Australia Pacific LNG Project

Volume 5: Attachments

Attachment 29: Air Quality Impact Assessment - LNG Facility

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AUSTRALIA PACIFIC LNG FACILITY, GLADSTONE, QUEENSLAND - AIR QUALITY IMPACT ASSESSMENT

Prepared for

WORLEY PARSONS

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Glossary

Term	Definition
Units of measurement	
ng	nanogram
µg	microgram
mg	milligram
g	grams
kg	kilograms
t	tonnes
ng/m^3	nanogram per cubic metre
$\mu g/m^3$	micrograms per cubic metre
mg/m^3	milligrams per cubic metre (at stack conditions)
mg/Nm^3	milligrams per normal cubic metre (0^oC, 1 Atm)
ppm	parts per million
tpa	tonnes per annum
Mtpa	million tonnes per annum
µm	microns
mm	millimetre
m	metre
km	kilometre
m^2	square metres
m^3	cubic metres
m/s	metres per second
m^3/s	cubic metres per second
Am^3/s	actual cubic metres per second (at stack conditions)
Nm^3/s	normalised cubic metres per second (0^oC, 1 Atm)
g/s	grams per second
km/h	kilometre per hour
Atm	atmosphere (pressure)
Pa	pascal
kPa	kilopascal
kPag	kilopascal gauge
hPa	hectopascal
°C	degrees Celsius
J	joule
kJ	kilojoule: $1.0 \times 10^3 J$
MJ	megajoule: $1.0 \times 10^6 J$
GJ	gigajoule: $1.0 \times 10^9 J$
TJ	terajoule: $1.0 \times 10^{12} J$
PJ	petajoule: $1.0 \times 10^{15} J$
GJ/hr	gigajoule per hour
GJ/s	gigajoule per second

Term	Definition
MW	megawatts
mol	mole
wt	weight

Air pollutants and chemical nomenclature

NO_X	oxides of nitrogen
NO_2	nitrogen dioxide
SO_2	sulphur dioxide
CO	carbon monoxide
CO_2	carbon dioxide
CH_4	methane
H_2S	hydrogen sulfide
N_2	nitrogen
O_2	oxygen
VOC	volatile organic compounds
PAH	polycyclic aromatic hydrocarbons
PM	particulate matter (fine dust)
TSP	total suspended particles
PM_{10}	particulate matter with an aerodynamic diameter less than 10 microns
$PM_{2.5}$	particulate matter with an aerodynamic diameter less than 2.5 microns
ou	odour units

Other abbreviations

APLNG	Australia Pacific LNG
Origin	Origin Energy
CSG	coal seam gas
LNG	liquefied natural gas
DERM	Department of Environment and Resource Management
NPI	National Pollutant Inventory
NEPM	National Environment Protection (Ambient Air Quality) Measure
Air Toxics NEPM	National Environment Protection (Air Toxics) Measure
EPP Air	Environmental Protection (Air) Policy
Approved Methods	Approved Methods for the Modelling and Assessment of Air Pollutants in NSW
VicSEPP	State Environmental Protection Policy of Victoria
TCEQ	Texas Commission on Environmental Quality Effects Screening Levels
Clean Air Regulation	NSW Protection of the Environment Operations (Clean Air) Regulation 2002
BoM	Bureau of Meteorology
ToR	Terms of Reference
EMP	Environmental Management Plan

Other abbreviations

EIS	Environmental Impact Statement
EIA	Environmental Impact Assessment
TAPM	The Air Pollution Model

Statistical terms

IOA	Index of agreement
MAE	Mean absolute error
FAC2	Factor or 2
PCC	Pearsons correlation coefficient

1. Executive Summary

Katestone Environmental has been commissioned by Worley Parsons to undertake an Air Quality Impact Assessment in preparation of an Environmental Impact Statement (EIS) for the Australia Pacific LNG (APLNG) Downstream Project. The APLNG Project (the Project) comprises a coal seam gas (CSG) to liquefied natural gas (LNG) development. APLNG is a joint venture between Origin Energy (Origin) and ConocoPhillips Australia LNG Pty Limited.

The proposed APLNG Project comprises the development of a green-field LNG production and export terminal at Curtis Island on the northern shore of Port Curtis, near Gladstone. The Project will facilitate the export of natural gas to international markets from an upstream supply of Coal Seam Gas (CSG) extracted from the APLNG gas fields in central southern Queensland. CSG will be processed in the field to extract moisture and compress the gas for transmission via a pipeline stretching approximately 450 km between the APLNG gas fields and the APLNG facility on Curtis Island. The Project is designed to supply approximately 18 million tonnes per annum (Mtpa) of LNG product to market through the development that may comprise a four train LNG facility with a LNG production capacity of approximately 4.5 Mtpa per train.

The objective of the assessment is to investigate the potential for all air emissions from the LNG facility to adversely impact on the air quality in the Gladstone region. Each emission source has been assessed for the following air pollutants during normal and non-routine operations at the plant:

- Oxides of nitrogen (NOX), as nitrogen dioxide (NO2)
- Carbon monoxide (CO)
- Sulphur dioxide (SO2)
- Particulates as PM10 and PM2.5
- Hydrocarbons

Modelling of NO_X emissions from background sources has been carried out using the Gladstone Airshed Modelling System version 3 (GAMSv3), a regional airshed management tool developed for the Department of Infrastructure and Planning (DIP) by Katestone Environmental. A cumulative assessment of the impacts from nitrogen dioxide (NO_2) has been conducted to include existing and approved industries, as well as other proposed LNG facilities including on Curtis Island and Fishermans Landing. Background levels of PM_{10}/$PM_{2.5}$ and CO for the assessment of cumulative air quality impacts have been obtained from monitoring data in the Gladstone region, where available. SO_2 emissions from the plant are negligible; however the LNG carriers may emit SO_2 depending on the fuel used. Therefore SO_2 from shipping emissions has been assessed in isolation.

Table 1 Summary of annual emissions from existing Gladstone industries and APLNG (t/yr)

	NO_x	CO	PM_{10}	SO_2
Existing Gladstone[1]	55,210	68,292	2,444	50,947
APLNG [2]	3,295	2,407	221	0
APLNG as % of	6%	4%	9%	0%

Notes: [1] Based on NPI reports for 2007-2008 period for existing industries only (no natural or anthropogenic emissions included)
[2] Total plant emissions for normal operations. All sources assumed to operate at 100% capacity for 8760 hours per year

The following conclusions may be drawn from the air quality impact assessment.

In relation to dispersion meteorology:

- The site is dominated by moderate winds typical of a coastal location, with an average wind speed of 3.7 m/s. This provides for relatively good dispersion conditions for stack sources.
- The prevailing wind direction at the site is from the east to south sector, whereas the main population centre of Gladstone is located to the south to west sector from the proposed AP LNG facility.
- Winds likely to carry emissions from the LNG facility over the population centre of Gladstone occur very infrequently.

A cumulative air quality assessment was undertaken that included all existing industrial sources in Gladstone and proposed future developments (including proposed LNG plants on Curtis Island and at Fishermans Landing) and has shown the following:

- All air quality objectives are met for normal and non-routine operation of the LNG facility (inclusive of background levels) at sensitive receptors for NO2, CO, PM10, PM2.5, odour, ozone, SO2 and hydrocarbons.

For all pollutants the contribution to the regional air quality is dominated by existing sources, which includes industrial, anthropogenic and natural sources.

A quantitative assessment has been conducted for emissions associated with the gas flares during maintenance and upset or emergency conditions of the LNG facility. The worst-case emergency conditions for a simultaneous release from the Dry and Wet Gas flare has been assessed and presented in this report. This condition is an extremely conservative scenario as the Dry and Wet flare is not likely to operate simultaneously. Additionally, 100 per cent flare capacity was modelled for non-routine conditions when, in most conditions the flare will operate at approximately 20% capacity (this information is based on the ConocoPhillips experience at Darwin LNG).

In relation to aviation safety, during normal plant operations the following conclusions can be drawn from the assessment:

- There is a potential for the average plume vertical velocity to exceed 4.3 m/s up to a maximum height of approximately 850 metres above ground level at a maximum downwind distance of approximately 166 metres. The maximum height is dominated by the merged plume from the gas turbine compressors.
- The merged plume from the gas turbine compressors is likely to cause the vertical velocity to be greater than 4.3 m/s at and above the PANS-OPS (400 metres) for approximately 28 hours per year or 0.32% of the time.

- Of all the plumes considered for normal operations, the highest critical height for the 0.1 percentile is approximately 550 metres above ground level (merged gas turbine compressors).

In relation to aviation safety, during non-routine plant operations for upset event such as excess flaring, the following conclusions can be drawn from the assessment:

- Each LNG train will have a planned shutdown scheduled to occur several years apart with associated maintenance and start-up flaring.
- A plume from the Marine Flare (stack not ground flare) would have a vertical velocity greater than 4.3 m/s above the height of the PANS-OPS (400 metres) for approximately 28 hours per year or 0.38% of the time, when assumed operation for every hour of the year.
- The Wet and Dry Gas Ground flare, which will typically operate if emergency depressurisation of the plant is required is likely to generate a plume with vertical velocities above 4.3 m/s well above the PANS-OPS under all conditions.
- An emergency release from the Wet and Dry Gas Ground flare is predicted to have a very low frequency of occurrence, with duration of approximately 20 minutes while the plant depressurises, but can potentially occur at any time. Under flaring, the ground flare is likely to always exceed the PANS-OPS above the site to a considerable vertical distance.

Discussions between the APLNG, Gladstone Airport and CASA will be required to determine an appropriate course of action to alert aircraft in the region should a ground flare event occur.

A cumulative assessment of aviation safety of the APLNG plumes and other existing or proposed industrial developments is not necessary as the plumes will not merge during normal operating conditions.

2. Introduction

Katestone Environmental has been commissioned by Worley Parsons to undertake an Air Quality Impact Assessment in preparation of an Environmental Impact Statement (EIS) for the Australia Pacific LNG Downstream Project. The APLNG Project (the Project) is proposed by Australia Pacific LNG Pty Limited (APLNG) and comprises a coal seam gas (CSG) to liquefied natural gas (LNG) development. APLNG is a joint venture between Origin Energy (Origin) and ConocoPhillips Australia LNG Pty Limited.

The proposed APLNG Project comprises the development of a green-field LNG production and export terminal at Curtis Island on the northern shore of Port Curtis, near Gladstone. The Project will facilitate the export of natural gas to international markets from Coal Seam Gas (CSG) extracted from the APLNG gas fields in the Walloons Fairway and Surat and Bowen Basins in central southern Queensland. CSG will be processed in the field to extract moisture and the gas will be pressurised for transmission via a pipeline stretching approximately 450 km to the LNG facility on Curtis Island. The Project is designed to supply up to approximately 18 million tonnes per annum (Mtpa) of LNG product to market through the development of a LNG facility which may comprise four LNG trains each with a production capacity of 4.5 Mtpa.

This report describes the methods and findings of an assessment of the potential effect on air quality due to the construction, operation and decommissioning of the proposed LNG facility at Curtis Island and an assessment of aviation safety.

The air quality assessment has focussed on the primary source of air emissions from the project during normal operations, including the:

- Gas turbines used to drive the gas compressors
- Gas turbines used for power generation
- Gas-fired hot oil heaters

Air emissions from other sources, such as vents from the nitrogen rejection unit and acid gas removal unit, emit gasses that are only important for a Greenhouse Gas Assessment and therefore have not been included in this assessment (ref volume 4 Chapter 14 for Greenhouse Gas Assessment).

The assessment has also considered the potential for non-routine operating conditions to affect air quality, including the combustion and discharging of process gasses through the flares for plant pressure management during maintenance or upset operating conditions. The potential impact due to shipping emissions have also been assessed.

Construction of the LNG facility may also give rise to the emissions of air pollutants, primarily associated with earthworks and land clearing, such as dust and combustion gas emissions from motor vehicles and earth moving equipment. These activities tend to be short-term and transient and air unlikely to influence air quality away from Curtis Island. Notwithstanding this, they will be considered and managed in accordance with a Construction Phase Environmental Management Plan (EMP). Decommissioning can be expected to result in emissions of air pollutants which are similar in type and quantity to the construction phase and will be considered and managed in accordance with a Decommissioning Phase EMP which will be developed closer to the time decommissioning is to occur.

The objective of the assessment is to investigate the potential for air emissions from the LNG facility to affect the air quality in the Gladstone region. All activities that are likely to emit air pollutants have been considered. The major air pollutant emitted during normal and non-routine operations of the LNG facility is oxides of nitrogen (NO_X), as nitrogen dioxide (NO_2). Minor emissions of carbon monoxide (CO), particulates as PM_{10} and $PM_{2.5}$, sulphur dioxide (SO_2) and hydrocarbons are also emitted from the LNG facility during normal and non-routine operations.

Emissions and management of greenhouse gases is not addressed in this report, but this issue is dealt with elsewhere in the EIS.

The air quality impact assessment has been carried out in accordance with the Environmental Impact Statement (EIS) Terms of Reference (November 2009), including consideration of the following components relating to air quality:

- Description of plant processes associated with the generation of air emissions
- Description of normal and non-routine plant operating conditions and their relationship to the generation of air emissions
- Description of air pollutant source characteristics, concentrations and emission rates
- Discussion of the local climate including the meteorological conditions important for the dispersion of air pollutants
- Discussion of existing air quality including emission rates of air contaminants from background sources within the region and Department of Environment and Resource Management (DERM) monitoring data
- Description of the methodology for the prediction of NO2 levels from background sources using the GAMSv3
- Description of the methodology for the development of meteorological inputs for dispersion modelling using TAPM and CALMET
- Description of the methodology for the prediction of ground-level concentrations of air pollutants using the CALPUFF dispersion model
- Assessment of all air pollutants including NOX, CO, PM10, PM2.5, SO2, odour and hydrocarbons
- Discussion and assessment of the potential for the generation of photochemical smog
- Assessment of vertical plume velocities, associated with stack and flare emission sources during both normal and non-routine operating conditions, in relation to Civil Aviation Safety Authority (CASA) guidelines

3. Overview of the Assessment Methodology

The air quality impact assessment of the proposed LNG facility has been conducted in accordance with the requirements of the Project's ToR issued by the Coordinator-General. The assessment is based on a dispersion modelling study that incorporates source characteristics and air pollutant emission rates based on the Project's FEED parameters and site-specific meteorology. This section outlines the impact assessment methodology adopted for the study.

Emissions information for air pollutants associated with the gas turbines, gas-fired heaters and flares have been sourced from the following:

- Project FEED parameters
- National Pollutant Inventory Emission Estimation Techniques (EET)
- Combustion Engines v3.0
- Combustion in Boilers v3.1
- USEPA AP-42 Emission Factors
- Chapter 3.1, Stationary Gas Turbines
- Chapter 1.4, Natural Gas Combustion
- Chapter 13.5, Industrial Flares

The existing environment in the region has been described in terms of:

- Climate, including temperature, solar radiation, relative humidity, rainfall and atmospheric pressure
- Meteorology, including wind speed and direction
- Terrain and land use
- Sensitive receptors
- Emissions associated with the existing local industries
- Ambient air quality including based on DERM monitoring data at multiple locations in the Gladstone airshed

The air quality objectives specified in the Environmental Protection (Air) Policy 2008 (EPP Air) were adopted for the assessment. For some air pollutants, the EPP Air does not specify air quality objectives. Where this is the case project objectives have been determined from the following documents:

- National Environment Protection Measure (Ambient Air Quality) 1998
- NSW Department of Environment and Climate Change (NSW DECC) Approved Methods for the Modelling and Assessment of Air Pollutants in NSW (2005)
- EPA Victoria (Vic SEPP) State Environment Protection Policy (Air Quality Management)
- World Health Organisation (WHO) Guidelines for Air Quality (Chapter 3) 2000
- Texas Commission on Environmental Quality Toxicological section list of Effects Screening

Levels

- National Exposure Standards for Atmospheric Contaminants in the Occupational Environment (NOHSC:1003(1995))

The approach adopted for the atmospheric dispersion modelling includes the following components:

- Background sources of NO2 based on GAMSv3 modelling for existing and approved sources
- Nested CALMET meteorological domain within the GAMSv3 at a fine scale resolution over the APLNG facility at Curtis Island
- CALMET inputs such as terrain and land use parameters were enhanced by the use of Geoscience Australia 9 second Digital Elevation Model (DEM) data and GIS and aerial image information
- CALPUFF runs for APLNG sources modelled on nested CALMET domain – APLNG model
- Air quality assessment for NO2 based on combined GAMSv3 and APLNG model predictions

The air quality assessment includes:

- Assessment of criteria pollutants (including NO2, CO, PM10, and PM2.5) cumulative ground-level concentration (incremental plus background) at sensitive receptor locations with the EPP Air quality objectives.
- Assessment of all other air pollutants (including SO2 and hydrocarbons) by comparison of the maximum incremental ground-level concentration at sensitive receptor locations with the relevant air quality objectives.
- Assessment of odour by comparison of the maximum incremental ground-level concentration at sensitive receptor locations with the DERM guideline.
- Quantitative assessment of photochemical smog (ozone).

The aviation assessment includes:

- Assessment of vertical plume velocities, associated with stack and flare emission sources during both normal and non-routine operating conditions.

4. Development Proposal

The APLNG facility is proposed to be situated on the western side of Curtis Island, across The Narrows and to the north-northeast of Fisherman's Landing. The layout of the plant is presented in Figure 1, while its location is illustrated in Figure 2.

The proposal comprises a four train LNG facility with a design capacity of approximately 18 Mtpa. The first LNG train is expected to begin producing LNG in 2014, the second train in 2015 and the third and fourth trains post-2015, depending on the LNG markets.

4.1 LNG Process Infrastructure and Operations

Project components that have the potential to emit air pollutants include:

- Operation of the LNG facility
- Shipping activities
- Construction activities including site clearing, and construction of the LNG plant

The assessment considers separately the emissions to air from both normal and non-routine operations at the LNG facility. For the purposes of the atmospheric dispersion modelling study, normal operations refer to the day-to-day running of the plant to produce LNG product. These production processes operate on a continual basis at a fixed location and include emissions generated by the combustion of CSG and the processing of CSG feed gas for liquefaction. Emissions sources include:

- Gas turbines to drive compressors
- Gas turbines for power generation
- Hot Oil Heaters
- Acid Gas Removal Unit
- Nitrogen Rejection Unit

Air emissions from the nitrogen rejection unit and acid gas removal unit are only important for a Greenhouse Gas Assessment and therefore have not been included in this assessment (ref Volume 4 Chapter 14 for GHG assessment).

Other activities of the LNG facility occur intermittently for a short duration, are mobile or are transient in nature. These activities are likely to be intermittent sources of air pollutants. Emission sources in this category include:

- Dry Gas Flare (maintenance or upset conditions)
- Wet Gas Flare (maintenance or upset conditions)
- Marine Flare (maintenance or upset conditions)
- Variable emissions from normal operating equipment during start up and shut down
- Construction activities
- Vehicle emissions

- LNG and LPG Carriers
- Tug boats
- Diesel generators

The assessment of the potential affect of non-routine operations on air quality has been conducted selectively to identify worst-case conditions. Consequently, a quantitative assessment has been conducted for emissions associated with the gas flares during maintenance and upset or emergency conditions of the LNG facility. The worst-case emergency conditions for a simultaneous release from the Dry and Wet Gas Flare has been assessed and presented in this report.

The berthing, loading/unloading and unberthing of LNG/LPG Carriers and the assisting tug boats may be conducted by a third party provider. As the details of shipping requirements for the ALPLG development have not been finalised emission information used by other LNG developments have been used as a guide to assess the potential impacts associated with shipping.

4.2 Process Units

This section details the process units associated with the production of LNG and their potential for the release of emissions to air. Figure 1 illustrates the APLNG facility and the location of each process unit.

4.2.1 Inlet separator

The feed gas entering the plant from the gas pipeline is initially processed through a vapour-liquid separator system to provide a gas, free of water and liquid hydrocarbons. CSG is very unlikely to contain any such liquids but the equipment is provided as a standard safeguard.

No emissions to air are likely from this process during normal and non-routine operation of the LNG facility. The gas flows on to the plant and the liquid hydrocarbons (if any) are collected in the inlet separator and sent to the wet gas flare for disposal.

4.2.2 Acid gas removal

Gas from the inlet separator is fed to the Acid Gas Removal System, which is designed to remove carbon dioxide (CO_2) from the feed gas using a conventional Acid Gas Removal Unit. Hydrogen sulfide (H_2S) and other sulphur compounds may also removed in order to meet LNG sulphur specifications. The acid gas removal unit will not have a thermal oxidiser (based on essentially nil H_2S in feed gas). While this is the base case, should gas testing show that H_2S needs to be considered, then a thermal oxidiser on the AGRU will be provided in the design. If the H_2S does end up being in the order of 4ppm, a thermal oxidiser will be required. Therefore, it can be assumed that there is a minimal amount of H_2S in the gas turbine fuel and hence SO_2 emissions will be negligible.

The Acid Gas Regenerator is vented to the atmosphere. Emissions to air comprise primarily of CO_2 with small quantities of methane (CH_4) and trace amounts of H_2S, but these are insignificant in the context of this assessment, but considered in the GHG assessment.

4.2.3 Dehydration

The treated gas leaving the absorber in the Acid Gas Removal Unit is chilled in the Propane Feed Chiller, prior to entering the Dryer Inlet Separator for separation of any condensed hydrocarbons and water. Heating for dehydrator beds is provided by waste heat recovery units on the gas turbines.

No emissions to air are likely from this process during normal and non-routine operation of the LNG facility.

4.2.4 Mercury removal

The dry gas from the dehydrators is passed through the Molecular Sieve After Filter prior to entering the Mercury Removal Beds. The gas is then dust filtered via the Mercury Removal After Filters before flowing to the refrigeration and liquefaction units.

No emissions to air are likely from this process during normal and non-routine operation of the LNG facility.

4.2.5 Liquefaction section

The gas is then fed to the refrigeration system where it is liquefied to LNG product through a combination of heat exchange with the refrigerants and pressure letdown.

The propane and ethylene systems are closed loop refrigeration systems and are provided with separate storage systems for each refrigerant makeup. The storage systems provided for Train 1 and 2 are planned to be shared with those for the Train 3 and 4 LNG Plant.

The methane refrigerant circuit is an open loop utilising the main feed gas system. Boil off and flash gases from the LNG storage tank are returned to the methane refrigeration loop. The liquefied LNG product is pumped to the LNG Storage Tanks.

No emissions to air are likely from the refrigeration processes during normal and non-routine operation of the LNG facility other than those from the gas turbine drivers that are described below.

4.2.6 Compressor gas turbine drivers

The gas compressors of the liquefaction system will be driven by six General Electric LM2500+G4 Dry Low NO_X gas turbines per train, with a total of 24 gas turbines for the 18 Mtpa facility. A waste heat recovery system is proposed to recover sufficient gas turbine driver exhaust heat for process heating requirements. The effect of the waste heat recovery units on emission characteristics has not been considered. Information pertaining to the impact of waste heat recovery on turbine exhaust characteristics will be generated during the detailed design phase of the Project.

Emissions to air from the gas turbines comprise primarily NO_X and CO and CO_2, small quantities of PM_{10}, $PM_{2.5}$ and trace quantities of hydrocarbons and SO_2.

4.2.7 Nitrogen removal

Nitrogen (N_2) will be stripped from the feed gas to meet LNG and fuel gas specifications.

The gas from the Nitrogen Removal Unit is vented to the atmosphere. Emissions to air comprise primarily of N_2 with small quantities of methane (CH_4), but these are insignificant in the context of this assessment and are considered in the GHG assessment (ref Volume 4 and Chapter 14).

Nitrogen (generated by an air separation plant) is also used as blanket gas for storage tanks, purge gas for the cold boxes, loading arm swivel joint purges, compressor gas seals and buffer, and as purge gas required for repair and maintenance services and for other general purposes.

4.2.8 Product storage

There are two operating LNG storage tanks with a capacity of 160,000 m^3 each, installed for

Train 1 and 2. A third LNG storage tank with a capacity of 160,000 m^3 is proposed as part of the future Train 3 expansion project. LNG Loading Pumps are installed in each tank. The combined capacity of any 8 pumps operating in parallel is 12,500 m^3/hr. At this rate, a ship may be loaded in approximately 13 hours, although a duration of 24 hours has been used for emission estimation purposes.

The design includes for operating LPG storage tank with a capacity of 100,000 m^3. Any capacity additions will be provided as part of Train 3 and 4. LPG will be unloaded from ship at 2,000 m^3/hr. Two LPG Spiking Pumps are installed in this tank. LPG vapor from this tank is re-liquefied under normal conditions and discharged under pressure control to the dry flare for non-routine situations.

4.2.9 Product loading

Currently, there is one ship loading facility proposed for Trains 1 and 2 of the APLNG facility. This would allow loading of one LNG ship with a capacity of between 125,000 m^3 to 220,000 m^3 each.

The jetty will be served by one LNG loading line, LNG loading arms, one LPG unloading arm and one LNG vapour return loading arm. The LNG product is pumped from the tanks to the dock via the loading line, and transferred to the ship via the LNG loading arms. The 16 inch vapour return arm handles displaced gas from the ship's tank, flashed gas, and vaporised gas from heat gain during ship loading. This gas is returned to the LNG tanks via a separate gas line.

The composite gas from the LNG tanks and from the ship loading system are compressed in boil off gas (BOG) compressors as required and returned to the open cycle Methane LNG Plant refrigerant systems. With all BOG compressors in operation, excess gas that may be generated during ship loading can be reinjected into the process without flaring.

A second ship berth will be provided when LNG trains 3 and 4 are constructed. LPG, which may be required for increasing the calorific value of LNG for certain markets, will be unloaded at the first LNG loading berth.

The Marine Flare is discussed in Section 4.4.2.

4.3 Plant Utility System

4.3.1 Hot oil system

A circulating hot oil system is included for amine process heating regeneration. The hot oil system will be heated using the gas turbine waste heat recovery units. Back-up heating from the hot oil heaters is only required during start-up and at a reduced load for trim heating during normal operations.

The Hot Oil System is a closed loop circulation system provided to service the heating requirements for the following units:

- Amine reboiler

- Inlet Gas Heater
- Fuel Gas Heaters
- Defrost Gas Heaters

The Hot Oil Heaters are gas-fired and, consequently, emissions to air consist primarily of NO_X and CO, and trace quantities of hydrocarbons, SO_2, PM_{10} and $PM_{2.5}$.

4.3.2 Power generation system

Electrical power will be self-generated based on a peak electrical load during ship loading operations. The power generation system will supply electricity for LNG processing and the common utility and offsites areas, such as the Jetty and Materials Offloading Facility. A low sulphur diesel powered generator will be provided for "blackstart" and emergency backup power requirements. The diesel powered generator will be operated rarely.

Power for the operation of four LNG Trains will be provided by Solar Titan 130 gas turbine power generator sets; which may consist of three per train with one spare unit on Train 1. These generators are rated at 15 MW each.

Dry low NO_X emissions technology has been proposed to maintain NO_X concentrations at less than 25 ppm.

The standby electrical power supply will consist of one 1500 kVA, 400 V diesel generator, one 3500 kVA, 6.6 kV diesel generator and two 500 kVA, 400 V diesel generators. The standby generators will supply power to standby loads during power system outages and will provide power to black start the gas turbine generators when required.

Emissions to air from the gas turbines comprise primarily NO_X and CO, small quantities of PM_{10} and $PM_{2.5}$, and trace quantities of hydrocarbons and SO_2.

4.3.3 Effluent treatment

Wastewater from an LNG plant includes runoff water, oily water, sewage that is collected and treated before disposal. The wastewater treatment plant design is for a closed tank system including an extended aeration-type activated sludge plant for treating the sanitary wastewater. The treated water will meet all applicable standards and would then be used for onsite reticulation or routed to the outfall in Curtis Bay. The digested sludge would be sent for disposal at an offsite landfill.

Odorous air emissions generated by wastewater treatment processes will be collected and treated using an appropriate odour control system, designed to meet the requirements of the DERM Odour Guideline (2004).

No emissions to air are likely from this process during normal and non-routine operation of the APLNG Facility.

4.4 Support Facilities

4.4.1 Dry and wet gas flare systems

Wet and dry gas flare systems are provided to support maintenance and non-routine operations of the process facilities. The Wet Gas Flare system is connected with the front end of the LNG train and processes the blowdown of wet, warm hydrocarbon gases, while the Dry Gas Flare system is

connected with the rear end of the LNG train and processes the blowdown of dry, cold hydrocarbon gases.

The proposed Wet and Dry Gas Flare systems will be designed as a ground flare rather than the conventional stack release. The design will be similar to the flare at the Darwin LNG Facility owned by ConocoPhillips. The source characteristics of the Darwin LNG Flare have been used to represent the LNG facility Wet and Dry Gas Flare system.

Three ground flares will be installed to service four trains. The Wet and Dry gas ground flare comprises a network of alternate wet/dry flare emission release manifolds and burners. The system will be continued within a heat shield.

Emissions from the flares under upset or maintenance conditions are considered to be non-routine in the context of the plant's operation and, consequently, have been assessed in isolation of the normal operating conditions at the facility. During an emergency it is likely that feed gas will be shut off to the affected process or train, shutting down normal operating processes and initiating a blowdown event to either of the Dry or Wet Gas Flares to reduce the pressure in the plant. It may be possible for the wet and dry gas flare systems to operate simultaneously, and for this assessment, the worst-case emergency scenario for a release from both flares has been considered. For the purposes of the dispersion modelling assessment, it is assumed that the normal operations will be shut down in the affected trains (i.e., Train 1 and 2) during gas discharge to the Dry and Wet Gas flares, while Trains 3 and 4 remain in normal operation.

Emissions to air from the Dry and Wet Gas Flares comprise primarily of NO_X, CO, CO_2 and hydrocarbons. Smokeless flares will be installed resulting in near zero particulate emissions.

4.4.2 Marine flare

The marine flare is for startup and emergency situations only, since other equipment is provided to minimise flaring during LNG tanker loading. The marine flare may also be used to assist in the cool-down of a warm ship but this is an infrequent requirement.

Boil off gas (BOG) generated on the LNG ships and during transfer will be returned to the plant for re-liquefaction via the BOG compressors. Gas flaring will typically be required in the event of a failure of the one or more of the BOG compressors. In this case, the ship loading rate can be reduced if there is insufficient compression capacity available. This will reduce the need to flare excessive amounts of LNG product, with gas flaring eventuating if compression capacity is exceeded.

Emissions to air from the Marine Flare comprise primarily of NO_X, CO, CO_2 and hydrocarbons. A smokeless flare will be installed resulting in near zero particulate emissions.

Operation of the Marine Flare is likely to be of short duration, 12-48 hours during a loading event, although there are mitigation measures to reduce effects while maintenance is occurring potentially reducing the duration of flaring. The emission rate of NO_X for a worst case Marine Flare blowdown event (Warm Ship Cool Down scenario) is 2.3% of that likely to be emitted from the Dry and Wet Gas ground flare. Consequently, the Marine Flare has not been considered as its potential to affect air quality is substantially lower than the worst case. The Marine Flare will be either a stack or ground flare.

5. Emissions

5.1 Air Pollutants

The air pollutants considered in this assessment are primarily associated with the combustion of carbon based fuels such as CSG. Other sources include the venting of process units used for the removal of impurities such as CO_2 and N_2. Consequently, the air pollutants emitted and assessed include NO_X, CO, PM_{10}, $PM_{2.5}$ and various hydrocarbon species.

Reduced sulphur compounds such as hydrogen sulfide (H_2S) are not expected to be present in the CSG resource. H_2S will be removed, if required, during the pre-treatment phase of the gas liquefaction process in order to meet LNG specifications. This removal of H_2S means there is a minimal amount of H_2S in the gas turbine fuel and hence SO_2 emissions will be negligible.

Emission rates of NO_X, CO, PM_{10} and hydrocarbons have been supplied by APLNG. $PM_{2.5}$ has been conservatively represented as being equal to PM_{10} emissions.

The chemical speciation of exhaust emissions from the gas turbines, gas-fired heaters and process flares has not been provided for specific hydrocarbon composition, with emission rates supplied as total hydrocarbons. In order to quantify emissions of specific hydrocarbons, the USEPA AP-42 emission factors (Table 2), have been used.

Table 2 USEPA AP-42 emission factor documents referenced for the determination of hydrocarbon emissions

Source	US EPA AP-42 document referenced
Gas turbines	Stationary Gas Turbines, Chapter 3.1
Hot oil heater	Natural Gas Combustion, Chapter 1.4
Flares (Dry gas, Wet gas, Marine)	Industrial Flares, Chapter 13.5

The AP-42 emission factors have been determined for gas-fired combustion sources using natural gas fuel in the United States of America. This US natural gas contains greater proportions of butane, pentane, hexane, sulphur and other hydrocarbons in addition to methane. The CSG fuel used in the gas turbines and gas-fired heaters of the LNG facility has substantially lower proportions of hydrocarbons other than methane and is therefore a cleaner burning fuel. Consequently, the quantification of hydrocarbon emissions using the AP-42 emission factors is considered conservative.

5.2 Standards of emission concentrations

The ToR for the APLNG Project states that the air quality impact assessment should include a comparison of the predicted level of emissions with the best practice national source emission standards.

In NSW, the *Protection of the Environment Operations (Clean Air) Regulation (2002)* provides standards of emission concentrations for scheduled premises. The standards for gas turbines and gas-fired boilers (assumed similar to the proposed heaters) are provided in Table 3 along with the Project standard which has been used in the development of emission rates for the APLNG sources. Plant and equipment that is proposed to be installed at the LNG facility will comply with these standards of concentration.

Table 3 Point source emission standards comparison

Air impurity	Applicability	NSW Standard of concentration	Project standard[1]
Oxides of nitrogen (as NO_2)	Gas turbines	70 mg/Nm^3 (35 ppm)	25 ppm
	Heaters/boilers	350 mg/Nm^3 (170 ppm)	170 ppm
PM_{10}	All combustion equipment	50 mg/Nm^3	50 mg/Nm^3
Carbon monoxide	All combustion equipment	125 mg/Nm^3	125 mg/Nm^3
	Firewater pumps	5,880 mg/Nm^3	5,880 mg/Nm^3
Volatile organic compounds	All combustion equipment	40 mg/Nm^3	40 mg/Nm^3
	Firewater pumps	1,140 mg/Nm^3	1,140 mg/Nm^3

Note:
[1] Project Standards Provided by Bechtel for APLNG sources (Bechtel, 2009)
Reference conditions:
Boiler - Dry, 273 K, 101.3 kPa, 3% oxygen content
Turbine - Dry, 273 K, 101.3 kPa, 15% oxygen content

5.3 Normal Operations

5.3.1 Gas turbine compressor drivers

The source characteristics of the LM2500+G4 gas turbines (fitted with a Dry Low Emissions (SoLoNOx) combustion system) used to drive the liquefaction process are presented in Table 4. A total of six gas turbines will be used for each train to produce up to 4.5 Mtpa of LNG. There will be a total of 24 LM2500+G4 gas turbines used for the four-train scenario. Source characteristics are presented for normal operating conditions with the gas turbines operating at 100% capacity. This is a worst case scenario as the turbines will not operate at 100% capacity all the time.

Table 4 Source characteristics of the LM2500+G4 gas turbine drivers under normal operating conditions at 100% capacity

Parameter	Units	Value
Number of stacks per turbine unit	--	1
Total number of turbine units (4 train case)	--	24
Stack base ground elevation (above sea level)	m	8
Stack height (above ground level)	m	25
Stack diameter	m	2.3
Exhaust gas temperature	K	803
Exhaust gas velocity	m/s	50.4

Parameter	Units	Value
Exhaust gas flow rate (actual stack conditions)	m^3/s	209.4
Normalised exhaust gas flow rate (0°C, 1 Atm)	Nm^3/s	71.2

The location of the stacks associated with each of the 24 gas turbine compressor drivers for the three-train case is presented in Table 5.

Table 5 Locations of the gas turbine emission stacks

Compressor Turbine Driver	Train 1		Train 2		Train 3		Train 4	
	X	Y	X	Y	X	Y	X	Y
1	315553	7371616	315553	7371784	315553	7371952	315553	7372120
2	315553	7371608	315553	7371776	315553	7371944	315553	7372112
3	315553	7371600	315553	7371768	315553	7371936	315553	7372104
4	315553	7371592	315553	7371760	315553	7371928	315553	7372096
5	315553	7371584	315553	7371752	315553	7371920	315553	7372088
6	315553	7371576	315553	7371744	315553	7371912	315553	7372080

Table note: MGA coordinates referenced to GDA94 (in metres)

Table 6 presents the concentrations and emission rates for NO_X, CO, $PM_{10}/PM_{2.5}$ and total hydrocarbons, while

Table 7 presents the likely contribution to total hydrocarbon emissions for all hydrocarbons identified in the US EPA AP-42 emission factors document for Stationary Gas Turbines.

Table 6 Concentration and emission rates of air pollutants from the LM2500+G4 gas turbine compressor drivers under normal operating conditions at 100% capacity

Parameter	Concentration[1] (mg/Nm^3)	Emission rate[2] (g/s)	Total annual emissions[3] (t/yr)
Oxides of nitrogen (as NO_2)	48.58	3.46	2,619
Carbon monoxide	29.62	2.11	1,597
PM_{10} / $PM_{2.5}$	3.37	0..24	182
Total Hydrocarbons[4]	12.79	0.91	690

Table note:
[1]Concentration calculated from emission rate data
[2]Information obtained from APLNG
[3] All turbines operating for 8,760 hours per year, 4 trains
[4]Total hydrocarbons presented as methane equivalents

Table 7 Breakdown of emission rates of hydrocarbons from the LM2500+G4 gas turbine compressor drivers

Pollutant	Molecular weight	Emission Factor[1] (lb/MMBtu)	Stack Concentration (mg/Nm^3)	Emission Rate (g/s)
1,3-Butadiene	54.10	4.3E-07	5.0E-04	3.6E-05
Acetaldehyde	44.10	4.0E-05	4.7E-02	3.3E-03
Acrolein	56.06	6.4E-06	7.4E-03	5.3E-04
Benzene	78.10	1.2E-05	1.4E-02	9.9E-04
Ethylbenzene	106.20	3.2E-05	3.7E-02	2.7E-03
Formaldehyde	30.03	7.1E-04	8.3E-01	5.9E-02
Methane	16.00	8.6E-03	1.0E+01	7.1E-01
Naphthalene	128.20	1.3E-06	1.5E-03	1.1E-04
PAH	252.31	2.2E-06	2.6E-03	1.8E-04
Propylene Oxide	58.10	2.9E-05	3.4E-02	2.4E-03
Toluene	92.10	1.3E-04	1.5E-01	1.1E-02
Xylene	106.20	6.4E-05	7.4E-02	5.3E-03

Table note:
[1]Source: US EPA AP-42

5.3.2 Power generation gas turbines

Electrical power for the LNG facility will be generated by combustion of CSG in a similar way to the gas turbine compressor drivers and is assumed as a base case to be provided by a series of Solar Titan 130 gas turbines with a Dry Low Emissions (SoLoNOx) combustion system. Three Solar Titan 130 gas turbines units per LNG train (12 operating turbine units in total) have been considered in the air quality assessment; however 13 are likely to be installed allowing one to be offline. Optimisation of power generation is ongoing but other configurations being considered would have a similar effect to the base case used here, as the same total electricity demand is required.

The assessment of the Solar Titan 130 turbines used for power generation has been conducted for the worst-case plant design scenario during an LNG Carrier loading event. During this scenario, maximum power generation is required to meet plant operating power demand. The source characteristics of the Solar Titan 130 gas turbines, used for power generation, are presented in Table 8.

Table 8 Source characteristics of the Solar Titan 130 gas turbines for power generation under normal operating conditions at 100% capacity

Parameter	Units	Value
Number of stacks per turbine unit	--	1
Total number of turbine units (4 train case)[1]	--	12
Stack base ground elevation (above sea level)	m	8
Stack height (above ground level)	m	25

Parameter	Units	Value
Stack diameter	m	1.9
Exhaust gas temperature	K	666
Exhaust gas velocity	m/s	33.3
Exhaust gas flow rate (actual stack conditions)	m^3/s	94.42
Normalised exhaust gas flow rate (0^oC, 1 Atm)	Nm^3/s	38.72

Table note:
[1] Train 1 has a spare Solar Titan 130 unit that will not operate during normal operations

The locations of the stacks associated with each of the three gas turbines for power generation for the four-train case are presented in Table 9.

Table 9 Locations of the power generation gas turbine emission stacks

Power Generation Turbine	Train 1		Train 2		Train 3		Train 4	
	X	Y	X	Y	X	Y	X	Y
1	315826	7371775	315826	7371738	315880	7371775	315880	7371738
2	315826	7371764	315826	7371725	315880	7371764	315880	7371725
3	315826	7371751	315826	7371714	315880	7371751	315880	7371714

Table note:
MGA coordinates referenced to GDA94 (in metres)

Table 10 presents the concentrations and emission rates of NO_X, CO, $PM_{10}/PM_{2.5}$ and total hydrocarbons, while Table 11 presents the likely contribution to total hydrocarbon emissions for all hydrocarbons identified in the US EPA AP-42 emission factors.

Table 10 Concentration and emission rates of air pollutants from the Solar Titan 130 gas turbines for power generation under normal operating conditions at 100% capacity

Parameter	Concentration[1] (mg/Nm^3)	Emission rate[2] (g/s)	Total annual emissions[3] (t/yr)
Oxides of nitrogen (as NO_2)	42.09	1.63	617
Carbon monoxide	51.91	2.01	761
PM_{10} / $PM_{2.5}$	2.32	0.09	34
Total Hydrocarbons[4]	14.72	0.57	216

Table note:
[1]Concentration calculated from emission rate data
[2]Information obtained from APLNG
[3] Assumed capacity for all turbines operating for 8,760 hours per year
[4]Total hydrocarbons presented as methane equivalents.

Table 11 Breakdown of emission rates of hydrocarbons from the LM2500+G4 gas turbines for power generation

Pollutant	Molecular weight	Emission Factor (lb/MMBtu)	Stack Concentration (mg/Nm^3)	Emission Rate (g/s)
1,3-Butadiene	54.10	4.3E-07	3.8E-04	2.2E-05
Acetaldehyde	44.10	4.0E-05	3.5E-02	2.1E-03
Acrolein	56.06	6.4E-06	5.6E-03	3.3E-04
Benzene	78.10	1.2E-05	1.0E-02	6.2E-04
Ethylbenzene	106.20	3.2E-05	2.8E-02	1.7E-03
Formaldehyde	30.03	7.1E-04	6.2E-01	3.7E-02
Methane	16.00	8.6E-03	7.5E+00	4.5E-01
Naphthalene	128.20	1.3E-06	1.1E-03	6.7E-05
PAH	252.31	2.2E-06	1.9E-03	1.1E-04
Propylene Oxide	58.10	2.9E-05	2.5E-02	1.5E-03
Toluene	92.10	1.3E-04	1.1E-01	6.7E-03
Xylene	106.20	6.4E-05	5.6E-02	3.3E-03
Table note: 1Source: US EPA AP-42				

5.3.3 Hot oil heaters

The Hot Oil Heaters will be used during start-up conditions, with the waste heat recovery system to provide pre-heating for various LNG production processes during normal operations. The Hot Oil Heaters will then be used during normal operation, at a 40% load, to trim the heating requirements of the facility and assist the waste heat recovery system. The heaters have been included in the air quality assessment for continual use during normal operating conditions at an assumed 100% load; this therefore constitutes a worst case scenario.

The heaters are gas-fired and heat a closed loop hot fluid system. Consequently, four Hot Oil Heaters for the four LNG train scenario have been used in this assessment.

The source characteristics of the Hot Oil Heaters are presented in Table 12.

Table 12 Source characteristics of the Hot Oil Heaters under normal operating conditions at 100% capacity

Parameter	Units	Value
Number of stacks per unit	--	1
Total number of units (4 train case)	--	4
Stack base ground level (above sea level)	m	8
Stack height (above ground level)	m	50
Stack diameter	m	0.76
Exhaust gas temperature	K	570

Parameter	Units	Value
Exhaust gas velocity	m/s	18.3
Exhaust gas flow rate (actual stack conditions)	m^3/s	8.3
Normalised exhaust gas flow rate (0°C, 1 Atm)	Nm^3/s	3.98

The location of the stacks associated with each of the four Hot Oil Heaters for the four-train case is presented in Table 13.

Table 13 Locations of the Regeneration Oil Heater emission stacks

Train 1		Train 2		Train 3		Train 4	
X	Y	X	Y	X	Y	X	Y
315411	7371346	315411	7371346	315411	7371346	315411	7371346

Table note:
MGA coordinates referenced to GDA94 (in metres)

Table 14 presents the concentrations and emission rates for NO_X, CO, $PM_{10}/PM_{2.5}$ and total hydrocarbons, while Table 15 presents the likely contribution to total hydrocarbon emissions for all hydrocarbons identified in the US EPA AP-42 emission factors document for gas-fired boilers (assumed similar to the Hot Oil Heaters). It should be noted that such factors used here are for generic hot oil heaters using a generic natural gas but CSG is a very lean gas and so is extremely unlikely to result in any such products at the quoted emission rates/stack concentrations and so the following should be considered extremely conservative, but included here for assessment purposes.

Table 14 Concentration and emission rates of air pollutants from the Hot Oil Heaters under normal operating conditions at 100% capacity

Parameter	Concentration[1] (mg/Nm^3)	Emission rate[2] (g/s)	Total annual emissions[3] (t/yr)
Oxides of nitrogen (as NO_2)	118.14	0.47	59
Carbon monoxide	98.03	0.39	49
PM_{10} / $PM_{2.5}$	10.05	0.04	5
Total Hydrocarbons[4]	2.51	0.01	1

Table note:
[1]Concentration calculated from emission rate data
[2]Information obtained from APLNG
[3] Assumed capacity for all heaters operating for 8,760 hours per year, which is conservative

Table 15 Breakdown of emission rates of hydrocarbons from the Hot Oil Heaters

Pollutant	Molecular weight	Emission Factor (lb/MMBtu)	Stack Concentration (mg/Nm^3)	Emission Rate (g/s)
2-Methylnaphthalene	142.19	2.4E-05	5.5E-06	2.2E-08
3-Methylchloranthrene	268.35	1.8E-06	4.1E-07	1.6E-09
7,12-Dimethylbenz(a) anthracene	256.34	1.6E-05	3.7E-06	1.5E-08
Acenaphthene	154.20	1.8E-06	4.1E-07	1.6E-09
Acenaphthylene	152.18	1.8E-06	4.1E-07	1.6E-09
Anthracene	178.23	2.4E-06	5.5E-07	2.2E-09
Benz(a)anthracene	228.28	1.8E-06	4.1E-07	1.6E-09
Benzene	78.10	2.1E-03	4.8E-04	1.9E-06
Benzo(a)pyrene	252.31	1.2E-06	2.7E-07	1.1E-09
Benzo(b)fluoranthene	252.32	1.8E-06	4.1E-07	1.6E-09
Benzo(g,h,i)perylene	276.32	1.2E-06	2.7E-07	1.1E-09
Benzo(k)fluoranthene	252.30	1.8E-06	4.1E-07	1.6E-09
Butane	58.12	2.1E+00	4.8E-01	1.9E-03
Chrysene	228.00	1.8E-06	4.1E-07	1.6E-09
Dibenzo(a,h)anthracene	278.33	1.2E-06	2.7E-07	1.1E-09
Dichlorobenzene	147.01	1.2E-03	2.7E-04	1.1E-06
Ethane	30.07	3.1E+00	7.1E-01	2.8E-03
Fluoranthene	202.26	3.0E-06	6.9E-07	2.7E-09
Fluorene	166.22	2.8E-06	6.4E-07	2.5E-09
Formaldehyde	30.03	7.5E-02	1.7E-02	6.8E-05
Hexane	86.18	1.8E+00	4.1E-01	1.6E-03
Indeno(1,2,3-cd) pyrene	276.32	1.8E-06	4.1E-07	1.6E-09
Methane	16.00	2.3E+00	5.3E-01	2.1E-03
Naphthalene	128.17	6.1E-04	1.4E-04	5.5E-07
Pentane	72.15	2.6E+00	5.9E-01	2.4E-03
Phenanathrene	178.23	1.7E-05	3.9E-06	1.5E-08
Propane	44.10	1.6E+00	3.7E-01	1.5E-03
Pyrene	202.25	5.0E-06	1.1E-06	4.5E-09
Toluene	92.10	3.4E-03	7.8E-04	3.1E-06

Table note:
[1]Source: US EPA AP-42

5.3.4 Summary of total annual emissions

A summary of the possible total annual emissions from the APLNG facility operating normally is presented in

Table 16. The summary includes all units operating at 100% load for 8760 hours per year, which is very conservative. Emissions from the Acid Gas Regeneration Units, the Nitrogen Removal Units, the Flares or shipping have not been included as they do not operate continuously and therefore will not contribute significantly to the total annual emissions from the facility.

Table 16 Summary of total annual emissions from the APLNG facility (normal operations) in tonnes per year

Source	Number of units operating	Emission Rate (t/yr)			
		NO_X	CO	PM_{10}/ $PM_{2.5}$	THC[1]
Gas turbine compressor drivers	24	2,619	1,597	182	690
Power generation turbines	12[2]	617	761	34	216
Hot Oil Heaters	4	59	49	5	1
Total Annual Plant Emissions [3]	--	3,295	2,407	221	907

Table note:
[1] Total hydrocarbons (THC) presented as methane equivalents.
2 Modelling was based on 12 turbines operating, however Australia Pacific LNG are still finalising the turbine configuration including the potential use of 14 turbines based on manufacturers recommendation.
[3] Normal operation does not include emissions from the Acid Gas Regeneration Units, the Nitrogen Removal Units or the Flares

5.4 Non-routine Operations

5.4.1 Wet and Dry Gas Ground Flares and Marine Flare

The principle function of the process system flares is to dispose of excess gases safely by controlled combustion in the event of an upset or plant maintenance. The basis for flaring scenarios as provided by APLNG are summarised in Table 17.

Table 17 Basis for emissions from flaring

Wet gas flare	
Flare configuration	Ground flare
Source of gas	Plant feed gas
Upset rate	25% of design rate
Estimated emission duration (hr/yr)	24-48 for each train
Maintenance rate	Flare use not expected for maintenance
Estimated emission duration (hr/yr)	Zero hours
Dry gas flare	
Source of gas	Methane (fuel composition)

Wet gas flare	
Upset rate	25% of methane recycle rate
Estimated emission duration (hr/yr)	24-48 for each train
Maintenance rate	Maintenance – 10% of methane recycle rate
Estimated emission duration (hr/yr)	96 for each train
Marine flare	
Flare configuration – elevated Source of gas	LNG storage tank vapours LPG loading vapours
Maintenance rate	Based on tank heat leakage when liquefaction plant is down. Breakdown of LPG vapour compressors
Estimated emission duration (hr/yr)	With a plant availability factor of 95%, assume 768 hr/yr
Table note: Information provided by APLNG	

Gas flaring will be staged, and it is expected that a process blowdown will occur for a duration of approximately fifteen minutes to half normal pressure, with the flow rate and energy release diminishing with time.

The source characteristics and assumptions applied to the modelling of the Dry and Wet Gas Ground Flare System during an upset and blowdown are presented in Table 18 and Table 19.

Table 18 Source characteristics of the Dry and Wet Gas Ground Flare system

Parameter	Flare	Units	Value
Configuration			
Burners per row[1]		--	38
No. of rows[1]	Wet	--	8
	Dry	--	7
Total no. of burners[1]	Wet	--	304
	Dry	--	266
Flare inlet (feed gas)			
Mass flow rate of methane to ground flare system[2]	Wet	kg/hr	562,000
	Dry	kg/hr	1,028,000
Mass flow rate to flare per burner per hour[2]	Wet	g/s/burner	513.5
	Dry	g/s/burner	3,864.7
Mass flow rate to flare per burner per 15 minute blow down[2]	Wet	g/s/burner	128.4
	Dry	g/s/burner	966.2
Flare outlet (exhaust)			
Mass flow rate[2]	Wet & dry combined	kg/hr	30,200,000
Actual volume flow rate[2] (538 °C)	Wet & dry combined	m^3/hr	199,261,084

Parameter	Flare	Units	Value
Normalised volume flow rate[2] (0 °C, 1 Atm)	Wet & dry combined	Nm^3/hr	67,100,000

Table note:
[1] Information provided by ConocoPhillips from the Darwin LNG Plant Flare Design Study
[2] Information provided by APLNG

Table 19 Energy release and plume buoyancy characteristics of the Dry and Wet Gas Ground Flare system

Parameter	Units	Dry gas flare	Wet gas flare	Dry & Wet gas flares combined
Peak Energy out[1]	MMBTU/hr	43,600	24,500	68,100
Peak Energy out[2]	GJ/hr	46,000	25,849	71,849
Peak Energy out[2] (per 15 minute blow down)	GJ/15 min	11,500	6,462	17,962
Peak Energy out[2] (per 15 minute blow down)	GJ/s	12.78	7.18	19.96
Temperature[1]	°C	--	--	538
Area of ground flare[1] (84 m x 76 m)	m^2	--	--	6,384
Effective radius[2]	m	--	--	45.08
Effective rise velocity[2,3]	m/s	--	--	13.93

Table note:
[1] Information provided by APLNG
[2] Calculated by Katestone Environmental
[3] Parameter calculated for CALPUFF dispersion model inputs

For the assessment of flare emissions in relation to air quality impacts the worst-case emergency conditions for a simultaneous release from the Dry and Wet Gas flare has been assessed. This condition is an extremely conservative scenario as the Dry and Wet flare is not likely to operate simultaneously. Additionally, 100 per cent flare capacity was modelled for non-routine conditions when, in most conditions the flare will operate at approximately 20% capacity (this information is based on the ConocoPhillips experience at Darwin LNG).

Only limited information is available for flare emissions and consequently emission factors have been employed based on US EPA AP-42 documents (Chapter 13.5, Industrial Flares) in conjunction with information supplied by APLNG. The emission factors for industrial flares and the emission rates used in the assessment for each of the pollutants are presented in Table 20. The USEPA AP-42 emission factors for industrial flares also consider particulate emissions for a range of flare types. APLNG propose to use smokeless flares with a negligible particulate emission.

Table 20 Emission factors and emission rates for the Dry and Wet Gas Ground Flare system during upset conditions

Parameter	Oxides of nitrogen	Carbon monoxide	Total hydrocarbons

Parameter	Oxides of nitrogen	Carbon monoxide	Total hydrocarbons
Emission factor (g/GJ)	29.3[1]	159.1[1]	60.2[1]
Dry gas flare emission rate (g/s)	93.4[2]	508.2[2]	182.2[2]
Wet gas flare emission rate (g/s)	52.4[2]	285.6[2]	102.4[2]
Combined flares	145.8[2]	793.8[2]	284.6[2]

Table note:
[1] From AP-42 Emission Factors
[2] Calculated from data supplied by APLNG as an hourly average assuming duration of flaring event is 15 minutes

5.4.2 Marine flare during upset conditions

The Marine Flare will operate in the event of a process upset, such as the failure of a BOG compressor. During these conditions, gases are safely disposed of through controlled combustion. The source characteristics of the Marine Flare System during an upset event are presented in Table 21. This Marine Flare is likely to be used less frequently, and the energy release and consequent emission rate of air pollutants is approximately 2.3% of the Dry Gas Flare emissions. The Marine Flare may be a ground flare or a stack, however, as the emissions are significantly less than the Dry Gas Flare the Marine Flare has not been included in the modelling of the worst case upset conditions, the design of the Marine Flare is not significant.

Table 21 Source characteristics for the Marine Flare during non-routine Upset conditions

Parameter	Units	Upset conditions
Nominal stack height[1]	m	25
Nominal flare tip diameter[1]	m	0.711
Temperature[2]	°C	1000
Gas exit velocity (modelled)[2]	m/s	20
Effective stack height (modelled)[2]	m	46.9
Effective flare tip diameter (modelled)[2]	m	7.0
Energy output[1]	GJ/hr	1,680
Energy output	GJ/s	0.467

Table note:
[1] From information supplied by APLNG.
[2] From USEPA Screen 3 Method.

The US EPA AP-42 emission factors for industrial flares and the Marine Flare emission rates for each of the pollutants, NO_X, CO, and total hydrocarbons (in methane equivalents), are presented in Table 22.

Table 22 Emission factors and pollutant emission rates for the Marine Flare during upset conditions

Parameter	Oxides of nitrogen	Carbon monoxide	Total hydrocarbons
Emission factor (g/GJ)	29.24[1]	159.07[1]	60.19[1]

Parameter	Oxides of nitrogen	Carbon monoxide	Total hydrocarbons
Marine flare emission rate (g/s)	13.64	74.23	28.09
Table note: [1] From AP-42 Emission Factors			

5.5 Plant Start Up and Shutdown Conditions

5.5.1 LNG processing plant

During start up and shut down conditions gas-turbine and gas-fired heaters will have lower emissions rates than during normal operations. There are four start-up stages for a LNG facility. The total duration for a cold start-up is around 10 days. A hot start-up, it will take approximately 4 hours. The potential affect on air quality of start-up would be less than the normal operations.

5.6 Construction activities

Emissions generated during construction activities are likely to consist of engine exhausts from vehicles and diesel generators and from dust generated by earthworks and vehicle movements on sealed and unsealed roads. The composition of engine exhaust emissions is expected to be primarily NO_X and CO with small quantities of hydrocarbons.

Due to the relatively low emission rates of mobile vehicles in comparison to the gas turbines and heaters (during operations), the short duration and transient nature of these emissions during project construction in such an isolated area on Curtis Island, these emissions have not been considered in this assessment. It is not expected that gaseous emissions to air during the construction phase will exceed those from the normal conditions of the full-scale operating four-train LNG facility.

Control strategies to minimise the emission rate of air pollutants from construction activities such as the generation of dust from vehicle movements and earthworks will be addressed in the Environmental Management Plan. Emissions during decommissioning activities such as the generation of dust from vehicle movements and earthworks will be similar to the construction phase and will be addressed in the Decommissioning Phase Environmental Management Plan which will be developed closer to the time of decommissioning.

During commissioning of each train the Dry and Wet Gas Flares will be used. The emissions for the flares during commissioning will be less than the worst case modelled for the non-routine operation scenario, and therefore have not been assessed.

6. Air Quality Criteria

6.1 Queensland Environmental Protection Policies

The *Environmental Protection Act 1994* (EP Act) provides for the management of the air environment in Queensland. The legislation applies to government, industry and individuals and provides a mechanism for the delegation of responsibility to other government departments and local government and provides all government departments with a mechanism to incorporate environmental factors into decision-making.

The object of the EP Act is summarised as follows:

> *The object of the Environmental Protection Act 1994 is to protect Queensland's environment while allowing for development that improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends. (Section 3, EP Act)*

The EP Act gives the Minister the power to create Environmental Protection Policies that aim to protect the environmental values identified for Queensland. The initial Environmental Protection (Air) Policywas gazetted in 1997. Subsequently, this policy was reviewed and the Environmental Protection (Air) Policy 2008 (EPP Air) commenced on 1 January 2009. The objective of the Environmental Protection (Air) Policy 2008 is:

> *to identify the environmental values of the air environment to be enhanced or protected and to achieve the object of the Environmental Protection Act 1994, i.e., ecologically sustainable development.(EPP Air Explanatory Notes)*

The application and purpose of the EPP Air 2008 is summarised as follows:

> *The purpose of this policy is to achieve the object of the Act in relation to the air environment (EPP Air Part 2, Section 5).*
>
> *The purpose of this policy is achieved by -*

- identifying environmental values to be enhanced or protected; and
- stating indicators and air quality objectives for enhancing or protecting the environmental values; and
- providing a framework for making consistent, equitable and informed decisions about the air environment (EPP Air Part 2, Section 6).

> *The environmental values to be enhanced or protected under the EPP Air are –*

- the qualities of the air environment that are conducive to protecting the health and biodiversity of ecosystems; and
- the qualities of the air environment that are conducive to human health and wellbeing; and
- the qualities of the air environment that are conducive to protecting the aesthetics of the environment, including the appearance of buildings structures and other property; and
- the qualities of the air environment that are conducive to protecting agricultural use of the environment. (EPP Air, section 7)

The administering authority must consider the requirements of the EPP Air when it decides on an

application for an environmental authority, amendment of a licence or approval of a draft Environmental Management Plan. Schedule 1 of the EPP Air specifies air quality objectives for various averaging periods.

6.2 National Environment Protection Measure

The National Environment Protection Council defines national ambient air quality standards and goals in consultation, and with agreement from, all state governments. These were first published in 1998 in the National Environment Protection (Ambient Air Quality) Measure (NEPM(Air)). Compliance with the NEPM(Air) standards is assessed via ambient air quality monitoring undertaken at locations prescribed by the NEPM(Air) and that are representative of large urban populations. The goal of the NEPM(Air) is for the ambient air quality standards to be achieved at these monitoring stations within ten years of commencement; that is in 2008. The EPP Air 2008 has adopted the NEPM(Air) goals as air quality objectives.

6.3 Relevant Ambient Air Quality Objectives for the Project

Table 23 presents a summary of the relevant ambient air quality goals for criteria pollutants adopted for this assessment.

Table 23 Relevant ambient air quality objectives for criteria air pollutants (EPP Air 2008)

Indicator	Environmental value	Averaging period	Air quality objective[1] (µg/m³)	Number of days of exceedance allowed per year
Nitrogen dioxide	Health and wellbeing	1-hour	250	1
		1-year	62	N/A
	Health and biodiversity of ecosystems	1-year	33	N/A
Carbon monoxide	Health and wellbeing	8-hour	11,000	1
Particles as PM_{10}	Health and wellbeing	24-hour	50	5
Particles as $PM_{2.5}$	Health and wellbeing	24-hour	25	N/A
		1-year	8	N/A
Ozone	Health and wellbeing	1-hour	210	1
		4-hour	160	1

Table note:
[1] Air quality objective at 0°C
N/A: Not applicable

In addition to the air pollutants detailed above, the combustion of coal seam gas in the gas turbines, gas-fired heaters and flares is also likely to produce small quantities of hydrocarbons. The full list of hydrocarbons likely to be emitted are presented with their relevant air quality objective in Appendix A. Where an air quality objective for a particular pollutant is not published in the EPP Air, an appropriate objective from another jurisdiction has been adopted. These include:

- NSW Department of Environment and Climate Change (NSW DECC) Approved Methods for the Modelling and Assessment of Air Pollutants in NSW (2005)
- EPA Victoria (Vic SEPP) State Environment Protection Policy (Air Quality Management)
- World Health Organisation (WHO) Guidelines for Air Quality (Chapter 3) 2000a
- National Exposure Standards for Atmospheric Contaminants in the Occupational Environment (NOHSC:1003(1995))
- Texas Commission on Environmental Quality (TCEQ) Effects Screening Levels 2008

7. Existing Environment

The existing environment in the region surrounding the proposed LNG facility is discussed here in terms of the background air quality and the geographical and meteorological conditions that are likely to influence the dispersion of air pollutants.

7.1 Background to the Gladstone Region and Surrounding Land Uses

The coastal town of Gladstone is located approximately 525 km north of Brisbane in Central Queensland. It is situated in a sub-tropical region comprising of a flat coastal plain bordered by a range of mountains up to 600 metres in elevation, typically 5-10 kilometres from the coast but with a major off-shore island, Curtis Island, for the northern part. The infrastructure of the region includes a deep-water port, rail and road connections and the Gladstone State Development Area (GSDA).

The proposed site of the LNG facility is on the western side of Curtis Island, across the Narrows and to the north-northwest of Fisherman's Landing. The proposed LNG facility is bordered by water at its southwestern border only. The proposed site is a mixture of undeveloped rural land, native bush land and forest.

Figure 2 shows that the terrain in the region is relatively flat coastal plain, flood plain and mangrove with mildly undulating hills with the exception of Mt Larcom. Curtis Island is a low lying coastal island with a ridge running through its centre from northwest to southeast, which rises up to approximately 50 metres above sea level. Vegetation types on Curtis Island include heath, grassland, stunted paperbark woodland, open eucalyptus forest and dry rainforest. The relatively flat terrain and coastline location of the proposed site will influence the wind patterns. Dominant meteorological conditions will include sea and land breezes.

The nearest industries to the proposed LNG facility are Cement Australia and Queensland Energy Resources, which lie on either side of Landing Road at Fisherman's Landing and are adjacent to the wharf facilities. Further significant industries within the region include Rio Tinto Aluminium Yarwun Refinery, Orica and the Gladstone Power Station, Queensland Alumina Ltd and Boyne Smelters. The location of the major industry in Gladstone, including the other proposed LNG facilities, is also shown in Figure 2.

It is important to consider the proximity of project infrastructure to sensitive receptors and land uses in the region. The LNG facility will be situated approximately 6 km from the nearest single residence on islands in Port Curtis, 10 km from major residential areas in Gladstone City across Port Curtis to the southeast, and 10 km from the community at South End on Curtis Island to the east. The closest sensitive receptors are the accommodation camps identified for the other LNG facilities proposed for Curtis Island. The location of sensitive receptors indentified and included in the assessment are illustrated in Figure 2.

7.2 Climate

This section is an overview of the climate in the Gladstone region and is based on long term monitoring information. Meteorological monitoring data from the Bureau of Meteorology (BoM) stations at Gladstone Airport and Radar Hill have been used to characterise long-term wind speed and direction, temperature, atmospheric pressure, rainfall and relative humidity in the Gladstone region. The location of the Gladstone Airport and Radar Hill monitoring stations are illustrated in

Figure 3. The meteorological parameters that are measured at the Gladstone Airport and Radar Hill monitoring stations are summarised in Table 24. Gladstone Airport has been chosen as the most representative monitoring station for the Gladstone region as the monitoring period is for thirteen continuous years (1996 – 2009). The monitoring station at Radar Hill has been operating since 1957 and has been used for rainfall averages in this assessment.

Table 24 Summary of Bureau of Meteorology monitoring sites and parameters

Site	Easting AMG	Northing AMG	Record Period	Parameters
Gladstone Airport	318895	7359053	01/96 – 06/09	Half-hourly measurements converted to 1-hour averages for – - temperature - relative humidity - wind speed - wind direction - surface air pressure
Radar Hill	323092	7360700	12/57 – 06/09	Daily total rainfall

7.2.1 Wind Speed and Direction

Wind speed and direction are important parameters for the transport and dispersion of air pollutants. Gladstone's coastal proximity, large deep water harbour and elevated terrain around Mt Larcom provide a number of complexities in the flow of winds across the region.

The annual distribution of wind speed and direction at Gladstone Airport for the period 1 January 1996 to 30 June 2009 is presented as a wind rose diagram in Figure 4. The seasonal and diurnal distributions of wind speed and direction at Gladstone Airport for the same period are presented in Figure 5 and Figure 6.

The predominant annual wind direction at Gladstone are from the sector between the northeast and south-southeast with 62.0% of winds blowing from this direction. These winds tend to dominate the daytime flows and early evening winds, particularly during spring, summer and autumn months. During the cooler late autumn and winter months there is a more pronounced nocturnal (midnight to 6am) drainage flow, with winds blowing from the southern and western sectors between the south-southeast and the west for 50.1% of the time (autumn and winter only). Variations in seasonal wind patterns are largely influenced at a synoptic scale by the southeast trade winds.

Diurnal variations in wind flows across the Gladstone region are strongly influenced by sea breezes, resulting in a high percentage of easterly daytime winds. The sea breeze generally develops around 10-11am each day and is often preceded by a significant shift in wind direction from the more southerly and westerly night time drainage flows. The distribution of wind speeds at Gladstone Airport for the period January 1996 to June 2009 is summarised in Table 25. Wind speeds are summarised for all directions as well as the dominant easterly sea breeze (ENE, E and ESE). The analysis indicates that the sea breezes recorded in the region are predominantly greater than five metres per second. The daily and seasonal variability are further illustrated in the wind roses presented in Figure 5 and Figure 6.

Table 25 Summary of the distribution of wind speeds at Gladstone Airport for all directions and the dominant easterly sea breeze sector (January 1996 – June 2009)

Direction	Wind speed	Wind speed range (m/s)	Percent (%)
All	Calm to light	0 – 1.99	8.5
	Moderate	2.0 – 4.99	61.8
	Strong	> 5.00	29.6
Easterly sector	Calm to light	0 – 1.99	4.8
	Moderate	2.0 – 4.99	35.8
	Strong	> 5.00	59.4

Table note:
Easterly sector refers to the directional zone between the ENE and ESE

A discussion of the local wind characteristics relevant to the proposed LNG facility is presented in modelling methodology section of this report.

7.2.2 Temperature and Solar Radiation

The annual average maximum daily temperature recorded at Gladstone Airport for the period 1993 – 2009 is 27.2°C, with an average minimum temperature of 18.0°C. The warmest months are January and February, with average maximum daily temperatures of 30.7°C and 30.5°C, respectively and an average minimum daily temperature of 23.0°C. The coolest month is July with an average maximum daily temperature of 22.9°C and an average minimum daily temperature of 11.7°C.

The range of daily average maximum and minimum temperatures and the highest and lowest daily temperatures by season are presented in Table 26 for the period 1993 – 2009 (BoM, as accessed 22.09.09).

Table 26 Summary of the range in daily temperatures by season as observed at Gladstone Airport for the period 1993 – 2009 (in °C)

Season	Average daily temperature		Highest temperature	Lowest temperature
	Maximum	Minimum		
Summer	30.4	22.7	39.3	16.7
Autumn	27.8	18.7	41.0	4.9
Winter	23.3	12.5	30.8	3.5

Season	Average daily temperature		Highest temperature	Lowest temperature
	Maximum	Minimum		
Spring	27.3	18.3	36.7	7.2

Figure 7 presents the mean daily solar radiation (in MJ/m²) recorded at Gladstone Airport during the period 1990 to 2009. This figure illustrates the typical monthly pattern of solar radiation, with the annual solar radiation 1.8 times greater during the summer than the winter.

7.2.3 Rainfall

The minimum, average and maximum monthly rainfall over the 52-year period from December 1957 to August 2009 at the Radar Hill monitoring station is presented in Table 27 (BoM, accessed 23.09.09). The annual average rainfall at Radar Hill is 873.2 mm/year. The maximum annual rainfall was 1,732 mm in 1971.

Consistent with a sub-tropical climate, the summer months are wetter and the winter months are drier. On average, the months of December, January and February account for 47.7% of the annual rainfall while the months of June through September total only 15.0%.

Table 27 Minimum, average and maximum, monthly rainfall at the Radar Hill monitoring station for the period 1957 – 2009

Month	Minimum (mm)	Maximum (mm)	Average (mm)	Monthly rainfall distribution (%)
January	0.4	640.1	143.4	16.5
February	7.2	709.8	143.4	16.5
March	2.4	311.6	82.6	9.5
April	3.8	250.4	46.4	5.3
May	0.2	316.4	59.6	6.8
June	0	220.3	38.9	4.5
July	0	170.2	34.4	3.9
August	0	141.6	31.2	3.6
September	0	89.6	26.5	3.0
October	0.4	276.8	62.3	7.1
November	1.4	218.1	74.2	8.5
December	2.8	508.9	128.8	14.8

7.2.4 Relative Humidity

The monthly average relative humidity at 9am and 3pm at Gladstone Airport for the period from 1993 to 2009 is presented in Figure 8.

There is no significant variation in the monthly average relative humidity recorded at 9am. However, the monthly average relative humidity at 3pm indicates slightly drier afternoon conditions during the winter months.

7.2.5 Surface Pressure

The monthly average surface pressure at Gladstone Airport is presented in Figure 9. The biannual patterns of peaks and troughs in the monthly average pressure field indicate that the months of January and July are generally dominated by low pressure features that are typically associated with either wetter (summer) and/or colder (winter) conditions. The months of April and October are generally dominated by high pressure features that are typically associated with clear, drier and warmer conditions.

7.2.6 Frequency of Droughts, Thunderstorms, Lightning and Tropical Cyclones

The Bureau of Meteorology reports the following frequencies of thunder, lightning and cyclones in the Gladstone region:

- Fifteen days of thunderstorms per year (based on ten years of data from 1990 to 1999)
- Two ground strikes of lightning per square kilometre per year (based on approximately 8 years of data, 1995 – 2002)
- For 101 years from 1906 to 2006:
- 6 tropical cyclones within 50 kilometres of the Port of Gladstone
- 14 tropical cyclones within 100 kilometres of the Port of Gladstone

7.3 Existing Industries in the Gladstone Region

There are a number of industries currently operating within the Gladstone regional airshed including a 1,650 MW coal-fired power station, two large alumina refineries, an aluminium smelter, an ammonium nitrate facility, coal handling and port facilities and a cement manufacturing facility. Emissions from industry include NO_X, CO, PM_{10}, SO_2 and various hydrocarbons. Further sources of NO_X and SO_2 include vehicle traffic and shipping, while general sources of dust in the region include bushfires, landfills, trains, exposed areas of land, construction activities and traffic. A summary of the currently operating industries reporting to the National Pollutant Inventory (NPI) is presented in Table 28.

Table 28 Existing industries in the Gladstone region for the 2007 to 2008 NPI reporting period

Source	Oxides of nitrogen (t/yr)	Carbon monoxide (t/yr)	PM_{10} (t/yr)	Sulphur Dioxide (t/yr)
Alinta Asset Management (Gas-supply meter	-	-	-	-

Source	Oxides of nitrogen (t/yr)	Carbon monoxide (t/yr)	PM_{10} (t/yr)	Sulphur Dioxide (t/yr)
stations)				
Austicks Pty Ltd (Wood product manufacturing)	4.5	12	10	0.5
Boyne Smelters Ltd (Aluminium smelting)	123	65,660	204	11,792
Cement Australia Queensland Pty Ltd (Cement production)	27	16	239	0.02
Gladstone Ports Corporation Queensland (Port and water transport terminal operations)	508	128	822	221
NRG Gladstone Operating Services (Fossil fuel electricity generation)	45,287	1,152	520	34,378
Orica Australia Pty Ltd (Basic inorganic chemical manufacturing)	238	-	1.1	0.2
Queensland Alumina Ltd (Alumina production)	8,188	1,201	425	3,800
Queensland Rail (Railway rolling stock manufacturing and repair services)	17,413	14,144	329	131
Rio Tinto Aluminium Ltd (Alumina production)	746,727	75,667	114,811	748,914
UNIMIN Australia Ltd (Construction material mining)	70,600	32,970	108,400	5,740

Table 29 Summary of annual emissions from existing Gladstone industries and APLNG (t/yr)

	Oxides of nitrogen (t/yr)	Carbon monoxide (t/yr)	PM_{10} (t/yr)	Sulphur Dioxide (t/yr)
Existing Gladstone industries[1]	55,210	68,292	2,444	50,947
APLNG [2]	3,295	2,407	221	Negligible
APLNG as % of existing industries	6%	4%	9%	0%
Notes 1 Based on NPI reports for 2007-2008 period for existing industries only (no natural or anthropogenic emissions included) 2 Total plant emissions for normal operations of 4 trains. All sources assumed to operate at 100% capacity for 8760 hours per year				

7.4 Existing Air Quality

The Gladstone region is highly industrialised and consequently the DERM operates a network of ambient air quality monitoring stations in the city and surrounding areas. A summary of DERM monitoring stations, pollutants measured and the recording period is presented in Table 30.

Table 30 DERM ambient air quality monitoring sites for Gladstone

Site name and location	Record Period	Criteria Gases	Particulate matter	Metals	VOCs	Carbonyls	PAHs	Acid/Caustic Aerosols	Fluorides	Cyanides	Dioxins/Furans/PCBs	Radionuclides
Boat Creek	2008 to present	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Clinton	2001 to present	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
South Gladstone	2001 to present	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Targinie (Stupkins Ln)	2001 to 2008	Y	Y									
Targinie (Swanns Rd)	1997 to present	Y	Y	Y	Y	Y	Y				Y	Y
Boyne Island (Beacon Ave.)	2008 to present	Y	Y	Y	Y	Y	Y		Y	Y	Y	Y

7.5 Criteria Pollutants

7.6 Nitrogen Dioxide

The maximum 1-hour average and annual average concentrations of NO_2 for each year measured at both the Targinie Stupkins Lane and Swanns Road monitoring stations are presented in Table 31. The EPP Air quality objective of 250 µg/m^3 for the 1-hour average concentrations has not been exceeded at either of the Targinie monitoring stations for the years for which NO_2 data is available. Additionally, there were no exceedances of the EPP Air objective of 62 µg/m^3 for annual average concentrations of NO_2.

Table 31 Summary of annual measurements of nitrogen dioxide from the DERM Targinie monitoring sites

Year	Maximum 1-hour average		Annual average	
	Targinie (Stupkins Lane)	Targinie (Swanns Road)	Targinie (Stupkins Lane)	Targinie (Swanns Road)
1997	-	78.1	-	4.1
1998	-	90.4	-	6.2
1999	-	86.3	-	8.2
2000	-	78.1	-	6.2
2001	96.5	78.1	10.3	6.2
2002	98.6	80.1	16.4	6.2
2003	84.2	71.9	8.2	6.2
2004	90.4	61.6	8.2	6.2
2005	96.5	80.1	8.2	6.2
2006	-	84.2	-	8.2
2007	-	73.9	-	6.2
2008	-	65.7	-	6.4
2009 [1]	-	78.0	-	-

Table note:
EPP Air objective for 1-hour average: 250 µg/m³
EPP Air objective for annual average: 62 µg/m³
[1] Data period January – May 2009 inclusive

7.7 Carbon Monoxide

A monitoring station at Beacon Avenue, Boyne Island has been recording carbon monoxide levels since 1 October 2008. The monitoring data for the period October 2008 to May 2009 shows a maximum 1-hour average carbon monoxide concentration of 749 µg/m^3 and maximum 8-hour average concentration of 343 µg/m^3, these are well below the EPP Air objective of 11,000 µg/m^3.

7.8 Particulate Matter

Table 32 presents the maximum and the 70th percentile PM_{10} concentrations for a 24-hour average

from measurements at the Targinie Stupkins Lane monitoring station between 2001 and 2008. The years 2002 and 2005 were unusual with relatively high peak concentrations of PM_{10} recorded. The EPP Air objective for the 24-hour average concentrations of PM_{10} of 50 µg/m^3 was exceeded at the Stupkins Lane/Swans Road monitoring station on 26 occasions between 2001 and May 2009. The EPP Air objective was exceeded during the following periods:

- October – November 2001
- July, October and December 2002
- December 2004
- January – February 2005
- November 2006
- March and April 2008
- March and May 2009

The high events during 2002 were attributed to bushfires while those during 2005 were attributed to dust storms that occurred for 2-3 days over a significant portion of Queensland.

Table 32 Maximum and 70th percentile 24-hour average concentrations of PM_{10} (µg/m^3) measured at the Targinie Stupkins Lane (2001 – 2008) and Targinie Swans Road (2009) monitoring sites

Year	Maximum 24-hour average	70th percentile 24-hour average
2001 [2]	93	20.4
2002 [2]	204	24.0
2003 [2]	50	20.1
2004 [2]	50	20.1
2005 [2]	222	17.9
2006 [2]	79	16.6
2007 [2]	36	15.4
2008 [2]	62	16.1
2009 [3]	64	20.4
EPP Air quality objective	*50* [1]	--

Table note:
[1] Five days of exceedances allowed per year
[2] Data recorded at Targinie Stupkins Lane
[3] Data recorded at Targinie Swans Road, period January to May 2009 inclusive

There are no long-term measurements of $PM_{2.5}$ for the Gladstone region, therefore data from the DERM monitoring station at Springwood (Brisbane) has been used for the assessment of background air quality. Springwood is a semi-industrial and residential area and is therefore considered a conservative representation of $PM_{2.5}$ concentrations for the Gladstone airshed.

7.9 Air toxics

The Clean and Healthy Air for Gladstone Project is a Queensland Government initiative, established to gain a better understanding of air pollution in the Gladstone area, and to identify any potential risks to public health. The monitoring program established as part of the program covered a wide range of air pollutants. The Queensland Government published an interim human health risk assessment report for the Gladstone Project area in 2009 (Queensland Health, 2009). The report presents monitoring results for several air toxic species in the Gladstone region and reports that the maximum concentrations of these species were low or very low.

8. Atmospheric Dispersion Modelling Methodology

Air dispersion modelling was conducted using a two-stage approach. Firstly, the CSIRO's meteorological model, TAPM (The Air Pollution Model) Version 3.0.7 (Hurley 2005), was used to simulate the regional meteorology in the Gladstone region. Further refinement of the wind field was then made through the CALMET Version 6.3 meteorological pre-processor. Secondly, the CALPUFF plume dispersion model was used to predict ground-level concentrations of air pollutants emitted from the LNG facility.

8.1 Development of Site-Specific Meteorology

The development of the regional-scale GAMSv3 and local-scale APLNG meteorological models adopted an identical methodology. Prognostic simulations from TAPM were input to the CALMET model at a resolution of one kilometre for the GAMSv3 model, while the same TAPM outputs were input to CALMET at a resolution of 300 m for the APLNG model. As the fine resolution APLNG model domain fits within the GAMSv3 domain, this allowed for the addition of the APLNG model domain within a sector of the broader GAMSv3 domain, to provide a better understanding of the dispersion of air pollutants from the APLNG facility and to make provision for cumulative effects of existing and future developments.

The following sections detail the setup and configuration of the APLNG model. An evaluation of the GAMSv3 is provided in Appendix B, with a summary of the correlation statistics used in the evaluation presented in Appendix C.

8.1.1 TAPM Meteorological Simulations

TAPM was developed by the CSIRO and has been validated by the CSIRO, Katestone Environmental and others for many locations in Australia, Southeast Asia and in North America (see www.dar.csiro.au/TAPM/ for more details on the model and validation results from the CSIRO). Katestone Environmental has used the TAPM model throughout Australia as well as in parts of New Caledonia, the United States of America, Bangladesh and Vietnam. This model generally has performed well for simulating winds in a region.

TAPM required synoptic meteorological information for the Gladstone region. This information was generated by a global model similar to the large-scale models used to forecast the weather. The data are supplied by the BoM on a grid resolution of approximately 75 km, and at elevations of 100 m to five kilometres above the ground. TAPM uses this synoptic information, along with specific details of the location such as surrounding terrain, land-use, soil moisture content and soil type to simulate the meteorology of a region as well as at a specific location.

TAPM solves the fundamental fluid dynamics equations to predict meteorology at a mesoscale (20 kilometre to 200 kilometre) and at a local scale (down to a few hundred metres). TAPM includes parameterisations for cloud/rain micro-physical processes, urban/vegetation canopy and soil, and radiative fluxes. TAPM is skilled at simulating the flows important to regional and local scale meteorology, such as the southeast trade winds and sea breezes.

TAPM was configured as follows:

- Mother domain of 30 km with 3 nested daughter grids of 10 km, 3 km and 1 km
- 40 x 40 grid points for all modelling domains resulting in a 40 x 40 km grid at 1 kilometre

resolution

- 25 vertical levels, from the surface up to an altitude of 8000 metres above ground level
- Geosciences Australia 9 second DEM terrain data
- The TAPM defaults for sea surface temperature
- Default options selected for advanced meteorological inputs
- Year modelled: 1 April 2006 to 31 March 2007
- Landuse and coastline data was refined based on high resolution images sourced from Google Earth and vegetation maps obtained from the DERM
- Local data assimilation using observations from three regionally representative sites

The land use for the inner grid required significant modification due to the coarseness of the TAPM dataset. Representative data was derived from vegetation maps obtained from DERM and from aerial imaging by Google Earth. The coastline was also re-defined in the database to better represent the complex coastline around Curtis Island. Detailed 9-second arc DEM elevation data (resolution approximately 100 metre) was obtained from Geosciences Australia for this modelling domain.

TAPM was used as the prognostic mesoscale meteorological model to provide three-dimensional hourly meteorological fields to CALMET, a diagnostic meteorological model and wind field pre-processor for the CALPUFF air dispersion model. The CALMET modelling grid was positioned within the TAPM simulation, effectively becoming a fifth nested grid. The three-dimensional meteorological fields generated by TAPM were then input into CALMET model to generate a fine resolution meteorological field.

8.1.2 CALMET Meteorological Simulations

CALMET is an advanced non-steady-state diagnostic three-dimensional meteorological model with micro-meteorological modules for overwater and overland boundary layers. The model is the meteorological pre-processor for the CALPUFF dispersion model. CALMET is capable of assimilating hourly meteorological data from multiple sites within the modelling domain, and can also be initialised with the gridded three-dimensional prognostic output from other meteorological models such as TAPM. This can improve dispersion model output, particularly over complex terrain as the near surface meteorological conditions are calculated for each grid point.

CALMET v6.3 was used to simulate meteorological conditions around Curtis Island. The modelling domain was setup to be nested within the one kilometre TAPM domain. CALMET treats the prognostic model output as the initial guess field for the diagnostic model wind fields. CALMET then adjusts the initial guess field for the kinematic effects of terrain, slope flows, blocking effects and 3-dimensional divergence minimisation. The coupled approach unites the mesoscale prognostic capabilities of TAPM with the refined terrain and land use capabilities of CALMET.

The use of the three-dimensional wind field provides a complete set of meteorological variables for every grid point and vertical level for each hour of the simulation period. This is a significant improvement in modelling approach to the method of data assimilation from discrete surface stations. No data assimilation was used in CALMET as no local data were available for the Curtis Island site. Regionally representative sites were, however, assimilated into TAPM.

The model was set up with twelve vertical levels with heights at 20 m, 60 m, 100 m, 180 m, 260 m, 360 m, 460 m, 600 m, 800 m, 1600 m, 2600 m and 4600 m at each grid point. The terrain and land

use were further refined from those used in the TAPM model to account for the increased resolution. The terrain was generated from the Geosciences Australia 9-second arc DEM dataset at a resolution of 300 m. All default options and factors were selected except where noted below.

Key features of CALMET used to generate the wind fields for the APLNG model are as follows:

- Domain area of 22.8 by 22.8 km with 300 m grid spacing
- 1 year time scale (1 April 2006 to 31 March 2007), divided into individual months for analysis
- Prognostic wind fields input as MM5/3D.Dat "initial guess" field only (as generated from TAPM)
- Step 1 wind field options include kinematic effects, divergence minimisation, Froude adjustment to a critical Froude number of 1 and slope flows
- Terrain radius of influence set at 2 kilometre
- Cloud cover calculated from prognostic relative humidity

8.2 Analysis of Dispersion Meteorology

8.2.1 Wind Speed and Direction

Curtis Island is a low lying barrier island located to the northeast of Gladstone, approximately five kilometres offshore. Coastal meteorology is dominant, which means the synoptic and mesoscale weather patterns have a significant impact on the area's meteorology. The winds on the eastern coast of the island can be expected to be significantly stronger than the more sheltered western coast. The island is bisected in a north-south direction by a small ridge that can generate light drainage winds at night under stable conditions; as such the model resolution was refined to incorporate these terrain features as they can have an important influence on the dispersion of air pollutants.

The annual distribution of winds at the APLNG site is presented as a wind rose in Figure 10. The wind rose indicates that the annual variability in the wind direction is dominated by winds from the east to southly sector. These winds account for 65% of the annual wind field, with maximum sustained winds of approximately 8 m/s. The second most dominant sector is from the north to northeast. Winds are infrequent from the southwest to northerly sector. The average wind speed for the site is 3.7 m/s, which is relatively high and typical of a costal location.

The seasonal distribution of winds is presented as a wind rose in Figure 11. Curtis Island is heavily influenced by monsoonal winds and precipitation patterns. The dry season (autumn to winter) is characterised by the southeast trade winds, while during the wet season (spring to summer), the trade winds continue with a distinctly north-easterly component along with intermittent and extended periods of light north-westerly flow.

The diurnal distribution of winds is presented as a wind rose in Figure 12. The diurnal wind pattern is dominated by the southeast trade winds, which usually begin to intensify by 9 am as a south-easterly flow and gradually rotate counter clockwise to a north-easterly flow by the mid afternoon. Embedded within this synoptic pattern is a sea breeze initiated by solar heating of inland regions. Night time flows predominantly consist of very light westerly drainage flows from the surrounding terrain.

8.2.2 Atmospheric Stability and Mixing Height

Stability is a term applied to the properties of the atmosphere that govern the acceleration of the vertical motion of an air parcel. The acceleration is positive in unstable atmosphere (turbulence increases), zero when the atmosphere is neutral and negative (deceleration) when the atmosphere is stable (turbulence is suppressed). There are six main atmospheric stabilities designated as A (highly unstable or convective), B (moderately unstable), C (slightly unstable), D (neutral), E (slightly stable) and F (stable). This is known as the Pasquill-Gifford stability classification and is widely used in atmospheric models to define the turbulent state of the atmosphere.

Unstable conditions (Class A-C) are characterised by strong solar heating of the ground that induces turbulent mixing in the atmosphere close to the ground, and usually results in material from a plume reaching the ground closer to the source than for neutral conditions or stable conditions. This turbulent mixing is the main driver of dispersion during unstable conditions. Dispersion processes for neutral conditions (Class D) are dominated by mechanical turbulence generated as the wind passes over irregularities in the local surface, such as terrain features and building structures. During night time, the atmospheric conditions are neutral or stable (Class D, E and F). During stable conditions the plume released from the stack will be subject to minimal atmospheric turbulence. A plume released below an inversion layer during stable conditions that has insufficient vertical momentum or thermal buoyancy to penetrate the inversion will be trapped beneath it and result in elevated ground-level concentrations. Conversely, a plume that is hotter than its surroundings and emitted above, or is able to penetrate the night time inversion through momentum, will remain relatively undiluted, and will not reach the ground unless it encounters elevated terrain.

Atmospheric stability class has been calculated using the USEPA approved Solar Radiation/Delta-T (SRDT) method (EPA, 2000). This method utilises the TAPM modelled wind speeds and solar radiation (W/m^2) to determine daytime stability, while nocturnal stability is determined by wind speeds and the vertical temperature gradient between the surface and the next vertical sigma level at the site location. This approach has been found to provide a more robust and verifiable classification scheme than the one produced internally in TAPM.

Table 33 shows the percentage distribution of stability classes for Curtis Island. There is a high percentage of D class stability (55%), indicative of coastal sites. This is due to the high heat capacity of water dampening the development of a strong convective boundary layer. The water has a similar effect at night, where the warmth of the water prevents the development of any strong temperature inversions.

Table 33 Percentage frequency distribution for atmospheric stability under the Pasquill-Gifford stability classification scheme for the Project area

Pasquill-Gifford Stability Class	Frequency (%)
A - Extremely unstable	1.8
B - Unstable	12.2
C - Slightly unstable	18.2
D - Neutral	54.9
E - Slightly stable	5.2
F - Stable	7.8

All stack emission points at the APLNG facility are relatively tall and hot with a high vertical velocity, giving the plume enough thermal and mechanical buoyancy at the release point to generate sufficient momentum for the plume to penetrate any low night time inversions, resulting in good plume dispersion conditions. These source characteristics also reduce the potential for building wake turbulence to affect plume dispersion.

The mixing height refers to the height above ground within which the plume can mix with ambient air. During stable atmospheric conditions at night, the mixing height is often quite low. During the day, solar radiation heats the air at ground level and causes the mixing height to rise through the growth of convection cells. The air above the mixing height during the day is generally colder. The growth of the mixing height is dependent on how well the air can mix with the cooler upper levels of air and therefore depends on meteorological factors such as the intensity of solar radiation and wind speed. During strong wind speed conditions the air will be well mixed, resulting in a high mixing height.

Mixing height information for Curtis Island has been extracted from CALMET for the modelling period, and is presented in Figure 13. The figure shows that the mixing height tends to develop around 6-7 am, peaks around 1-2 pm before decreasing gradually around sunset (5-6 pm).

8.3 CALPUFF Dispersion Modelling Methodology

Atmospheric dispersion modelling was carried out using the CALPUFF Version 6.113 dispersion model. CALPUFF is a non-steady-state puff dispersion model, and is accepted for use by the DERM for application in environments where wind patterns and plume dispersion is strongly influenced by complex terrain and the land-sea interface. The Gladstone region consists of highly complex meteorology, and includes complex terrain, highly variable land uses and a land-sea interface and coastal islands. The CALPUFF dispersion model was used to predict ground-level concentrations of air contaminants downwind of this source. The same grid size and resolution developed for the fine resolution CALMET model was used for the dimensions of the CALPUFF domain.

8.4 Assessment of Cumulative Impacts

For the assessment of impacts to air quality associated with NO_X emissions, a two-level approach was adopted to predict the cumulative effect of emissions from the LNG facility and existing, approved and other potential industrial developments in the Gladstone region. This assessment utilised the Gladstone Airshed Modelling System Version 3 (GAMSv3), a regional airshed dispersion modelling tool developed by Katestone Environmental for the Department of Infrastructure and Planning for use in planning studies. GAMv3 was used to predict background levels of NO_X. A fine resolution micro-scale dispersion model was used to predict ground-level concentrations due to the LNG facility.

The industrial plants included in GAMSv3 are:

- Gladstone Power Station
- Queensland Alumina refinery
- Boyne Smelters
- Rio Tinto Yarwun refinery Stage 1
- Rio Tinto Yarwun refinery Stage 2 (approved but not built)
- Cement Australia Yarwun plant
- Orica Yarwun facility

- Queensland Energy Resources (approved but not built)
- Queensland Pacific Nickel (approved but no built)

Background concentrations of CO and PM_{10} were based on DERM monitoring data in the region. Background concentrations for $PM_{2.5}$ were based on DERM monitoring data from Springwood. No background concentrations were assumed for the assessment of hydrocarbons in accordance with conventional practice.

Table 34 Summary of background concentrations used in the assessment

Pollutant	Background (µg/m³)	Source
Nitrogen dioxide	Modelled	GAMSv3
Carbon monoxide	124.9	95th percentile from measurements [1]
PM_{10}	24	70th percentile from measurements [2]
$PM_{2.5}$	7.3 – 24 hour average 6.6 – Annual average	70th percentile from measurements [3] Maximum annual average from measurements [4]
Hydrocarbons	No background included	-

Table note:
[1] Boyne data set 1October 2008 to 31 May 2009 8 hour average data
[2] Targinie Stupkins Lane Data set 1 Jan 2001 to 1 June 2008, Maximum annual 70th percentile from 24 hour average data
[3] Springwood data set 1 Jan 2003 - May 2009, Maximum annual 70th percentile from 24 hour average data
[4] Springwood data set 1 Jan 2003 - May 2009, Maximum annual average

There are as many as five other LNG production projects currently proposed for the Gladstone region, including:

- Queensland Curtis LNG (QCLNG) at Curtis Island
- Gladstone LNG (Santos) at Curtis Island
- LNG Limited (LNG Ltd) at Fishermans Landing
- SUN LNG at Fishermans Landing
- Shell LNG at Curtis Island

Information is currently available for the QCLNG, Santos and LNG Ltd proposals through the publication of the Project EISs. The Shell LNG facility has released an initial advice statement, but has yet to release an EIS. The cumulative effects of the projects which have released a public EIS has been determined by incorporating NO_X emissions into GAMSv3. For the SUN LNG project the EIS has not been made publicly available, and consequently, gas turbine and heater emission characteristics similar to the other LNG plants have been incorporated into the model and the assessment made based on NO_X emission rates pro-rated from the proposed LNG facility capacity.

This approach provides for the prediction of the cumulative 1-hour and annual average ground-level

concentrations of NO_2 across the Gladstone region for the LNG facility, existing and approved industries and other proposed LNG facilities.

8.5 Method for the Conversion of Oxides of Nitrogen to Nitrogen Dioxide

The prediction of ground-level concentrations of NO_2 has been conducted by modelling the total emission rate in grams per second for NO_X from each source, with the results scaled by an empirical nitric oxide/nitrogen dioxide conversion ratio. Measurements around power stations in Central Queensland show that under worst case conditions a conversion ratio of 25 - 40% of nitric oxide to nitrogen dioxide occurs within the first ten kilometres of plume travel. During days with elevated background levels of hydrocarbons (generally originating from bush-fires, hazard reduction burning or other similar activities), the resulting conversion is usually below 50% in the first thirty kilometres of plume travel (Bofinger *et al*., 1986). For this assessment a conservative ratio of 30% conversion of the NO_X to NO_2 has been applied.

8.6 Method for the Calculation of Photochemical Smog Generation

Photochemical smog is not directly released as a primary pollutant from the engines, heaters and power generators, rather it is generated through photochemical oxidation of nitrogen dioxide and nitrates in the atmosphere. The exhausts of combustion plant contain approximately 90-95% of oxides of nitrogen as nitric oxide (NO). Once this NO has been transformed into nitrogen dioxide and nitrates, photochemical smog (as evidenced by the presence of ozone) may be produced via a multi-stage process. The rate at which photochemical smog is generated is a function of:

- The in-plume concentration of oxides of nitrogen
- The concentration and reactivity of volatile organic compounds (VOC) in the ambient air
- The rate of plume dispersion
- The prevailing atmospheric conditions, including temperature and solar radiation fluxes

The transformation of NO_X and possible formation of ozone involves a number of chemical reactions. Generally, during the first phase of chemical transformations, the mixing of the exhaust plume with ambient air results in a local reduction of ambient ozone, through titration of the emitted nitric oxide as it reacts with ozone to form nitrogen dioxide. The second phase (ozone generation) will commence only if the ambient air is sufficiently photochemically aged (i.e. reactions have reached an equilibrium where no more nitrogen dioxide is produced). This phase continues with ozone being both generated and diluted in the plume. The generation continues until the final phase, the NO_X-limited state, is reached in the plume. The duration of each phase will depend on the nature of the ambient air, the emission rates and characteristics of the industrial source, and the dispersion rates.

Ozone levels near the surface have a pronounced diurnal variation, with levels of 1-5 parts per billion (ppb) (2-10 $\mu g/m^3$) overnight rising relatively quickly in the early to mid-morning and reaching a maximum of 25-35 ppb in the early afternoon. The origins of ozone in a non-urban area are the downward diffusion of stratospheric ozone and the interaction between naturally occurring hydrocarbons and NO_X. For urban areas, the maximum values can often be enhanced to 35-50 ppb by the presence of anthropogenic emissions of VOC, NO_X and water vapour.

Within Queensland, there are relatively few studies of ozone generation within industrial plumes. Monitoring networks around the Tarong, Callide and Gladstone Power Stations have tended to focus on those areas closer than 10-15 kilometres of the main sources, areas that are unlikely to experience the highest degree of ozone generation. There have not been any readily identifiable episodes of ozone generation during those times when the industrial plumes have been present at the monitoring locations.

The first investigation of the chemical transformations in industrial plumes was undertaken in 1986 around Gladstone Power Station, a major emitter of NO_X (over 2000 g/s at full load, significantly more than the total emission rate for the entire proposed LNG facility). An aerial survey was conducted to measure NO_X and ozone concentrations at distances out to 200 kilometres for a set of late winter conditions. These studies have been very useful and show the relatively slow rate of transformation of emitted nitric oxide into NO_2. However, there were no events when an ozone generation stage was encountered.

Due to the proportionally low emissions of NO_X from the LNG facility in comparison to the background emissions from the power station and other industrial sources in Gladstone, photochemical modelling has not been conducted for this assessment. In order to assess the potential of the LNG facility to generate ozone, an extremely conservative method has been applied. The assessment has assumed that 100% of the ground-level concentration of NO_2 at the nearest sensitive receptor for the 1-hour average is converted to ozone. This concentration has then been added to the maximum 1-hour average ozone concentration recorded at the Targinie monitoring station and compared to the air quality objective. This is an extremely conservative estimate as ozone is a secondary air pollutant that transforms by several photochemically catalysed reactions of NO_X and other VOCs over time during plume transport, with concentrations peaking at a distance of approximately 10 - 15 km downwind of the source.

8.7 Odour

LNG facilities are not normally regarded as odour generating activities. Mercaptans, the scent normally associated with gas, is an additive and is not a component of LNG. Natural gas is a colourless and odourless gas; similarly LNG is also an odourless and colourless gas. No mercaptans are added into the gas.

The primary gaseous air pollutants emitted during the process are NO_X and CO, with trace quantities of H_2S and hydrocarbons. The assessment of the effect of the LNG facility on odour has been conducted based on the odour thresholds and predicted ambient concentrations of odorous compounds. The assessment was based on the primary air pollutant emitted from the LNG facility identified as being odorous and with a predicted maximum ground-level concentration at the most affected sensitive receptor of greater than one percent of their air quality objective. No assessment of the potential synergistic effects of gaseous mixtures has been made.

For hydrocarbons, not all species identified in the air emissions are considered odorous. Air quality objectives are normally the stricter of the threshold for odour or health effects. Hence, where the concentration of a compound is less than 1% of its objective it would have a negligible contribution to odour.

8.8 Air Quality Impact Assessment Scenarios

For each of the scenarios, it was assumed that the facility will operate 24 hours a day, for all days of the year. While this is a reasonable assumption under normal conditions this is likely to overestimate

the effect of non-routine and upset conditions, particularly when the flare is operating. Two operating scenarios were investigated as summarised in Table 35.

Table 35 Air quality impact assessment scenarios modelled

Scenario number	Scenario	Operations	Operations modelled	Sources
1	APLNG normal plant operations	Continuous	Continuous	4 trains operating consisting of Compressors, Hot Oil Heaters and Gas Turbines
2	APLNG non-routine	Intermittent	Continuous	2 trains operating plus Flare

For NO_2 contour plots have been presented for the plant in isolation for each scenario for 1- hour and annual averages. Contours are also presented with the inclusion of GAMSv3 background and with GAMSv3 plus other LNG facilities proposed in the region. These results are also presented in tabular form at the sensitive receptors.

The assessment of particulate matter and CO has been done for the plant in isolation and with the inclusion of a background based on monitoring data. Contour plots are presented for cumulative impacts only. Results have also been tabulated to present the predicted concentrations at sensitive receptors.

Assessment of hydrocarbons and odour has been made at the most impacted sensitive receptor and presented as maximum concentrations for the LNG plant in isolation.

Assessment of the potential contribution of the facility to regional photochemcial smog has been made as maximum concentrations for the LNG plant in isolation.

As assessment of shipping emissions has been made in conjunction with normal operations of the plant and presented as predicted incremental concentrations at the most sensitive receptor locations.

9. Results of Air Quality Impact Assessment

This section presents the results of the air quality impact assessment for NO_2, PM_{10}, $PM_{2.5}$, CO, ozone, odour and all identified hydrocarbons for the normal and non-routine operating conditions.

9.1 Normal Operations – Scenario 1

9.1.1 Nitrogen Dioxide

The assessment of the maximum 1-hour average ground-level concentrations of NO_2 has been made for the 99.9th percentile value.

Table 36 presents the predicted maximum 1-hour and annual average ground-level concentrations at sensitive receptors in isolation, including existing and approved industries (GAMSv3), and the other proposed LNG facilities in the Gladstone region (as showing in Figure 2).

The table indicates that the predicted maximum short term and long term concentrations of NO_2 are low and well below the air quality objectives. The concentrations within the region are dominated by existing sources with only a minor contribution due to the addition of the APLNG facility (no change within significant figures presented in the table).

Figure 14 and Figure 17 present the predicted maximum 1-hour and annual average ground-level concentrations of NO_2, respectively, for the LNG facility during normal operations operating in isolation.

Figure 15 and Figure 18 present the predicted maximum 1-hour and annual average ground-level concentrations of NO_2, respectively, for the LNG facility during normal operations operating including existing and approved industries (GAMSv3).

Figure 16 and Figure 19 present the predicted maximum 1-hour and annual average ground-level concentrations of NO_2, respectively, for the LNG facility during normal operations and including existing and approved industries (GAMSv3) and the other proposed LNG facilities in the Gladstone region.

The plots show that the maximum short-term concentrations due to the plant are predicted to occur on site and on elevated terrain to the north and at Mount Larcom. The highest annual average concentrations are predicted to occur to the northwest of the site due to the dominance of winds from the southeast.

Table 36 Predicted maximum 1-hour and annual average ground-level concentrations of nitrogen dioxide for the LNG facility in isolation, existing and approved industries (GAMSv3), and LNG facility with existing and approved industries (GAMSv3) and other proposed LNG plants (in µg/m^3)

Location	APLNG facility in isolation	Existing and approved industries (GAMSv3) and proposed LNG plants	APLNG facility with existing and approved industries (GAMSv3) and proposed LNG plants

	1-hour average	Annual average	1-hour average	Annual average	1-hour average	Annual average
R1	6.7	0.16	44	3.0	44	3.0
R2	6.1	0.09	45	3.3	45	3.3
R3	4.8	0.07	52	3.4	52	3.4
R4	5.2	0.06	66	4.3	66	4.3
R5	7.1	0.07	79	5.3	79	5.3
R6	5.0	0.06	85	5.8	85	5.8
R7	7.6	0.07	81	5.9	81	5.9
R8	3.3	0.04	67	4.5	67	4.5
R9	3.0	0.03	63	3.0	63	3.0
R10	4.6	0.05	53	1.3	53	1.3
R11	5.0	0.05	54	1.2	54	1.2
R12	3.6	0.02	36	0.6	36	0.6
R13	3.3	0.02	38	0.6	38	0.6
R14	2.8	0.02	17	0.5	17	0.5
R15	2.7	0.02	23	0.5	23	0.5
R16	2.8	0.02	27	0.4	27	0.4
R17	2.9	0.01	22	0.4	22	0.4
R18	2.7	0.01	20	0.4	20	0.4
R19	2.4	0.01	18	0.3	18	0.3
R20	10.0	0.11	45	1.3	45	1.3
R21	12.5	0.11	41	2.0	41	2.0
Air quality objective	250	62[1] /33[2]	250	62[1] /33[2]	250	62[1] /33[2]

Table notes:
[1] Objective for health and wellbeing
[2] Objective for health and biodiversity of ecosystems

9.1.2 Carbon Monoxide

The assessment of the maximum 8-hour average ground-level concentrations of CO has been made for the 100th percentile value. Table 37 presents the predicted maximum 8-hour average ground-level concentrations of CO at any sensitive place, in isolation and including background. A contour plot is presented in Figure 20 for the predicted maximum 8-hour average ground-level concentrations of CO for the LNG facility during normal operations and including background.

The modelling results indicate that the ground-level concentrations due to the emissions from the LNG Plant are low and well below the air quality objectives. The cumulative impacts are dominated by the background level of CO due to other sources of CO in the region. The combined concentrations are only a few percent of the air quality objective.

The contour plot indicates maximum concentrations are predicted to occur on site and on elevated

terrain to the north of the site.

Table 37 Predicted maximum 8-hour average ground-level concentrations of carbon monoxide for the APLNG facility in isolation and with the existing background combined (in µg/m³)

Location	APLNG facility in isolation	APLNG facility with background
R1	9.3	134
R2	8.8	134
R3	6.3	131
R4	5.4	130
R5	6.1	131
R6	6.5	131
R7	11.6	137
R8	4.7	130
R9	4.9	130
R10	9.9	135
R11	9.3	134
R12	7.0	132
R13	6.6	131
R14	5.1	130
R15	4.8	130
R16	6.2	131
R17	4.1	129
R18	3.6	129
R19	3.3	128
R20	21.1	146
R21	33.4	158
Air quality objective	11,000	

9.1.3 PM10 and PM2.5

The assessment of ground-level concentrations of PM_{10} and $PM_{2.5}$ have been made for the 100th percentile value. Tabulated results for PM_{10} and $PM_{2.5}$ at the sensitive receptors are presented in Table 38 and Table 39, respectively.

The modelling results indicate that the ground-level concentrations of PM_{10} and $PM_{2.5}$ due to the emissions from the LNG facility in isolation are low and well below the air quality objectives. The cumulative concentrations are dominated by the background level due to other sources in the region including natural and industrial sources. The combined effect of the plant and background sources is also below the ambient air quality objectives for PM_{10} and $PM_{2.5}$.

The contour plot indicates maximum 24 hour average concentrations are predicted to occur close to the site and on elevated terrain to the north of the site. The highest annual average concentrations of $PM_{2.5}$ are predicted to the northwest of the site due to the predominant wind direction.

Figure 21 and Figure 22 present the predicted maximum 24-hour average ground-level concentrations of PM_{10} and $PM_{2.5}$, respectively for the LNG facility during normal operations and including background. Annual average concentrations of $PM_{2.5}$ for the LNG facility during normal operations and including background are presented in Figure 23.

Table 38 Predicted maximum 24-hour average ground-level concentrations of PM_{10} for the APLNG facility in isolation and with the existing background combined (in µg/m^3)

Location	APLNG facility in isolation	APLNG facility with background
R1	0.37	24
R2	0.35	24
R3	0.35	24
R4	0.27	24
R5	0.32	24
R6	0.29	24
R7	0.48	24
R8	0.22	24
R9	0.19	24
R10	0.31	24
R11	0.30	24
R12	0.24	24
R13	0.22	24
R14	0.16	24
R15	0.15	24
R16	0.20	24
R17	0.17	24
R18	0.14	24
R19	0.11	24
R20	0.69	25
R21	0.86	25
Air quality objective	50	

Table 39 Predicted maximum 24-hour and annual average ground-level concentrations of $PM_{2.5}$ for the APLNG facility in isolation and with the existing background combined (in µg/m^3)

Location	APLNG facility in isolation		APLNG facility with background	
	24-hour	Annual	24-hour	Annual

Location	APLNG facility in isolation		APLNG facility with background	
	24-hour	Annual	24-hour	Annual
R1	0.37	0.04	7.67	6.64
R2	0.35	0.02	7.65	6.62
R3	0.35	0.02	7.65	6.62
R4	0.27	0.01	7.57	6.61
R5	0.32	0.01	7.62	6.61
R6	0.29	0.01	7.59	6.61
R7	0.48	0.01	7.78	6.61
R8	0.22	0.01	7.52	6.61
R9	0.19	0.01	7.49	6.61
R10	0.31	0.01	7.61	6.61
R11	0.30	0.01	7.60	6.61
R12	0.24	0.01	7.54	6.61
R13	0.22	0.01	7.52	6.61
R14	0.16	0.00	7.46	6.60
R15	0.15	0.00	7.45	6.60
R16	0.20	0.00	7.50	6.60
R17	0.17	0.00	7.47	6.60
R18	0.14	0.00	7.44	6.60
R19	0.11	0.00	7.41	6.60
R20	0.69	0.02	7.99	6.62
R21	0.86	0.02	8.16	6.62
Air Quality Objective	25	8	25	8

9.1.4 Hydrocarbons

Table 40 presents a summary of the predicted maximum ground-level concentrations of various hydrocarbons at sensitive receptors due to emissions to air from the LNG facility under normal operations.

The modelling results indicate that, of the 34 identified hydrocarbon species potentially associated with emissions from the LNG facility, none were found to exceed the ambient air quality objectives at sensitive receptor locations. The highest predicted ground-level concentration of a hydrocarbon compound at a sensitive receptor relative to its air quality objective is 4.9% for the acrolein. This is predicted at Receptor 21 (the QCLNG site). The predicted concentrations (which are extremely conservative as mentioned previously because CSG is such a lean gas) at residential receptors are considerably lower and well below the air quality objectives.

Table 40 Predicted maximum ground-level concentrations of specific species of hydrocarbons at sensitive receptors

Hydrocarbon	Averaging Period	Air Quality Objective used for Assessment (µg/m³)	Predicted maximum ground-level concentration (µg/m³)	Percentage of Air Quality Objective (%)
1,3-Butadiene	1-hour	40	1.4E-03	3.5E-03
	Annual	2.4	5.8E-06	2.4E-04
2-Methylnaphthalene	1-hour	60	2.8E-08	4.7E-08
3-Methylchloranthrene	1-hour	60	2.1E-09	3.5E-09
7,12-Dimethylbenz(a)anthracene	1-hour	0.5	1.9E-08	3.7E-06
Acenaphthene	1-hour	1	2.1E-09	2.1E-07
Acenaphthylene	1-hour	1	2.1E-09	2.1E-07
Acetaldehyde	1-hour	42.00	1.3E-01	3.1E-01
Acrolein	1-hour	0.42	2.1E-02	4.9
Anthracene	1-hour	0.5	2.8E-09	5.6E-07
Benz(a)anthracene	1-hour	0.5	2.1E-09	4.2E-07
Benzene	1-hour	29	3.9E-02	1.3E-01
Benzo(a)pyrene	Annual	0.0003	3.0E-12	9.9E-07
Benzo(b)fluoranthene	1-hour	0.5	2.1E-09	4.2E-07
Benzo(g,h,i)perylene	1-hour	0.5	1.4E-09	2.8E-07
Benzo(k)fluoranthene	1-hour	0.5	2.1E-09	4.2E-07
Butane	1-hour	19,000	2.5E-03	1.3E-05
Chrysene	1-hour	0.5	2.1E-09	4.2E-07
Dibenzo(a,h)anthracene	1-hour	0.5	1.4E-09	2.8E-07
Dichlorobenzene	1-hour	600	1.4E-06	2.3E-07
Ethane	1-hour	12,000	3.6E-03	3.0E-05
Ethylbenzene	1-hour	8,000	1.0E-01	1.3E-03
Fluoranthene	1-hour	0.5	3.5E-09	7.0E-07
Fluorene	1-hour	0.5	3.3E-09	6.5E-07
Formaldehyde	30-minute	110	2.6	2.4
	24-hour	54	2.6E-01	4.8E-01

Hydrocarbon	Averaging Period	Air Quality Objective used for Assessment ($\mu g/m^3$)	Predicted maximum ground-level concentration ($\mu g/m^3$)	Percentage of Air Quality Objective (%)
Hexane	1-hour	3,200	2.1E-03	6.5E-05
Indeno(1,2,3-cd)pyrene	1-hour	0.5	2.1E-09	4.2E-07
Naphthalene	1-hour	52,000	4.2E-03	8.1E-06
Pentane	1-hour	33,000	3.0E-03	9.2E-06
Phenanathrene	1-hour	0.5	2.0E-08	4.0E-06
Propane	1-hour	18,000	1.9E-03	1.0E-05
Propylene Oxide	1-hour	90	9.4E-02	1.0E-01
Pyrene	1-hour	0.5	5.8E-09	1.2E-06
Toluene	1-hour	360	4.2E-01	1.2E-01
Xylene	1-hour	190	2.1E-01	1.1E-01

9.1.5 Photochemical Smog

The assessment of photochemical smog impacts has been conducted assuming 100% conversion of NO_2 to ozone. This is an extremely conservative assumption. The current atmospheric environment in Gladstone receives very low ozone levels with only a few hours per year receiving levels slightly above background concentrations.

The peak predicted contribution of the proposed LNG facility to levels of NO_2 at a sensitive receptor is 12.5 $\mu g/m^3$. Consequently, the predicted maximum incremental increase of ozone at this location is estimated to be 13 $\mu g/m^3$. This is an extremely conservative assumption as the most affected sensitive receptor, R21, for which this assessment is made, is situated approximately two kilometres to the southeast of the LNG facility. As discussed in Section 8.6, ozone is a secondary air pollutant that transforms via several photochemically catalysed reactions of NO_X and other VOCs over time during plume transport, with concentrations peaking approximately 10-15 km downwind. Consequently, an assessment of the potential for ozone transformation at R21, in close proximity to the LNG provides a worst case estimate.

Adding the maximum contribution due to the proposed LNG facility at the most affected sensitive receptor to the maximum ozone concentration recorded at the Targinie monitoring station of 110 $\mu g/m^3$ results in a maximum ozone concentration of 123 $\mu g/m^3$, which is less than 60% of the ambient air quality objective of 210 $\mu g/m^3$ for a 1-hour average. Therefore, the contribution of the proposed LNG facility to regional photochemical activity is at worst, minor and unlikely to be of any cause for concern or require further assessment.

9.1.6 Odour

A qualitative assessment of the potential for odour impacts has been conducted based on odour thresholds of individual compounds. The assessment was based on the predicted maximum ground-

level concentration at the most affected sensitive receptor. Pollutants considered were NO_2 and odorous hydrocarbons with a maximum ground-level concentration of greater than one percent of their air quality objective.

By definition, one odour unit (1 ou) is equivalent to the odour threshold of a substance or a mixture of substances. Consequently, the DERM odour guideline (QEPA, 2004) of 1 ou (for a tall wake free stack) is equivalent to the substance's odour threshold. Therefore, if the predicted ambient concentration of the substance is below the substance's odour threshold, it is unlikely that the odour associated with the substance will be detected. This assessment does not account for any synergistic effects that may alter the odour character or odour threshold of the substance, and does not account for the concentrations of the compounds in the gas mixture at the 1 ou odour concentration level. Predicted ground-level odour concentrations for identified pollutants are presented in Table 41. Note that the assessment has been made against the maximum percentile, while the odour guideline is for a 99.5th percentile. This will give a conservative assessment.

The modelling results indicate that the potential levels of odour due to emissions from the LNG facility are very low and well below the DERM odour guideline of 1 ou.

Table 41 Predicted maximum 1-hour average ground-level odour concentration for identified pollutants

Pollutant	Odour threshold[1] (µg/m^3)	Predicted concentration (µg/m^3)	Predicted odour concentration (ou)	Percent of odour guideline (%)
Nitrogen dioxide	100[2]	12.5	0.13	13
Formaldehyde	36[3]	2.6	0.07	7
Acrolein	50[4]	0.021	0.0004	0.04
Total	-	-	0.2	20.3

Table note:
[1] Odour threshold in micrograms per cubic metre is equivalent to one odour unit
[2] Odour threshold for nitrogen dioxide 0.05-0.22 ppm (WHO, 2000b)
[3] Odour threshold for formaldehyde 0.027-1.9 ppm (CCOHS, 2006)
[4] Odour threshold for acrolein 50 - 4,122 µg/m^3 (OMoE, 2005)

9.2 Non-routine Operations - Scenario 2

This section present the results for the non-routine operations of the plant and the release from the flares, during plant upset or emergency conditions. As this is a short term operating scenario annual averages have not been included. It should also be noted that particulate emissions are not expected from the flares.

9.2.1 Nitrogen Dioxide

The assessment of the maximum 1-hour average ground-level concentrations of NO_2 for the flare has been made for the 99.9th percentile. Contours are presented for the flares in isolation (Figure 24) and with the addition of background sources (GAMSv3) and all other proposed LNG facilities in Gladstone (Figure 25). The results are also presented at the sensitive receptors in Table 42.

The modelling indicates that the predicted maximum concentrations of NO_2 are low and well below the air quality objectives. The maximum concentrations within the region are dominated by existing

sources with only a minor contribution due to the addition of the LNG facility flares.

Table 42 Predicted maximum 1-hour ground-level concentrations of nitrogen dioxide for the APLNG facility Scenario 2 in isolation, with existing and approved industries (GAMSv3) and other proposed LNG plants (in µg/m³)

Location	APLNG facility in isolation	APLNG facility with existing and approved industries (GAMSv3) and all proposed LNG plants
R1	9.4	44
R2	11.6	45
R3	7.2	52
R4	6.8	66
R5	6.6	79
R6	6.3	85
R7	8.1	81
R8	6.0	67
R9	6.0	63
R10	8.6	53
R11	6.8	54
R12	10.1	36
R13	9.0	38
R14	7.5	17
R15	6.4	23
R16	5.8	27
R17	9.9	22
R18	9.0	20
R19	7.6	18
R20	16.4	45
R21	18.4	41
Air quality objective	250	

9.2.2 Carbon Monoxide

The assessment of the maximum 8-hour average ground-level concentrations of CO for the flares has been made for the 100th percentile. Contours are presented for the LNG flares with the addition of a background concentration (Figure 26). The results are also presented at the sensitive receptors in Table 43.

The modelling indicates that the predicted maximum concentrations of CO are low and well below the air quality objectives. The maximum concentrations are predicted approximately 3 km to the southeast of the site.

Table 43 Predicted maximum 8-hour average ground-level concentrations of carbon monoxide for Scenario 2 in isolation, and with background included (in µg/m³)

Location	APLNG facility in isolation	APLNG facility with background
R1	134	259
R2	204	329
R3	74	199
R4	47	172
R5	68	193
R6	63	188
R7	85	210
R8	63	188
R9	82	207
R10	84	209
R11	77	201
R12	144	269
R13	107	232
R14	65	190
R15	83	207
R16	52	177
R17	160	285
R18	127	252
R19	92	217
R20	372	497
R21	249	374
Air quality objective	11,000	

9.3 Shipping

This section present the results for the normal operations of the plant plus the potential emissions associated with shipping (LNG carriers and tug boats at dock). As this is a short term operating scenario long term averages have not been included.

Table 44 Predicted maximum 1-hour average ground-level concentrations of nitrogen dioxide and sulphur dioxide for the APLNG facility, including shipping, in isolation (in µg/m³)

Location	NO_2	SO_2
R1	14.0	17.1

Location	NO_2	SO_2
R2	11.6	14.3
R3	17.4	16.1
R4	24.6	18.7
R5	12.7	10.9
R6	12.2	14.8
R7	11.3	11.4
R8	8.1	9.0
R9	7.3	9.7
R10	7.5	9.5
R11	7.0	7.8
R12	5.2	4.2
R13	5.2	4.7
R14	4.1	2.5
R15	3.9	3.2
R16	3.6	1.9
R17	3.5	1.1
R18	3.2	1.0
R19	2.8	0.9
R20	12.3	12.6
R21	14.6	9.8
Air quality objective	250	570

The modelling of the potential emissions due to shipping associated with the APLNG facility indicates the impacts are minimal and well below the air quality objectives at all sensitive receptors.

10. Assessment of Vertical Plume Velocities for Aviation Safety

10.1 Overview

An assessment of the vertical velocities associated with stack exhaust plumes at the proposed LNG facility was carried out, based on the guidelines for aviation safety published by the Australian Civil Aviation Safety Authority (CASA) in *Guidelines for conducting plume rise assessments (CASA, 2004)*.

The aim of the assessment was to investigate the vertical and horizontal extent of the plume from various sources at the facility, and to estimate the height and downwind distance at which the average vertical plume velocities diminish to the critical value of 4.3 m/s. The Gladstone Airport Development Plan (Sullivan, 2008) describes a PANS-OPS (surface above which planes can fly) over the LNG facility of 400 metres above the ground.

The frequencies with which the plume exhaust velocities under normal and non-routine operating conditions achieve or exceed the PANS-OPS above the facility have been assessed. Details of the methodology and findings of the vertical plume velocity assessment for aviation safety are presented in Appendix D.

10.2 Summary of Assessment Findings

10.2.1 Plume heights for normal operations

The assessment found the following in terms of plume heights for normal operations:

- There is a potential for the average plume vertical velocity to exceed 4.3 m/s up to a maximum height of approximately 846 metres above ground level at a maximum downwind distance of approximately 166 metres.
- The merged plume from the gas turbine compressors is likely to cause the vertical velocity to be greater than 4.3 m/s at and above the PANS-OPS (400 metres) for 28 hours per year or 0.32% of the time.
- Of all the plumes considered for normal operations, the highest critical height for the 0.1 percentile is approximately 548 metres above ground level

It is recommended that discussion between APLNG, Gladstone Airport and CASA will be required to determine an appropriate course of action.

10.2.2 Plume heights for non-routine operations (unplanned events)

The assessment found the following in terms of plume heights for non-routine operations:

- Each LNG train will have a planned shutdown expected to be every several years with associated maintenance and start-up flaring.
- Use of the Marine Flare under maintenance operations: the average plume vertical velocity does not exceed 4.3 m/s above the PANS-OPS.
- Use of the Marine Flare under loading of a warm ship: there is a potential for the average plume vertical velocity to exceed 4.3 m/s above the PANS-OPS.

- For non-routine operating conditions of the Marine Flare under warm ship loading, there is a potential for the average plume vertical velocity to exceed 4.3 m/s up to a maximum height of approximately 784 metres above ground level at a maximum downwind distance of approximately 138 metres.
- A plume from the Marine Flare would have a vertical velocity greater than 4.3 m/s above the height of the PANS-OPS (400 metres) for 28 hours per year or 0.38% of the time, when assumed operation for every hour of the year.
- The highest critical height for the Marine Flare under non-routine operations, for the 0.1 percentile is approximately 488 metres above ground level, if it is assumed to operate for every hour of the year.
- The Wet and Dry Gas Ground flare, which will only operate if emergency depressurisation of the plant is required, is likely to generate a plume with vertical velocities above 4.3 m/s well above the PANS-OPS under all conditions.
- This event is predicted to have a very low frequency of occurrence, with duration of approximately 20 minutes while the plant depressurises. Under flaring, the ground flare is likely to always exceed the PANS-OPS above the site to a considerable vertical distance.

During commissioning of each train the Dry and Wet Gas Flares will be used. The emissions for the flares during commissioning will be less than the worst case modelled for the non-routine operation scenario, and therefore have not been assessed.

Flaring configuration investigations and optimisation are continuing during the design phase which may incorporate the marine flare within the ground flare enclosure.

10.2.3 Cumulative assessment of vertical plume velocities

A cumulative assessment of aviation safety of the APLNG plumes and other existing or proposed industrial developments is not necessary as the plumes will not merge during normal operating conditions.

A cumulative assessment of the risk due to increased frequency of events when all other potential LNG operators are also considered has not been undertaken in this assessment. Assessments of aviation safety undertaken by other LNG developments have also identified operating scenarios that do not meet the CASA guideline for vertical velocities above the PANS-OPS. The CASA Advisory Circular does not include a method for dealing with a cumulative assessment. Should an assessment of plume vertical velocities for a particular development indicate an exceedence of the CASA guideline above the PAN-OPS, CASA refers to Air Services Australia to amend the flight charts.

Discussions between APLNG and other LNG Plant developers, the Gladstone Airport, CASA and Air Services Australia will be required in order to determine a response to the accumulated effect of LNG developments on the Gladstone airport.

11. Conclusions

An air quality impact assessment has been conducted for the proposed LNG facility to be constructed and operated on the western shore of Curtis Island in Port Curtis near Gladstone, Queensland.

The air quality impact assessment investigated the potential for impacts associated with emissions to air from stack sources during normal and non-routine operating scenarios. The assessment included both regional and local scale meteorological and dispersion models to assess the effect of emissions to air from the APLNG facility in isolation and with background emissions from existing, approved and proposed industries in the Gladstone region.

Emissions from the site are mainly due to the combustion of natural gas, therefore NO_X is the key pollutant. Small quantities of PM_{10}, $PM_{2.5}$, CO and hydrocarbons are also released during normal plant operations. SO_2 released during normal operation of the APLNG plant will be negligible; however the LNG carriers may emit SO_2 depending on the fuel used. Therefore SO_2 from shipping emissions has been assessed in isolation.

Detailed emissions information was supplied by APLNG project engineers except for the breakdown of hydrocarbon compounds. Hydrocarbon emissions were estimated from the best available emission factors.

Background levels were assessed in two ways including dispersion modelling for NO_2 using the GAMSv3, and ambient monitoring station data for CO and particulates. Hydrocarbon species, odour and ozone and were assessed in isolation.

Table 45 Summary of annual emissions from existing Gladstone industries and APLNG (t/yr)

	NO_x	CO	PM_{10}	SO_2
Existing Gladstone[1]	55,210	68,292	2,444	50,947
APLNG [2]	3,295	2,407	221	Negligable
APLNG as % of	6%	4%	9%	0%

Notes 1 Based on NPI reports for 2007-2008 period for existing industries only (no natural or anthropogenic emissions included)
2 Total plant emissions for normal operations. All sources assumed to operate at 100% capacity for 8760 hours per year

The following conclusions may be drawn from the air quality impact assessment.

In relation to dispersion meteorology:

- The site is dominated by moderate winds typical of a coastal location, with an average wind speed of 3.7 m/s. This provides for relatively good dispersion conditions for stack sources.
- The prevailing wind direction at the site is from the east to south sector, whereas the main population centre of Gladstone is located to the south to west sector from the proposed AP LNG facility.
- Winds likely to carry emissions from the LNG facility over the population centre of Gladstone occur very infrequently.

A cumulative air quality assessment was undertaken that included all existing industrial sources in Gladstone and proposed future developments (including proposed LNG plants on Curtis Island and at Fishermans Landing) and has shown the following:

- All air quality objectives are met for normal and non-routine operation of the LNG facility (inclusive of background levels) at sensitive receptors for NO2, CO, PM10, PM2.5, odour, ozone, SO2 and hydrocarbons.

For all pollutants the contribution to the regional air quality is dominated by existing sources, which includes industrial, anthropogenic and natural sources.

In relation to aviation safety, during normal plant operations the following conclusions can be drawn from the assessment:

- There is a potential for the average plume vertical velocity to exceed 4.3 m/s up to a maximum height of approximately 850 metres above ground level at a maximum downwind distance of approximately 166 metres. The maximum height is dominated by the merged plume from the gas turbine compressors.
- The merged plume from the gas turbine compressors is likely to cause the vertical velocity to be greater than 4.3 m/s at and above the PANS-OPS (400 metres) for approximately 28 hours per year or 0.32% of the time.
- Of all the plumes considered for normal operations, the highest critical height for the 0.1 percentile is approximately 550 metres above ground level (merged gas turbine compressors).

In relation to aviation safety, during non-routine plant operations for upset event such as excess flaring, the following conclusions can be drawn from the assessment:

- Each LNG train will have a planned shutdown scheduled to occur several years apart with associated maintenance and start-up flaring.
- A plume from the Marine Flare (stack not ground flare) would have a vertical velocity greater than 4.3 m/s above the height of the PANS-OPS (400 metres) for approximately 28 hours per year or 0.38% of the time, when assumed operation for every hour of the year.
- The Wet and Dry Gas Ground flare, which will typically operate if emergency depressurisation of the plant is required is likely to generate a plume with vertical velocities above 4.3 m/s well above the PANS-OPS under all conditions.
- An emergency release from the Wet and Dry Gas Ground flare is predicted to have a very low frequency of occurrence, with duration of approximately 20 minutes while the plant depressurises, but can potentially occur at any time. Under flaring, the ground flare is likely to always exceed the PANS-OPS above the site to a considerable vertical distance.

Discussions between APLNG, the Gladstone Airport and CASA will be required to determine an appropriate course of action to alert aircraft in the region should a ground flare event occur.

A cumulative assessment of aviation safety of the APLNG plumes and other existing or proposed industrial developments is not necessary as the plumes will not merge during normal operating conditions.

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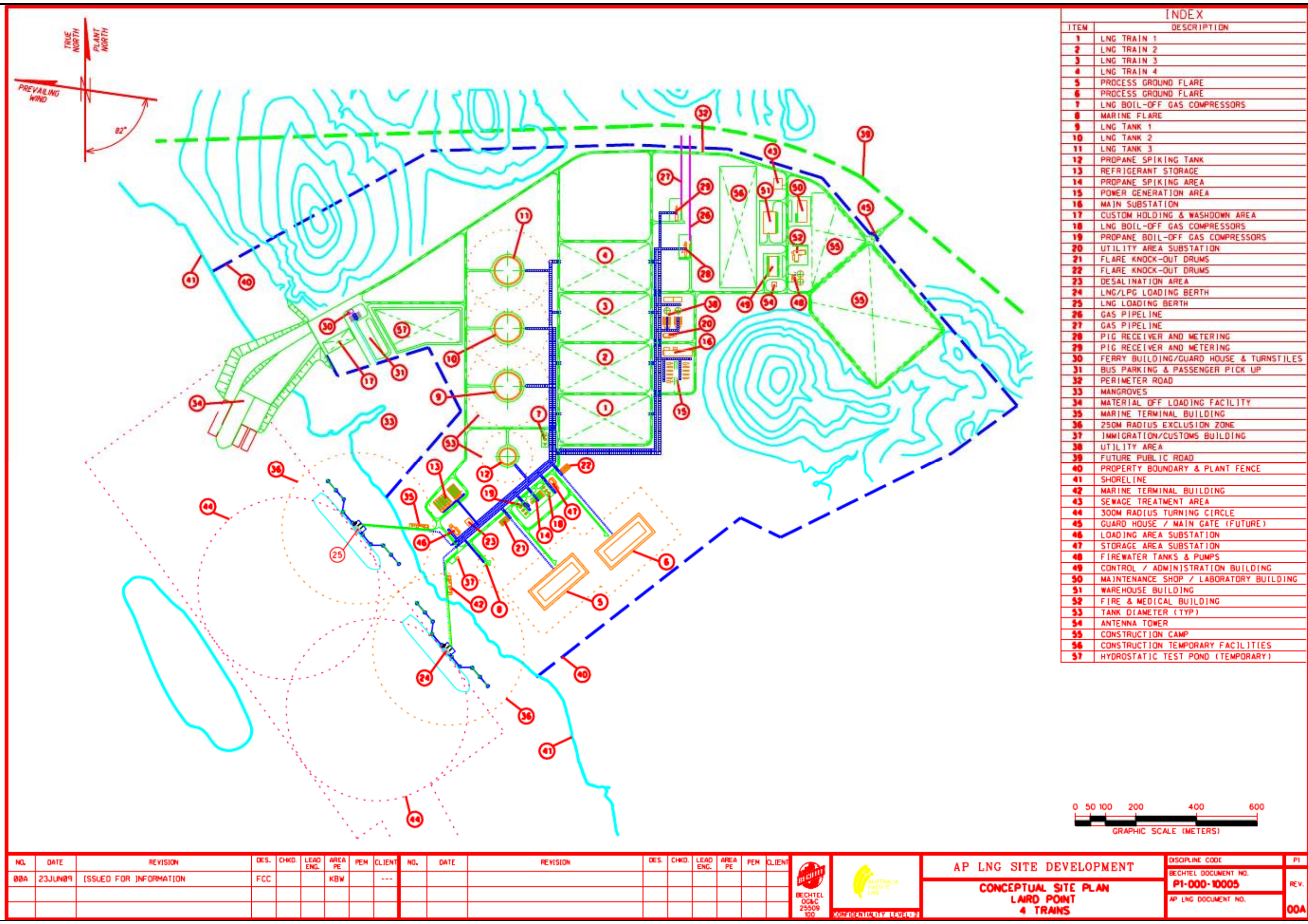

Figure 1 The layout of the proposed APLNG Project on Curtis Island

Location: Curtis Island, Gladstone region, QLD	**Type:** APLNG Project plan	**Provided by:** APLNG

Figure 2 Map showing the terrain contours, the location of other major industries and sensitive receptors in the Gladstone region

Location: Gladstone Region, QLD	**Date:** December 2009
Type: Project area terrain contour map	**Prepared by:** A. Balch

Figure 3 Location of the Bureau of Meteorology monitoring stations in the Gladstone region (AMG coordinates in metres)

Location: Gladstone Region, QLD	**Date:** October 2009
Type: Project area map (Google Earth)	**Prepared by:** A. Balch

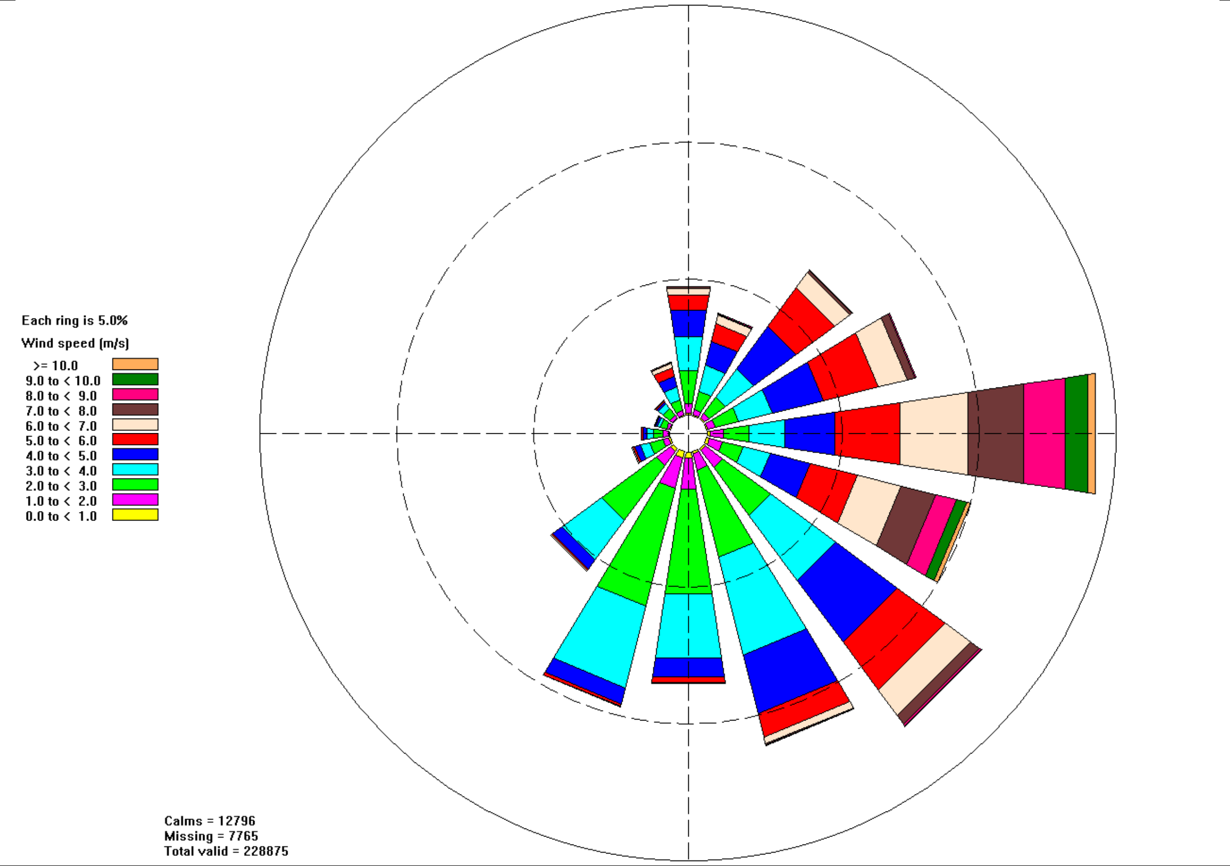

Figure 4 Annual distribution of wind speed and direction for Gladstone

Location:	**Period:**	**Data source:**	**Units:**
Gladstone Airport	January 1996 – June 2009	Bureau of Meteorology	m/s and °
Type:		**Prepared by:**	**Date:**
Wind rose diagram		S. Menzel	September 2009

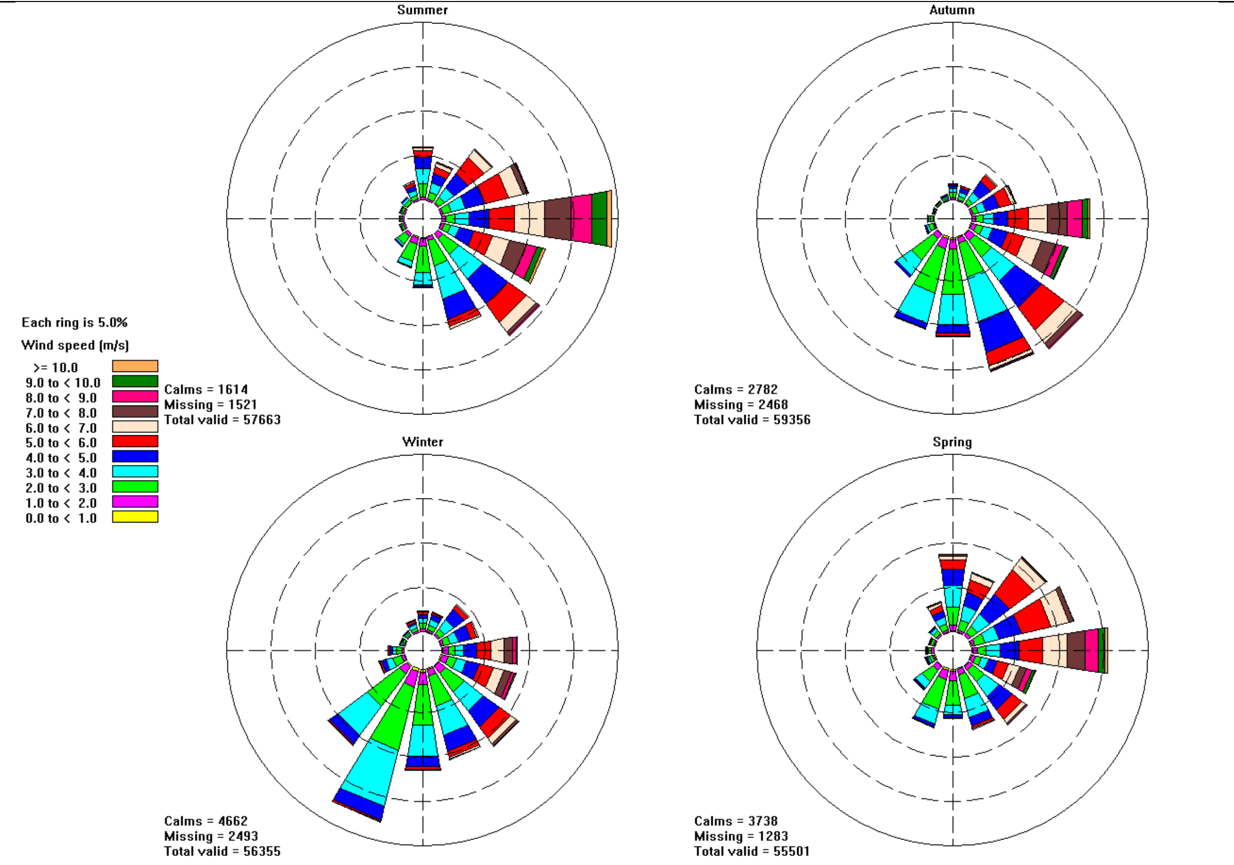

Figure 5 Seasonal distribution of wind speed and direction for Gladstone

Location:	Period:	Data source:	Units:
Gladstone Airport	January 1996 – June 2009	Bureau of Meteorology	m/s and °
Type:		**Prepared by:**	**Date:**
Wind rose diagram		S. Menzel	September 2009

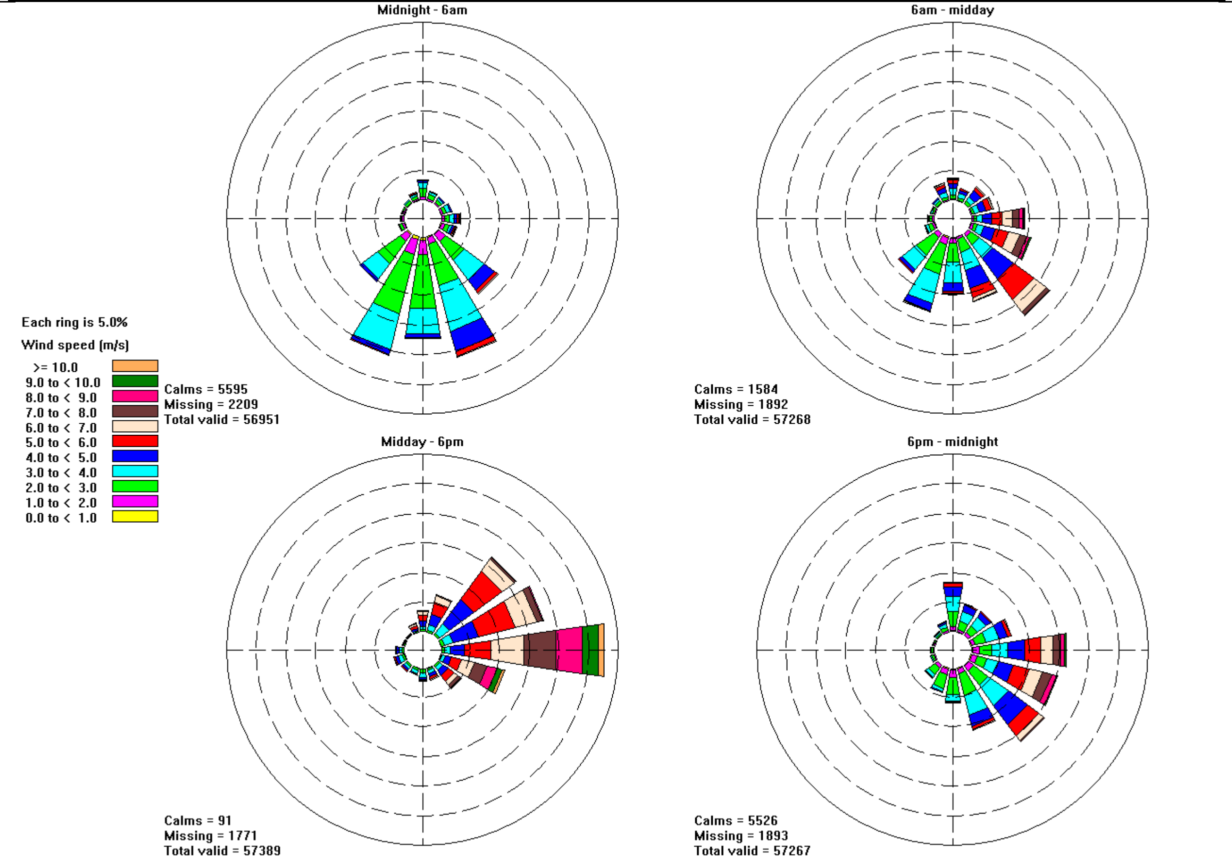

Figure 6 Diurnal distribution of wind speed and direction for Gladstone

Location: Gladstone Airport	**Period:** January 1996 – June 2009	**Data source:** Bureau of Meteorology	**Units:** m/s and °
Type: Wind rose diagram		**Prepared by:** S. Menzel	**Date:** September 2009

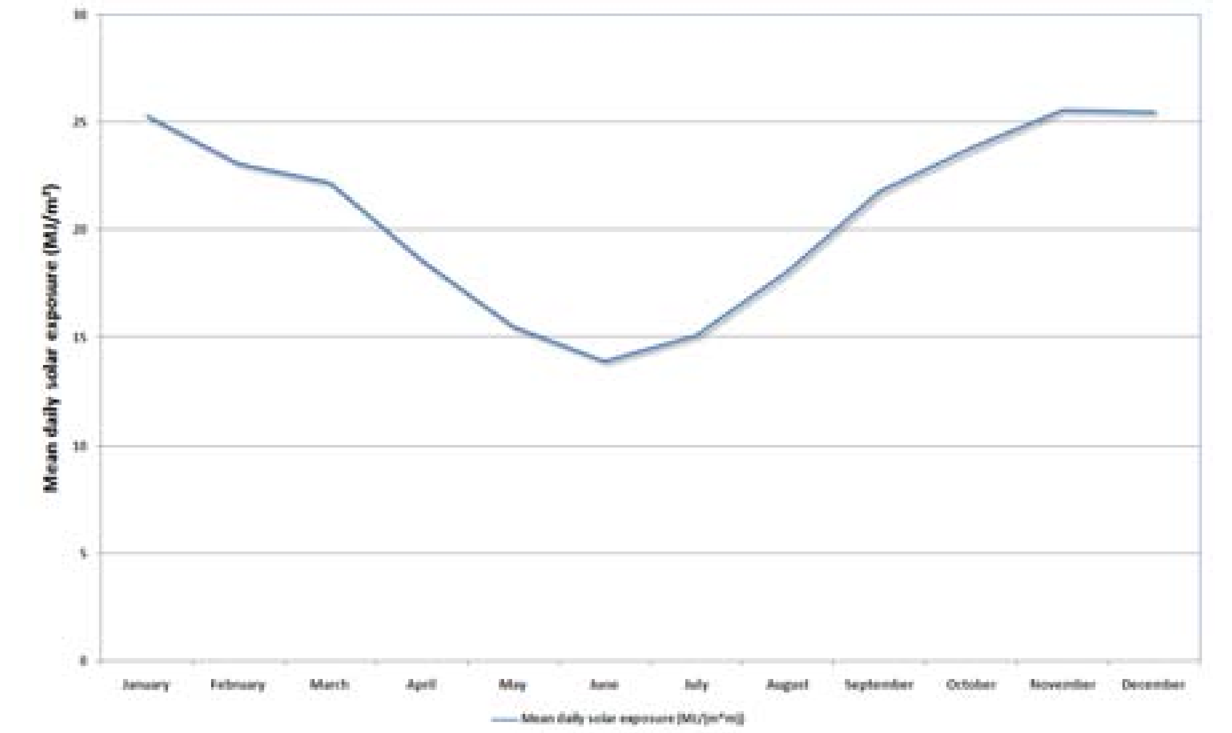

Figure 7 Average daily solar exposure for Gladstone

Location: Gladstone Airport	**Period:** 1990 – 2009	**Data source:** Bureau of Meteorology	**Units:** MJ/m²
Type: Time-series chart	**Averaging period:** Monthly	**Prepared by:** S. Menzel	**Date:** October 2009

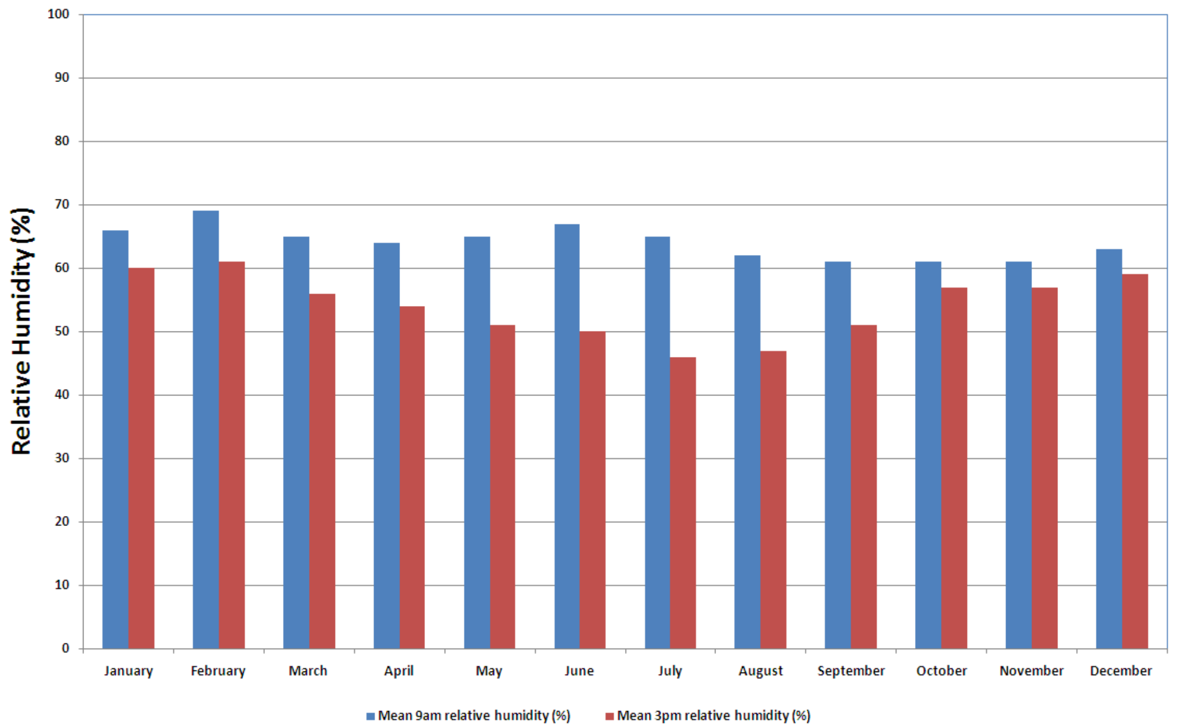

Figure 8 Relative humidity at 9am and 3pm by month for Gladstone

Location: Gladstone Airport	**Period:** 1993 – 2009	**Data source:** Bureau of Meteorology	**Units:** Percentage
Type: Histogram	**Averaging period:** Monthly	**Prepared by:** S. Menzel	**Date:** September 2009

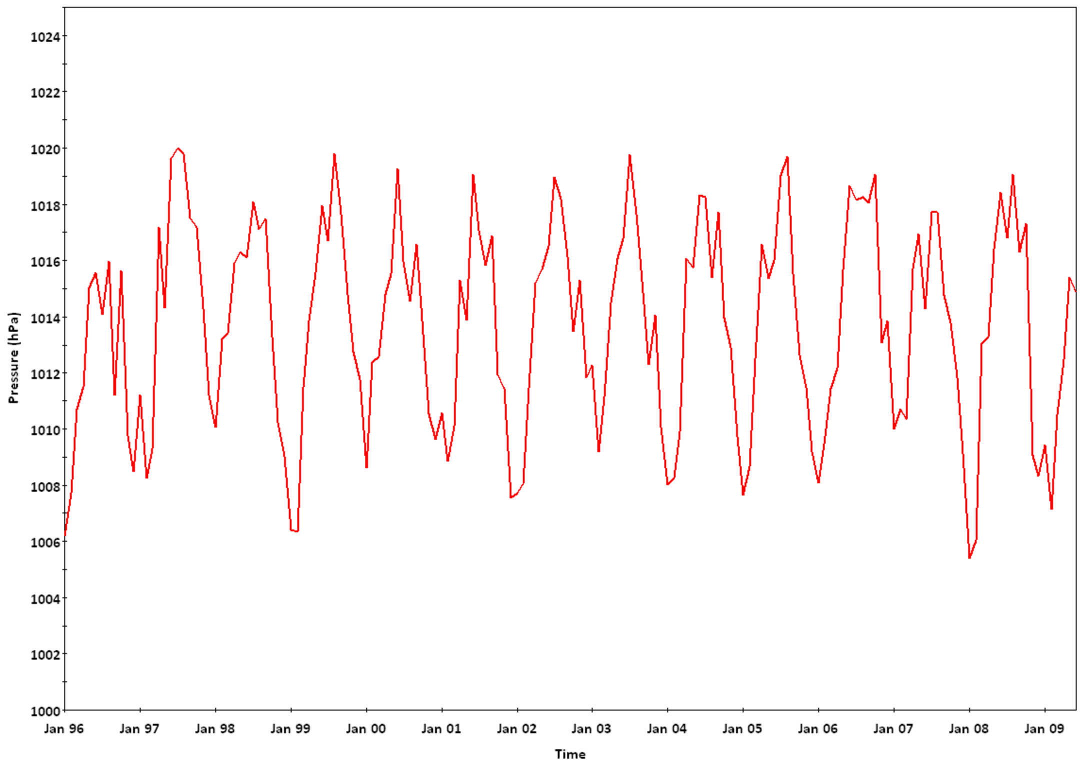

Figure 9 Surface atmospheric pressure for Gladstone

Location:	**Period:**	**Data source:**	**Units:**
Gladstone Airport	January 1996 – June 2009	Bureau of Meteorology	hPa
Type:	**Averaging period:**	**Prepared by:**	**Date:**
Time-series chart	Monthly	S. Menzel	September 2009

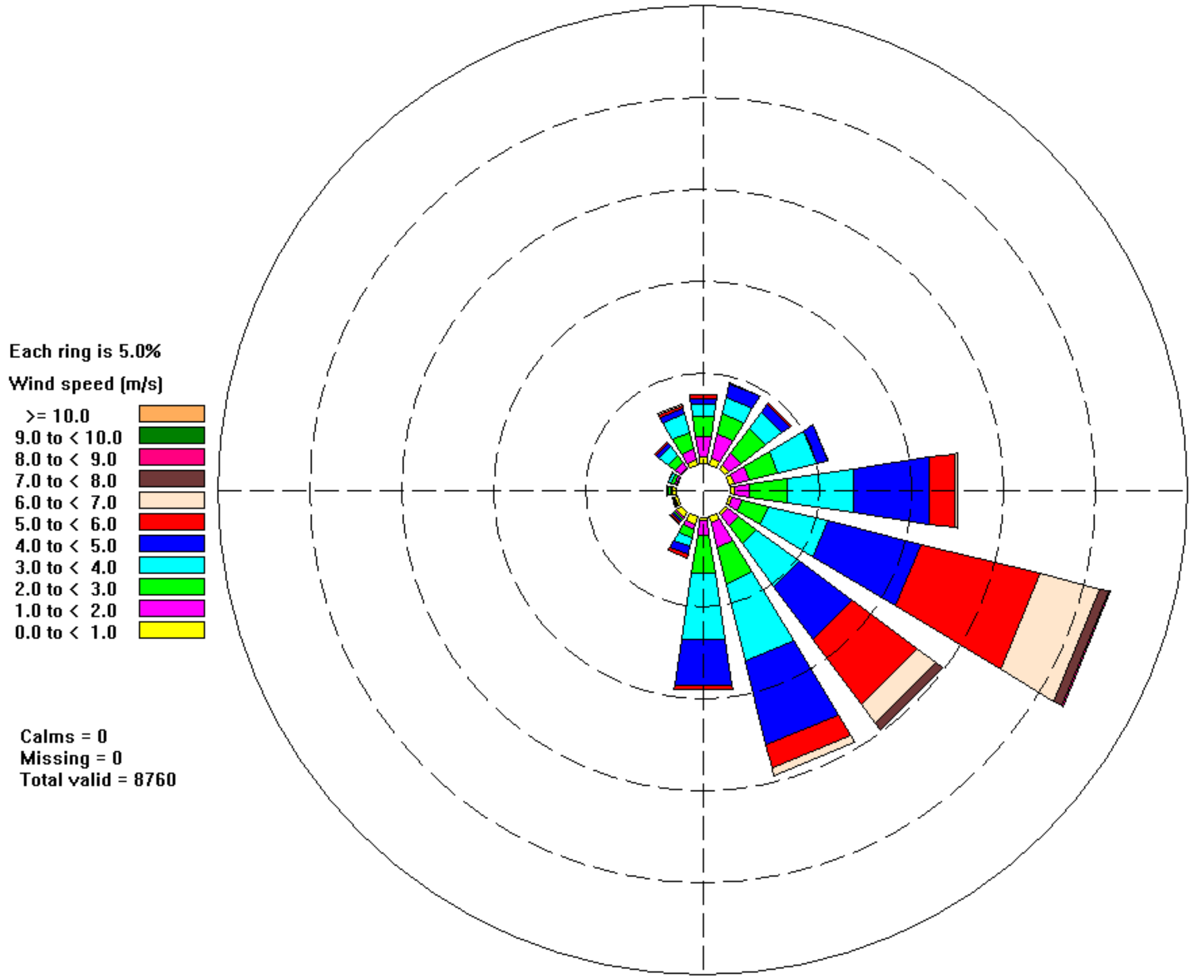

Figure 10 Annual wind rose

Location: APLNG facility site	**Period:** 1 April 2006 – 31 March 2007	**Data source:** Generated by CALMETv6.3	**Units:** m/s and degrees
Type: Wind Rose		**Prepared by:** A. Schloss	**Date:** December 2009

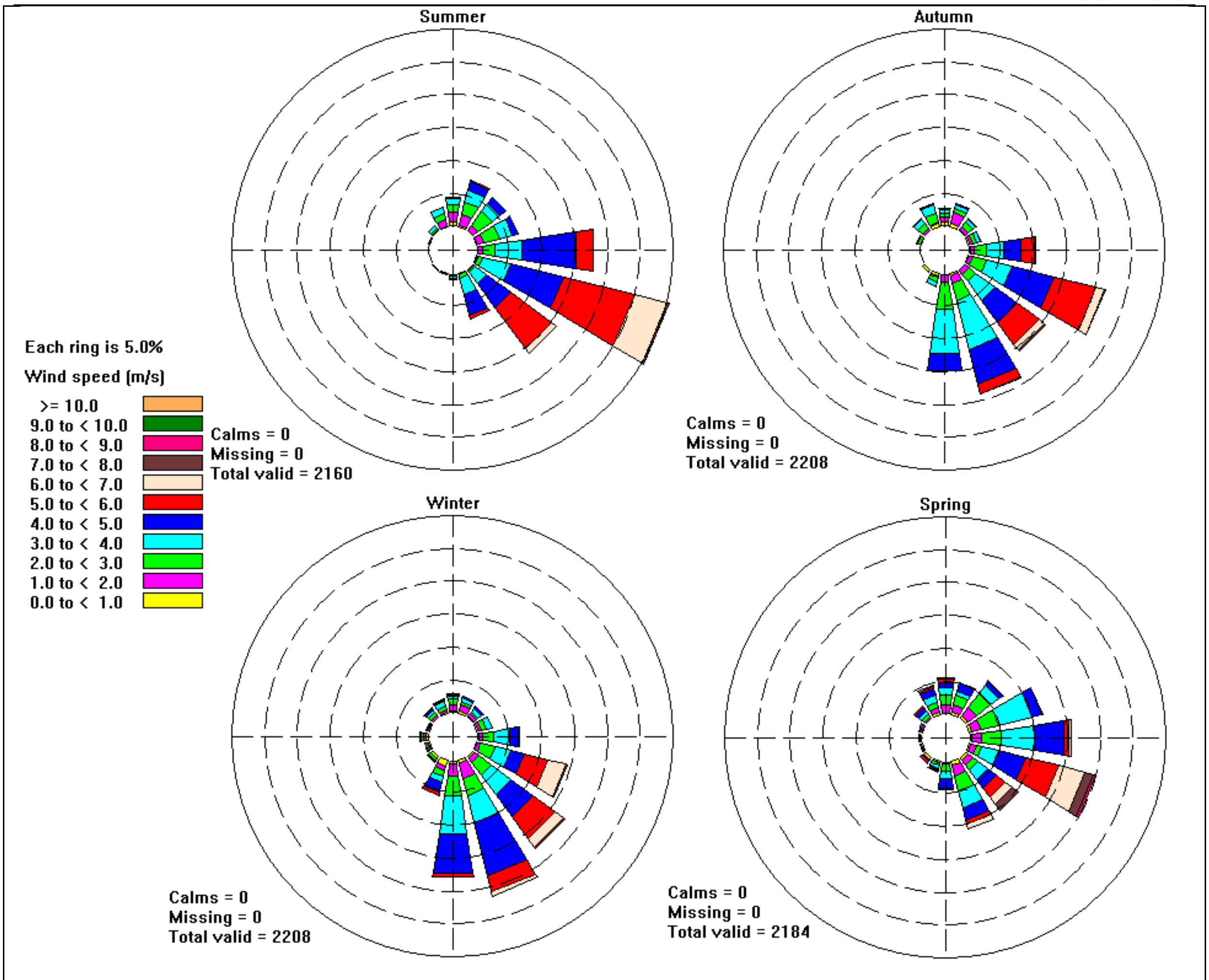

Figure 11 Seasonal wind rose

Location: APLNG facility site	**Period:** 1 April 2006 – 31 March 2007	**Data source:** Generated by CALMETv6.3	**Units:** m/s and degrees
Type: Wind Rose		**Prepared by:** A. Schloss	**Date:** December 2009

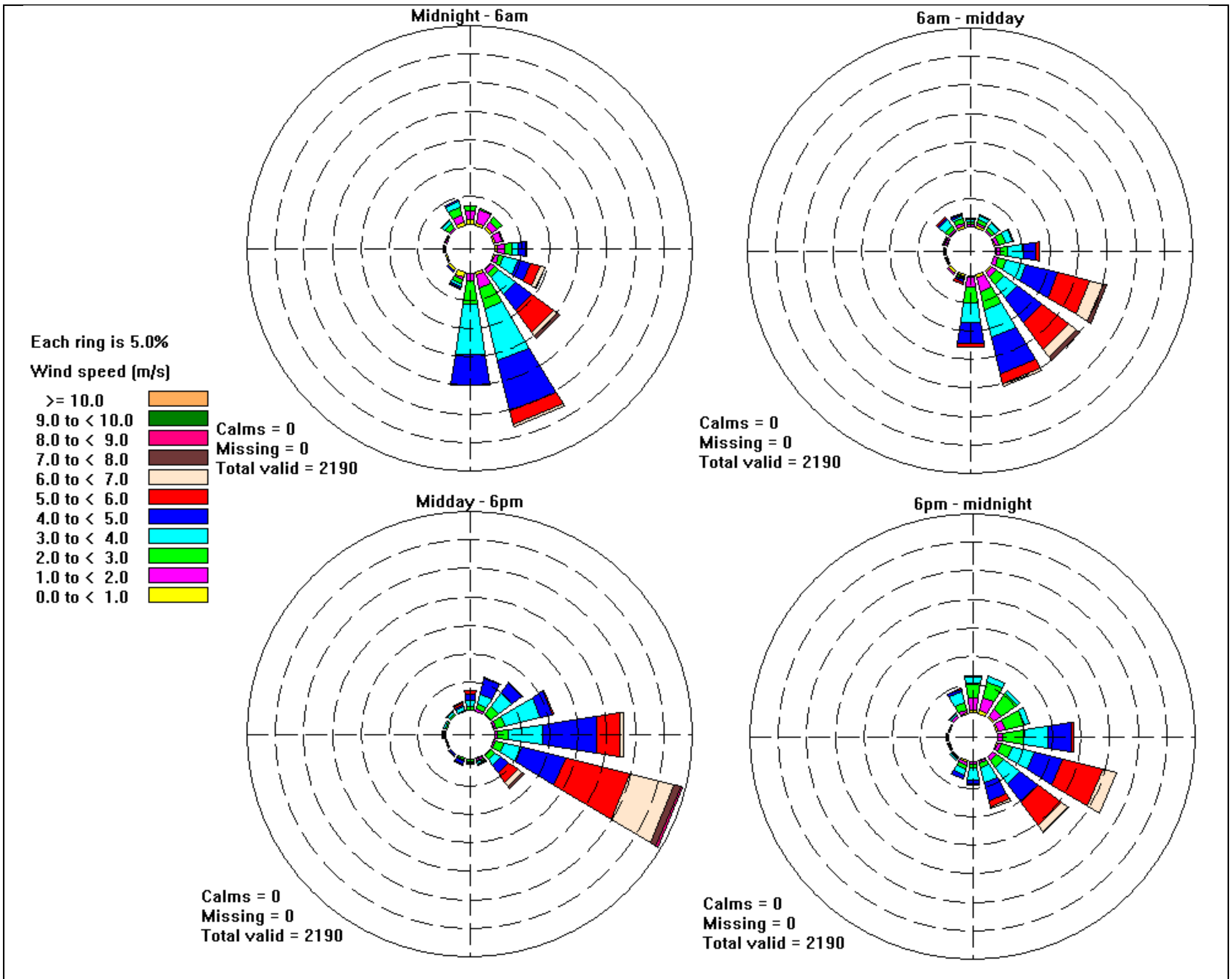

Figure 12 Daily wind rose

Location:	Period:	Data source:	Units:
APLNG facility site	1 April 2006 – 31 March 2007	Generated by CALMETv6.3	m/s and degrees
Type: Wind Rose		**Prepared by:** A. Schloss	**Date:** December 2009

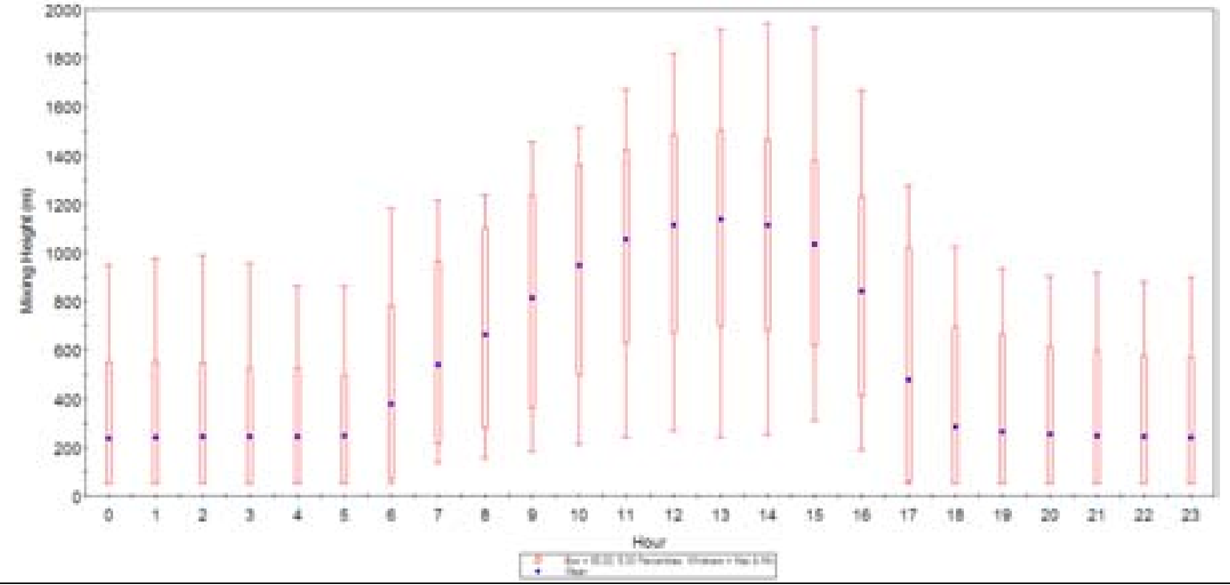

Figure 13 Daily variation in mixing heights

Location:	**Period:**	**Data source:**	**Units:**
APLNG facility site	1 April 2006 – 31 March 2007	Generated by CALMETv6.3	Metres above ground
Type: Box and Whisker Plot		**Prepared by:** A. Schloss	**Date:** December 2009

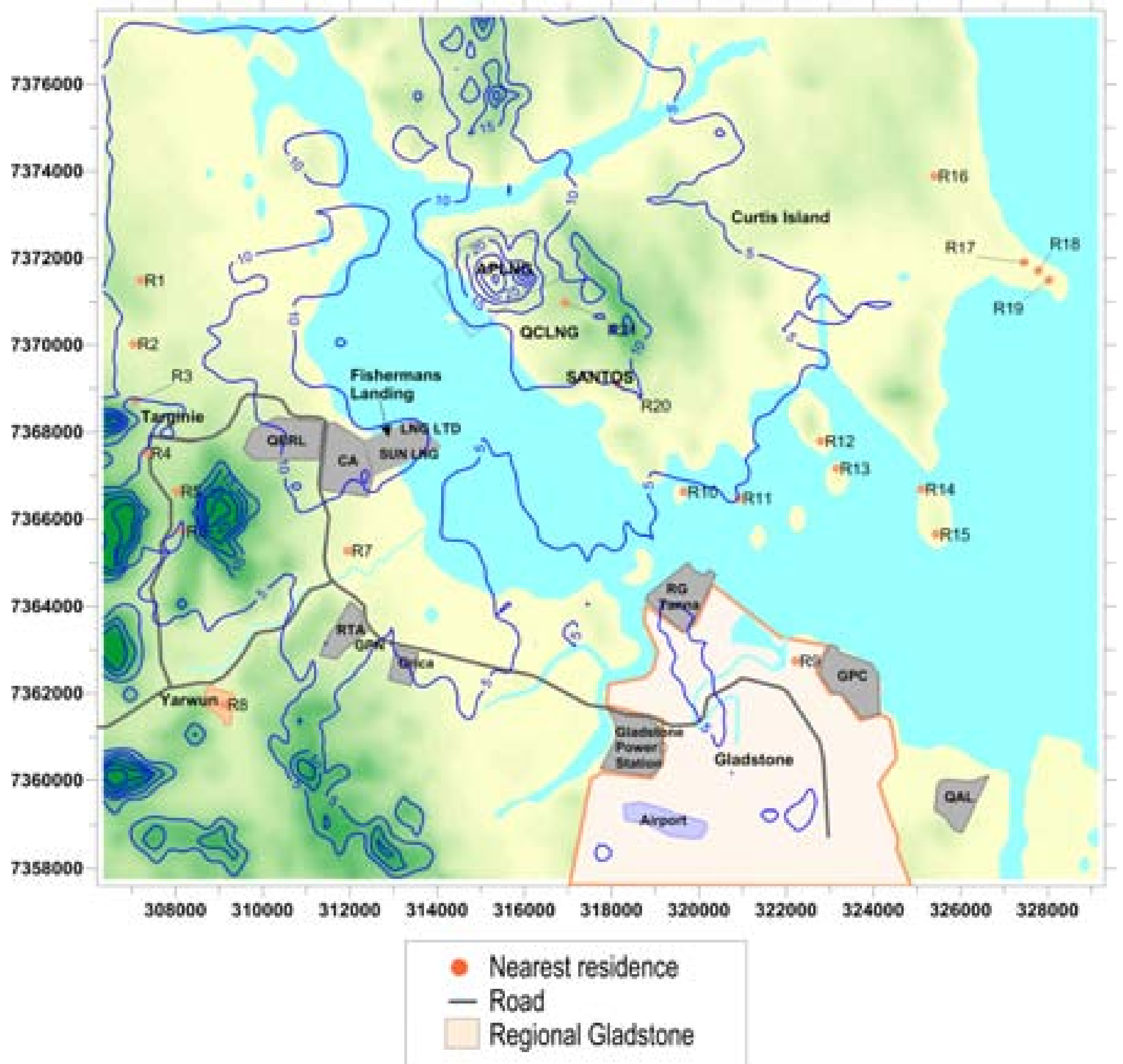

Figure 14 Scenario 1 - Predicted maximum 1-hour average ground-level concentrations of nitrogen dioxide for the LNG facility during normal operations, in isolation

Location: APLNG project area, Gladstone	**Averaging period:** 1-hour	**Data source:** CALPUFF	**Units:** µg/m³
Type: NO_2 maximum (99.9th percentile) 1-hour average contour plot	**Air quality objective:** Health and wellbeing: 250 µg/m³	**Prepared by:** S. Menzel and A. Schloss	**Date:** December 2009

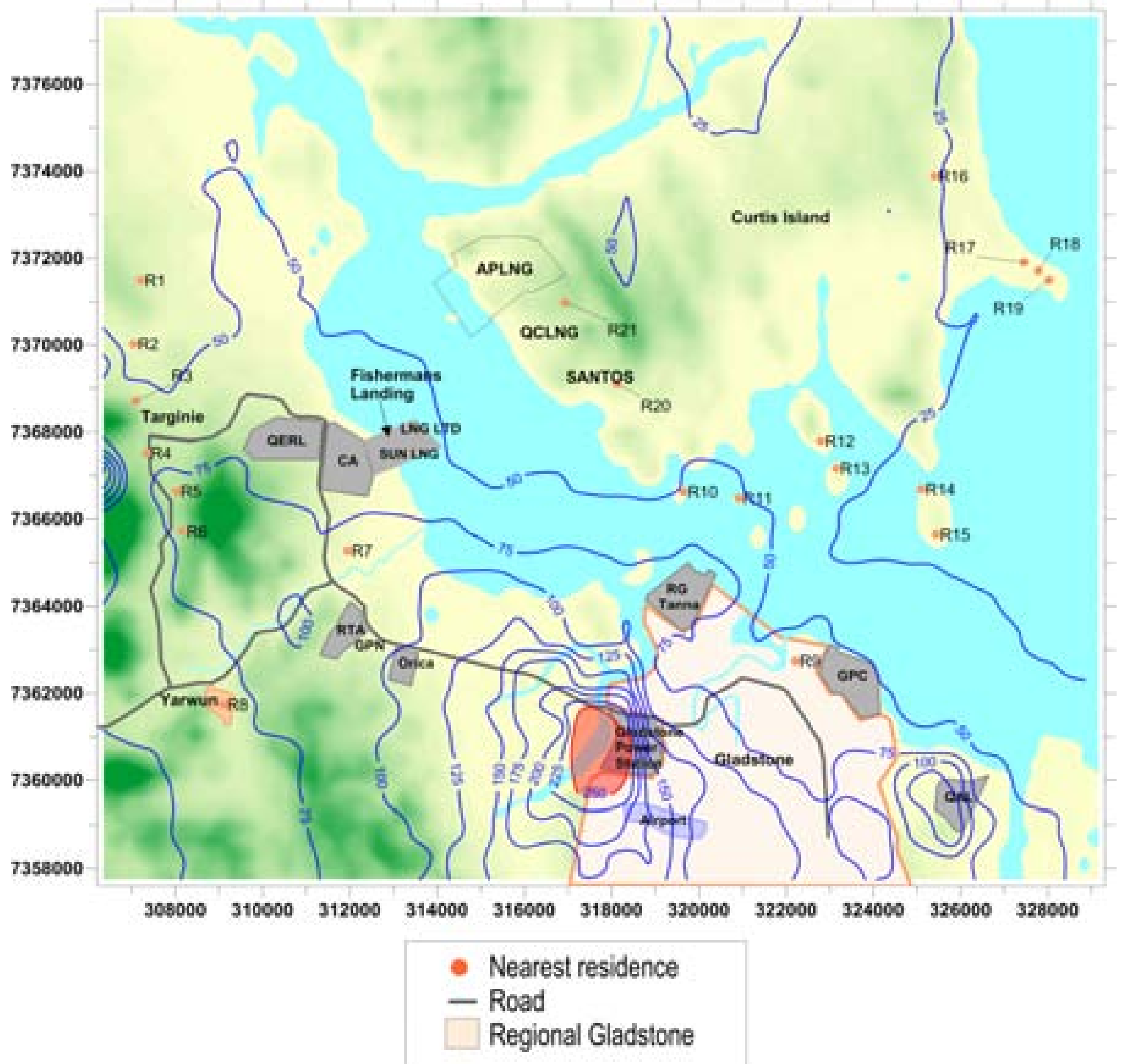

Figure 15 Scenario 1 - Predicted maximum 1-hour average ground-level concentrations of nitrogen dioxide for the LNG facility during normal operations, with GAMSv3 background

Location:	**Averaging period:**	**Data source:**	**Units:**
APLNG project area, Gladstone	1-hour	CALPUFF and GAMSv3	µg/m³
Type:	**Air quality objective:**	**Prepared by:**	**Date:**
NO_2 maximum (99.9th percentile) 1-hour average contour plot	Health and wellbeing: 250 µg/m³	S. Menzel and A. Schloss	December 2009

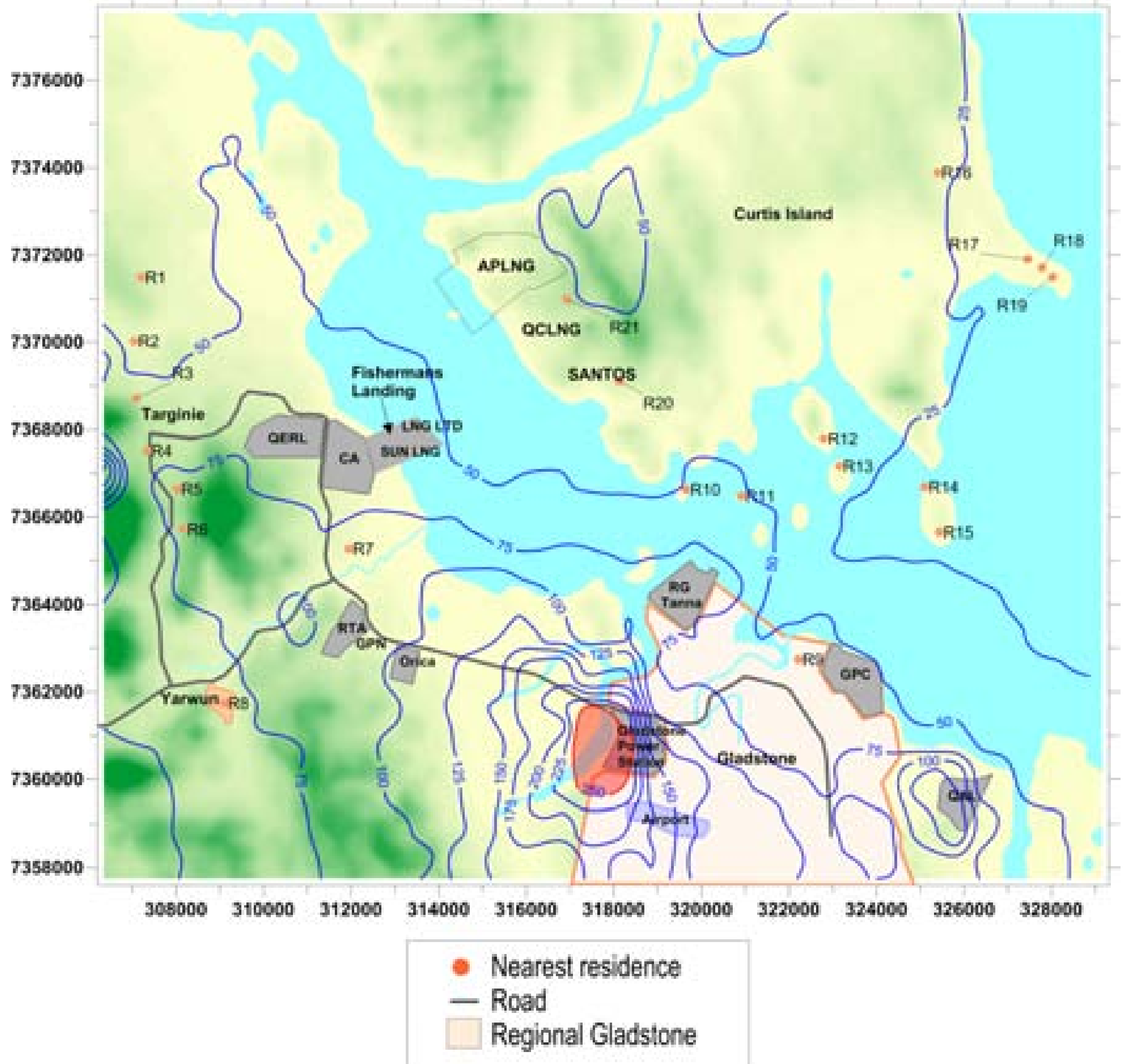

Figure 16 Scenario 1 - Predicted maximum 1-hour average ground-level concentrations of nitrogen dioxide for the LNG facility during normal operations, with GAMSv3 background plus all other LNG plants

Location: APLNG project area, Gladstone	**Averaging period:** 1-hour	**Data source:** CALPUFF and GAMSv3	**Units:** µg/m³
Type: NO_2 maximum (99.9th percentile) 1-hour average contour plot	**Air quality objectives:** Health and wellbeing: 250 µg/m³	**Prepared by:** S. Menzel and A. Schloss	**Date:** December 2009

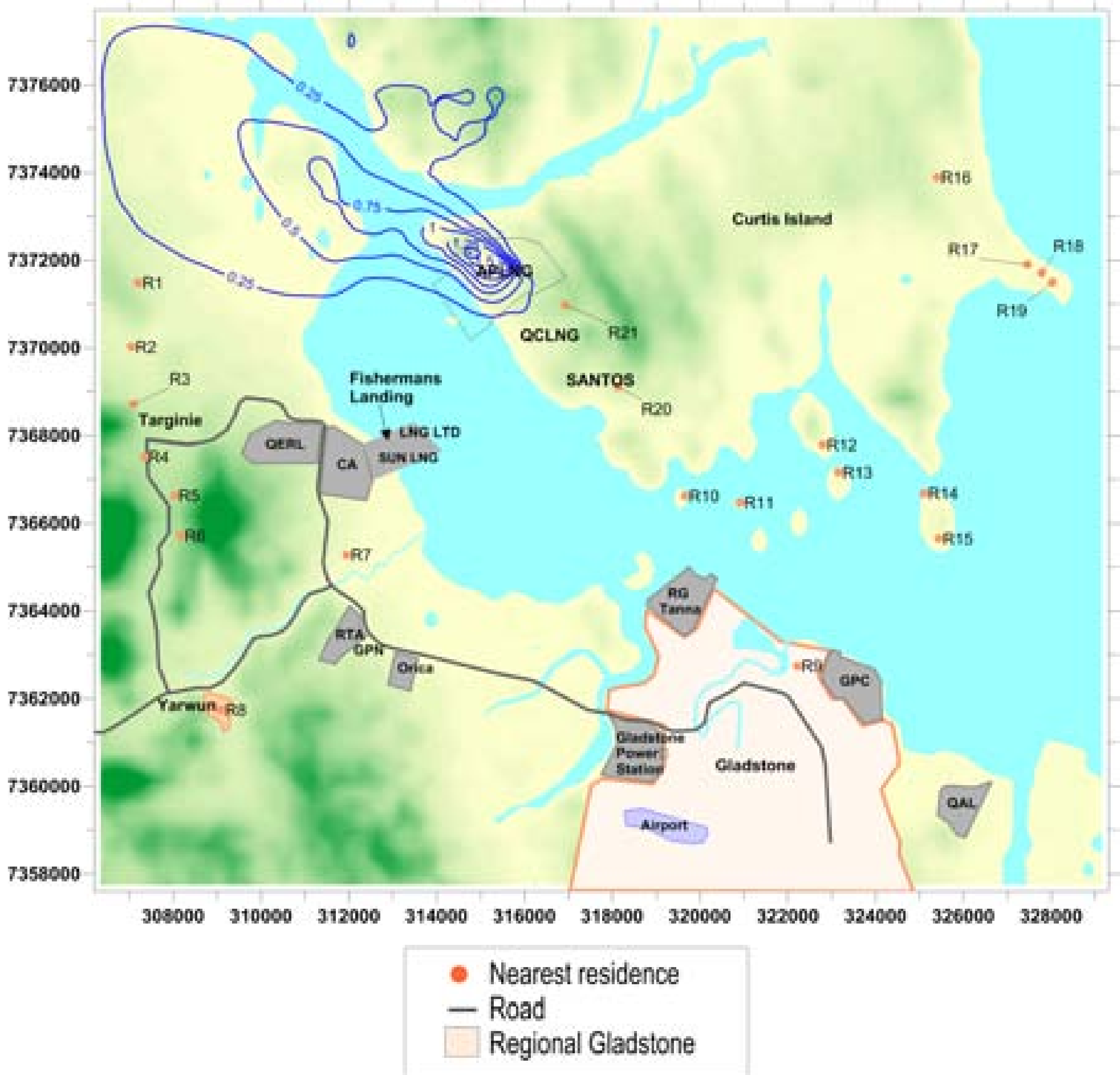

Figure 17 Scenario 1 - Predicted annual average ground-level concentrations of nitrogen dioxide for the LNG facility during normal operations, in isolation

Location: APLNG project area, Gladstone	**Averaging period:** Annual	**Data source:** CALPUFF	**Units:** µg/m³ and metres
Type: NO_2 annual average contour plot	**Air quality objectives:** Health and wellbeing: 62 µg/m³ Health and Biodiversity of ecosystems: 33 µg/m³	**Prepared by:** S. Menzel and A. Schloss	**Date:** December 2009

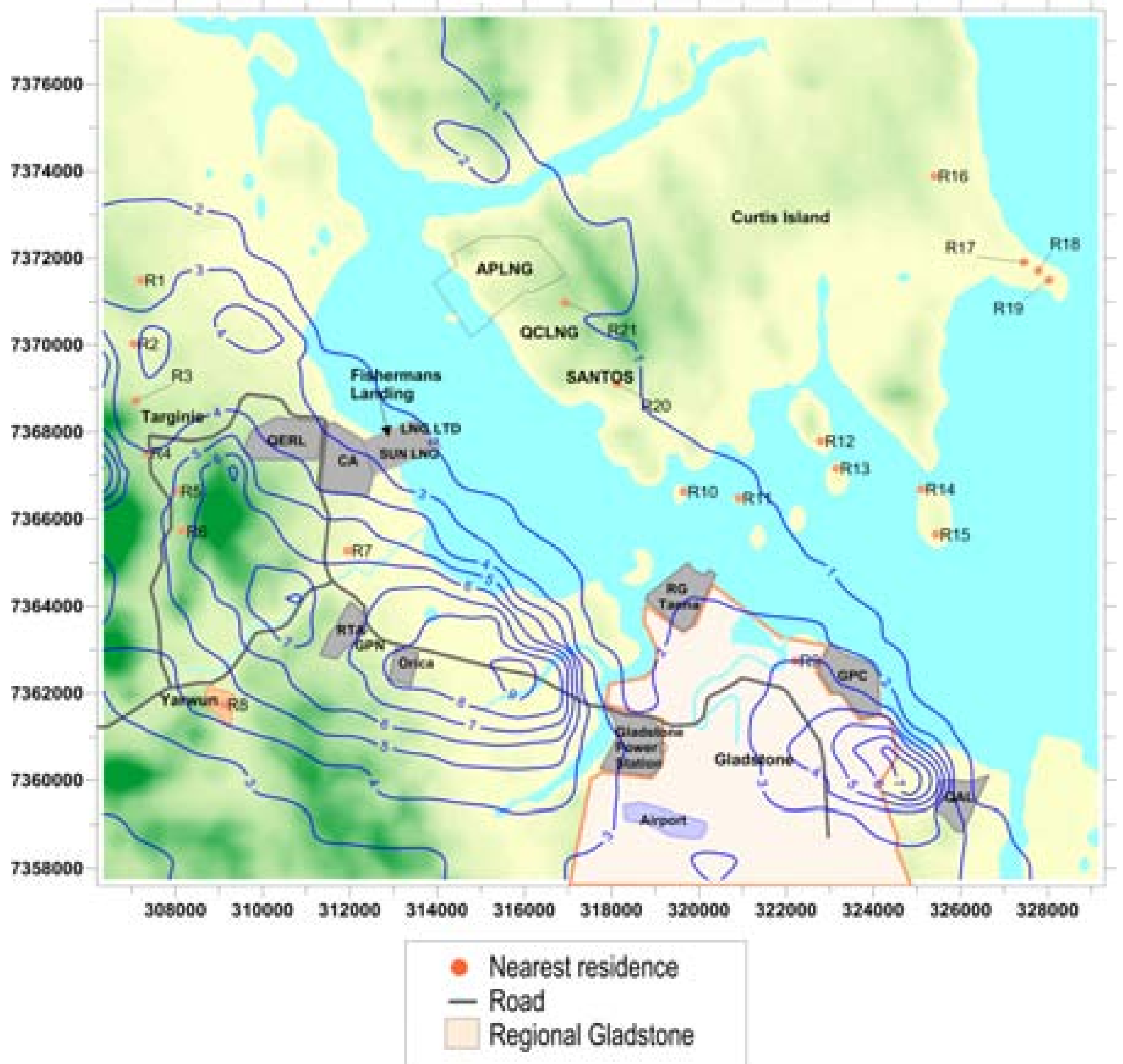

Figure 18 Scenario 1 - Predicted annual average ground-level concentrations of nitrogen dioxide for the LNG facility during normal operations, with GAMSv3 background

Location:	**Averaging period:**	**Data source:**	**Units:**
APLNG project area, Gladstone	Annual	CALPUFF and GAMSv3	µg/m³
Type:	**Air quality objectives:**	**Prepared by:**	**Date:**
NO_2 annual average contour plot	Health and wellbeing: 62 µg/m³ Health and Biodiversity of ecosystems: 33 µg/m³	S. Menzel and A. Schloss	December 2009

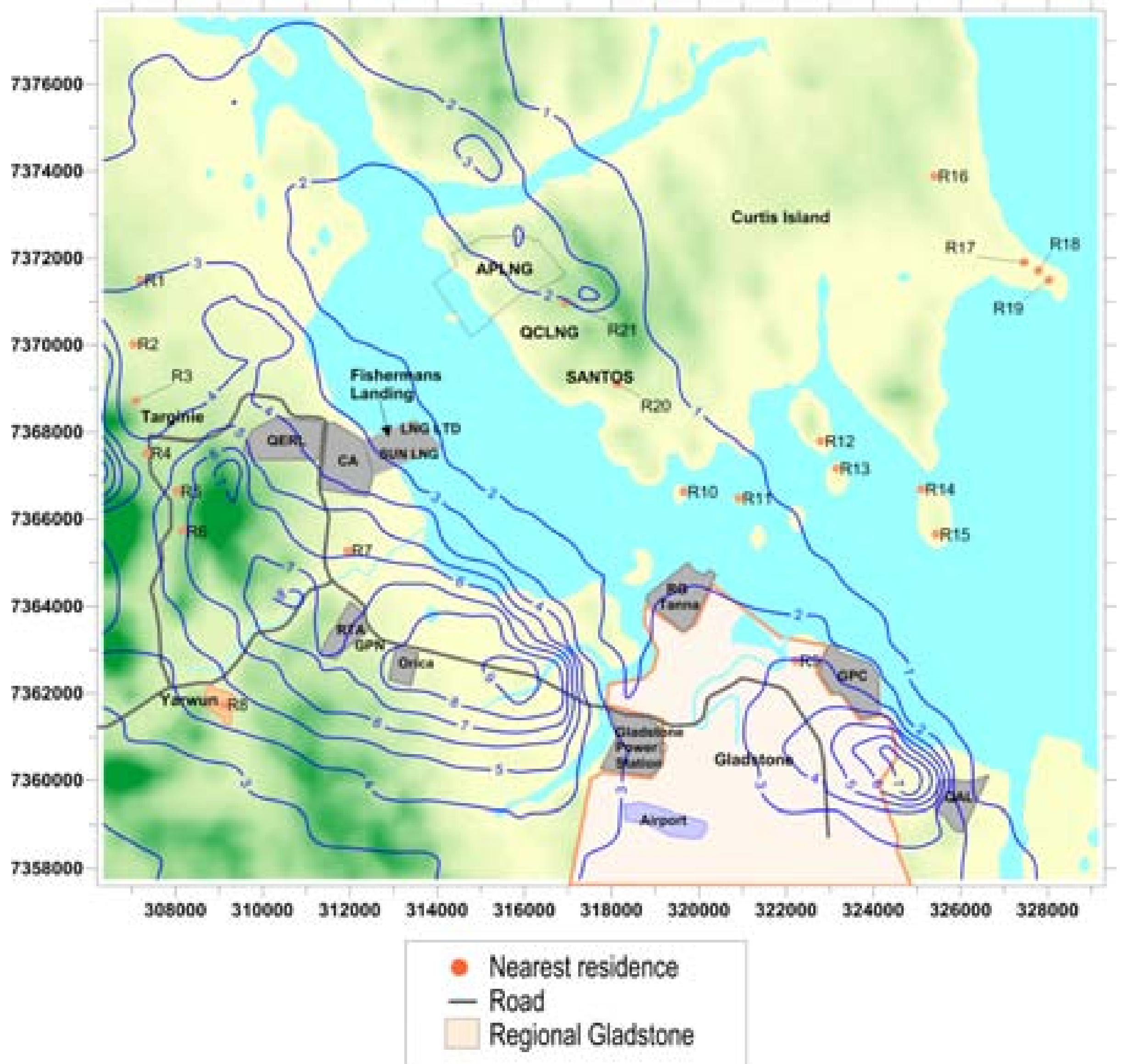

Figure 19 Scenario 1 - Predicted annual average ground-level concentrations of nitrogen dioxide for the LNG facility during normal operations, with GAMSv3 background plus all other LNG plants

Location: APLNG project area, Gladstone	**Averaging period:** Annual	**Data source:** CALPUFF and GAMSv3	**Units:** µg/m³
Type: NO_2 annual average contour plot	**Air quality objectives:** Health and wellbeing: 62 µg/m³ Health and Biodiversity of ecosystems: 33 µg/m³	**Prepared by:** S. Menzel and A. Schloss	**Date:** December 2009

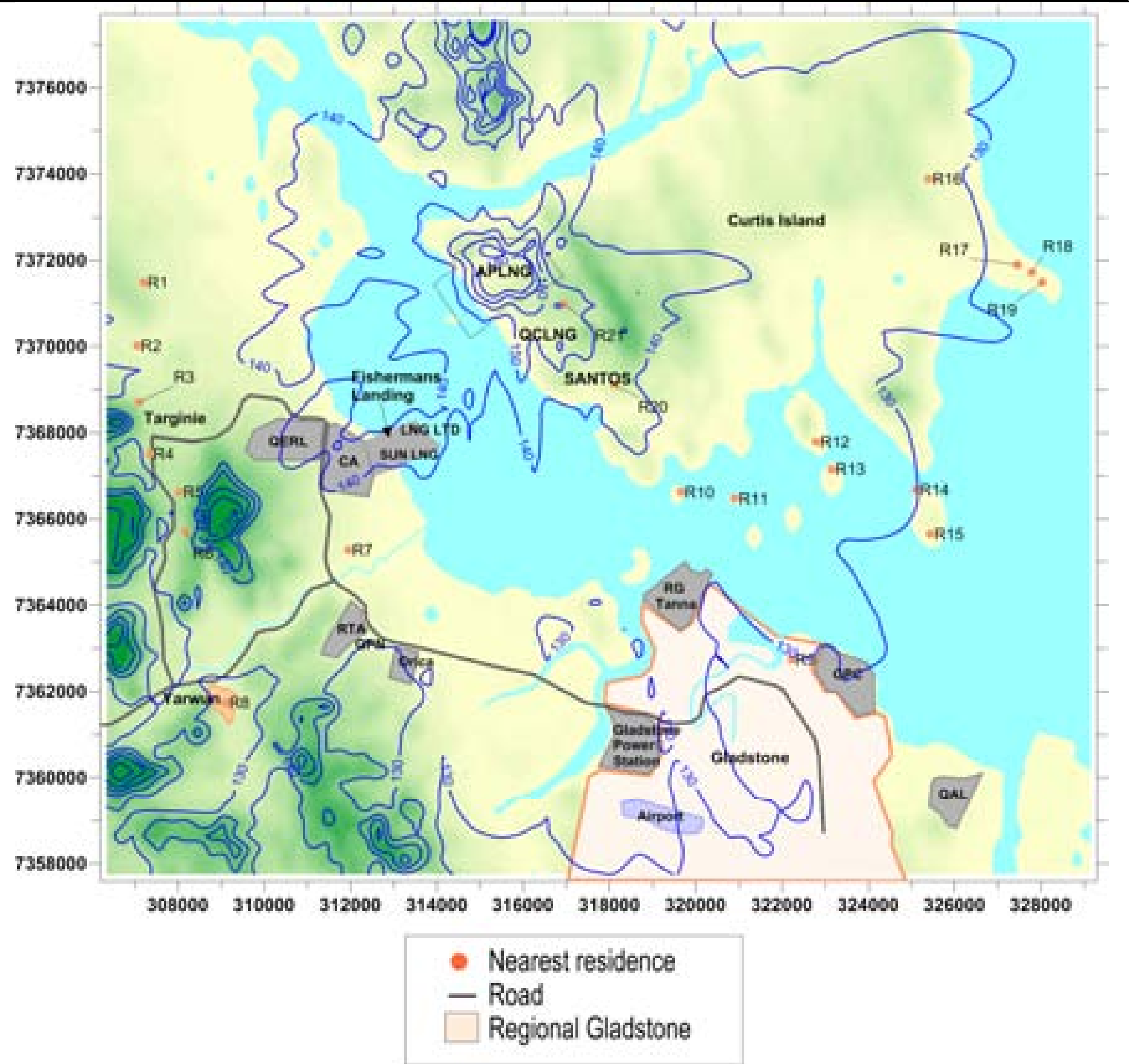

Figure 20 Scenario 1 - Predicted maximum 8-hour average ground-level concentrations of carbon monoxide for the LNG facility during normal operations, with background

Location: APLNG project area, Gladstone	**Averaging period:** 8-hour	**Data source:** CALPUFF	**Units:** µg/m³
Type: CO maximum 8-hour average contour plot	**Air quality objective:** Health and wellbeing: 11,000 µg/m³	**Prepared by:** S. Menzel and A. Schloss	**Date:** December 2009

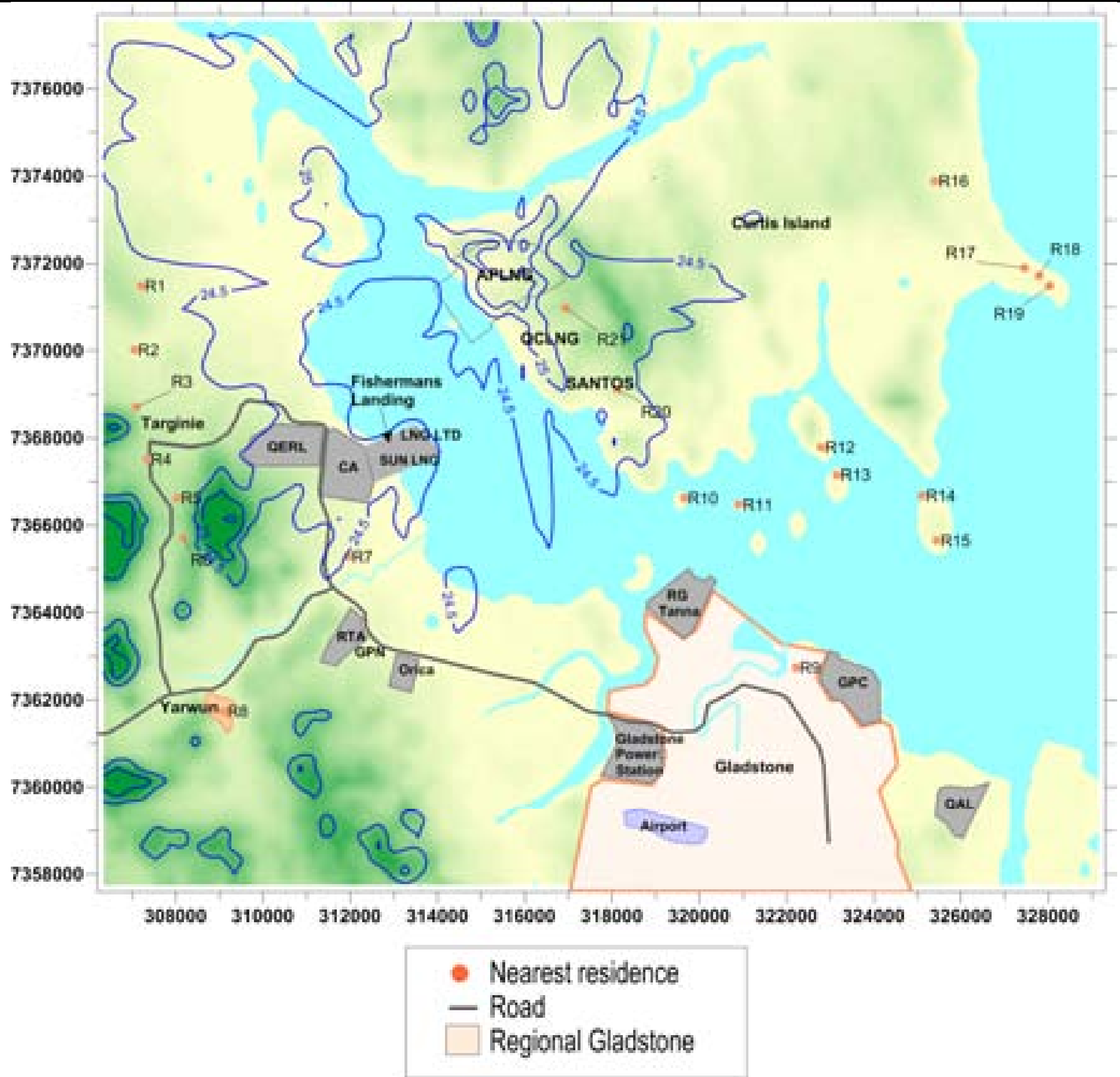

Figure 21 Scenario 1 - Predicted maximum 24-hour average ground-level concentrations of PM_{10} for the LNG facility during normal operations, with background

Location: APLNG project area, Gladstone	**Averaging period:** 24-hour	**Data source:** CALPUFF	**Units:** µg/m³
Type: PM_{10} maximum 24-hour average contour plot	**Air quality objective:** Health and wellbeing: 50 µg/m³	**Prepared by:** S. Menzel and A. Schloss	**Date:** December 2009

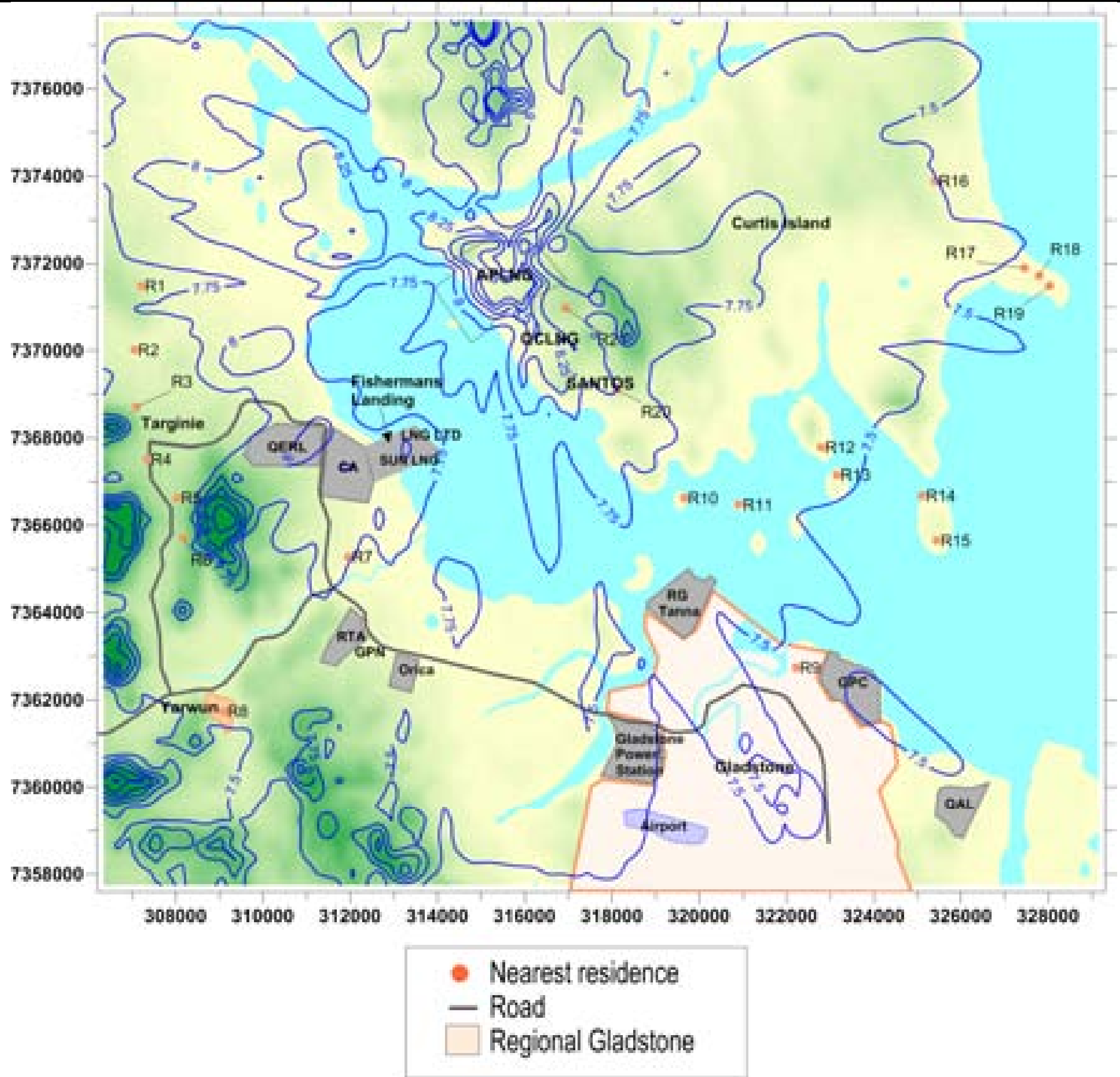

Figure 22 **Scenario 1 - Predicted maximum 24-hour average ground-level concentrations of $PM_{2.5}$ for the LNG facility during normal operations, with background**

Location: APLNG project area, Gladstone	**Averaging period:** 24-hour	**Data source:** CALPUFF	**Units:** µg/m³
Type: $PM_{2.5}$ maximum 24-hour average contour plot	**Air quality objective:** Health and wellbeing: 25 µg/m³	**Prepared by:** S. Menzel and A. Schloss	**Date:** December 2009

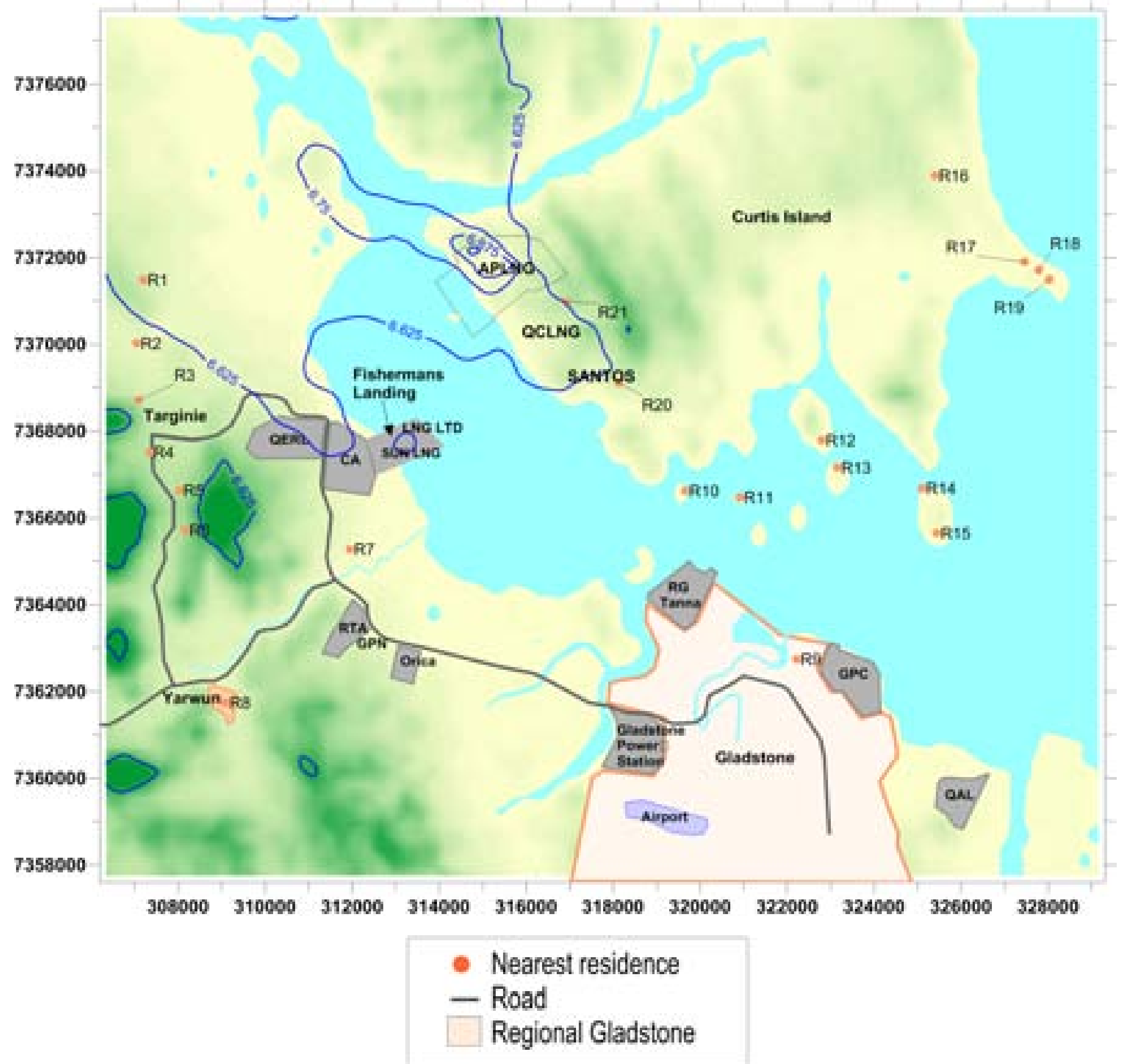

Figure 23 Scenario 1 - Predicted annual average ground-level concentrations of $PM_{2.5}$ for the LNG facility during normal operations, with background

Location: APLNG project area, Gladstone	**Averaging period:** Annual	**Data source:** CALPUFF	**Units:** µg/m³
Type: $PM_{2.5}$ contour plot	**Air quality objective:** Health and wellbeing: 8 µg/m³	**Prepared by:** S. Menzel and A. Schloss	**Date:** December 2009

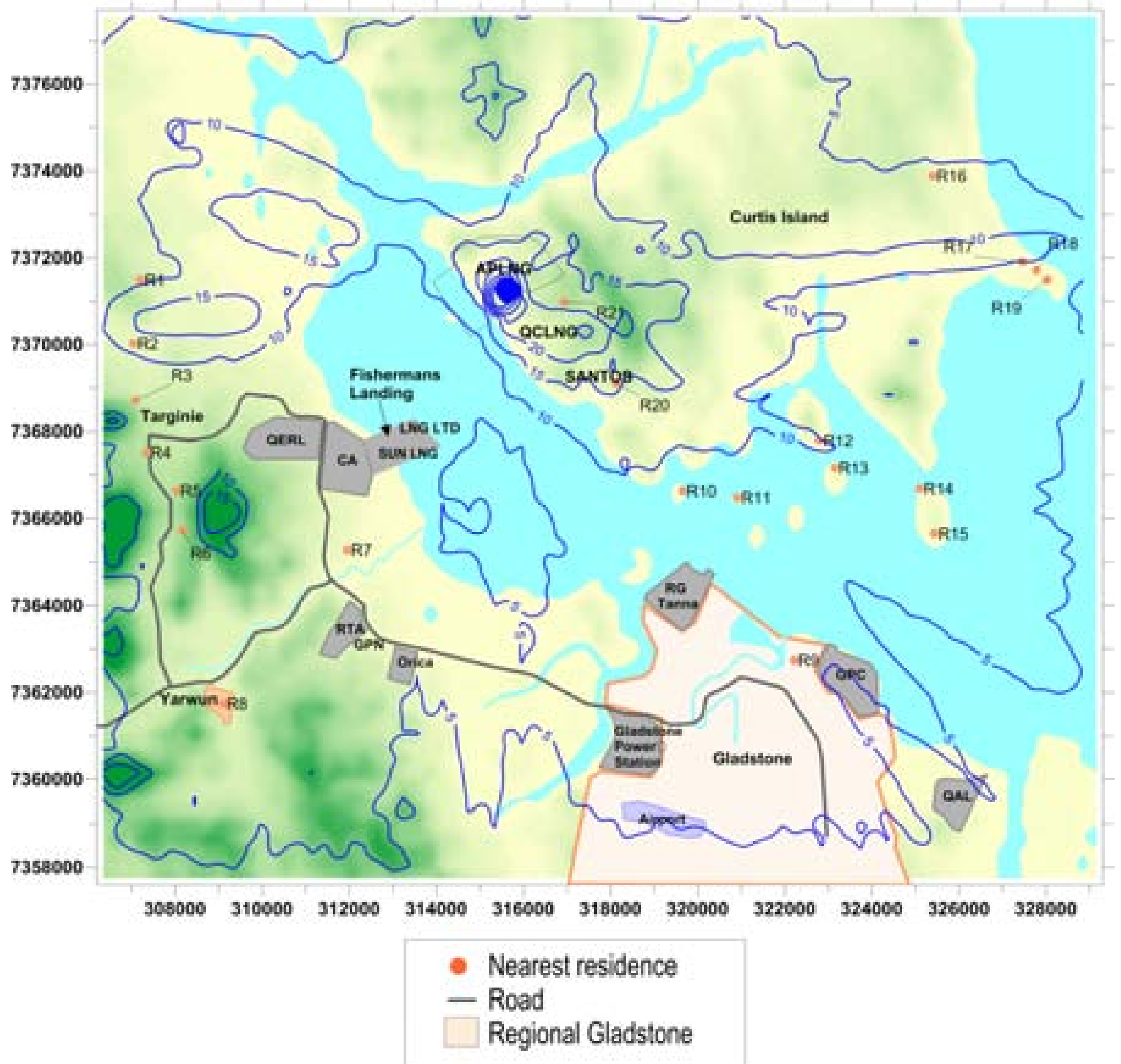

Figure 24 Scenario 2 - Predicted maximum 1-hour average ground-level concentrations of nitrogen dioxide for the APLNG flares, in isolation

Location:	Averaging period:	Data source:	Units:
APLNG project area, Gladstone	1-hour	CALPUFF	µg/m³
Type:	**Air quality objective:**	**Prepared by:**	**Date:**
NO_2 maximum (99.9 percentile) 1-hour average contour plot	Health and wellbeing: 250 µg/m³	S. Menzel and A. Schloss	December 2009

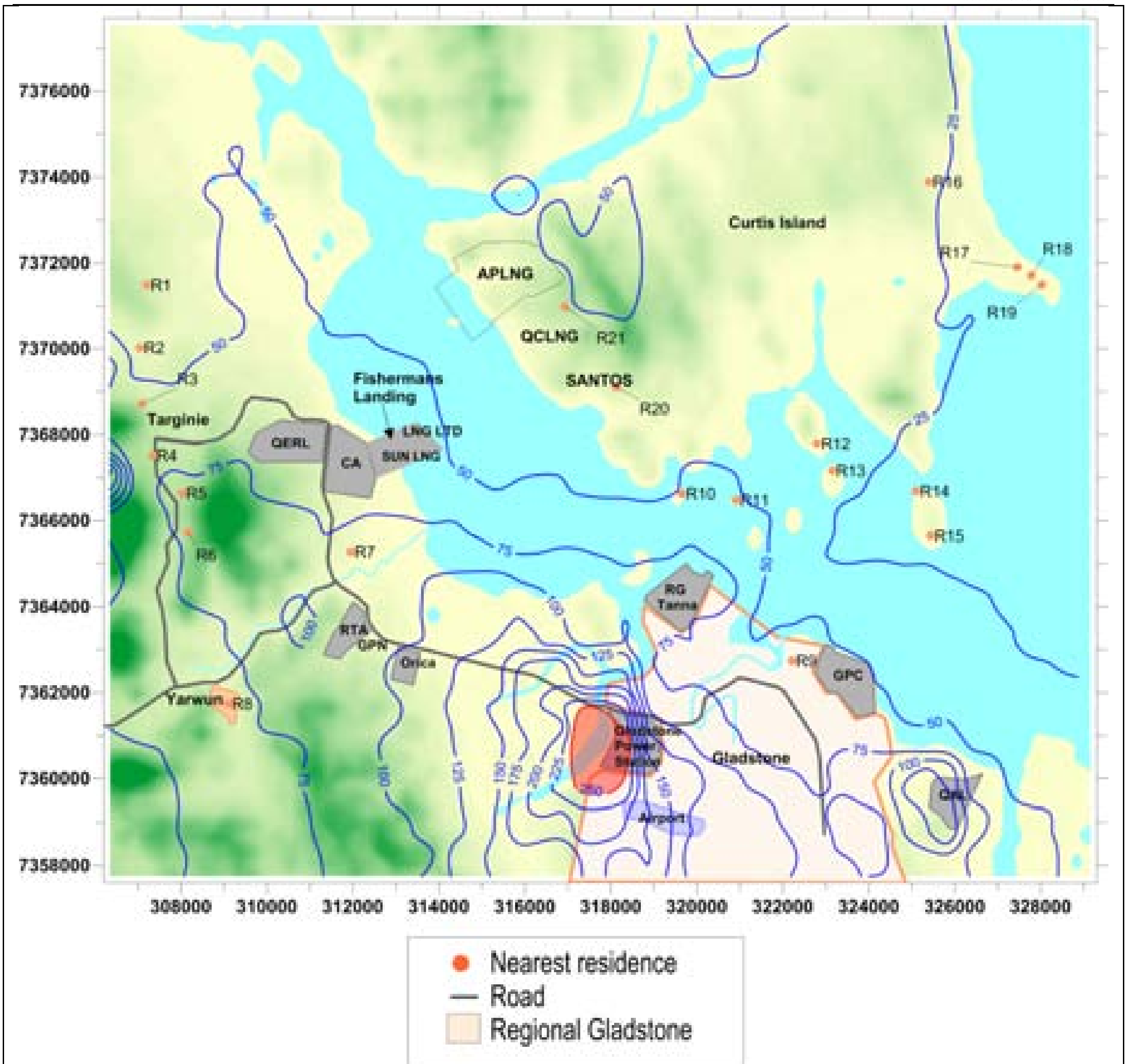

Figure 25 Scenario 2 - Predicted maximum 1-hour average ground-level concentrations of nitrogen dioxide for the APLNG flares, with GAMSv3 background plus all other LNG plants

Location: APLNG project area, Gladstone	**Averaging period:** 1-hour	**Data source:** CALPUFF and GAMSv3	**Units:** µg/m³
Type: NO_2 maximum (99.9th percentile) 1-hour average contour plot	**Air quality objective:** Health and wellbeing: 250 µg/m³	**Prepared by:** S. Menzel and A. Schloss	**Date:** December 2009

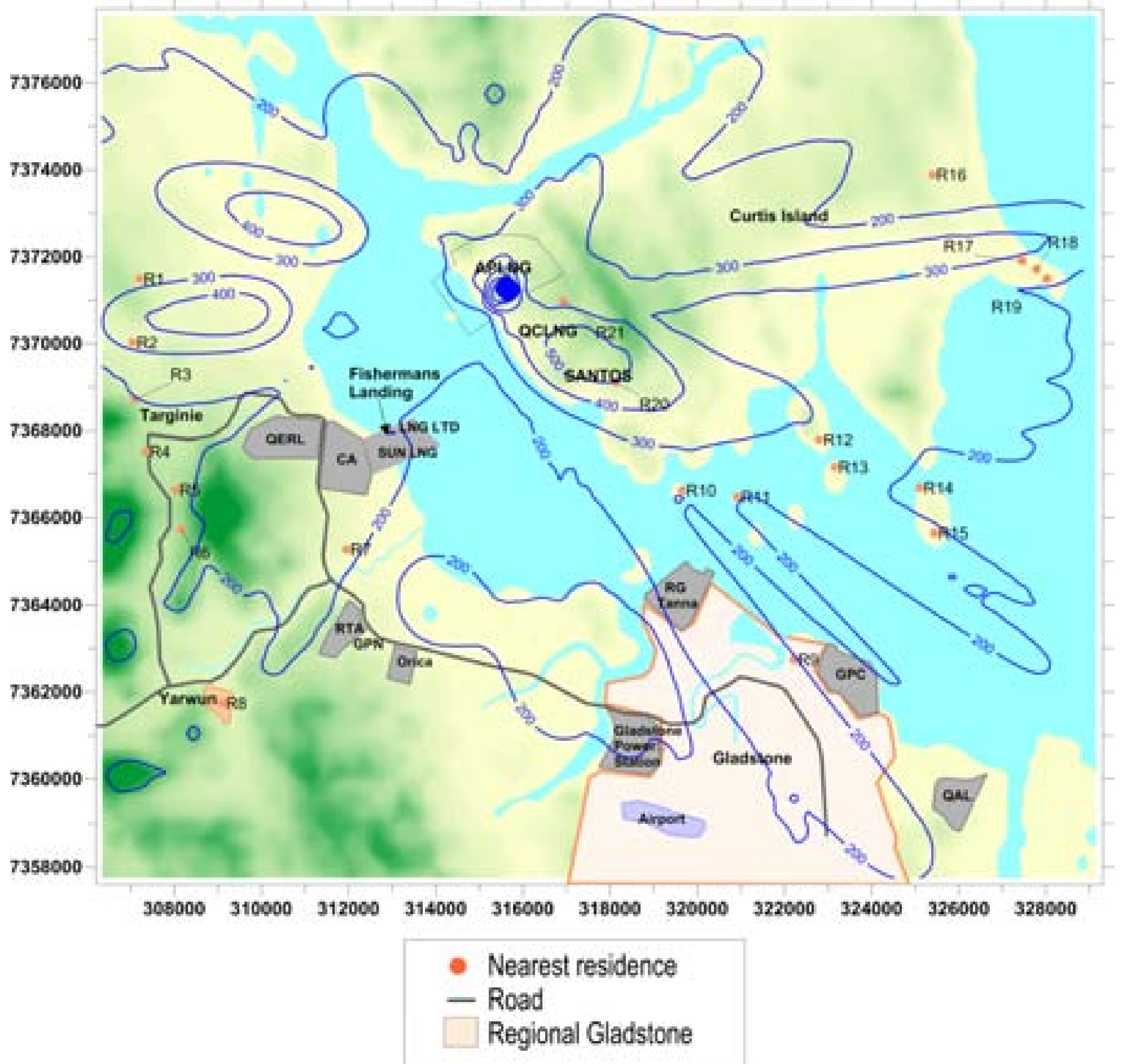

Figure 26 Scenario 2 - Predicted maximum 8-hour average ground-level concentrations of carbon monoxide for the APLNG flares with background

Location: APLNG project area, Gladstone	**Averaging period:** 8-hour	**Data source:** CALPUFF	**Units:** µg/m³
Type: CO maximum 8-hour average contour plot	**Air quality objective:** Health and wellbeing: 11,000 µg/m³	**Prepared by:** S. Menzel and A. Schloss	**Date:** December 2009

APPENDIX A

RELEVANT AMBIENT AIR QUALITY OBJECTIVES AND STANDARDS FOR HYDROCARBONS ASSESSED FOR THE LNG FACILITY

January 2010

Table A1 Relevant ambient air quality objectives and standards for hydrocarbons

Indicator	Environmental value	Averaging period	Air quality objective or standard (µg/m³)	Source
Acenaphthene (Ethylene naphthalene)	Health	1-hour	1	TCEQ
Acenaphthylene (as acenaphthene)	Health	1-hour	1	TCEQ
Acetaldehyde	Toxicity (odour based)	3-minute	5,900	Vic SEPP
Acetylene	Health	1-hour	26,600	TCEQ
Acrolein	Toxicity (Class 3)	3-minute	0.77	Vic SEPP
Anthracene	Health	1-hour	0.5	TCEQ
Benz(a)anthracene	Health	1-hour	0.5	TCEQ
Benzene	Health and wellbeing	1-hour	29	NSW DECC
		1-year	10	EPP(Air)
Benzo(a)pyrene	Health and wellbeing	1-year	0.0003	EPP(Air)
Benzo(b)fluoranthene	Health	1-hour	0.5	TCEQ
Benzo(g, h, i,)perylene	Health	1-hour	0.5	TCEQ
Benzo(k)fluoranthene	Health	1-hour	0.5	TCEQ
1,3 Butadiene	Health and wellbeing	1-year	2.4	EPP(Air)
Butane	Occupational environment	8-hour	1,900,000	NOHSC:1003
Chrysene	Health	1-hour	0.5	TCEQ
Dibenzo(a, h)anthracene (as acenaphthene)	Health	1-hour	0.5	TCEQ
Dichlorobenzene, m-	Health	1-hour	2,500	TCEQ
Dichlorobenzene, o-	Health	1-hour	600	TCEQ
Dichlorobenzene, p-	Health	1-hour	600	TCEQ
7,12-Dimethylbenz(a)anthracene	Health	1-hour	0.5	TCEQ
Ethane	Health	1-hour	12,000	TCEQ
Ethylbenzene	Health and wellbeing	1-hour	8,000	NSW DECC
Fluoranthene (Benzo(j, k)fluorene)	Health	1-hour	0.5[1]	TCEQ
Fluorene	Health	1-hour	0.5[2]	TCEQ

Indicator	Environmental value	Averaging period	Air quality objective or standard (µg/m³)	Source
Formaldehyde	Health and wellbeing	24-hour	54	EPP(Air)
	Protecting aesthetic environment	30-minute	110	EPP(Air)
Hexane	Health and wellbeing	1-hour	3,200	NSW DECC
Indeno(1, 2, 3-cd)pyrene	Health	1-hour	0.5	TCEQ
2-Methylnaphthalene	Odour	1-hour	60	TCEQ
3-Methylchloranthrene	Odour	1-hour	60	TCEQ
Naphthalene	Occupational environment	8-hour	52,000	NOHSC:1003
Pentane	Health and wellbeing	1-hour	33,000	NSW DECC
Phenanthrene	Health	1-hour	0.5	TCEQ
Propane	Health	1-hour	18,000	TCEQ
Propylene	Health	1-hour	8,750	TCEQ
Propylene oxide				
Pyrene	Health	1-hour	0.5	TCEQ
Toluene	Health and wellbeing	24-hour	4,100	EPP(Air)
		1-year	410	EPP(Air)
	Protecting aesthetic environment	30-minutes	1,100	EPP(Air)
Xylenes	Health and wellbeing	24-hour	1,200	EPP(Air)
		1-year	950	EPP(Air)

Table note:
[1] Air quality objective not found: Fluoranthene (or Benzo(j, k)fluorene) is a polycyclic aromatic hydrocarbon (PAH) and a structural isomer of the alternant PAH pyrene. Consequently, the same 1-hour average air quality objective of 0.5 µg/m^3 has been applied for this assessment.
[2] Air quality objective not found: Fluorene is a PAH, and consequently, in line with other PAHs referenced by the TCEQ Effects Screening Levels an air quality objective of 0.5 µg/m^3 has been applied for this assessment.

APPENDIX B
GAMS V3 MODEL EVALUATION

January 2010

Contents

Tables

Figures

B1. GAMSv3 Methodology

The performance of the dispersion and meteorological modelling methodology was extensively evaluated for accuracy and precision in regards to predicting the meteorology parameters and ground-level concentrations of air pollutants during the development of the Gladstone Airshed Modelling System Version 3 (GAMSv3). The TAPM generated three-dimensional meteorological files were taken from the GAMSv3 model and used to initialise the refined CALMET model for Curtis Island. Figure B1 illustrates the GAMSv3 modelling domain and APLNG CALMET modelling domain. The GAMSv3 meteorological fields show exceptional skill in simulating the wind fields and dispersion characteristics throughout the modelled Gladstone airshed.

Seven meteorological stations, summarised in Table B1, were used in the evaluation of the GAMSv3. Three sites, Gladstone Radar (GLR), Boyne Smelter (BOY), and Targinie Swanns Road (YAR) were assimilated into the TAPM model, while the remaining sites, Auckland Point (AUP), Aldoga (ALD), South Gladstone (QAL) and Clinton (CLI), were used for evaluation purposes. The locations of the assimilation and evaluation monitoring stations used in the development and validation of the GAMSv3 are also presented in Figure B1.

Table B1 Names, locations and heights above ground in metres of meteorological stations within the modelling domain

Station	Code	Easting (km)	Northing (km)	Height (m)	Elevation (m)
Auckland Point (GPCL)	AUP	322.065	7362.865	10	10
Gladstone Airport/Clinton (BoM/EPA)	CLI	318.719	7359.178	10	15
South Gladstone Ann St (EPA)	QAL	323.742	7359.988	10	5
Targinie Swanns Rd (EPA)	YAR	306.949	7369.454	10	47
Aldoga (EPA)	ALD	302.697	7362.093	10	62
Gladstone Radar (BoM)	GLR	322.005	7359.024	10	98
Boyne Smelter (BSL)	BOY	331.879	7352.131	30	2

B2. Meteorological Model Performance Evaluation

Table B2 shows the performance statistics of the GAMSv3 meteorology at the four evaluation sites. Wind direction has been separated into its vector components of easting (u) and northing (v) by:

u = - wind speed x sin (wind direction)
and
v = - wind speed x cos (wind direction)

The vector correlation method described by Breaker *et al*. (1994) to measure the accuracy of wind direction was also applied. The method accounts for the magnitude (wind speed) and phase (wind direction) in unison, where a magnitude of 1 is a 100% correlation, and the phase is the counter clockwise rotation of the wind direction in degrees. Further description of the correlation statistics used in the model evaluation is provided in Appendix B.

Table B2 Performance statistics of predicted versus observed wind speed (WS) and wind direction vector components U and V

Location	Variable	rmse	rmse_s	rmse_u	IOA	SE	SV	SR	MAE	Vector correlation (magnitude, phase)
AUP	WS	2	1.5	1.3	0.82	0.5	0.8	0.8	1.6	0.92, -12.46
	U	1.9	1.3	1.4	0.93	0.3	0.8	0.5	1.5	-
	V	2	1.5	1.3	0.87	0.4	0.7	0.6	1.5	-
ALD	WS	1.8	1.5	0.9	0.75	0.4	0.5	0.7	1.5	0.8, -7.3
	U	1.6	1.1	1.2	0.85	0.5	0.7	0.6	1.3	-
	V	1.5	1.1	1.03	0.73	0.6	0.8	0.9	1.2	-
CLI	WS	1.2	0.9	0.8	0.87	0.4	0.7	0.6	1	0.92, 3.26
	U	1.2	1.3	1.4	0.94	0.5	0. 9	0.5	0.97	-
	V	1.1	1	1.3	0.93	0.7	1.1	0.6	0.83	-
QAL	WS	0.9	0.4	0.8	0.86	0.7	1.1	0.8	0.7	0.86, 16
	U	1.3	0.6	1.1	0.86	0.7	1.2	0.8	1.01	-
	V	1.2	0.7	1	0.85	0.5	0.8	0.7	0.9	-

AUP: Auckland Point
ALD: Aldoga
CLI: Clinton
QAL: South Gladstone near QAL
rmse: root mean square error
rmse_s: root mean square error
rmse_u: root mean square error
ioa: index of agreement
se: unsystematic RMSE/obs standard deviation
sv: mod standard deviation/obs standard deviation
sr: RMSE/obs standard deviation
MAE: Mean Absolute Error

The performance evaluation shows that the model accurately characterises the meteorology within the modelling domain, with high correlations and indexes of agreement between observed and modelled variables. Model error has been minimised and is well within the recommended factor of two evaluation threshold (NIWA, 2004). The RMSE error was also found below the standard deviation of the observed variables indicating that the model errors are within the natural degree of variability to be expected in the observations.

These results give confidence the modelled wind fields and dispersion characteristics in areas where observational data is sparse or non-existent, such as Curtis Island, would be reliable and accurate representation of reality.

Figure B2 and Figure B3 illustrate the refined terrain and land use data files respectively, adapted for input to the GAMSv3.

B3. Pollution Model Performance Evaluation

A similar approach for assessing the accuracy of model predictions for wind speed and direction was employed for ground-level concentration of SO_2 and NO_x. Particular attention was paid to the high end of the distribution as these predictions are most relevant to intended use of GAMSv3.

Table B3 and Table B4 show the summary statistics of the observed and modelled datasets. It is apparent that the model tends to over predict average ground-level concentrations at CLI and QAL, while YAR shows a slight under prediction of the mean. The observed standard deviation of SO_2 at the CLI is 17 while the model results indicate a standard deviation of 83, this means that the modelled concentrations display a large amount of variability and partially explains the abnormally high maximum one hour concentration of 600 µg/m^3 compared to the observed maximum of 207 µg/m^3. The NO_x statistics display a similar relationship as does the results of for NO_x at the QAL monitor, where an over prediction of the standard deviation appears to coincide with an over prediction of the mean and maximum.

Table B3 Summary Statistics for observed and modelled sulphur dioxide (SO_2)

Site	Variable	Average	Standard deviation	Min	Max	Number of Observations
CLI	OBS_SO2	19.3	17.01	10.01	207.4	600
	MOD_SO2	58.1	83.1	15.2	600.9	600
QAL	OBS_SO2	31.2	31.1	10.01	266.01	1577
	MOD_SO2	45.2	18.8	24.7	215.1	1577
YAR	OBS_SO2	29.6	18.7	10.01	130.2	1282
	MOD_SO2	24.2	20.5	6.4	154.5	1282

Table B4 Summary Statistics for observed and modelled nitrogen oxide (NO_x)

Site	Variable	Average	Standard deviation	Min	Max	Number of Observations
CLI	OBS_NOx	34.2	21	18.7	173.6	1056
	MOD_NOx	51.3	88.5	10.01	805.9	1056
QAL	OBS_NOx	31.8	29.1	10.1	245.2	2861
	MOD_NOx	63.9	46.2	6.9	467	2861
YAR	OBS_NOx	31.1	20.5	10.2	237.4	2241
	MOD_NOx	27.9	21.9	8.3	190.5	2241

Figure B4 and Figure B5 show the mean, 95th, 98th, 99th, 99.9th percentiles, robust highest concentration (RHC) and the maximum one hour observed and modelled ground-level concentration at the three sites. GAMSv3 does a good job of simulating the distribution at the top end of the concentration spectrum at the three sites. Modelled SO_2 and NO_x is significantly higher than the observations at the CLI location, while SO_2 is slightly under predicted at QAL but NO_x is significantly over predicted. YAR shows the closest relationship with means, standard deviations and maximum being very close to the observed.

Table B5 shows the performance statistics of the models predictions of ground-level SO_2 and NO_x concentrations at YAR, CLI and QAL. The RMSE for CLI and QAL were quite high,

with the majority of the error being systematic. This means that errors in the model prediction are due to inherent limitations of the model set up or the emission inventory. The relatively coarse final resolution of the model and the proximity of the monitoring stations to significant sources are most likely responsible for these large errors. YAR scored a relatively low RMSE with an SO_2 systematic error of 5.7 μg/m^3 and an unsystematic error of 2.9 μg/m^3. The reverse situation was found for NO_x errors with the unsystematic error being nearly twice that of the systematic. This implies that there is a small but significant amount of variability in the observed NO_x that is not being taken into account by the model. It is thought that this may be due to ship emissions originating from the port. QAL and YAR both scored IOA's for SO_2 and NO_x close 0.8 and 0.9. CLI scored an IOA's of 0.5 and 0.6 for SO_2 and NO_x, respectively. Skill measures showed encouraging results for QAL and YAR with good SE and SR scores. Skill measures for CLI indicate that the model predictions vary significantly from the observed dataset, particularly at the high end of the distribution where the model is consistently a factor of 2 above the observed.

The model displayed a good ability to predict hourly averaged ground-level concentrations throughout the modelling domain within a factor of the 2 of the observations (FAC2). YAR performed the best with nearly 80% of SO_2 to 100% of NO_X predictions falling within a factor of 2 of the observations. CLI also performed well with 68% and 92% of SO_2 and NO_x predictions also being within a factor of two. QAL showed the poorest performance with less than 50% of the predictions being with a factor of 2. The derivation of false negative and false positive scores helps illustrate the conservative nature of the model. The FBfn is the fractional bias of all predictions that are below the observations while the FBfp is the fractional bias of predictions that are above the predictions. Simply this gives a better interpretation of the fractional bias by determining what proportion of the bias is an under prediction and what is an over prediction. For a conservative model a bias towards a false positive is desirable. YAR has a very low FBfn and FBfp meaning that the under and over predictions are minimal, illustrated by the low (0.5, -3.3 μg/m^3) ME for SO_2 and NO_x respectively. QAL and CLI have significantly larger proportion of false positives and a large ME values (QAL NO_x ME = 54 4 μg/m^3), indicating a mean over prediction of 54 μg/m^3.

Table B5 Performance statistics predicted versus observed sulphur dioxide (SO_2) and nitrogen oxide (NO_x)

Parameter	CLI_SO2	QAL_SO2	YAR_SO2	CLI_NOx	QAL_NOx	YAR_NOx
intercept	-32.68	26.86	-7.97	-86.95	17.31	-4.29
slope	4.70	0.59	1.09	4.04	1.47	1.03
rmse	77.24	19.52	6.37	70.71	39.07	6.55
rmse_s	73.88	18.96	5.67	66.14	34.85	3.32
rmse_u	22.54	4.64	2.91	24.99	17.69	5.64
IOA	0.48	0.86	0.97	0.59	0.78	0.98
se	1.32	0.15	0.16	1.19	0.61	0.28
sv	4.88	0.61	1.10	4.22	1.59	1.07
sr	4.54	0.63	0.34	3.37	1.34	0.32
MAE	38.75	18.51	5.90	23.92	54.46	7.96
FB	1.23	0.37	-0.20	1.17	0.67	-0.11
ME	38.75	4.71	0.53	17.15	54.46	-3.25
NMSE	5.33	0.26	0.06	2.85	1.49	0.10
FAC2	0.68	0.43	0.78	0.92	0.44	1.00
FBfn	0	0.06	0.211	0.08	0.003	0.133

FBfp	1	0.425	0.009	0.48	0.674	0.023

Cumulative frequency distribution plots (Figure B6 and Figure B7) show the 99.99th , 99.97th, 99.93th, 99.9th, 99.84th, 99.75th, 99.6th, 99.5th, 99.37th, 99th, 98.3th, 97.1th, 95th, 93th, 90th, 80th percentile observed versus modelled SO_2 and NO_x concentrations. There is good agreement at the YAR and QAL sites, with predictions at CLI being consistently high by a factor of 2 above the observed.

B4. Conclusion

The performance of the Gladstone Airshed Modelling System Version 3 (GAMSv3) dispersion and meteorological modelling predictions were extensively evaluated for accuracy and precision in predicting meteorology parameters and ground-level concentrations of air pollutants.

Overall GAMSv3 provides a reliable basis for representing dispersion meteorology and for predicting ground-level concentrations of air pollutants. The majority of variation between modelled and observed concentrations of air pollutants was found in the highest percentile concentrations. With GAMSv3 tending to be high compared to the observations, indicating that GAMSv3 is a conservative model.

B5. Reference

Breaker, L.C., Gemmill, W.H. and Crosby, D.S. 1994: The application of a technique for vector correlation to problems in meteorology and oceanography. *Journal of Applied Meteorology*, 33, 1354-1365.

Ministry for the Environment. 2004 'Good practice guide for atmospheric dispersion modelling'. Prepared by the National Institute of Water and Atmospheric Research (NIWA), Aurora Pacific Limited and Earth Tech.

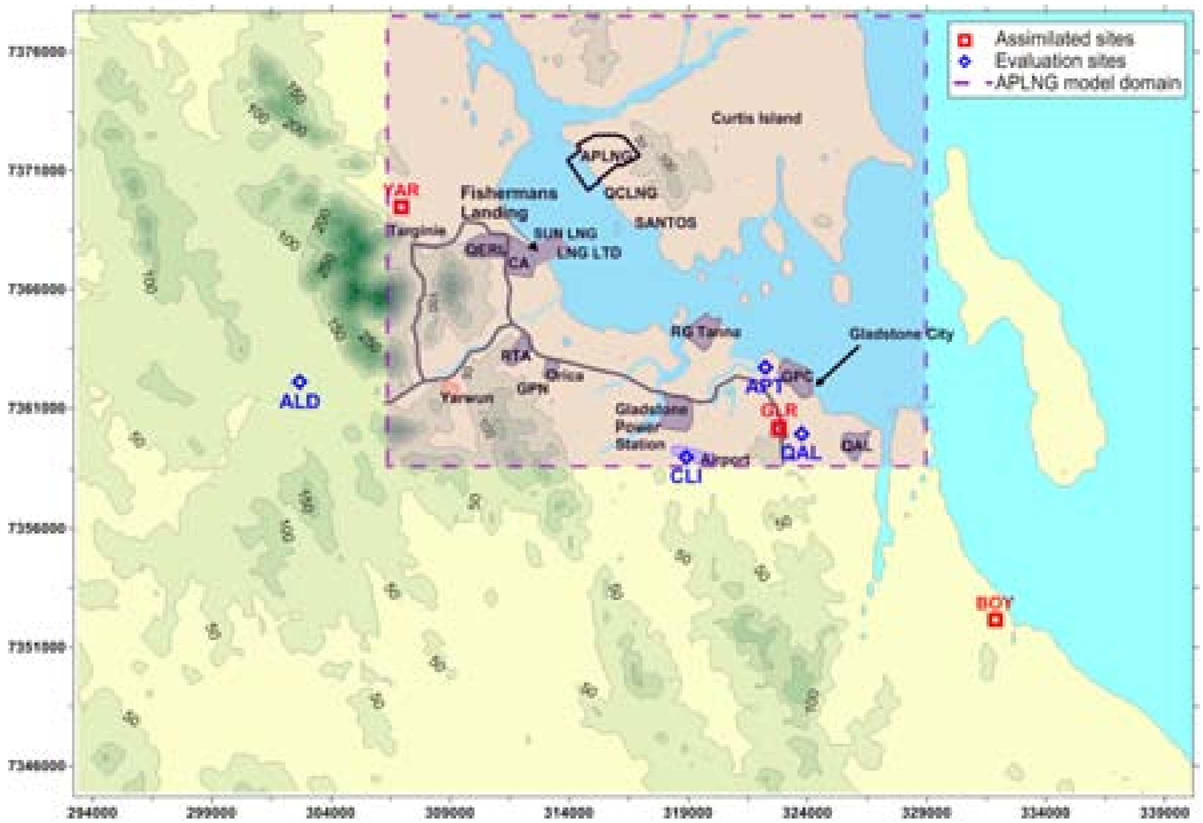

Figure B1 Location of APLNG site, assimilated and evaluated meteorological sites and APLNG modelling domain within the GAMSv3 parent domain

Location: Gladstone	**Data source:** Google Earth and Surfer v8	**Units:** AGD66
Type: Satellite image	**Prepared by:** S. Menzel	**Date:** 17 December 2009

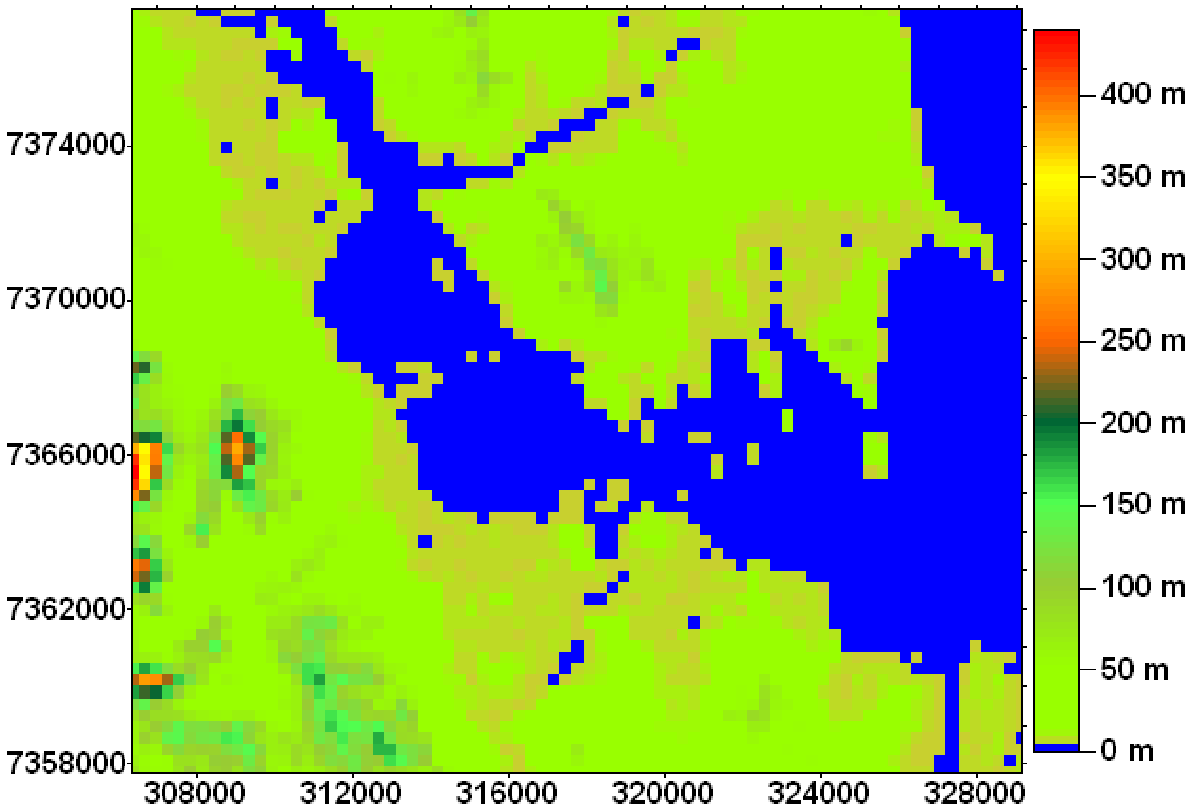

Figure B2 Refined CALMET terrain used in the meteorological model

Location: Gladstone	**Data source:** Generated by CALMETv6.4 and Surfer	**Units:** Metres (m) above sea level
Type: Image map	**Prepared by:** A. Wiebe	**Date:** 5 March 2009

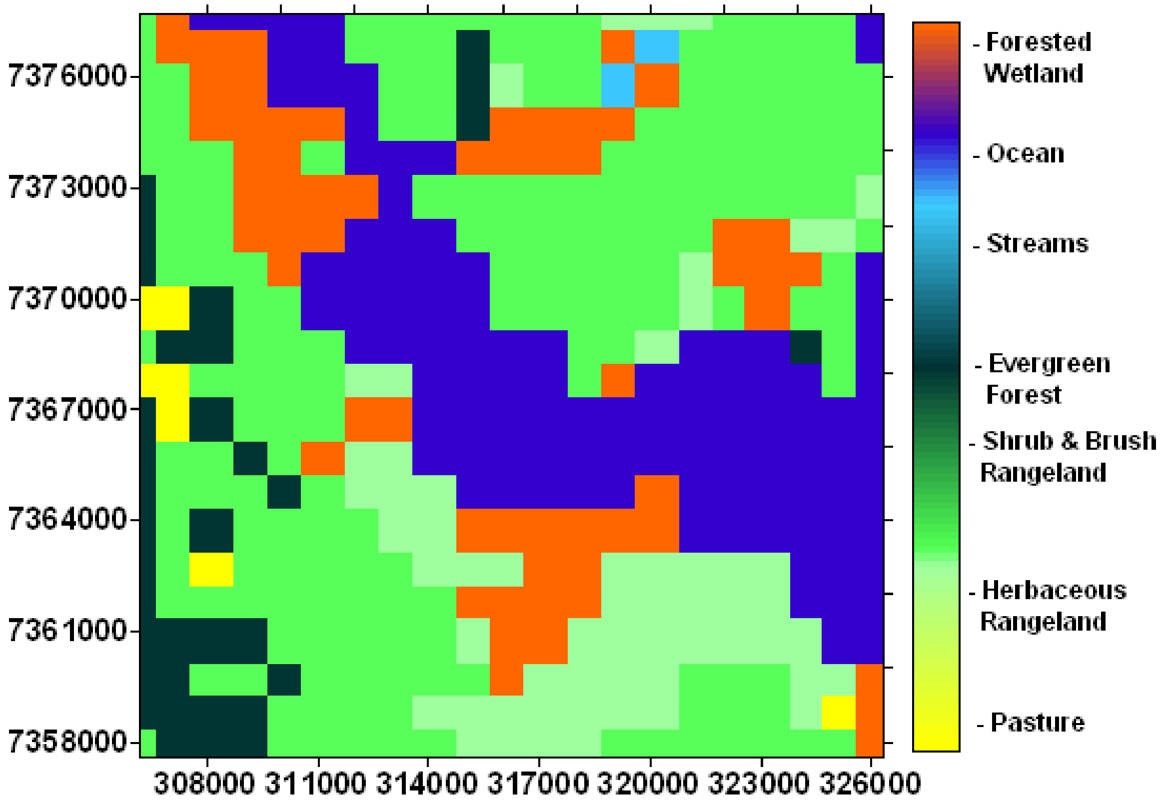

Figure B3 Refined CALMET Level II land use classifications used in the meteorological model

Location: Gladstone	Data source: Generated by CALMETv6.3 and Surfer	Units: CALMET Level II land use classifications
Type: Image map	**Prepared by:** A. Wiebe	**Date:** 5 March 2009

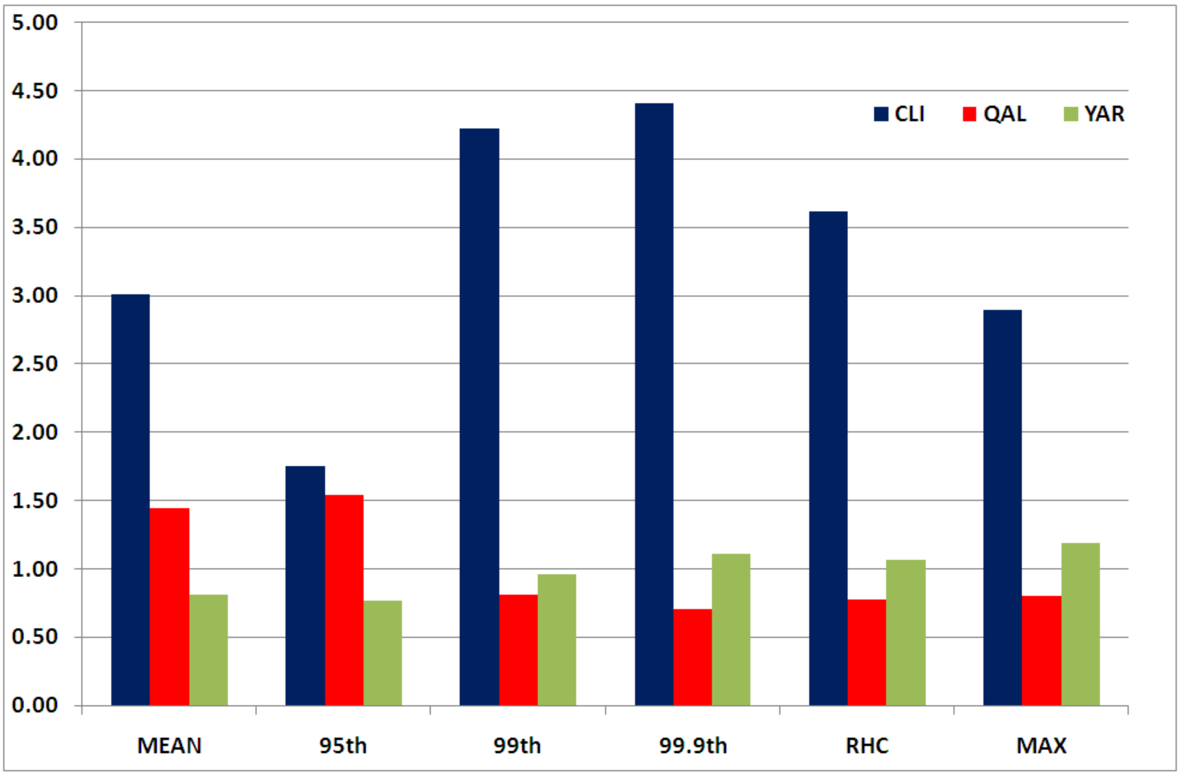

Figure B4 Sulphur dioxide (SO_2) top end distribution error (modelled – observed)

Location: CLI, QAL and YAR	**Period:** April 06 to March 07	**Data source:** CALPUFF	**Units:** µg/m³
Type: Bar chart		**Prepared by:** Andrew Wiebe	**Date:** January 09

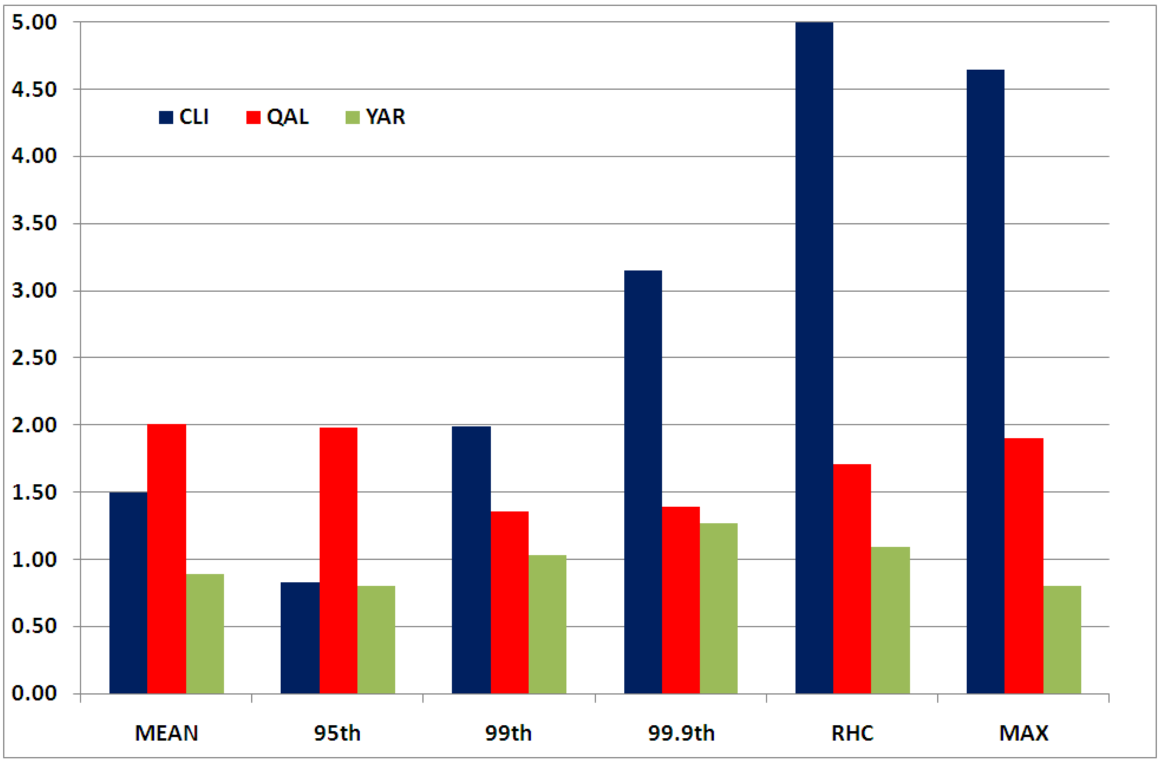

Figure B5 Oxides of Nitrogen (NO_x) top end distribution difference (modelled – observed)

Location: CLI, QAL and YAR	**Period:** April 06 to March 07	**Data source:** CALPUFF	**Units:** µg/m³
Type: Bar chart		**Prepared by:** Andrew Wiebe	**Date:** January 09

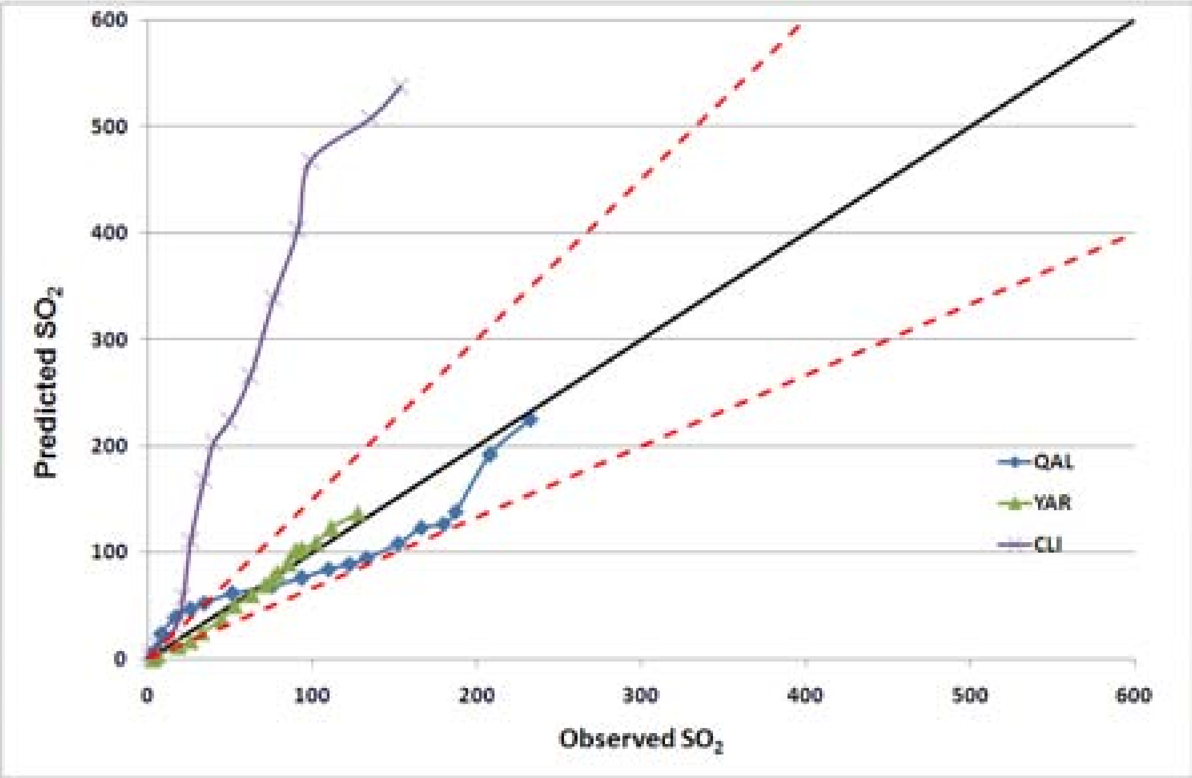

Figure B6 **Sulphur dioxide (SO_2) cumulative frequency distribution of observed and predicted concentrations. Black line is the 1 to 1 line the red dashed lines indicate a factor of 2 over and under prediction**

Location: CLI, QAL and YAR	**Period:** April 06 to March 07	**Data source:** Observations and CALPUFF	**Units:** µg/m^3
Type: X Y scatter plot		**Prepared by:** Andrew Wiebe	**Date:** January 09

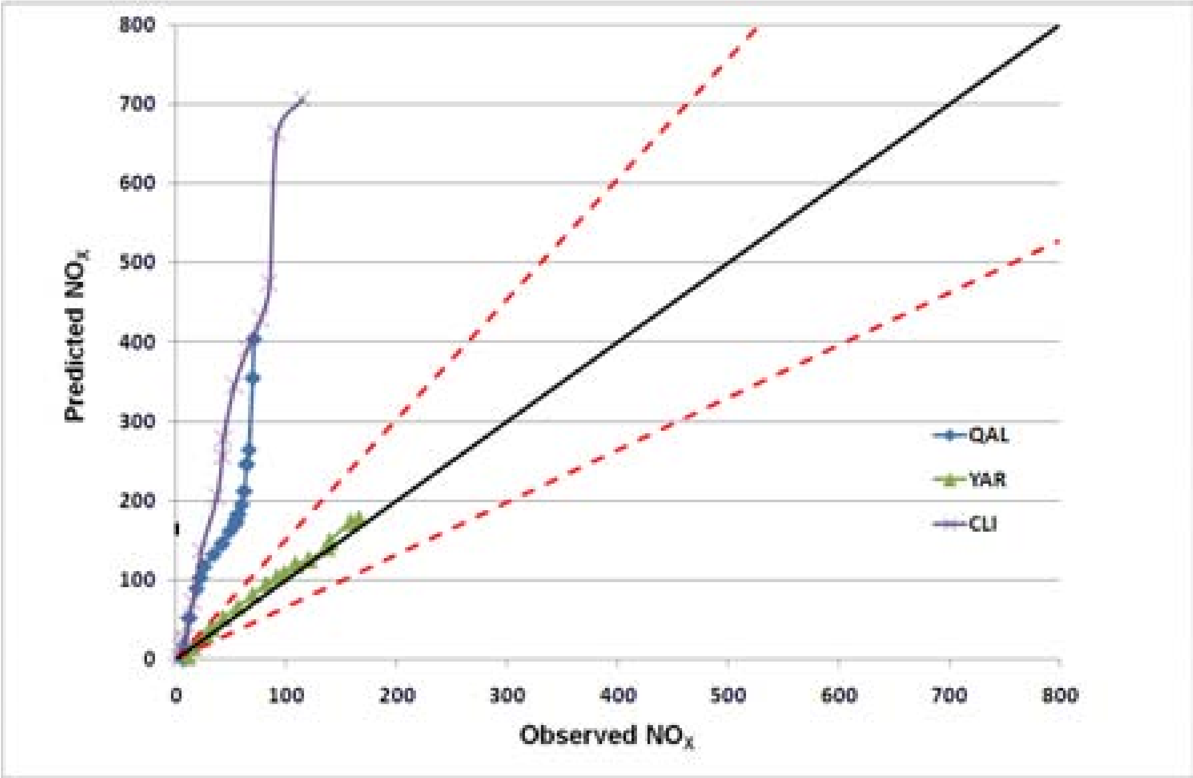

Figure B7 Oxides of Nitrogen (NO_x) cumulative frequency distribution of observed and predicted concentrations. Black line is the 1 to 1 line the red dashed lines indicate a factor of 2 over and under prediction

Location: CLI, QAL and YAR	**Period:** April 06 to March 07	**Data source:** Observations and CALPUFF	**Units:** µg/m^3
Type: X Y scatter plot		**Prepared by:** Andrew Wiebe	**Date:** January 09

APPENDIX C
STATISTICAL METHODS

January 2010

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C1. Pearson Correlation Coefficient

The Pearson Correlation Coefficient (RCOR) is a measure of the strength of the linear relationship between the predicted and observed measurements (defined in Equation 1). The closer this value is to unity the stronger the relationship.

$$r = \frac{N\left(\sum_{i=1}^{N} O_i P_i\right) - \left(\sum_{i=1}^{N} O_i\right)\left(\sum_{i=1}^{N} P_i\right)}{\sqrt{\left[N\left(\sum_{i=1}^{N} O_i^2\right) - \left(\sum_{i=1}^{N} O_i\right)^2\right]\left[N\left(\sum_{i=1}^{N} P_i^2\right) - \left(\sum_{i=1}^{N} P_i\right)^2\right]}}$$

Equation 1. Pearson Correlation Coefficient

Where N is the number of samples in the dataset, P_i is the hourly predictions and O_i is the hourly observations.

C2. Index of Agreement

The IOA is a measure the match between the departure of the departure of each prediction from the observed mean and the departure of each observation from the observed mean. The Index Of Agreement (IOA) is defined in Equation 2 and gives an index from 0-1 (1 representing strong agreement).

$$IOA = 1 - \frac{\sum_{i=1}^{N} (P_i - O_i)^2}{\sum_{i=1}^{N} (|P_i - O_{mean}| + |O_i - O_{mean}|)^2}$$

Equation 2. Index of Agreement

Where O_{mean} is the observed mean

C3. Mean Absolute Error

The Mean Absolute Error (MAE) measures the average magnitude of the error of a set of predictions in reference to the observed quantity. It is a relatively simple difference statistic defined by Wilmott (1982) as,

$$MAE = N^{-1} \sum_{i=1}^{N} |P_i - O_i|$$

Equation 3. Mean Absolute Error

The MAE is a good overall measure of model performance as it summarizes the mean difference between the predicted and the observed in the relative units of O and P (i.e. an MAE of 1.2 for wind speed is read as 1.2 m/s).

C4. Complex Vector Correlation

A vector requires both magnitude and phase to define the relationship between two sets of vector quantities. Wind direction is a vector as well as a circular function with a cross over point at 0º and 360º. Thus negating any attempt to characterise the relationship between predicted and observed wind direction measurements using standard linear correlation techniques. However vectors can be represented by their scalar components in a Cartesian or Spherical coordinate system. In the case of wind direction this decomposition results in the scalar quantities of *u* (east-west) and *v* (north-south) thereby allowing independent statistical analyses to take place. Scalar decomposition however, is limited by confining the analysis to individual scalar components not the vector as a whole, as well as, its inherent reliance on the subjective choice of coordinate system used in the decomposition process (Crosby, Breaker and Gemmill 1993). An alternative method is to incorporate the effects of magnitude and direction directly thereby yielding a scalar quantity defining the degree of association between the two datasets (Kundu 1976). The complex correlation coefficient is presented as Equation 4, following the methods described in Kundu (1976),

$$p = \frac{\langle u_1 u_2 + v_1 v_2 \rangle}{\langle u_1^{\ 2} + v_1^{\ 2} \rangle^{1/2} \langle u_2^{\ 2} + v_2^{\ 2} \rangle^{1/2}} + i \frac{\langle u_1 v_2 - u_2 v_1 \rangle}{\langle u_1^{\ 2} + v_1^{\ 2} \rangle^{1/2} \langle u_2^{\ 2} + v_2^{\ 2} \rangle^{1/2}}$$

Equation 4. Complex Correlation Coefficient

where *u* and *v* are the scalar components of the vector and $i = \sqrt{-1}$ yielding the complex conjugate of the vector components. Therefore, the complex correlation coefficient (*p*) can be defined as the normalised inner product between the two vector quantities. The phase angle is then defined by

$$\alpha_{av} = \tan^{-1} \frac{\langle u_1 v_2 - v_1 u_2 \rangle}{\langle u_1 u_2 + v_1 v_2 \rangle}$$

Equation 5. Phase Angle

Where the resulting quantities are independent of coordinate system and a complex number whose magnitude gives the measure of correlation and whose phase angle gives the average counter clockwise angle of the second vector in relation to the first. Of course phase angle is only meaningful if the correlation coefficient is high. The magnitudes of the instantaneous vectors are used to weight the averaging process in order to estimate the mean angular displacement between the two datasets.

C5. References

Crosby, D., L. Breaker, and W. Gemmill, 1993: A Proposed Definition for Vector Correlation in Geophysics: Theory and Application. *J. Atmos. Oceanic Technol.*, **10**, 355–367.

Kundu, P.K., 1976: Ekman Veering Observed near the Ocean Bottom. *J. Phys. Oceanogr.*, **6**, 238–242.

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APPENDIX D
AVIATION SAFETY ASSESSMENT

January 2010

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Tables

Figures

D1. Introduction

The assessment presented in this report is based on the guidelines for aviation safety published by the Australian Civil Aviation Safety Authority (CASA) in *Guidelines for conducting plume rise assessments (CASA, 2004)*.

The aim of this assessment is to estimate the height at which the average vertical plume velocities associated with stack emissions at the proposed APLNG facility on Curtis Island, achieve the critical value of 4.3 m/s. For the assessment of the vertical plume velocities, vertical wind profiles have been generated using the prognostic weather model TAPM for a five year simulation period.

The Gladstone Airport Development Plan (Sullivan, 2008) describes a PANS-OPS over the APLNG processing facility of 400 – 450 metres above ground (see Figure D2). The frequencies with which the plume exhaust velocities under normal and non-normal operating conditions achieve or exceed this given height have been assessed in this report.

D2. Local terrain and surrounding land use

The proposed APLNG facility is located on Curtis Island on the northern shores of Port Curtis in the Gladstone region. The Gladstone Airport is located approximately 14.5 kilometres to the south-southeast of the proposed facility. The area surrounding the site is relatively flat with little significant terrain in the near field. Figure D1 shows the region surrounding the APLNG facility and the proximity to the Gladstone Airport. Figure D3 presents a site layout of the APLNG facility.

D3. Vertical plume velocity guidelines

Since the development of an open-cycle gas-turbine power station at the end of a runway at Oakey in the mid 1990s, the CASA has taken a keen interest in the siting of industries with discharges to the atmosphere. Potential hazards that could affect the safety of aircraft include tall visible or invisible obstructions. Visible obstructions include structures such as tall stacks or communication towers. Invisible obstructions include vertical industrial exhausts that are of high velocity and buoyancy, such as gas-turbines. CASA has issued an Advisory Circular, (CASA 2004) that specifies the requirements and methodologies to be used to assess whether a new industrial plume is likely to have adverse implications for aviation safety.

The general CASA requirement is to determine the height at which the in-plume (or plumes) could exceed an average in-plume vertical velocity threshold of 4.3 m/s and to determine the dimensions of the plume in these circumstances. The frequency of in-plume vertical velocities at the lowest height an aircraft may travel over the site, and at other heights are also required. For large plumes that are remote from airports, CASA requires an assessment that determines the size of a hazard zone to alert pilots to the potential hazard.

For this report, the extent of the plume based on the average vertical velocity has been presented. While there are some sections of the plume that may have a vertical velocity higher than that for the average, it has been Katestone Environmental's experience that the peak plume velocity predictions do not assess aviation safety risk appropriately. Past discussions between Katestone Environmental and CASA have concluded that analysis of the average plume vertical velocity is appropriate for these assessments. The threshold limit of 4.3 m/s for the average vertical velocity has been used throughout this assessment for the critical plume height calculations.

D4. Emission characteristics

The proposed APLNG facility consists of a number of stacks that emit plumes that have the potential to generate vertical plume velocities above the facility. The assessment has addressed the plume vertical velocity profiles of both normal and non-normal operations. For normal operations the sources investigated include gas turbine compressors and power generation turbines. For normal operations the plumes have been assessed against a full range of meteorological conditions assuming they operate continuously.

For non-normal operations a ground flare and a marine flare could operate. The expected frequency of these flaring events for non-normal operations at the plant is as yet unknown and have been assessed against a full range of meteorological condition assuming continuous operation.

The planned development of the APLNG plant will consist of four trains, each train consists of generally the same number of sources for normal operations. Within one train, there is the potential that individual source plumes will merge, generating a more buoyant plume. This has been assessed for the multiple gas turbines to determine the potential worst case impact on vertical plume velocities for normal operations.

The trains have a separation distance of 208 metres. Investigation of the maximum downwind distance from a train has been made to evaluate whether additional enhancement of the plume from neighboring trains occurs.

The stack characteristics for Train 1 of normal operation of the APLNG facility are shown in Table D1. The stack characteristics for non-normal operation of the APLNG facility are shown in Table D2. To enable a dispersion model to adequately model a flare the characteristics of the plume need to be modified to account for the buoyancy correctly. This is done using the USEPA program SCREEN3. This program determines an effective stack height and diameter and sets the plume temperature and exit velocity. Both actual and effective (or modelled) parameters are included in Table D2.

For the modelling of the Wet and Dry Gas Ground Flare, which consists of a large array of burners spanning a broad area of 84 x 76 metres, an assessment of the plume with respect to aviation safety has been performed using CALPUFF. CALPUFF was used in preference to TAPM as it is the only model capable of adequately representing the characteristics of a buoyant area source. Source and emission characteristics required for the modelling of the ground flare in CALPUFF are presented in Table D3.

Table D1 Stack and emission characteristics for the proposed APLNG processing facility – normal operations

Parameter	Height	Diameter	Velocity	Temperature	Number of Sources per train
Units	metres	metres	m/s	°C	
Gas Turbine Compressors	25	2.3	50.4	803	6
Power Generation Turbines	25	1.9	33.3	666	4

Table D2 Stack and emission characteristics for the proposed APLNG processing facility – non normal operations

Parameter	Units	Marine Flare – Maintenance	Marine Flare – Warm ship
Easting	GDA94 (m)	315219	315219
Northing	GDA94 (m)	315219	315219
Height (actual)	metres	25	25
Height (modelled)	metres	31.8	46.9
Diameter (actual)	metres	0.711	0.711
Diameter (modelled)	metres	2.08	7.0
Velocity	m/s	20	20
Temperature	°C	1000	1000

Table D3 Emission characteristics for the proposed APLNG Wet and Dry Gas Ground Flare – non normal operations

Parameter	Value	Units
W_p	Initial vertical velocity	n/a
g	Specific gravity	m/s^2
Q_h	is the heat release rate	J/s
r_p	Radius of fire	m
T_p	Plume temperature	K
T_a	Ambient temperature	K
g	9.81	m/s^2
Q_h	71,849	GJ/hr
	17,962	GJ/15 min flare release
	19.9581	GJ/s
	19,958,142,667	J/s
r_p	45.08	m
T_p	811.15	K
T_a	298.15	K
W_p	13.93	m/s
Flare gas Temperature	538	^oC
	811.15	K
Ambient air temperature	25	^oC
	298.15	K
Total ground flare length	84	m
Total ground flare Width	76	m
Ground flare Height above ground	18	m
Ground base elevation	9	m
Flare X-Sect Area	6,384	m^2
Eff-Rad (r_p)	45.08	m

D5. Methodology

In Australia, CASA requires that the proponent of a facility with an exhaust plume that has an average vertical velocity exceeding the threshold value 4.3 m/s at the Obstacle Limitation Surface or at 110 metres above ground level anywhere else to assess the level of risk posed by the plume to aircraft operations. Attachment A of CASA's Advisory Circular provides a recommended methodology that adopts TAPM (The Air Pollution Model) to conduct plume rise assessments for single exhaust plumes. The CASA Advisory Circular does not specify a method for dealing with multiple plumes and possible buoyancy enhancements but allows for the use of alternative techniques.

For a scenario involving the merging of stack plumes, plume growth will involve several stages:

(a) In the first stage very close to the stack exit, the high plume momentum will result in a short section in which the conditions at the centre of each plume are unaffected by ambient conditions. The potential core in which maximum core velocity and temperature remain constant extends approximately a distance of 6.25 D (D is the stack diameter) above the outlet in calm conditions. At the end of this stage, the plume-average velocity has decreased to half of the exit velocity, with a corresponding increase in effective plume diameter.

(b) In the second stage, the plume dynamics and trajectories respond to ambient conditions, with much cooler air being entrained into the outer regions of the plume. The momentum and buoyancy of the plume significantly influence its rise as this air mixes into the plume and provides dilution of the exhaust. This dilution is very sensitive to ambient wind speed.

(c) In the third stage of plume development, plume rise is due entirely to the buoyancy of the plume and continues until there is an equalization of turbulence conditions within and outside the plume. This final rise is often only achieved at distances over 100 metres downstream of the stack; the effective average vertical velocity is then close to zero.

In this study TAPM (Version 4.0.2) was used to calculate the plume height and horizontal movement downwind after discharge from the stack for five years of meteorological conditions. Possible buoyancy enhancement associated with multiple plumes has been accounted for as follows:

- A single gas turbine plume is modelled using TAPM.
- The methodology described by Manins et al (1992) has been used to calculate the enhancement of vertical velocities that would occur if the plumes from multiple stacks merge and form a higher buoyancy combined plume. The average final plume rise height of a single plume, the number of stacks and the average separation distance between stacks is used to derive the buoyancy enhancement factor.
- This enhancement factor is input into TAPM as a second iteration to represent the impacts on vertical velocities from the merged turbine plumes.

The methodology presented and used in this assessment is the recommended approach in the TAPM documentation, using data assimilation at three sites as configured in GAMSv3.

For the modelling of the Wet and Dry Gas ground flare in CALPUFF, a single year simulation year for the period April 2006 to March 2007, has been performed utilising the pollution dispersion model setup for this project.

D6. Results

A five year meteorological simulation has been prepared using the TAPM model, utilising synoptic data for the period January 2004 to December 2008 to quantify:

(a) The height at which the average vertical velocity of the plume falls below 4.3 m/s, called the critical plume height.

(b) The frequency at which critical plume heights of various magnitudes are likely to occur.

(c) The downwind distance or extent of the plume with average vertical velocity above 4.3 m/s for various heights.

D6.1 Normal Operations

Results for the proposed APLNG facility for normal operations for all hours of the five year period are presented in Table D4.

Table D4 indicates that the critical plume height of the six merged gas turbine compressors under normal operations is likely to exceed the PANS-OPS above the site.

Table D5 presents the number of hours in which the PANS-OPS is exceeded per annum. The critical plume heights are predicted to exceed the PANS-OPS of 400 metres above the site for an average 28 hours per year or 0.32% of the time for the merged plumes of the gas turbines. Of all the sources assessed, the highest critical height for the 0.1 percentile is approximately 548 metres for the six merged gas turbine compressors from one train. The 0.1 percentile ranges between 507 metres and 595 m depending on the year assessed.

The merged power generation turbine sources are well below the height of the gas turbine compressors. The merged power generation turbines have a critical height ranging from 203 to 252 metres for the 0.1 percentile for the five years assessed. These turbines do not exceed an average vertical velocity of 4.3 m/s above the PANS-OPS.

Figure D5 to Figure D8 show the calculated critical plume height for the normal operation of the gas turbines as a function of time of day. Highest critical plume heights occur during the late afternoon and early hours of the morning for the merged gas turbine plumes.

The extent of the plume is shown in Table D6 for various heights above ground level during normal operations. For example, for a critical plume height in the range height of 500 to 600 metres, the vertical velocity of the merged gas turbine plume falls below 4.3 m/s at a maximum downwind distance of approximately 166 metres from the stacks. Table D6 shows that the vertical velocity of the plume is likely to be below 4.3 m/s under all meteorological conditions at a distance of up to 166 metres from the stacks of the APLNG facility under normal operations.

With a maximum downwind distance of 166 metres and a separation distance between trains of 208 metres, the plumes generated from each train are far enough apart not to merge and result in a higher critical threshold height.

Table D4 Critical plume height for the proposed APLNG facility for normal operations and the proportion of the time that the critical height is exceeded

Percentiles (%)	Hours per year	Critical Height (m)			
		Power generation (Single)	Power generation (Merged)	Gas Turbine Compressor (Single)	Gas Turbine Compressor (Merged)
90	7884	40	40	43	54
80	7008	40	40	43	59
70	6132	40	40	43	64
60	5256	40	40	44	66
50	4380	40	40	44	72
40	3504	40	45	45	78
30	2628	40	46	45	88
20	1752	41	51	50	100
10	876	42	62	52	128
9	789	42	66	52	132
8	701	42	67	56	139
7	614	42	69	56	146
6	526	46	73	57	154
5	438	46	78	58	165
4	351	47	84	62	179
3	263	47	93	67	199
2	176	52	107	73	228
1	88	62	134	89	290
0.5	44	63	160	105	357
0.3	27	64	181	116	409
0.2	18	68	196	125	463
0.1	9	75	232	142	548
0.05	5	79	261	155	607
Maximum	1	103	375	214	846

Table D5 Predicted number of exeedences of the threshold height above the proposed APLNG facility for six merged gas turbine compressors

Parameter	PANS-OPS Threshold (m AGL)	2004	2005	2006	2007	2008	2004-2008	Average per annum
Six Merged Gas Turbine Compressors	400	42	16	25	26	32	141	28
	450	28	14	17	20	20	99	20

Table D6 Predicted plume extent (plume radius + distance downwind in metres) where the average vertical velocity exceeds the 4.3 m/s threshold for various heights for normal operations

Height above ground (m)	Predicted plume extent (m)	Single Gas Turbine Compressor	Six Merged Gas Turbine Compressors
< 100	Min	13	26
	Mean	26	52
	0.1	41	71
	Max	44	72
100 - 200	Min	20	64
	Mean	41	77
	0.1	58	102
	Max	58	105
200 - 300	Min	56	61
	Mean	57	97
	0.1	58	123
	Max	58	123
300 - 400	Min	NA	70
	Mean	NA	112
	0.1	NA	145
	Max	NA	145
400 - 500	Min	NA	90
	Mean	NA	123
	0.1	NA	145
	Max	NA	145
500 - 600	Min	NA	101
	Mean	NA	130
	0.1	NA	166
	Max	NA	166
600 - 700	Min	NA	113
	Mean	NA	135
	0.1	NA	160
	Max	NA	160
700 - 800	Min	NA	126
	Mean	NA	129
	0.1	NA	135
	Max	NA	135
800 - 900	Min	NA	137
	Mean	NA	141
	0.1	NA	145
	Max	NA	145

D6.2 Non-Normal Operations

Results for the proposed APLNG facility for non-normal operations for the marine flare are presented in Table D7.

Table D7 indicates that the critical plume height of the marine flare under emergency flaring whilst warm ship loading is likely to exceed the PANS-OPS above the site with a threshold height for the 0.1 percentile of 488 metres. The marine flare maintenance scenario has a very low critical height and is not of concern.

Table D8 presents the number of hours in which the PANS-OPS is exceeded per annum if the marine flare under was under continuous operation. The critical plume heights are predicted to exceed the PANS-OPS of 400 metres above the site for an average 22 hours per year or 0.25% of the time for the marine flare, warm ship case.

For the marine flare, the highest critical height over the five years assessed is approximately 784 metres. The 0.1 percentile ranges between 477 metres and 531 m depending on the year assessed. The marine flare plume for the warm ship scenario is shown in Table D9, for various heights above ground level assuming continuous operation of the flare.

Figure D9 presents the calculated critical plume height for the marine flare as a function of time of day assuming continuous operation. Highest critical plume heights occur during the late afternoon and early hours of the morning, similar to the profile of merged gas turbine compressor plumes.

The extent of the plume is shown in Table D9 for various heights above ground level during operation. For a critical plume height in the range height of 500 to 600 metres, the vertical velocity of the flare plume falls below 4.3 m/s at a maximum downwind distance of approximately 138 metres from the stacks. Table D9 shows that the vertical velocity of the plume is likely to be below 4.3 m/s under all meteorological conditions at a distance of up to 138 metres from the stacks of the APLNG facility under non-normal operation of the marine flare.

Figure D10 presents the calculated critical plume height for the ground flare as a function of time of day assuming continuous operation. The Wet and Dry Gas Ground flare which will only operate if emergency depressurisation of the plant is required will generate the most buoyant plume.

This event is predicted to have a very low frequency of occurrence, with duration of approximately 20 minutes while the plant depressurises. When operating, the ground flare will always generate vertical velocities above 4.3 m/s well above the PANS-OPS to a vertical distance of up to 2.6 kilometres. The vertical velocity of the flare plume falls below 4.3 m/s at a maximum downwind distance of approximately 1180 metres from the flare.

Table D7 Critical plume height for the proposed APLNG facility for non-normal operations and the proportion of the time that the critical height is exceeded

Percentiles (%)	Hours per year	Critical Height (m)		
		Ground Flare	Marine Flare Maintenance -	Marine Flare Warm ship
90	7884	940	39	65
80	7008	1044	44	70
70	6132	1136	44	71
60	5256	1225	44	76
50	4380	1304	44	81
40	3504	1389	44	87
30	2628	1498	49	94
20	1752	1658	50	105
10	876	1893	59	129
9	789	1922	59	134
8	701	1954	60	140
7	614	1990	64	147
6	526	2035	65	154
5	438	2098	65	163
4	351	2161	70	175
3	263	2235	71	193
2	176	2304	75	220
1	88	2407	78	273
0.5	44	2489	91	330
0.3	27	2548	91	376
0.2	18	2562	91	421
0.1	9	2614	99	488
0.05	5	2661	109	550
Maximum	1	2699	117	784

Table D8 Predicted number of exeedences of the threshold height above the proposed APLNG facility for the Marine Flare, warm ship scenario

Parameter	PANS-OPS Threshold (m AGL)	2004	2005	2006	2007	2008	2004-2008	Average per annum
Ground Flare	400 / 450	n/a	n/a	8784	n/a	n/a	n/a	8784
Marine Flare Warm ship	400	13	20	21	23	22	110	22
	450	10	10	14	13	13	66	13

Table D9 Predicted plume extent (plume radius + distance downwind in metres) where the average vertical velocity exceeds the 4.3 m/s threshold for various heights for non-normal operations

Height above ground (m)	Predicted plume extent (m)	Marine Flare – Warm ship
< 100	Min	27
	Mean	44
	0.1	58
	Max	58
100 - 200	Min	52
	Mean	64
	0.1	87
	Max	91
200 - 300	Min	55
	Mean	85
	0.1	116
	Max	116
300 - 400	Min	65
	Mean	96
	0.1	120
	Max	120
400 - 500	Min	84
	Mean	108
	0.1	134
	Max	134
500 - 600	Min	91
	Mean	109
	0.1	138
	Max	138
600 - 700	Min	104
	Mean	115
	0.1	132
	Max	132
700 - 800	Min	106
	Mean	123
	0.1	134
	Max	134
800 - 900	Min	NA
	Mean	NA
	0.1	NA
	Max	NA

D7. Conclusions

An aviation safety assessment has been conducted in accordance with the Australian Civil Aviation and Safety Authority (CASA) requirements for the proposed APLNG facility. The conclusions of the study are as follows:

Site characteristics

- The proposed APLNG facility is to be located approximately 14.5 kilometres from the Gladstone airport
- The PANS-OPS above the site is between 400 – 450 metres above ground level.

Plume heights for normal operations

The assessment found the following in terms of plume heights for normal operations:

- There is a potential for the average plume vertical velocity to exceed 4.3 m/s up to a maximum height of approximately 846 metres above ground level at a maximum downwind distance of approximately 166 metres.
- The merged plume from the gas turbine compressors is likely to cause the vertical velocity to be greater than 4.3 m/s at and above the PANS-OPS (400 metres) for 28 hours per year or 0.32% of the time.
- Of all the plumes considered for normal operations, the highest critical height for the 0.1 percentile is approximately 548 metres above ground level
- Discussion between APLNG Gladstone Airport and CASA will be required to determine an appropriate course of action.

Plume heights for non-normal operations

The assessment found the following in terms of plume heights for non-normal operations:

- Each LNG train will have a planned shutdown every several years with associated maintenance and start-up flaring.
- Use of the Marine Flare under maintenance operations: the average plume vertical velocity does not exceed 4.3 m/s above the PANS-OPS.
- Use of the Marine Flare under loading of a warm ship: there is a potential for the average plume vertical velocity to exceed 4.3 m/s above the PANS-OPS.
- For non-normal operating conditions of the Marine Flare under warm ship loading, there is a potential for the average plume vertical velocity to exceed 4.3 m/s up to a maximum height of approximately 784 metres above ground level at a maximum downwind distance of approximately 138 metres.
- A plume from the Marine Flare would have a vertical velocity greater than 4.3 m/s above the height of the PANS-OPS (400 metres) for 28 hours per year or 0.38% of the time, when assumed operation for every hour of the year.
- The highest critical height for the Marine Flare under non-normal operations, for the 0.1 percentile is approximately 488 metres above ground level, if it is assumed to operate for every hour of the year.
- The Wet and Dry Gas Ground flare which will only operate if emergency depressurisation of the plant is required is likely to generate a plume with vertical velocities above 4.3 m/s for the 0.1 percentile to a height of 2.6 kilometres above ground level and at a maximum downwind distance of approximately 1180 metres.

- This event is predicted to have a very low frequency of occurrence, with duration of approximately 20 minutes while the plant depressurises. Under flaring, the ground flare is likely to be well above the PANS-OPS under all conditions.
- Discussions between the Gladstone Airport and CASA will be required to determine an appropriate course of action to alert aircraft in the region should a ground flare event occur.

D8. References

Best P, Jackson L, Killip C, Kanowski M and Spillane K (2003), 'Aviation Safety and Buoyant Plumes', Clean Air Conference, Newcastle, New South Wales, Australia.

CASA (2004), 'Guidelines for conducting plume rise assessments' – Civil Aviation Safety Authority, Publication AC 139-05(0), November 2004

Manins P, Carras J and Williams D. 1992 'Plume rise from multiple stacks' Clean Air 26, pp. 65-68,

Sullivan, Rod (2008) Gladstone Airport Development Plan Draft Plan V2 April 2008.

TAPM (2009) Version 4.0.2 developed by the CSIRO (http://www.csiro.au/products/TAPM.html)

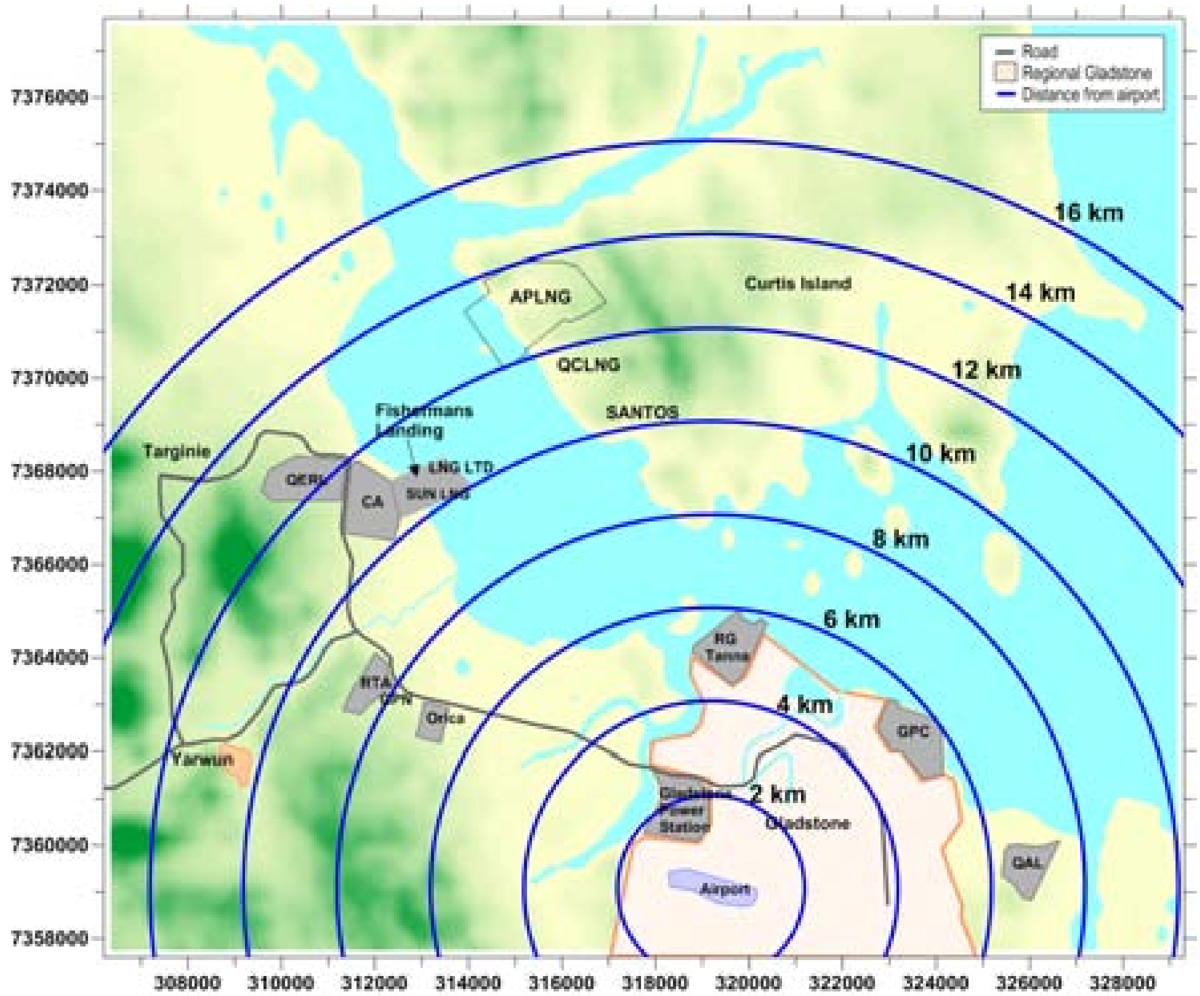

Figure D1 Location of APLNG and Gladstone Airport

Location:	Data source:	Units:
Gladstone	Google Earth	Radial distance in kilometres from Gladstone airport
Type:	**Prepared by:**	**Date:**
Aerial	A. Schloss	December 2009

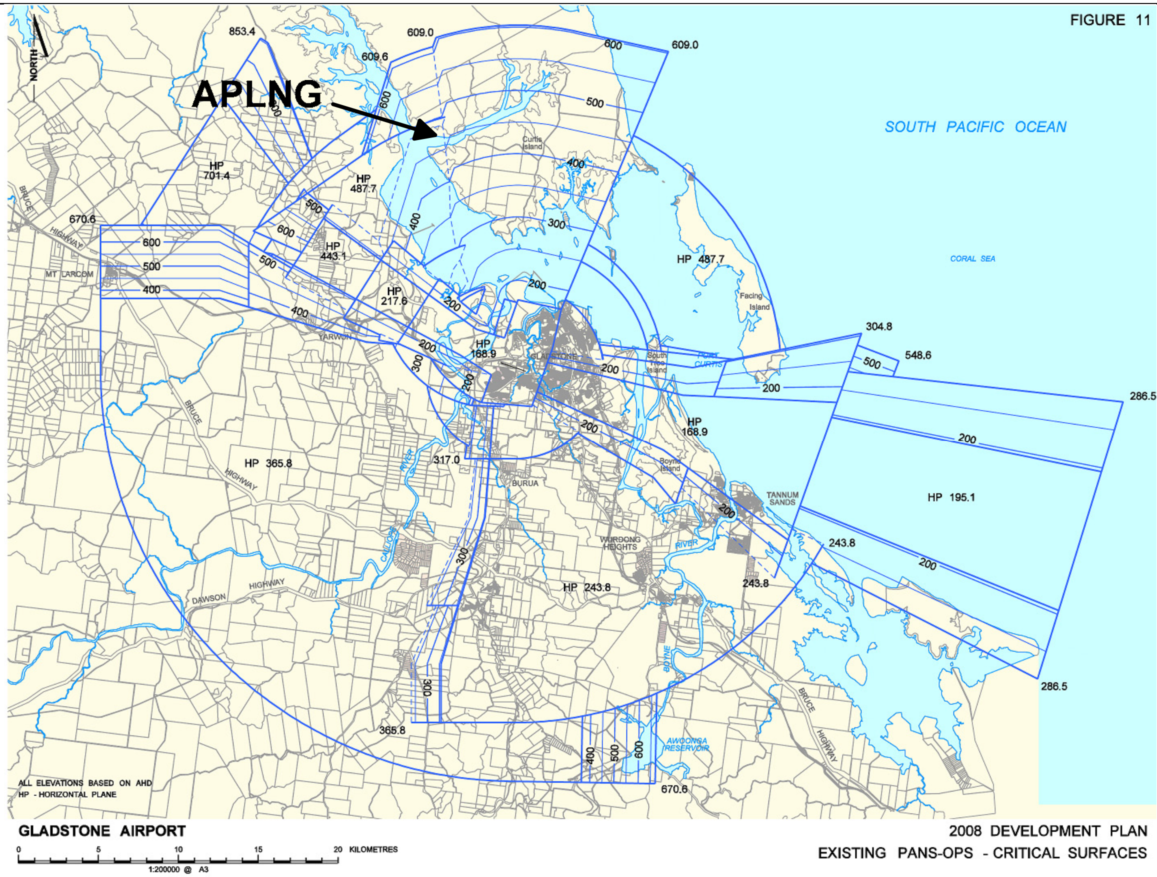

Figure D2 PANS-OPS surface for Gladstone

Location:	Data source:	Units:
Gladstone	Gladstone Airport Development Plan	AHD
Type:	**Prepared by:**	**Date:**
Aerial	A. Schloss	Deceember 2009

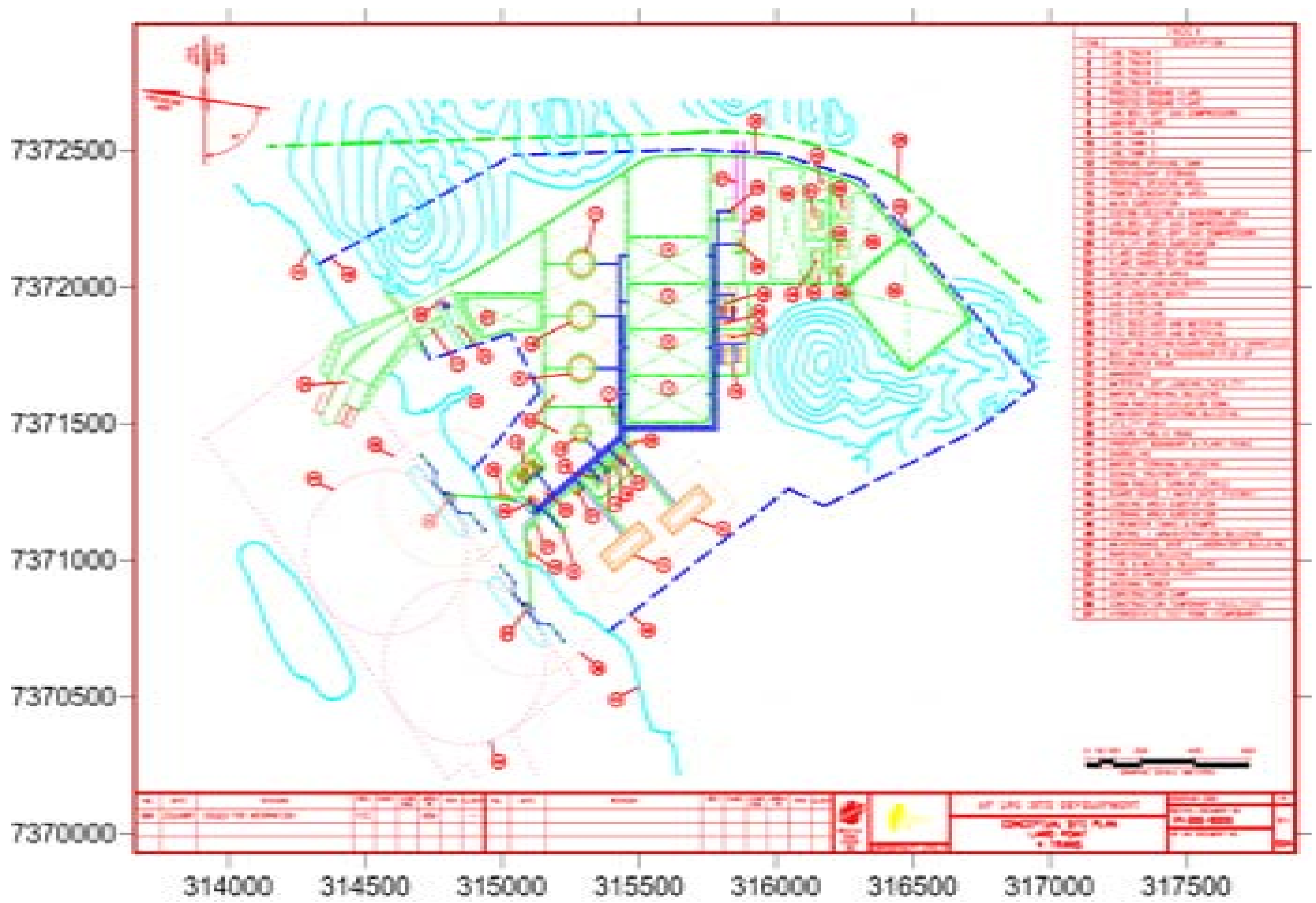

Figure D3 Site layout of APLNG processing facility	
Location: Curtis Island	**Data source:** WORLEY PARSONS
Type: Aerial map	**Prepared by:** WORLEY PARSONS

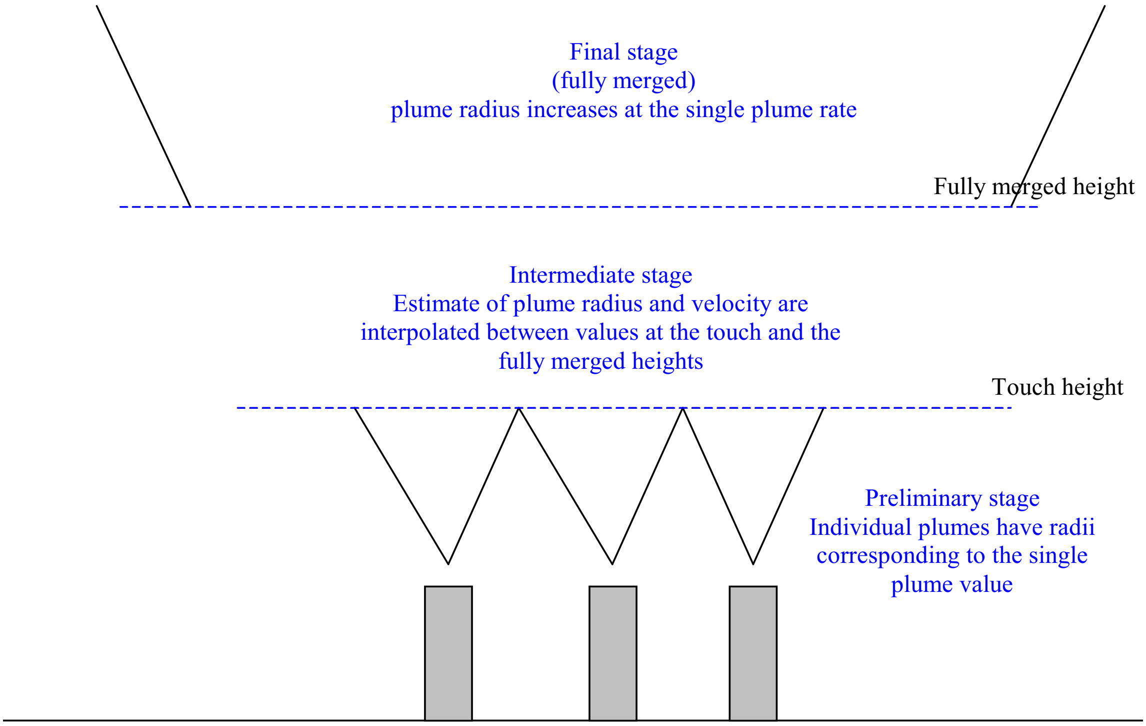

Figure D4 Description of the three phases of plume merging from multiple stacks

Type: Diagram	**Data source:** Katestone Environmental
Prepared by: Christine Killip	**Date:** December 2009

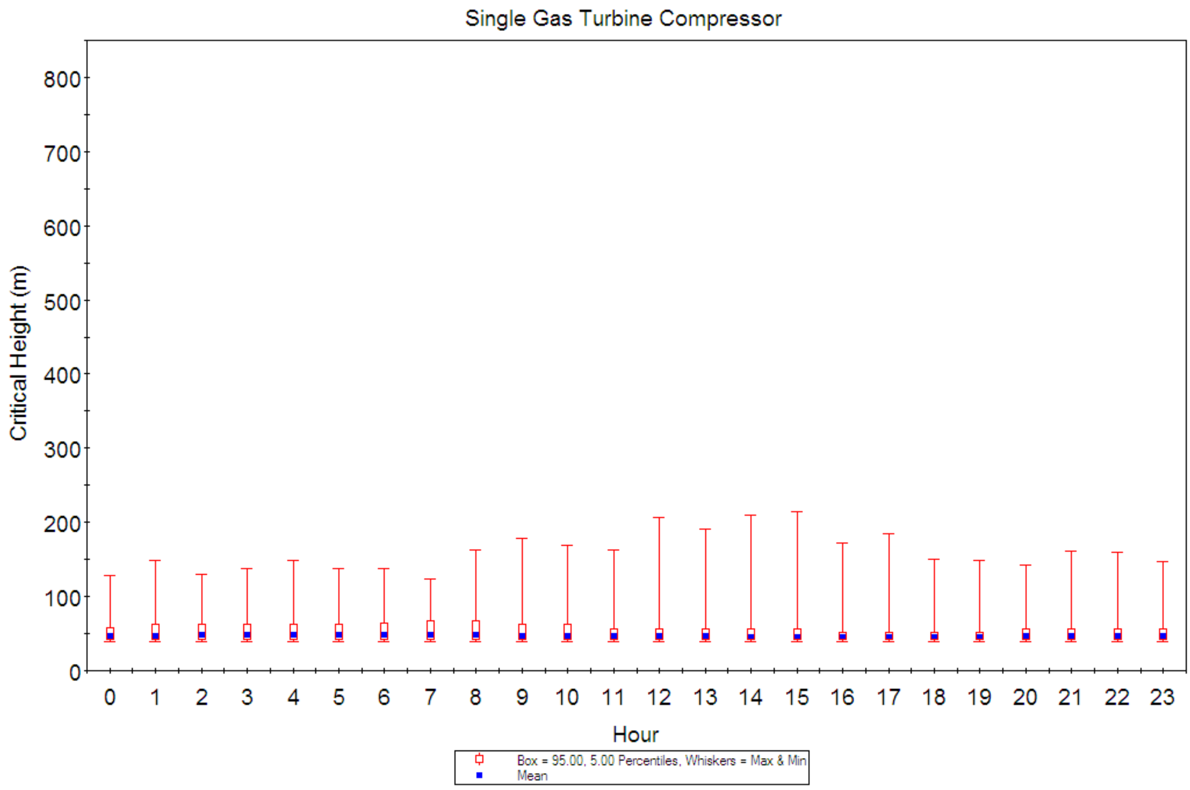

Figure D5 Critical plume height versus time of day for normal operations of a single gas turbine plume scenario modelled in TAPM

Location: Gladstone	**Averaging period:** 1-hour	**Data source:** TAPM	**Units:** Metres
Type: Box and Whiskers		**Prepared by:** A. Schloss	**Date:** December 2009

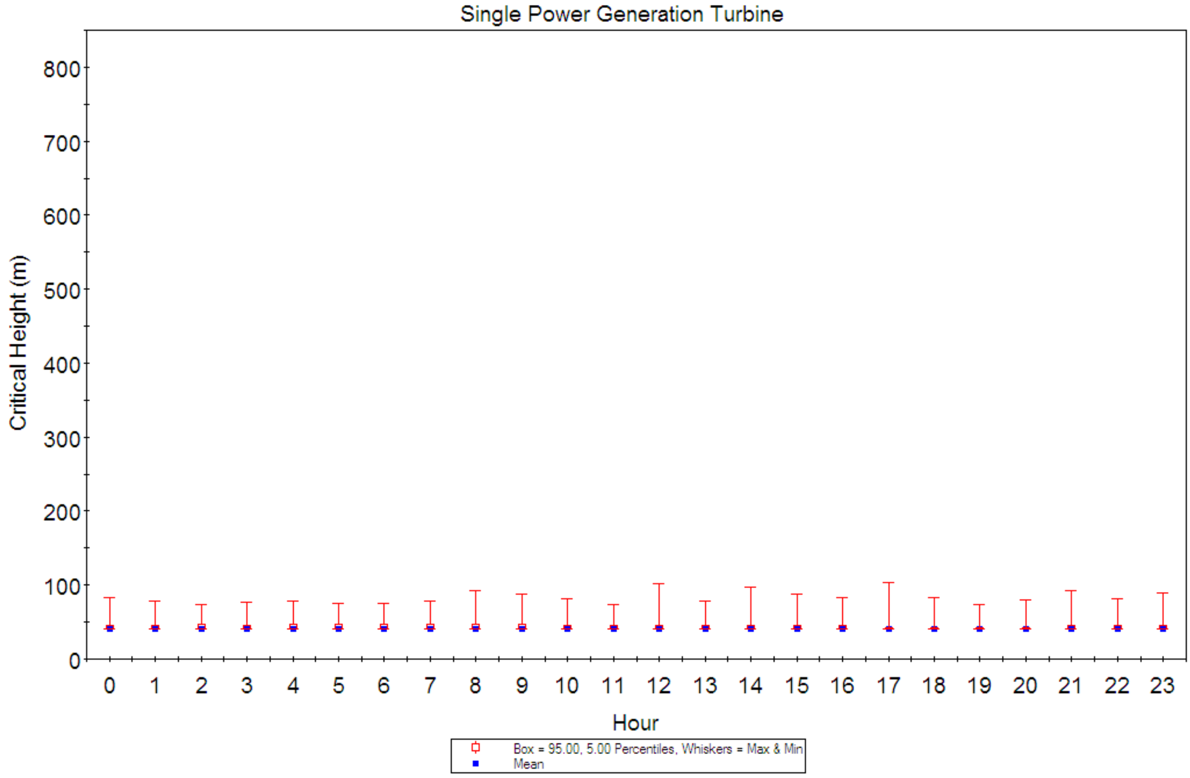

Figure D6 Critical plume height versus time of day for normal operations of a single power generation turbine plume scenario modelled in TAPM

Location: Gladstone	**Averaging period:** 1-hour	**Data source:** TAPM	**Units:** Metres
Type: Box and Whiskers		**Prepared by:** A. Schloss	**Date:** December 2009

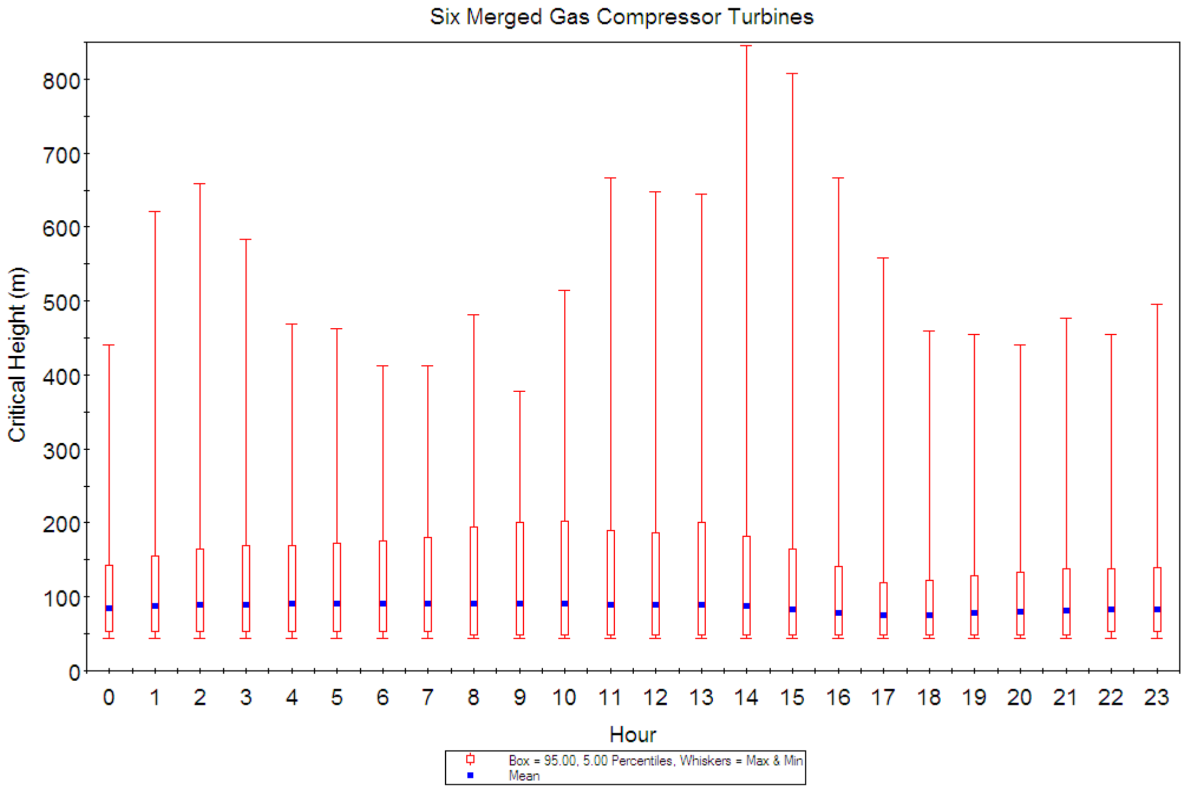

Figure D7 Critical plume height versus time of day for normal operations of merged gas compressor plume scenario modelled in TAPM

Location: Gladstone	**Averaging period:** 1-hour	**Data source:** TAPM	**Units:** Metres
Type: Box and Whiskers		**Prepared by:** A. Schloss	**Date:** December 2009

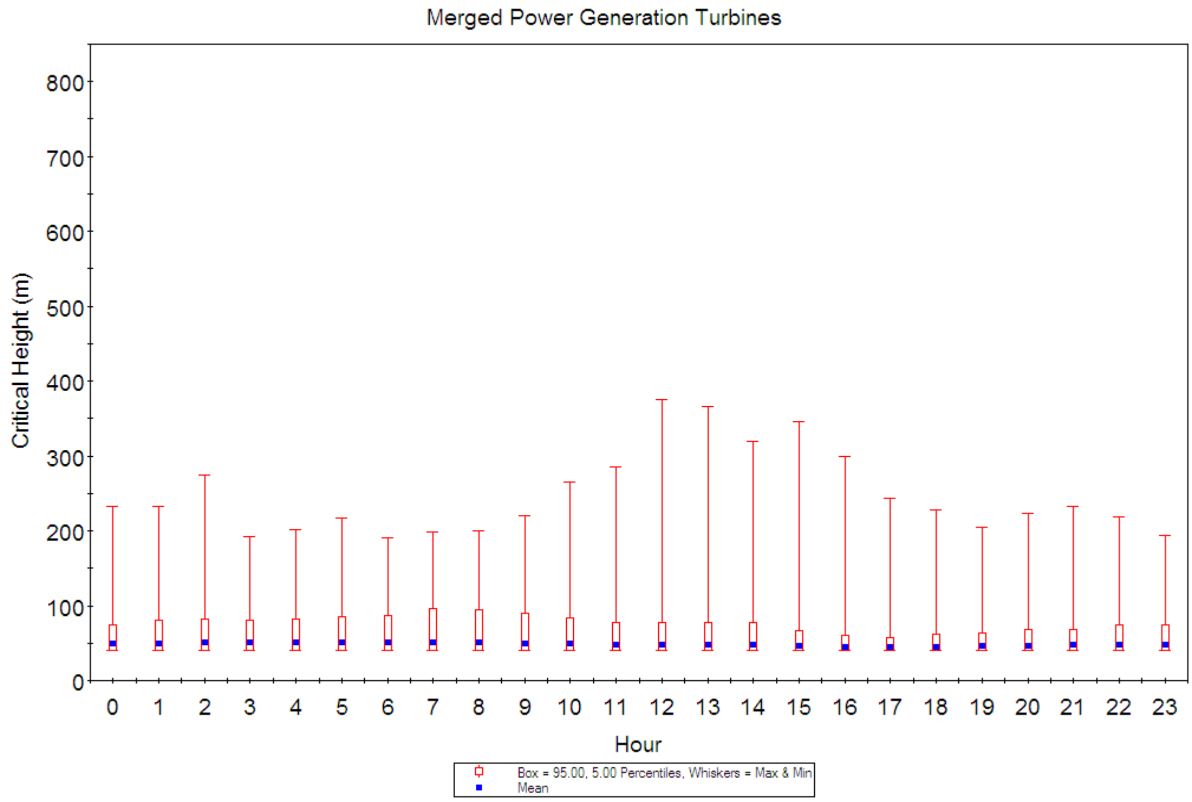

Figure D8 Critical plume height versus time of day for normal operations of the merged power generation turbine plume scenario modelled in TAPM

Location: Gladstone	**Averaging period:** 1-hour	**Data source:** TAPM	**Units:** Metres
Type: Box and Whiskers		**Prepared by:** A. Schloss	**Date:** December 2009

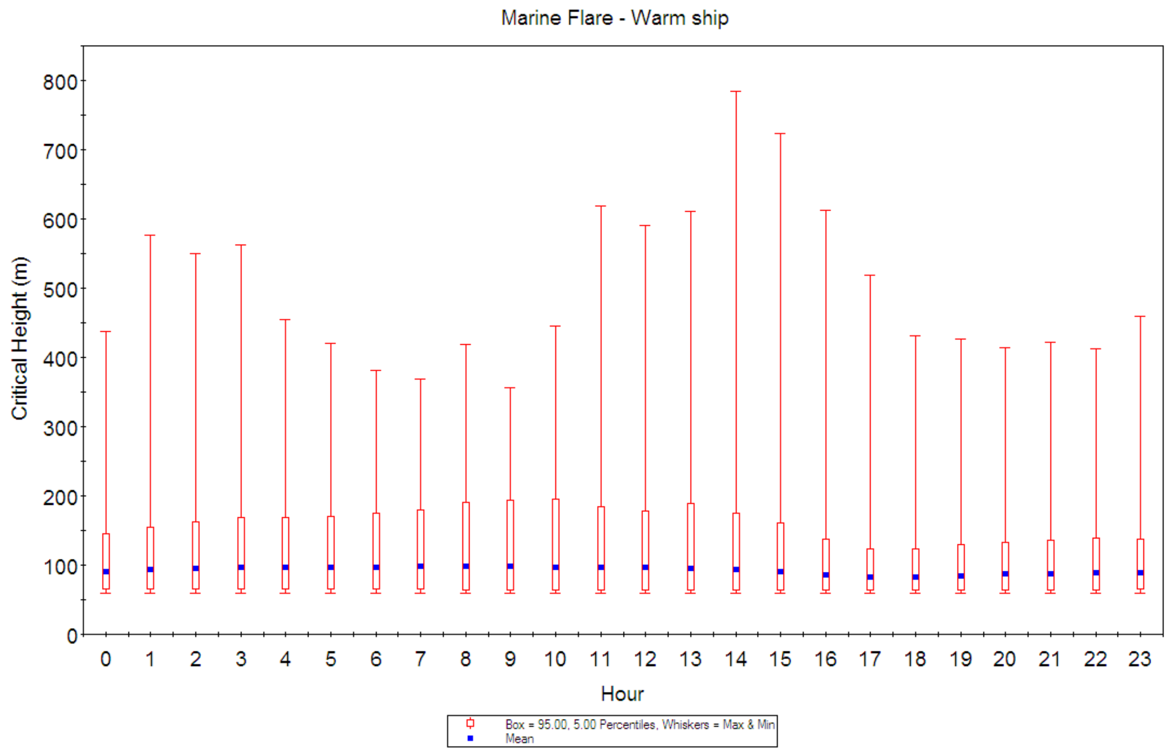

Figure D9 Critical plume height versus time of day for the non-normal operation of the marine flare

Location: Gladstone	**Averaging period:** 1-hour	**Data source:** TAPM	**Units:** Metres
Type: Box and Whiskers		**Prepared by:** A. Schloss	**Date:** December 2009

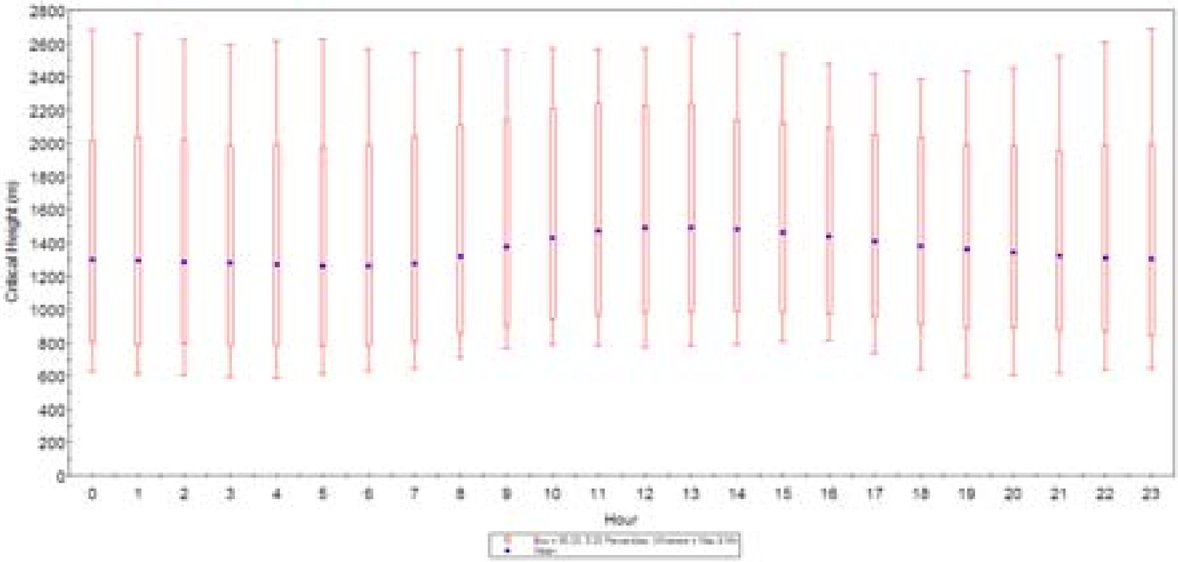

Figure D10 Critical plume height versus time of day for the non-normal operation of the ground flare

Location: Gladstone	**Averaging period:** 1-hour	**Data source:** TAPM	**Units:** Metres
Type: Box and Whiskers		**Prepared by:** A. Schloss	**Date:** December 2009