraft in the region; and*
>
> *To use the assessment results as input information into the options analysis for the Digby Island site.*

CASA has stipulated in the advisory circular (CASA 2012) (Appendix A) that:

> *The Civil Aviation Safety Authority has identified that there is a need to assess the potential hazard to aviation posed by vertical exhaust plumes in excess of 4.3 metres per second (m/s) velocity. Relevant legislation includes the potential hazard, under Regulation 139.370 of CASR 1998 and the potential danger, under Regulation 6 of the Airspace Regulations 2007.*

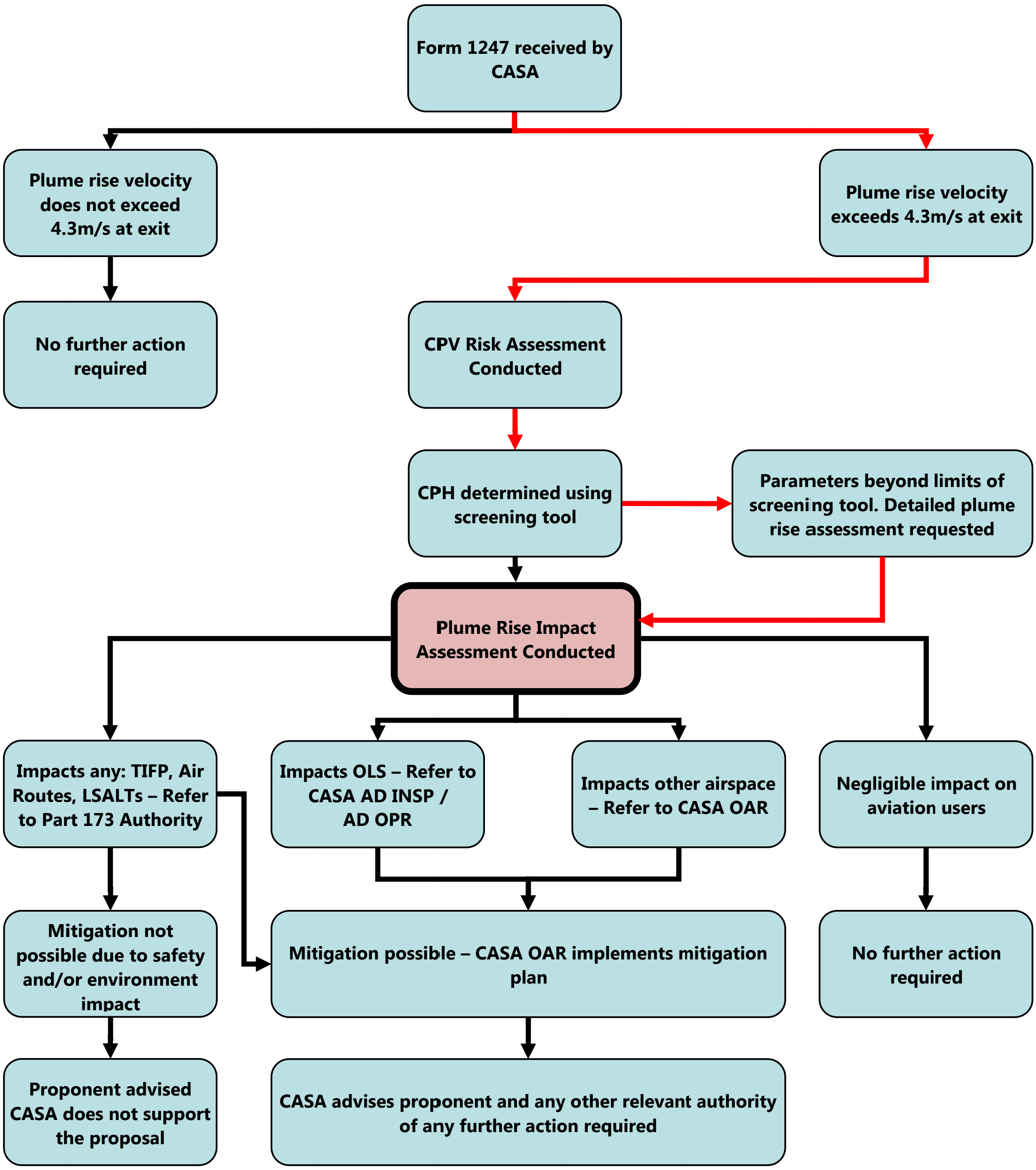
In addition, the CASA advisory circular also states:

> *The Manual of Aviation Meteorology (2003) defines severe turbulence as commencing at a vertical wind gust velocity in excess of 10.6 m/s; which may cause a momentary loss of control.*

The 2012 advisory circular is an update to a previously published advisory circular (CASA 2004), simplifying the process by the introduction of a screening tool used by CASA itself. The preliminary plant designs are likely to result in buoyant plumes outside the calculation capability of the screening tool. In this situation, CASA requires a full Plume Rise Impact Assessment to be conducted using the methods defined in (CASA 2012). This report documents the method, results and conclusions of the Plume Rise Impact Assessment for these proposed plume sources.

A flow chart indicating the overarching assessment process, extracted from Appendix A in the advisory circular (Appendix A), is presented in Figure 1-1. The status of the assessment process for the proposed Aurora LNG Facility, if the assessment was under CASA jurisdiction, is highlighted.

Figure 1-1: Plume Rise Assessment Process (CASA 2012)



1.2 Scope of Work

The scope of work for this assessment is provided below:

1. Re-check the meteorological dataset sued for the previous assessment remains valid for the location as input information into the dispersion model.

2. Revise the inventory of the primary sources of buoyant plumes as input information into the dispersion model.

3. Conduct plume rise modelling in accordance with the method prescribed by CASA (2012).

4. Process the model output data to quantify the plume behaviour in the vicinity of the proposed emission sources.

5. Report the assessment results and provide any recommendations relevant to the conclusions drawn.

1.3 Proposed LNG Facility Operations

The proposed Aurora LNG Facility, at full plant build, incorporates the following operations, relevant to a plume rise impact assessment:

- Four (4) natural gas liquefaction trains, each comprising:
  - Pre-treatment Train:
    - One (1) Thermal Oxidiser; and
    - One (1) Fired Heater.
  - Liquefaction Train:
    - Two (2) Propane/HP Mixed Refrigerant Compressor Gas Turbines; and
    - Two (2) MR Compressor Gas Turbines.
  - All Gas Turbines (GTs) are Siemens Trent 60 models.
- A power generation plant, comprising:
  - Six (6) Simple Cycle Gas Turbines (GE LM6000 PF [DLE] models).
- One (1) Wet Gas, one (1) Dry Gas and one (1) BOG flare, all elevated flare designs.
- Two (2) Emergency Diesel Generators, supplying Trains 1-2 and 3-4 respectively.
- Two (2) Diesel Firewater Pump engines, supplying Trains 1-2 and 3-4 respectively.

Note: An optional ground flare system design is being investigated; however, this is outside the scope of this assessment and is excluded from this report.

Further details of the buoyant plume sources are provided in Section 3.

1.4 Nearby Airports

The nearest airport to the proposed Digby Island site is the Prince Rupert Airport, located on the western coast of Digby Island. The proposed LNG facility site is located approximately 4 km southeast of the airport on the south-eastern peninsula of the island. According to CASA (2012), it is standard protocol in Australia that, any facility with the potential to produce an elevated plume meeting the hazard criteria specified in Section 1.1 within 15 km of an aerodrome, requires assessment to determine the potential obstacle hazard the plumes present to low-flying aircraft. As examples, this type of assessment has been conducted as standard practice for the three (3) LNG facilities located adjacent to each other on Curtis Island in Gladstone Queensland, Australia.

It is also noted that the city of Prince Rupert operates aircraft flying under Visual Flight Rules (VFR) in the local area. This assessment however, focusses on the potential impact on Prince Rupert Airport due to its proximity to the proposed Aurora LNG Facility and the anticipated volume of air traffic.

1.5 General Assumptions

The following general assumptions have been made to undertake this assessment:

- For conservatism, the facility has been modelled at a full plant build, with all sources in operation. This simulates the maximum possible plume rise and ensures that all meteorological conditions are identified.
- All flares have been simulated as point sources as recommended in (Hurley, P. 2008a) and (Hurley, P. 2008b).
- All flares have been simulated operating at their indicated maximum flow rates.
- Buoyancy enhancement associated with the combination of multiple exhaust plumes in close proximity was included to determine the most conservative impact.

Further details of the assumptions made relating to the plume sources are also provided in Section 3.

1.6 Modelling Domain

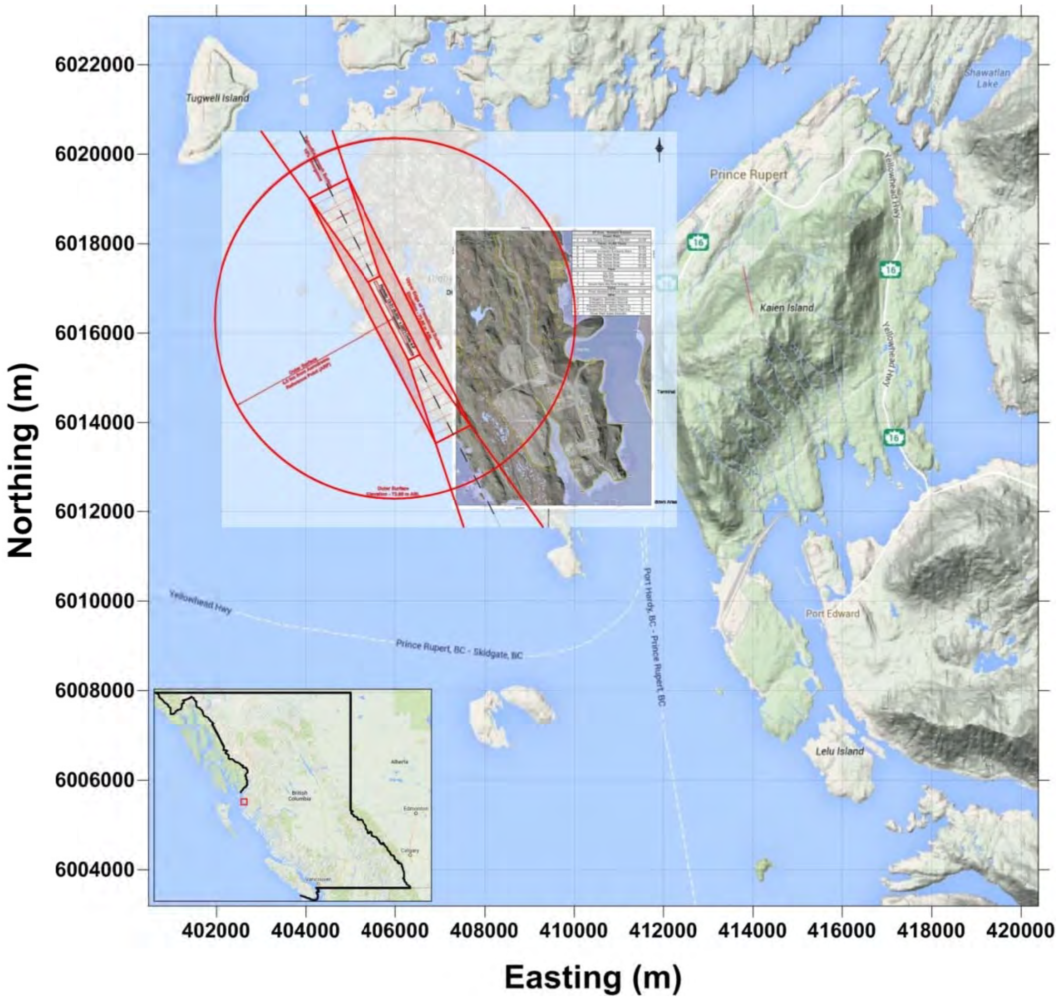
The modelling domain chosen for this assessment was centred on the proposed facility location.

The domain is located along the western coast of British Columbia; approximately 41 km south of the Canadian border with Alaska and the centre point of the modelling domain was located as near to the centroid of the proposed facility location as the model allows (Figure 1-2).

The modelling domain is defined by the following coordinates:

- East – West: 400481 m – 420381 m;
- North – South: 6003186 m – 6023086 m;
- Domain centre point: UTM Zone – 9U, Easting – 410431 m, Northing – 6013137 m.

Figure 1-2: Modelling Domain and Project Context



2 Existing Environment

The following section describes the existing environmental factors the influence plume dispersion behaviour in the local airshed. These factors include climatic conditions and the surrounding land use and topography.

Climatic data is collected from a network of Automated Weather Stations (AWSs) distributed over the country. Three AWSs are located in close proximity to the proposed LNG facility:

- Prince Rupert Airport (Station Number: 1066482);
- Lucy Island Lightstation (Station Number: 1064728); and
- Holland Rock (Station Number: 1063496).

The climatic data presented in the following section is based on the meteorological observations made at the Prince Rupert Airport AWS as it is the most relevant AWS to the meteorological conditions on Digby Island. All data has been sourced from the Government of Canada website (http://climate.weather.gc.ca/) (GC 2014a to 2014c).

The meteorological observations were reported on an hourly basis and spans the period 3 June 2010 when the available dataset commenced to 30 September 2014.

2.1 Prince Rupert Airport Automated Weather Station

The analysis focusses on meteorological factors that have the potential to affect the plume rise of the plume dispersion in relation to this study. The buoyancy of a plume is driven by the gas density differential between the plume and the surrounding ambient air. The primary parameters that affect plume dispersion and dictate the density of the ambient air are as follows:

Plume Dispersion:

- Wind Speed and Direction – Dictates plume flow direction.

Ambient Air Density:

- Temperature – Higher temperatures reduce ambient air density, reducing relative plume buoyancy;
- Relative Humidity – Higher relative humidity increases ambient air density, increasing relative plume buoyancy; and
- Barometric Pressure – Higher pressure increases ambient air density, increasing relative plume buoyancy.

2.1.1 Wind Speed and Direction

The wind speed and direction are the most important meteorological phenomena in relation to plume dispersion modelling as it is the primary factor dictating plume behaviour. The annual and quarterly wind roses for the Prince Rupert Airport AWS for 2010 to 2014 are presented in Figure 2-1.

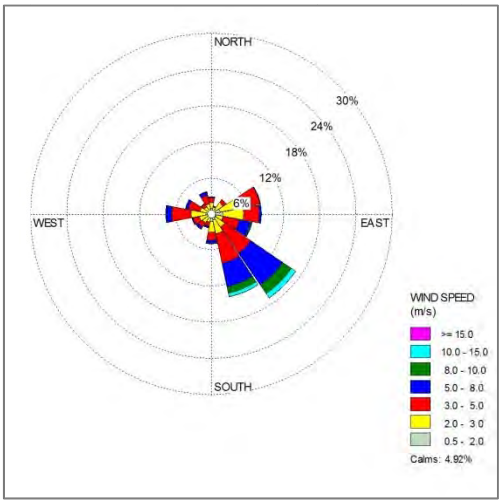
The prevailing winds for each quarter are:

- **Quarter 1 (January – March):** Predominantly moderate to strong south-easterly winds, ranging in the south-southeast to east-northeast arc. Winds from the southeast are frequently above 5.0 m/s and can range above 10.0 m/s.
- **Quarter 2 (April – June):** The prevailing winds are from the south-southeast and west. The south-easterly winds tend to be higher velocity, with a significant proportion above 5.0 m/s, whereas the westerly winds are of lower velocity primarily less than 5.0 m/s.
- **Quarter 3 (July – September):** Very similar trends to Quarter 2 are apparent. South-easterly and westerly winds prevail, with similar proportions and speeds.
- **Quarter 4 (October – December):** Very similar trends to Quarter 1 with moderate to strong south-easterly winds ranging in the south-southeast to east-northeast arc.

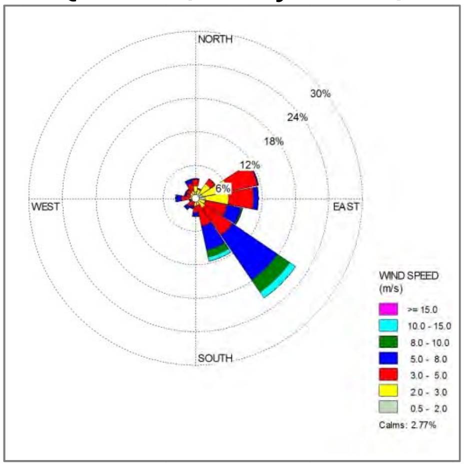
The similar trends between Quarters 1 and 4 and Quarters 2 and 3 indicate two distinct seasonal behaviours; however, it is important to note that south-east is by far the most prevailing wind direction and displays the highest proportion of higher wind speeds. The westerly winds appear to only occur during the warmer months.

Figure 2-1: Wind Roses for the Prince Rupert Airport AWS (2010 – 2014)

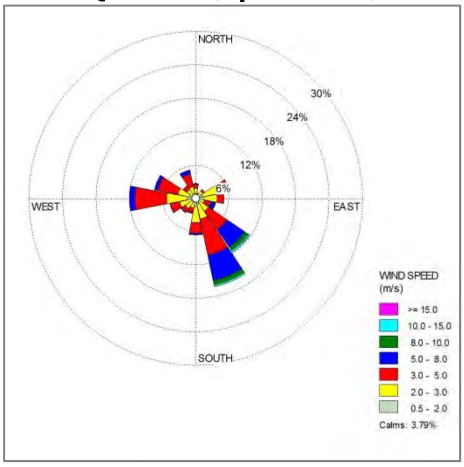
Full Year



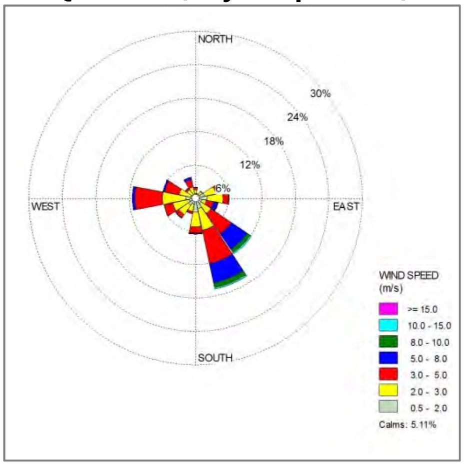
Quarter 1 (January – March)



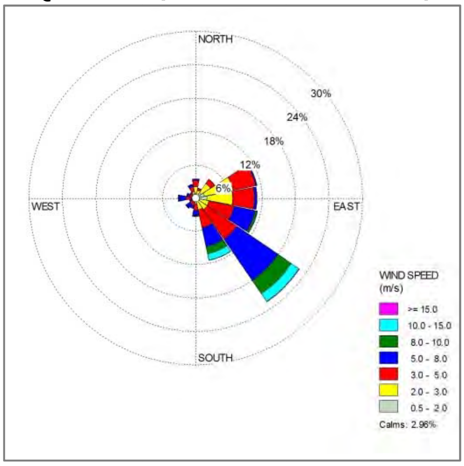
Quarter 2 (April – June)



Quarter 3 (July – September)

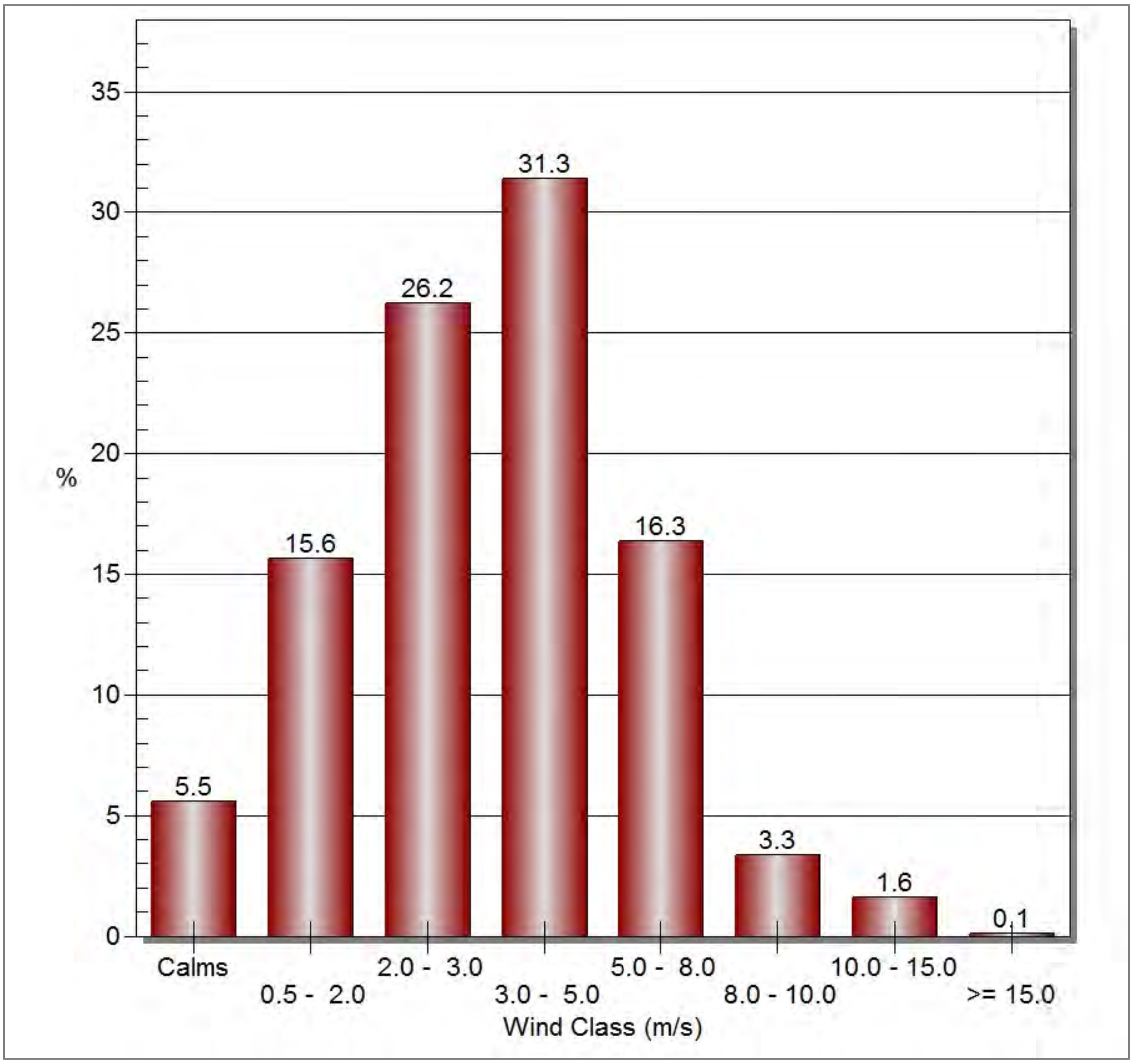


Quarter 4 (October – December)



The wind speed frequency histogram for this period is presented in Figure 2-2. It is apparent that a majority (57.5%) of the wind speeds fall between 2.0 m/s and 5.0 m/s considered as 'moderate' winds. Important to note is the frequency of wind speeds less than 0.5 m/s (commonly known as 'Calms'). Despite the coastal location of the AWS, usually resulting in a low proportion of Calms, 5.5% have been reported. These conditions can lead to increased plume rise as there are a lower proportion of winds to 'bend over' the exhaust plumes.

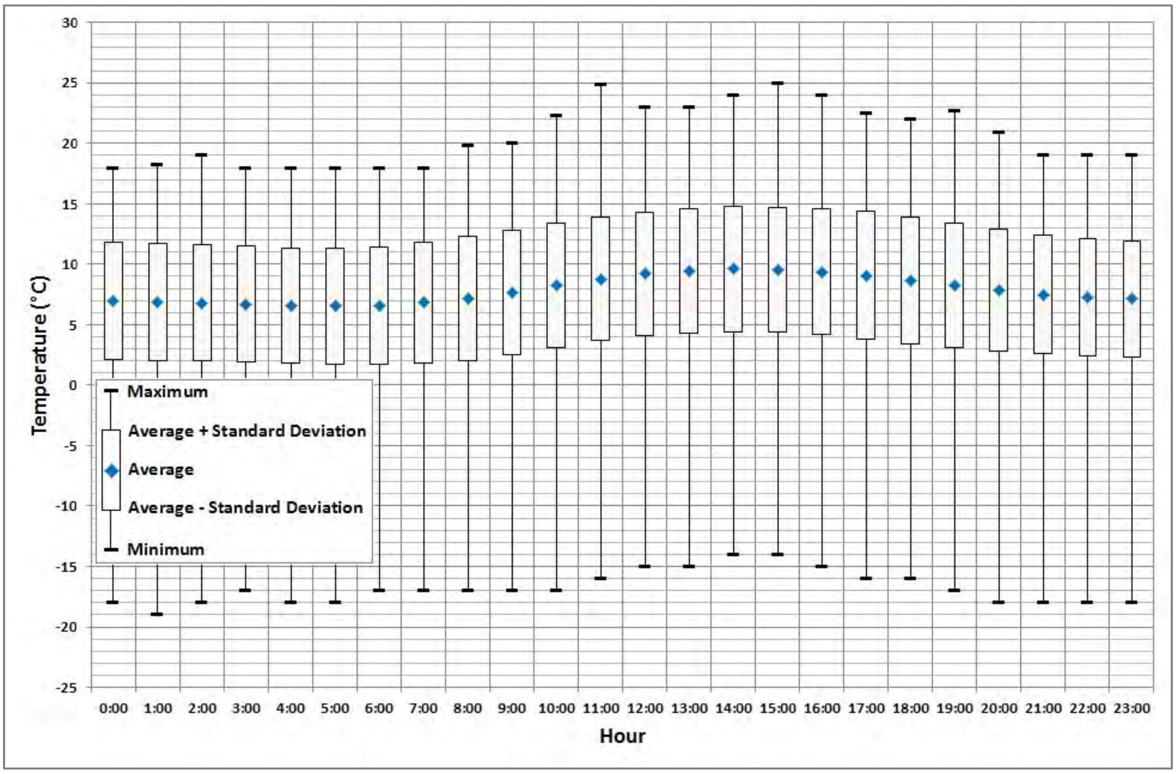
Figure 2-2: Prince Rupert Airport AWS – Wind Speed Frequency Distribution (2010 – 2014)



2.1.2 Temperature

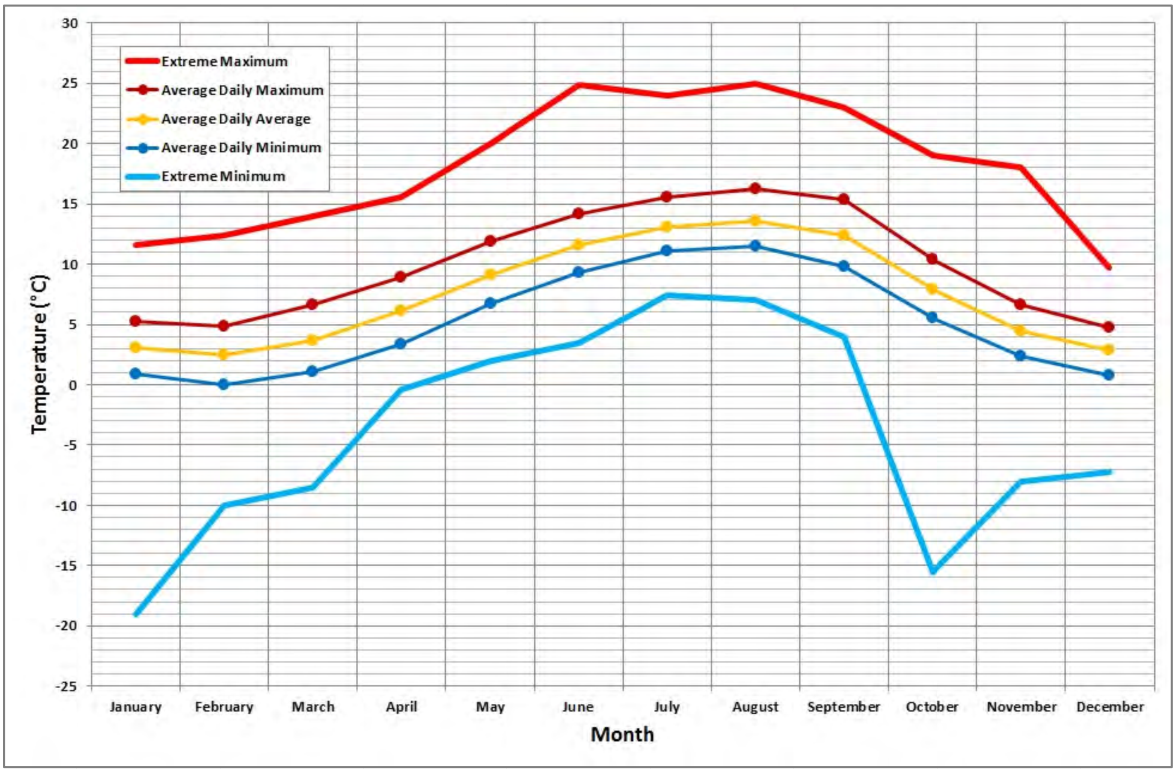
Hourly temperature data has been reported at the Prince Rupert Airport AWS for the same period as the wind speed and direction. The long-term average daily temperature profile is presented in the box and whisker plot (Figure 2-3). The standard deviations of the temperatures are represented by the boxes, whereas the extreme maximum and minimum temperatures reported are represented by the whiskers. The temperature increases on average to approximately 10°C at 2:00 pm and falls to 6.5°C at 5:00 am; however the extreme minima per hour is approximately 25°C lower. Most hours of the day show an extreme minimum temperature of below -15°C.

Figure 2-3: Prince Rupert AWS – Daily Temperature Profile (2010 – 2014)



The monthly temperature profile presents the average daily maxima, minima and average per month as well as the extreme maxima and minima (Figure 2-4). The average daily temperature variation is consistently approximately 5°C; however significant variations between extremes are apparent for all months, in particular the winter period. The potential for cold weather events increases the potential buoyancy of a plume due to the differences in gas densities; however, in comparison to the temperatures of the gas turbine and flare exhaust gases, the ambient temperature variations are small.

Figure 2-4: Prince Rupert Airport AWS – Average Daily Temperatures (2010 – 2014)

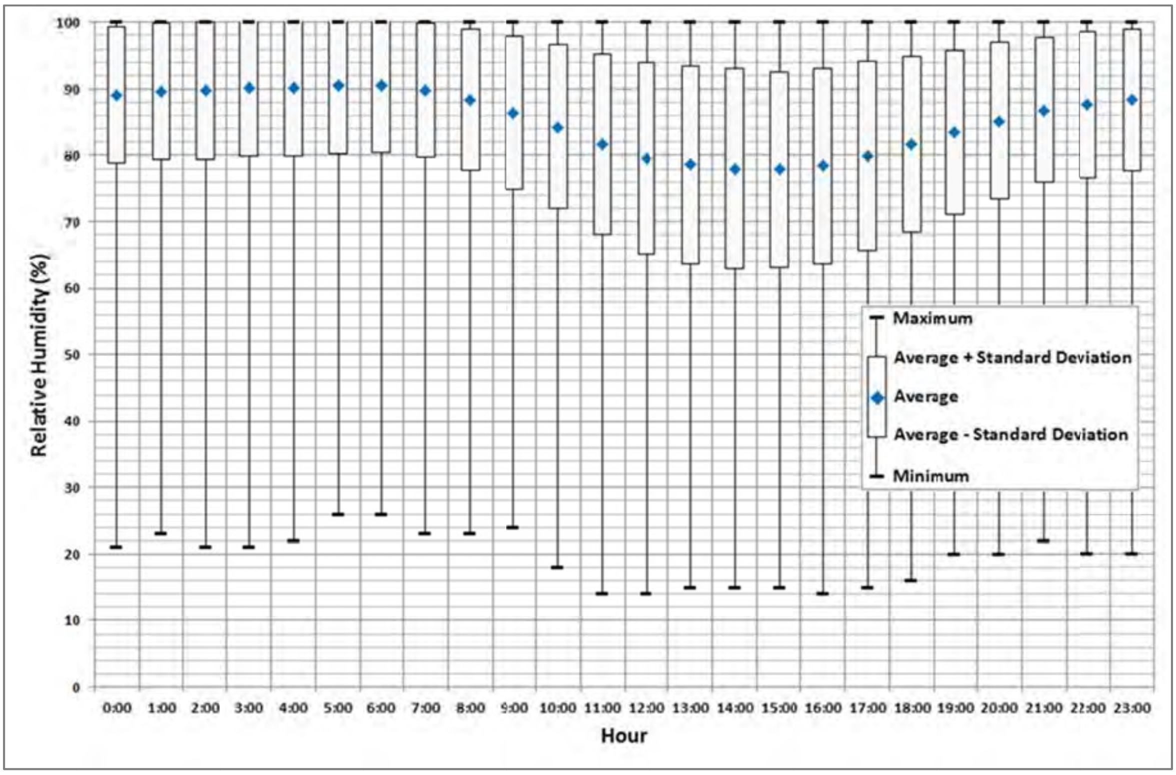


2.1.3 Relative Humidity

The relative humidity for the Prince Rupert Airport AWS was reported for the same period as above. The daily profile of relative humidity is presented as a box and whisker plot in Figure 2-5. The average relative humidity throughout the day remains above 75% with the maximum humidity occurring on average at 6:00 am with 90.5% and the minimum average humidity occurring at 3:00 pm with 78%. It is apparent that the extreme minimum humidity ranges between 14% and 26% and can occur throughout the day.

High levels of humidity as experienced at Prince Rupert Airport can lead to increased plume buoyancy due to the higher density of the ambient air relative to the plume.

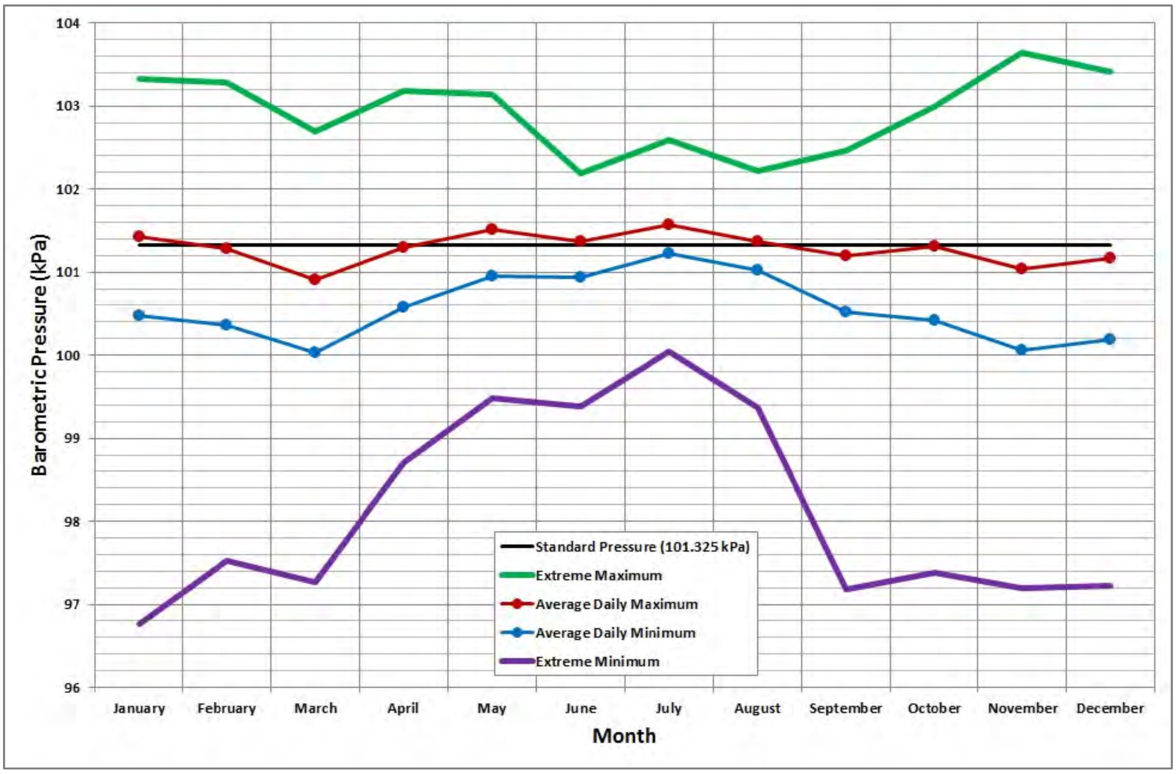
Figure 2-5: Prince Rupert Airport AWS – Daily Relative Humidity Profile (2010 – 2014)



2.1.4 Barometric Pressure

The barometric pressure was reported at the Prince Rupert Airport AWS for the same periods as above. The daily statistics per month showing: average daily maximum; average daily minimum; extreme maximum; and extreme minimum are presented in Figure 2-6. It is apparent that, in comparison to standard pressure (101.325 kPa), Prince Rupert Airport experiences marginally lower pressures throughout the year. This would have the effect of marginally reducing plume buoyancy as the ambient air density is reduced relative to the plumes.

Figure 2-6: Prince Rupert Airport AWS – Average Daily Barometric Pressure (2010 – 2014)

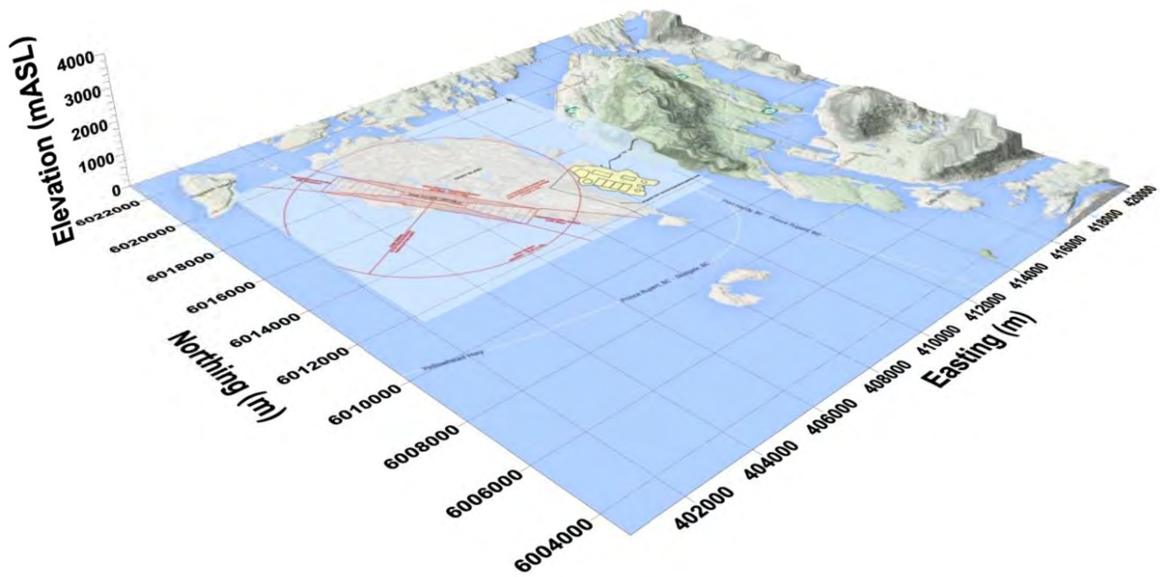


2.2 Surrounding Land Use and Topography

A majority of the modelling domain is part of the Dixon Entrance and associated straights and passages along the western coast of Canada. As such a majority of the 'terrain' within the modelling domain is flat with an elevation of zero. The eastern half of the modelling domain includes several mountain range cliffs and bluffs with steep inclines to elevations in excess of 700 m Above Sea Level (mASL). Considering the wider region is mountainous, these topographical features are likely to significantly influence the wind patterns of the region. This is evidenced by the prevailing wind direction running parallel to the generalised coastline, as described in Section 2.1.1. For reference, a three-dimensional (3D) plot of the topographical features within the domain is presented in Figure 2-7.

The nearby township of Prince Rupert on Kaien Island to the east has a major port facility primarily for container and freight transport. However, the operations are considered transient by nature and relatively insignificant with-respect-to buoyant plume sources to be included in the model. Mining and ship-loadout operations are being undertaken at Bishop Island, to the south of Kaien Island, through Port Edward. These operations, although have the potential to produce significant buoyant plumes, their distance from the primary sources within the model result in them having no influence on the plumes from the proposed LNG facility. In addition, the mountainous terrain tends to shield the different operations from each other.

Figure 2-7: Three-Dimensional Topographical Plot of the Modelling Domain



3 Emissions Inventory

The following section describes the method undertaken to estimate the plume sources for this assessment.

3.1 Plume Emission Sources

The plant design layout is provided in Appendix A of the *LNG Facility – Basis of Environment Assessment – Air Emission* (Aurora LNG 2016).

Seven (7) primary plume source types have been identified for the proposed LNG Facility:

- Refrigerant Compressor Gas Turbine (GT) exhausts;
- Thermal Oxidiser exhausts;
- Fired Heater exhausts;
- Emergency Diesel Generators;
- Diesel Firewater Pump exhausts;
- Power Generation GT exhausts; and
- Flares.

Three (3) flares have been modelled in this assessment:

- Wet Gas Flare;
- Dry Gas Flare; and
- Boil Off Gas (BOG) Flare.

These flares sources are discussed in more detail in the following section.

3.2 Flare Emissions Calculation

As the proposed Aurora LNG Facility incorporates the combustion of the vented gas via three elevated flares and considering the TAPM software does not include specific options for flare sources, the flares must be approximated as a point source with adjusted stack parameters to simulate the flame component appropriately. This effectively simulates a stack source with physical parameters representing the dimensions of the top of the flame, where the combustion product gases are emitted.

The calculation to approximate these parameters is based upon the method provided by the Alberta Environment and Sustainable Resource Development department (http://environment.gov.ab.ca/info/library/7223.xls) and involves the following steps:

1. Determine the molar flow of the fuel gas to be combusted.

$$M_{Flow} = \frac{m_{Flow}}{M_{Fuel\,Gas}}$$

$$M_{Fuel\,Gas} = \sum_i Fraction(\%)_i \times M_i$$

Where:

M_{Flow}	=	Molar flow (mole/s)
m_{Flow}	=	Mass flow (g/s)
$M_{Fuel\,Gas}$	=	Weighted average molecular mass of fuel gas (g/mole)
$Fraction(\%)_i$	=	Molar fraction of fuel component (%)
M_i	=	Molecular mass of fuel component (g/mole)

2. Use the molar fraction of the fuel gas and the Lower Heating Value (LHV) of each compound to determine the total heat release rate for the fuel gas mixture.

$$Heat_{Release} = \sum_i LHV_i \times V_{Flow,i}$$

Where:

$Heat_{Release}$	=	Total heat release (MJ/s)
LHV_i	=	LHV of fuel component (MJ/m^3)
$V_{Flow,i}$	=	Volumetric flow of fuel component (m^3/s)

3. Using the total heat release rate (cal/s) and the flare heat radiation loss, determine the buoyancy flux of the exhaust gas.

$$B_{Flux} = 0.000037 \times Heat_{Release} \times \left(1 - \frac{Heat_{Loss}}{100}\right)$$

Where:

B_{Flux}	=	Buoyancy flux (m^4/s^3)
$Heat_{Loss}$	=	Heat radiation loss (%)

4. Using the fuel gas exit velocity, the buoyancy flux, the assumed exhaust gas temperature and the ambient temperature to determine the effective stack diameter.

$$v_{Fuel\,Gas} = V_{Flow}/A_{Stack}$$

$$D_{eff} = \sqrt{\frac{4 \times B_{Flux} \times T_{Exhaust}}{9.806 \times v_{Fuel\,Gas} \times (T_{Exhaust} - T_{Ambient})}}$$

Where:

$v_{Fuel\,Gas}$	=	Fuel gas exit velocity (m/s)
A_{Stack}	=	Stack area (m^2)

D_{eff} = Effective stack diameter (m)
$T_{Exhaust}$ = Exhaust gas temperature (K)
$T_{Ambient}$ = Ambient temperature (K)

5. Using the stack flare height and the total heat release rate, determine the flame length and therefore the effective stack height.

$$H_{eff} = H_{Stack} + 0.00456 \times (Heat_{Release})^{0.478}$$

Where:
H_{eff} = Effective stack height (m)
H_{Stack} = Actual stack height (m)

6. Using the Stoichiometric ratios of the combustion products with the assumed combustion efficiency, determine the total volumetric flow of the exhaust gas mixture.

$$V_{Exhaust} = \frac{R \times T_{Exhaust}}{P_{Ambient}} \left(\sum_i V_{Flow,i} \times \left(1 - \frac{C}{100}\right) + \sum_i V_{Flow,i} \times S_i \times \frac{C}{100} \right)$$

Where:
$V_{Exhaust}$ = Volumetric flow of exhaust gas mixture (m^3/s)
R = Gas Constant (8.3144621 m^3.Pa/K.mole)
$P_{Ambient}$ = Ambient pressure (Pa)
C = Combustion efficiency (%)
S_i = Stoichiometric ratio of fuel component to combustion product

7. Using the calculated effective stack diameter and the volumetric flow rate of the exhaust gas, determine the effective exhaust gas exit velocity.

$$v_{eff} = \frac{V_{Exhaust}}{\pi \times \left(\frac{D_{eff}}{2}\right)^2}$$

Where:
v_{eff} = Effective exhaust gas exit velocity (m/s)

The following input information was supplied to the above calculation to determine the resulting adjusted stack parameters for the flares. Data was obtained from the *LNG Facility – Basis of Environment Assessment – Air Emission* (Aurora LNG 2016).

Table 3-1: Combustion Gas Compositions for Simulated Flares

Flare	Compound		Molar Fraction (%)	Molecular Mass (g/mole)	Lower Heating Value (MJ/m^3)
Dry Gas Flare	Propane	C_3H_8	100%	44.1	93.094
	Weighted Average			**44.1 g/mole**	**93.094 MJ/m^3**
Wet Gas Flare	Hydrogen	H_2	0.01%	2.016	10.753
	Helium	He	0.03%	4.0026	N/A
	Carbon Dioxide	CO_2	1.826%	44.01	N/A
	Nitrogen	N_2	0.5%	28.0134	N/A
	Methane	CH_4	97.44%	16.04	35.857
	Ethane	C_2H_6	0.13%	30.07	64.015
	Propane	C_3H_8	0.003%	44.1	93.094
	i-Butane	C_4H_{10}	0.001%	58.12	115.817
	n-Butane	C_4H_{10}	0.00192%	58.12	117.197
	i-Pentane	C_5H_{12}	0.00192%	72.15	139.193
	n-Pentane	C_5H_{12}	0.00192%	72.15	145.47
	Hexane	C_6H_{14}	0.00192%	86.18	164.088
	Heptane	C_7H_{16}	0.00192%	100.2	190.021
	Hydrogen Sulfide	H_2S	0.0004%	34.08	21.864
	Weighted Average			**16.637071 g/mole**	**35.0418 MJ/m^3**
BOG Flare	Methane	CH_4	94%	16.04	35.857
	Nitrogen	N_2	6%	28.0134	N/A
	Weighted Average			**16.758404 g/mole**	**35.857 MJ/m^3**

Table 3-2: Flare Calculation Input Information

Physical Parameter	Wet Gas Flare	Dry Gas Flare	BOG Flare
Flare Parameter			
Flare Tip Diameter	0.5 m	0.5 m	0.5 m
Flare Height (Above Ground Level)	100 mAGL	150 mAGL	100 mAGL
Maximum Mass Flow (kg/hr)	1,440,000	2,725,000	108,000
Fuel Gas Temperature	4°C (Assumed)	-20°C (Assumed)	25°C (Assumed)
Exhaust Gas Temperature	982°C		
Heat Radiation Loss	25% (Assumed)		
Hydrocarbon Combustion Efficiency	98% (Assumed)		
Ambient Conditions			
Temperature	25°C (Assumed)		
Pressure	101.325 kPa (Assumed)		

3.3 Buoyancy Enhancement

The phenomenon of plume buoyancy enhancement is critical to quantify to conduct a plume rise assessment. In the situation where multiple buoyant plumes are located in close proximity to each other, they have a tendency to merge and enhance the overall buoyancy of the plumes relative to the ambient atmosphere.

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) provides an option within TAPM to simulate this enhancement by calculating an enhancement factor for each plume. This parameter applies to groups of sources located near each other and is calculated via the following method:

1. Determine the average distance between the plume sources.
2. Determine the average/typical plume rise without buoyancy enhancement.
3. Calculate the following parameter:
4. Calculate the enhancement factor:

$$\boldsymbol{S = 6 \times \left(\frac{(N-1) \times D_{ave}}{N^{1/3}} \Big/ Z \right)^{2/3}}$$

Where:

S	=	Calculation parameter
N	=	Number of sources in group
D_{ave}	=	Average distance between sources (m)
Z	=	Average/typical plume rise without enhancement (m)

5. Calculate the enhancement factor:

$$\boldsymbol{EF = \frac{N+S}{1+S}}$$

Where:

EF	=	Buoyancy enhancement factor

Several groups of sources were considered for this assessment:

- Sources from each Train as a group, as follows:
  - One (1) Thermal Oxidiser Stack;
  - One (1) Fired Heater Stack;
  - Two (2) Propane/HP Mixed Refrigerant Compressor Gas Turbine Stacks; and
  - Two (2) MR Compressor Gas Turbine Stacks.

- The Power generation Gas Turbine Stacks (6 in total);
- The Trains 1-2 Emergency Diesel Generator And Diesel Firewater Pump Exhaust Stacks;
- The Trains 3-4 Emergency Diesel Generator And Diesel Firewater Pump Exhaust Stacks; and
- The Flares.

3.4 Model Input Emission Parameters

The emission parameters used for the modelling are presented in Table 3-3 below. The spatial distribution of the emission sources is presented in Figure 3-1.

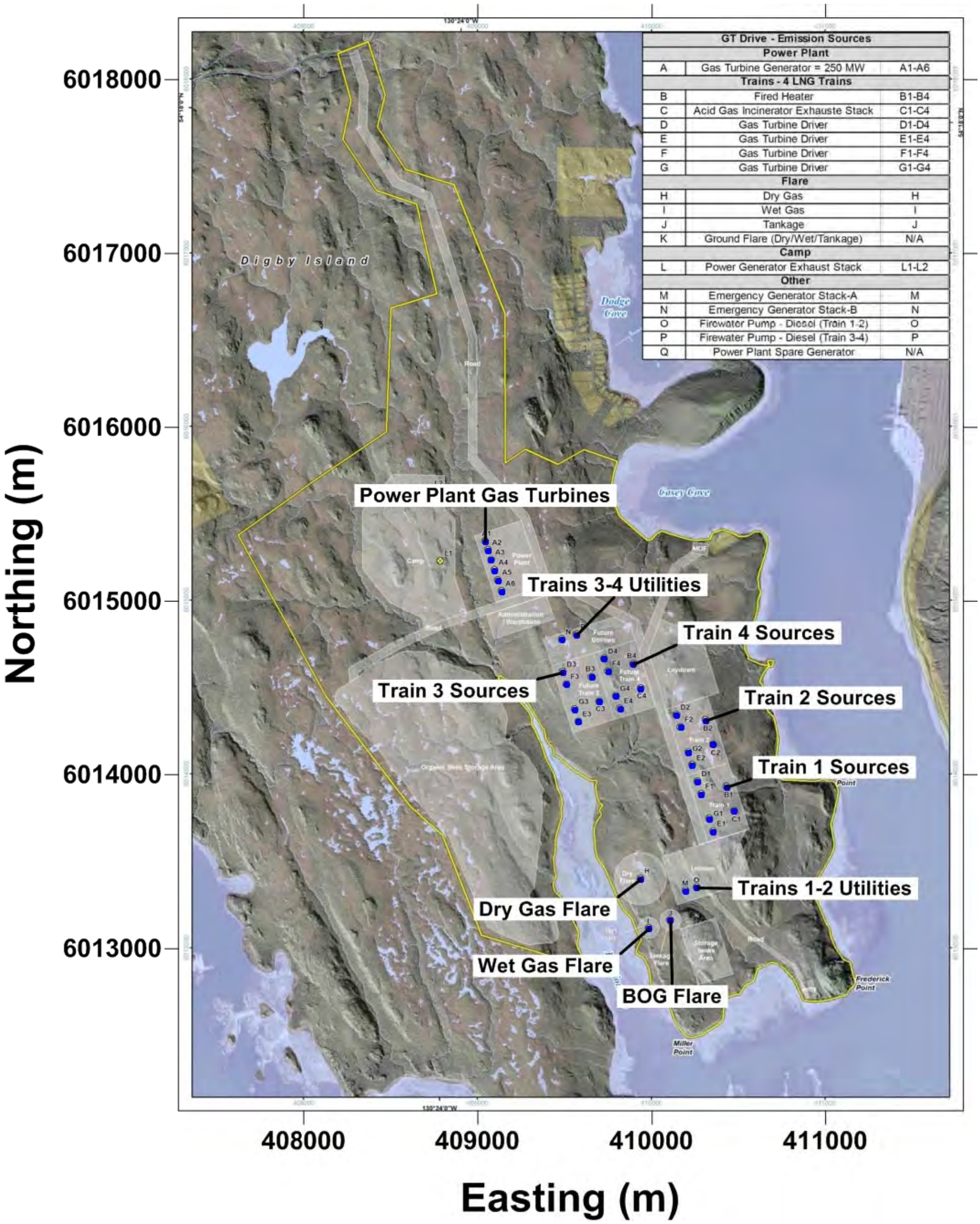
Table 3-3: Plume Source Emissions Parameters

Plume Source		Mode[1]	Coordinates		Effective Stack Height (m)	Effective Stack Radius (m)	Buoyancy Enhancement Factor[2]	Emission Ratios[3]		Exit Velocity (m/s)	Exhaust Temperature (K)	Tracer Gas Emission Rate (g/s)[3]
			Easting (m)	Northing (m)				NO / NO_X	FPM / APM[4]			
Train 1	TO Stack	1	410477	6013787	40	0.9	1.7	0	0	20	1,144.15	0
	FH Stack	1	410433	6013928	30	0.9	1.7	0	0	20	1,144.15	0
	MR GT 1	1	410266	6013957	40	2.7	1.7	0	0	35	704.15	0
	MR GT 2	1	410357	6013671	40	2.7	1.7	0	0	35	704.15	0
	MR GT 3	1	410289	6013886	40	2.7	1.7	0	0	35	704.15	0
	MR GT 4	1	410335	6013742	40	2.7	1.7	0	0	35	704.15	0
Train 2	TO Stack	1	410357	6014169	40	0.9	1.7	0	0	20	1,144.15	0
	FH Stack	1	410313	6014310	30	0.9	1.7	0	0	20	1,144.15	0
	MR GT 1	1	410146	6014340	40	2.7	1.7	0	0	35	704.15	0
	MR GT 2	1	410237	6014053	40	2.7	1.7	0	0	35	704.15	0
	MR GT 3	1	410169	6014269	40	2.7	1.7	0	0	35	704.15	0
	MR GT 4	1	410215	6014125	40	2.7	1.7	0	0	35	704.15	0
Train 3	TO Stack	1	409700	6014416	40	0.9	1.7	0	0	20	1,144.15	0
	FH Stack	1	409656	6014557	30	0.9	1.7	0	0	20	1,144.15	0
	MR GT 1	1	409489	6014587	40	2.7	1.7	0	0	35	704.15	0
	MR GT 2	1	409580	6014300	40	2.7	1.7	0	0	35	704.15	0
	MR GT 3	1	409512	6014515	40	2.7	1.7	0	0	35	704.15	0
	MR GT 4	1	409558	6014372	40	2.7	1.7	0	0	35	704.15	0
Train 4	TO Stack	1	409938	6014492	40	0.9	1.7	0	0	20	1,144.15	0
	FH Stack	1	40894	6014633	30	0.9	1.7	0	0	20	1,144.15	0
	MR GT 1	1	409727	6014662	40	2.7	1.7	0	0	35	704.15	0
	MR GT 2	1	409818	6014376	40	2.7	1.7	0	0	35	704.15	0
	MR GT 3	1	409750	6014591	40	2.7	1.7	0	0	35	704.15	0
	MR GT 4	1	409796	6014447	40	2.7	1.7	0	0	35	704.15	0
Power Generation	GT 1	1	409044	6015341	40	1.85	3.5	0	0	35	815.15	0
	GT 2	1	409060	6015289	40	1.85	3.5	0	0	35	815.15	0
	GT 3	1	409078	6015233	40	1.85	3.5	0	0	35	815.15	0
	GT 4	1	409098	6015175	40	1.85	3.5	0	0	35	815.15	0
	GT 5	1	409117	6015117	40	1.85	3.5	0	0	35	815.15	0
	GT 6	1	409138	6015054	40	1.85	3.5	0	0	35	815.15	0
Flares	Wet Gas	1	409983	6013115	289	2.5	2.3	0	0	382.7	1,255.15	0
	Dry Gas	1	409936	6013399	396	4.0	2.3	0	0	242.6	1,255.15	0
	BOG	1	410110	6013159	156	2.4	2.3	0	0	28.9	1,255.15	0
Emergency Diesel Generators	EDG T1-2	1	410198	6013329	12.5	0.4	1.8	0	0	45	700.15	0
	EDG T3-4	1	409484	6014774	12.5	0.4	1.8	0	0	45	700.15	0
Diesel Firewater Pumps	DFP T1-2	1	410263	6013349	7.5	0.2	1.8	0	0	45	700.15	0
	DFP T3-4	1	409569	6014802	7.5	0.2	1.8	0	0	45	700.15	0

Note:

1. Mode (-1 = Off, 0 = Eulerian Transport, 1 = Eulerian and Lagrangian Transport).
2. Buoyancy Enhancement (1 = No enhancement).
3. Non-critical parameter for a plume rise assessment, but required for the model definition.
4. FPM = Fine Particulate Matter ($PM_{2.5}$), APM = All Particulate Matter (PM_{10})

Figure 3-1: Modelled Plume Sources



4 Modelling Method

The following section details the modelling method undertaken for this assessment. Overall, the assessment was conducted in a staged manner:

1. Generate local meteorological conditions using the CSIRO-developed three-dimensional prognostic meteorological model "The Air Pollution Model (TAPM) version 4.0.5".

2. Assimilate observed meteorological data obtained from the Government of Canada (GC 2014a to 2014c); to adjust the generated data to better fit actual observations. Refer to Section 4.2 for a description of the assimilation method.

3. Validate the adjusted meteorological dataset against the actual observations.

4. Determine emissions input parameters for buoyant plume sources to be modelled. Details are provided in Section 3.

5. Using the validated meteorological dataset and the emissions parameters, conduct plume dispersion modelling using TAPM v4.0.5 in accordance with (CASA 2012).

6. Process the model output data to determine the maximum plume centreline displacement and maximum plume spread.

7. Generate a series of tables and figures analysing the wind speed and direction and plume behaviour patterns in accordance with (CASA 2012).

Note that stages 1 to 3 were conducted in the previous assessment (WorleyParsons 2015).

4.1 Model Definition

TAPM v4.0.5 generates site-specific meteorological data by referencing several databases: terrain elevation; vegetation/land use and soil type; sea-surface and deep soil temperatures; and synoptic-scale meteorological analyses. TAPM is able to predict meteorological events at a mesoscale (20 km – 200 km) and a local scale (approximately 200 m) by solving the fundamental fluid dynamics equations (Hurley, P. 2008a) and (Hurley, P. 2008b).

The following configuration settings were provided to TAPM v4.0.5 to generate the site-specific meteorological dataset:

- Model Grid Centre Coordinates:
  - clat = 54° 15.5′ North and clon = 130° 22.5′ West.
- Local Coordinates:
  - cx = 410431 m and cy = 6013137 m.

- A 25 point x 25 point, 4-layer nested grid domain with the following grid spacing respectively:
  - 30 km; 10 km; 3 km; and 1 km.
- 30 vertical grid levels with 25 levels stored in the output file.
- Meteorological Data Range: 5 years, as required by CASA (2012). 1 January 2009 to 31 December 2013 split into calendar year periods allowing for 1 additional day of simulation time prior to each calendar year for the model to adequately define time-dependent boundary conditions.
- Default sea-surface and deep soil temperature data.
- Default topographical height database with a 1 km resolution grid.

Hourly meteorological observations from the following AWS locations for the corresponding date range (1 January 2009 to 31 December 2013).

Table 4-1: Sources of Wind Observation Data for Model Assimilation

AWS Name	AWS Number	Location Coordinates (UTM)			Assimilated Observations	
		Zone	Easting	Northing	Commence	End
Prince Rupert Airport	1066482	9	405953	6016318	03/06/2010	31/12/2013
Lucy Island	1064728	9	395285	6017641	01/01/2009	31/12/2013
Holland Rock	1063496	9	411168	6003540	01/01/2009	31/12/2013

The additional plume dispersion configuration settings provided to TAPM v4.0.5 are listed below:

- Pollutant: Tracer
- Pollutant sub-grid: 398431 m – 422431 m; 6001137 m – 6025137 m; 500 m x 500 m spacing (i.e. 49 point x 49 point grid).
- Prognostic pollutant concentration variance equation = On.
- 1 model level to mix surface emissions.
- pH of liquid water = 4.5 (default).
- Refer to Table 3-3 for details of plume emission sources.
- Lagrangian calculations enabled.
- All remaining options are set to their default values.

4.2 Assimilation of Wind Observation Data

Wind observation data can be assimilated into the TAPM-generated output to adjust the three-dimensional wind vector field so it provides a better fit to actual recorded observational data. The method adopted in TAPM v4.0.5 is provided in (Hurley, P. 2008b) and is based on the approach of (Stauffer and Seaman 1994).

Metadata for the observation data used for this assessment is listed in Table 4-1 above. All meteorological stations were assumed to have an anemometer height of 10 mAGL.

The data quality value was set for each observational site to 75% of the percentage of available observation data for the relevant year. For example, as the Prince Rupert Airport site was not operational during the 2009 calendar year and hence has a data quality indicator of zero; whereas for the same period 99.6% of data was available for the Lucy Island AWS, hence the quality value was set to 75% of 0.996 which equates to 0.7475. The choice for 75% proportion was to ensure that for near complete datasets the model did not completely force the winds to conform to the measurements, potentially creating localised areas of wind vectors out of context with the wider modelling domain.

Considering the proximity of the AWS locations to each other and the complex topography of the region the radius of influence for each site was set to 7,000 m. This provided a slight overlap of the influenced areas for the Prince Rupert Airport and Holland Rock sites to ensure representative data was simulated. All observations were assimilated over three vertical model levels about the anemometer height; in this case these levels correspond to: 10 m; 25 m and 50 mAGL.

4.3 Output Data Post-Processing

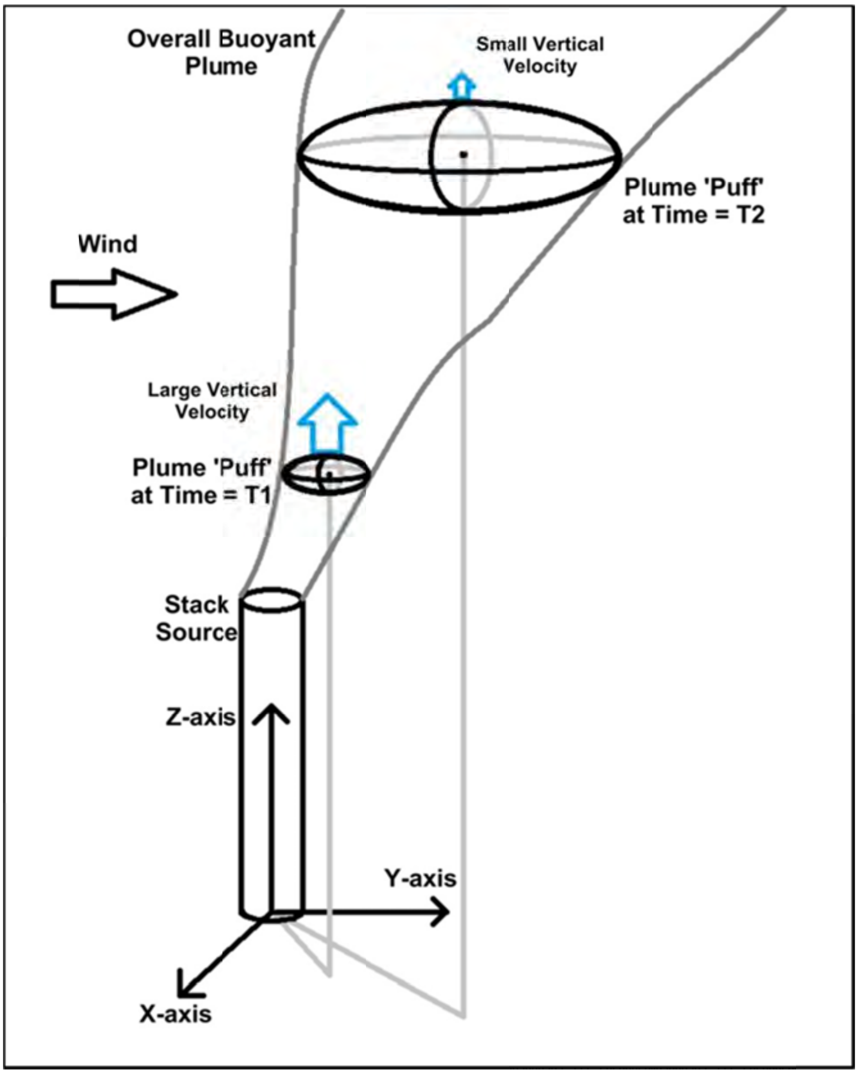
This section details the method undertaken to process the model output data to determine the dimensions of the plume with a vertical velocity in excess of the critical plume velocity (4.3 m/s or 10.6 m/s). The processing was conducted on a per source basis, evaluating the plume for each source individually.

As TAPM was set to model the plume in Lagrangian mode, this simulates the plume as a series of oblate spheroid 'puffs' emitted from each source, tracking their progression in a three-dimensional space over time, as required by CASA (2012). The 'puff' behaves by the following rules:

- The 'puff' centre point traverses down-wind according to the 3D wind vector field simulated in the meteorological model.
- The 'puff' centre point elevation increases in accordance with the plume momentum determined by the plume buoyancy and vertical velocity.
- The 'puff' spread, both horizontally and vertically, increases over time as the gas disperses into the surrounding atmosphere.

This concept is presented diagrammatically in Figure 4-1.

Figure 4-1: Diagram of Plume 'Puff' Dispersion Method



The steps undertaken to determine the plume spread are as follows:

1. An executable file specifically designed by CSIRO for CASA Plume Rise Assessments and supplied with TAPM v4.0.5 was run over the output plume rise file from TAPM which filtered out all data in which the plume 'puffs' have a vertical velocity below the critical plume velocity (4.3 m/s or 10.6 m/s). The resulting data have the following parameters:
   - Date;
   - Hour;
   - Source number;
   - Time increment within hour (seconds);
   - Vertical velocity (m/s);
   - Elevation above ground level of plume 'puff' centre point (metres);
   - Horizontal radius of plume 'puff' (metres);
   - Vertical radius of plume 'puff' (metres);
   - East-West displacement of plume 'puff' centre point from source point (metres); and
   - North-South displacement of plume 'puff' centre point from source point (metres).
2. The data are imported into the Microsoft Excel spread sheet software package and sorted by elevation.
3. The maximum value of the sum of the displacement of the plume 'puff' centre point and the horizontal plume radius is determined for each elevation was determined.

As the maximum horizontal extent of the plume 'puff' centre point and 'puff' spread is the important factor to determine at each elevation and that the time required for the plume's vertical velocity to fall below the critical value is on the order of seconds, the path in which the plume reached the location in which its vertical velocity fell below the critical plume velocity was assumed to be a straight line from the efflux point of the emission source.

To determine the frequency percentage for each elevation the frequency of the elevation occurring in the processed dataset was divided by the total number of hours in the dataset and linearly interpolated to obtain the desired percentage value (i.e. 100%, 90%, 80%, etc.).

For graphical purposes an algorithm was defined to run over the output data and determine the three-dimensional space in which all the combined 'puffs' occupied. This allows a realistic visualisation of the potential obstacle the buoyant plumes can present in relation to any critical plume heights defined at that location.

5 Meteorological Model Validation

Comparisons of the meteorological output data from the models were made against the observations recorded at the Prince Rupert Airport AWS for the corresponding time period in order to validate the meteorological model.

5.1 Wind Speed and Direction

Figure 5-1 presents a comparison between the annual wind roses for measured data at the Prince Rupert Airport AWS and the original and adjusted TAPM-generated datasets at the same location for the corresponding 5-year modelled period. Measured and adjusted TAPM-generated wind roses and wind speed frequency distribution histograms are also presented in Figure 5-2 and Figure 5-3 respectively.

The following observations have been made:

Annual Wind Roses:

- The original TAPM-generated dataset shows an increased proportion of winds blowing from the southwest and a decreased proportion of winds blowing from the east-northeast and west than the measured dataset.
- These trends are more closely represented in the adjusted TAPM-generated dataset.

Quarterly Wind Roses:

- In general, the seasonal wind direction trends are well represented by the adjusted TAPM-generated dataset;
- TAPM marginally under predicts the proportion of higher wind speeds from the southeast during the colder months (October – March); and
- TAPM marginally over predicts the proportion of lower wind speeds (2 – 3 m/s) during the warmer months (April – September).

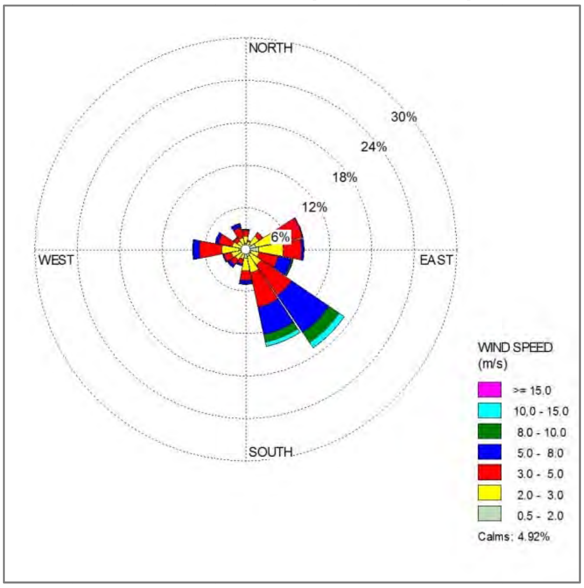
Wind Speed Frequency Distributions:

- The observations from the quarterly wind roses is corroborated with decreased proportions of higher wind speeds predicted by TAPM and an increased proportion of lower speed (2 – 3 m/s) winds.

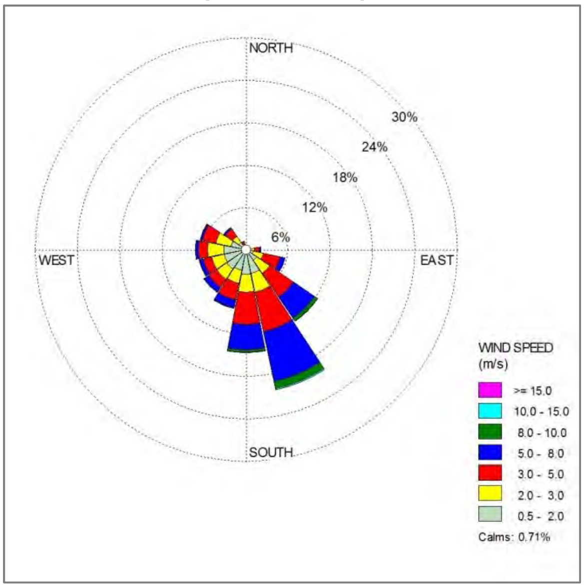
Notably, an increased frequency of lower wind speed conditions is likely to result in more frequent vertically-oriented plumes, which is considered the more conservative scenario with-respect-to aircraft flight obstacles. Hence, for the purposes of this assessment, the adjusted TAPM-generated dataset is considered appropriate and representative of the conditions at the site.

Figure 5-1: Annual Wind Roses for Measured and TAPM-Generated Datasets for Prince Rupert Airport

Measured Data (2010 – 2014)



Original TAPM-Generated Data (2009 – 2013)



Adjusted TAPM-Generated Data (2009 – 2013)

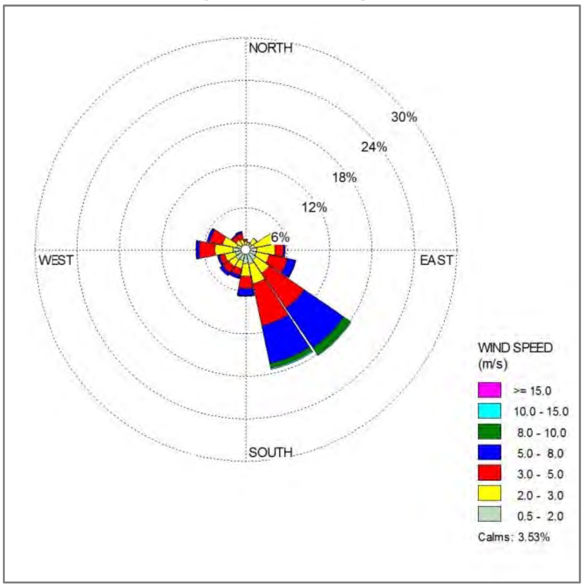
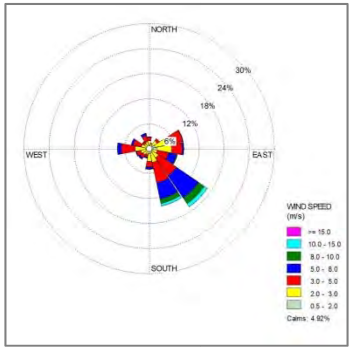
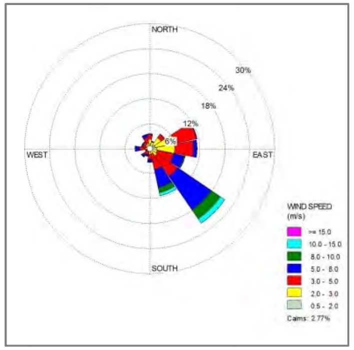


Figure 5-2: Quarterly Wind Roses for Measured and Adjusted TAPM-Generated Datasets for Prince Rupert Airport

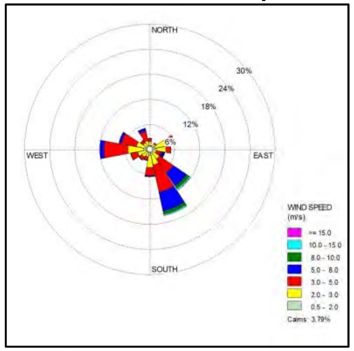
Measured Data (Annual)



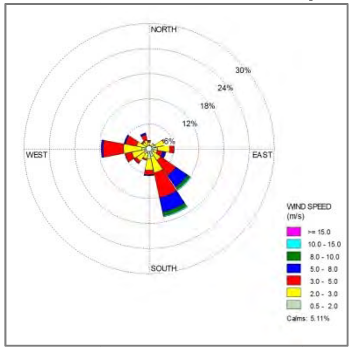
Measured Data 10-14 (Jan-Mar)



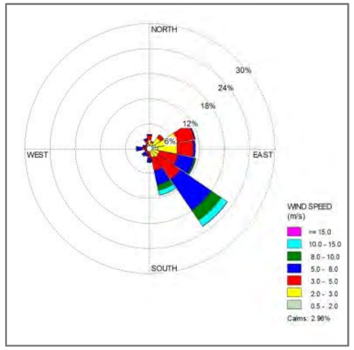
Measured Data 10-14 (Apr-Jun)



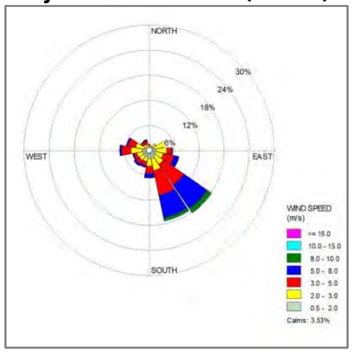
Measured Data 10-14 (Jul-Sep)



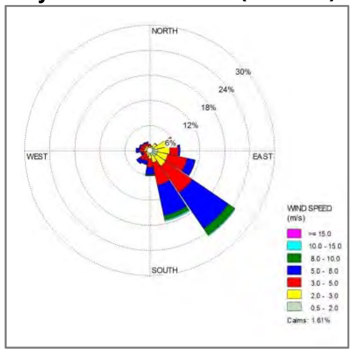
Measured Data 10-14 (Oct-Dec)



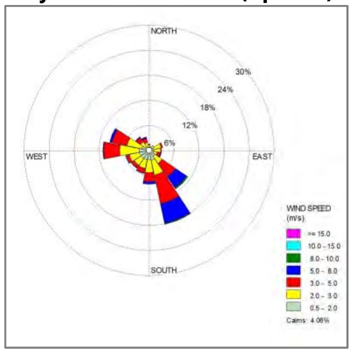
Adjusted TAPM 09-13 (Annual)



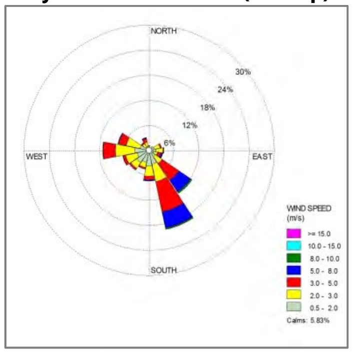
Adjusted TAPM 09-13 (Jan-Mar)



Adjusted TAPM 09-13 (Apr-Jun)



Adjusted TAPM 09-13 (Jul-Sep)



Adjusted TAPM 09-13 (Oct-Dec)

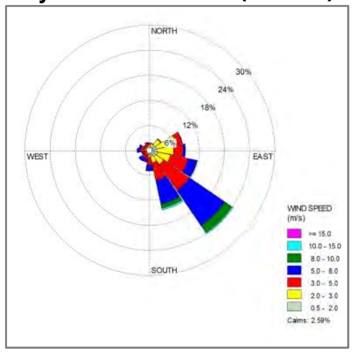
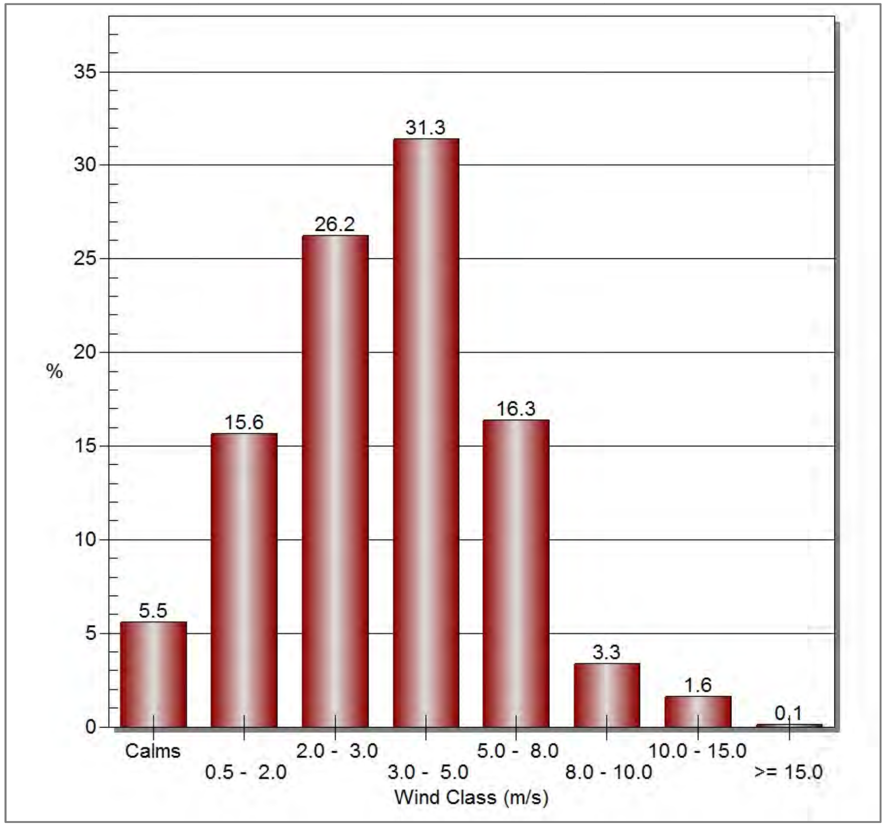
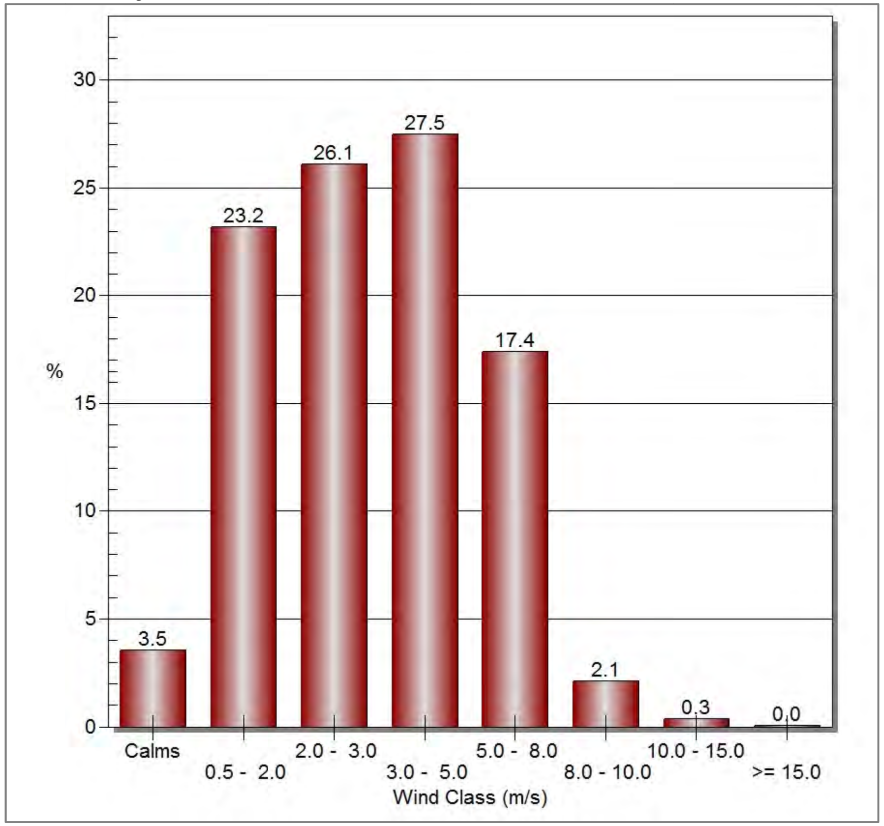


Figure 5-3: Wind Speed Frequency Distribution Histograms for Measured and Adjusted TAPM-Generated Datasets for Prince Rupert Airport

Measured Data 2009-2014 (Full Year)



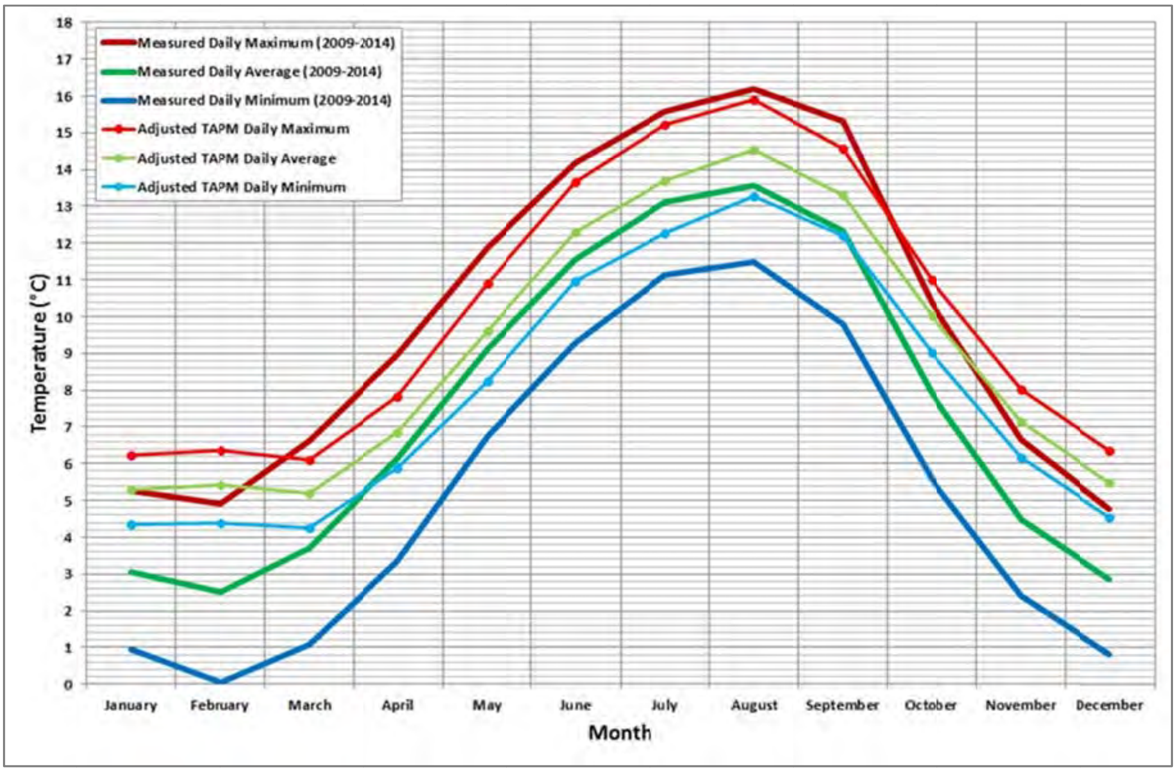
Adjusted TAPM-Generated Data 2009-2013 (Full Year)



5.2 Temperature

The monthly temperature profile comparison between the measured and adjusted TAPM-generated data is presented in Figure 5-4. It is apparent that TAPM over-predicts the average daily minimum temperature, particularly in the winter months where the minima tend to 0°C. The over-prediction can be up to approximately 4°C in February. In general, the daily maximum temperature is predicted reasonably well with a minor trend of under-prediction during the warmer months and over-prediction during the colder months.

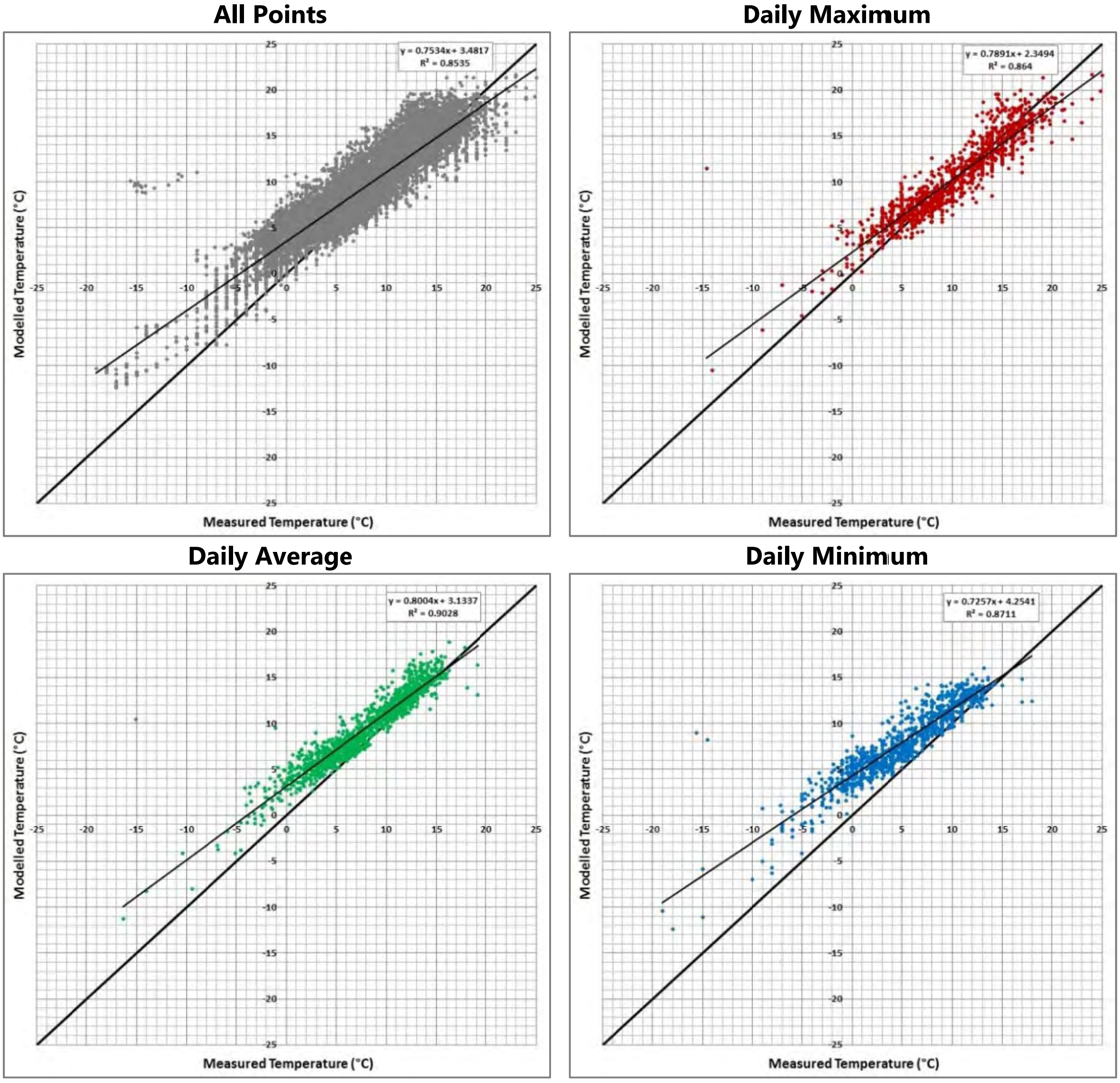
Figure 5-4: Prince Rupert Temperature Profile - Measured versus Adjusted TAPM Data



Correlation scatter plots for: all points; daily maxima; daily average; and daily minima are presented in Figure 5-5. These plots show the general trends of over-prediction of the colder temperatures and under-prediction of warmer temperatures. It is important to note however that the lines of best fit all have a correlation coefficient (R^2) of 0.85 or better, indicating that the temperature is reasonably predictable and the scatter is relatively small.

The overall effect of these temperature predictions are that buoyancy of the plume may be marginally under-predicted when the ambient temperatures are at or below freezing; however, the difference between the buoyancy is likely to be minimal as the temperature differential between the plumes and ambient conditions are proportionally much larger.

Figure 5-5: Measured versus Adjusted TAPM-Predicted Temperature Correlation Plots



5.3 Discussion

In general, it is apparent that TAPM does not predict the more extreme weather conditions (i.e. very cold ambient temperatures and high wind speeds) well. This is to be expected as these are atypical outlier events and are by nature not easily predictable by computer simulation. However, in the context of a plume rise impact assessment, particularly for the wind profiles, the adjusted TAPM-generated dataset is representative of site conditions and tends to more conservative results when it deviates from the measured dataset. Hence the adjusted TAPM-generated dataset is considered appropriate for the purposes of this assessment.

6 Modelling Results

The following section presents and discusses the results of the plume dispersion modelling.

6.1 Wind Analysis

Meteorological data, specifically wind speeds and directions were output from TAPM v4.0.5 at varying heights above ground level. Table 6-1 presents the relative altitudes for these heights at the proposed LNG facility and the TAPM grid levels they correspond with.

Table 6-1: Relative Altitudes at Facility Location

TAPM Grid Level	Height Above Ground Level	Altitude Above Sea Level (mASL) Site Ground Elevation: 30 mASL
1	10 mAGL	40 mASL
3	50 mAGL	80 mASL
5	100 mAGL	130 mASL
9	300 mAGL	330 mASL
13	500 mAGL	530 mASL
16	1,000 mAGL	1,030 mASL
20	2,000 mAGL	2,030 mASL
23	3,000 mAGL	3,030 mASL

The frequencies in which the modelled wind speeds fell below certain critical low values at varying heights above ground level are presented in Table 6-2. There is a drop in frequency of low wind speeds at 300 mAGL. This corresponds with a change in prevailing wind direction and shows where the topographical influences change from localised small-scale influences to the larger scale mountainous channelling along the coastline.

Table 6-2: Low Wind Speed Frequency Analysis

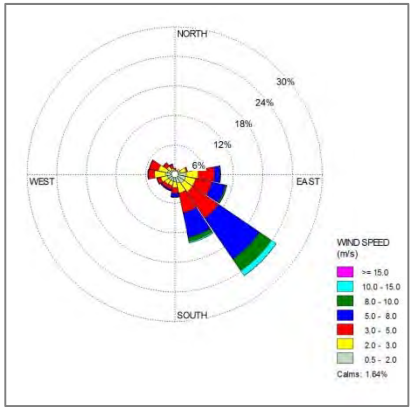
Wind Speed Threshold (m/s)	Frequency of Wind Speed Falling Below Threshold (%)								
	Height (m)	10	50	100	300	500	1,000	2,000	3,000
	Altitude (mASL)	40	80	130	330	530	1,030	2,030	3,030
0.5		2.344%	1.627%	1.547%	0.559%	0.511%	0.559%	0.377%	0.288%
0.4		1.636%	1.091%	1.075%	0.393%	0.333%	0.381%	0.269%	0.201%
0.3		1.063%	0.689%	0.726%	0.233%	0.224%	0.281%	0.187%	0.123%
0.2		0.621%	0.345%	0.424%	0.137%	0.139%	0.169%	0.116%	0.048%
0.1		0.278%	0.164%	0.178%	0.078%	0.071%	0.075%	0.050%	0.016%

The five year wind roses and the wind speed frequency distributions for each height above ground level are presented in Figure 6-1 and Figure 6-2 respectively. Figure 6-3 presents the cumulative frequency for wind speeds ranging from 0 m/s to 38 m/s. Figure 6-4 presents diagrammatically the prevailing wind directions at each altitude.

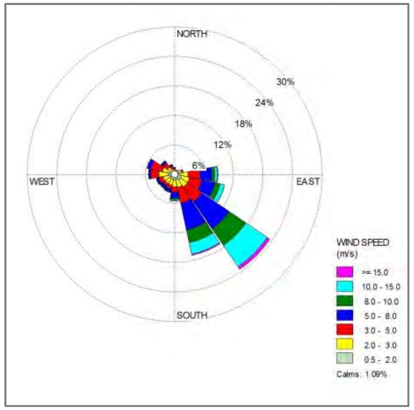
It is apparent that a transition occurs above 100 mAGL. A significant increase in high wind speeds (> 15 m/s), predominantly blowing from the southwest occurs at higher altitudes. This corresponds with the localised winds merging into the synoptic-level high-altitude winds where local topographical effects are less significant.

Figure 6-1: Five-Year (2009 – 2013) Wind Roses for Varying Altitudes

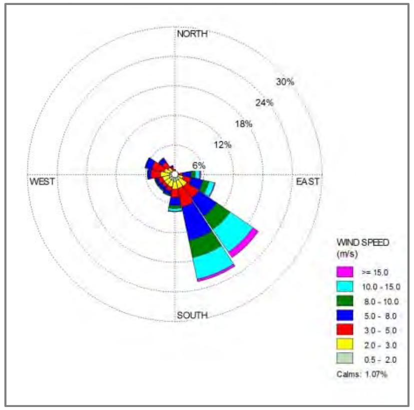
10 m / 40 mASL



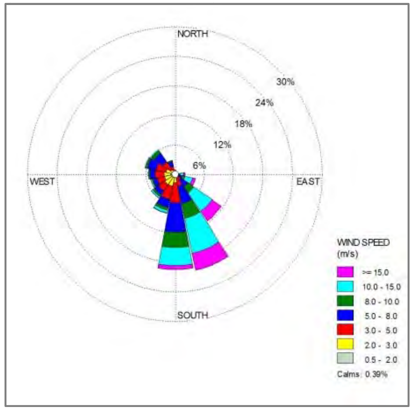
50 m / 80 mASL



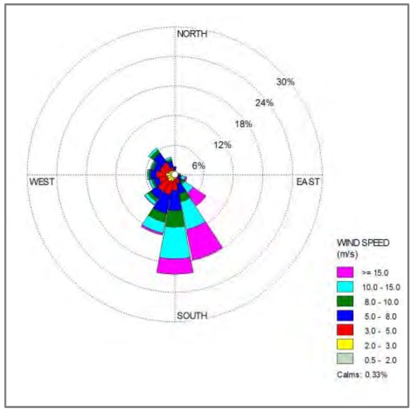
100 m / 130 mASL



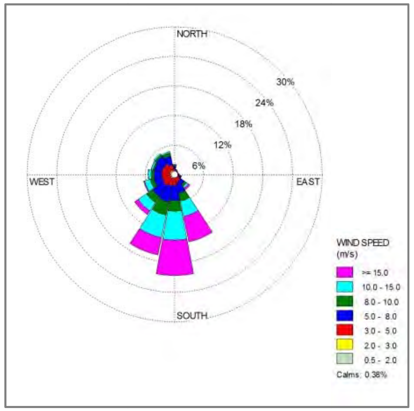
300 m / 330 mASL



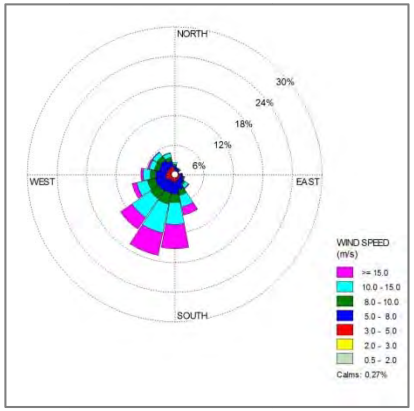
500 m / 530 mASL



1,000 m / 1,030 mASL



2,000 m / 2,030 mASL



3,000 m / 3,030 mASL

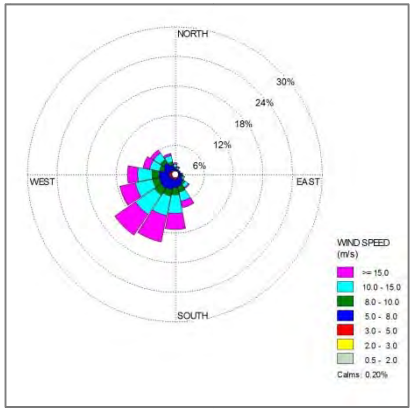


Figure 6-2: Five-Year (2009 – 2013) Wind Speed Frequency Distribution Histograms for Varying Altitudes

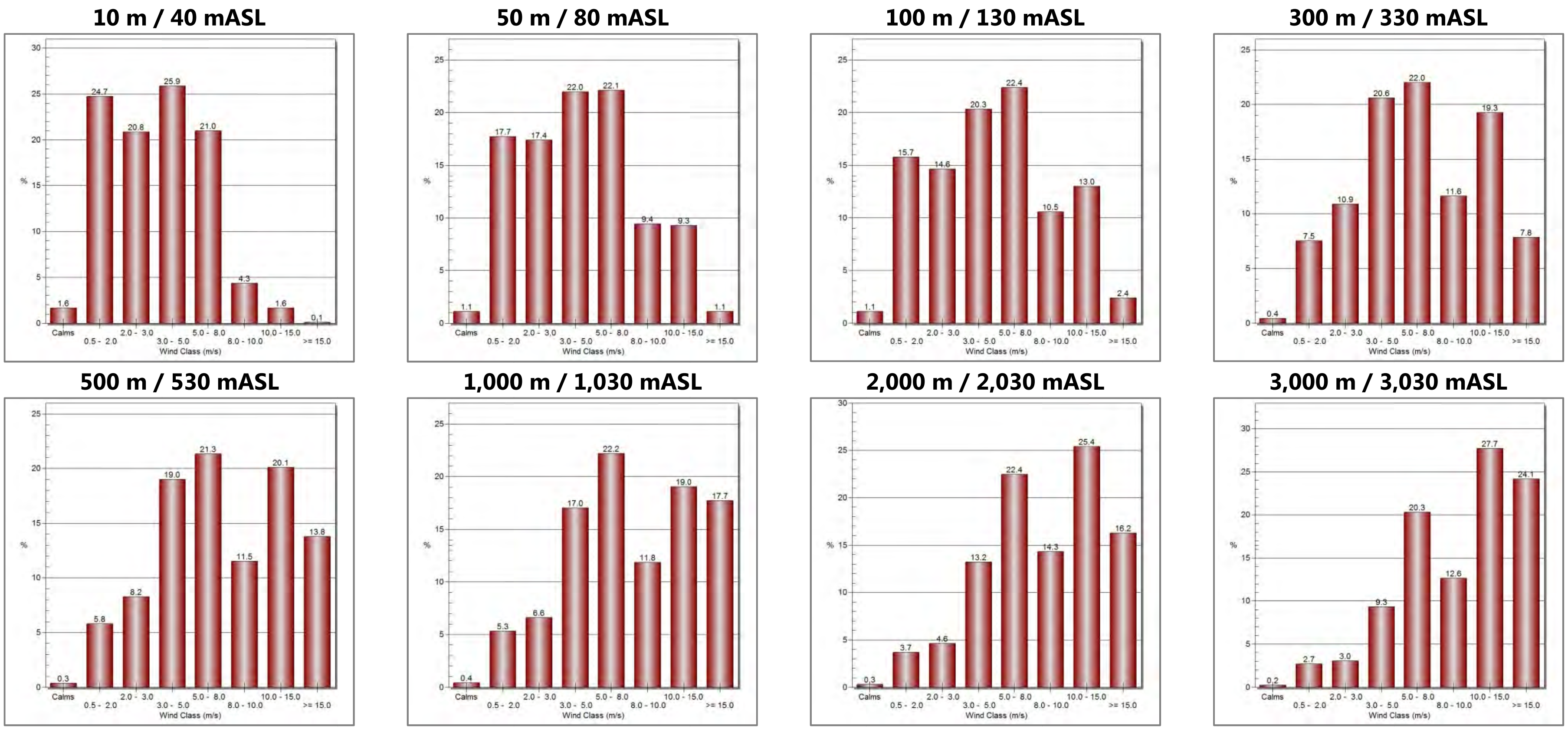


Figure 6-3: Wind Speed Cumulative Frequency Distribution for Varying Altitudes

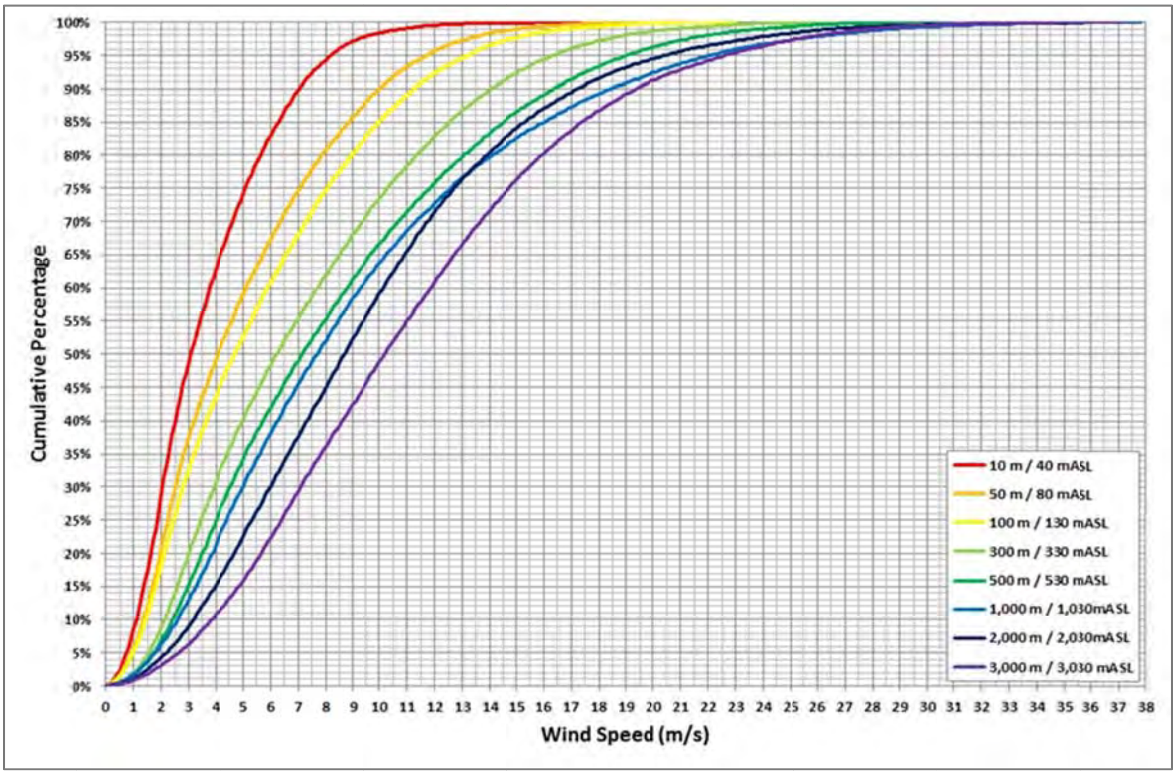
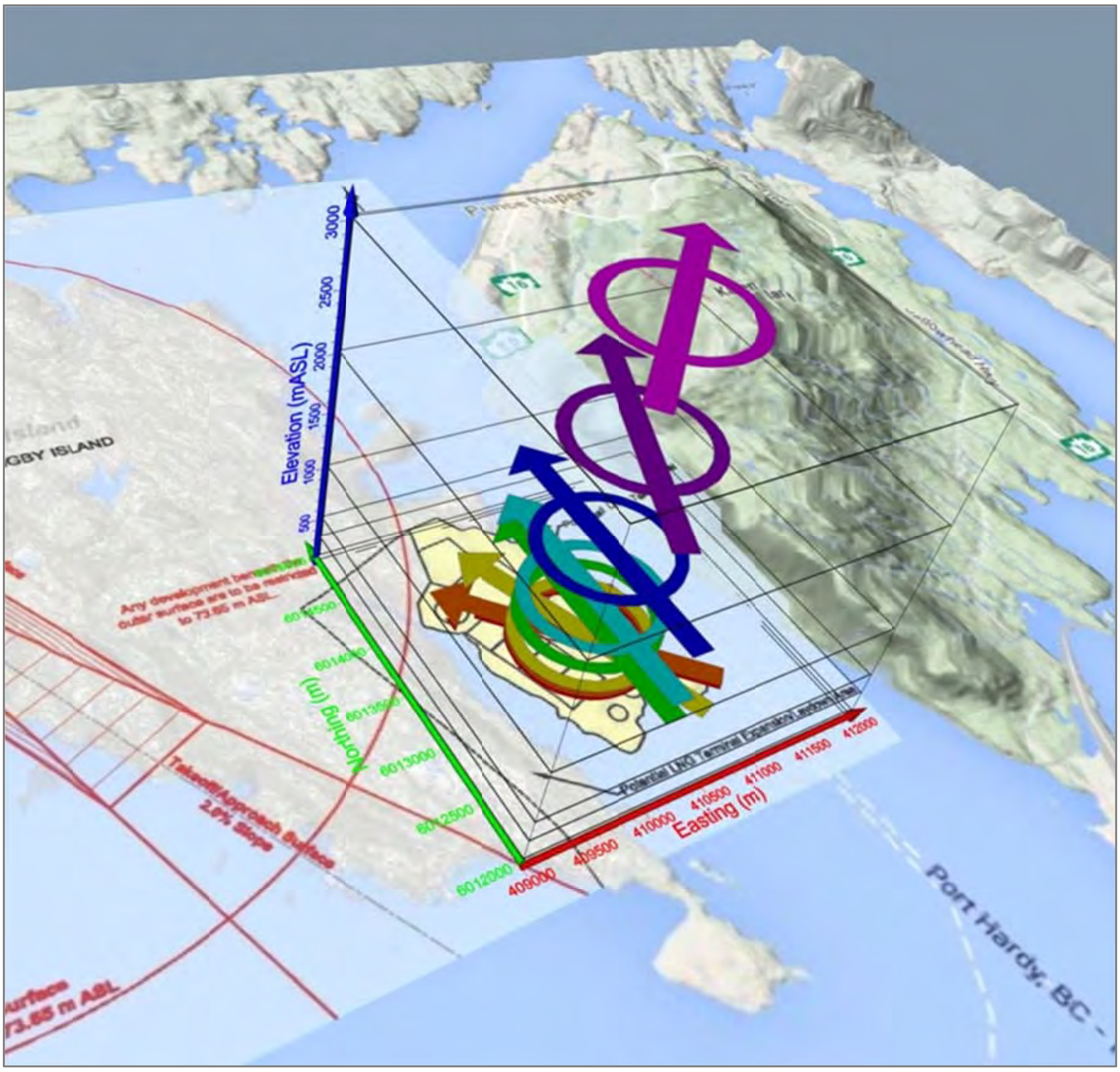


Figure 6-4: Prevailing Wind Direction Diagram at Varying Altitudes



Note: Map imagery obtained from Google Maps™.

6.2 Maximum Plume Dimension Analysis

The maximum plume dimensions calculated are presented in Table 6-3 and represented graphically in Figure 6-5. Note that the dimensions include the plume spread, both vertically and horizontally and represent the maximum values each plume could potentially reach. As discussed in more detail in Section 6.3, the probability of any plumes reaching their maximum value is 1 hour in 5 years (43,824 hours) or 0.0023%. Three-dimensional representations of the plume volumes are presented in Appendix C and Appendix D.

The Wet Gas Flare produces both the tallest (3,395 mASL) and widest (1,718 m) plume profile. The Wet Gas Flare is proposed to be located approximately 1,400 m east of the outer limits of and 2,125 m east of the centreline of the southern approach / take-off vector of the Price Rupert Airport. Therefore, it is anticipated that the plume profile will laterally overlap the approach / take-off vector by approximately 318 m at an altitude of 2,368 mAGL (2,398 mASL).

Additionally, several plume sources are located within the outer limits of the Obstacle Limitation Surface (OLS) for the Prince Rupert Airport, namely:

- All Power Plant Gas Turbines (6 sources);
- Utility sources for Trains 3 and 4 (Emergency Diesel Generator and Diesel Firewater Pump, 2 sources); and
- MR Gas Turbines 1 and 3 for Train 3 (2 sources).

Only the Utility sources did not produce plumes greater than the OLS height of 73.65 mASL.

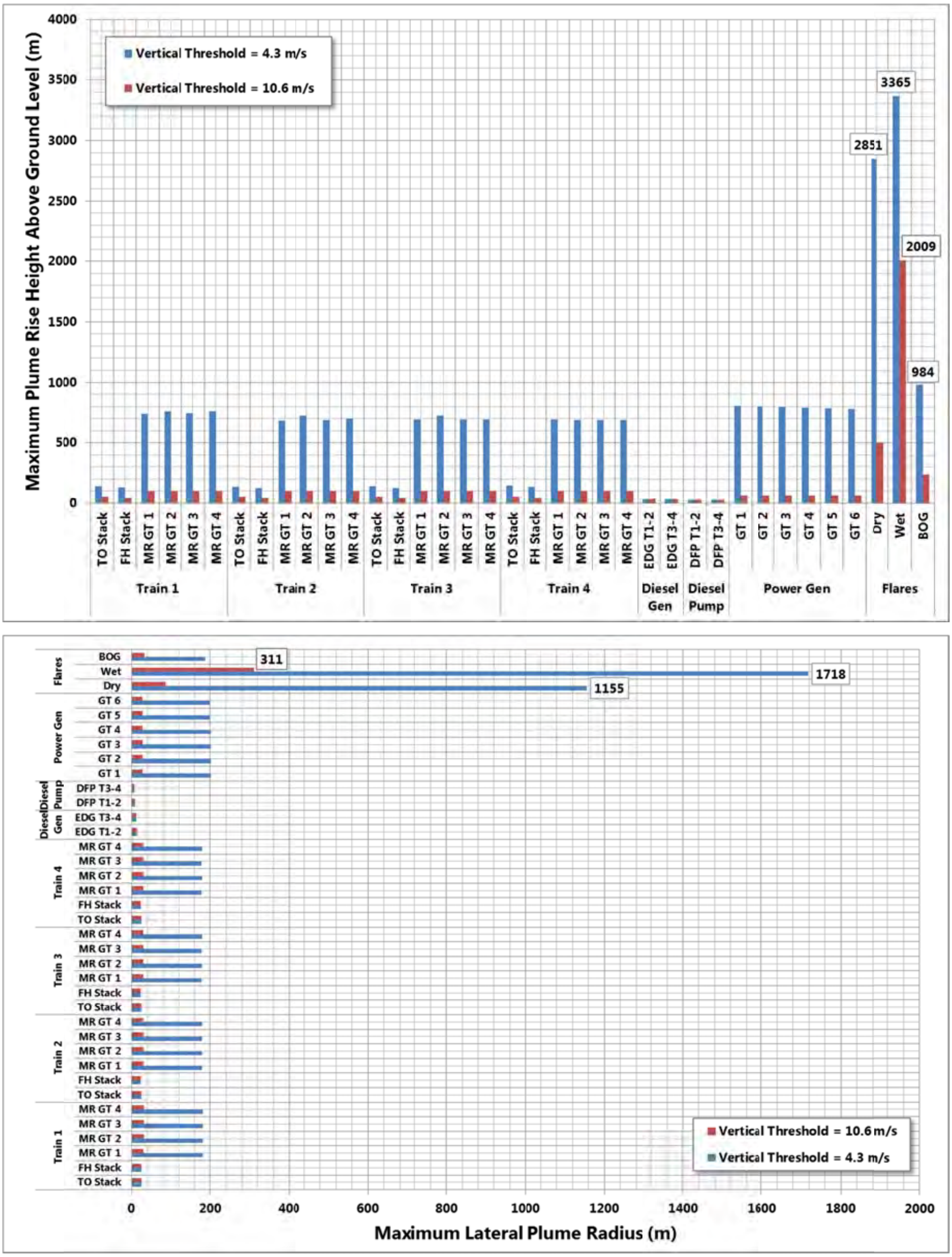
Therefore, the obstacles that these plumes create to low-flying aircraft may present a safety hazard that requires assessment by the Canadian aviation regulators.

Table 6-3: Maximum Plume Dimensions for Varying Vertical Velocity Thresholds

Plume Source		Vertical Velocity Threshold					
		4.3 m/s			10.6 m/s		
		Max. Plume Rise Height		Max. Lateral Plume Radius (m)	Max. Plume Rise Height		Max. Lateral Plume Radius (m)
		m	mASL		m	mASL	
Train 1	TO Stack	140	170	24	53	83	24
	FH Stack	128	158	24	43	73	24
	MR GT 1	740	770	182	98	128	30
	MR GT 2	757	787	181	98	128	30
	MR GT 3	746	776	181	98	128	30
	MR GT 4	757	787	181	98	128	30
Train 2	TO Stack	137	167	24	53	83	24
	FH Stack	126	156	23	43	73	23
	MR GT 1	682	712	180	99	129	30
	MR GT 2	724	754	181	98	128	30
	MR GT 3	687	717	180	99	129	30
	MR GT 4	696	726	181	99	129	30
Train 3	TO Stack	139	169	24	53	83	24
	FH Stack	123	153	23	43	73	23
	MR GT 1	691	721	179	98	128	30
	MR GT 2	723	753	180	99	129	30
	MR GT 3	693	723	179	99	129	30
	MR GT 4	695	725	180	99	129	30
Train 4	TO Stack	144	174	24	53	83	24
	FH Stack	134	164	23	43	73	23
	MR GT 1	693	723	179	99	129	30
	MR GT 2	688	718	181	99	129	30
	MR GT 3	687	717	179	99	129	30

Plume Source		Vertical Velocity Threshold					
		4.3 m/s			10.6 m/s		
		Max. Plume Rise Height		Max. Lateral Plume Radius (m)	Max. Plume Rise Height		Max. Lateral Plume Radius (m)
		m	mASL		m	mASL	
	MR GT 4	687	717	180	99	129	30
Emergency Diesel Generators	EDG T1-2	34	64	13	34	64	13
	EDG T3-4	34	64	13	34	64	13
Diesel Firewater Pumps	DFP T1-2	29	59	9	29	59	9
	DFP T3-4	29	59	8	29	59	8
Power Generation Plant	GT 1	805	835	203	64	94	28
	GT 2	799	829	202	64	94	28
	GT 3	793	823	202	64	94	28
	GT 4	791	821	201	64	94	28
	GT 5	785	815	200	64	94	28
	GT 6	778	808	199	64	94	28
Flares	Dry	2,851	2,881	1,155	498	528	86
	Wet	3,365	3,395	1,718	2,09	2,039	311
	BOG	984	1,014	188	236	266	33

Figure 6-5: Maximum Plume Dimensions



6.3 Plume Rise Analysis

The interaction between the exhaust plume and the surrounding atmosphere progressively reduces the plumes' vertical velocity over time. A plume is considered to reach its maximum altitude when its vertical velocity drops below the critical plume velocity. Therefore, with increasing height above ground level, the probability of the exhaust plume having a vertical velocity greater than the critical plume velocity (4.3 m/s or 10.6 m/s) decreases proportionally. Hence a proportional correlation can be determined between height above ground level and the probability that a plume may reach that height at any given time.

As required by CASA (2012), an analysis of the frequency in which a buoyant plume may reach any given altitude is required. For ease of interpretation, Table 6-4 has been provided to give a comparison of the probability percentages to the frequency of plume reaching a certain altitude.

Table 6-4: Comparison of Percentage to Frequency of an Hourly Event

Percentage Probability (%)	Frequency of an Hour Event
100%	Every hour
50%	Every second hour
40%	Approximately 10 hours per day
20%	Approximately 5 hours per day
10%	2 – 3 hours per day
4%	Approximately one hour per day
1%	Approximately one hour per four days
0.5%	Approximately one hour per week
0.1%	Approximately one hour per six weeks
0.05%	Approximately 5 hours per year
0.0023%	One hour per 5 years

The following section discusses the vertical velocities of the plumes for the proposed Aurora LNG Facility.

Table 6-5 and Table 6-6 present the probabilities of the plumes reaching a certain height above ground level with the vertical velocity greater than the 4.3 m/s threshold. Figure 6-6 and Figure 6-7 present the average heights at each probability for each type of plume source. There is a strong correlation between the plume rise height and the plume source type, for example: all compressor Gas Turbine plumes behave similarly; and all power generation Gas Turbines behave similarly.

Note: The height values in this section refer to the plume 'puff' centre point and do not include the vertical spread as this facilitates analysis of the particle tracking within the dispersion modelling.

The following observations have been made:

- **Thermal Oxidiser Exhausts:** Produce reasonably small maximum plume rise heights of 133 mAGL (4.3 m/s threshold).

- **Fired Heater Exhausts:** Behave very similarly to the thermal oxidiser plumes, except are approximately 10 m smaller, as the stacks are 10 m shorter. Maximum plume rise height of 121 mAGL (4.3 m/s threshold).
- **Compressor Gas Turbine Exhausts:** Behave very similarly to the power generation gas turbines, with marginally smaller maximum plume rise heights, with 655 mAGL (4.3 m/s threshold).
- **Power Generation Gas Turbines Exhausts:** Produce the largest maximum plume rise height, from a non-flare emission source, with 729 mAGL (4.3 m/s threshold).
- **Emergency Diesel Generator Exhausts:** The second smallest maximum plume rise height of 31 mAGL (4.3 m/s threshold).
- **Diesel Firewater Pump Exhausts:** The smallest maximum plume rise height of 26 mAGL (4.3 m/s threshold).

Flares:

- **Wet Gas Flare:** Produces the largest plume by far with a maximum plume rise height of 3,365 mAGL (4.3 m/s threshold).
- **Dry Gas Flare:** Produces the second largest plume with a maximum plume rise height of 2,851 mAGL (4.3 m/s threshold).
- **BOG Flare:** Behaves similarly to the power generation gas turbine exhausts, except approximately 100 m larger, with a maximum plume rise height of 984 mAGL (4.3 m/s threshold).

Table 6-5: Plume Rise Frequency Analysis Summary – 4.3 m/s Vertical Velocity Threshold

Probability of Plume Vertical Velocity > Threshold	Elevation Above Ground Level (mAGL)																	
	Train 1						Train 2						Train 3					
	TO Stack	FH Stack	MR GT1	MR GT2	MR GT3	MR GT4	TO Stack	FH Stack	MR GT1	MR GT2	MR GT3	MR GT4	TO Stack	FH Stack	MR GT1	MR GT2	MR GT3	MR GT4
100%	43	34	51	51	51	51	43	34	51	51	51	51	44	34	51	51	51	51
90%	46.18	36.20	61.45	61.41	61.43	61.42	46.18	36.20	61.50	61.46	61.49	61.47	46.21	36.23	61.90	61.81	61.88	61.83
80%	46.39	36.42	67.06	66.94	67.04	67.01	46.40	36.43	67.15	67.08	67.14	67.10	46.44	36.48	67.67	67.55	67.64	67.58
70%	46.61	36.64	72.90	72.52	72.81	72.59	46.62	36.66	73.14	73.01	73.11	73.04	46.67	36.72	73.85	73.66	73.80	73.70
60%	46.82	36.86	79.60	79.44	79.56	79.47	46.83	36.88	79.85	79.66	79.80	79.70	46.89	36.96	84.53	80.95	84.34	82.08
50%	47.04	37.10	91.53	91.26	91.47	91.33	47.06	37.13	91.92	91.61	91.83	91.67	47.14	37.21	96.63	93.76	96.33	94.67
40%	47.33	37.38	107.67	107.08	107.53	107.23	47.34	37.40	108.78	107.89	108.57	108.07	47.40	37.46	110.67	110.25	110.57	110.38
30%	47.61	37.65	128.36	128.28	128.37	128.34	47.62	37.66	128.54	128.37	128.52	128.35	47.66	37.71	129.63	129.63	129.65	129.62
20%	47.90	37.92	157.21	157.45	157.26	157.35	47.90	37.93	156.72	157.12	156.90	157.01	47.92	37.96	156.27	156.98	156.49	156.80
10%	51.91	42.15	208.20	209.31	208.48	208.99	51.94	42.21	206.26	207.65	206.66	207.15	52.01	42.33	203.96	205.51	204.20	205.19
9%	52.37	42.56	216.10	217.05	216.41	216.85	52.40	42.62	214.74	215.62	215.08	215.32	52.45	42.73	211.66	213.37	212.08	212.96
8%	52.81	42.97	224.69	226.00	225.21	225.76	52.84	43.47	222.90	224.40	223.34	223.91	52.89	45.11	219.41	221.72	219.93	221.26
7%	57.04	47.16	234.38	235.13	234.55	234.88	57.03	47.23	233.10	233.78	233.33	233.61	57.13	47.35	228.96	230.99	229.46	230.47
6%	57.52	47.62	245.09	246.13	245.39	246.04	57.51	47.69	243.33	244.61	243.38	244.15	57.61	47.85	238.45	240.66	239.31	240.31
5%	58.00	48.50	256.62	257.78	257.05	257.62	57.98	50.28	254.97	256.44	255.19	255.91	59.68	52.20	249.63	251.85	250.23	251.29
4%	62.64	52.75	271.50	272.97	272.10	272.78	62.61	52.84	269.31	271.05	269.81	270.48	62.81	53.13	263.55	265.42	264.16	265.13
3%	67.38	57.56	288.45	289.92	288.64	289.51	67.31	57.65	286.21	287.79	286.70	287.43	67.83	58.02	280.29	282.94	280.84	282.68
2%	73.10	63.28	311.73	313.32	312.03	312.92	73.14	63.32	309.23	311.30	309.32	310.96	73.47	63.73	302.41	305.55	302.98	305.03
1%	83.78	73.62	355.19	356.39	355.60	356.42	84.02	73.92	352.35	354.29	352.97	353.47	85.30	75.51	342.97	344.98	344.29	344.98
0.50%	94.16	83.99	397.38	398.94	397.74	398.31	94.76	85.24	394.78	396.98	395.41	395.76	95.19	86.45	388.38	391.47	389.10	390.31
0.30%	99.12	91.61	431.38	433.26	431.26	432.53	99.22	92.17	426.76	428.79	426.38	428.38	99.43	91.68	417.51	423.35	419.53	422.88
0.20%	102.45	94.74	453.45	456.35	453.87	454.78	102.29	94.64	451.18	451.35	452.35	451.35	102.38	95.09	447.68	447.18	448.06	448.35
0.10%	106.02	98.80	497.35	494.35	496.45	494.88	105.69	99.02	497.59	498.94	498.94	497.70	105.24	98.46	495.18	492.35	494.12	491.59
0.05%	109.42	102.11	537.53	541.26	543.18	541.18	109.02	102.03	532.18	535.44	531.18	534.18	108.02	100.91	527.35	532.26	529.18	533.18
Statistical Parameters																		
Max. Height (0.0023%)	133	121	683	699	689	699	130	119	627	668	632	641	132	117	641	667	642	644
Min. Height	41	32	46	46	46	46	41	32	46	46	46	46	42	32	46	46	46	46
Average Height	48.21	38.30	115.66	115.64	115.66	115.65	48.22	38.35	115.72	115.65	115.69	115.64	48.33	38.49	116.52	116.56	116.54	116.56

Probability of Plume Vertical Velocity > Threshold	Elevation Above Ground Level (mAGL)																		
	Train 4						Emergency Diesel Generator		Diesel Firewater Pump		Power Generation						Flares		
	TO Stack	FH Stack	MR GT1	MR GT2	MR GT3	MR GT4	EDG T1-2	EDG T3-4	DFP T1-2	DFP T3-4	GT 1	GT 2	GT 3	GT 4	GT 5	GT 6	Wet	Dry	BOG
100%	44	34	51	51	51	51	23	23	17	17	51	51	51	51	51	51	603	448	162
90%	46.20	36.22	61.75	61.68	61.73	61.70	23.28	23.39	17.78	18.07	62.57	62.50	62.41	62.32	62.24	62.14	738.89	541.35	166.13
80%	46.42	36.46	67.50	67.39	67.47	67.42	23.57	23.77	18.12	18.23	71.07	71.04	71.01	69.32	68.48	67.24	815.73	587.34	176.85
70%	46.65	36.70	73.61	73.46	73.57	73.50	23.85	24.09	18.28	18.39	77.74	77.71	77.67	77.64	77.60	77.56	896.40	638.11	180.69
60%	46.88	36.94	80.89	80.52	80.79	80.61	24.12	24.31	18.45	18.55	89.22	89.16	89.11	89.05	88.99	88.88	978.74	698.38	190.29
50%	47.12	37.19	93.73	92.74	93.31	92.86	24.36	24.52	18.62	18.70	102.33	102.25	102.13	102.02	101.92	101.82	1,066.08	767.44	197.89
40%	47.39	37.44	110.19	109.72	110.10	109.82	24.60	24.74	18.78	18.86	119.32	119.23	119.17	119.08	118.99	118.88	1,157.48	850.05	214.55
30%	47.65	37.70	129.43	129.39	129.38	129.39	24.85	24.96	18.95	19.06	138.68	138.63	138.57	138.58	138.52	138.53	1,260.60	943.78	234.53
20%	47.92	37.95	156.37	156.67	156.47	156.64	25.24	25.42	19.36	19.49	166.31	166.35	166.40	166.45	166.53	166.59	1,392.60	1,058.50	266.37
10%	52.02	42.32	204.02	205.95	204.12	205.37	25.88	25.95	19.87	19.92	215.32	215.50	215.70	215.94	216.19	216.48	1,584.14	1,227.21	316.48
9%	52.44	42.71	211.72	213.78	211.98	213.21	25.95	26.02	19.92	19.97	223.05	223.29	223.47	223.65	223.69	223.78	1,612.16	1,250.49	324.76
8%	52.87	44.68	219.98	221.68	220.29	221.37	26.04	26.21	19.97	20.04	231.10	231.13	231.26	231.51	231.63	231.88	1,641.88	1,274.55	334.10
7%	57.06	47.30	229.57	231.28	230.01	231.05	26.24	26.40	20.08	20.24	240.49	240.72	240.99	241.09	241.30	241.65	1,676.87	1,303.80	344.31
6%	57.56	47.77	238.67	240.95	239.12	240.32	26.44	26.60	20.28	20.44	250.25	250.49	250.68	250.86	251.18	251.51	1,720.50	1,336.76	357.32
5%	59.00	52.08	250.75	252.91	251.35	252.44	26.63	26.79	20.48	20.64	261.85	262.33	262.68	262.82	262.87	263.12	1,765.85	1,372.71	372.23
4%	62.74	53.00	264.13	266.88	264.64	266.25	26.83	26.98	20.68	20.84	275.90	276.31	276.62	276.74	276.94	277.32	1,814.26	1,418.88	389.95
3%	67.55	57.82	280.65	283.72	281.68	283.17	27.08	27.43	20.89	21.12	294.11	294.37	294.61	295.01	295.01	295.58	1,881.70	1,474.40	413.55
2%	73.23	63.56	303.32	305.58	303.54	304.89	27.61	27.90	21.31	21.67	317.58	317.79	317.88	318.55	318.50	319.25	1,965.93	1,549.72	448.59
1%	84.90	74.99	345.08	347.68	345.35	347.15	28.37	28.75	22.02	22.48	361.59	361.38	362.11	362.13	362.42	363.20	2,096.28	1,660.36	506.96
0.50%	95.36	86.84	388.49	391.63	389.27	390.81	29.08	29.49	22.95	23.22	405.55	405.70	405.81	406.44	407.44	407.94	2,212.64	1,754.23	566.18
0.30%	100.50	91.97	422.53	421.76	423.69	422.88	29.72	29.91	23.61	23.81	450.18	450.18	450.18	449.63	449.84	449.63	2,270.27	1,805.27	601.26
0.20%	102.57	94.89	447.12	446.18	446.18	445.18	30.06	30.29	23.96	24.21	475.67	475.59	475.35	475.35	476.68	477.45	2,323.12	1,857.36	629.35
0.10%	105.74	98.88	491.39	493.78	491.59	493.09	30.67	30.80	24.66	24.82	524.09	524.18	524.18	523.53	523.53	524.18	2,430.37	1,978.36	676.18
0.05%	109.62	101.62	532.35	531.09	536.06	532.35	30.97	30.80	25.10	25.40	556.09	556.09	556.13	556.09	556.09	557.26	2,536.18	2,089.72	729.09
Statistical Parameters																			
Max. Height (0.0023%)	137	127	642	636	637	637	31	31	26	26	742	736	730	728	722	716	3,066	2,614	922
Min. Height	42	32	46	46	46	46	21	21	15	15	46	46	46	46	46	46	411	545	158
Average Height	48.29	38.44	116.17	116.17	116.16	116.17	24.02	24.18	18.26	18.39	122.81	122.78	122.73	122.69	122.64	122.62	833.97	1,121.94	225.72

Figure 6-6: Probability of Plume Vertical Velocity > 4.3 m/s vs Height Above Ground Level

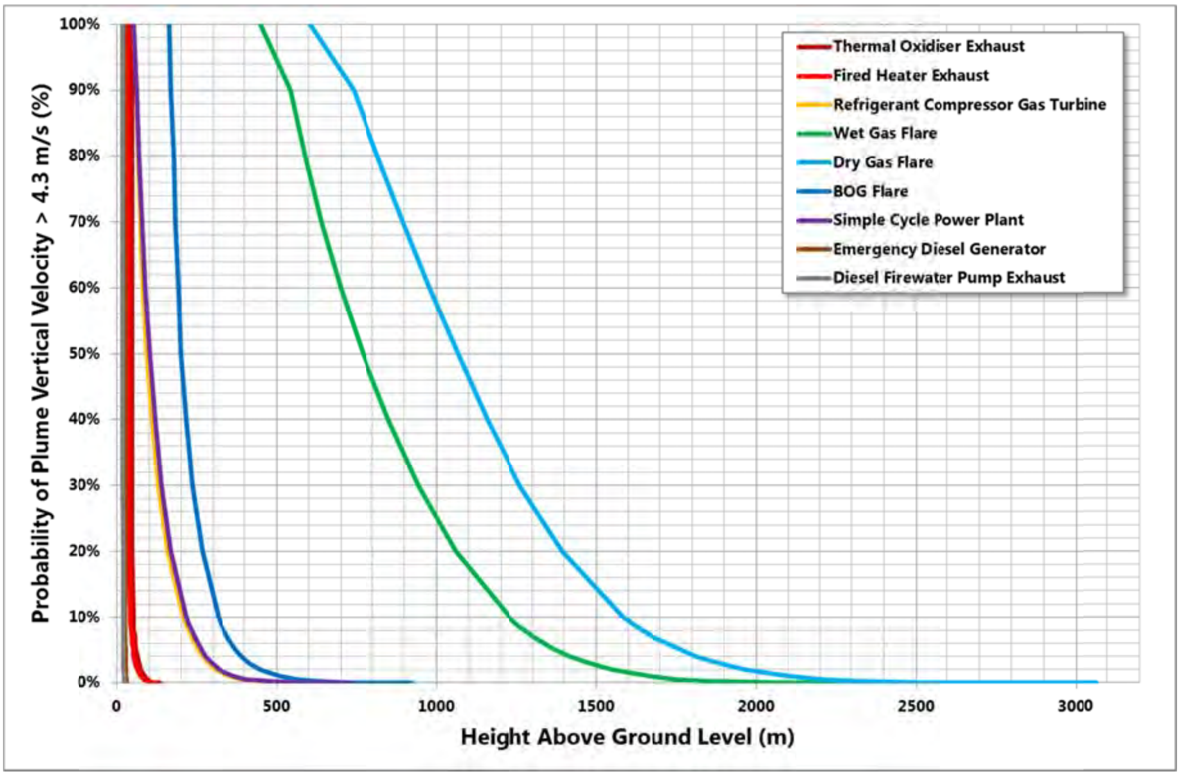
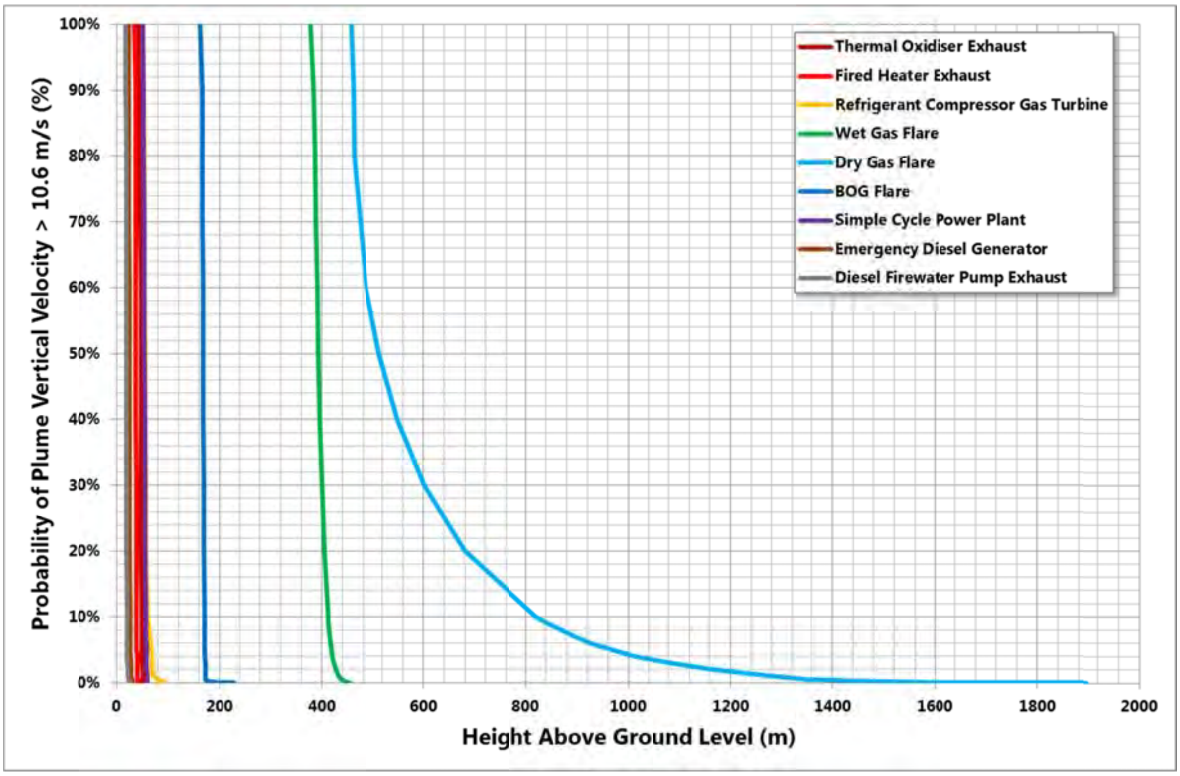


Table 6-6: Plume Rise Frequency Analysis Summary – 10.6 m/s Vertical Velocity Threshold

Probability of Plume Vertical Velocity > Threshold	Elevation Above Ground Level (mAGL)																	
	Train 1						Train 2						Train 3					
	TO Stack	FH Stack	MR GT1	MR GT2	MR GT3	MR GT4	TO Stack	FH Stack	MR GT1	MR GT2	MR GT3	MR GT4	TO Stack	FH Stack	MR GT1	MR GT2	MR GT3	MR GT4
100%	43	34	51	51	51	51	43	34	51	51	51	51	44	34	51	51	51	51
90%	46.18	36.20	52.46	52.44	52.45	52.45	46.18	36.20	52.47	52.46	52.47	52.47	46.21	36.23	52.59	52.57	52.58	52.57
80%	46.39	36.42	53.01	52.98	53.00	52.99	46.40	36.43	53.04	53.02	53.04	53.03	46.44	36.48	53.20	53.17	53.19	53.18
70%	46.60	36.64	53.52	53.49	53.51	53.50	46.62	36.66	53.56	53.53	53.55	53.54	46.67	36.72	53.73	53.69	53.72	53.70
60%	46.82	36.86	54.04	54.00	54.03	54.00	46.83	36.88	54.09	54.05	54.08	54.06	46.89	36.96	54.30	54.24	54.28	54.26
50%	47.04	37.10	54.65	54.61	54.64	54.62	47.06	37.13	54.71	54.67	54.70	54.68	47.14	37.21	54.90	54.85	54.88	54.86
40%	47.33	37.38	55.26	55.23	55.25	55.23	47.34	37.40	55.31	55.27	55.30	55.28	47.40	37.46	55.44	55.41	55.43	55.41
30%	47.61	37.65	55.85	55.83	55.84	55.83	47.62	37.66	55.88	55.86	55.88	55.87	47.66	37.71	55.96	55.95	55.96	55.95
20%	47.90	37.92	56.49	56.47	56.48	56.48	47.90	37.93	56.51	56.49	56.50	56.50	47.92	37.96	56.55	56.54	56.55	56.54
10%	48.54	38.58	59.83	59.79	59.81	59.80	48.55	38.59	60.08	59.86	60.04	59.91	48.57	38.64	60.34	60.20	60.32	60.20
9%	48.63	38.66	61.20	61.16	61.18	61.17	48.63	38.67	61.41	61.23	61.38	61.26	48.66	38.71	61.74	61.59	61.73	61.61
8%	48.71	38.74	62.57	62.53	62.55	62.54	48.71	38.75	62.74	62.59	62.73	62.61	48.74	38.79	63.15	62.98	63.13	63.02
7%	48.79	38.82	63.94	63.90	63.92	63.90	48.80	38.83	64.07	63.95	64.07	63.96	48.82	38.87	64.55	64.37	64.53	64.43
6%	48.88	38.90	65.31	65.28	65.29	65.27	48.88	38.91	65.40	65.31	65.42	65.31	48.90	38.94	65.95	65.76	65.94	65.84
5%	48.96	38.98	66.68	66.65	66.66	66.64	48.96	38.99	66.74	66.68	66.77	66.66	48.99	39.06	67.67	67.30	67.65	67.45
4%	49.16	39.20	68.17	68.17	68.16	68.17	49.16	39.23	68.19	68.17	68.18	68.18	49.23	39.31	68.35	68.30	68.34	68.31
3%	49.44	39.48	68.59	68.59	68.59	68.59	49.44	39.50	68.61	68.59	68.60	68.60	49.50	39.56	68.74	68.69	68.73	68.70
2%	49.72	39.75	69.04	69.02	69.03	69.02	49.73	39.77	69.05	69.04	69.06	69.04	49.77	39.81	69.26	69.19	69.24	69.20
1%	50.00	40.10	69.85	69.83	69.84	69.83	50.05	40.13	69.87	69.85	69.87	69.86	50.16	40.20	70.00	69.98	69.99	69.98
0.50%	50.56	40.61	80.53	80.51	80.52	80.50	50.58	40.63	80.61	80.54	80.60	80.57	50.63	40.65	80.79	80.78	80.79	80.78
0.30%	50.78	40.81	80.95	80.94	80.94	80.94	50.80	40.82	81.53	80.98	81.28	80.99	50.82	40.83	81.35	84.39	84.41	84.32
0.20%	50.89	40.92	85.64	85.49	85.49	85.48	50.91	40.92	86.69	85.54	86.09	81.51	50.91	40.92	81.76	88.68	88.29	88.53
0.10%	50.89	40.92	91.25	91.23	91.26	91.30	50.91	40.92	91.38	91.20	91.33	91.07	50.91	40.92	91.65	91.84	91.51	91.65
0.05%	50.89	40.92	91.25	91.23	91.26	91.30	50.91	40.92	92.33	91.20	92.25	92.20	50.91	40.92	91.65	92.48	92.30	92.37
Statistical Parameters																		
Max. Height (0.0023%)	51	41	92	92	92	92	51	41	93	92	93	93	51	41	92	93	93	93
Min. Height	41	32	46	46	46	46	41	32	46	46	46	46	42	32	46	46	46	46
Average Height	46.72	36.76	54.87	54.84	54.86	54.85	76.73	36.77	54.91	54.88	54.91	54.88	46.77	36.83	55.10	55.05	55.09	55.07

Probability of Plume Vertical Velocity > Threshold	Elevation Above Ground Level (mAGL)																		
	Train 4						Emergency Diesel Generator		Diesel Firewater Pump		Power Generation						Flares		
	TO Stack	FH Stack	MR GT1	MR GT2	MR GT3	MR GT4	EDG T1-2	EDG T3-4	DFP T1-2	DFP T3-4	GT 1	GT 2	GT 3	GT 4	GT 5	GT 6	Wet	Dry	BOG
100%	44	34	51	51	51	51	23	23	17	17	51	51	51	51	51	51	458	378	162
90%	46.20	36.22	52.55	52.53	52.54	52.53	23.28	23.39	17.78	18.07	52.16	52.15	52.15	52.15	52.14	52.14	461.85	384.32	166.00
80%	46.42	36.46	53.15	53.12	53.14	53.13	23.57	23.77	18.12	18.23	52.59	52.59	52.58	52.58	52.57	52.56	463.36	386.42	166.30
70%	46.65	36.70	53.68	53.64	53.67	53.65	23.85	24.09	18.28	18.39	53.04	53.03	53.02	53.01	53.00	52.99	475.34	388.44	166.60
60%	46.88	36.94	54.24	54.18	54.22	54.20	24.12	24.31	18.45	18.55	53.55	53.54	53.53	53.53	53.52	53.51	488.12	390.67	166.90
50%	47.12	37.19	54.85	54.79	54.83	54.81	24.36	24.52	18.62	18.70	54.06	54.05	54.05	54.04	54.03	54.02	512.25	393.38	167.34
40%	47.39	37.44	55.40	55.37	55.40	55.38	24.60	24.74	18.78	18.86	54.55	54.54	54.54	54.53	54.52	54.52	548.95	396.52	167.84
30%	47.65	37.70	55.94	55.93	55.94	55.93	24.85	24.96	18.95	19.06	55.04	55.03	55.03	55.03	55.02	55.02	601.39	400.27	168.46
20%	47.92	37.95	56.54	56.53	56.54	56.53	25.24	25.42	19.36	19.49	55.65	55.64	55.64	55.64	55.63	55.63	680.37	405.06	169.17
10%	48.57	38.63	60.29	60.17	60.30	60.19	25.88	25.95	19.87	19.92	56.56	56.56	56.55	56.55	56.55	56.54	819.97	411.81	170.14
9%	48.65	38.70	61.67	61.54	61.67	61.56	25.95	26.02	19.92	19.97	56.70	56.69	56.69	56.69	56.68	56.68	843.02	412.80	170.31
8%	48.74	38.78	63.05	62.90	63.04	62.94	26.04	26.21	19.97	20.04	56.83	56.83	56.83	56.82	56.82	56.81	869.64	413.93	170.47
7%	48.82	38.86	64.43	64.27	64.41	64.31	26.24	26.40	20.08	20.24	56.97	56.97	56.96	56.96	56.96	56.95	896.30	415.21	170.64
6%	48.90	38.93	65.81	65.64	65.78	65.69	26.44	26.60	20.28	20.44	57.19	57.19	57.18	57.18	57.17	57.16	928.01	416.71	170.80
5%	48.98	39.03	67.32	67.02	67.25	67.10	26.63	26.79	20.48	20.64	57.45	57.44	57.44	57.43	57.42	57.42	965.85	418.39	170.96
4%	49.21	39.28	68.28	68.23	68.26	68.24	26.83	26.98	20.68	20.84	57.70	57.70	57.69	57.68	57.68	57.67	1012.94	420.40	171.24
3%	49.48	39.53	68.67	68.65	68.66	68.66	27.08	27.43	20.89	21.12	57.95	57.95	57.94	57.93	57.93	57.93	1079.03	422.91	171.54
2%	49.75	39.79	69.14	69.13	69.13	69.14	27.61	27.90	21.31	21.67	58.38	58.38	58.37	58.35	58.35	58.35	1166.82	426.63	171.85
1%	50.10	40.14	69.96	69.94	69.95	69.95	28.37	28.75	22.02	22.48	58.85	58.85	58.84	58.84	58.84	58.84	1272.18	432.33	172.39
0.50%	50.60	40.63	80.74	80.70	80.73	80.72	29.08	29.49	22.96	23.22	59.27	59.26	59.25	59.25	59.26	59.26	1352.67	437.76	172.78
0.30%	50.81	40.82	81.25	81.18	81.27	81.24	29.72	29.91	23.61	23.81	59.57	59.56	59.56	59.55	59.56	59.56	1405.81	441.02	172.94
0.20%	50.91	40.92	81.67	81.66	81.72	81.71	30.06	30.29	23.96	24.21	59.72	59.71	59.71	59.70	59.71	59.71	1454.44	443.36	176.01
0.10%	50.91	40.92	91.36	91.46	91.60	91.62	30.67	30.80	24.66	24.82	59.87	59.86	59.86	59.85	59.86	59.86	1520.87	446.51	187.62
0.05%	50.91	40.92	92.35	92.34	92.38	92.40	30.97	30.80	25.10	25.40	59.94	59.94	59.93	59.93	59.93	59.94	1619.54	448.90	193.43
Statistical Parameters																			
Max. Height (0.0023%)	51	41	93	93	93	93	31	31	26	26	60	60	60	60	60	60	1,898	455	229
Min. Height	42	32	46	46	46	46	21	21	15	15	46	46	46	46	46	46	359	440	158
Average Height	46.76	36.81	55.04	55.00	55.03	55.01	24.02	24.18	18.26	18.39	53.71	53.70	53.69	53.69	53.68	53.68	395.68	586.42	167.23

Figure 6-7: Probability of Plume Vertical Velocity > 10.6 m/s Height Above Ground Level



6.4 Discussion

The maximum plume dimensional analysis identified that the Wet Gas Flare plume overlaps the southern approach / take-off vector for the Prince Rupert Airport by approximately 318 m at 2,368 m (2,398 mASL), when considering the 4.3 m/s vertical velocity threshold. This may present a level of risk that Transport Canada is unwilling to accept.

Several additional factors need to be accounted for when considering the potential impact risk. Appendix F includes the aerodrome chart for Prince Rupert airport listing the departure procedure for Runway 13:

> Rwy 13 - ½ – Right turn then CLB between TRKS 195° CW to 310° from "PR" NDB to 2500 BPOC.

This indicates that due to obstacles relating to terrain on Digby Island and Mount Hays on Kaien Island to the east, all aircraft when taking-off to the south are to make a right turn (westward). Flight is to then take a heading between 195° (south southwest) and 310° (approximately northwest) as they climb to 2500 feet ASL.

This would assist in ensuring that aircraft avoid the plume obstacles created by the plant.

A potential risk mitigation measure to address the obstacle issue is to relocate the Wet Gas Flare a minimum of approximately 350 m to the east. This would move the plume obstacle out of the southern approach / take-off vector of the airport.

It is shown however, in the Prince Rupert Visual Flight Rules (VFR) Terminal Procedures Chart (Appendix F), that the "South Corridor Route" for aircraft operating under VFR runs along the eastern coast of Digby Island. Therefore there is the potential that the plume obstacle from the relocated flare may impinge upon this route. Hence, if this mitigation method were to be implemented, the Southern Corridor Route may need to be redefined or its use discontinued. It is important to note that there are alternative routes to the South Corridor Route for aircraft operating under VFR, specifically the "Backway Route" running along the eastern coast of Kaien Island.

A quantitative risk analysis of adverse aircraft impact would facilitate determining the level of risk to aviation presented by the buoyant plumes, particularly for the flares. The risk would be compared against a risk matrix developed by the U.S. Federal Aviation Administration (FAA) using the likelihood versus severity paradigm.

7 Conclusions and Recommendations

The following conclusions have been drawn from this assessment:

- Significant plume buoyancy enhancement occurs, given the proposed plant layout and configuration.
- The Wet Gas Flare produces the largest maximum plume dimensions:
  - Rise height: 3,365 m (3,395 mASL); and
  - Radius: 1,718 m.
- The combination of all plume profiles produces a significant potential obstacle to low-flying aircraft.
- The plume radius for the Wet Gas Flare overlaps the southern approach / take-off vector for the Prince Rupert Airport, by approximately 318 m at 2,368 m (2,398 mASL).
- Therefore, the potential obstacle presented by the Wet Gas Flare may present a level of risk that Transport Canada is unwilling to accept.
- A potential risk mitigation measure is to relocate the Wet Gas Flare approximately 350 m to the east.
- If the Wet Gas Flare were to be relocated, this may then impinge upon the "South Corridor Route" for VFR operations; hence the route may need to be redefined or its use discontinued.
- Based on the revised plant layout, all sources from the power generation plant and sources from Train 3 overlap the outer edge of the Price Rupert Airport Obstacle Limitation Surface (OLS, set at 73.65 mASL).
- All sources, except of the Emergency Diesel Generators and the Diesel Firewater Pumps, produce plume rise heights greater than the outer surface boundary of the OLS (73.65 mASL) when considering the 4.3 m/s vertical velocity threshold.
- All sources, except of the Emergency Diesel Generators, the Diesel Firewater Pumps and the Fired Heater Stacks, produce plume rise heights greater than the outer surface boundary of the OLS (73.65 mASL) when considering the 10.6 m/s vertical velocity threshold.

In light of the above conclusions, it is recommended that:

- A quantitative risk analysis is conducted for the plumes defined in this study to accurately determine the level of risk presented by the buoyant plumes; and
- Nexen review the results of the study and discuss the issue with the Canadian aviation regulators (Transport Canada).

8 References

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Appendix A CASA Advisory Circular 139-5(1) (November 2012)

Australian Government
Civil Aviation Safety Authority

Advisory Circular

AC 139-5(1) NOVEMBER 2012

PLUME RISE ASSESSMENTS

CONTENTS **Page**

1. REFERENCES

- Regulation 6 of the Airspace Regulations 2007.
- Regulation 139.370 of the *Civil Aviation Safety Regulations 1998* (CASR 1998) – Hazardous Objects.
- Part 173 of CASR 1998 – Instrument Flight Procedure Design.
- *Manual of Aviation Meteorology*, Bureau of Meteorology (Published by Airservices Australia, 2003).

Advisory Circulars (ACs) are intended to provide advice and guidance to the aviation community to illustrate a means, but not necessarily the only means, of complying with the Regulations, or to explain certain regulatory requirements by providing informative, interpretative and explanatory material. The purpose of this AC is to provide guidelines for conducting plume rise assessments.

Where an AC is referred to in a 'Note' below the regulation, the AC remains as guidance material.

ACs should always be read in conjunction with the referenced regulations.

This AC has been approved for release by the Executive Manager, Standards Division.

2. PURPOSE

2.1 The purpose of this Advisory Circular (AC) is to provide:

- a standard method of determining the critical velocity of a vertical exhaust plume so that the impact of a plume near aerodromes and away from aerodromes can be assessed in a consistent and reliable way;
- guidance to persons involved in the design, construction and operation of facilities with vertical exhaust plumes about the information required to assess the potential hazard from a plume to aircraft operations; and
- guidance to proponents and stakeholders on the plume rise assessment process.

2.2 The Civil Aviation Safety Authority (CASA) has identified that there is a need to assess the potential hazard to aviation posed by vertical exhaust plumes in excess of 4.3 metres per second (m/s) velocity. Relevant legislation includes the potential hazard, under Regulation 139.370 of CASR 1998 and the potential danger, under Regulation 6 of the Airspace Regulations 2007.

3. STATUS OF THIS ADVISORY CIRCULAR

3.1 This is the first revision of the AC relating to conducting plume rise assessments and replaces AC 139-5(0) issued in June 2004. It has been simplified due to the introduction of computer-based modelling (referred to as the "Screening Tool", see paragraph 5.1) to assist in the assessment process. The plume rise assessment process has also been clarified.

4. ACRONYMS

AC	Advisory Circular
AD INSP	Aerodrome Inspector
AD OPR	Aerodrome Operator
CASA	Civil Aviation Safety Authority
CASA OAR	CASA Office of Airspace Regulation
CASR	Civil Aviation Safety Regulations 1998
CPH	Critical Plume Height
CPV	Critical Plume Velocity
LSALT	Lowest Safe Altitude
m/s	metres per second
OLS	Obstacle Limitation Surface
TAPM	The Air Pollution Model
TIFP	Terminal Instrument Flight Procedure

5. DEFINITIONS

5.1 For the purposes of this document:

Buoyancy Enhancement describes a situation in which multiple vertical exhaust plumes in close proximity can merge to alter the plume characteristics.

Critical Plume Height means the height up to which the plume of critical velocity may impact the handling characteristics of an aircraft in flight such that there may be a momentary loss of control.

Critical Plume Velocity means the velocity at which the vertical plume rise may affect the handling characteristics of an aircraft in flight such that there may be a momentary loss of control.

Obstacle Limitation Surfaces are a series of planes associated with each runway at an aerodrome that defines the desirable limits to which objects may project into the airspace around the aerodrome so that aircraft operations may be conducted safely.

Regulated Aerodromes are Certified and Registered aerodromes to which the CASR Part 139 - Aerodromes applies. At these aerodromes the aerodrome operator must ensure that the obstacle limitation surfaces are established in accordance with the standards set out in these regulations.

Screening Tool is the computer generated method of plume rise analysis used by CASA's Office of Airspace Regulation (OAR) to derive the heights at which the plume rise velocity is 4.3 m/s and 10.6 m/s. The Screening Tool is based on The Air Pollution Model (TAPM) methodology which includes a buoyancy enhancement factor for multiple plumes.

TAPM is The Air Pollution Model derived by the CSIRO.

Terminal Instrument Flight Procedure means an instrument approach procedure or instrument departure procedure. These procedures are protected by a series of design surfaces. Penetration of the design surfaces will result in an alteration to the associated instrument approach or departure procedure. Copies of the design surfaces for an aerodrome can be obtained from the aerodrome operator.

6. BACKGROUND

6.1 Exhaust plumes can originate from any number of sources. For example: industrial facilities release process emissions through stacks or vents; industrial flares create an instantaneous release of hot gases during the depressurisation of gas systems; cooling towers produce large volumes of buoyant gases that can rise a significant distance into the atmosphere and exhaust gases from power generation facilities can produce plumes of varying velocities during different operating scenarios.

6.2 Aircraft operations in various stages of flight may be affected by an exhaust plume of significant vertical velocity (i.e. a plume rise). A light aircraft in approach configuration is more likely to be affected by a plume rise than a heavy aircraft cruising at altitude. In addition, helicopters and light recreational aircraft may be severely affected by a high temperature plume and the altered air mixture above an exhaust plume and should therefore avoid low flight over such facilities.

6.3 Part 139.370 of CASR 1998 provides that CASA may determine that a gaseous efflux having a velocity in excess of 4.3 m/s is or will be a hazard to aircraft operations because of the velocity or location of the efflux.

6.4 The *Manual of Aviation Meteorology (2003)* defines severe turbulence as commencing at a vertical wind gust velocity in excess of 10.6 m/s; which may cause a momentary loss of control.

7. KEY STAGES OF THE PLUME RISE ASSESSMENT PROCESS

7.1 The key stages of the plume rise assessment process are:

- completion of Form 1247 by the proponent;
- assessment of the critical plume velocity (CPV);
- assessment of the critical plume height (CPH);
- assessment of the impact of the plume; and
- implementation of mitigation.

7.2 More detail on the process is provided at Appendix A to this AC.

8. ASSESSMENT OF CRITICAL PLUME VELOCITY (CPV)

8.1 The CPV under scrutiny (4.3 m/s or 10.6 m/s) will be determined based on the type of operations at the location and any associated risks identified by CASA. Considerations may include the following:

- phase of flight affected;
- size of aircraft affected;
- geographical factors such as high terrain;
- frequently used flight paths;
- navigation method in use (visual versus instrument);
- presence of Air Traffic Control;
- human factors considerations; and
- proximity to a regulated aerodrome.

9. ASSESSMENT OF CRITICAL PLUME HEIGHT (CPH)

9.1 CASA will determine the CPH for the CPV under scrutiny using the Screening Tool.

9.2 A plume rise not exceeding a velocity of 4.3 m/s at exit does not require assessment by CASA. However, augmentation of an existing facility producing a plume rise may require CASA assessment. If in doubt, a completed Form 1247 should be forwarded to CASA for screening assessment.

9.3 To guide in the planning process preliminary screening of locations under consideration can be undertaken. To discuss this option contact CASA OAR (email: oar@casa.gov.au). Alternative methods of assessment may also be put forward for consideration by CASA.

10. ASSESSMENT OF THE IMPACT OF THE PLUME RISE PROPOSAL

10.1 The impact of the plume rise proposal is assessed using the CPH at the location.

10.2 Near aerodromes the plume rise may penetrate the obstacle limitation surface (OLS) and may therefore be referred to a CASA Aerodrome Inspector (AD INSP)/Aerodrome Operator (AD OPR) to check this impact and any requirements for obstacle lighting or markings.

10.3 In the vicinity of aerodromes the plume rise may impact Terminal Instrument Flight Procedures (TIFPs). If so, CASA may determine that it is a hazard under Regulation 139.370 of the CASR 1998. If the proposal cannot be altered to avoid this impact, changes to TIFPs may be required. Government planning authorities will be advised to include these requirements in the development approval. Should the impact of the plume rise be significant, such that it would be difficult to achieve re-design of TIFPs without compromising the safety and/or environmental impact of the resulting design, CASA may not support the proposal.

10.4 Away from aerodromes, if the plume rise affects air routes and Lowest Safe Altitudes (LSALTs), this may require the CASR Part 173 authority (Airservices Australia) to make changes to these which may have cost implications for proponents.

10.5 When necessary, CASA will refer proposals to other relevant authorities including: the Department of Defence, Airservices Australia, GE Aviation (Naverus), Jeppesen and the Department of Infrastructure and Transport.

10.6 In some circumstances, the impact of the plume rise may be difficult to determine using the OAR Screening Tool. In such cases, CASA may request a detailed plume rise assessment be conducted which may have cost implications for proponents. Proponents should refer to the technical brief for further information (refer to paragraph 12 of this AC).

11. MITIGATION OF THE IMPACT OF THE PLUME RISE PROPOSAL

11.1 Mitigation options for a plume rise exceeding the relevant CPV may include the following:

- insertion of a symbol and a height on aviation charts to enhance awareness of the plume rise;
- designation of a Danger Area in accordance with Regulation 6 of the Airspace Regulations 2007 to alert pilots to the potential danger to aircraft flying over the area; and
- designation of a Restricted Area in accordance with Regulation 6 of the Airspace Regulations 2007 to restrict the flight of aircraft over the area.

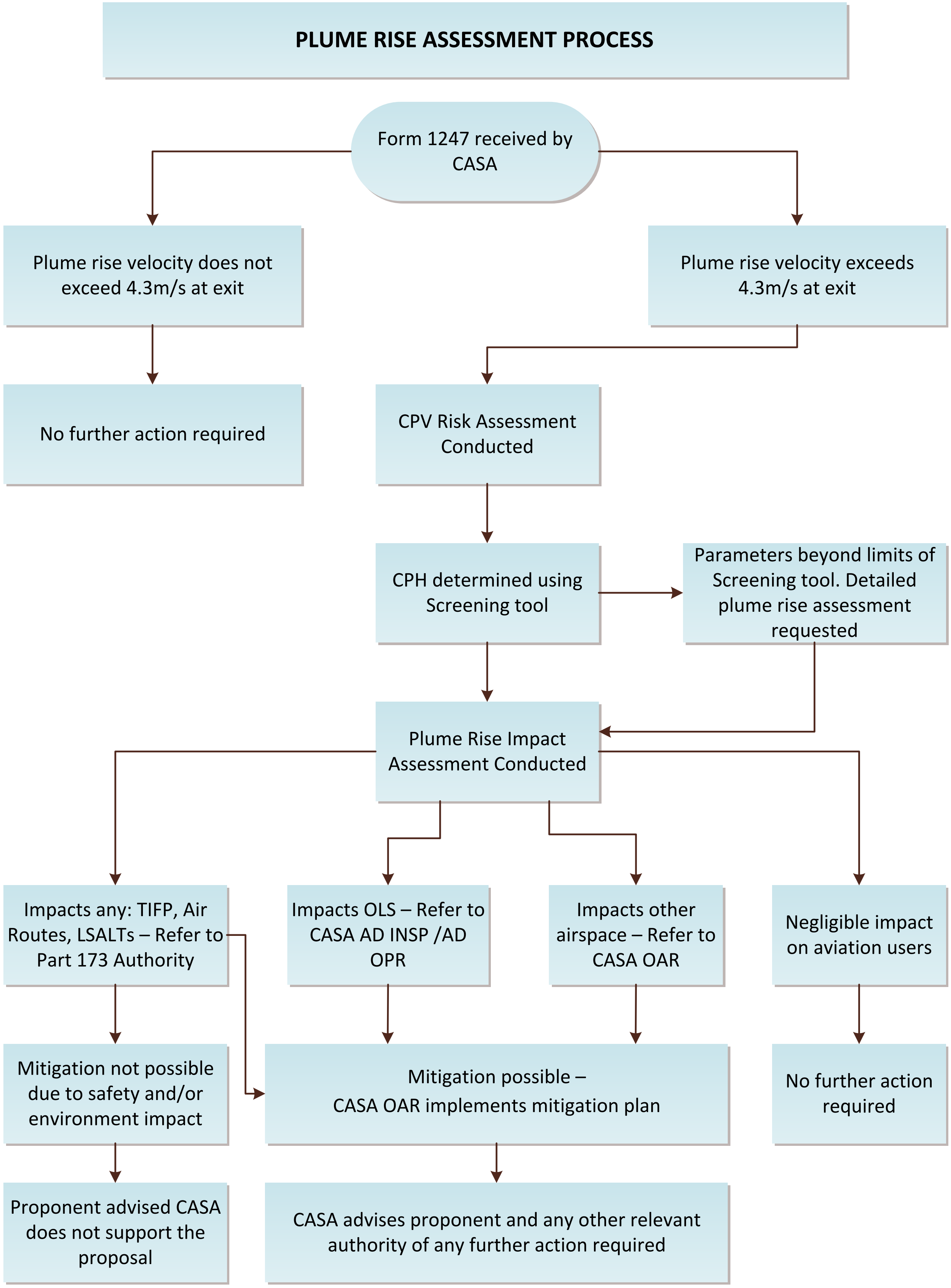
12. FURTHER INFORMATION

12.1 A technical brief regarding the application of plume rise models for the purpose of detailed plume rise assessments is available on request from CASA OAR.

Executive Manager
Standards Division

November 2012

APPENDIX A


PLUME RISE ASSESSMENT PROCESS
Form 1247 received by CASA
Plume rise velocity does not exceed 4.3m/s at exit
Plume rise velocity exceeds 4.3m/s at exit
No further action required
CPV Risk Assessment Conducted
CPH determined using Screening tool
Parameters beyond limits of Screening tool. Detailed plume rise assessment requested
Plume Rise Impact Assessment Conducted
Impacts any: TIFP, Air Routes, LSALTs – Refer to Part 173 Authority
Impacts OLS – Refer to CASA AD INSP /AD OPR
Impacts other airspace – Refer to CASA OAR
Negligible impact on aviation users
Mitigation not possible due to safety and/or environment impact
Mitigation possible – CASA OAR implements mitigation plan
No further action required
Proponent advised CASA does not support the proposal
CASA advises proponent and any other relevant authority of any further action required

Appendix B Basis of Environment Assessment – Air Emission (Aurora LNG 2016)

aurora LNG

COMMUNITY COMMITMENT CONNECTION

LNG Facility
Basis of Environment Assessment
Air Emission

Document No: CO-BC1100-RG25DBM-0001

Document Owner: Dan Murray						
Security Classification: 1		*(1 – All, 2 – Author Team Only, 3 – Confidential)*				
ISSUE RECORD SUMMARY						
B	28-Apr-2016	Issued for Information	NP	DM	RS	NW
A	16-Mar-2016	Issued for Review	NP			
Rev	**Date**	**Revision Description**	**Prepared**	**Checked**	**Approved (Nexen)**	**Approved (IGBC)**

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1.0 INTRODUCTION

Nexen Energy ULC (Nexen) and its joint venture partner, IGBC (Inpex Gas British Columbia Ltd.) are studying the viability of building and operating the proposed Aurora LNG liquefaction and export terminal on Digby Island, British Columbia.

The purpose of this Basis of Environmental Assessment is to describe key design elements and associated parameters used in the Environmental Assessment. The data includes a range of emissions number that will be used to produce both "best case" and "worst case" outcomes based on the possible scenarios and equipment configurations that are currently being studied. The following scenarios have been considered:

- 24 MTPA liquefaction capacity using gas turbine driven (GTD) refrigerant compressors. This scenario includes the installation of onsite power generation facilities to provide expected electrical power to balance of plant (BOP) loads.

- 24 MTPA liquefaction capacity using electric motor driven refrigerant compressor (E-LNG) systems. This scenario includes the installation of a near site power generation facility that will provide the total electrical power demand to the facility.

The project has considered two options for flare stacks (1) elevated flare stacks and (2) ground flares. In addition, there are two options for the plot plans, parallel layout of trains and tandem layout of trains. These all options resulted in below scenarios:

1. 24 MTPA facility GTD with parallel trains layout and elevated flare stacks
2. 24 MTPA facility GTD with tandem trains layout and elevated flare stacks
3. 24 MTPA facility GTD with tandem trains layout and ground flare stacks
4. 24 MTPA facility E-LNG with near site simple cycle power plant , parallel trains layout and elevated flare stacks
5. 24 MTPA facility E-LNG with near site simple cycle power plant , tandem trains layout and elevated flare stacks
6. 24 MTPA facility E-LNG with near site simple cycle power plant, tandem trains layout and ground flare stacks
7. 24 MTPA facility E-LNG with IPP, parallel trains layout and elevated flare stacks
8. 24 MTPA facility E-LNG with IPP, tandem trains layout and elevated flare stacks
9. 24 MTPA facility E-LNG with IPP, tandem trains layout and ground flare stacks

The emission model will be developed for scenarios 2, 3, 5 & 6 and a governing scenario in terms of the highest emission will be submitted to the regulatory agency. As per preliminary analysis, the parallel and tandem layouts of the trains will not change the emission from the facility and IPP option is under review and considered not a governing scenario for the EA Assessment. The technical data incorporated in this EA report include major emission sources, its flow rates and compositions. All of the data included in this document is based on the selected cases of 24 MTPA which can be prorated for 12 MTPA or any other reference cases. The emission sources and parameters are summarized in Section-12.

Since the project is currently at a conceptual phase it is intended that equipment selection during the final design phase will include careful consideration to environmental impacts.

2.0 TERMINAL LOCATION

The Aurora LNG Terminal (Terminal) will be located on Digby Island, British Columbia as illustrated in Figure 1 and Figure 2.

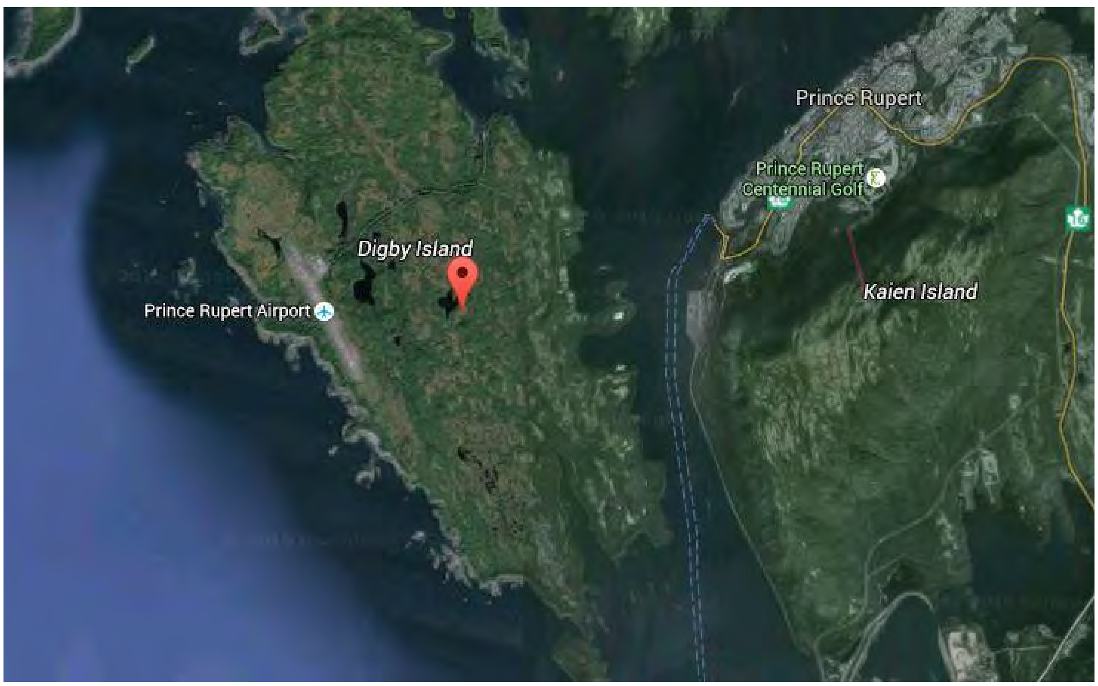


Figure 1. Aurora LNG Project Location

Figure 2. Aurora LNG Project Location

3.0 GENERAL DESIGN ASSUMPTIONS

The scope of this document includes the onshore Terminal up to its battery limits, as well as the marine facility. The scope does not include the natural gas pipeline that will supply the Terminal up to the Terminal battery limits and does not include the LNG carriers that will attend the Terminal.

The following general design assumptions will be used as the basis for the Environmental Assessment.

Facility Capacity.. 12 MTPA and 24 MTPA

No. of Marine Jetties..1

Number of Marine Berths...2

LNG Carrier Capacity (Min / Max) .... 125, 000m3/ 215,000m^3

No. of LNG Storage Tanks .... (12 MTPA Case = 2, 24 MTPA Case = 3)

LNG Storage Tank Capacity (Each Net) ....195,000 m^3

LNG Storage Tank Containment Design.. Full Containment

4.0 TERMINAL LAYOUT

Refer to Appendix- A for the related plot plans.

5.0 FEED GAS SPECIFICATION

The project will receive feed gas at the battery limits (prior to pretreatment) at the range of conditions illustrated in Table 1. This gas composition is based on the gas currently produced from the Horn River basin, and does not account for future expansion in that region. CO2 and H2S ranges are assumed to be dependent on gas processing technology selection. The feed gas hydrocarbon dewpoint is -10 ^{0}C at pipeline pressure and water content of less than 4 lbs/mmcfd. The presence of the trace components, total Sulphur and heavy hydrocarbons will be defined in the next stage of project by a sampling program.

Table 1. Pipeline Feed Gas Composition Range

Component	Nexen Design (Mol%)
Hydrogen	0.01
Helium	0.03
CO_2	1.826
Nitrogen	0.55
Methane	97.44
Ethane	0.13
Propane	0.003
Iso Butane	0.001
N-Butane	0
Iso Pentane	0
N-Pentane	0
Hexane	0
Heptanes +	0

Unless otherwise noted, the following impurities in the feed gas are to be considered for all design cases:

Hydrogen Sulfide (Nexen Design Case Only)... 4 ppmv

Total Sulfur .... 9 mg/m^3

Due to the possibility of importing natural gas via pipeline from 3rd party suppliers, excursions of total sulfur up to 115 mg/m^3 are also to be considered.

Feed gas battery limits are:

Pressure ....70-90 bara

Temperature ....4 Deg C

The feed conditions are preliminary which will be revised per the LNG facility requirements.

6.0 FEED GAS PRETREATMENT SYSTEM

A Pretreatment Facility will be installed at the Terminal to provide feed gas conditioning required by the natural gas liquefaction process. This will be accomplished via 2 or 4 pretreatment "trains" sized to match the Terminal liquefaction design capacity (2 trains for the 12 MTPA liquefaction capacity scenario and 4 trains for the 24 MTPA scenario) to remove CO2, sulfur compounds, water and mercury to meet the liquefaction feed gas specifications.

Figure 3 illustrates a typical schematic of a feed gas pretreatment facility and its relationship to heavy hydrocarbon removal, liquefaction and LNG storage.

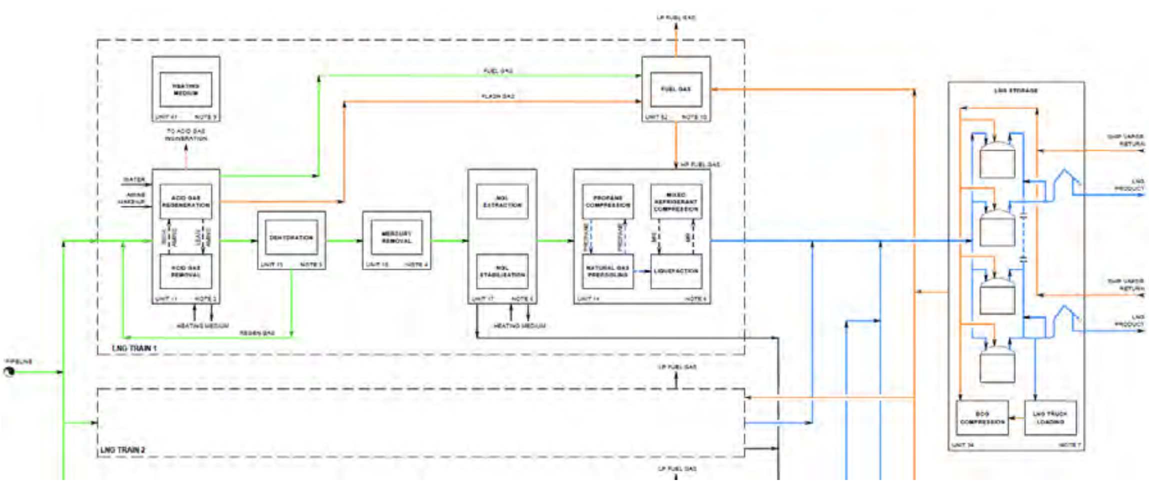


Figure 3. Typical Pretreatment Facility Schematic

The pipeline gas feeds to Acid Gas Recovery Unit (AGRU) which is a conventional amine absorbent gas sweetening system with a dedicated Amine Regeneration Unit. Lean amine liquid from the Amine Regenerator Unit will enter the top of the Amine Contactor, and rich amine liquid leaving the Amine Contactor will be returned to the Amine Regenerator. The "sweetened" gas will be cooled down through a cooler and then enter a Contactor Overhead Scrubber, where condensed water and entrained amine will be recovered and returned to an Amine Flash Drum. The Amine Regenerator will remove absorbed CO2 and sulfur compounds from the amine solution, which will exit in the overhead vapor. The heat required for the Amine Regenerator Reboiler will be supplied by a recirculating heat medium system.

The gas from the Contactor Overhead Scrubber will exit the amine system, flow through a particulate/entrained-liquid filter and then flow down through one of the parallel Dehydrators.

The Dehydrators will be vessels containing beds of regenerable molecular sieve, which will remove almost all water from the process gas stream. The Dehydrator molecular sieve will be routinely regenerated by reverse flow of hot, dry gas up through the beds. The sweetened, dry gas from the Dehydrators will flow through another particulate filter and then flow through a Mercury Removal Bed. Gas from the Mercury Removal Bed will flow through a final particulate filter and to the Liquefaction Facility.

The Pretreatment Facility will include bulk storage of “fresh” amine and storing storage area for demineralized water. Transfer pumps from both the amine storage and demineralized water storage will allow makeup for amine solution losses within the Amine System. The recirculating amine solution will may also require corrosion inhibitor, anti-foam and/or other chemical injection.

Sources of emissions to air during normal operation of the Feed Gas Pretreatment Facility described above are:

- Fired heater to heat oil recirculating in the amine regenerator system to remove absorbed CO2 and sulfur compounds and also to heat regen gas for regeneration of the dehydration system.

- Thermal oxidizer – incineration of CO2 and sulfur compounds (including H2S) removed from feed gas in the amine system.

7.0 LNG LIQUEFACTION SYSTEM

7.1 PROCESS DESIGN

No liquefaction facility technology decisions have been made at this moment in time. However, based on present day technology, assuming multiples of 6 MTPA capacity LNG liquefaction trains the technology decisions are limited to the APCI C3MR and ConocoPhillips Cascade concepts. These technologies will therefore form the basis for the Environmental Assessment.

Design production rate from the liquefaction facility will be a nominal net 12 MTPA or 24 MTPA into the LNG tank(s), which may include Boil Off Gas (BOG).

Figure 4 illustrates a single liquefaction train for the APCI C3 MR concept.

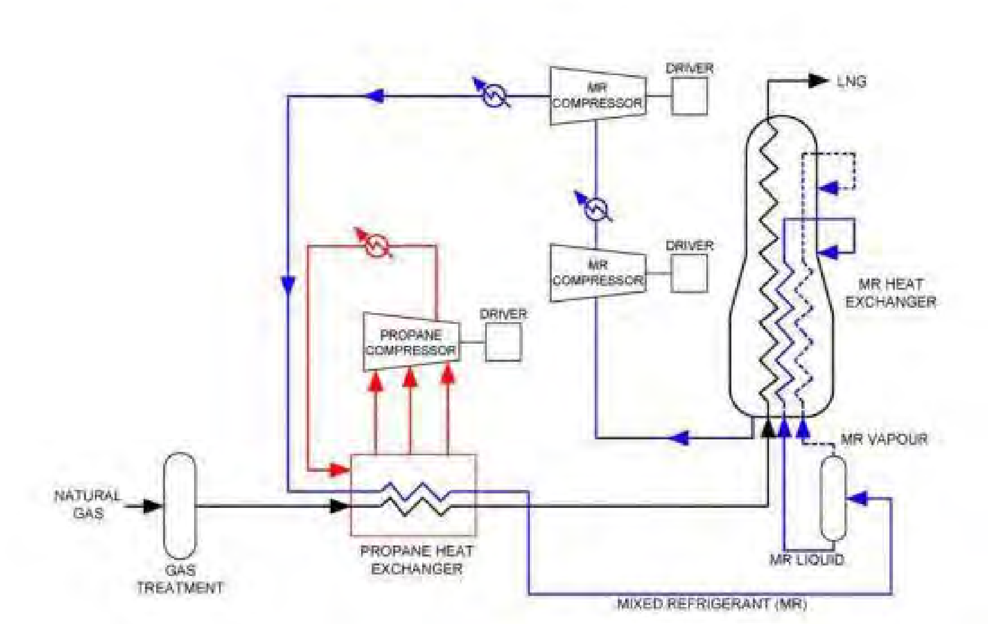


Figure 4. APCI C3 MR Liquefaction Train Schematic

Figure 5 illustrates a single liquefaction train for the ConocoPhillips Cascade concept.

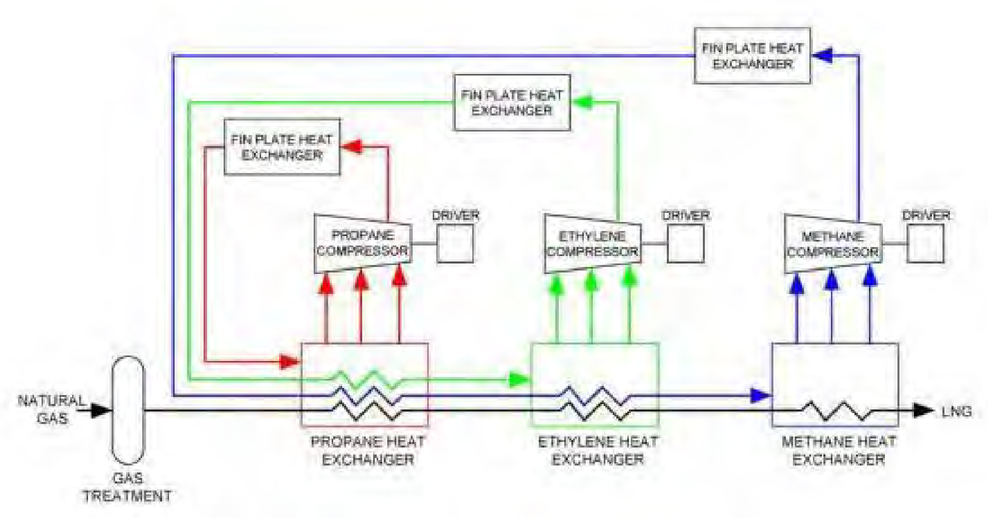


Figure 5. ConocoPhillips Cascade System Liquefaction Train Schematic

7.2 REFRIGERANT COMPRESSION DRIVERS

Using the concepts illustrated in Figure 4 and Figure 5, refrigerant compressors will be driven by either gas turbines or electric motors.

In the case of Gas Turbine driven refrigerant compressors, the temperature of LNG from liquefaction (to the LNG storage tank) will be optimized to control flashing such that fuel gas for the continuous operation of the gas turbines will be sourced from the flash gas, which will have the following assumed composition:

- Methane 89 Mol%
- Nitrogen 11 Mol% (Based on Feed gas N_2 concentration of 0.55 Mol%)

For the purposes of the Environmental Assessment Siemens Trent 60 gas turbines will be assumed and the following assumptions at ISO rated conditions fired by natural gas will be used as the basis for the Environmental Assessment data collection:

- Rated power output of Gas Turbine = 54.2MW
- Net heat rate - 8,258 kJ/kwh (Ref Siemens product specification)
- Net efficiency %, LHV = 43.6% (Ref Siemens product specification) Data will be presented at site rated conditions.

NOx and CO emission factors will be based on the BC Emissions Criteria for Gas Turbines greater than 25 MW (Max 15ppmv) and typical operating data for Trent 60 and LM6000PF gas Turbines. These emissions factors will be reviewed further with input from Stantec and will be adjusted for the application.

All PM are assumed to be less than PM2.5. PM and VOC emission factors will be in accordance with B.C. Best Practices Methodology for Quantifying Greenhouse Gas Emissions published by the Ministry of Environment Victoria, B.C. November, 2014.

In the case of motor driven refrigerant compressors, the LNG from liquefaction will be subcooled to prevent flashing once the LNG enters the LNG storage tank.

8.0 FLARE SYSTEMS

8.1 FLARE REQUIREMENTS

The Terminal will be designed to minimize venting during normal operations. Discharges from relief valves and process vent/drains should be directed to the flare system.

- A Wet Gas Flare will be installed and sized for the maximum emergency release during operation of the Pretreatment Facility.
- A Dry Gas Flare will be installed and sized for the maximum emergency release during operation of the Liquefaction Facility.

- A BOG Flare will be installed and designed to accommodate the worst case scenario associated with the BOG Handling System.

The Wet and Dry Flares are typically installed in a common derrick structure, and for large baseload liquefaction plants a spare common flare is also installed in the same derrick structure and it serves as a back-up of the Wet Flare or the Dry Flare. The Dry Flare design load typically determines the height of both flare stacks. The height of the stack is generally based on the radiant heat intensity generated by the flame. The maximum radiation level at grade, where emergency actions lasting several minutes may be required by personnel without shielding but with appropriate clothing should not exceed 1,500 British Thermal Units (Btu) per hour per square foot (API 521).

The elevated flare stack is most preferable option even though the project will also consider the ground flare option to develop the air dispersion model due to the geographical site conditions. The more in-depth study will be pursued in the engineering phase to define the best option.

Relief, depressurization and flaring systems are typically designed in accordance with the relevant American Petroleum Institute (API) Recommended Practice documents and particular project overpressure protection and vent philosophy documents.

Only the largest flow rates are taken into account for the hydraulic design constraints of the flare system. Therefore, smaller loads such as fire area depressurization load, thermal reliefs in pressure safety valves, etc., are not considered in the flare systems described in this section of the Basis of Environmental Assessment.

8.2 WET FLARE

A Wet Flare is provided in LNG Export facilities that incorporate pre-treatment units to clean the natural gas feed removing the acid gases (primarily CO2, H2S, and trace compounds), mercury and other contaminants that would react with and freeze out and block downstream equipment located in the cryogenic section of the plant.

During upset conditions (note that during normal operation any wet acid gases are disposed of via a dedicated incinerator rather than a flare), wet natural gas, and acid gases may need to be relieved, and the Wet Flare is designed to accommodate such gases.

Feed natural gas enters the pre-treatment facility at high pressure. The maximum flow condition of the Wet Flare typically represents 100% of the design feed gas flow into a pretreatment unit. The facility information is very preliminary and not enough data available to predict the flare load, so the flare load of similar size of facility is considered for EA input. Table 2 illustrates the estimated maximum relieving scenario of a wet flare.

Table 2. Wet Flare Maximum Flow Condition (four 6 MTPA production trains)

	Feed Gas Mass Flow (kg/h]
Mass Flow	1,440,000
Composition	Natural Gas (Table 1)

8.3 DRY FLARE

The Dry Flare will collect cold and dry hydrocarbon streams that result from the liquefaction unit upsets or operating conditions such as start-up, shutdown, venting, draining and de-inventorying equipment for maintenance, gas purging, and heating or cooling of equipment or piping.

The cryogenic section of an LNG Export facility comprises several refrigeration loops, which contain among other pieces of equipment, compressors that handle a variety of hydrocarbon mixtures. In the case of the APCI C3MR Liquefaction Process one refrigeration loop contains only propane, and the other one contains a mixture of different hydrocarbons, also known as “Multi Component Refrigerant” (mostly methane, ethane or ethylene, propane and nitrogen). The maximum flow condition of the Dry Flare is typically a blocked outlet condition of the propane compressor and it represents the 100% design capacity of the compressor, which would release to the flare via pressure relief valves.

As with the Wet Flare the maximum flow condition has to include coincident relieving loads from multiple trains, the Dry Flare is typically designed based on the maximum flow condition of a single train. Table 3 illustrates the maximum relieving scenario of the Dry Flare.

Table 3. Dry Flare Maximum Flow Condition (single 6 MTPA production train)

	PR Compressor outlet blockage [kg/h]
Mass Flow	2,725,000
Composition	Propane

8.4 BOG FLARE

The low pressure BOG Flare is designed to collect vapor releases from the LNG Storage Tanks and the loading dock area.

Due to the low back pressure requirement for this flare it is not possible to discharge these vapors to the Dry / Wet Flare Headers. The controlling case for the design of the Low Pressure Flare is typically a power failure while loading an LNG carrier at maximum rate. A typical loading rate is 10,000 m^3/hr of LNG. While loading the LNG into the LNG Carrier, Boil-off Gas (BOG) is generated due to flashing of the LNG (unless the LNG is supplied to the Carrier subcooled), due to vapor displacement and heat leak. Excess BOG is returned to the LNG facility for compression and reprocessing. A power outage would stop these BOG compressors and the BOG would need to be evacuated to the BOG Flare.

The BOG Flare is not typically designed to handle vapor loads generated under emergency scenarios such as tank rollover. This vapor would be relieved to atmosphere via the LNG storage tank relief valves.

Table 4 illustrates the maximum relieving scenario of the BOG Flare.

Table 4. BOG Flare Maximum Flow Condition

Mass Flow	**108,000 Kg/hr**
Composition	Methane 94 Mol% Nitrogen 6 Mol%

8.5 FLARE OPERATION

As previously described:

- The Wet Gas Flare will be used for emergency releases during operation of the Pretreatment Facility.
- The Dry Gas Flare will be used for emergency release during operation of the Liquefaction Facility.
- The BOG Flare will accommodate the worst case scenario associated with the BOG Handling System

Table 5 lists the frequency of operation and duration of each flare system. The values are preliminary.

Table 5. Flare System Operation Data

Flare	Type of Operation	Frequency of Operation	Duration
Wet Gas Flare	Startup/ shutdown Emergency	1 train per year 1 event per year	24 hours Continuous 10 minute- 1 hour
Dry Gas Flare	Startup/ shutdown Emergency	1 train per year 1 event per year	24 hours Continuous 10 minute- 1 hour
BOG Flare	Emergency Operation	1 event per year	10 minute – 70 hours

9.0 POWER REQUIREMENTS

9.1 ELECTRIC MOTOR DRIVEN REFRIGERANT COMPRESSOR CASES

Electric motor driven refrigerant compressors consume approximately 75-80% of all power required to drive an LNG liquefaction facility. A 24 MTPA facility will require 900 MW of electrical power to drive the refrigerant compressors. Approximately 200 MW of electrical power will be required for all remaining balance of plant equipment.

Electrical power supply to the proposed Digby Island site is limited. BC Hydro is the local electric utility company and although it could provide up to approximately 250MW of electrical power subsequent to installation of transmission system upgrades. Aurora project is looking into different options to develop the power plant facility. The installation of a near site simple cycle power generation facility capable of supplying electrical power for the electric motor driven refrigerant compressor case will be assumed for the purposes of this Basis of Environmental Assessment. The IPP option is also considered but it is assumed not a governing scenario for the EA assessment. The following assumptions will be used for emissions data associated with the near site power generation facility:

- Configuration of power generation facility will be simple cycle gas turbine generators. Data and plot plan layout are derived from the preliminary studies.
- 4+1 (1 standby) simple cycle Siemens SGT6-5000F and 1+1 (1 standby) Trent 60 DLE GTGs are assumed for 1,000MW of electrical power for the 24 MTPA liquefaction capacity case. The technical specifications of the generators are listed in Table 6.
- Fuel gas composition assumed to be the pipeline gas and the design gas composition listed in Table 1 will be assumed

Table 6. Power Plant GTGs Technical Specifications

GTG Model#	ISO Output Power, MW	Net Heat Rate, kJ/kWh	Gross Efficiency, %	Exhaust Mass Flow, kg/s
SGT6-5000F	242	9,230	39.0	576
Trent 60 DLE	54.2	8258	43.6	158

- GT Fuel LHV = 47,140 kJ/kg (corresponding to abovementioned fuel gas composition)
- SCR will not be installed in GT exhaust stream (It will be confirmed during next stage of the project based on NOx emission factor and local regulation requirements)
- PM2.5, PM10, VOC, CH4 & N2O data calculated by use of emission factors taken from US EPA:

  http://cfpub.epa.gov/webfire/index.cfm?action=fire.FactorsBasedOnDetailedSearch
  http://www3.epa.gov/ttnchie1/ap42/ch03/final/c03s01.pdf

- No spare generation capacity assumed

9.2 GAS TURBINE DRIVEN REFRIGERANT COMPRESSOR CASES

In the case of gas turbine driven refrigerant compression systems, the following on-site power will be provided. A 24 MTPA facility will require approximately 250 - 300 MW of power to drive balance of plant equipment.

Power generation in each case will be achieved using aero derivative combustion turbine(s) in a simple cycle configuration. The following data shall be used as the Basis of Environmental Assessment:

- Model = GE LM6000 PF (DLE)
- Rated output = 44MW at ISO conditions
- SC Net heat rate (kJ/kWh, LHV) = 8778, (Ref GE product specification)
- Net efficiency %,LHV = 41% (Ref GE product specification)

9.3 EMERGENCY POWER GENERATION

The Terminal design will include diesel engine driven electrical power generation to provide approximately 2.5 MW of power during power outages. The following equipment for both the Electric and Gas Turbine driven refrigerant compression systems will be powered with power from the emergency diesel power generation system:

- Emergency lighting

- Security monitoring systems
- Electrical trace heating, including LNG storage tank foundation heaters
- Motor Control Center (MCC) Monitoring and Operation Systems
- Distributed Control Systems (DCS) – including via UPS
- Fire protection and monitoring systems – including via UPS
- Hazard detection systems – including via UPS
- LNG sendout pump (1x) to maintain recirculation in cryogenic pipeline systems.

10.0 TERMINAL AVAILABILITY AND OPERATION

Terminal liquefaction capacity is the total amount of LNG that can be produced by the liquefaction trains after outage losses have been accounted for and within the range of design feed gas compositions.

In the case of a gas turbine driven refrigerant compression system, an availability of 94.5% will be assumed, meaning that for approximately 345 days of the year on average the liquefaction facility will be available to operate at maximum capacity and that the facilities will be out of service for the remaining 20 days of the year to perform routine maintenance and to undertake repairs due to forced outages.

Liquefaction facility refrigerant compressors driven by electrical motors will require significantly less scheduled maintenance than gas turbines and therefore total availability losses will be in the order of approximately 1 - 2.5% per year on average, which equates to a corresponding increase in liquefaction train production capacity. Therefore, in the case of electric motor driven refrigerant compression systems, an average annual availability of 97.5% will be assumed, which equates to approximately 356 days on average to operate at maximum capacity.

11.0 FUGITIVE EMISSIONS

To minimize fugitive emissions the design of the Terminal:

- Will maximize the use of all welded connections in cryogenic piping, thereby minimizing the use of flanges.
- All cryogenic valves will be welded unless specifically identified otherwise.
- Vessels and equipment will use welded connections, except where entry for inspections or maintenance after start-up is anticipated or required, such as exchangers. In these cases there shall be a case-by-case evaluation to confirm flanges are required.
- Belleville® washers shall be utilized for all flanged connections in LNG or cryogenic service.

- Will include the use of dry seals where applicable in compression systems.
- Will implement a comprehensive maintenance management system based on best practices that will include leak monitoring and repair programs to promote efficient repair of leaks identified in the process and reduce the overall potential for fugitive emissions.

12.0 ENVIRONMENTAL ASSESSMENT DATA

12.1 24 MTPA FACILITY- GT DRIVE REFRIGRANT COMPRESSION EMISSION DATA

Pretreatment Facilities	Heat Load (MW)	Operating Days Per Year
Pretreatment Train 1 - Thermal Oxidizer Exhaust Stack	16.5	345
Pretreatment Train 1 - Fired Heater Exhaust Stack	48.5	345
Pretreatment Train 2 - Thermal Oxidizer Exhaust Stack	16.5	345
Pretreatment Train 2 - Fired Heater Exhaust Stack	48.5	345
Pretreatment Train 3 - Thermal Oxidizer Exhaust Stack	16.5	345
Pretreatment Train 3 - Fired Heater Exhaust Stack	48.5	345
Pretreatment Train 4 - Thermal Oxidizer Exhaust Stack	16.5	345
Pretreatment Train 4 - Fired Heater Exhaust Stack	48.5	345

Liquefaction Refrigerant Compressors	Engine Information					Fuel Composition			Operating Days Per Year
	Driver	Rated Power Output (MWe)	Net Heat Rate (KJ/KW LHV)	Net Efficiency (% LHV)	Fuel Flow (Kg/s).	Methane (% Mol)	Nitrogen (% Mol)	Propane (% Mol)	
Liquefaction Train 1 – Propane/ HP Mixed Refrigerant Compressor GT Drive 1	Siemens Trent 60	54.2	8,258	43.6	3.0	89	11	NA	345
Liquefaction Train 1 – Propane/ HP Mixed Refrigerant Compressor GT Drive 2	Siemens Trent 60	54.2	8,258	43.6	3.0	89	11	NA	345
Liquefaction Train 1 – LP MR Compressor GT Drive 3	Siemens Trent 60	54.2	8,258	43.6	3.0	89	11	NA	345
Liquefaction Train 1 – LP MR Compressor GT Drive 4	Siemens Trent 60	54.2	8,258	43.6	3.0	89	11	NA	345
Liquefaction Train 2 - Propane/ HP Mixed Refrigerant Compressor GT Drive 1	Siemens Trent 60	54.2	8,258	43.6	3.0	89	11	NA	345
Liquefaction Train 2 - Propane/ HP Mixed Refrigerant Compressor GT Drive 2	Siemens Trent 60	54.2	8,258	43.6	3.0	89	11	NA	345
Liquefaction Train 2 – LP MR Compressor GT Drive 3	Siemens Trent 60	54.2	8,258	43.6	3.0	89	11	NA	345
Liquefaction Train 2 – LP MR Compressor GT Drive 4	Siemens Trent 60	54.2	8,258	43.6	3.0	89	11	NA	345
Liquefaction Train 3 - Propane/ HP Mixed Refrigerant Compressor GT Drive 1	Siemens Trent 60	54.2	8,258	43.6	3.0	89	11	NA	345
Liquefaction Train 3 - Propane/ HP Mixed Refrigerant Compressor GT Drive 2	Siemens Trent 60	54.2	8,258	43.6	3.0	89	11	NA	345
Liquefaction Train 3 – LP MR Compressor GT Drive 3	Siemens Trent 60	54.2	8,258	43.6	3.0	89	11	NA	345
Liquefaction Train 3 – LP MR Compressor GT Drive 4	Siemens Trent 60	54.2	8,258	43.6	3.0	89	11	NA	345
Liquefaction Train 4 - Propane/ HP Mixed Refrigerant Compressor GT Drive 1	Siemens Trent 60	54.2	8,258	43.6	3.0	89	11	NA	345
Liquefaction Train 4 - Propane/ HP Mixed Refrigerant Compressor GT Drive 2	Siemens Trent 60	54.2	8,258	43.6	3.0	89	11	NA	345
Liquefaction Train 4 – LP MR Compressor GT Drive 3	Siemens Trent 60	54.2	8,258	43.6	3.0	89	11	NA	345
Liquefaction Train 4 – LP MR Compressor GT Drive 4	Siemens Trent 60	54.2	8,258	43.6	3.0	89	11	NA	345

On-Site BOP Power Generation	Engine Information					Fuel Composition	Operating Days Per Year
	Driver	Rated Power Output (MWe)	Net Heat Rate (KJ/KW LHV)	Net Efficiency (% LHV)	Fuel Flow (Kg/s)		
Simple Cycle Power Plant GT 1 Exhaust Stack	GE LM6000 PF (DLE)	44 ISO Conditions	8778	41%	2.5	Use pipeline feed gas composition	345
Simple Cycle Power Plant GT 2 Exhaust Stack	GE LM6000 PF (DLE)	44 ISO Conditions	8778	41%	2.5	Use pipeline feed gas composition	345
Simple Cycle Power Plant GT 3 Exhaust Stack	GE LM6000 PF (DLE)	44 ISO Conditions	8778	41%	2.5	Use pipeline feed gas composition	345
Simple Cycle Power Plant GT 4 Exhaust Stack	GE LM6000 PF (DLE)	44 ISO Conditions	8778	41%	2.5	Use pipeline feed gas composition	345
Simple Cycle Power Plant GT 5 Exhaust Stack	GE LM6000 PF (DLE)	44 ISO Conditions	8778	41%	2.5	Use pipeline feed gas composition	345
Simple Cycle Power Plant GT 6 Exhaust Stack	GE LM6000 PF (DLE)	44 ISO Conditions	8778	41%	2.5	Use pipeline feed gas composition	345

Flare System	Mass Flow		Gas Composition		Duration per Year	
	Feed Gas Mass Flow (Kg/hr)	Startup Loads (Kg/hr)	Feed Gas	Startup	Startup	Emergency
Wet gas flare	1,440,000	NA	Feed Gas Composition	NA	24 Hours	10 mins
Dry gas flare	2,725,000	NA	100% Propane	NA	24 Hours	10 mins
BOG flare	108,000	NA	Methane 94 Mol%	NA	N/A	10 mins
			Nitrogen 6 Mol%	NA		

Diesel Engines	Engine Power (KW)	Fuel Composition	Operating Duration Per Year		
			Emergency	Testing	Total Hours
Emergency Diesel Generator (Train 1-2)	2,500	Ultra Low Sulfur Diesel	24 hrs cont (1 event)	52 hrs (1hr per week)	76
Emergency Diesel Generator (Train 3-4)	2,500	Ultra Low Sulfur Diesel	24 hrs cont (1 event)	52 hrs (1hr per week)	76
Diesel Firewater Pump (Train 1-2)	300	Ultra Low Sulfur Diesel	24 hrs cont (1 event)	52 hrs (1hr per week)	76
Diesel Firewater Pump (Train 1-2)	300	Ultra Low Sulfur Diesel	24 hrs cont (1 event)	52 hrs (1hr per week)	76

Exhaust Stack Design and Operating Parameters

	Location (Approximate)		Source	Exhaust Stack Design Data (Stantec will determine the stack diameter)				Exhaust Stack Operating Parameters (Information will be revised per Stantec input)		
	X_UTMz9N83Meters	Y_UTMz9N83 Meters	Continuous/ Intermittent	Height (m)	Diameter (m)	Orientation (Vertical or otherwise)	Rain Capped (yes or no)	Exit Velocity (m/s)	Exit Temperature (Deg C)	Exhaust Mass Flow (Kg/hr)
Pretreatment Train 1 - Thermal Oxidizer Exhaust Stack	410476.8	6013786.8	Continuous	40	1.8	V	No	20	871	210,760
Pretreatment Train 1 - Fired Heater Exhaust Stack	410432.7	6013927.5	Continuous	30	1.8	V	No	20	871	210,760
Pretreatment Train 2 - Thermal Oxidizer Exhaust Stack	410356.8	6014169.1	Continuous	40	1.8	V	No	20	871	210,760
Pretreatment Train 2 - Fired Heater Exhaust Stack	410312.7	6014309.9	Continuous	30	1.8	V	No	20	871	210,760
Pretreatment Train 3 - Thermal Oxidizer Exhaust Stack	409699.7	6014416.3	Continuous	40	1.8	V	No	20	871	210,760
Pretreatment Train 3 - Fired Heater Exhaust Stack	409655.5	6014557.1	Continuous	30	1.8	V	No	20	871	210,760
Pretreatment Train 4 - Thermal Oxidizer Exhaust Stack	409938.0	6014491.9	Continuous	40	1.8	V	No	20	871	210,760
Pretreatment Train 4 - Fired Heater Exhaust Stack	409893.9	6014632.6	Continuous	30	1.8	V	No	20	871	210,760
Liquefaction Train 1 - Propane/ HP Mixed Refrigerant Compressor GTD 1 Exhaust	410266.2	6013957.2	Continuous	40	5.3	Lateral GT Exhaust & Vertical Stack	No	35	431	568,800
Liquefaction Train 1 - Propane/ HP Mixed Refrigerant Compressor GTD 2 Exhaust	410356.6	6013670.5	Continuous	40	5.3	Lateral GT Exhaust & Vertical Stack	No	35	431	568,800
Liquefaction Train 1 - MR Compressor GTD 3 Exhaust	410288.6	6013885.6	Continuous	40	5.3	Lateral GT Exhaust & Vertical Stack	No	35	431	568,800
Liquefaction Train 1 - MR Compressor GTD 4 Exhaust	410334.6	6013742.2	Continuous	40	5.3	Lateral GT Exhaust & Vertical Stack	No	35	431	568,800
Liquefaction Train 2 - Propane/ HP Mixed Refrigerant Compressor GTD 1 Exhaust	410146.2	6014339.5	Continuous	40	5.3	Lateral GT Exhaust & Vertical Stack	No	35	431	568,800
Liquefaction Train 2 - Propane/ HP Mixed Refrigerant Compressor GTD 2 Exhaust	410236.6	6014052.8	Continuous	40	5.3	Lateral GT Exhaust & Vertical Stack	No	35	431	568,800
Liquefaction Train 2 - MR Compressor GTD 3 Exhaust	410169.2	6014269.1	Continuous	40	5.3	Lateral GT Exhaust & Vertical Stack	No	35	431	568,800
Liquefaction Train 2 - MR Compressor GTD 4 Exhaust	410214.7	6014124.5	Continuous	40	5.3	Lateral GT Exhaust & Vertical Stack	No	35	431	568,800
Liquefaction Train 3 - Propane/ HP Mixed Refrigerant Compressor GTD 1 Exhaust	409489.0	6014586.7	Continuous	40	5.3	Lateral GT Exhaust & Vertical Stack	No	35	431	568,800
Liquefaction Train 3 - Propane/ HP Mixed Refrigerant Compressor GTD 2 Exhaust	409579.5	6014300.0	Continuous	40	5.3	Lateral GT Exhaust & Vertical Stack	No	35	431	568,800
Liquefaction Train 3 - MR Compressor GTD 3 Exhaust	409511.5	6014515.1	Continuous	40	5.3	Lateral GT Exhaust & Vertical Stack	No	35	431	568,800
Liquefaction Train 3 - MR Compressor GT 4 Exhaust	409557.5	6014371.7	Continuous	40	5.3	Lateral GT Exhaust &	No	35	431	568,800

	Location (Approximate)		Source	Exhaust Stack Design Data (Stantec will determine the stack diameter)				Exhaust Stack Operating Parameters (Information will be revised per Stantec input)		
	X_UTMz9N83Meters	Y_UTMz9N83 Meters	Continuous/ Intermittent	Height (m)	Diameter (m)	Orientation (Vertical or otherwise)	Rain Capped (yes or no)	Exit Velocity (m/s)	Exit Temperature (Deg C)	Exhaust Mass Flow (Kg/hr)
						Vertical Stack				
Liquefaction Train 4 - Propane/ HP Mixed Refrigerant Compressor GTD 1 Exhaust	409727.3	6014662.2	Continuous	40	5.3	Lateral GT Exhaust & Vertical Stack	No	35	431	568,800
Liquefaction Train 4 - Propane/ HP Mixed Refrigerant Compressor GTD 2 Exhaust	409817.8	6014375.6	Continuous	40	5.3	Lateral GT Exhaust & Vertical Stack	No	35	431	568,800
Liquefaction Train 4 - MR Compressor GTD 3 Exhaust	409749.8	6014590.6	Continuous	40	5.3	Lateral GT Exhaust & Vertical Stack	No	35	431	568,800
Liquefaction Train 4 - MR Compressor GTD 4 Exhaust	409795.8	6014447.3	Continuous	40	5.3	Lateral GT Exhaust & Vertical Stack	No	35	431	568,800
Wet gas flare (N/A if Ground Flare is used)	409983.2	6013114.6	Intermittent	100	0.5	V	No	20	982	See above
Dry gas flare (N/A if Ground Flare is used)	409936.0	6013398.4	Intermittent	150	0.5	V	No	20	982	See above
BOG flare (N/A if Ground Flare is used)	410110.3	6013158.7	Intermittent	100	0.5	V	No	20	982	See above
Ground Flare 1- Wet Gas Flare (N/A if Elevated Flare is used)	409912.4	6013351.1	Intermittent	N/A	N/A	N/A	N/A	20	982	See above
Ground Flare 2- Dry Gas Flare(N/A if Elevated Flare is used)	409861.5	6013507.7	Intermittent	N/A	N/A	N/A	N/A	20	982	See above
Ground Flare 3- BOG Flare(N/A if Elevated Flare is used)	409810.9	6013663.7	Intermittent	N/A	N/A	N/A	N/A	20	982	See above
Simple Cycle Power Plant GT 1 Exhaust Stack	409043.5	6015340.8	Continuous	40	3.7	Lateral	No	35	542	450,000
Simple Cycle Power Plant GT 2 Exhaust Stack	409059.8	6015288.9	Continuous	40	3.7	Lateral	No	35	542	450,000
Simple Cycle Power Plant GT 3 Exhaust Stack	409078.4	6015233.1	Continuous	40	3.7	Lateral	No	35	542	450,000
Simple Cycle Power Plant GT 4 Exhaust Stack	409097.8	6015174.6	Continuous	40	3.7	Lateral	No	35	542	450,000
Simple Cycle Power Plant GT 5 Exhaust Stack	409117.0	6015116.6	Continuous	40	3.7	Lateral	No	35	542	450,000
Simple Cycle Power Plant GT 6 Exhaust Stack	409138.0	6015053.7	Continuous	40	3.7	Lateral	No	35	542	450,000
Emergency Diesel Generator Exhaust Stack (Train 1-2)	410198.4	6013329.1	Intermittent	12.5	0.4	V	No	45	427	100,000
Emergency Diesel Generator Exhaust Stack (Train 3-4)	409484.0	6014773.8	Intermittent	12.5	0.4	V	No	45	427	100,000
Diesel Firewater Pump Exhaust Stack (Train 1-2)	410263.1	6013349.1	Intermittent	7.5	0.2	V	No	45	427	50,000
Diesel Firewater Pump Exhaust Stack (Train 3-4)	409568.6	6014801.6	Intermittent	7.5	0.2	V	No	45	427	50,000

Exhaust Stack Discharge Concentrations

	Discharge Concentrations (Stantec will provide update on discharge concentration)								
	NOx mg/m^3	CO mg/m^3	PM2.5 mg/m^3	PM10 mg/m^3	VOC mg/m^3	SO_2 mg/m^3	CH_4 mg/m^3	CO_2 mg/m^3	N_2O mg/m^3
Pretreatment Train 1 - Thermal Oxidizer Exhaust Stack	52	42	4	4	3	45	4	182487	3
Pretreatment Train 1 - Fired Heater Exhaust Stack	52	42	4	4	3	45	4	182487	3
Pretreatment Train 2 - Thermal Oxidizer Exhaust Stack	52	42	4	4	3	45	4	182487	3
Pretreatment Train 2 - Fired Heater Exhaust Stack	52	42	4	4	3	45	4	182487	3
Pretreatment Train 3 - Thermal Oxidizer Exhaust Stack	52	42	4	4	3	45	4	182487	3
Pretreatment Train 3 - Fired Heater Exhaust Stack	52	42	4	4	3	45	4	182487	3
Pretreatment Train 4 - Thermal Oxidizer Exhaust Stack	52	42	4	4	3	45	4	182487	3
Pretreatment Train 4 - Fired Heater Exhaust Stack	52	42	4	4	3	45	4	182487	3
Liquefaction Train 1 - Propane/ HP Mixed Refrigerant Compressor GTD 1 Exhaust	30	30	7	7	2	0.2546	10	127986	10
Liquefaction Train 1 - Propane/ HP Mixed Refrigerant Compressor GTD 2 Exhaust	30	30	7	7	2	0.2546	10	127986	10
Liquefaction Train 1 - MR Compressor GTD 3 Exhaust	30	30	7	7	2	0.2546	10	127986	10
Liquefaction Train 1 - MR Compressor GTD 4 Exhaust	30	30	7	7	2	0.2546	10	127986	10
Liquefaction Train 2 - Propane/ HP Mixed Refrigerant Compressor GTD 1 Exhaust	30	30	7	7	2	0.2546	10	127986	10
Liquefaction Train 2 - Propane/ HP Mixed Refrigerant Compressor GTD 2 Exhaust	30	30	7	7	2	0.2546	10	127986	10
Liquefaction Train 2 - MR Compressor GTD 3 Exhaust	30	30	7	7	2	0.2546	10	127986	10
Liquefaction Train 2 - MR Compressor GTD 4 Exhaust	30	30	7	7	2	0.2546	10	127986	10
Liquefaction Train 3 - Propane/ HP Mixed Refrigerant Compressor GTD 1 Exhaust	30	30	7	7	2	0.2546	10	127986	10
Liquefaction Train 3 - Propane/ HP Mixed Refrigerant Compressor GTD 2 Exhaust	30	30	7	7	2	0.2546	10	127986	10
Liquefaction Train 3 - MR Compressor GTD 3 Exhaust	30	30	7	7	2	0.2546	10	127986	10
Liquefaction Train 3 - MR Compressor GT 4 Exhaust	30	30	7	7	2	0.2546	10	127986	10
Liquefaction Train 4 - Propane/ HP Mixed Refrigerant Compressor GTD 1 Exhaust	30	30	7	7	2	0.2546	10	127986	10
Liquefaction Train 4 - Propane/ HP Mixed Refrigerant Compressor GTD 2 Exhaust	30	30	7	7	2	0.2546	10	127986	10
Liquefaction Train 4 - MR Compressor GTD 3 Exhaust	30	30	7	7	2	0.2546	10	127986	10
Liquefaction Train 4 - MR Compressor GTD 4 Exhaust	30	30	7	7	2	0.2546	10	127986	10
Simple Cycle Power Plant GT 1 Exhaust Stack	30	30	7	7	2	0.2546	10	127986	10
Simple Cycle Power Plant GT 2 Exhaust Stack	30	30	7	7	2	0.2546	10	127986	10
Simple Cycle Power Plant GT 3 Exhaust Stack	30	30	7	7	2	0.2546	10	127986	10
Simple Cycle Power Plant GT 4 Exhaust Stack	30	30	7	7	2	0.2546	10	127986	10
Simple Cycle Power Plant GT 5 Exhaust Stack	30	30	7	7	2	0.2546	10	127986	10
Simple Cycle Power Plant GT 6 Exhaust Stack	30	30	7	7	2	0.2546	10	127986	10
	NOx g/s	CO g/s	PM2.5 g/s	PM10 g/s	VOC g/s	SO_2 g/s	CH_4 g/s	CO_2 g/s	N_2O g/s
Emergency Diesel Generator Exhaust Stack (Train 1-2)	8.34	3.53	0.45	0.45	0.45	0.24		758	
Diesel Firewater Pump Exhaust Stack (Train 1-2)	1.57	0.34	0.12	0.11	1.09	0.03		59.7	
Emergency Diesel Generator Exhaust Stack(Train 3-4)	8.34	3.53	0.45	0.45	0.45	0.24		758	
Diesel Firewater Pump Exhaust Stack (Train 3-4)	1.57	0.34	0.12	0.11	1.09	0.03		59.7	

General Notes:

Units of mg/m^3 at reference conditions of 20 degrees C, 101.325 kPa, and dry gas concentration corrected to fuel gas oxygen content of 15% by volume
Diameter & Exit Velocity Assumed Values
Where source data in ppmv then converted to mg/m3 using mg/m3 = (ppmV)(12.187)(MW)/(273.15+ °C)
Gas Turbine Assumptions
NOx and CO emission factors are based on the BC Emissions Criteria for Gas Turbines greater than 25 MW (Max 15ppmv) and typical operating data for Trent 60 and LM 6000 PF gas Turbines
All PM are assumed to be less than PM2.5. PM and VOC emission factors will be in accordance with B.C. Best Practices Methodology for Quantifying Greenhouse Gas Emissions published by the Ministry of Environment Victoria, B.C. November, 2014
Thermal Oxidizer Assumptions
NOx and CO Representative vendor guarantee emission factors
All PM assumed to be less than PM2.5. PM and VOC emission estimates as per US EPA emission factors for natural gas combustion (US EPA 1998) (Thermal Oxidizers)
Fired Heater assumed to have similar emissions to oxidizers
Flare Assumptions
Flare PM emissions are expected to be negligible
Diesel Generator Assumptions
Emission estimates are based on US EPA emission factors for large stationary diesel engines (US EPA 1996a). PM10 is assumed to be equivalent to PM2.5.
Diesel Firewater Pump Assumptions
Emission estimates are based on US EPA emission factors for diesel industrial engines (US EPA 1996b). Total PM is assumed to be equivalent to both PM10 and PM2.5.

12.2 24 MTPA FACILITY- E-LNG REFRIGERANT COMPRESSION EMISSION DATA

Pretreatment Facilities	Heat Load (MW)	Operating Days Per Year
Pretreatment Train 1 - Thermal Oxidizer Exhaust Stack	16.5	356
Pretreatment Train 1 - Fired Heater Exhaust Stack	48.5	356
Pretreatment Train 2 - Thermal Oxidizer Exhaust Stack	16.5	356
Pretreatment Train 2 - Fired Heater Exhaust Stack	48.5	356
Pretreatment Train 3 - Thermal Oxidizer Exhaust Stack	16.5	356
Pretreatment Train 3 - Fired Heater Exhaust Stack	48.5	356
Pretreatment Train 4 - Thermal Oxidizer Exhaust Stack	16.5	356
Pretreatment Train 4 - Fired Heater Exhaust Stack	48.5	356

Flare System	Mass Flow		Gas Composition		Duration per Year	
	Feed Gas Mass Flow (Kg/hr)	Startup Loads (Kg/hr)	Feed Gas	Startup	Startup	Emergency
Wet gas flare	1,440,000	NA	Feed Gas Composition	NA	24 Hours	10 minutes
Dry gas flare	2,725,000	NA	100% Propane	NA	24 Hours	10 minutes
BOG flare	108,000	NA	Methane 94 Mol% Nitrogen 6 Mol%	NA NA	N/A	10 minutes

Diesel Engines	Engine Power (KW)	Fuel Composition	Operating Duration Per Year		
			Emergency	Testing	Total Hours
Emergency Diesel Generator (Train 1-2)	2,500	Ultra Low Sulfur Diesel	24 hrs cont (1 event)	52 hrs (1hr per week)	76
Diesel Firewater Pump (Train 1-2)	300	Ultra Low Sulfur Diesel	24 hrs cont (1 event)	52 hrs (1hr per week)	76
Emergency Diesel Generator (Train 3-4)	2,500	Ultra Low Sulfur Diesel	24 hrs cont (1 event)	52 hrs (1hr per week)	76
Diesel Firewater Pump (Train 3-4)	300	Ultra Low Sulfur Diesel	24 hrs cont (1 event)	52 hrs (1hr per week)	76

Near Site Power Generation.(1000 MW)	Engine Information					Fuel Composition	Operating Days Per Year
	Driver	Rated Power Output (MWe)	Net Heat Rate (KJ/KW LHV)	Net Efficiency (%)	Exhaust Mass Flow (Kg/s)		
Simple Cycle Power Plant GT 1 Exhaust Stack	STG6-5000F	242 ISO Conditions	9,230	39	576	Use pipeline feed gas composition	356
Simple Cycle Power Plant GT 1 Exhaust Stack	STG6-5000F	242 ISO Conditions	9,230	39	576	Use pipeline feed gas composition	356
Simple Cycle Power Plant GT 1 Exhaust Stack	STG6-5000F	242 ISO Conditions	9,230	39	576	Use pipeline feed gas composition	356
Simple Cycle Power Plant GT 1 Exhaust Stack	STG6-5000F	242 ISO Conditions	9,230	39	576	Use pipeline feed gas composition	356
Simple Cycle Power Plant GT 5 Exhaust Stack	Trent 60 (DLE)	54.2 ISO Conditions	8,258	43.6	177	Use pipeline feed gas composition	356

Exhaust Stack Design and Operating Parameters

	Location (Approximate)		Source	Exhaust Stack Design Data (Stantec will determined the stack diameter)				Exhaust Stack Operating Parameters (Information will be revised per Stantec input)		
	X_UTMz9N83M eters	Y_UTMz9N83 Meters	Continuous/ Intermittent	Height (m)	Diameter (m)	Orientation (Vertical or otherwise)	Rain Capped (yes or no)	Exit Velocity (m/s)	Exit Temperature (Deg C)	Exhaust Mass Flow Rate (Kg/hr)
Pretreatment Train 1 - Thermal Oxidizer Exhaust Stack	410173.6	6013845.6	Continuous	40	1.8	V	No	20	871	210,760
Pretreatment Train 1 - Fired Heater Exhaust Stack	410097.5	6013588.6	Continuous	30	1.8	V	No	20	871	210,760
Pretreatment Train 2 - Thermal Oxidizer Exhaust Stack	410411.9	6013921.1	Continuous	40	1.8	V	No	20	871	210,760
Pretreatment Train 2 - Fired Heater Exhaust Stack	410335.8	6013664.1	Continuous	30	1.8	V	No	20	871	210,760
Pretreatment Train 3 - Thermal Oxidizer Exhaust Stack	409655.5	6014557.1	Continuous	40	1.8	V	No	20	871	210,760
Pretreatment Train 3 - Fired Heater Exhaust Stack	409579.5	6014300.0	Continuous	30	1.8	V	No	20	871	210,760
Pretreatment Train 4 - Thermal Oxidizer Exhaust Stack	409893.9	6014632.6	Continuous	40	1.8	V	No	20	871	210,760
Pretreatment Train 4 - Fired Heater Exhaust Stack	409817.8	6014375.6	Continuous	30	1.8	V	No	20	871	210,760
Wet gas flare (N/A if Ground Flare is used)	409983.2	6013114.6	Intermittent	100	0.5	V	No	20	982	See above
Dry gas flare (N/A if Ground Flare is used)	409936.0	6013398.4	Intermittent	150	0.5	V	No	20	982	See above
BOG flare (N/A if Ground Flare is used)	410110.3	6013158.7	Intermittent	100	0.5	V	No	20	982	See above

	Location (Approximate)		Source	Exhaust Stack Design Data (Stantec will determined the stack diameter)				Exhaust Stack Operating Parameters (Information will be revised per Stantec input)		
	X_UTMz9N83Meters	Y_UTMz9N83 Meters	Continuous/ Intermittent	Height (m)	Diameter (m)	Orientation (Vertical or otherwise)	Rain Capped (yes or no)	Exit Velocity (m/s)	Exit Temperature (Deg C)	Exhaust Mass Flow Rate (Kg/hr)
Ground Flare 1- Wet Gas Flare (N/A if Elevated Flare is used)	409912.4	6013351.1	Intermittent	N/A	N/A	N/A	N/A	20	982	See above
Ground Flare 2- Dry Gas Flare(N/A if Elevated Flare is used)	409861.5	6013507.7	Intermittent	N/A	N/A	N/A	N/A	20	982	See above
Ground Flare 3- BOG Flare(N/A if Elevated Flare is used)	409810.9	6013663.7	Intermittent	N/A	N/A	N/A	N/A	20	982	See above
Simple Cycle Power Plant GT 1 Exhaust Stack	409046.2	6015339.2	Continuous	40	3.7	Lateral	No	35	542	2,073,600
Simple Cycle Power Plant GT 2 Exhaust Stack	409073.5	6015259.4	Continuous	40	3.7	Lateral	No	35	542	2,073,600
Simple Cycle Power Plant GT 3 Exhaust Stack	409108.9	6015151.9	Continuous	40	3.7	Lateral	No	35	542	2,073,600
Simple Cycle Power Plant GT 4 Exhaust Stack	409140.0	6015054.1	Continuous	40	3.7	Lateral	No	35	542	2,073,600
Simple Cycle Power Plant GT 5 Exhaust Stack	409216.7	6015395.3	Continuous	40	3.7	Lateral	No	35	542	568,800
Emergency Diesel Generator Exhaust Stack (Train 1-2)	410198.4	6013329.1	Intermittent	12.5	0.4	V	No	45	427	100,000
Emergency Diesel Generator Exhaust Stack (Train 3-4)	409484.0	6014773.8	Intermittent	12.5	0.4	V	No	45	427	100,000
Diesel Firewater Pump Exhaust Stack (Train 1-2)	410263.1	6013349.1	Intermittent	7.5	0.2	V	No	45	427	50,000
Diesel Firewater Pump Exhaust Stack (Train 3-4)	409568.6	6014801.6	Intermittent	7.5	0.2	V	No	45	427	50,000

Exhaust Stack Discharge Concentrations

	Discharge Concentration (Stantec will provide update on discharge concentration)								
	NOx (mg/m^3)	CO (mg/m^3)	PM2.5 (mg/m^3)	PM10 (mg/m^3)	VOC (mg/m^3)	SO_2 (mg/m^3)	CH_4 (mg/m^3)	CO_2 (mg/m^3)	N_2O (mg/m^3)
Pretreatment Train 1 - Thermal Oxidizer Exhaust Stack	52	42	4	4	3	45	4	182487	3
Pretreatment Train 1 - Fired Heater Exhaust Stack	52	42	4	4	3	45	4	182487	3
Pretreatment Train 2 - Thermal Oxidizer Exhaust Stack	52	42	4	4	3	45	4	182487	3
Pretreatment Train 2 - Fired Heater Exhaust Stack	52	42	4	4	3	45	4	182487	3
Pretreatment Train 3 - Thermal Oxidizer Exhaust Stack	52	42	4	4	3	45	4	182487	3
Pretreatment Train 3 - Fired Heater Exhaust Stack	52	42	4	4	3	45	4	182487	3
Pretreatment Train 4 - Thermal Oxidizer Exhaust Stack	52	42	4	4	3	45	4	182487	3
Pretreatment Train 4 - Fired Heater Exhaust Stack	52	42	4	4	3	45	4	182487	3
Simple Cycle Power Plant GT 1 Exhaust Stack	30	30	7	7	2	0.2546	10	127986	10
Simple Cycle Power Plant GT 2 Exhaust Stack	30	30	7	7	2	0.2546	10	127986	10
Simple Cycle Power Plant GT 3 Exhaust Stack	30	30	7	7	2	0.2546	10	127986	10
Simple Cycle Power Plant GT 4 Exhaust Stack	30	30	7	7	2	0.2546	10	127986	10
Simple Cycle Power Plant GT 5 Exhaust Stack	30	30	7	7	2	0.2546	10	127986	10
	NOx (g/s)	CO (g/s)	PM2.5 (g/s)	PM10 (g/s)	VOC (g/s)	SO_2 (g/s)	CH_4 (g/s)	CO_2 (g/s)	N_2O (g/s)
Emergency Diesel Generator Exhaust Stack (Train 1-2)	8.34	3.53	0.45	0.45	0.45	0.24		758	
Diesel Firewater Pump Exhaust Stack (Train 1-2)	1.57	0.34	0.12	0.11	1.09	0.03		59.7	
Emergency Diesel Generator Exhaust Stack (Train 3-4)	8.34	3.53	0.45	0.45	0.45	0.24		758	
Diesel Firewater Pump Exhaust Stack (Train 3-4)	1.57	0.34	0.12	0.11	1.09	0.03		59.7	

General Notes:

Units of mg/m3 at reference conditions of 20 degrees C, 101.325 kPa, and dry gas concentration corrected to fuel gas oxygen content of 15% by volume
Diameter & Exit Velocity Assumed Values
Where source data in ppmv then converted to mg/m3 using mg/m3 = (ppmV)(12.187)(MW)/(273.15+ °C)

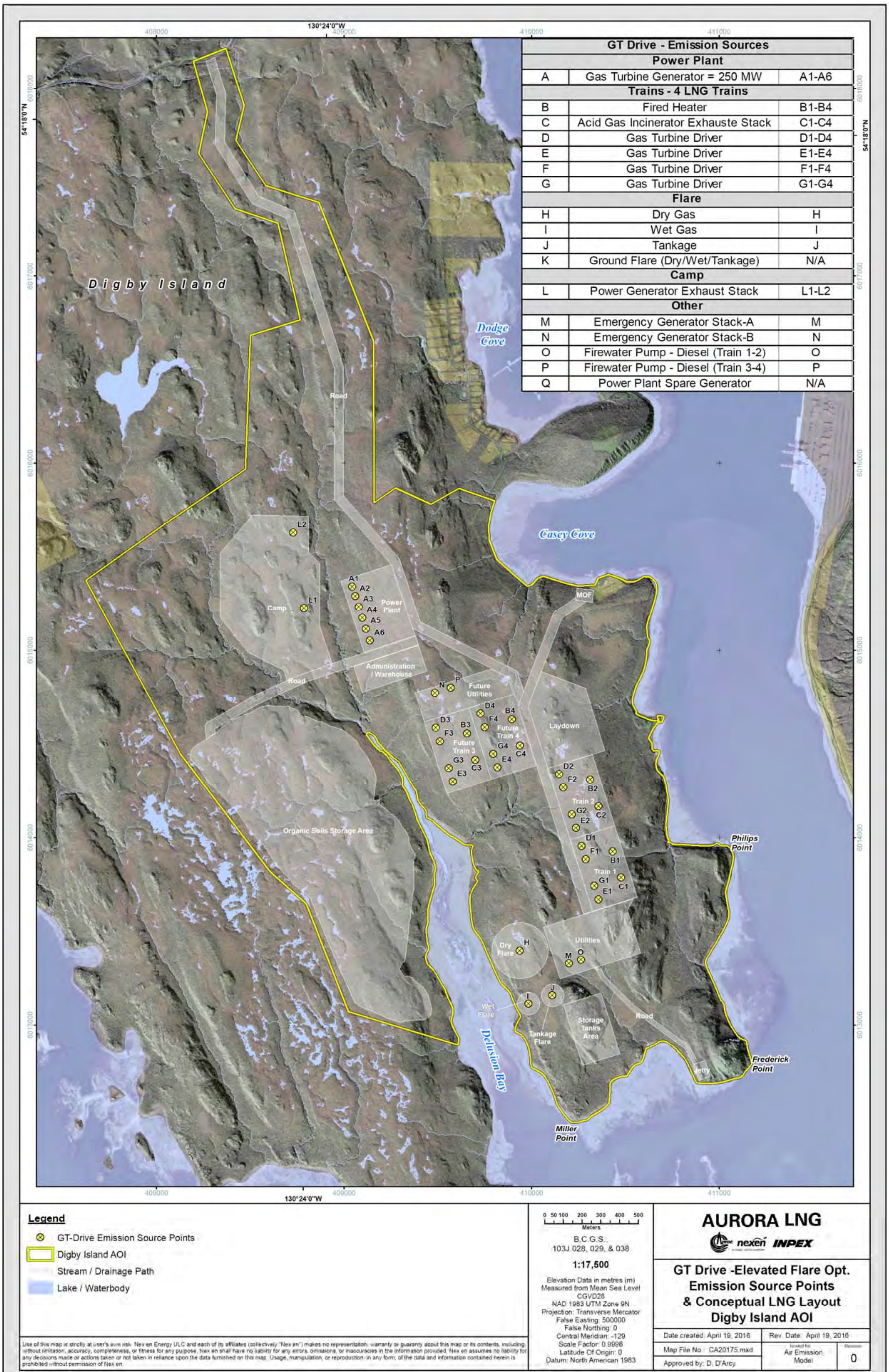
Thermal Oxidizer Assumptions
NOx and CO Representative vendor guarantee emission factors
All PM assumed to be less than PM2.5. PM and VOC emission estimates as per US EPA emission factors for natural gas combustion (US EPA 1998) (Thermal Oxidizers) Fired Heater assumed to have similar emissions to oxidizers

Flare Assumptions
Flare PM emissions are expected to be negligible

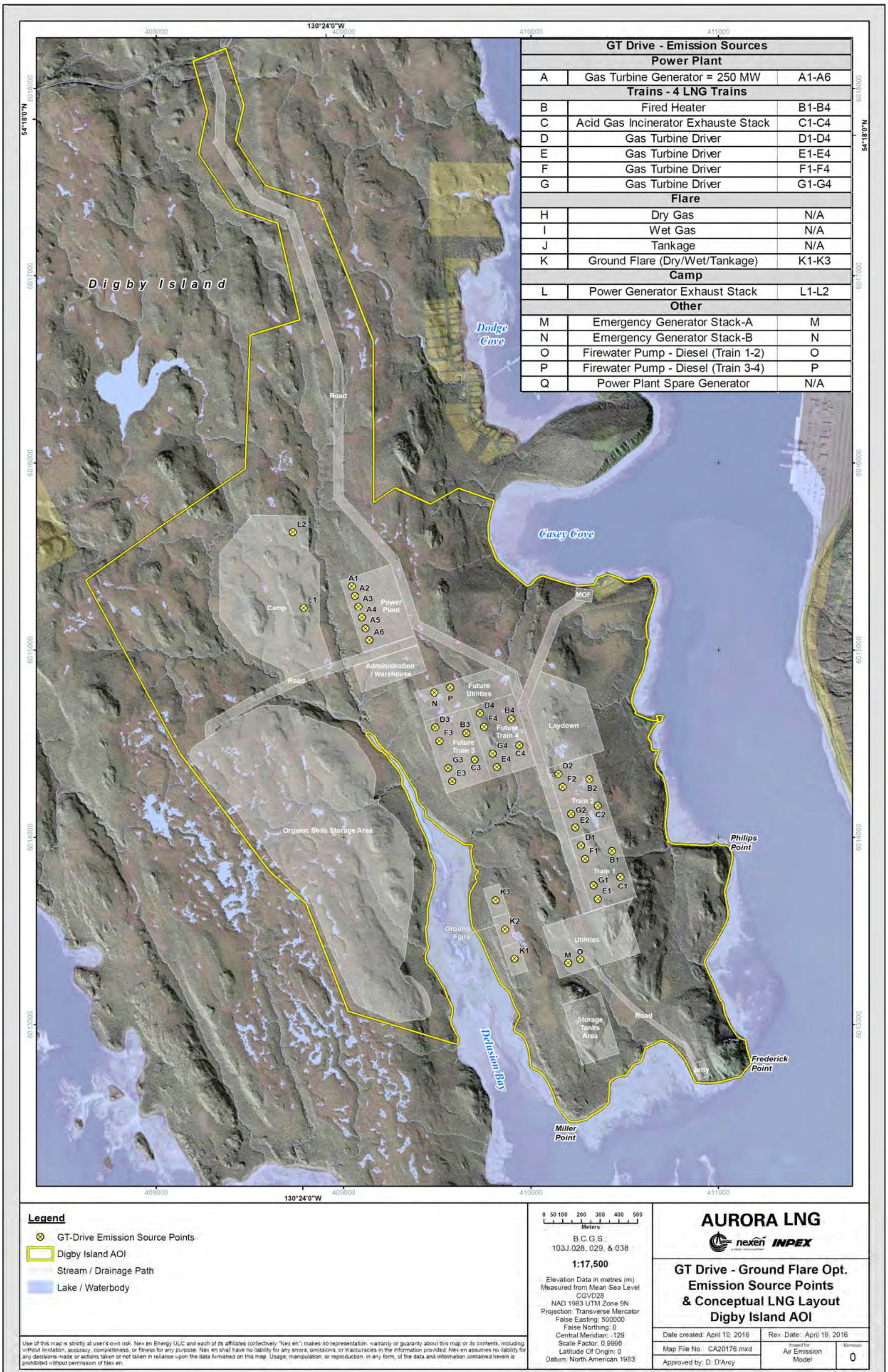
Diesel Generator Assumptions
Emission estimates are based on US EPA emission factors for large stationary diesel engines (US EPA 1996a). PM10 is assumed to be equivalent to PM2.5.

APPENDIX A

GTD ELEVATED FLARE OPTION EMISSION SOURCE POINTS PLOT PLAN

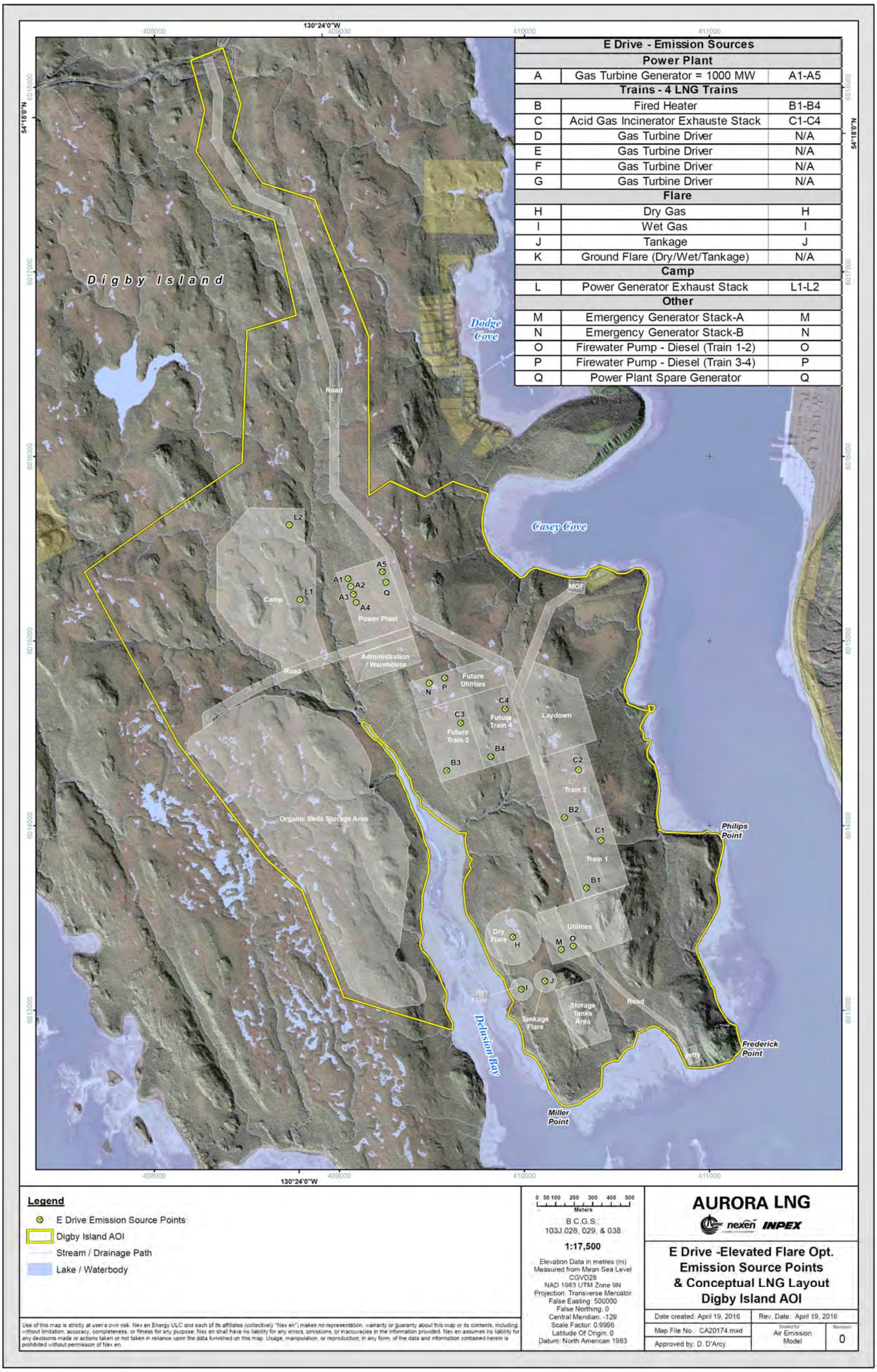


GTD GROUND FLARE OPTION EMISSION SOURCE POINTS PLOT PLAN

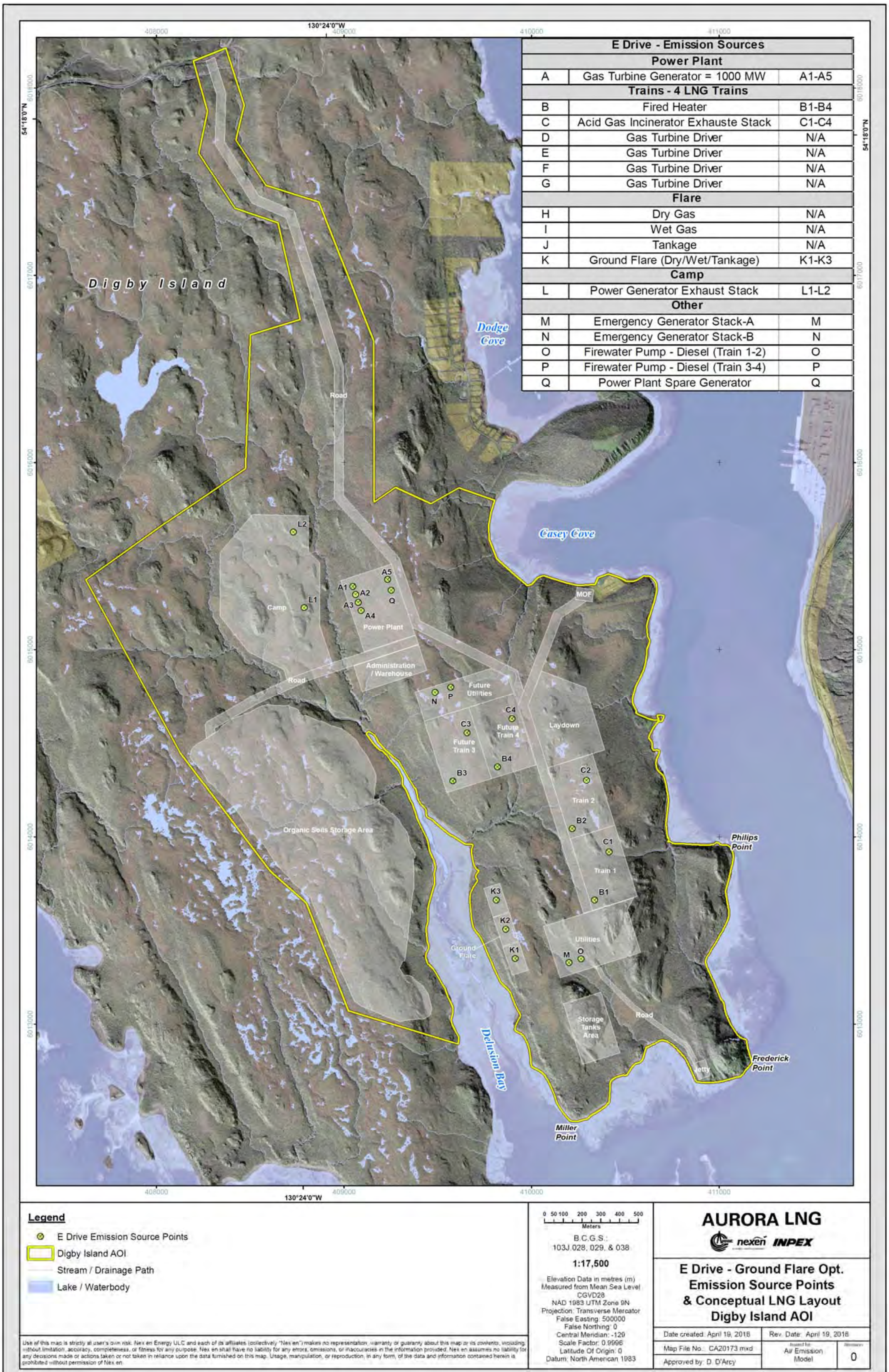


GT Drive - Emission Sources		
Power Plant		
A	Gas Turbine Generator = 250 MW	A1-A6
Trains - 4 LNG Trains		
B	Fired Heater	B1-B4
C	Acid Gas Incinerator Exhauste Stack	C1-C4
D	Gas Turbine Driver	D1-D4
E	Gas Turbine Driver	E1-E4
F	Gas Turbine Driver	F1-F4
G	Gas Turbine Driver	G1-G4
Flare		
H	Dry Gas	N/A
I	Wet Gas	N/A
J	Tankage	N/A
K	Ground Flare (Dry/Wet/Tankage)	K1-K3
Camp		
L	Power Generator Exhaust Stack	L1-L2
Other		
M	Emergency Generator Stack-A	M
N	Emergency Generator Stack-B	N
O	Firewater Pump - Diesel (Train 1-2)	O
P	Firewater Pump - Diesel (Train 3-4)	P
Q	Power Plant Spare Generator	N/A

E-LNG ELEVATED FLARE OPTION EMISSION SOURCE POINTS PLOT PLAN

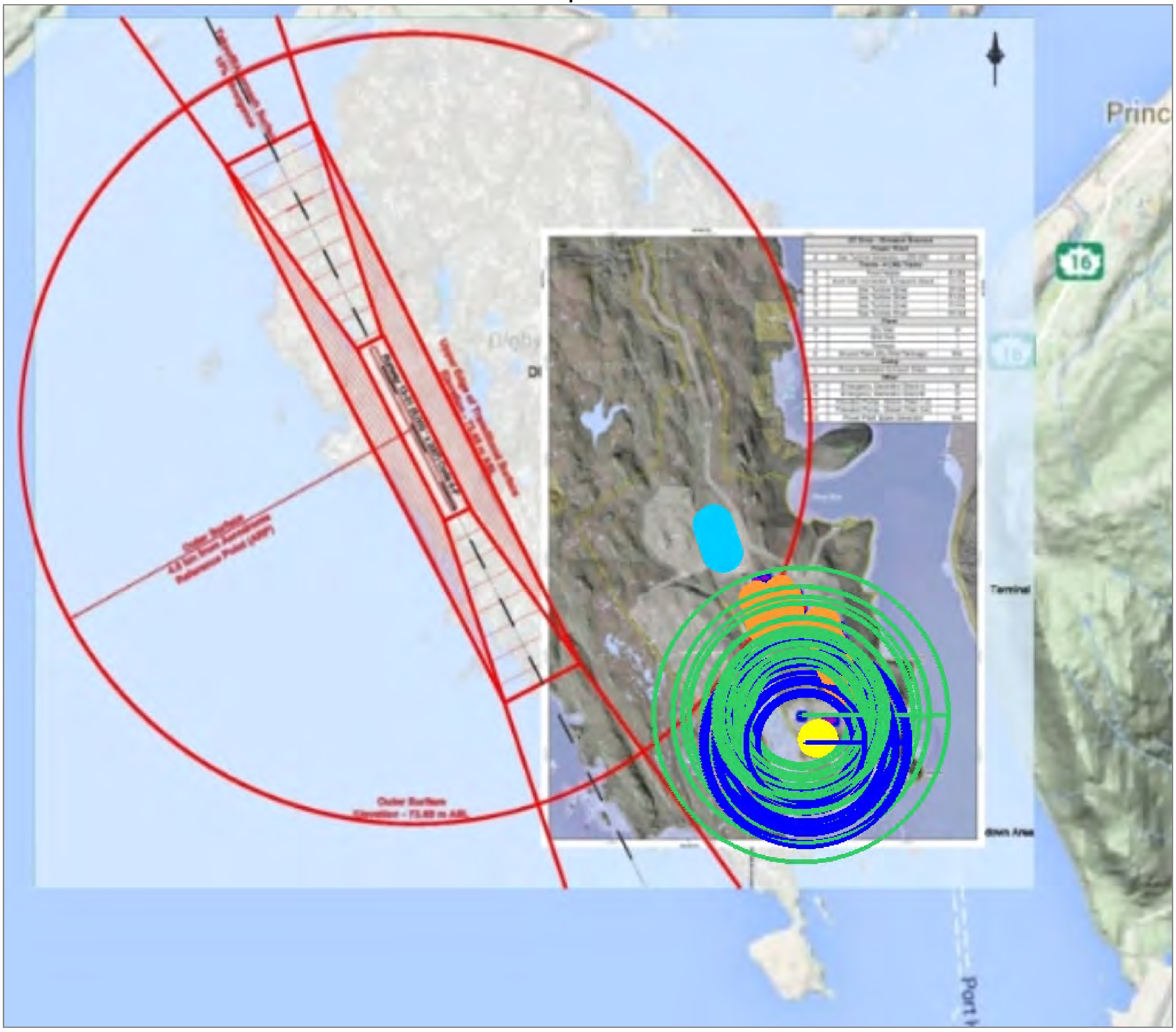


E-LNG GROUND FLARE OPTION EMISSION SOURCE POINTS PLOT PLAN

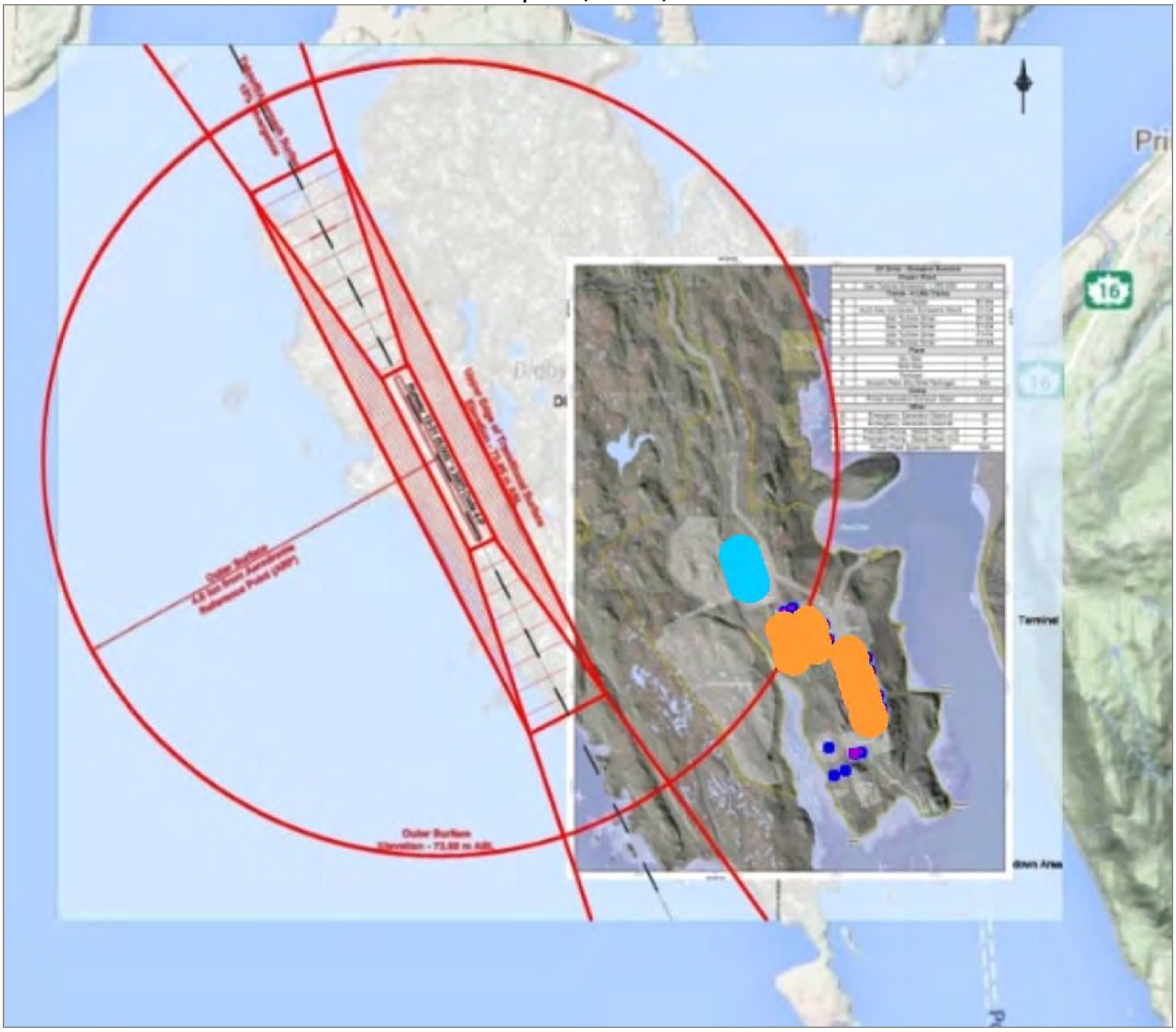


Appendix C 3D Plume Plots (4.3 m/s Threshold)

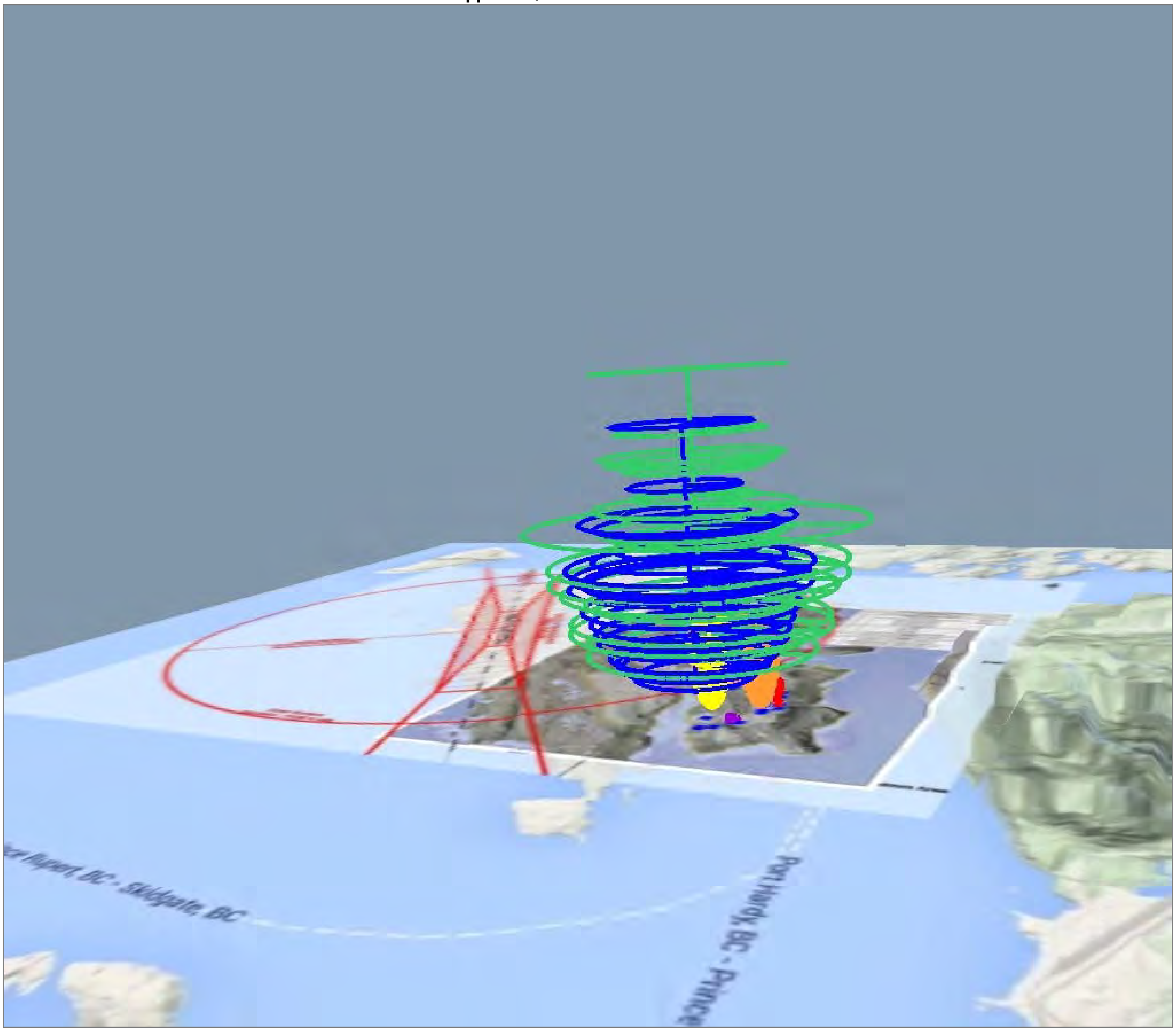
Top View



Top View (No Flares)



Approach / Take-off Vector View

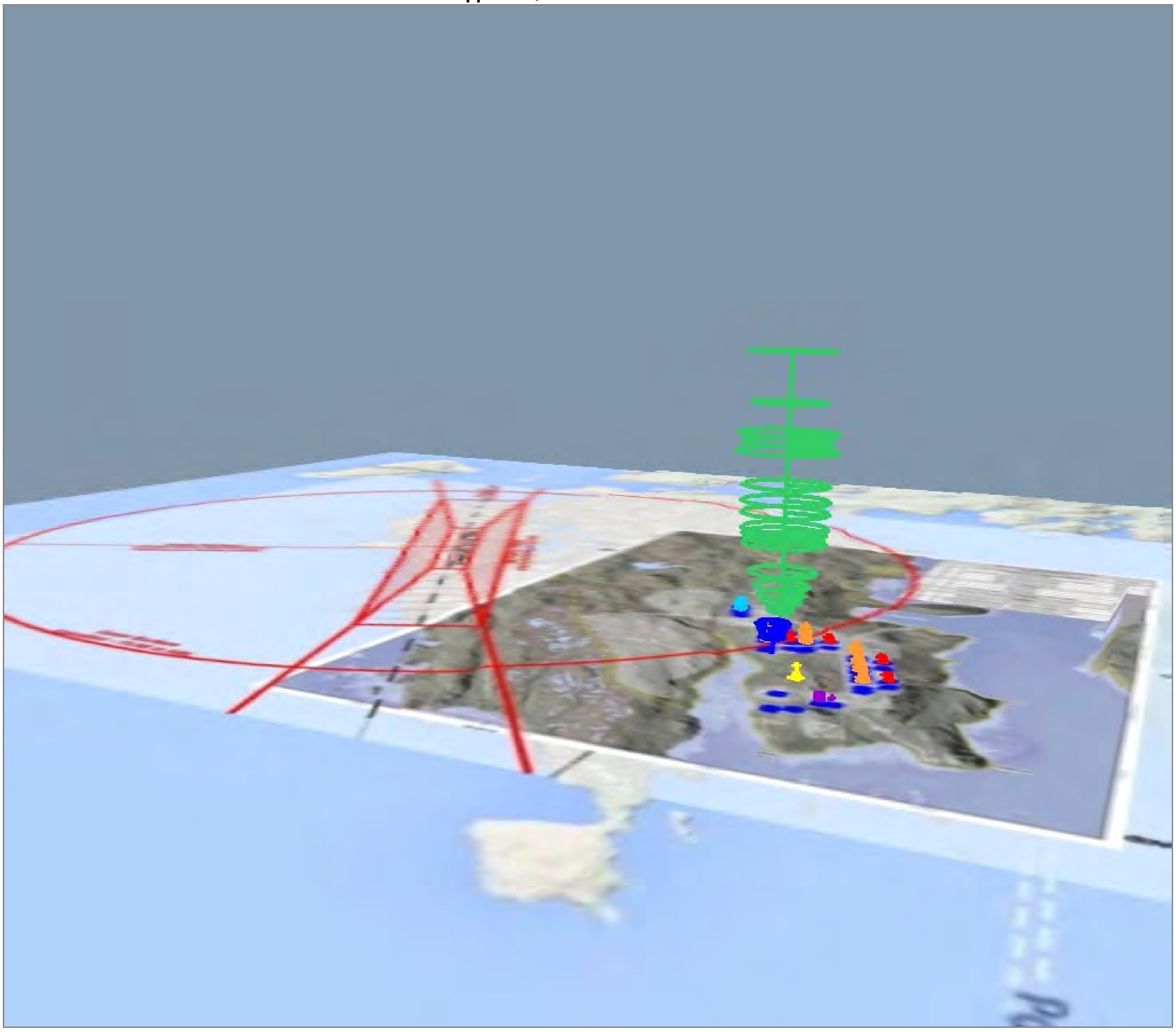


Appendix D 3D Plume Plots (10.6 m/s Threshold)

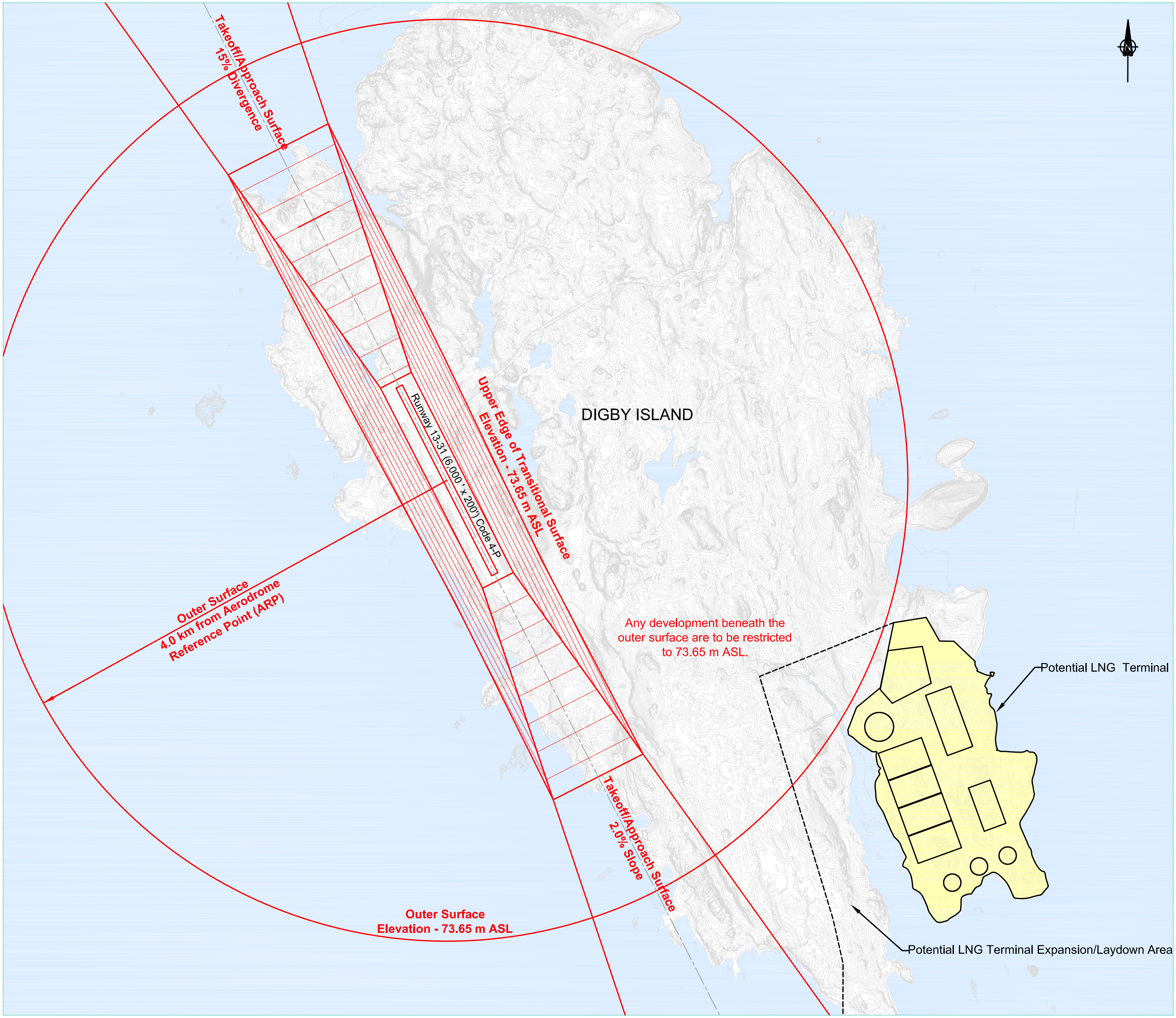
Top View

Top View (No Flares)

Approach / Take-off Vector View



Appendix E Digby Island Physical Zoning Analysis



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Client

nexen

Title

PROPOSED DIGBY ISLAND LNG TERMINAL

PRINCE RUPERT AIRPORT

PHYSICAL ZONING ANALYSIS

Notes

1. Preliminary
2. All dimensions approximate

DRAFT

Figure No.	1
Drawn By	EDH
Approved By	RAM
Date	7/18/2014
Scale	NTS
Filename	EZ

Appendix F Prince Rupert Airport Navigational Procedures

AERODROME CHART

PRINCE RUPERT
PRINCE RUPERT BC

VOT 115.7	◑RADIO RUPERT O/T TERRACE RDO (RCO) 122.5 (MF)	DEP VANCOUVER CENTRE 128.0 284.0

DECLARED DISTANCES	13	31						
TORA	6000	6000						
TODA	6853	7000						
ASDA	6000	6000						
LDA	6000	6000						

* DEPARTURE PROCEDURE

Rwy 13 -½ - Right turn then CLB between TRKS **195°** CW to **310°** from "PR" NDB to **2500** BPOC.

Rwy 31 -½ - CLB between TRKS **310°** CCW to **195°** from "PR" NDB to **3200** BPOC.

TAKE-OFF MINIMA	SCALE IN FEET
Rwys 13; 31: ★	1000 0 1000

AERODROME CHART
EFF 13 APR 06

CHANGE: Editorial.

PRINCE RUPERT BC
PRINCE RUPERT
NAD83

AERONAUTICAL INFORMATION CIRCULAR 22/14

PRINCE RUPERT, BRITISH COLUMBIA
CLOSURE OF THE FLIGHT SERVICE STATION

NAV CANADA, the country's provider of civil air navigation services, conducted an aeronautical study that reviewed the air traffic service requirements for the Prince Rupert airport. The Study concluded that the services provided by the flight service station (FSS) located at Seal Cove were not required and recommended closure of the FSS.

This Notice outlines the operational changes resulting from the closure. For airport operations and for pilots, essentially the same procedures and responsibilities that are currently in effect for the 14-hours per day when the FSS is closed will be in effect 24-hours per day. Following are the key aspects of operations after the FSS closure:

- The existing mandatory frequency (MF) area and control zone will be retained. Pilots will be responsible for communicating amongst themselves to coordinate their flights through broadcasting their aircraft's position and intentions on the MF. To help facilitate pilot situational awareness, common visual flight rules (VFR) routes within the MF area will be published on the Prince Rupert VFR Terminal Procedures Chart in the *Canada Flight Supplement* (CFS) (see sketch below);
- Vehicle operators when conducting operations on the airport manoeuvring area will be responsible for monitoring the MF and communicating directly with pilots to coordinate their activity;
- The airport operator will forward runway surface condition (RSC) reports to the Kamloops flight information centre (FIC) (Pacific Radio). Pilots will obtain the RSC directly from vehicle operators on the MF or from Pacific Radio via the flight information service en route (FISE) remote communications outlet (RCO) or Vancouver area control centre (ACC) via the PAL;
- Pilots will activate the airport runway lighting via the type 'K' aircraft radio control of aerodrome lighting (ARCAL) system;
- Pilots conducting instrument flight rules (IFR) flights will obtain IFR clearances from the Vancouver ACC via the peripheral air-ground link (PAL);
- Pilot requests for authorization of special VFR flight within the control zone will be made with the Vancouver ACC via the PAL; and
- Pilots can open, close or make modifications to flight plans and obtain flight-planning information from Pacific Radio via the FISE RCO.

This change will take effect 24 July 2014 at 0901 Coordinated Universal Time (UTC). The appropriate aeronautical publications will be amended.

For further information please contact:

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Tel.: 800-876-4693
Fax: 877-663-6656
E-mail: service@navcanada.ca

Prince Rupert—New VFR Two-way Routes

NORTH CORRIDOR RTE	NORTH CORRIDOR ROUTE
SOUTH CORRIDOR RTE	SOUTH CORRIDOR ROUTE
BACKWAY RTE	BACKWAY ROUTE
TUCK RTE	TUCK ROUTE
SILVER CREEK RTE	SILVER CREEK ROUTE

NOT FOR NAVIGATION

Chuck Montgomery
Director, AIS and Flight Inspection