SUPPLEMENTARY AIR QUALITY IMPACT ASSESSMENT OF UPSTREAM GASFIELD INFRASTRUCTURE FOR THE QCLNG PROJECT

Prepared for

QUEENSLAND GAS COMPANY

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Glossary

Term	***Definition***
EPA	Environmental Protection Agency
EPP(Air)	Environmental Protection (Air) Policy
NPI	National Pollutant Inventory
BoM	Bureau of Meteorology
CSG	Coal seam gas
CSM	Coal seam methane
^{0}C	degrees Celsius
W	Watt
MW	Megawatt
MWh	Megawatt-hour: 1 MWh = 3,600 J
J	Joule
kJ	Kilojoule: 1.0 x 10^3J
MJ	Megajoule: 1.0 x 10^6J
GJ	Gigajoule: 1.0 x 10^9J
TJ	Terajoule: 1.0 x 10^{12}J
PJ	Petajoule: 1.0 x 10^{15}J
GJ/s	Gigajoule per second
L	Litre
kL	kilolitres
kL/day	kilolitres per day
µm	micron
mm	millimetre
m	metre
km	kilometre
M	million
m^2	square metre
m^3	cubic metre
m/s	metre per second
m^3/s	cubic metre per second
µg	microgram
mg	milligram
g	gram
kg	kilogram
t	tonne
Mt	million tonnes
Mtpa	million tonnes per annum
µg/m^3	microgram per cubic metre
mg/m^3	milligram per cubic metre
mg/Nm^3	milligram per normalised cubic metre (0^oC, 1 Atm)
Atm	Atmosphere (unit of pressure)
NO_X	Oxides of nitrogen
NO	Nitric oxide
NO_2	Nitrogen dioxide
CO	Carbon monoxide

Term	***Definition***
PM	Particulate matter (fine dust)
$PM_{2.5}$ and PM_{10}	Particulate matter less than 2.5 or 10 microns, respectively
VOC	Volatile organic compounds
PAH	Polycyclic aromatic hydrocarbons
CO_2	Carbon dioxide
CO_2-e	Carbon dioxide equivalents
NMNEHC	Non-methane, non-ethane hydrocarbons
GHG	Greenhouse Gas
%	percent
<	less than
>	greater than
No.	Number
e.g.	for example
i.e.	that is,

1. Introduction

Katestone Environmental has been commissioned by Queensland Gas Company (QGC) to undertake a Supplementary Air Quality Impact Assessment (SAQIA) as part of the Supplementary Environmental Impact Statement (SEIS) for the proposed development of a coal seam gas (CSG) extraction and transmission network located in the Surat Basin of south central Queensland. The project is known as the Queensland Curtis Liquefied Natural Gas (QCLNG) project. The gasfield extraction infrastructure and the associated compressor stations will link into a transmission pipeline that will pump gas to a proposed QCLNG processing facility to be located at Curtis Island near Gladstone.

The SAQIA considers the more detailed design information that has been developed since the completion of the EIS. The SAQIA seeks to address the key components of the project that have changed as a result of the development of the detailed design. Outside of this, the findings of the air quality study that was conducted for the EIS, remain valid.

The objective of the SAQIA is to investigate the potential affect of air emissions that could be generated by the project on air quality in the region.

The assessment has focused on the following key air pollutants that were found to be of importance in the EIS, namely:

- Oxides of nitrogen (NO_X), as nitrogen dioxide (NO_2)
- Carbon monoxide (CO)
- Hydrocarbons (VOC) - formaldehyde, acrolein, benzene, phenanthrene and ethylchloride

The assessment of air quality has been carried out using atmospheric dispersion modelling. The location of each emission source has been provided by QGC for input into the dispersion model. The locations are not definitive and may change as the project develops further. Notwithstanding this, the outcome of the assessment is not expected to change substantially as a result of final siting details being determined. However, they represent likely locations within the gasfield tenement boundaries owned by QGC.

The predicted ground-level concentrations of air pollutants have been compared with the relevant state, national and international ambient air quality objectives and standards including:

- Queensland Environmental Protection (Air) Policy 2008
- 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)*
- Texas Commission on Environmental Quality Toxicological section list of Effects Screening Levels

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

- Discussion of local meteorological conditions important to the dispersion of air pollutants
- Discussion of existing air quality including emission rates of air contaminants from background sources within the region
- Quantification of emissions from all proposed activities across the gasfield
- Dispersion modelling of the background sources of air pollutants and QCLNG infrastructure
- Assessment of ground-level concentrations of air pollutants including NO_2, CO and VOC by comparison to EPP(Air) objectives and other relevant guidelines

2. Development Proposal

2.1 Project Area

The project area for upstream infrastructure comprises the current QCLNG gasfield exploration and development areas in the Walloon Fairway of the Surat Basin that covers an area of 7,500 km^2. Figure 1 illustrates the project area.

2.2 Gas Extraction, Processing, and Transmission Infrastructure and Processes

The QCLNG project comprises three components: Upstream, Pipeline and LNG facility. The LNG facility and Pipeline components are not considered in this SAQIA. The Upstream infrastructure comprise a network of CSG extraction, processing and transmission sites designed to deliver gas to the proposed LNG facility at Curtis Island, in preparation for export.

CSG is extracted from each well and is transmitted via pipeline to the nearest Field Compressor Station (FCS) where either electric or gas-fired engines would drive compressors to compress the CSG, removing a small proportion of moisture in the process. The CSG will then be transmitted via a Trunk Pipeline to the regional Central Processing Plant (CPP) where it is compressed to a pressure suitable for transmission in the Main Export Pipeline that will carry the CSG from the gasfields to the QCLNG facility at Curtis Island. Moisture is also removed at the CPP. At the CPP, the CSG is compressed using either gas-fired turbine compressors or electric compressors.

In the gasfields that are southeast of Miles, all CPP and FCS compressors will be powered by electricity from the grid.

In the gasfields that are northwest of Miles, all CPP and FCS compressors and the water treatment plant located in the “Woleebee Creek” gasfield, will be powered by both gas-fired turbines and engines or by electricity from a purpose-built decentralised power station.

Wellhead compressors and water pumps will be powered by gas-fired engines across the entire gasfield. The water treatment plant located in the “Kenya” gasfield would be powered by a purpose-built gas-fired turbine generator.

2.3 Air Quality Impact Assessment Scenarios

The impact assessment has then been carried out for five scenarios. The selected scenarios cover two regions of the project area; northwest of Miles and southeast of Miles. The scenarios have been selected to represent worst-case emissions throughout the project lifetime.

2.3.1 Scenario 1

Scenario 1 includes all QCLNG infrastructure located to the northwest of Miles with the following power generation option:

- Emissions from 1 CPP plant (3 x GE LM2500 gas turbine driven compressors)
- Emissions from 12 FCSs (6 x G3516 gas-fired reciprocating engines with single stage Ariel screw compressors)

- Emissions from CAT G3304 well head compressor engines (assuming 1079 wells with compressors)
- Emissions from a single GE LM2500 gas turbine for power generation at the water treatment plant located in the “Woleebee Creek” gasfield
- Emissions from water pump Waukesha L5794GSI engines
- Maintenance Flare emissions and
- Background NO_2 emissions from power stations

The proposed location of each source in Scenario 1 is shown in Figure 2.

2.3.2 Scenario 2

Scenario 2 also includes all QCLNG infrastructure located to the northwest of Miles, shown in Figure 3, with the following power generation option:

- Decentralised power station used to power CPP, FCSs and water treatment plant engines/turbines
- Emissions from CAT G3304 well head compressor engines (assuming 1079 wells with compressors)
- Emissions from water pump Waukesha L5794GSI engines
- Maintenance Flare emissions
- Background NO_2 emissions from power stations

2.3.3 Scenario 3

Scenario 3 includes all QCLNG infrastructure located to the southeast of Miles, shown in Figure 4 including the following:

- Emissions from a single GE LM2500 gas turbine for power generation at the water treatment plant located in the “Kenya” gasfield
- Emissions from CAT G3304 well head compressor engines (assuming 75% of wells with compressors)
- Emissions from water pump Waukesha L5794GSI engines
- Maintenance Flare emissions
- Background NO_2 emissions from power stations

2.3.4 Scenario 4

Scenario 4 has not been explicitly modelled. A semi-quantitative assessment of flare emissions at the wells has been carried out for emergency shutdowns of the QCLNG plant.

2.3.5 Scenario 5

Scenario 5 considers the potential air quality impact of increasing the number of screw compressor engines at a single FCS located in the “Paradise Downs” gasfield to the northwest of Miles. This FCS, as is shown in later sections, contributes a significant amount to the total ground-level concentration with six screw compressor engines (Scenario 1). During the lifetime of the QCLNG project there is a potential to use the FCSs for reasons other than to compress CSG. This could mean eight screw compressors would be required at an FCS. Therefore, Scenario 5 includes emissions from an FCS with six and eight screw compressor engines to provide a comparison of results.

3. Emissions

3.1 Normal Operations

3.1.1 Air Pollutants

The air pollutants considered in the SAQIA are associated with the combustion of CSG fuel in the gas engines and turbines proposed to be used. The key pollutants identified in the EIS include NO_X, CO and various hydrocarbon species. Sulfur is not present in the CSG, and therefore sulfur dioxide or any other compounds containing sulfur will not be present in the exhaust emissions of fuel burning equipment.

Emission rates of NO_X and CO, have been supplied by the proponent from gas engine specification technical data. Chemical speciation of the hydrocarbons that could be found in the exhaust emissions from the gas-fired engines was not available in the gas engine specifications. The conventional approach to speciating hydrocarbon emissions is to use the USEPA AP-42 document *Natural Gas-fired Reciprocating Engines (Chapter 3.1).*

It should also be noted that the AP-42 emission factors have been determined for gas-fired reciprocating engines using natural gas fuel in the United States of America. The natural gas fuel combusted in AP-42 emission tests has a composition that is different to the CSG used in the QCLNG Project.

In particular, it has been found that hydrocarbons such as acrolein do not occur in the exhausts of the engines when fired on CSG because, unlike the natural gas that is used as the basis of the AP-42 emission factors, the CSG does not contain propene the necessary precursor for the formation of acrolein. This was demonstrated in sampling of G3512 and G3608 reciprocating engines fuelled on CSG (Leeder Consulting, 2009). Consequently, acrolein emission rates have been characterised in this study using the results of Leeder Consulting sampling rather than AP-42.

The EIS dispersion modelling found that formaldehyde, benzene, ethylchloride, phenanthrene and acrolein to be of concern. Therefore, the assessment of hydrocarbons for the supplementary assessment has focused on these species.

3.1.2 Field Compressor Stations

The FCSs that have been included within this assessment are the FCSs located to the north-west of Miles. In this area, twelve FCSs are proposed. The performance characteristics of the Caterpillar G3516 gas engines with single stage Ariel screw compressors, to be located at each FCS, is presented in Table 1. Performance information is presented for normal operating conditions with the gas engines operating at 100% capacity. Each FCS will consist of six screw compressors in scenario 1 and either six or eight in scenario 5. Table 2 presents the concentrations and emission rates for NO_X, CO and total hydrocarbons, while Table 3 presents the rates of formaldehyde, benzene, ethylchloride, phenanthrene and acrolein.

Table 1 Performance and source characteristics for the Caterpillar G3516 gas engines with single stage Ariel screw compressors under normal operating conditions at 100% capacity

Parameter	**Units**	**Value**[1]
Engine power	bkW	999
Nominal engine efficiency	%	33.7
Nominal fuel consumption	MJ/bkW-hr	10.67
Stack height	m	7.2
Stack diameter	m	0.26
Exhaust gas temperature	^{o}C	457
Exhaust gas velocity	m/s	25.1
Exhaust mass flow rate (0^{o}C, 1 Atm, wet)	kg/bkW-hr	6.03
Exhaust gas flow rate (0^{o}C, 1 Atm, wet)	Nm^3/bkW-hr	4.8
Exhaust gas flow rate (actual stack conditions)	m^3/s	2.1
Normalised exhaust gas flow rate (0^{o}C, 1 Atm)	Nm^3/s	1.3

Note:
[1] Source characteristics data obtained from Catepillar gas engine technical data sheet.

Table 2 Emission rate for oxides of nitrogen, carbon monoxide and hydrocarbons for the Caterpillar G3516 gas engines with single stage Ariel screw compressors

Parameter	**Concentration**[1] **(mg/Nm^3 @ 3% O$_2$)**	**Emission rate**[1] **(g/s)**
Oxides of nitrogen (as NO$_2$)	300	0.558
Carbon monoxide	370	0.699
NMNEHC	60	1.14

Note:
[1] Information calculated from Catepillar gas engine technical data sheet.
[2] Total hydrocarbons as non-methane hydrocarbons and presented as methane equivalents.

Table 3 Breakdown of emission rates for hydrocarbons from the Caterpillar G3516 gas engines with single stage Ariel screw compressors

Pollutant	Molecular weight	Emission1 factor[1]	Emission Rate (g/s)
Benzene	78.1	4.4×10^{-4}	5.6×10^{-4}
Acrolein[2]	56.06	-	1.24×10^{-5}
Phenanthrene	178.23	1.04×10^{-5}	1.32×10^{-5}
Formaldehyde	30.03	5.28×10^{-2}	6.72×10^{-2}
Ethylchloride	64.52	1.87×10^{-6}	2.38×10^{-6}
Note: [1] Source: USEPA [2] Acrolein emission rate calculated from measurements made by Leeder Consulting			

3.1.3 Central Processing Plant and Water Treatment Plants

The performance characteristics of the GE LM2500 gas turbine proposed to be located at the CPP northwest of Miles and the WTP's located in the "Woleebee Creek" and "Kenya" gasfields, is presented in Table 4, while pollutant concentrations and emission rates are presented in Table 5. Performance information is presented for normal operating conditions with the gas engine operating at 100% capacity. The CPP will include three turbines and the WTP will include one. Table 6 presents the likely contribution to total hydrocarbon emissions assessed for this project.

Table 4 Source characteristics for the LM2500+G4 gas turbine drivers operating at 100% capacity

Parameter	Units	Value[1]
Number of units	-	3
Stack height	m	28.3
Stack diameter	m	3
Exhaust stack temperature	°C	837
Exhaust gas velocity	m/s	30
Exhaust gas flow rate (actual stack conditions)	m^3/s	173.94
Normalised exhaust gas flow rate (0°C, 1 Atm)	Nm^3/s	59.24
Note: [1] Source characteristics data obtained from Catepillar gas engine technical data sheet.		

Table 5 Emission rate for oxides of nitrogen, carbon monoxide and total hydrocarbons for the LM2500+G4 gas turbine

Parameter	Concentration[1] (mg/Nm^3 @ 15% O_2)	Emission rate[1] (g/s)
Oxides of nitrogen (as NO_2)	51	3.34
Carbon monoxide	31	2.03
Total Hydrocarbons[2]	30	0.21
Note: [1] Information obtained from GE gas engine technical data sheet. [2] As n-propane equivalent.		

Table 6 Breakdown of emission rates for hydrocarbons from the GE LM2500 gas turbine

Pollutant	Molecular weight	Emission factor[1] (lb/MMBtu)	Emission rate (g/s)
Benzene	78.1	1.2×10^{-5}	3.42×10^{-4}
Acrolein	56.06	6.4×10^{-6}	1.82×10^{-4}
Formaldehyde	30.03	7.1×10^{-4}	2.02×10^{-2}
Note: [1]Source: US EPA AP-42			

3.1.4 Well Head Compressors

The performance characteristic of the Caterpillar G3304 gas-fired engine, located at each well requiring compression, is presented in Table 7. While pollutant concentrations and emission rates are presented in Table 8. Performance information is presented for normal operating conditions with the gas engine operating at 100% capacity and assuming the installation of catalytic reduction of NO_x, CO and hydrocarbons. Table 6 presents the likely contribution from the G3304 to total hydrocarbon emissions assessed for this project.

Table 7 Source characteristics for the Caterpillar G3304 gas engines at 100% capacity

Parameter	Units	Value[1]
Engine power	bkW	71
LHV input	kW	56.5
Nominal engine efficiency	%	
Nominal fuel consumption	MJ/bkW-hr	11.14
Stack height	m	2
Stack diameter	m	0.105
Exhaust stack temperature	^{o}C	548
Exhaust gas velocity	m/s	25
Exhaust gas flow rate (actual stack conditions)	m^3/s	0.2
Normalised exhaust gas flow rate ($0^{o}C$, 1 Atm)	Nm^3/s	0.07
Note: [1]Source characteristics data obtained from Catepillar gas engine technical data sheet.		

Table 8 Concentration and emission rate for oxides of nitrogen, carbon monoxide and total hydrocarbons for the Caterpillar G3304 gas engines with two stage Ariel reciprocating compressors and catalytic reduction

Parameter	Concentration[1] (g/bkW-hr)	Emission rate[1] (g/s)
Oxides of nitrogen (as NO_2)	2.83	0.06
Carbon monoxide	0.43	0.008
Total Hydrocarbons	1.61	0.03
Note: [1]Information obtained from Catepillar gas engine technical data sheet and assuming catalytic reduction for NO_x of 90%, CO of 80% and hydrocarbons of 50%.		

Table 9 Breakdown of emission rates for hydrocarbons from the Caterpillar 3608 gas engines with two stage Ariel reciprocating compressors

Pollutant	Molecular weight	Emission factor[1] (lb/MMBtu)	Emission rate (g/s)
Benzene	78.1	1.58×10^{-3}	7.45×10^{-5}
Acrolein[2]	56.06	-	6.24×10^{-7}
Formaldehyde	30.03	2.05×10^{-2}	9.66×10^{-4}
Note: [1]Source: US EPA AP-42 [2]Acrolein emission rates calculated from measurements made by Leeder Consulting			

3.1.5 Water Pumps

The performance characteristic of the Waukesha L5794GSI gas-fired engine that is proposed to be located at each water pumping station, is presented in Table 10. Pollutant concentration rates are presented in Table 8. Performance information is presented for normal operating conditions with the gas engine operating at 100% capacity. Table 12 presents the hydrocarbon emission rates.

Table 10 Performance and source characteristics for the Waukesha L5794GSI gas engines operating at 100% capacity

Parameter	Units	Value[1]
Engine power	bkW	1029
Nominal fuel consumption	kJ/bkW-hr	10,625
Stack height	m	2
Stack diameter	m	0.33
Exhaust stack temperature	°C	587
Exhaust gas velocity	m/s	25.3
Exhaust gas flow rate (actual stack conditions)	m^3/s	2.1
Normalised exhaust gas flow rate (0°C, 1 Atm)	Nm^3/s	0.67
Note: [1]Source characteristics data obtained from Waukesha gas engine technical data sheet.		

Table 11 Concentration and emission rate for oxides of nitrogen, carbon monoxide and total hydrocarbons for the Waukesha L5794GSI gas engines with catalytic reduction

Parameter	Concentration[1] (g/bhp-hr)	Emission rate[1] (g/s)
Oxides of nitrogen (as NO_2)	1.39	0.49
Carbon monoxide	1.76	0.63
NMHC	0.15	0.05
Note: [1]Information obtained from Waukesha gas engine technical data sheet assuming catalytic reduction of NO_x of 90%, CO of 80% and hydrocarbons of 50%		

Table 12 Breakdown of emission rates for hydrocarbons from Waukesha L5794GSI gas engines

Pollutant	Molecular weight	Emission factor[1] (lb/MMBtu)	Emission rate (g/s)
Benzene	78	1.58×10^{-3}	1.03×10^{-3}
Acrolein[2]	56.06	-	6.25×10^{-6}
Formaldehyde	30.03	2.05×10^{-2}	1.34×10^{-2}

Note: [1] Source: US EPA AP-42

[2] Acrolein emission rates calculated from measurements made by Leeder Consulting

3.1.6 Decentralised gas powered turbine

The performance characteristics of the GE LMS100 gas-turbines that could be used for shipping power to the CPPs, FCSs and water treatment plant in the gasfield northwest of Miles is presented in Table 13, while pollutant concentrations are presented in Table 14. Performance information is presented for normal operating conditions with the gas turbine operating at 100% capacity.

Table 15 presents the hydrocarbon emission rates.

Table 13 Performance and source characteristics for the GE LMS100 gas turbine operating at 100% capacity

Parameter	Units	Value[1]
Nominal fuel consumption	MJ/GJ/hr	868.4
Stack height	m	14.6
Stack diameter	m	3.3
Exhaust stack temperature	°C	414.6
Exhaust gas velocity	m/s	10.2
Exhaust gas flow rate (actual stack conditions)	m^3/s	166
Normalised exhaust gas flow rate (0°C, 1 Atm)	Nm^3/s	60.7

Note:

[1] Source characteristics data obtained from Catepillar gas engine technical data sheet.

Table 14 Concentration and emission rate for oxides of nitrogen, carbon monoxide and total hydrocarbons for the GE LMS100 gas turbine

Parameter	Concentration[1] (mg/Nm^3 @ 15% O_2)	Emission rate[1] (g/s)
Oxides of nitrogen (as NO_2)	51	10.3
Carbon monoxide	194	39
Hydrocarbons[2]	20	1.06

Note:

[1] Information obtained from Catepillar gas engine technical data sheet.

[2] As n-propane

Table 15 Breakdown of emission rates for hydrocarbons from the GE LMS100gas turbine

Pollutant	Molecular weight	Emission factor[1] (lb/MMBtu)	Emission rate (g/s)
Benzene	78	1.2×10^{-5}	1.2×10^{-3}
Acrolein	56.06	6.4×10^{-6}-	6.6×10^{-4}
Formaldehyde	30.03	7.1×10^{-4}	7.36×10^{-2}

3.1.7 Flares

During normal operation of the QCLNG gasfield infrastructure each gas well will require maintenance every two years. During this period, which lasts 6 days, the CSG extracted from the well will be flared. A worst case scenario results in a maximum of 53 wells flaring across the entire gasfield at any one time. Table 16 and Table 17 provide flare characteristics and emission rates per well during this process.

Table 16 Emission characteristics of the proposed flares, located at well during maintenance

Parameter	Units	Well Maintenance
Nominal stack height	m	2
Nominal flare tip diameter	m	0.15
Temperature	^{o}C	1273
Gas exit velocity (modelled)	m/s	20
Effective stack height (modelled)	m	2.9
Effective flare tip diameter (modelled)	m	0.26
Energy output	GJ/hr	2.3
Exhaust gas mass rate	g/s	0.64
Exhaust Gas flow rate	m^3/s	0.0004
Note: [1] From information supplied by QCLNG. [2] From AP-42 Emission Factors. [3] From USEPA Screen 3 Method.		

Table 17 Emission rates of pollutants from maintenance flaring

Parameter	Oxides of nitrogen	Carbon monoxide	Total hydrocarbons
Emission factor (g/GJ)[1]	29.2	159.1	60.2
Emission rate (g/s)[2]	0.02	0.1	0.04
Note: [1]From AP-42 emission factors [2]From AP-42 emission factors and flare energy output data supplied by QCLNG.			

3.2 Emergency Operations

In the event of an emergency shutdown or scheduled maintenance at the QCLNG plant located on Curtis Island, coal seam gas will be combusted in a flare at each gas well across the gasfield. Information on the characteristics and emission rates from a gas well flare during emergency operations are presented in Table 18 and Table 19.

Table 18 Emission characteristics of the proposed flares, located at well during emergency operations

Parameter	Units	Emergency operations
Nominal stack height	m	2
Nominal flare tip diameter	m	0.15
Temperature	°C	1273
Gas exit velocity (modelled)	m/s	20
Effective stack height (modelled)	m	2.3
Effective flare tip diameter (modelled)	m	0.08
Energy output	GJ/hr	0.2
Exhaust gas mass rate	g/s	0.06
Exhaust Gas flow rate	m^3/s	0.00003

Note:
[1] From information supplied by QCLNG.
[2] From AP-42 Emission Factors.
[3] From USEPA Screen 3 Method.

Table 19 Emission rates of pollutants from emergency operations flaring

Parameter	Oxides of nitrogen	Carbon monoxide	Total hydrocarbons
Emission factor (g/GJ)[1]	29.2	159.1	60.2
Emission rate (g/s)[2]	0.002	0.01	0.003

Note: [1]From AP-42 emission factors
[2]From AP-42 emission factors and flare energy output data supplied by QCLNG.

3.3 Summary of Emission Sources

Table 20 presents a summary of the emission sources during both normal and non-normal operations across the QCLNG project area.

Table 20 Summary of emission sources for the project

Unit	No. of process units	Type of source at each unit						Total no. of sources
		Cat G3516 engines	GE LMS2500	Waukesha L5794GSI	Cat G3304 engines	LMS100	Flare	
FCS	12	72	0	0	0	0	0	72
CPP	1	0	3	0	0	0	0	3
Water Pumps	170	0	0	170	0	0	0	170
Well heads	6000	0	0	0	4500	0	53/6000	53/6000
Power Station	1	0	0	0	0	1	0	1
Water Treatment Plants	2	0	2	0	0	0	0	2

3.4 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 unsealed roads. The composition engine exhaust emissions are 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 compressor engines, short duration and transient nature of these emissions during project construction over such a large region, these emissions have not been considered in this assessment.

Construction of the QCLNG gasfield has the potential to cause elevated levels of dust if it is not appropriately managed. Dust minimisation and management strategies should be implemented from the commencement of construction.

Dust management should include regular watering of roads and exposed areas to reduce wheel-generated dust, and restricting vehicle speeds to below 40 kilometres per hour. During high wind conditions, dust-generating activities such as earthworks, which could potentially affect nearby sensitive receptors should not be carried out. Haul vehicles should be covered when moving outside the construction site. Long-term stockpiles should be revegetated to prevent wind erosion. Regular cleaning of machinery and vehicle tyres will prevent track-out of dust to public roads. Burning or incineration of cleared vegetation or other materials should not be carried out on site at any time.

Before construction commences a dust management plan (DMP) should be developed to assist in minimising nuisance dust. Dust measures that will assist in minimising dust from construction activities include:

- Limiting the amount of cleared area
- Erecting physical barriers
- Site traffic control
- Earth moving management
- Watering sprays
- Soil compaction
- Physical Stabilisation
- Vegetative stabilisation

4. Air Quality Criteria

4.1 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. (EPP(Air) Explanatory notes, General outline)*

The EP Act gives the Environment Minister the power to create Environmental Protection Policies that aim to protect the environmental values identified for Queensland. In accordance with the EP Act, the Environmental Protection (Air) Policy (EPP(Air)) is to be reviewed every ten years, with the initial EPP(Air) having been gazetted in 1997. Consequently, the EPP(Air) was scheduled for revision in 2008 and the revised EPP(Air) 2008 commenced on 1 January 2009.

The objective of the EPP(Air) 2008 is summarised as follows:

> *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.*

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

> *The purpose of the EPP(Air) 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 -*
>
> *a) Identifying environmental values to be enhanced or protected; and*
> *b) Stating indicators and air quality objectives for enhancing or protecting the environmental values; and*
> *c) 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 –*
>
> *a) the qualities of the air environment that are conducive to protecting the health and biodiversity of ecosystems; and*
> *b) the qualities of the air environment that are conducive to human health and wellbeing; and*
> *c) 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*
> *d) the qualities of the air environment that are conducive to protecting agricultural use of the environment.*

The administering authority must consider the requirements of the EPP(Air) when it decides 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.

4.2 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 are 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.

4.3 Relevant Ambient Air Quality Goals for the Project

Table 21 presents a summary of the relevant ambient air quality goals for criteria pollutants adopted for this assessment.

Table 21 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 exceedence allowed
Nitrogen dioxide	Health and wellbeing	1-hour	250	1
		1-year	62	0
	Health and biodiversity of ecosystems	1-year	33	0
Carbon monoxide	Health and wellbeing	8-hour	11,000	1

Note
[1] Air quality objective at 0°C

In addition to the air pollutants detailed above, the combustion of coal seam gas in the gas-fired engines and flares is also likely to produce small quantities of hydrocarbons. The hydrocarbons that were found in the EIS to be relatively significant in the exhausts of gas-fired reciprocating engines are presented in Table 22 with their relevant air quality objective. The source of air quality objectives is discussed in the EIS.

Table 22 Relevant ambient air quality objectives and standards for hydrocarbons

Indicator	Environmental value	Averaging period	Air quality objective or standard (µg/m³)	Source of standard or goal
Acrolein (2-propenal)	Health (Extremely toxic - USEPA)	1-hour	0.42	NSW DECC
Benzene	Health and wellbeing	1-hour	29	NSW DECC
		1-year	10	EPP(Air)
Ethylchloride (Chloroethane)	Health and wellbeing	1-hour	0.048	NSW DECC
Formaldehyde	Health and wellbeing	24-hour	54	EPP(Air)
	Protecting aesthetic environment	30-minute	110	EPP(Air)
Phenanthrene	Health	1-hour	0.5	TCEQ
	Health	1-year	0.05	TCEQ

Compliance has been assessed by comparison of the predicted maximum concentration in the modelling domain to the air quality objective.

5. Existing Environment

The existing environment in the region surrounding the proposed QCLNG project area 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 released by the project's operations.

5.1 Terrain and Land Use

The Surat Basin constitutes part of the Great Artesian Basin of Australia and covers an area of approximately 122,655 km^2. The proposed project area located near Miles, situated in the Western Downs on the western slopes of the Great Dividing Range, is approximately 280 km inland from the Queensland coast. The terrain in the region is predominantly flat with mildly undulating hills. The soils primarily consisting of bentonite clays and sandy clay loams. Land use in the region is predominantly agriculture and mining, with the remaining land comprising of native shrub-land.

The flat, low-lying hills in the project area result in a relatively uniform wind field across the region as there are no significant terrain influences, such as tall peaks, lakes and coastline, to generate highly localised affects. The flat areas with shrubby, low vegetation also present a low surface roughness resulting in a higher proportion of moderate (3-5 m/s) winds.

5.2 Location of Sensitive Receptors

There are several small towns throughout the study area, including Wandoan and Jackson closest to the north west section of the project area. The town of Miles, with a population of approximately 1,163 people is located between the two sections of the study area. There are several towns within the south east section of the study area including Chinchilla and Dalby. There are also several isolated residential properties within the study area.

5.3 Climate

The climate of the Darling Downs in southern central Queensland is largely dominated by tropical/sub-tropical weather patterns that lead to relatively drier winters and wetter summers. This climate is strongly influenced by various short- and long-term cyclical climate patterns including the annual migration of the Inter-tropical Convergence Zone (ITCZ), which generates the wet and dry seasons, while the intensity of these seasons are further influenced by shorter timescale cycles such as the Cloncurry Heat Low associated with the Queensland Trough and longer timescale cycles such as the El Nino Southern Oscillation (ENSO). The short-term cycles such as the Queensland Trough influence daily weather patterns while the longer-term ENSO cycle tends to intensify the weather associated with the tropical/monsoonal climate patterns, leading to extended or more intense periods of drying that periodically lead to drought conditions (El Nino), or intense precipitation resulting in flooding (La Nina).

The summertime weather pattern across central Queensland is dominated by a major trough in the trade-wind easterlies located to the west of the Great Dividing Range at an average meridional position of 700 kilometres from the coast. The Queensland trough is associated with a low pressure cell at its northern extremity known as the Cloncurry Heat Low, generated by intense solar heating of the surface.

The Queensland trough tends to be very shallow due to the convergence of air between 1,500 and 3,000 metres. This is the result of ascending air associated with the surface level low pressure system converging on the subsiding air from an upper level high pressure system. This is largely caused by the equator-ward slope with height of the subtropical ridge. Outflow at 3,000 metres compensates for low level convergence into the heat low. (Sturman and Tapper, 2002).

The Queensland trough and associated heat-low systems adjust daily throughout the warmer months and are largely driven by intense solar heating during the day. This occurs most markedly in arid and semi-arid regions where there is insufficient cloud formation to moderate the intensity of solar insolation at the ground surface. At night when temperatures are at their daily minimum, the trough is relatively weak and lies well inland from the coast. However, during the day when solar heating and temperatures are at their maximum, the pressure of the surface trough deepens and migrates hundreds of kilometres north-eastward, effectively tightening the pressure gradient between the trough and the ridge along the coast. Radiative cooling from the land surface at night weakens the trough and returns it to its original inland position. (Sturman and Tapper, 2002)

This daily cycle of deepening and moving the Queensland trough over the interior initiates thunderstorm activity to the east of the trough axis. Consequently, it is this summertime weather activity that generates the wetter spring and summer months relative to the drier autumn and winter months when the solar incidence is less intense. It is important to note that this weather phenomenon is largely driven by intense solar heating of the land surface, which tends to be relatively sparsely vegetated, rather than any orographic effects associated with low surface pressure generated on the lee side of the Great Dividing Range. However, while the trough of low pressure typically resides over the inland to the west of the Great Divide, the trough's influence is seen in the deflection of the Pacific Ocean trade winds from southeast to east or northeast as they cross the Australian tropical and sub-tropical coast.

5.4 QCLNG Upstream Project Area

Meteorological data from the BoM monitoring stations located at Dalby and Miles have been used to characterise the climate in the QCLNG Upstream Project area. The Dalby and Miles monitoring stations have been selected for their close proximity to the proposed gasfields and processing facilities and the availability of data. These monitoring stations have been selected to provide a summary of the regional climate, where data collection has been carried out for between 12 – 114 years. The meteorological parameters that are measured at the Dalby and Miles monitoring stations include long-term temperature, solar radiation, atmospheric pressure, rainfall, relative humidity and wind speed and direction. The parameters used from each site are summarised in Table 23.

Table 23 Bureau of Meteorology monitoring stations and meteorological parameters used in the climate summary

Region	Location	Latitude/longitude	Record period	Parameters
Miles	Post Office	26.66 °S 150.18 °E	1885 – 2009	Temperature, solar exposure, relative humidity and rainfall
	Constance St	26.66 °S 150.18 °E	1997 – 2009	Surface pressure, wind speed and wind direction
Dalby	Airport	27.16 °S 151.26 °E	1992 – 2009	Temperature, solar exposure, relative humidity and rainfall

5.4.1 Temperature and Solar Radiation

The average daily minimum and maximum temperature at Miles and Dalby is presented in Table 24 for each season. A histogram of the average daily maximum and minimum temperature in each region is presented in Figure 5. The analysis identifies a seasonal temperature profile typical of the sub-tropical Queensland climate, with cooler winter months of June, July and August and warmer summer months of December, January and February.

The average maximum daily temperature recorded at the sites during summer ranges from 31.8 °C at Dalby to 32.8 °C at Miles. The average minimum daily temperature recorded at the sites during winter ranges from 4.5 °C at Miles to 4.8 °C at Dalby. On average, daily temperatures tend to increase to the west across the project area.

Table 24 Average daily temperature ranges by season across the QCLNG Project area (in °C)

Location	Spring		Summer		Autumn		Winter	
	Min	Max	Min	Max	Min	Max	Min	Max
Miles	12.6	28.3	19.1	32.8	12.4	27.2	4.5	20.2
Dalby	12.3	28.0	18.3	31.8	12.4	27.1	4.8	20.5

Table note:
Averages based on recording period –
Miles: 1908 – 2009
Dalby: 1992 – 2009

As described above, the amount of solar radiation at the surface is a primary driver for the weather patterns and climatic cycles that influence the Darling Downs and central Queensland region. Average daily solar exposure (MJ/m²) at Miles and Dalby for the period 1990 - 2009 is presented in a time series chart in Figure 6. The analysis illustrates the seasonal pattern whereby summertime solar exposure is twice that of the wintertime.

5.4.2 Rainfall

The annual pattern of rainfall illustrates the sub-tropical climate in the region were 51% (Miles) and 57% (Dalby) of the annual precipitation occurs during the monsoonal months of November to February. The average and highest recorded monthly rainfall at Miles and Dalby is presented in Table 25 and illustrated graphically in Figure 7.

Table 25 Average and highest monthly rainfall at Miles and Dalby (in millimetres)

Average rainfall													
Location	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Ann**
Miles	95	75	58	37	39	40	37	29	31	54	66	89	649
Dalby	74	89	37	21	39	35	24	20	30	58	83	99	604
Highest rainfall													
Location	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Ann**
Miles	318	252	473	211	240	196	267	171	151	194	263	443	1,179
Dalby	226	225	108	91	216	147	78	72	96	166	151	174	847

Table note:
Averages based on recording period –
Miles: 1885 – 2009
Dalby: 1992 – 2009

The annual average rainfall across the region ranges between 604 millimetres at Dalby and 649 millimetres at Miles, with the maximum monthly average rainfall occurring in December, January and February for Dalby (99 mm) and Miles (95 mm) respectively. While rainfall predominantly occurs during the monsoonal summer period illustrating its sub-tropical climate, the relatively low amount of annual rainfall shows that the region is still quite dry due to its inland, semi-arid setting, when compared to the tropical north of Australia. On average, the total rainfall during the monsoonal months is slightly more than twice that of the drier months. In comparison in Darwin, approximately ten times as much rainfall occurs during the monsoonal months (November-March) that in the drier months (April – October).

5.4.3 Relative Humidity

As discussed above, the seasonal availability of moisture is another important factor in influencing the climate, by affecting the transfer of heat in the atmosphere through the balance between sensible and latent heat fluxes, and the occurrence of precipitation. Relative humidity is one of several measures used to describe the amount of moisture in the atmosphere, and is the ratio of the actual amount of moisture in the atmosphere to the maximum amount that could be held, at a given temperature.

Relative humidity has been analysed from long-term averages based on daily measurements collected at 9am and 3pm at Miles and Dalby. The monthly average relative humidity at 9am and 3pm at each location is presented in Table 26 and Figure 8.

Table 26 Average daily relative humidity ranges at 9am and 3pm across the QCLNG Project area (in %)

Location	Time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Miles	9am	60	64	63	64	71	75	72	63	55	53	53	56	62
	3pm	41	42	40	41	46	48	44	38	34	34	35	37	40
Dalby	9am	68	71	67	68	76	81	76	68	63	60	61	63	68
	3pm	46	49	41	40	47	49	45	39	37	38	42	44	43

Table note:
Averages based on recording period –
Miles: 1938 – 2005 at 9am and 1961 – 2005 at 3pm
Dalby: 1992 – 2009

The analysis indicates that the cooler late autumn and winter months (May – July) tend to be relatively more humid than the warmer spring and summer months (September – January). While this may appear to contradict the suggestion that the summer months are wetter than the winter months in terms of precipitation, it is an artifact of the measure of relative humidity, where it is the ratio of the actual water vapour content and the maximum capacity of the atmosphere to hold water, at a given temperature. Considering the significant number of drought affected years during the recent measurement period, rainfall has not significantly varied between seasons, while the amount of solar heating of the surface, and subsequent temperature, has continued in its typical summer-winter cycle. As the air temperature increases so too does it ability to hold water. However, if the amount of available water remains relatively constant, the relative humidity is reduced. Consequently, the seasonal temperature variation influences the atmosphere's ability to hold water and, therefore, the relative humidity. As discussed in the rainfall section above, only twice the amount of rainfall occurs in the wet season in comparison to the dry season, while twice the amount of solar radiation occurs in the summer to that in the winter.

In regard to average daily variations, the analysis indicates that relative humidity is 60% higher at 9am than at 3pm across the region on average.

5.4.4 Surface Pressure

As discussed above, long- and short-term fluctuations in atmospheric pressure are important when describing climatic patterns across the region. Monitoring data from Miles has been used to characterise the mean sea-level pressure (MSLP) in the region during the period 2002 – 2009. Longer term seasonal cycles in MSLP at Miles are shown graphically in Figure 9.

The longer term cycles are evident in the seasonal fluctuations of MSLP, which fluctuates around an average pressure of 1020 hPa during the drier winter months (May – August), and 1010 hPa during the wetter summer months (November – February) (Figure 9). Within this seasonal cycle, MSLP fluctuates on a diurnal basis between 3 - 4 hPa, with solar heating of the ground during the midday-afternoon period reducing the atmospheric pressure above the ground. At night when the temperature falls, atmospheric pressure increases again.

The seasonal fluctuations are generated by the passage of high pressure systems across the low to mid latitudes during the winter months and tend to produce relatively dry, clear, stable synoptic conditions due to the subsidence of cool air from aloft. Conversely during the summer months, the passage of low pressure systems across the low to mid latitudes associated with the development of the Queensland trough and southward shift in the ITCZ, and along with more intense solar heating, tend to produce warmer conditions and the development of afternoon thunderstorms.

5.4.5 Wind Speed and Direction

Wind speed and wind direction are important parameters for the transport and dispersion of air pollutants. The wind fields in the QCLNG Project Area of southern central Queensland reflect the geographic situation and physical environment of the region. The environment consists of relatively flat terrain on the lee side of the Great Dividing Range, dry to semi-arid conditions with a mixture of agricultural, pastoral, and forest land uses, dispersed with small rural towns and industries, all located a significant distance from the Queensland coast. Consequently the winds across the region are largely driven by synoptic scale influences such as pressure gradients, convergence and convection, and subsidence of cool air from aloft, rather than orographic affects and ocean-land interactions such as land-sea breezes.

The distributions of wind speed and direction observed at Miles has been used to characterise the wind fields in the QCLNG Project Area. The annual distribution of winds at Miles, for the period January 1999 to June 2009, are presented as a wind rose diagram in Figure 10, while the seasonal and diurnal distributions are presented in Figure 11. A summary of the main wind field characteristics at Miles are also presented in Table 27.

The analysis of the distribution of winds across the QCLNG Project Area has identified two dominant features of the regional wind fields:

1. A large proportion of the winds blow from the northeastern quadrant (between the north and east). These winds tend to be moderate (% of the time) or strong (% of the time).
2. There is a significant amount of calms in the region, particularly at Miles.

The seasonal distribution of winds at Miles indicates that the winds from the northeast quadrant, and in particular from the north and north-northeast direction, dominate all year round. The seasonal distribution also shows that winds from the south to southwest also make up another significant proportion of the winds across the region, particularly during the autumn and winter months, and to a lesser extent during the spring.

The diurnal distribution of winds also illustrates the dominance of the winds from the northeast quadrant, and in particular from the north and north-northeast direction, and show that the wind blows from this direction at all times of the day. However, the north and north-northeasterly winds are particularly prevalent during the night and early morning periods and slightly less frequent during the late evening. The diurnal profile also indicates that the winds during the afternoon, the warmest time of the day, are more evenly distributed from all directions.

Table 27 Summary of the distribution of wind speed and direction at Miles

Wind direction	Distribution of wind speeds (% of total winds)			
	Light Calm to <2 m/s	Moderate 2 – 4.99 m/s	Strong > 5m/s	Total
All directions (100%)	40%	55%	5%	100%
North-eastern sector (350° to 100°)	7%	32%	3%	41%
South-western sector (180° to 220°)	3%	8%	1%	12%
Note: Statistics based on a 97.6% data recovery during the 2004 – 2008 monitoring period				

5.5 Ambient Air Quality in the Region

5.5.1 Existing Industries and Sources of Oxides of Nitrogen

There is currently no monitoring of ambient air quality performed in the Bowen or Surat Basins or the Walloons development area. Notwithstanding this, the existing air quality in the region is likely to be fairly good due to the nature of land use. Industries identified through a review of the National Pollutant Inventory include:

- Coal mining
- Electricity generation
- Gas supply
- Log sawmilling and timber dressing
- Meat and meat product manufacturing
- Mineral, metal and chemical wholesaling
- Oil and gas extraction
- Sheep, beef cattle, poultry, pig and grain farming
- Waste treatment, disposal and remediation services

The most significant sources of air pollution, likely to impact on regional air quality, are associated with coal and gas-fired power stations at Kogan Creek, Braemar, Tarong, Millmerran and Oakey. Other currently proposed power stations in the region, including, Condamine and Darling Downs, will also provide a cumulative impact in the region in the future.

5.5.2 Determination of Background Levels for Oxides of Nitrogen

In order to quantify an appropriate ambient background concentration of NO_2 for the provision of cumulative impacts in the air quality assessment, the aforementioned power stations have been included in the assessment. Table 28 presents the source characteristics and emission rates for the existing and approved power stations assessed, their location in the region are illustrated in Figure 23. The primary background air pollutant for this air quality assessment is $NO_{X.}$ Predicted maximum 1-hour average ground-level concentrations of NO_2 due to emissions from the approved power stations is shown in Figure 24.

Table 28 **Source characteristics of power stations in south central Queensland included in the dispersion modelling for background air quality**

Parameter	Units	Darling Downs	Braemer	Daandine	Tarong	Tarong North	Millmerran	Oakey	Kogan Creek	Condamine
Fuel type	-	Gas-fired combined cycle	Gas-fired open cycle	Gas-fired	Coal-fired	Coal-fired	Coal-fired	Gas- and diesel fired open cycle	Coal-fired	Gas-fired open cycle
Height of stack	m	35	30	8	210	260	141	35	160	34
Diameter of stack	m	4.88	6.1	6.1	10	5.7	7.98	6.2	7.0	3.7
Exhaust gas exit velocity	m/s	22.9	37.5	32	29	23.5	24.4	38.9	24	13.7
Stack temperature	°C	82.1	536	425	145	120	143	562	125	127.3
NO_X emission rate	g/s	21.4	115	19.5	2060	243	1098	40.5	542	6.9
Location										
AMG East	m	291199	292265	295723	392500	392500	330700	369250	276250	228310
AMG North	m	6998970	6999360	7002247	7036850	7038850	6905500	6959250	7020300	7047429

6. Atmospheric Dispersion Modelling Methodology

The SAQIA was conducted in accordance with recognised techniques for dispersion modelling and emission estimation.

- The prognostic model TAPM (developed by CSIRO, version 4 and the diagnostic meteorological model CALMET (developed by EarthTec, version 6) were used in conjunction with nearby Bureau of Meteorology station data to develop a 3-dimensional windfield representing wind flows in the region. Refer to Appendix A for model details.
- The dispersion model CALPUFF (developed by EarthTec, version 7) was used in the assessment of ground-level concentrations of pollutants. Refer to Appendix A for model details.

6.1 Calpuff Configuration

Calpuff is an advanced non-steady-state meteorological and air quality modelling system. The model has been adopted by the US EPA in its Guideline on Air Quality Models as the preferred model for assessing long range transport of pollutants and on a case-by-case basis for certain near-field applications involving complex meteorological conditions.

The Calpuff component of the modelling system deals with the dispersion of air pollutants in the atmosphere. For regional existing sources of air pollutants, the model was configured to include emissions of NO_x from nine power stations within the study area. For each source, emission rates have been calculated for a full year of operation. It has been assumed that the power stations will be operational for all hours for the entire year.

For QCLNG emission sources the Calpuff model was configured to include all sources that are proposed as part of the Project. This modelling has quantified emissions of NO_x, CO and VOCs from the CPPs, FCSs, WTP, Power Plant and the Well head compressors. For each source, emission rates have been calculated for a full year of operation. Normal operations and non normal emergency operations have been modelled.

6.2 Development of site specific meteorology for dispersion modelling

A three dimensional wind field was required for inclusion in the dispersion modelling of potential impacts from the Project. A coupled approach using the meteorological models TAPM (CSIRO, version 4) and CALMET (Earthtech, version 6) in conjunction with the measurements taken at the Miles, Dalby and Roma have been used. Details of this modelling approach are provided in Appendix A.

6.2.1.1 Wind Speed and Direction

Wind speed and direction are important parameters for the transport and dispersion of air pollutants. The annual, seasonal and diurnal frequency distributions of observed winds have been extracted from CALMET for the period 1 January – 31 December 2008 for two locations. Location 1 represents meteorological conditions in the northwest part of the study area and Location 2 represents the southeast section of the study area. The wind roses for Location 1 and Location 2 and shown in Figure 15 to Figure 20.

The figures illustrate that the winds experienced at Location 1 are predominantly light to moderate and from the southeast, whereas at Location 2 the predominant wind direction is from the east.

At both locations there is a diurnal variation in the winds experienced. For the morning hours between 6am and midday at Location 1, the predominant wind direction is from the east and after midday the wind direction changes to southeast and southwest. The pattern is similar for Location 2 but the wind speeds experienced are slightly higher. The winds experienced at night at Location 1 are predominantly from the southeast, whereas at location 2 at night the wind direction is predominantly from the east.

The figures demonstrate the presence of a seasonal variation in the winds and the seasonal pattern is similar at Location 1 and 2. Location 2 experience slightly higher winds speeds than Location 1. In summer there is a strong predominant wind direction from the east and by autumn the direction has changed to an east to south east direction. In winter winds are predominantly from the southwest. Spring is characterised by a less pronounced pattern with winds experienced from the northeast direction.

6.2.1.2 Atmospheric Stability and Mixing Height

Atmospheric stability is typically classified under the Pasquill-Gifford scheme and ranges from Class A, which represents very unstable atmospheric conditions that may typically occur on a sunny day, to Class F which represents very stable atmospheric conditions that typically occur during light wind conditions at night. Stability refers to the vertical movement of the atmosphere and is therefore an important factor in the dispersion and transport of pollutants within the boundary layer.

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, will remain relatively undiluted, and will not reach the ground unless it encounters elevated terrain. While the reciprocating engine stacks are relatively short, the emission’s elevated temperature and vertical velocity are likely to generate sufficient thermal and mechanical buoyancy for the plume to penetrate any low night time inversion conditions, resulting in good plume dispersion conditions.

Table 29 shows the distribution of stability classes for the site at Location 1 and 2. There is a high percentage of F class stability (48 and 45%), indicative of stable night-time inversions and neutral conditions.

Table 29 Percentage frequency distribution for atmospheric stability under the Pasquill-Gifford stability classification scheme

Pasquill-Gifford Stability Class	Frequency (%)	
	Location 1	Location 2
A	4	2
B	21	16
C	19	22
D	6	10
E	2	5
F	48	45

The relatively high proportion of B and C class stability is due to the combination of daytime surface heating and moderate wind speeds, with the small percentage of extremely unstable (Class A) conditions the result of the low proportion of light winds. At night, the D class stability is indicative of a stable boundary layer with moderate winds. The stable (Class F) conditions occur during light wind conditions at night.

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 (inversion) is often quite low. During these atmospheric conditions, the plume is unlikely to touch the ground as there is a lack of significantly elevated terrain in the region, and the combination of plume's vertical velocity and high temperature is likely to provide it with adequate mechanical and thermal buoyancy to penetrate any low stable layer or temperature inversion.

During the day, solar radiation heats the air at the ground-level and causes the mixing height to rise. 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. During periods when the mixing height is high, the plume emissions will disperse and will be diluted by the large volume of air. At night when the mixing height is low the plume can become trapped under the mixing layer and have limited air available to mix with, resulting in higher ground-level concentrations.

Mixing height information for Location 1 and 2 has been extracted from CALMET and is presented in Figure 21 and Figure 22. The data shows a very similar pattern for both locations, the mixing height tends to develop around 8am, peaks around early afternoon (2pm) before decreasing again around sunset (6pm). The figures also indicates the mixing height's diurnal profile with the 95th percentile extending to approximately 1,500 m around early afternoon, and collapsing below 50 m during the night.

6.3 Conversion of oxides of nitrogen

The assessment of the impacts of NO_X associated with emissions from the QCLNG project has been made for each scenario.

Background concentrations of NO_X have been quantified using emissions from coal- and gas-fired power stations in the south central Queensland region.

The prediction of the impacts of NO_2 has been determined by modelling the total emission rate in grams per second for NO_X. The conversion of NO_x to NO_2 that occurs in the atmosphere as a result of sunlight and the presence of other compounds has been characterised using empirical information. Measurements around Power stations in Central

Queensland show, under worst possible cases, a conversion of 25-40% of NO_2 to NO_2 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.

The modelled scenarios have been compared with the relevant NO_2 EPP(Air) air quality objectives.

7. Interpretation of Air Quality Impacts

This section presents the results of the SAQIA for NO_2, CO and hydrocarbons for all assessment scenarios.

7.1 Scenario 1 – Gas-fired CPP and FCSs in the northwest

Scenario 1 refers to emissions from infrastructure to the northwest of Miles and includes; emissions from engines used at the CPP and FCSs, emissions from well head compressor engines (assuming 75% of wells require compression), emissions from the water treatment plant, emissions from water pumps, normal maintenance emissions (well flaring) and background NO_2 from power stations.

7.1.1 Nitrogen Dioxide

Figure 26 and Figure 27 present the predicted maximum 1-hour and annual average ground-level concentrations of NO_2 respectively, for Scenario 1 in isolation. Table 30 presents the predicted maximum 1-hour and annual average ground-level concentrations of NO_2 resulting from Scenario 1 emissions, in isolation and including background concentrations.

Table 30 Predicted maximum 1-hour and annual average ground-level concentrations of nitrogen dioxide for Scenario 1 in isolation and including background

Pollutant	Averaging Period	Incremental predicted maximum concentration (µg/m³)	Predicted maximum concentration with background (µg/m³)	Air quality objective (µg/m³)	Percent of air quality objective (%)
NO_2	1-hour	83	83.3	250	33.3
	Annual	2.6	2.7	62[1] / 33[2]	4.3 / 8.1

Note:
[1] EPP(Air) Health and wellbeing objective
[2] EPP(Air) Health and biodiversity of ecosystems objective

The results show the following:

- There are no exceedances predicted of the EPP(Air) air quality objective for the 1-hour and annual average ground-level concentration of NO_2 due to Scenario 1, assessed in isolation and including background concentrations.
- The predicted maximum 1-hour average ground-level concentration of NO_2 in isolation is 83 µg/m^3 or 83.3 µg/m^3 including background which is 33.3% of the EPP(Air) air quality objective of 250 µg/m^3.
- The predicted annual average ground-level concentration of NO_2 in isolation is 2.6 µg/m^3 or 2.7 µg/m^3 including background which is 4.3% of the EPP(Air) air quality objective of 62 µg/m^3

7.1.2 Carbon Monoxide

Figure 28 presents the predicted maximum 8-hour average ground-level concentrations of CO for Scenario 1 in isolation. Table 31 presents the predicted maximum 8-hour average ground-level concentration resulting from Scenario 1 emissions in isolation.

Table 31 Predicted maximum 8-hour average ground-level concentration of carbon dioxide for Scenario 1 in isolation

Pollutant	Predicted maximum concentration (µg/m³)	Air quality objective (µg/m³)	Percent of air quality objective (%)
CO	134.9	11,000	1.2

The results show the following:

- There are no exceedances predicted of the EPP(Air) air quality objective for the 8-hour average ground-level concentration of CO due to Scenario 1, assessed in isolation

- The predicted maximum 8-hour average ground-level concentration of CO from Scenario 1 in isolation is 134.9 µg/m^3, which is 1.2% of the EPP(Air) air quality objective of 11,000 µg/m^3

7.1.3 Hydrocarbons

Table 32 presents a summary of maximum ground-level concentrations of key hydrocarbons for Scenario 1.

Table 32 Predicted maximum formaldehyde, acrolein, benzene, ethylchloride and phenanthrene concentrations for Scenario 1 in isolation

Pollutant	Averaging Time	Air Quality Guideline (µg/m³)	Predicted maximum concentration (µg/m³)	Percent of air quality objective (%)
Formaldehyde	30-minute	110	18.3	16.7
	24-hour	54	3.0	5.6
Acrolein	1-hour	0.42	0.01	1.4
Benzene	1-hour	29	0.2	0.6
Ethylchloride	1-hour	0.048	0.001	1.1
Phenanthrene	1-hour	0.5	0.003	0.6

The results show the following:

- There are no exceedances predicted of relevant air quality objectives for ground-level concentrations of the top 5 Hydrocarbons due to Scenario 1, assessed in isolation

- The predicted maximum 30-minute average ground-level concentration of Formaldehyde from Scenario 1 in isolation is 18.3 µg/m^3, which is 6.7% of the air quality objective of 110 µg/m^3. The predicted maximum 24-hour average ground-level concentration of Formaldehyde from Scenario 1 in isolation is 3.0 µg/m^3, which is 5.6% of the air quality objective of 54 µg/m^3.

- Concentrations of all other hydrocarbons are less 1.5% of the relevant air quality objectives.

7.2 Scenario 2 – Power Station supplying power to CPP and FCSs in the northwest

Scenario 2 refers to emissions from infrastructure to the northwest of Miles and includes; emissions from a power station to power engines at the CPP and FCSs, emissions from well head compressor engines (assuming 75% of wells require compression), emissions from water pumps, normal maintenance emissions (well flaring) and background NO_2 from power stations.

7.2.1 Nitrogen Dioxide

Figure 28 and Figure 29 present the predicted maximum 1-hour and annual average ground-level concentrations of NO_2 respectively, for Scenario 2 in isolation. Table 32 presents the predicted maximum 1-hour and annual average ground-level concentrations of NO_2 resulting from Scenario 2 emissions in isolation and including background concentrations.

Table 33 Predicted maximum 1-hour and annual average ground-level concentrations of nitrogen dioxide for Scenario 2 in isolation and including background

Pollutant	Averaging Period	Incremental predicted maximum concentration (µg/m³)	Predicted maximum concentration with background (µg/m³)	Air quality objective (µg/m³)	Percent of air quality objective (%)
NO_2	1-hour	25.5	26.1	250	10.5
	Annual	1.9	2.0	62[1] / 33[2]	3.2 / 6.1

Note:
[1] EPP(Air) Health and wellbeing objective
[2] EPP(Air) Health and biodiversity of ecosystems objective

The results show the following:

- There are no exceedances predicted of the EPP(Air) air quality objective for the 1-hour and annual average ground-level concentration of NO_2 due to Scenario 2, assessed in isolation and including background concentrations.
- The predicted maximum 1-hour average ground-level concentration of NO_2 in isolation is 25.5 $\mu g/m^3$ or 26.1 $\mu g/m^3$ including background which is 10.5% of the EPP(Air) air quality objective of 250 $\mu g/m^3$.
- The predicted annual average ground-level concentration of NO_2 in isolation is 1.9 $\mu g/m^3$ or 2.0 $\mu g/m^3$ including background which is 3.2% of the EPP(Air) air quality objective of 62 $\mu g/m^3$

7.2.2 Carbon Monoxide

Figure 31 presents the predicted maximum 8-hour average ground-level concentrations of CO for Scenario 2 in isolation. Table 34 presents the predicted maximum 8-hour average ground-level concentration resulting from Scenario 2 emissions in isolation.

Table 34 Predicted maximum 8-hour average ground-level concentration of carbon dioxide for Scenario 2 in isolation

Pollutant	Predicted maximum concentration (µg/m³)	Air quality objective (µg/m³)	Percent of air quality objective (%)
CO	33.3	11,000	0.3

The results show the following:

- There are no exceedances predicted of the EPP(Air) air quality objective for the 8-hour average ground-level concentration of CO due to Scenario 2, assessed in isolation
- The predicted maximum 8-hour average ground-level concentration of CO from Scenario 2 in isolation is 33.3 µg/m^3, which is 0.3% of the EPP(Air) air quality objective of 11,000 µg/m^3

7.2.3 Hydrocarbons

Table 35 presents a summary of key maximum ground-level concentrations of hydrocarbons for Scenario 2. There are no emissions of ethylchloride and phenanthrene as a result of Scenario 2.

Table 35 Predicted maximum formaldehyde, acrolein, benzene, ethylchloride and phenanthrene concentrations for Scenario 2 in isolation

Pollutant	Averaging Time	Air Quality Guideline (µg/m³)	Predicted maximum concentration (µg/m³)	Percent of air quality objective (%)
Formaldehyde	30-minute	110	2.7	2.5
	24-hour	54	0.5	1
Acrolein	1-hour	0.42	0.003	0.6
Benzene	1-hour	29	0.2	0.6

The results show the following:

- There are no exceedances predicted of relevant air quality objectives for ground-level concentrations of the key hydrocarbons due to Scenario 2, assessed in isolation
- The predicted maximum 30-minute average ground-level concentration of Formaldehyde is 2.7 µg/m^3, which is 2.5% of the air quality objective of 110 µg/m^3. The predicted maximum 24-hour average ground-level concentration of Formaldehyde is 0.5 µg/m^3, which is 1% of the air quality objective of 54 µg/m^3.
- Concentrations of all other hydrocarbons are less 1% of the relevant air quality objectives.

7.3 Scenario 3 - QCLNG infrastructure southeast of Miles

Scenario 3 refers to emissions from infrastructure to the southeast of Miles and includes; emissions from a water treatment plant in the “Kenya” gasfield, emissions from well head compressor engines (assuming 75% of wells require compression), emissions from water pumps, normal maintenance emissions (well flare) and background NO_2 from power stations.

7.3.1 Nitrogen Dioxide

Figure 32 and Figure 33 present the predicted maximum 1-hour and annual average ground-level concentrations of NO_2 respectively for Scenario 3 in isolation. Table 36 presents the predicted maximum 1-hour and annual average ground-level concentrations of NO_x resulting from Scenario 3 emissions, in isolation and including background concentrations.

Table 36 Predicted maximum 1-hour and annual average ground-level concentrations of nitrogen dioxide for Scenario 3 in isolation and including background

Pollutant	Averaging Period	Incremental predicted maximum concentration (µg/m³)	Predicted maximum concentration with background (µg/m³)	Air quality objective (µg/m³)	Percent of air quality objective (%)
NO_2	1-hour	51.8	68.8	250	27.5
	Annual	3.6	3.6	62[1] / 33[2]	6.1 / 10.9

Note:
[1] EPP(Air) Health and wellbeing objective
[2] EPP(Air) Health and biodiversity of ecosystems objective

The results show the following:

- There are no exceedances predicted of the EPP(Air) air quality objective for the 1-hour and annual average ground-level concentration of NO_2 due to Scenario 3, assessed in isolation and including background concentrations.

- The predicted maximum 1-hour average ground-level concentration of NO_2 in isolation is 51.8 µg/m^3 or 68.8 µg/m^3 including background which is, at most, 27.5% of the EPP(Air) air quality objective of 250 µg/m^3.

- The predicted annual average ground-level concentration of NO_2 is 3.6 µg/m^3 including background which is, at most, 7% of the EPP(Air) air quality objective of 62 µg/m^3

7.3.2 Carbon Monoxide

Figure 34 presents the predicted maximum 8-hour average ground-level concentrations of CO for Scenario 3 in isolation. Table 37 presents the predicted maximum 8-hour average ground-level concentration resulting from Scenario 3 emissions in isolation.

Table 37 Predicted maximum 8-hour average ground-level concentration of carbon dioxide for Scenario 3 in isolation

Pollutant	Predicted maximum concentration (µg/m³)	Air quality objective (µg/m³)	Percent of air quality objective (%)
CO	44.8	11,000	0.4

The results show the following:

- There are no exceedances predicted of the EPP(Air) air quality objective for the 8-hour average ground-level concentration of CO due to Scenario 3, assessed in isolation

- The predicted maximum 8-hour average ground-level concentration of CO from Scenario 3 in isolation is 44.8 µg/m^3, which is 0.4% of the EPP(Air) air quality objective of 11,000 µg/m^3

7.3.3 Hydrocarbons

Table 38 presents a summary of maximum ground-level concentrations of key hydrocarbons for Scenario 3. There are no emissions of ethylchloride and phenanthrene as a result of Scenario 3.

Table 38 Predicted maximum formaldehyde, acrolein, benzene, ethylchloride and phenanthrene concentrations for Scenario 3 in isolation

Pollutant	Averaging Time	Air Quality Guideline (µg/m³)	Predicted maximum concentration (µg/m³)	Percent of air quality objective (%)
Formaldehyde	30-minute	110	4.2	3.8
	24-hour	54	0.9	1.7
Acrolein	1-hour	0.42	0.002	0.5
Benzene	1-hour	29	0.3	0.9

The results show the following:

- There are no exceedances predicted of relevant air quality objectives for ground-level concentrations of the key hydrocarbons due to Scenario 3, assessed in isolation

- The predicted maximum 30-minute average ground-level concentration of Formaldehyde is 4.2 µg/m^3, which is 3.8% of the air quality objective of 110 µg/m^3.

- The predicted maximum 24-hour average ground-level concentration of Formaldehyde is 0.9 µg/m^3, which is 1.7% of the air quality objective of 54 µg/m^3.

- Concentrations of all other hydrocarbons are less 1% of the relevant air quality objectives.

7.4 Scenario 4 - QCLNG emergency flaring of gasfield

Scenario 4 has not been explicitly model. The potential affect of gasfield flaring on ground-level concentrations of air pollutants can be inferred from the emissions information presented in Section 3.

The emission rates of air pollutants that have been estimated for Scenario 4 are approximately 10% of the maintenance flaring emissions per wellhead. The maximum predicted 1-hour average ground-level concentration of NO_2 due to maintenance flaring of wellheads is approximately 2 µg/m³. Under the extreme case of all wells flaring simultaneously, there may be approximately 120 times more wells flaring compared with the maintenance scenario. On this basis, the maximum 1-hour average ground-level concentration of NO_2 would be less than 30 µg/m³. This is 12% of the EPP(Air) objective 250 µg/m³. No other QCLNG upstream activities would be occurring in this extreme case.

Predicted ground-level concentrations of all other air pollutants would be a lower proportion of their respective air quality objectives.

7.5 Scenario 5

Figure 35 and Figure 36 present the predicted maximum 1-hour average ground-level concentration of NO_2 from a single FCS located in the "Paradise Downs" gasfield with six and eight screw compressor engines, respectively. Table 39 presents the maximum ground level concentration of all assessed air pollutants.

Table 39 Predicted maximum ground-level concentration of air pollutants for a single FCS with either 6 or 8 screw compressor engines

Pollutant	Averaging Time	Air Quality Guideline (µg/m³)	Predicted maximum concentration (µg/m³)	
			6 screw compressors	8 screw compressors
NO_2	1-hour	250	76.1	101.5
	Annual	62	1.1	1.5
CO	8-hour	11,000	91.0	121.4
Formaldehyde	30-minute	110	17.5	23.4
	24-hour	54	2.7	3.6
Acrolein	1-hour	0.42	0.0005	0.0007
Benzene	1-hour	29	0.003	0.004

The results show the following:

- There are no exceedances predicted of relevant air quality objectives for ground-level concentrations of all pollutants as a result of a single FCS operating with either six or eight screw compressors.

- Considering the maximum ground-level concentration of NO_2 predicted for Scenario 1 is 83 µg/m^3 and the predicted maximum for Scenario 5 with 6 screw compressors is 76 µg/m^3, the cumulative impact of Scenario 5 with eight screw compressors would be approximately 110 µg/m^3, 44% of the air quality objective.

- Ground-level concentrations of all air pollutants increase when the FCS operates with eight screw compressors compared to six.

- The predicted maximum 1-hour average ground-level concentration of NO_2 with eight screw compressor engines is 101.5 µg/m^3 which is 40.6% of the EPP(Air) air quality objective of 250 µg/m^3.

- The predicted annual average ground-level concentration of NO_2 with eight screw compressor engines is 1.5 µg/m^3 which is 2.4% of the EPP(Air) air quality objective of 62µg/m^3.

- The predicted maximum 8-hour average ground-level concentration of CO with eight screw compressor engines is 121.4 µg/m^3 which is 1.1% of the EPP(Air) air quality objective of 250 µg/m^3.

- The predicted maximum 30-minute average ground-level concentration of Formaldehyde with eight screw compressor engines is 23.4 µg/m^3, which is 21.3% of the air quality objective of 110 µg/m^3.

- The predicted maximum 24-hour average ground-level concentration of Formaldehyde with eight screw compressor engines is 3.6 µg/m^3, which is 6.7% of the air quality objective of 54 µg/m^3.

- Concentrations of all other hydrocarbons with eight screw compressor engines are less 1% of the relevant air quality objectives.

8. Conclusions

A supplementary air quality impact assessment has been conducted for the proposed QCLNG Project to be located within the Surat Basin of south central Queensland.

The air quality assessment focussed on the key pollutants identified in the EIS, namely:

- Nitrogen dioxide
- Carbon monoxide
- Acrolein
- Benzene
- Formaldehyde
- Phenanthrene
- Ethylchloride

The following conclusions can be drawn from the supplementary air quality impact assessment for the proposed QCLNG project model scenarios 1-4:

- Ground-level concentrations of nitrogen dioxide are well below the EPP(Air) air quality objectives for the 1-hour and annual averaging period, due to the proposed QCLNG project assessed with the inclusion of background concentrations from all major electricity generating facilities in the south central Queensland region, at any location within the modelled domain.

- Ground-level concentrations of carbon monoxide are well below the EPP(Air) air quality objective for the 8-hour averaging period due to the proposed QCLNG Project, assessed in isolation, at any location within the modelled domain.

- Ground-level concentrations of key hydrocarbons are well below the air quality objectives for acrolein, benzene, ethylchloride, phenanthrene and formaldehyde, due to the proposed QCLNG, assessed in isolation, at any location within the modelled domain.

Scenario 5 shows that ground-level concentrations of all pollutants would increase when a single FCS increases the number of screw compressors from six to eight. However, the increase still results in all concentrations below the relevant air quality objectives. The cumulative impact of eight screw compressors with the remaining QGC infrastructure and other background sources would be below the air quality objectives.

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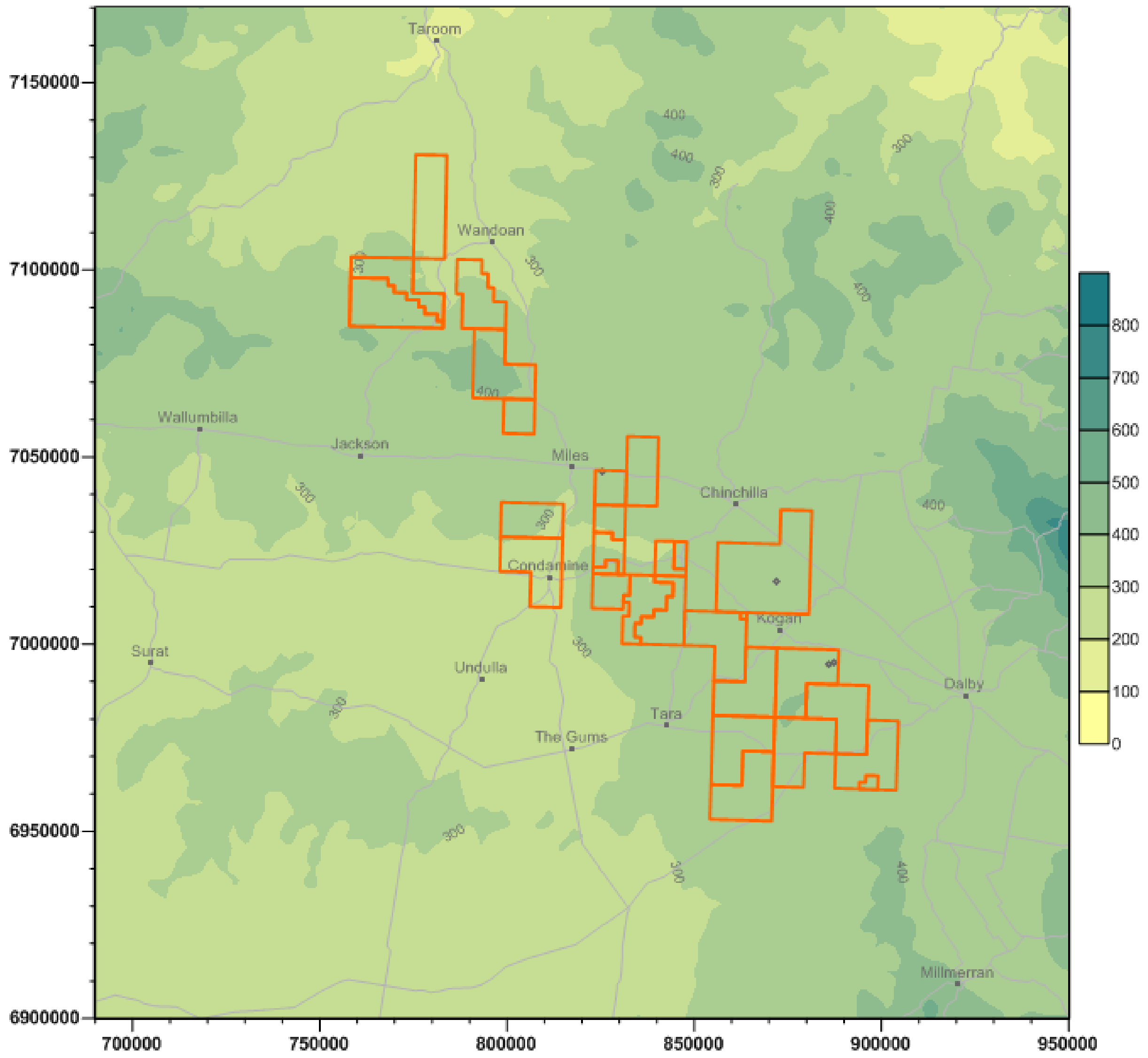

Figure 1 The QCLNG gasfield exploration and development project area

Location: Surat Basin region, QLD	**Data source:** QCLNG and TAPM	**Units:** Metres
Type: Project area and terrain map	**Prepared by:** Andrew Vernon	**Date:** December 2009

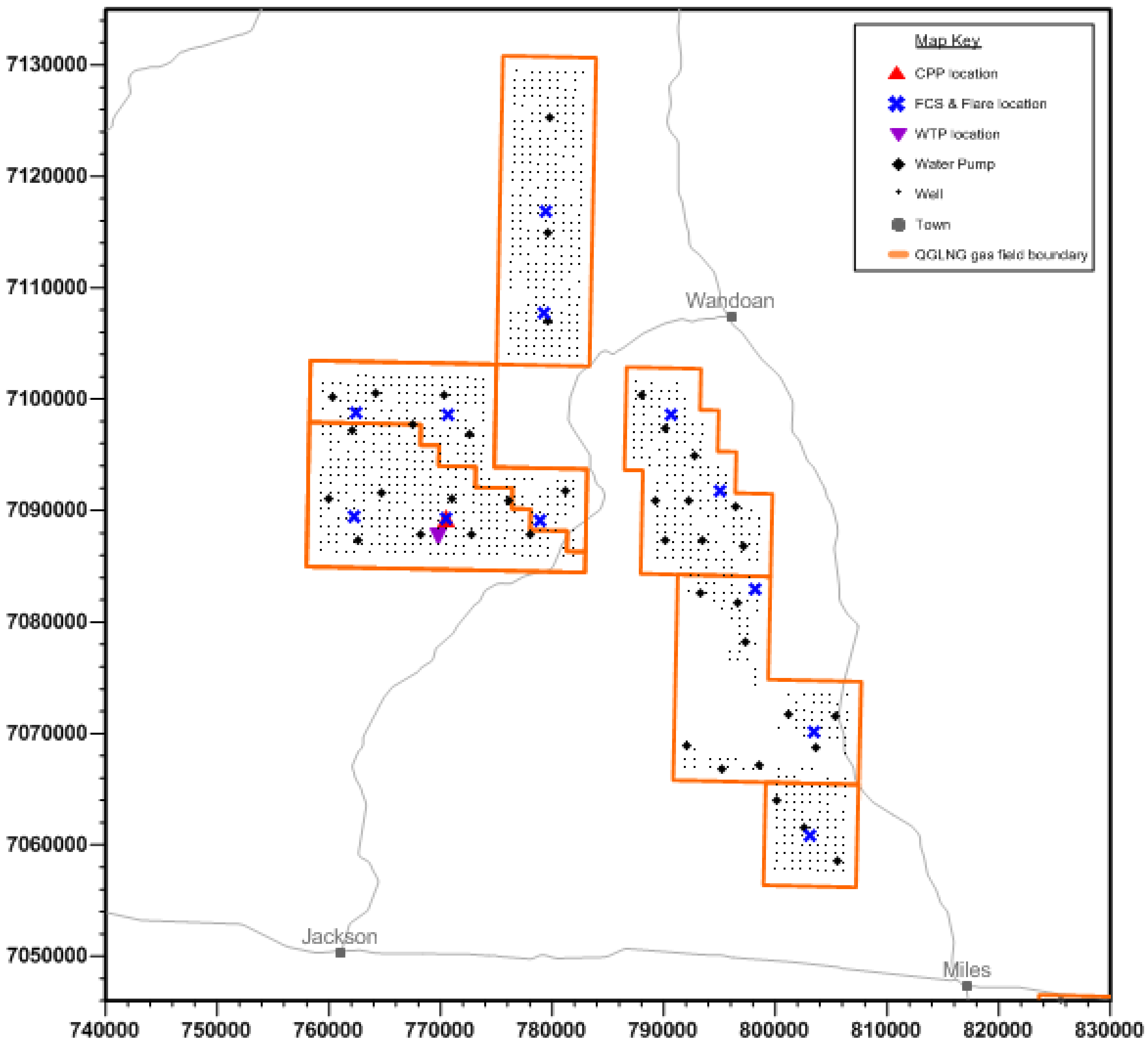

Figure 2 Location of Scenario 1 emission sources – QCLNG Project northwest of Miles

Location: Surat Basin region, QLD	**Data Source:** QCLNG	**Units:** Metres
Type: Location map	**Prepared by:** Andrew Vernon	**Date:** January 2010

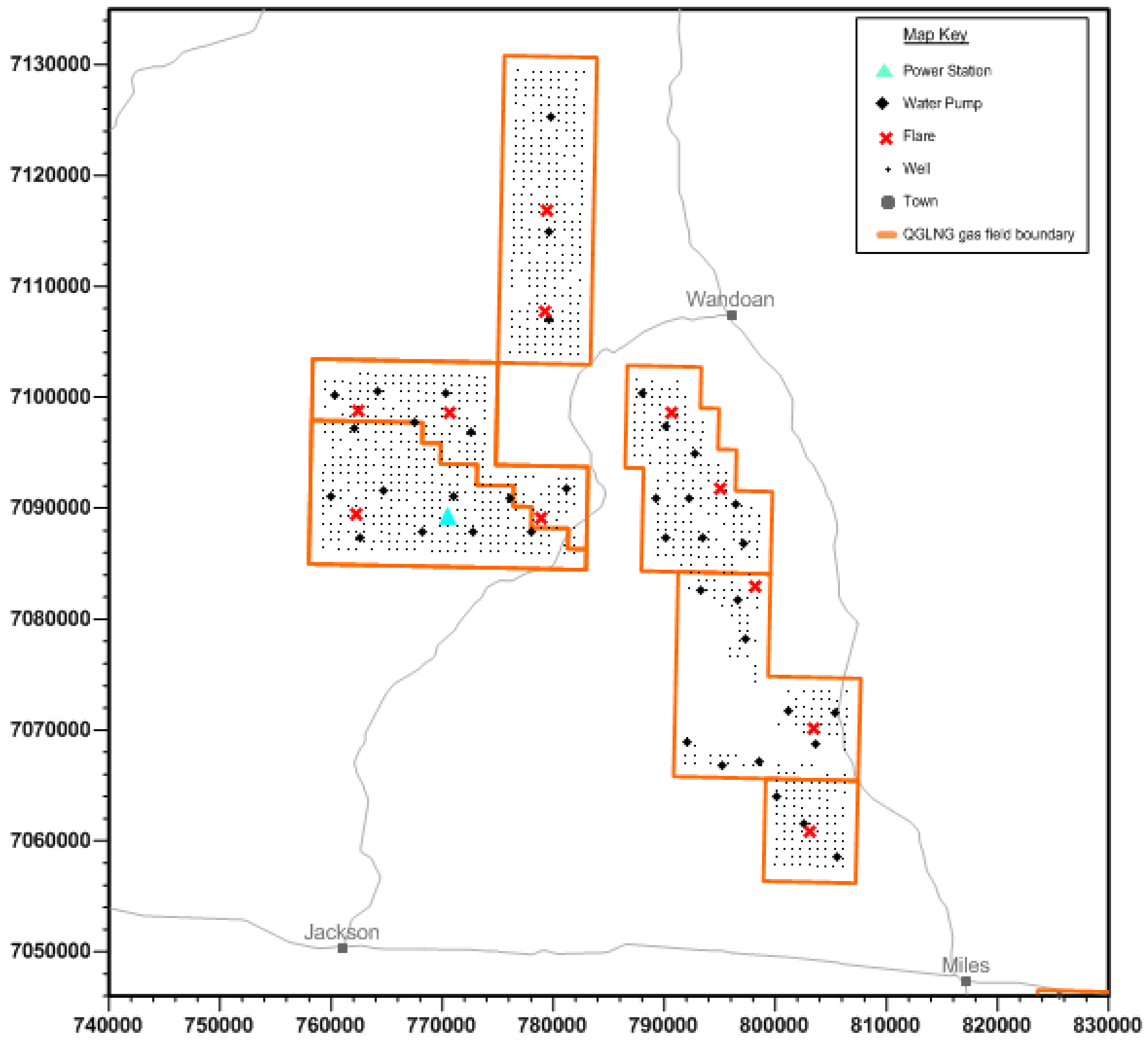

Figure 3 Location of Scenario 2 emission sources – QCLNG Project northwest of Miles

Location: Surat Basin region, QLD	**Data Source:** QCLNG	**Units:** Metres
Type: Location map	**Prepared by:** Andrew Vernon	**Date:** December 2009

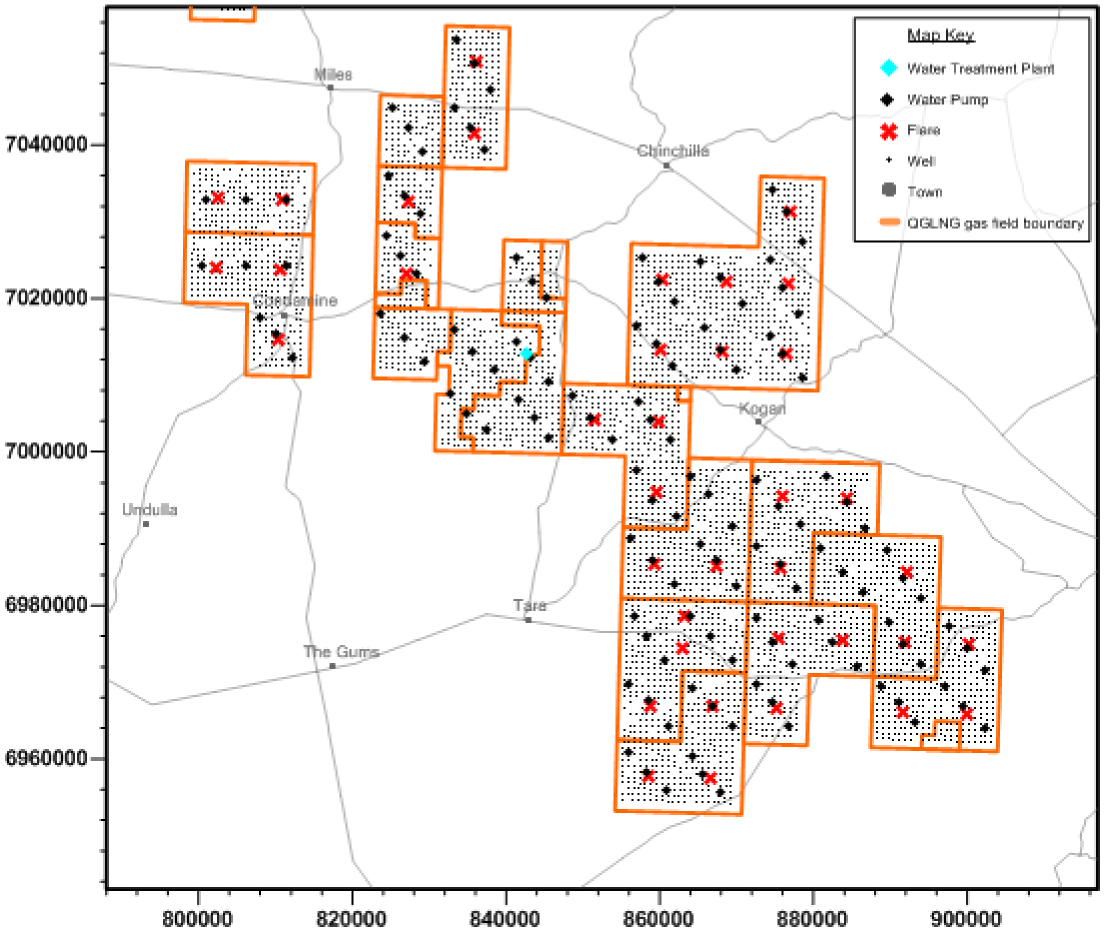

Figure 4 Location of Scenario 3 emission sources – QCLNG Project southeast of Miles

Location: Surat Basin region, QLD	**Data Source:** QCLNG	**Units:** Metres
Type: Location map	**Prepared by:** Andrew Vernon	**Date:** December 2009

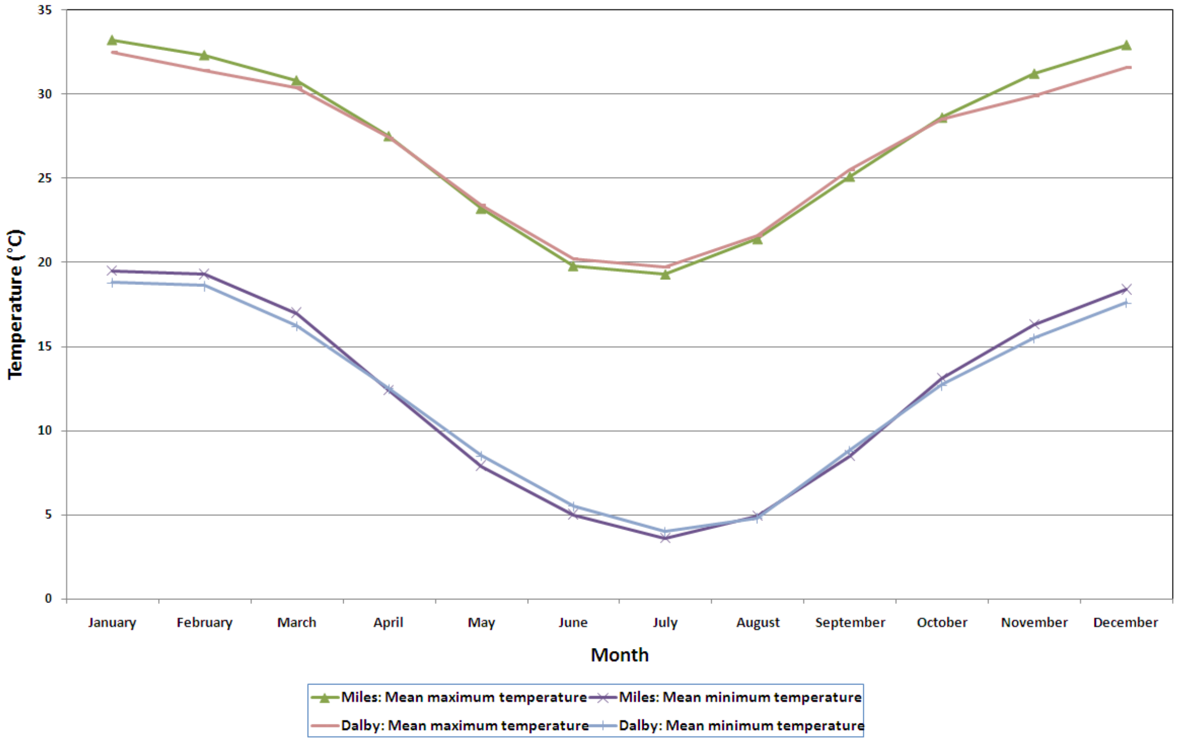

Figure 5 Average daily maximum and minimum temperatures (°C) for Miles and Dalby

Location: Miles and Dalby	**Data source:** BoM	**Units:** Degrees Celsius
Type: Histogram	**Prepared by:** Andrew Vernon	**Date:** December 2009

Figure 6 Mean daily solar radiation (MJ/m²) for Miles and Dalby

Location: Miles PO and Dalby Aero	**Data source:** BoM	**Units:** MJ/m²
Type: Histogram	**Prepared by:** Andrew Vernon	**Date:** December 2009

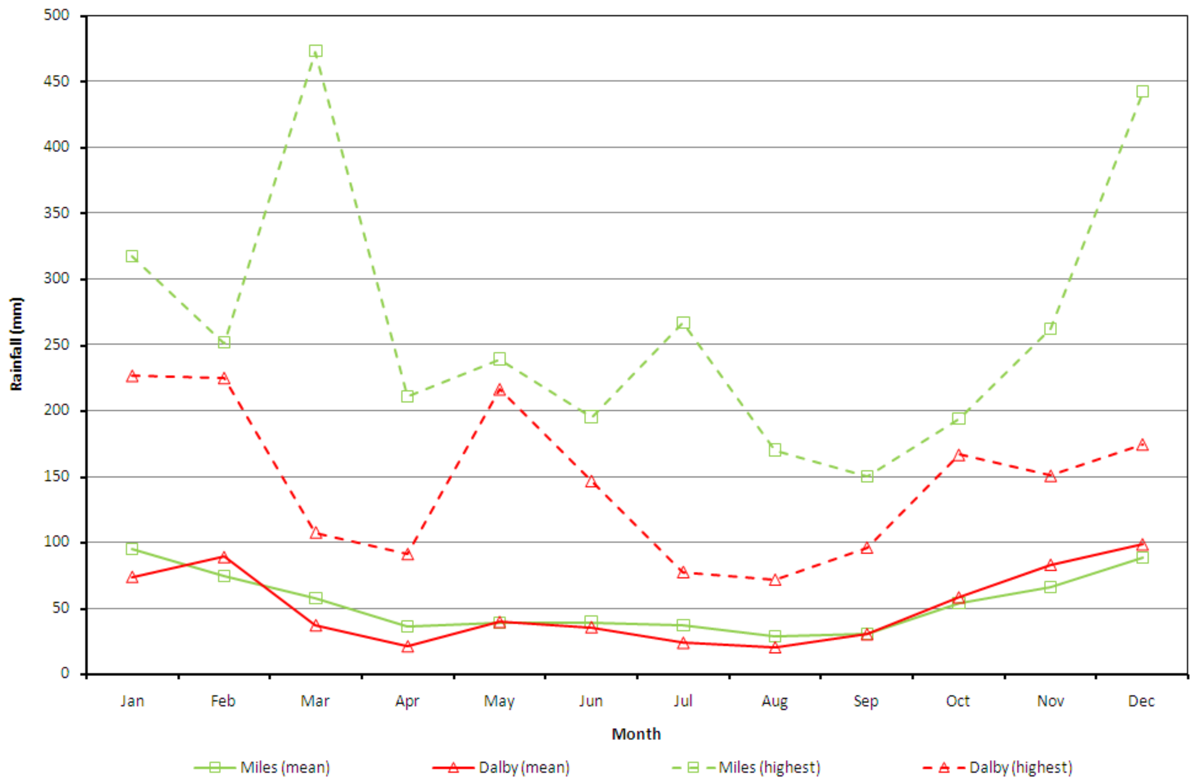

Figure 7 Average and highest monthly rainfall at Miles and Dalby

Location: Miles and Dalby	**Data source:** BoM	**Units:** Millimetres per month
Type: Histogram	**Prepared by:** Andrew Vernon	**Date:** December 2009

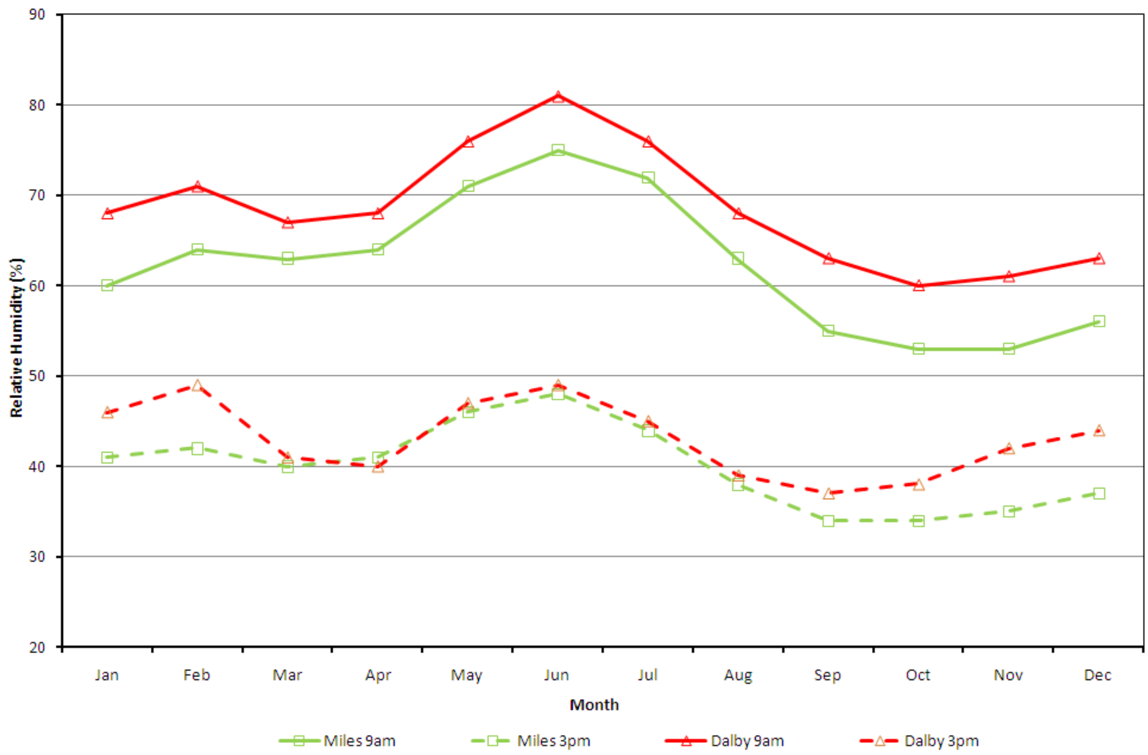

Figure 8 Monthly averaged 9am and 3pm measurements of relative humidity (%) for Miles and Dalby

Location: Miles and Dalby	**Data source:** BoM	**Units:** Percentage
Type: Histogram	**Prepared by:** Andrew Vernon	**Date:** December 2009

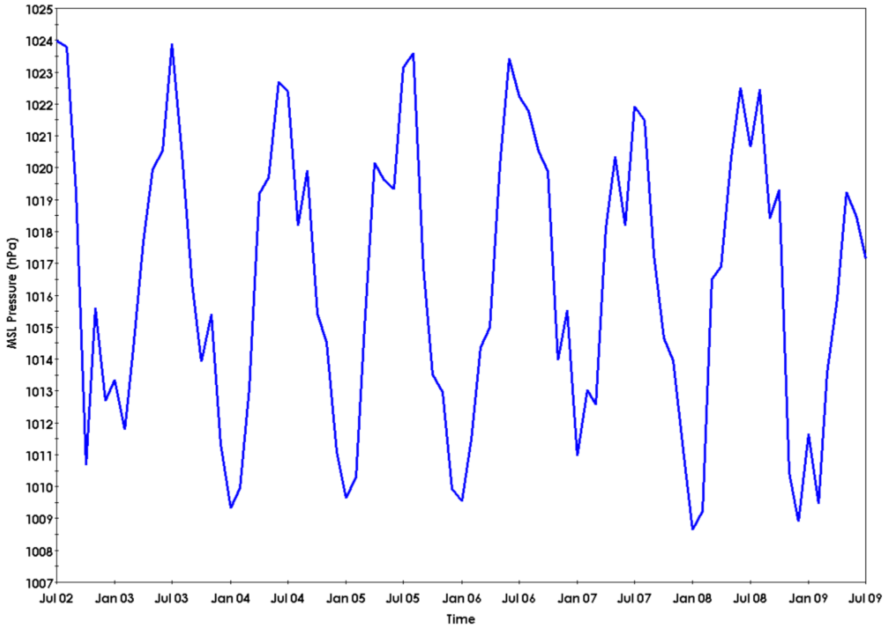

Figure 9 Monthly average mean sea-level pressure at Miles

Location: Miles	**Data source:** BoM (2002-2009)	**Units:** hPa
Type: Time series	**Prepared by:** S. Menzel	**Date:** November 2009

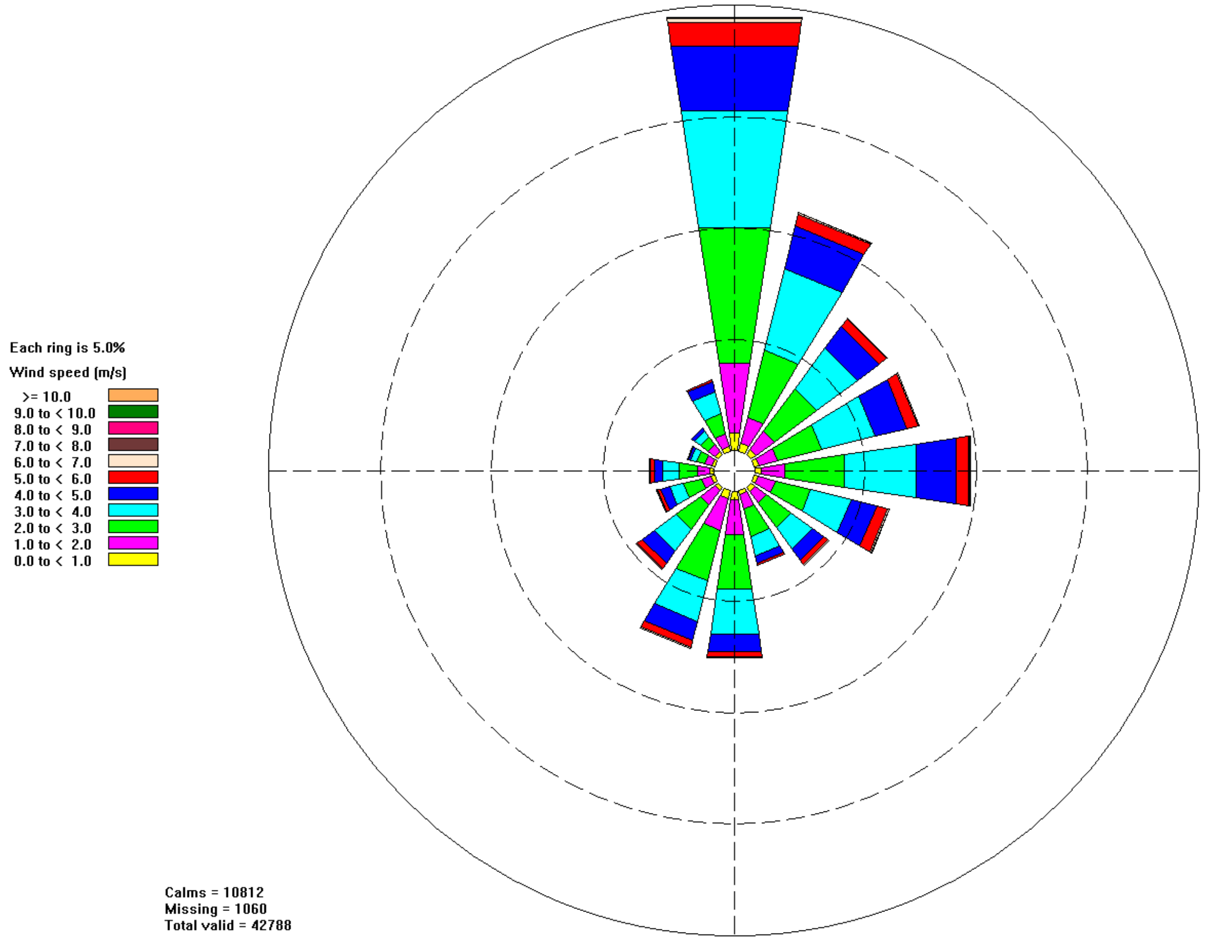

Figure 10 Annual distribution of winds at Miles

Location: Miles	**Period:** 1999 – 2009	**Data source:** BoM	**Units:** m/s and °
Type: Wind rose	**Averaging Period:** 1-hour	**Prepared by:** S. Menzel	**Date:** October 2009

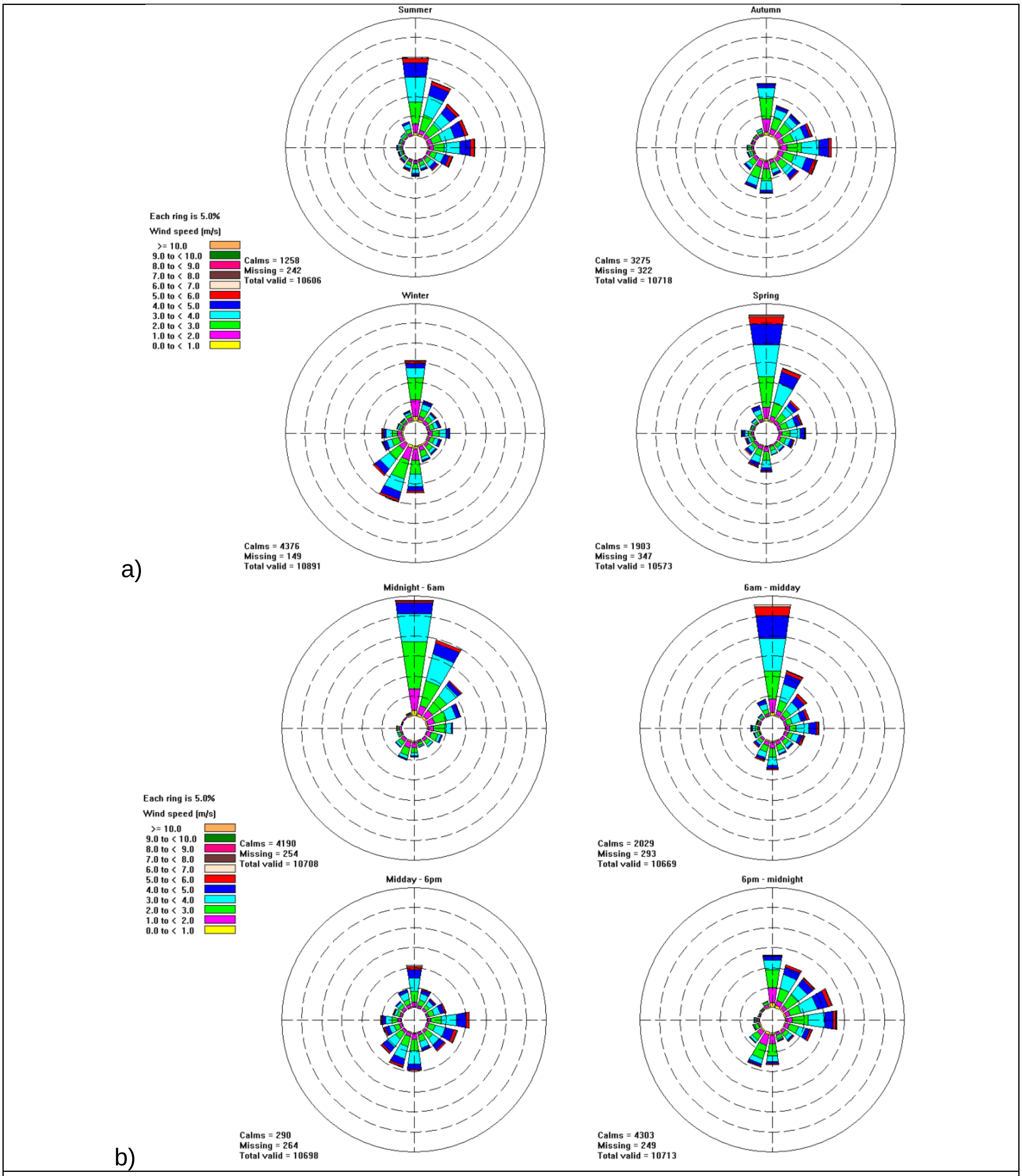

Figure 11 Seasonal (a) and diurnal (b) distributions of winds at Miles

Location: Miles	**Period:** 1999 – 2009	**Data source:** BoM	**Units:** m/s and °
Type: Wind rose	**Averaging Period:** 1-hour	**Prepared by:** S. Menzel	**Date:** October 2009

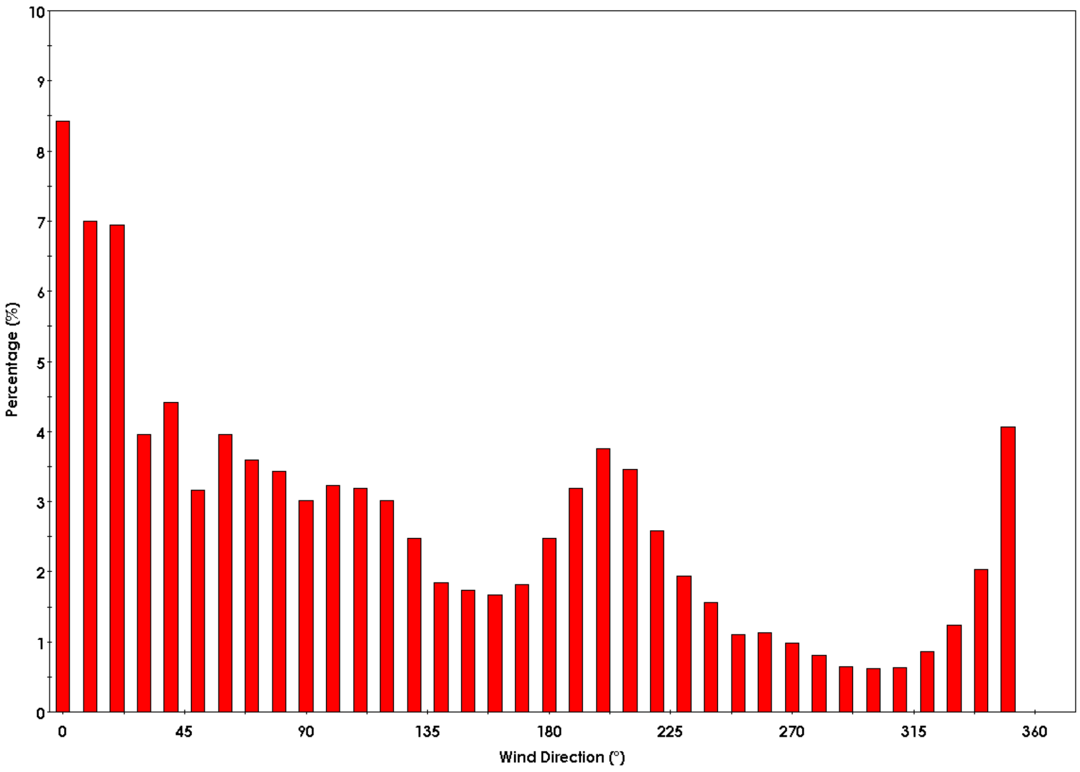

Figure 12 Annual frequency distribution of wind direction at Miles

Location: Miles	**Period:** 1999 – 2009	**Data source:** BoM	**Units:** m/s and %
Type: Histogram	**Averaging Period:** 1-hour	**Prepared by:** S. Menzel	**Date:** November 2009

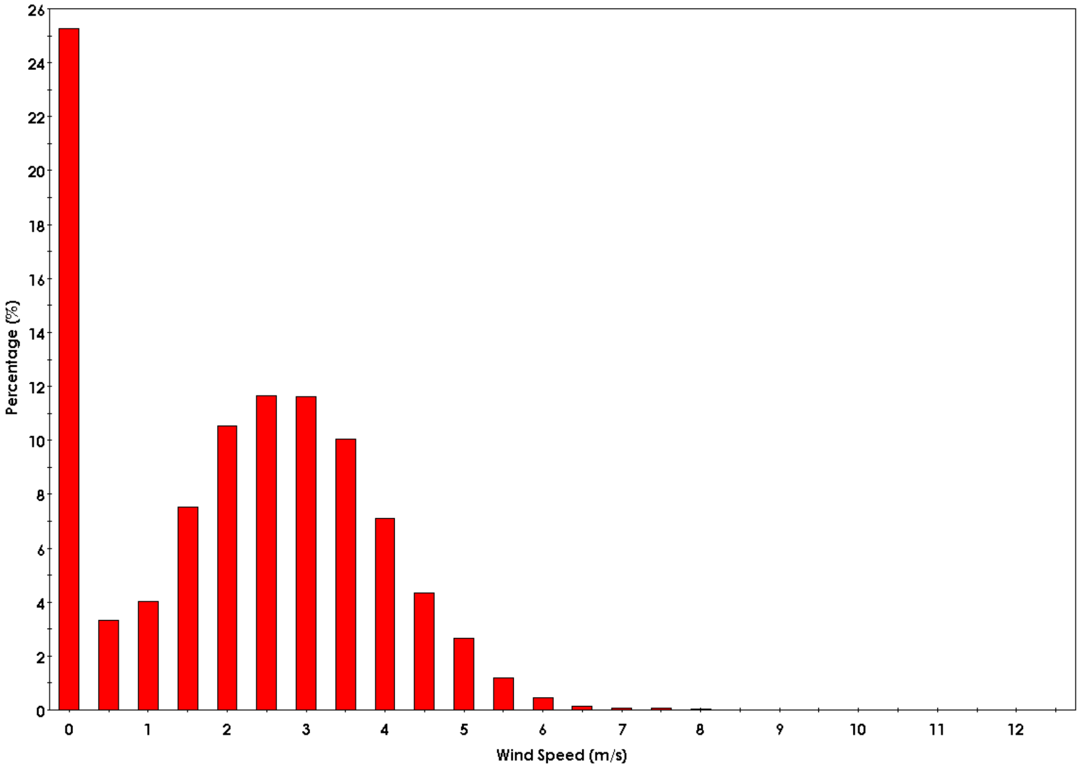

Figure 13 Annual frequency distribution of wind speeds at Miles

Location: Miles	**Period:** 1999 – 2009	**Data source:** BoM	**Units:** m/s and %
Type: Histogram	**Averaging Period:** 1-hour	**Prepared by:** S. Menzel	**Date:** November 2009

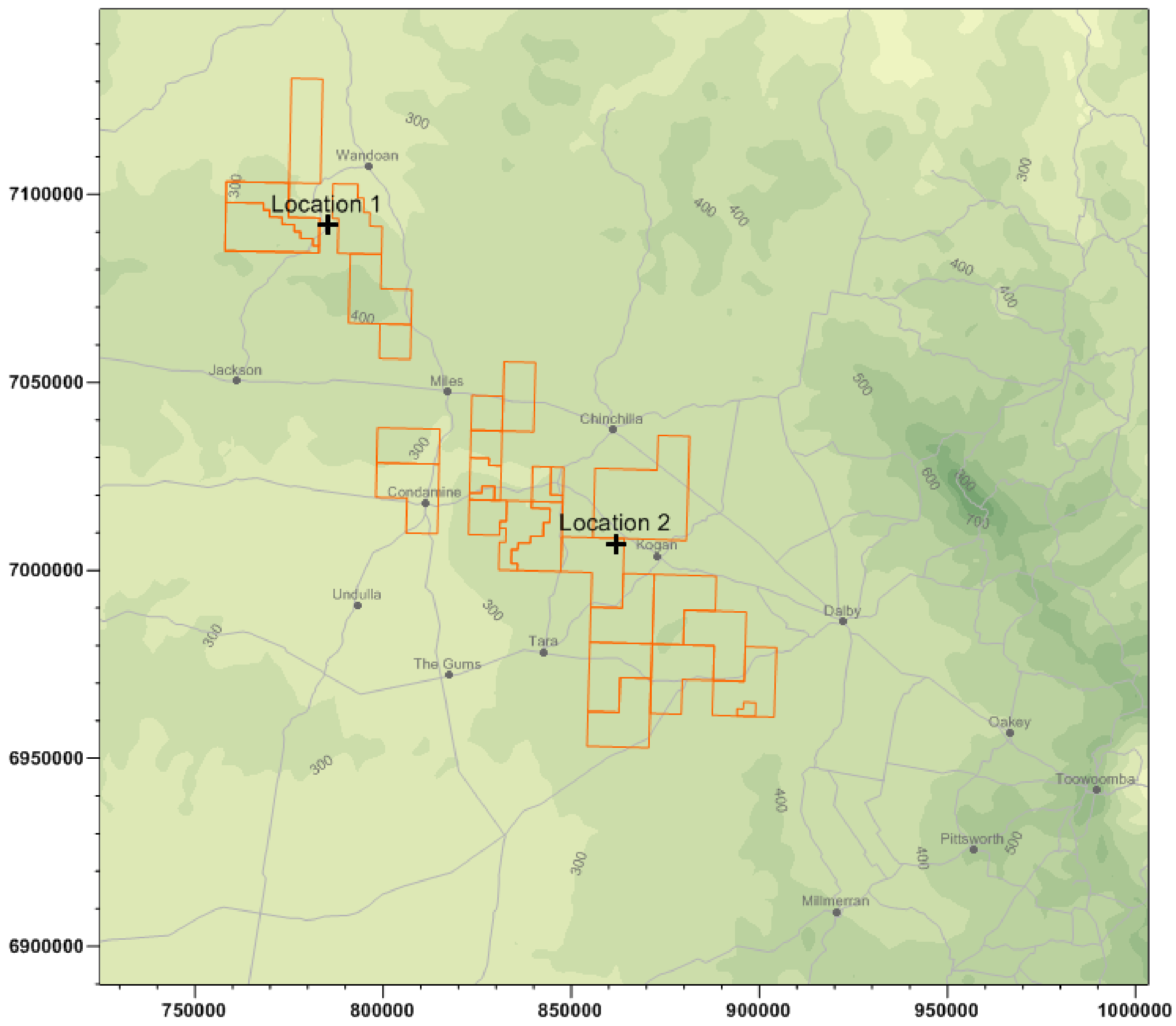

Figure 14   The locations selected for Meteorological analysis

Location: Surat Basin region, QLD	**Data source:** QCLNG	**Units:** Metres
Type: Project area map	**Prepared by:** Sarah-Jane Donnelly	**Date:** December 2009

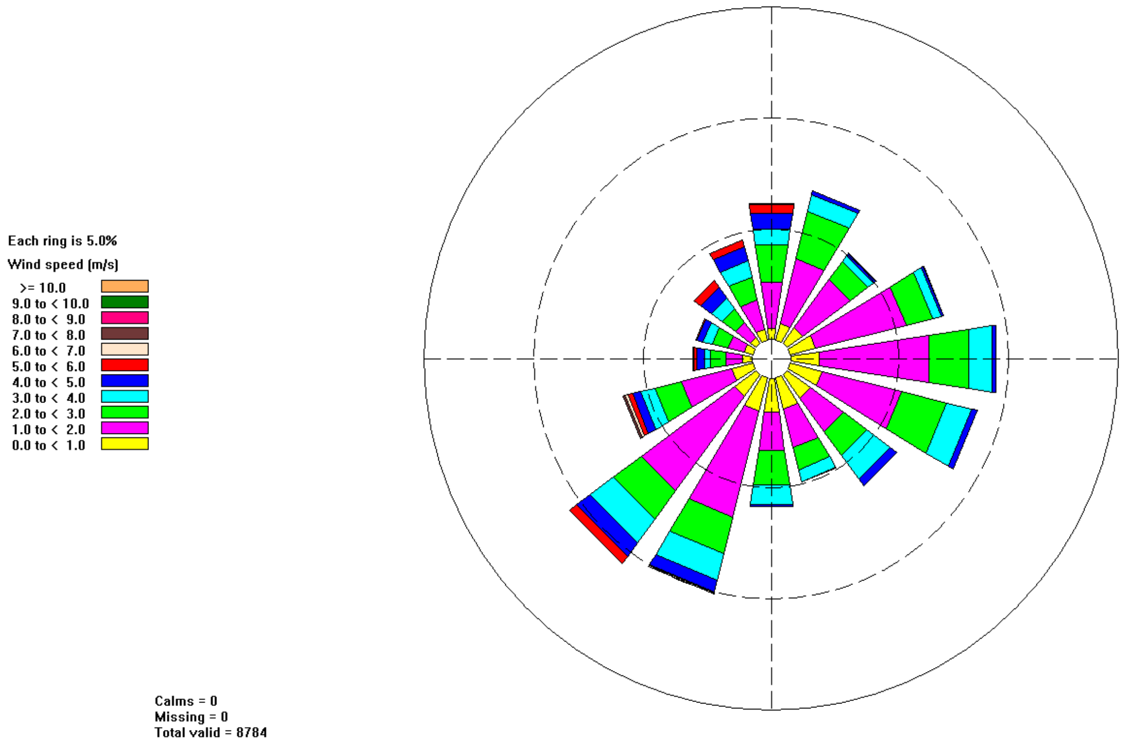

Figure 15 Wind rose for all hours for Location 1

Location: Location 1 of study area	**Period:** 1 January- 31 December 2008	**Data source:** Generated by CALMET	**Units:** m/s and °
Type: Wind rose	**Averaging Period:** 8784 hourly average records	**Prepared by:** Sarah-Jane Donnelly	**Date:** 10th December 2009

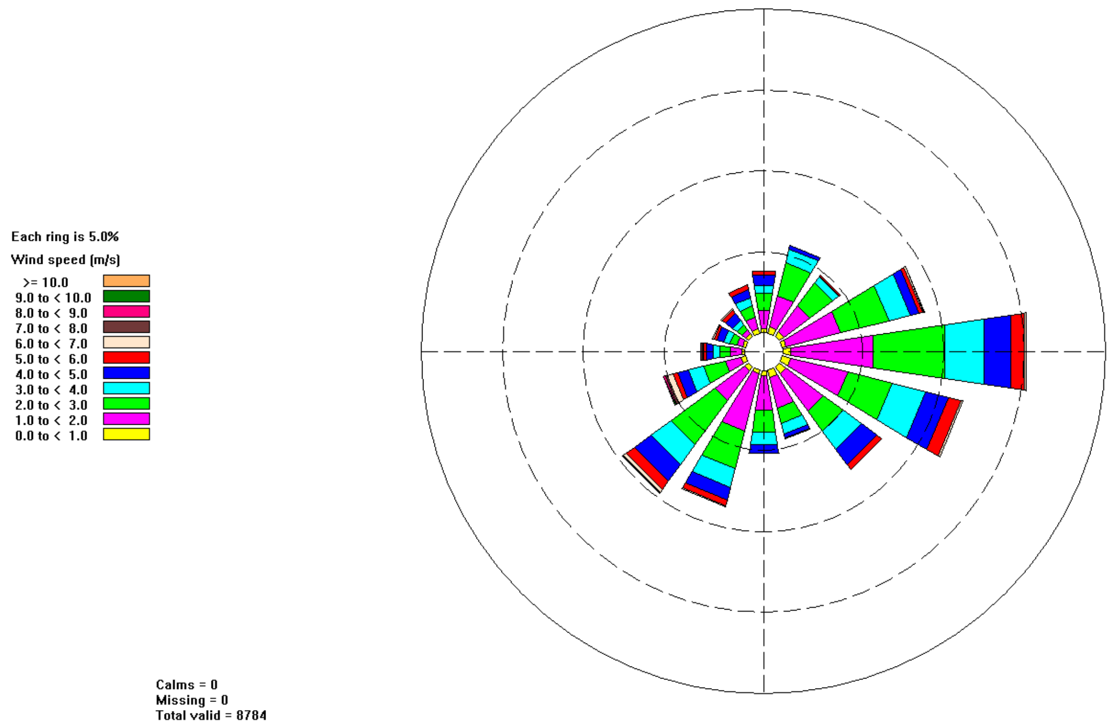

Figure 16 Wind rose for all hours for Location 2

Location: Location 2 of study area	**Period:** 1 January- 31 December 2008	**Data source:** Generated by CALMET	**Units:** m/s and °
Type: Wind rose	**Averaging Period:** 8784 hourly average records	**Prepared by:** Sarah-Jane Donnelly	**Date:** 10th December 2009

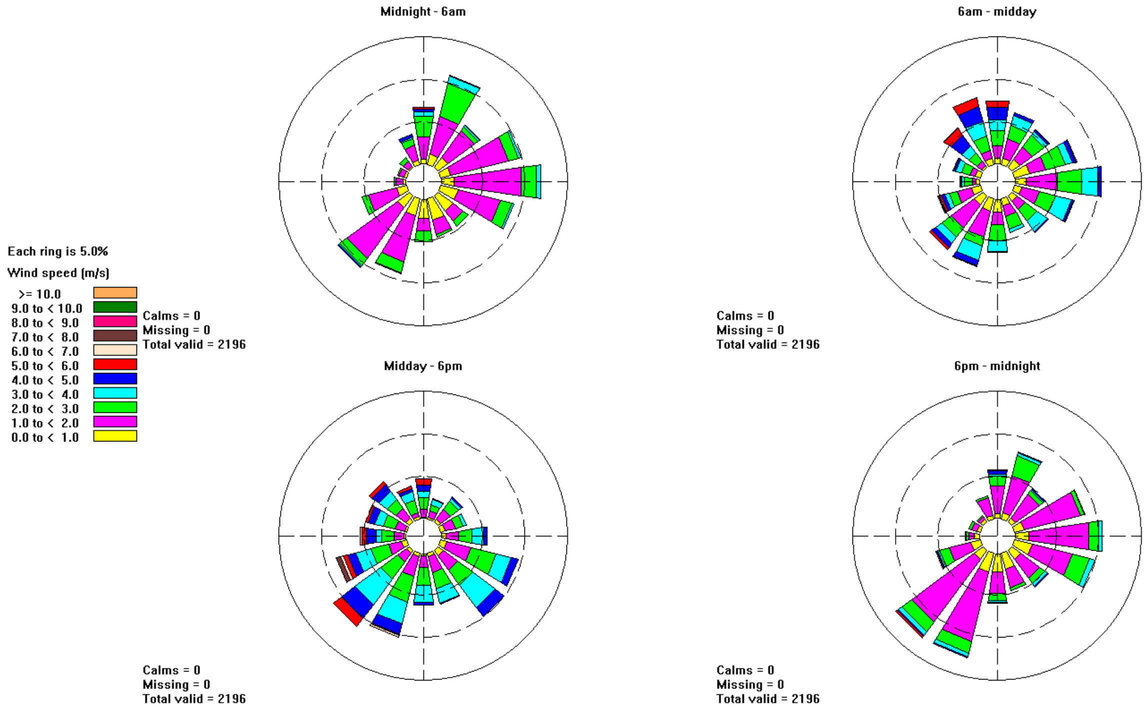

Figure 17 Wind rose by time of day for Location 1

Location: Location 1 of study area	**Period:** 1 January- 31 December 2008	**Data source:** Generated by CALMET	**Units:** m/s and °
Type: Wind rose	**Averaging Period:** 8784 hourly average records	**Prepared by:** Sarah-Jane Donnelly	**Date:** 10th December 2009

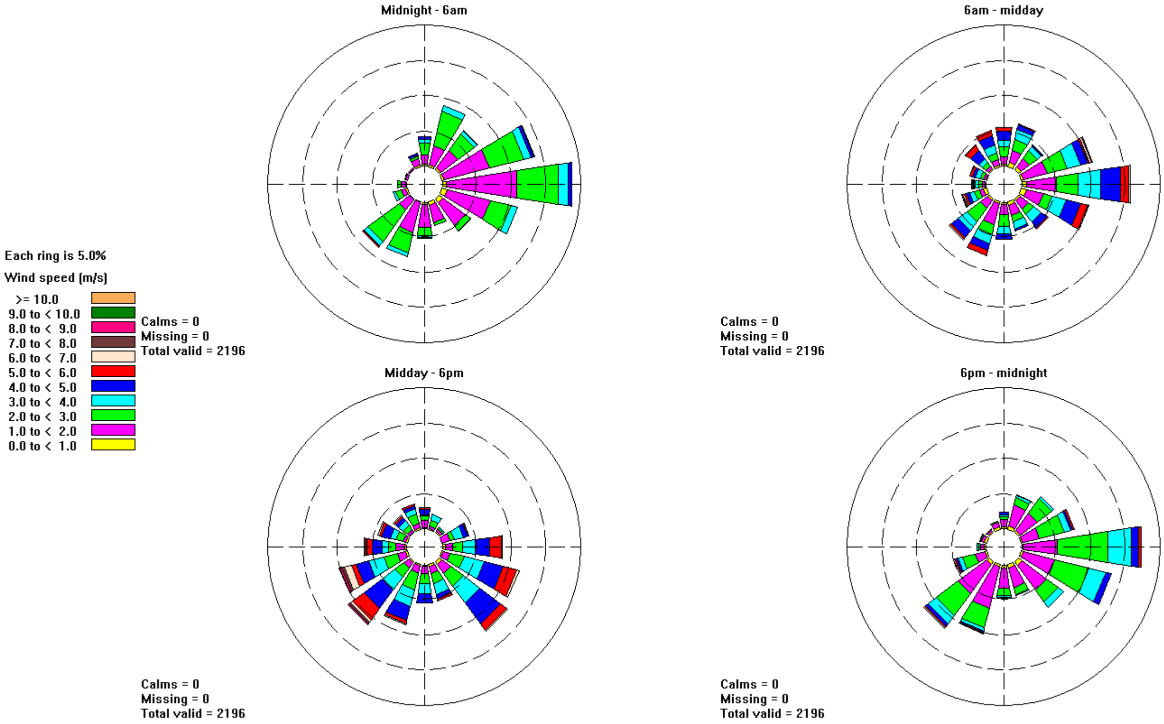

Figure 18 Wind rose by time of day for Location 2

Location: Location 2 of study area	**Period:** 1 January- 31 December 2008	**Data source:** Generated by CALMET	**Units:** m/s and °
Type: Wind rose	**Averaging Period:** 8784 hourly average records	**Prepared by:** Sarah-Jane Donnelly	**Date:** 10th December 2009

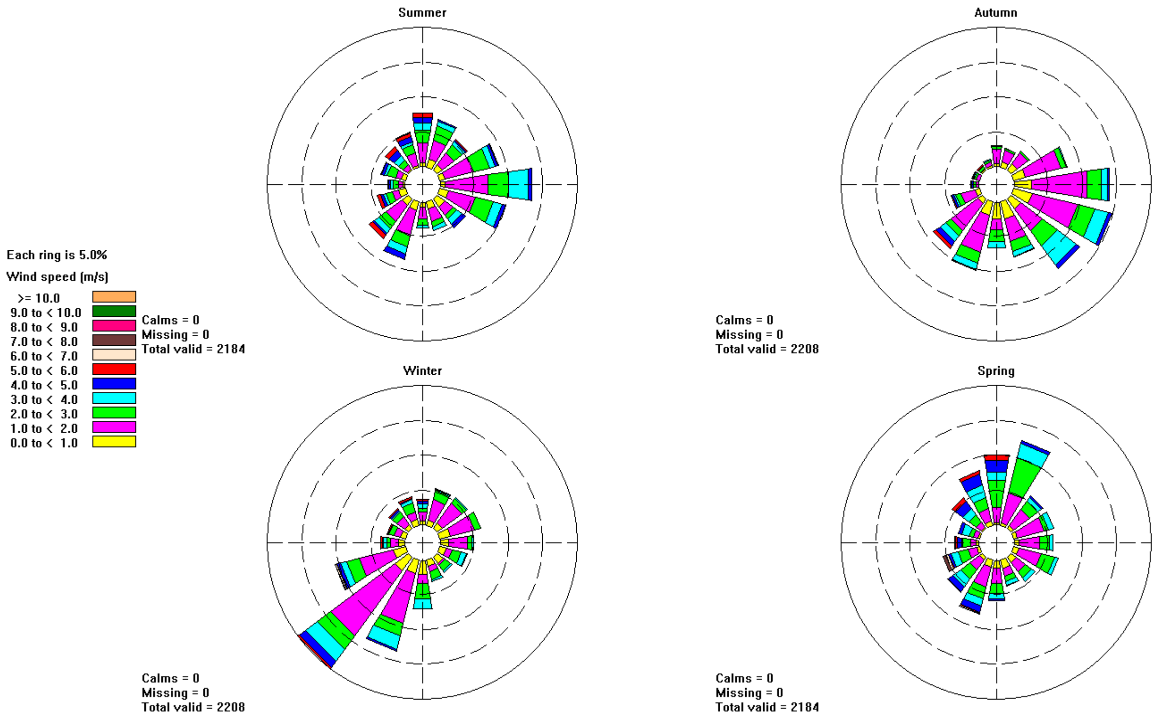

Figure 19 Wind rose for each season for Location 1

Location: Location 1 of study area	**Period:** 1 January- 31 December 2008	**Data source:** Generated by CALMET	**Units:** m/s and °
Type: Wind rose	**Averaging Period:** 8784 hourly average records	**Prepared by:** Sarah-Jane Donnelly	**Date:** 10th December 2009

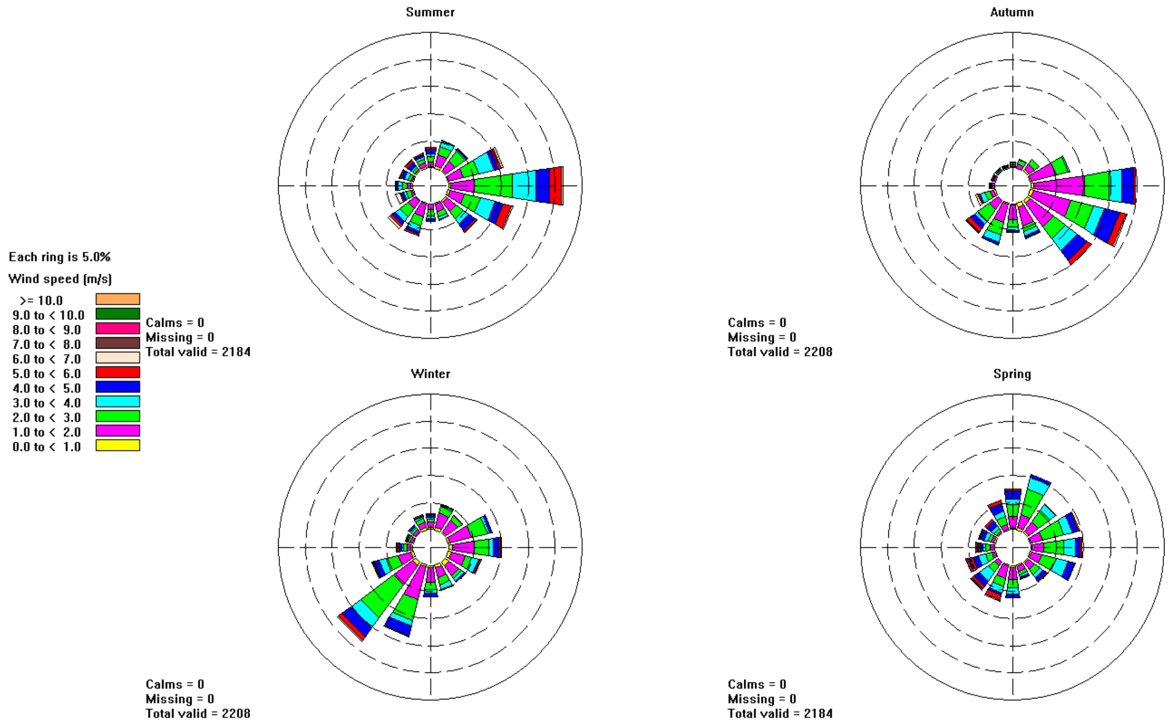

Figure 20 Wind rose for each season for Location 2

Location: Location 2 of study area	**Period:** 1 January- 31 December 2008	**Data source:** Generated by CALMET	**Units:** m/s and °
Type: Wind rose	**Averaging Period:** 8784 hourly average records	**Prepared by:** Sarah-Jane Donnelly	**Date:** 10th December 2009

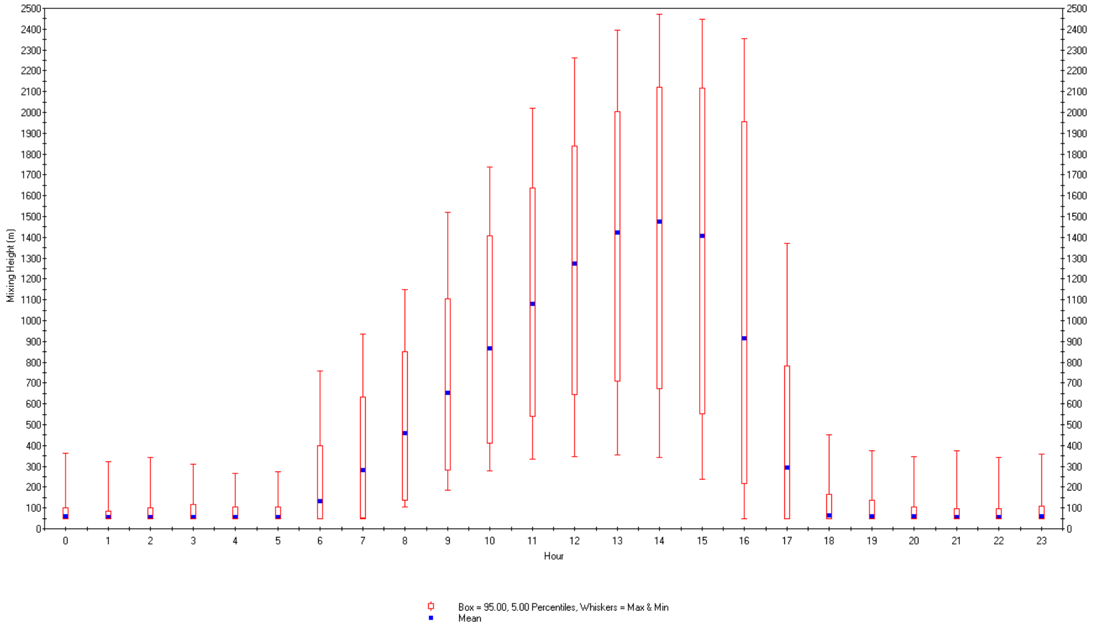

Figure 21 **Box and Whisker plot of mixing height for each hour of the day for location 1**

Location: Location 1 of study area	**Period:** 1 January- 31 December 2008	**Data source:** Generated by CALMET	**Units:** Metres and hours
Type: Box and Whisker Plot	**Averaging Period:** 8784 hourly average records	**Prepared by:** Sarah-Jane Donnelly	**Date:** 10th December 2009

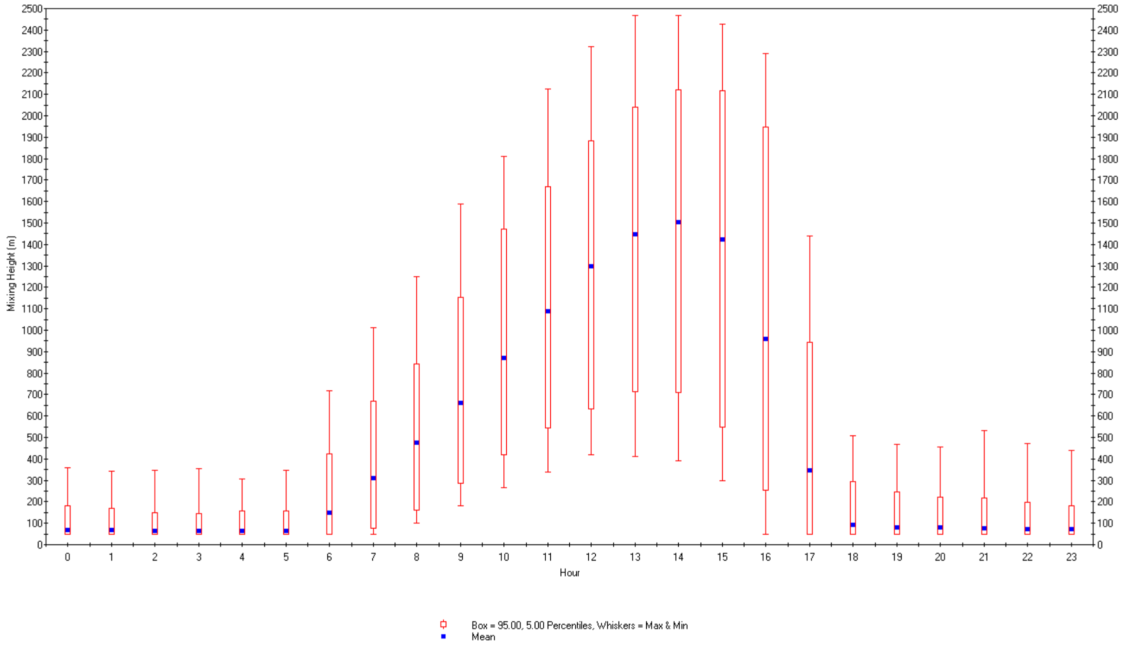

Figure 22 Box and Whisker plot of mixing height for each hour of the day for location 2

Location: Location 2 of study area	**Period:** 1 January- 31 December 2008	**Data source:** Generated by CALMET	**Units:** Metres and hours
Type: Box and Whisker Plot	**Averaging Period:** 8784 hourly average records	**Prepared by:** Sarah-Jane Donnelly	**Date:** 10th December 2009

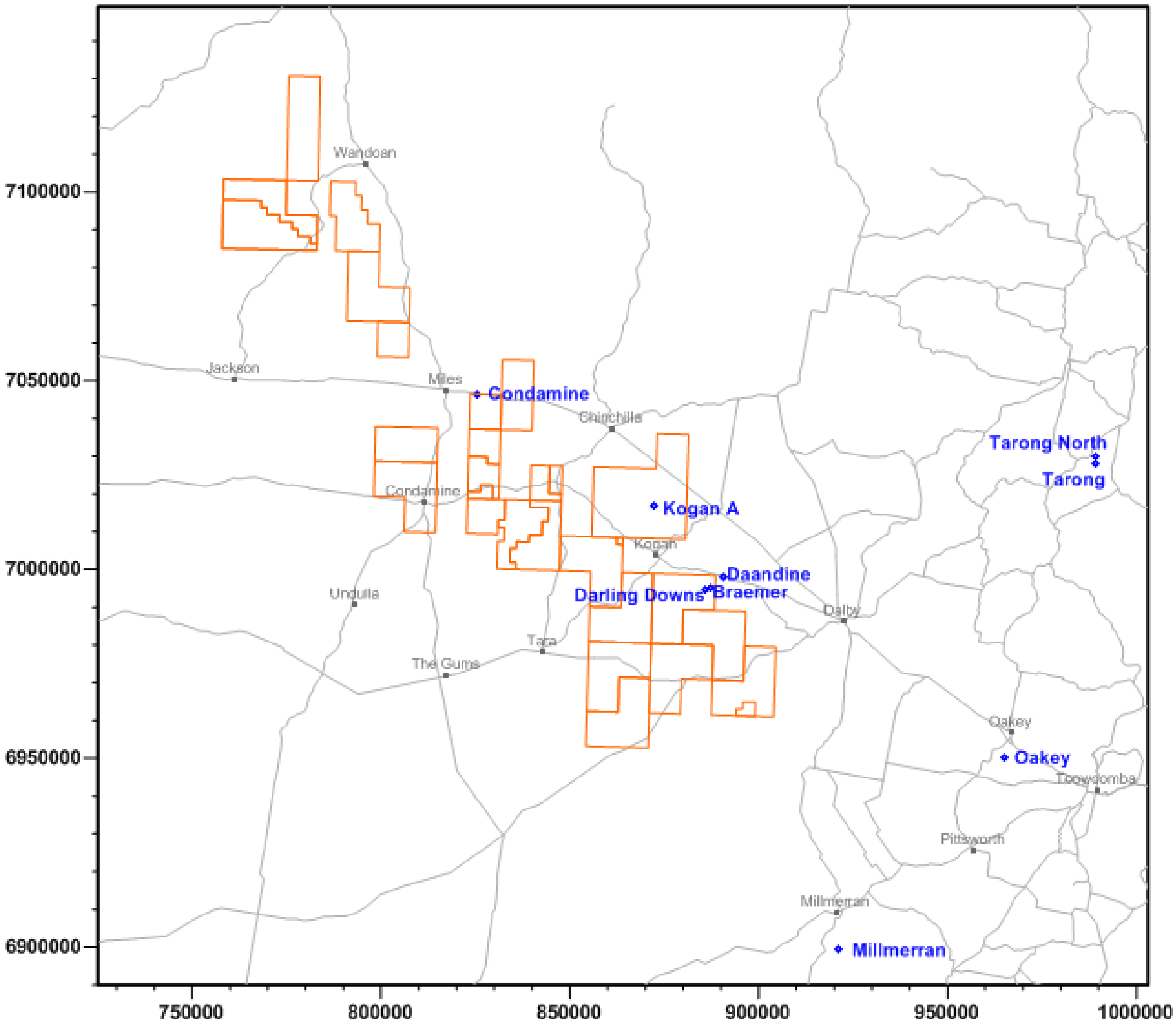

Figure 23 QCLNG exploration and production leases and the location of the existing and approved power stations included in the assessment of background concentrations of oxides of nitrogen in the region

Location: South-central QLD	**Data Source:** Various	**Units:** Metres
Type: Location map	**Prepared by:** Andrew Vernon	**Date:** January 2010

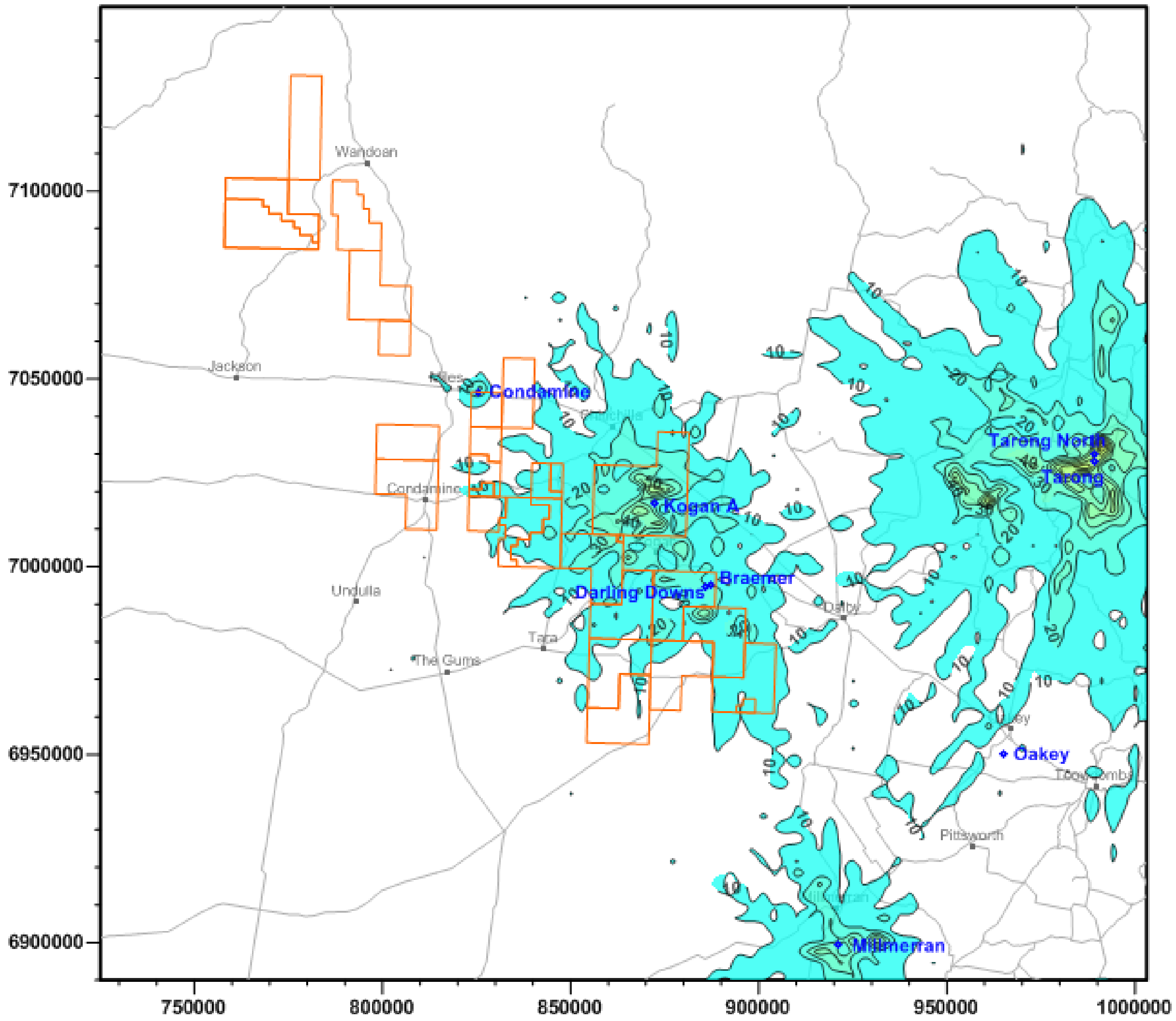

Figure 24 Predicted maximum 1-hour average ground-level concentrations of nitrogen dioxide from background power stations

Location: South-central, QLD	**Averaging period:** 1-hour	**Data source:** CALPUFF	**Units:** µg/m³ and metres
Type: NO_2 (100th percentile) contour plot	**Air quality objective:** 250 µg/m³	**Prepared by:** Andrew Vernon	**Date:** December 2009

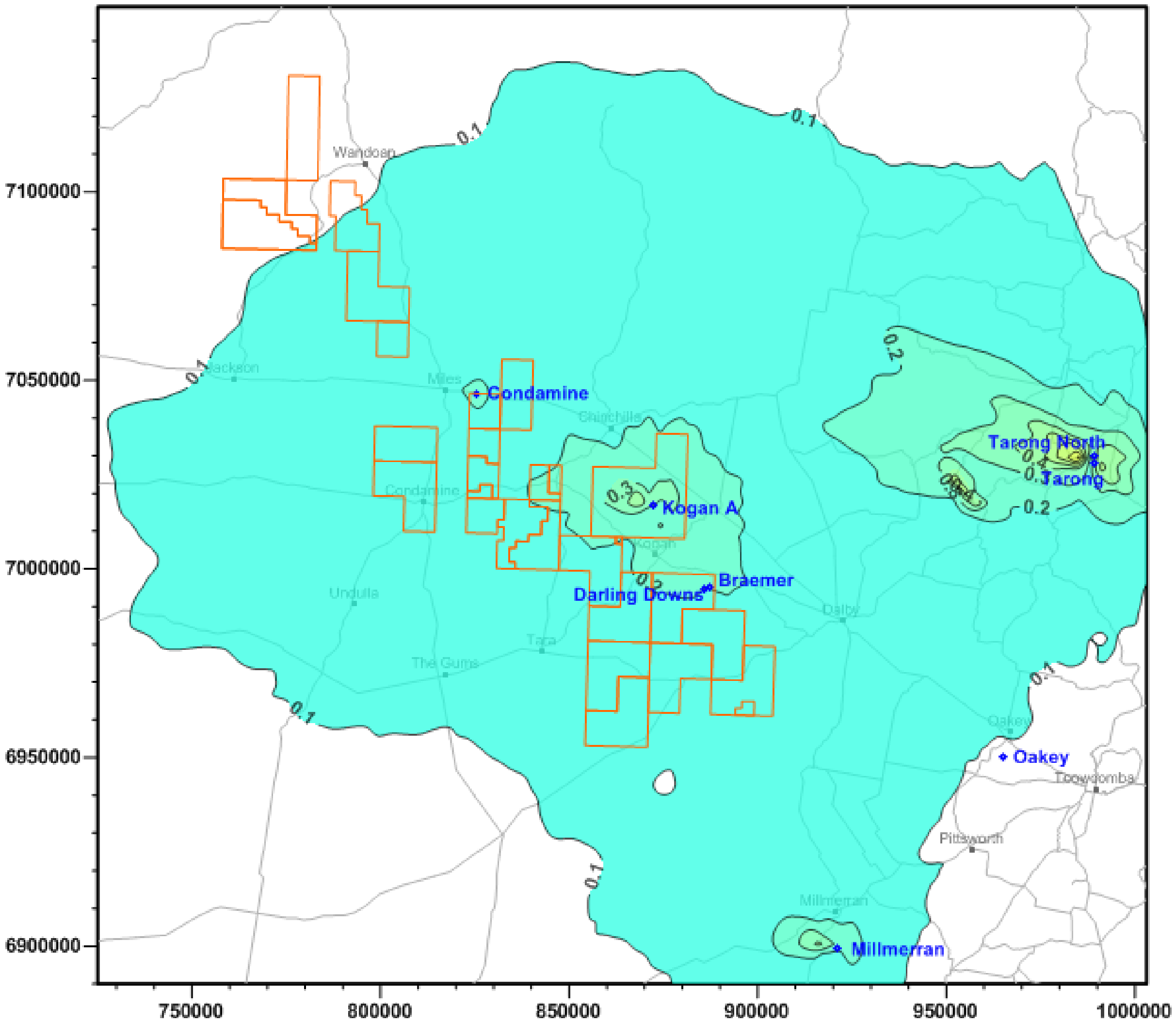

Figure 25 Predicted annual average ground-level concentrations of nitrogen dioxide from background power stations

Location: South-central, QLD	**Averaging period:** Annual	**Data source:** CALPUFF	**Units:** $\mu g/m^3$ and metres
Type: NO_2 (100th percentile) contour plot	**Air quality objective:** Health and wellbeing 62 $\mu g/m^3$	**Prepared by:** Andrew Vernon	**Date:** December 2009

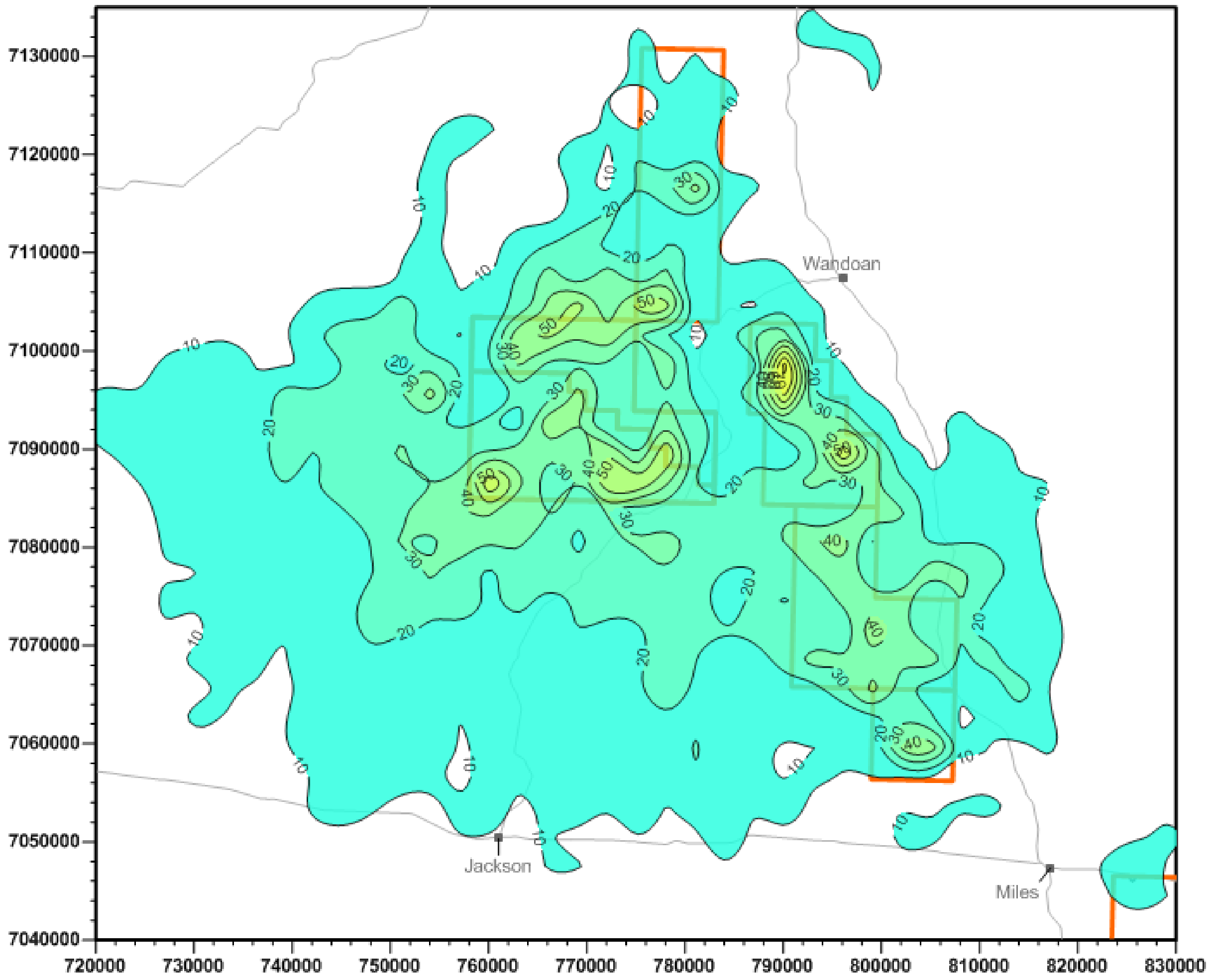

Figure 26 Predicted maximum 1-hour average ground-level concentrations of nitrogen dioxide for Scenario 1, in isolation

Location: NW of Miles, QLD	**Averaging period:** 1-hour	**Data source:** CALPUFF	**Units:** µg/m³ and metres
Type: NO_2 (100th percentile) contour plot	**Air quality objective:** 250 µg/m³	**Prepared by:** Andrew Vernon	**Date:** January 2010

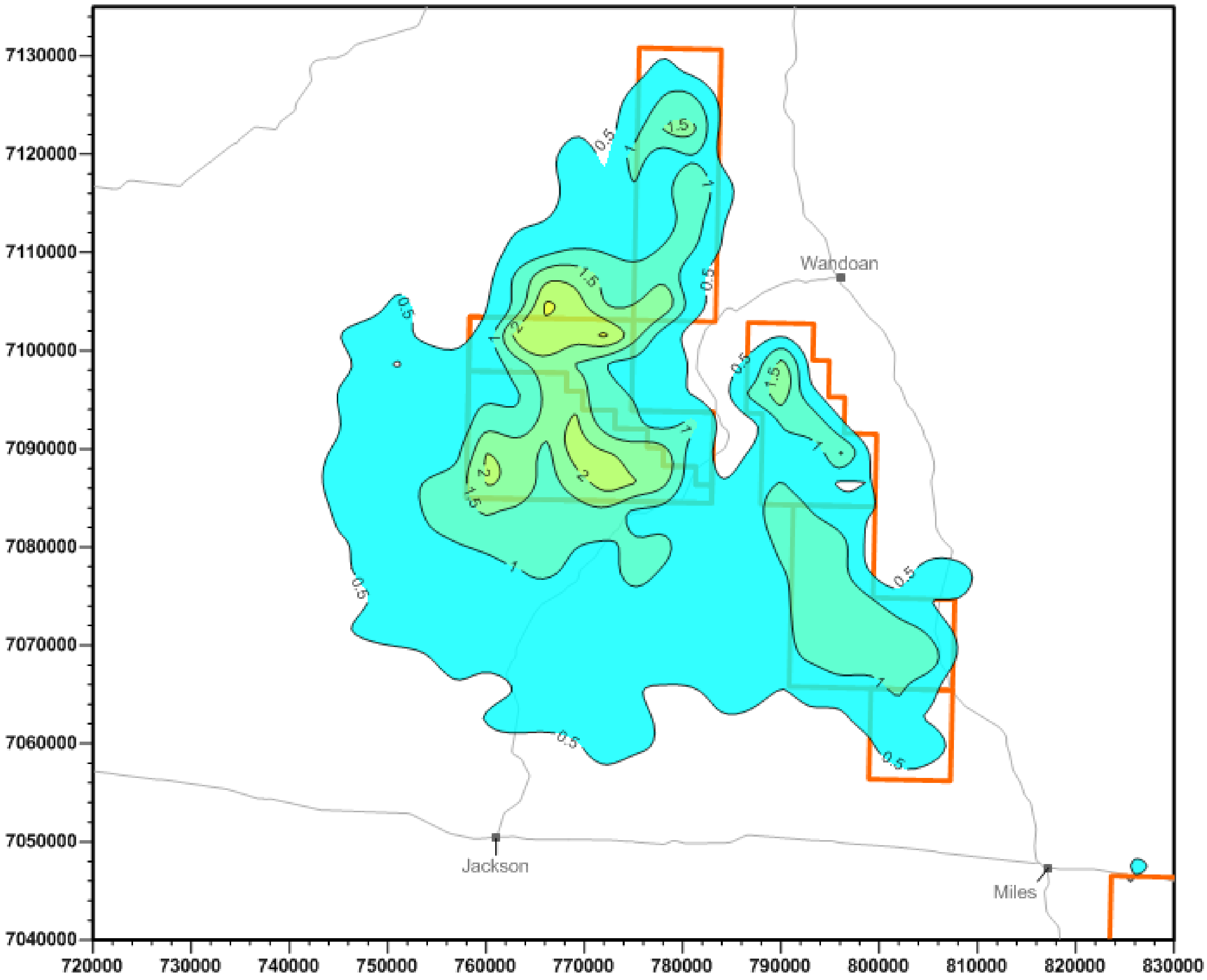

Figure 27 Predicted annual average ground-level concentrations of nitrogen dioxide for Scenario 1, in isolation

Location: NW of Miles, QLD	**Averaging period:** Annual	**Data source:** CALPUFF	**Units:** µg/m³ and metres
Type: NO_2 (100th percentile) contour plot	**Air quality objective:** Health and wellbeing 62 µg/m³	**Prepared by:** Andrew Vernon	**Date:** January 2010

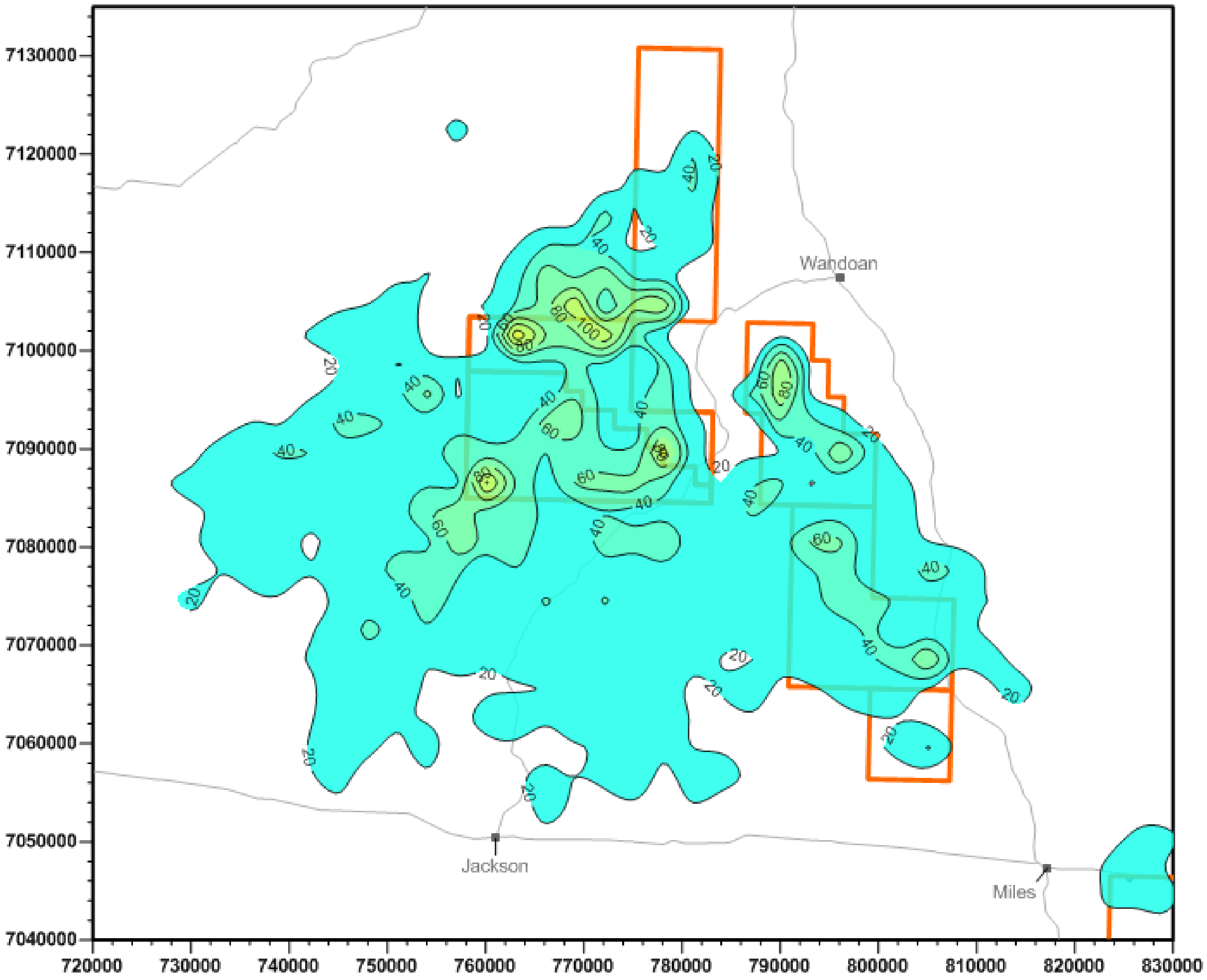

Figure 28 Predicted maximum 8-hour average ground-level concentrations of carbon monoxide for Scenario 1, in isolation

Location: NW of Miles, QLD	**Averaging period:** 8-hour	**Data source:** CALPUFF	**Units:** µg/m³ and metres
Type: CO (100th percentile) contour plot	**Air quality objective:** 11,000 µg/m³	**Prepared by:** Andrew Vernon	**Date:** January 2010

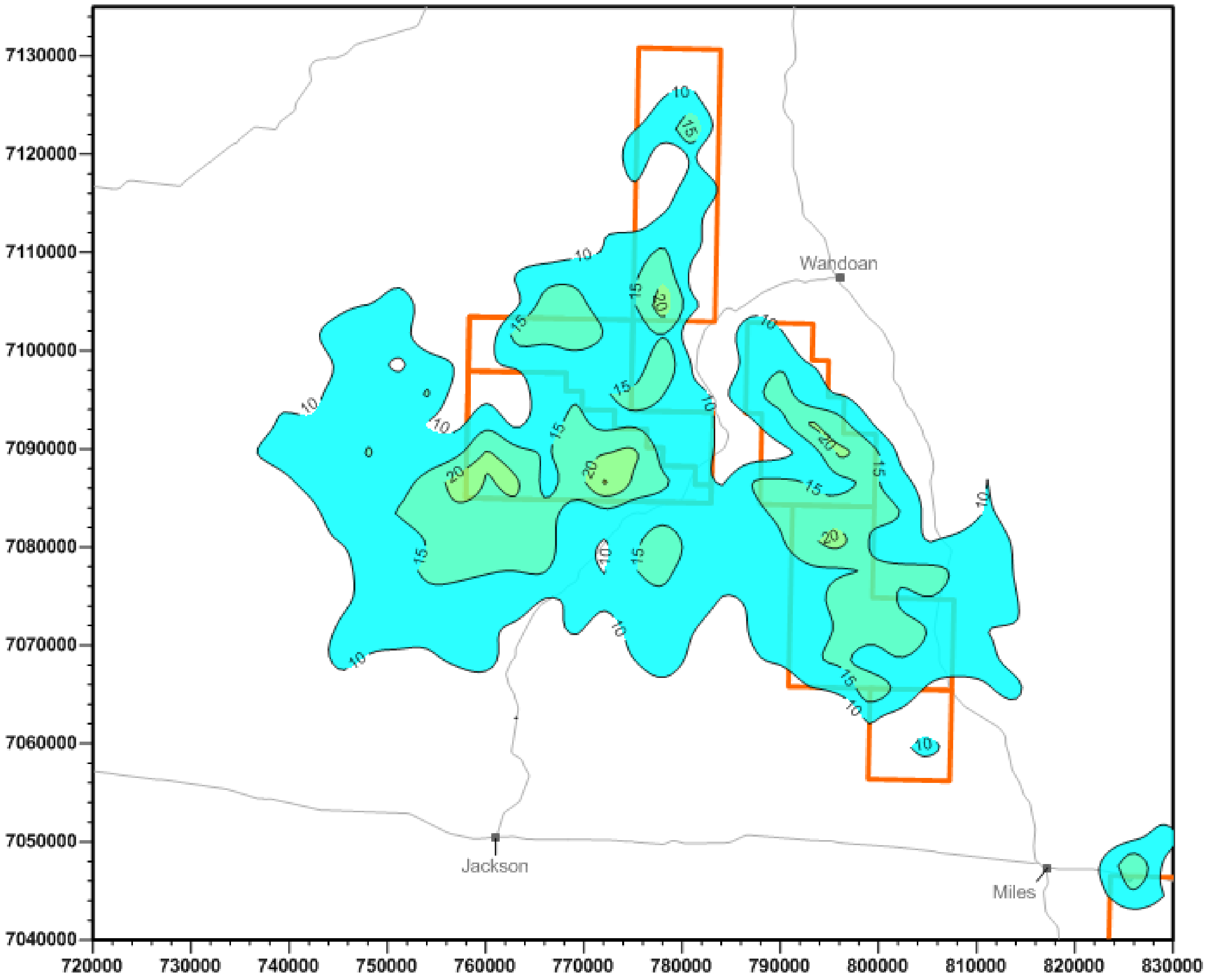

Figure 29 Predicted maximum 1-hour average ground-level concentrations of nitrogen dioxide for Scenario 2, in isolation

Location: NW of Miles, QLD	**Averaging period:** 1-hour	**Data source:** CALPUFF	**Units:** µg/m³ and metres
Type: NO_2 (100th percentile) contour plot	**Air quality objective:** 250 µg/m³	**Prepared by:** Andrew Vernon	**Date:** December 2009

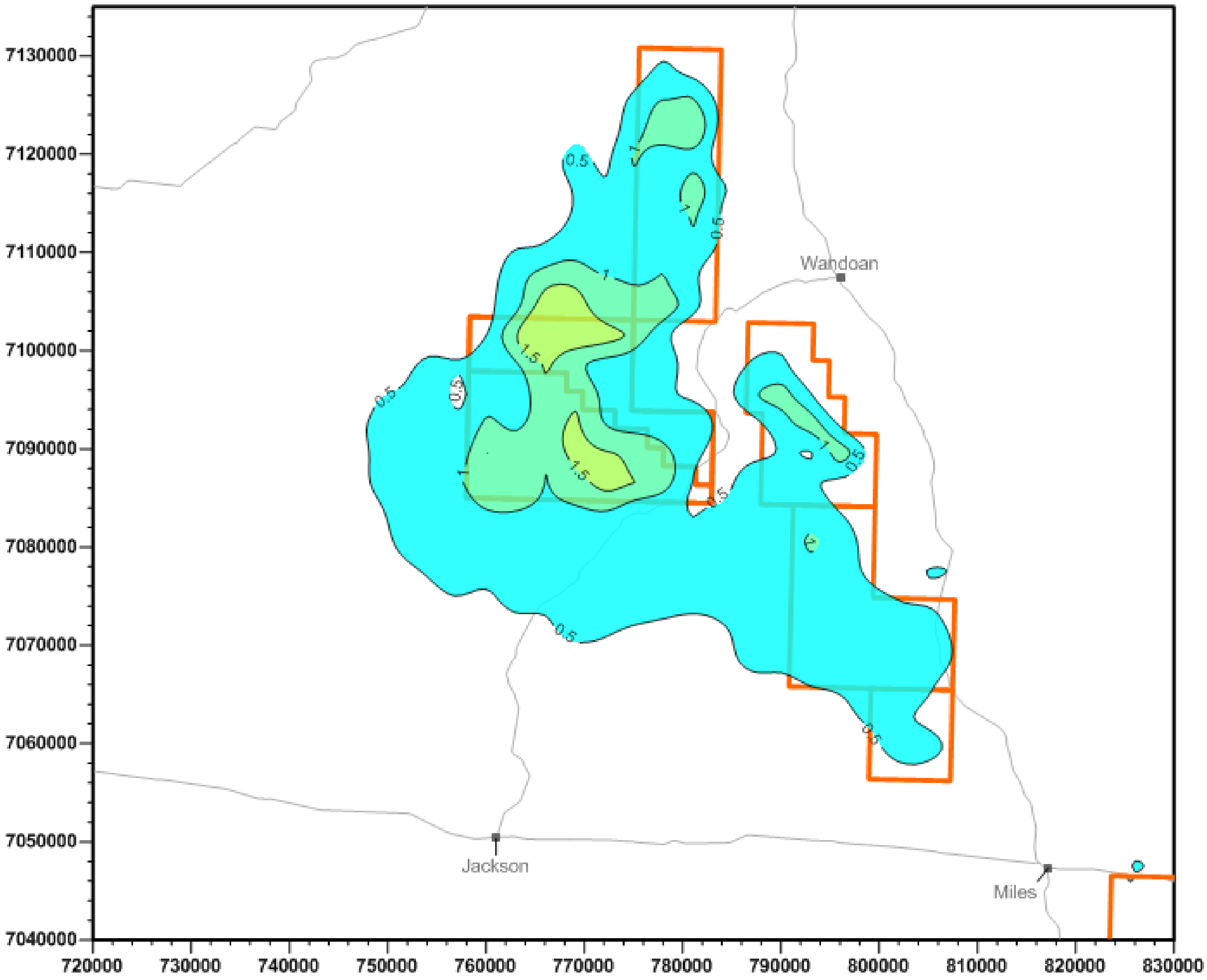

Figure 30 Predicted annual average ground-level concentrations of nitrogen dioxide for Scenario 2, in isolation

Location: NW of Miles, QLD	**Averaging period:** Annual	**Data source:** CALPUFF	**Units:** µg/m³ and metres
Type: NO_2 (100th percentile) contour plot	**Air quality objective:** Health and wellbeing 62 µg/m³	**Prepared by:** Andrew Vernon	**Date:** December 2009

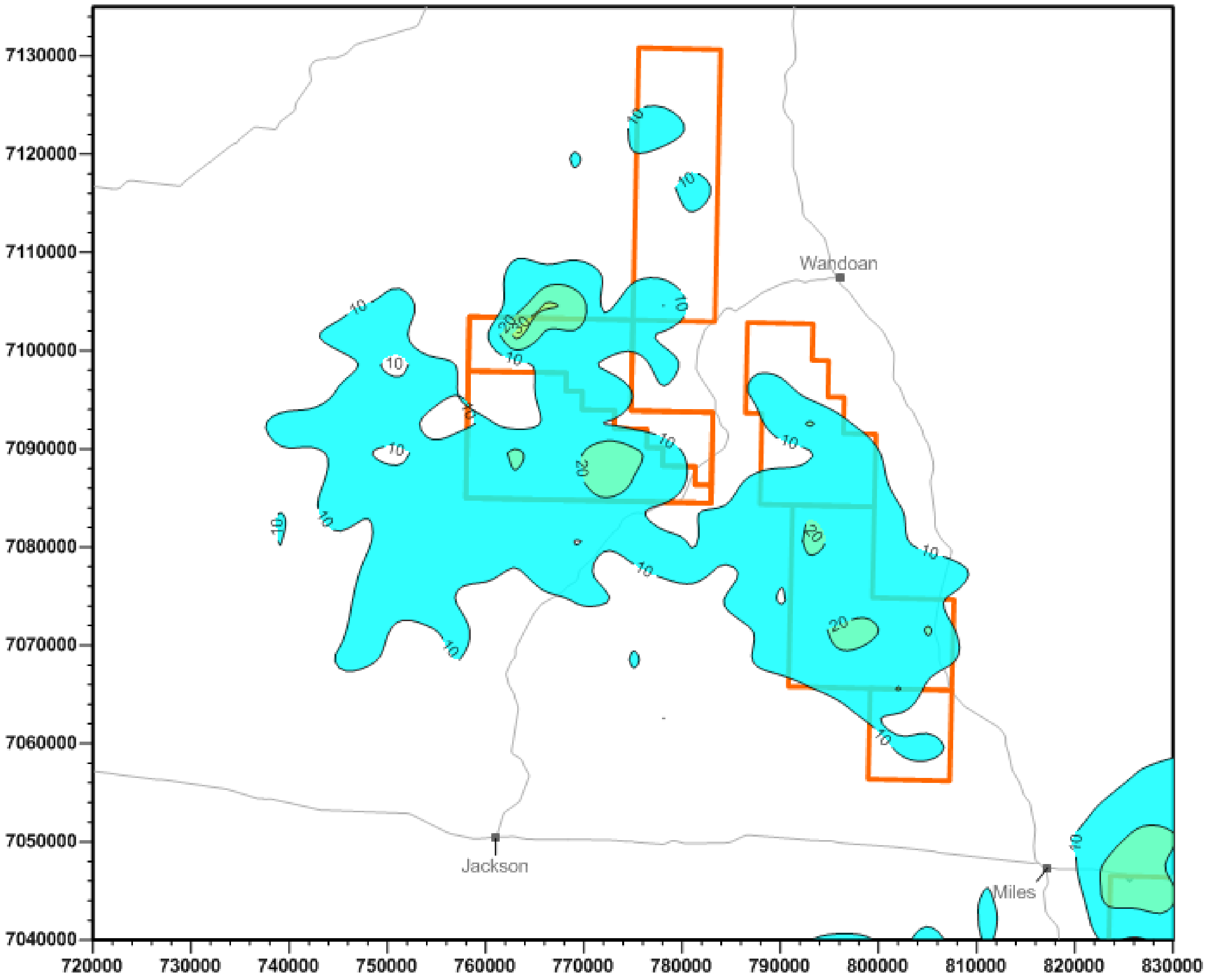

Figure 31 **Predicted maximum 8-hour average ground-level concentrations of carbon monoxide for Scenario 2, in isolation**

Location: NW of Miles, QLD	**Averaging period:** 8-hour	**Data source:** CALPUFF	**Units:** µg/m³ and metres
Type: CO (100th percentile) contour plot	**Air quality objective:** 11,000 µg/m³	**Prepared by:** Andrew Vernon	**Date:** December 2009

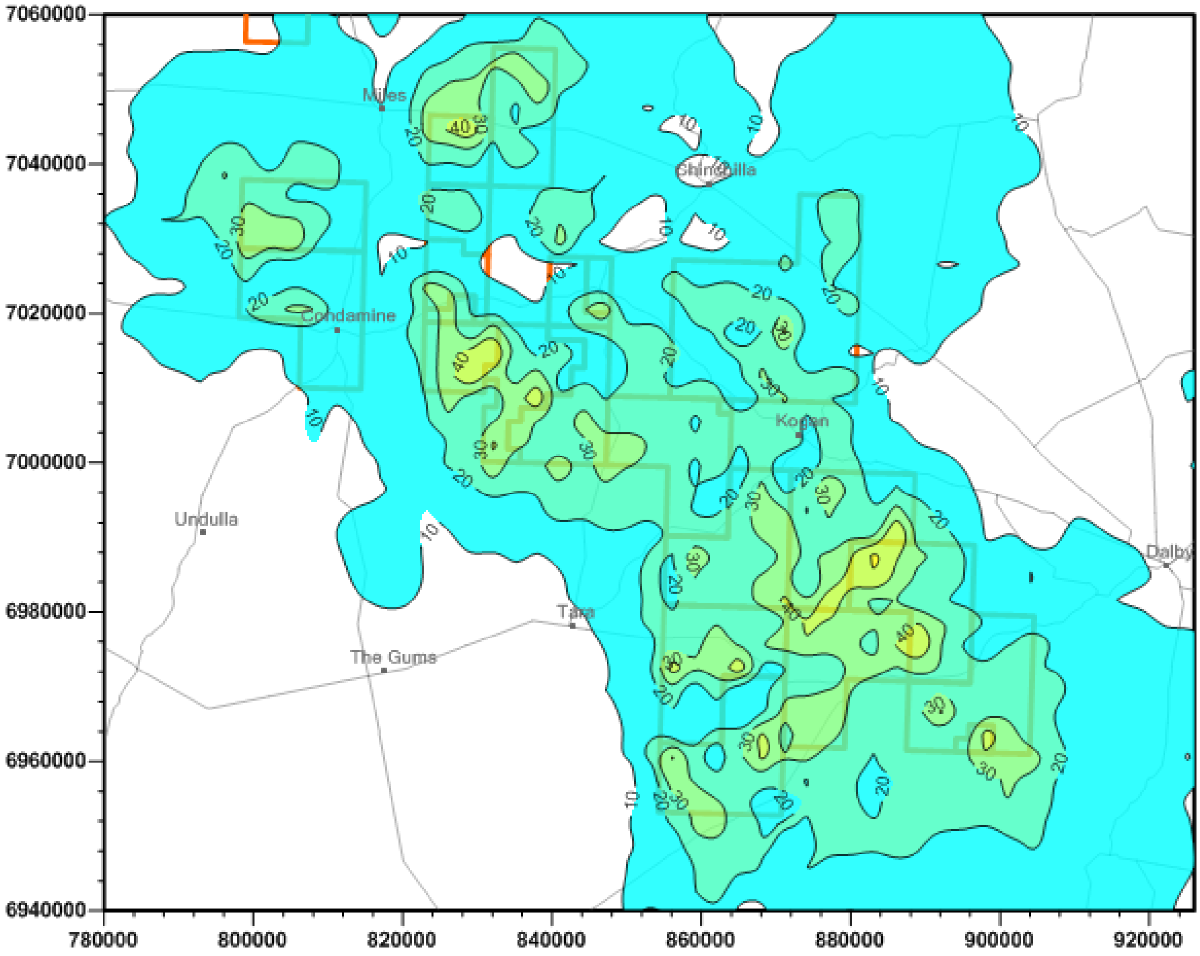

Figure 32 Predicted maximum 1-hour average ground-level concentrations of nitrogen dioxide for Scenario 3, in isolation

Location: SE of Miles, QLD	**Averaging period:** 1-hour	**Data source:** CALPUFF	**Units:** µg/m³ and metres
Type: NO_2 (100th percentile) contour plot	**Air quality objective:** 250 µg/m³	**Prepared by:** Andrew Vernon	**Date:** December 2009

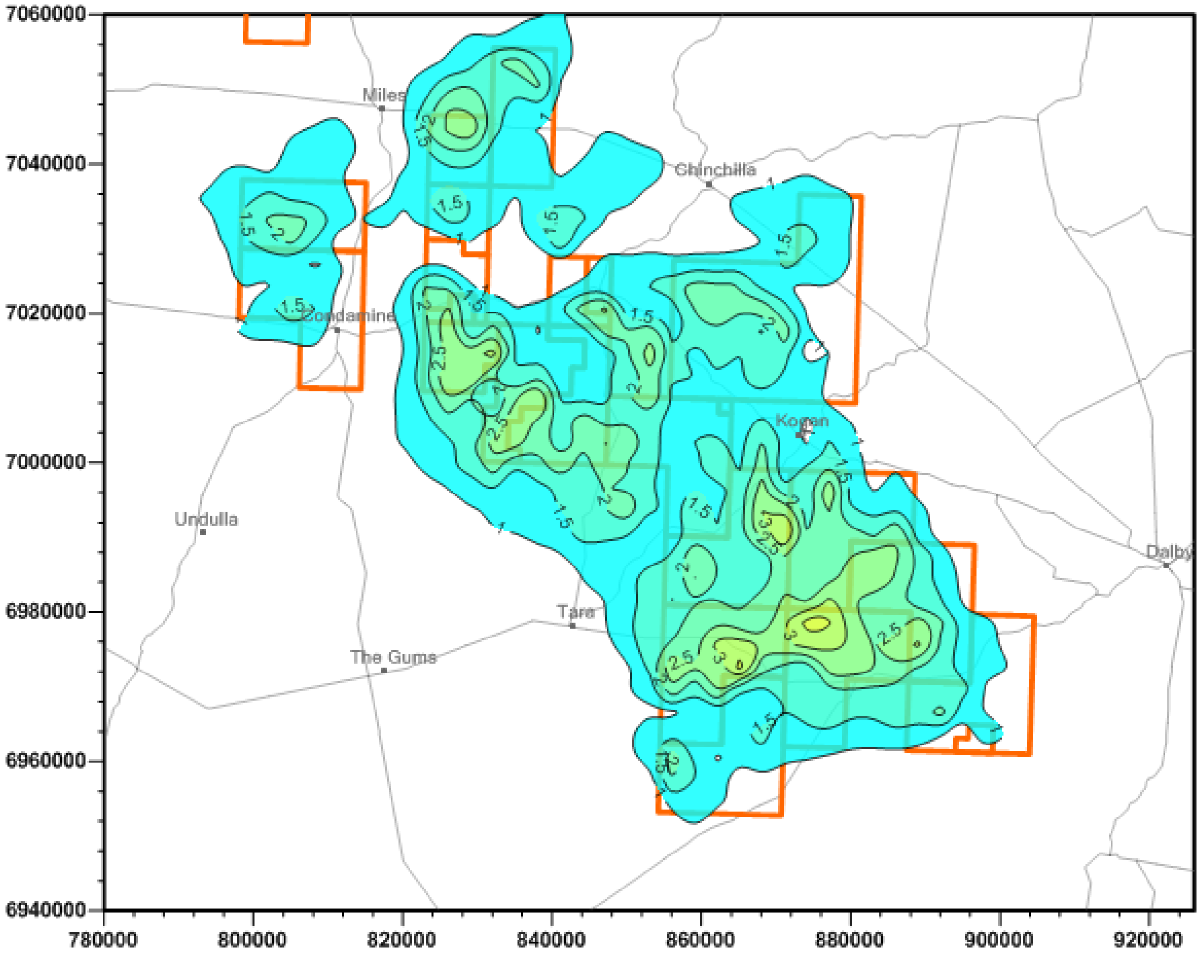

Figure 33 **Predicted annual average ground-level concentrations of nitrogen dioxide for Scenario 3, in isolation**

Location: SE of Miles, QLD	**Averaging period:** Annual	**Data source:** CALPUFF	**Units:** µg/m³ and metres
Type: NO_2 (100th percentile) contour plot	**Air quality objective:** Health and wellbeing 62 µg/m³	**Prepared by:** Andrew Vernon	**Date:** December 2009

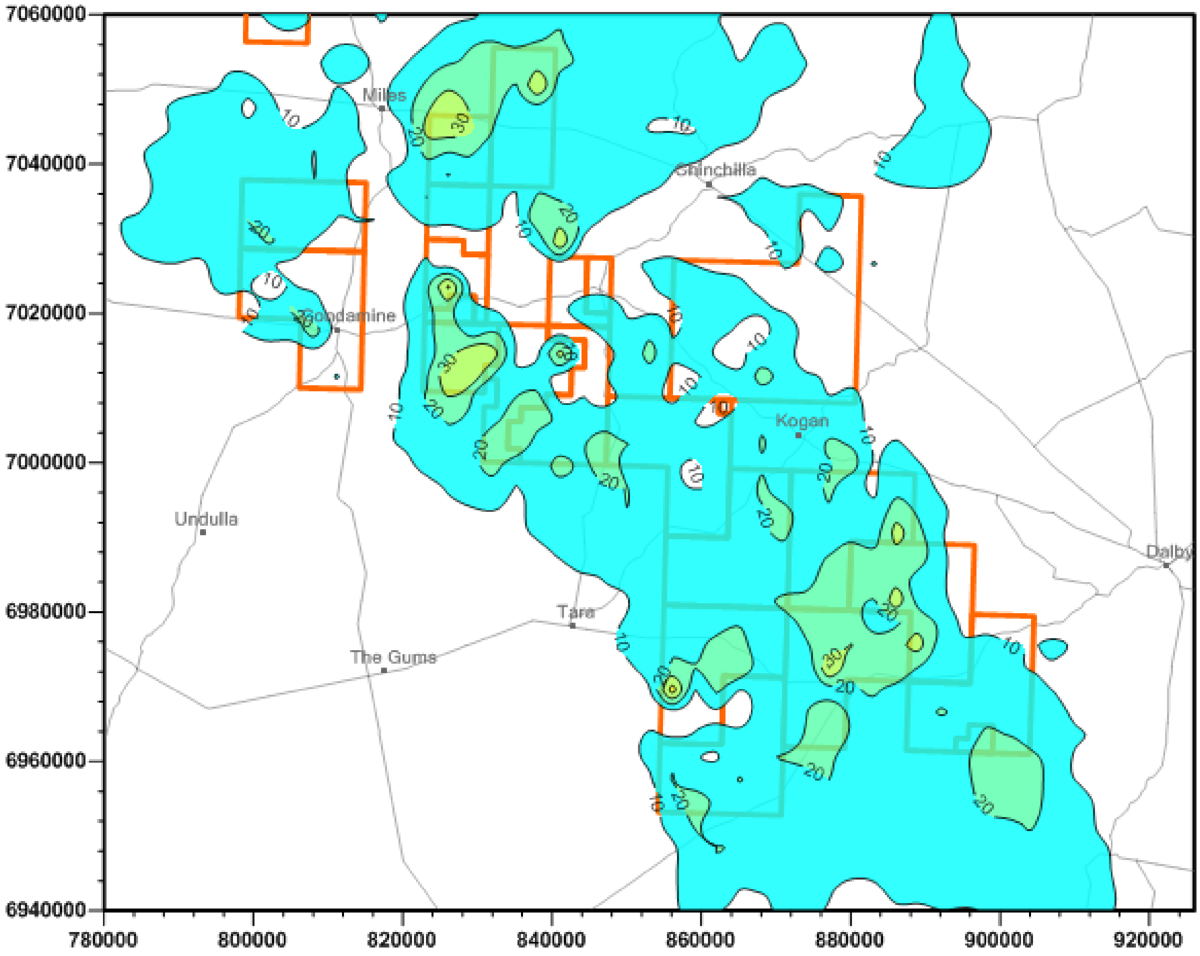

Figure 34 **Predicted maximum 8-hour average ground-level concentrations of carbon monoxide for Scenario 3, in isolation**

Location: SE of Miles, QLD	**Averaging period:** 8-hour	**Data source:** CALPUFF	**Units:** µg/m³ and metres
Type: CO (100th percentile) contour plot	**Air quality objective:** 11,000 µg/m³	**Prepared by:** Andrew Vernon	**Date:** December 2009

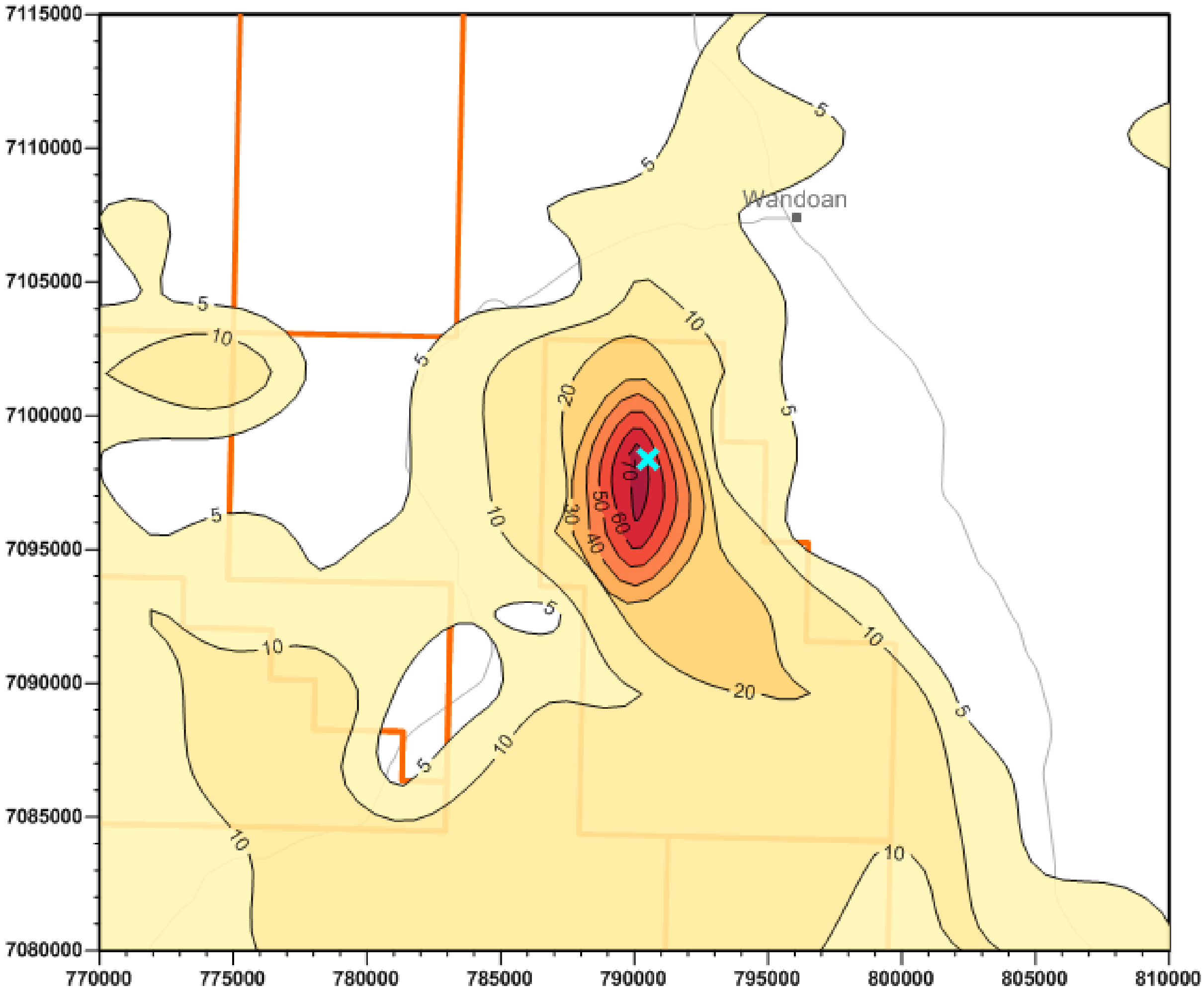

Figure 35 Predicted maximum 1-hour average ground-level concentration of nitrogen dioxide for a single FCS with 6 screw compressor engines

Location: NE of Miles, QLD	**Averaging period:** 1-hour	**Data source:** CALPUFF	**Units:** $\mu g/m^3$ and metres
Type: NO_2 (100th percentile) contour plot	**Air quality objective:** 250 $\mu g/m^3$	**Prepared by:** Andrew Vernon	**Date:** January 2010

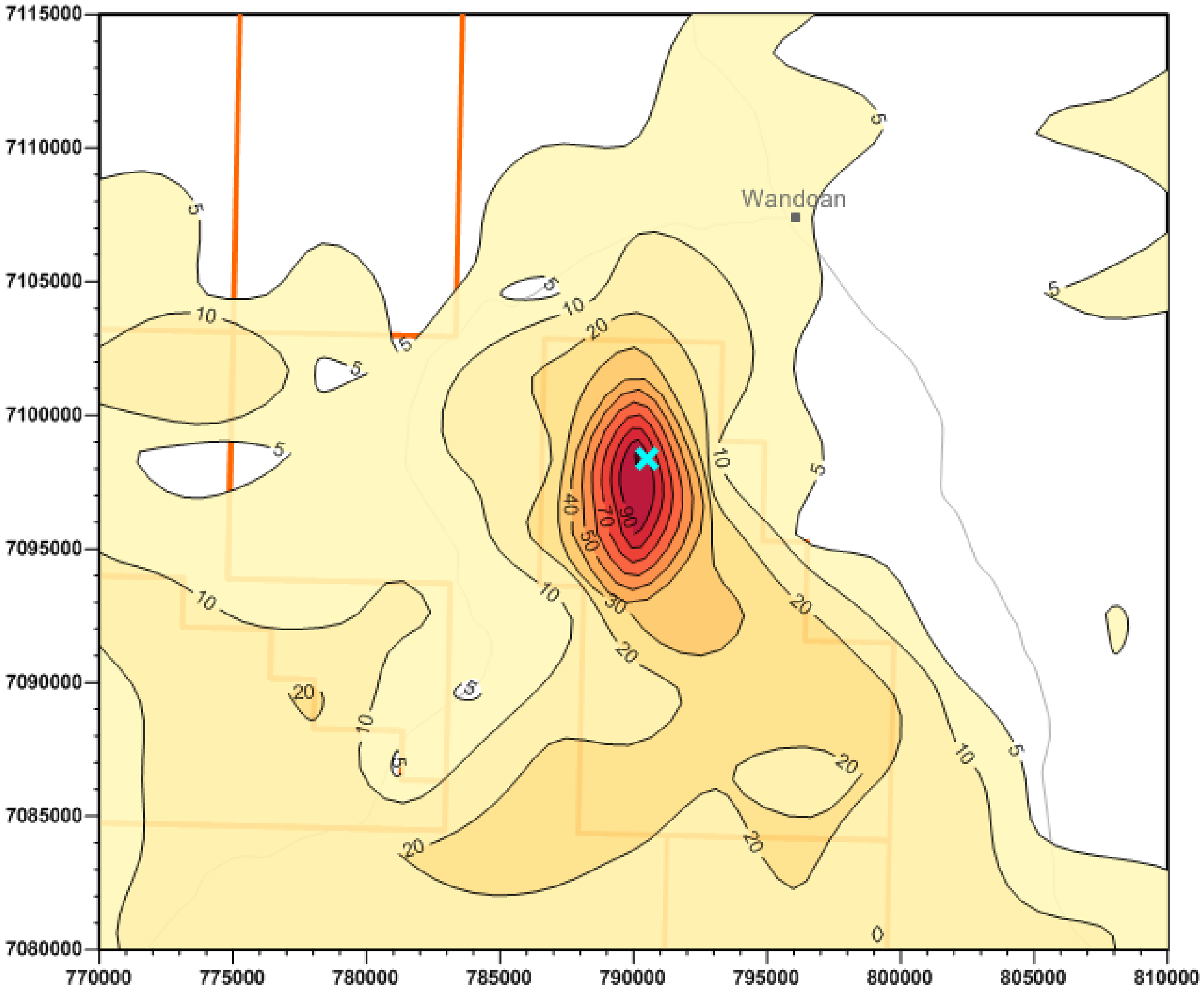

Figure 36 Predicted maximum 1-hour average ground-level concentrations of nitrogen dioxide for a single FCS with 8 screw compressor engines

Location: NE of Miles, QLD	**Averaging period:** 1-hour	**Data source:** CALPUFF	**Units:** $\mu g/m^3$ and metres
Type: NO_2 (100th percentile) contour plot	**Air quality objective:** 250 $\mu g/m^3$	**Prepared by:** Andrew Vernon	**Date:** January 2010

Appendix A

Meteorological and Dispersion Modelling Methodology

The meteorological data for this study was generated by coupling TAPM, a prognostic mesoscale model to CALMET, a diagnostic dispersion model. The coupled TAPM/CALMET modelling system was developed by Katestone Environmental to enable high resolution modelling capabilities for regulatory and environmental assessments. The modelling system incorporates synoptic, mesoscale and local atmospheric conditions, detailed topography and land use categorisation schemes to simulate synoptic and regional scale meteorology for input into pollutant dispersion models, such as CALPUFF. Details of the model configuration are supplied in the following sections.

TAPM meteorological simulations

The meteorological model, TAPM (The Air Pollution Model) Version 4, was developed by the CSIRO and has been validated by the CSIRO, Katestone Environmental and others for many locations in Australia, in southeast Asia and in North America (see www.cmar.csiro.au/research/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, Bangladesh, America and Vietnam. This model has performed well for simulating regional winds patterns. TAPM has proven to be a useful model for simulating meteorology in locations where monitoring data is unavailable.

TAPM is a prognostic meteorological model which predicts the flows important to regional and local scale meteorology, such as sea breezes and terrain-induced flows from the larger-scale meteorology provided by the synoptic analyses. TAPM solves the fundamental fluid dynamics equations to predict meteorology at a mesoscale (20 km to 200 km) 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 requires synoptic meteorological information for the study region. This information is generated by a global model similar to the large-scale models used to forecast the weather. The data are supplied on a grid resolution of approximately 75 km, and at elevations of 100 m to 5 km 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 was configured with the following parameters:

- Mother domain with a horizontal grid resolution of 27 km
- Nested domain with a horizontal grid resolution of 9 km
- 55 x 55 grid points for both modelling domains
- Grid centred on latitude -26.86°S, longitude 150.27°E
- 25 vertical levels, from the surface up to an altitude of 8000 metres above ground level
- Geoscience Australia 9 second DEM terrain data
- The TAPM defaults for sea surface temperature
- Default options selected for advanced meteorological inputs
- Default TAPM landuse data
- The synoptic data used in the simulation is for the year 2008 as provided by the CSIRO
- Local data assimilation using observations from the following three regionally representative sites

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 the meteorological models performance, particularly over complex terrain as the near surface meteorological conditions are calculated for each grid point.

CALMET Version 6.3 was used to simulate meteorological conditions in the APLNG gas fields project area. The modelling domain was setup to be nested within the coarse resolution 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 meso-scale prognostic capabilities of TAPM with the refined capabilities of CALMET to account for terrain and land use.

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, which are limited in their ability to represent local scale wind patterns across large distances.

CALMET was configured with the following parameters:

- Grid domain area of 360 km by 360 km
- Horizontal grid cell resolution of 3 km by 3 km
- 12 vertical levels with heights at 20m, 60m, 100m, 150m, 200m, 250m, 350m, 500m, 800m, 1600m, 2600m and 4600m
- 1-year time scale (1 January – 31 December 2008)
- The terrain and land use were refined from those used in the TAPM model to account for the increased resolution, with the terrain generated from the Geosciences Australia 9-second arc DEM dataset at a resolution of 3 km
- Prognostic wind fields input as MM5/2D.dat "initial guess" field only (as generated from TAPM)
- All default options and factors were selected with the exception of the following:
    - 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 km
    - Cloud cover calculated from prognostic relative humidity

CALPUFF dispersion modelling

The CALPUFFv6.0 dispersion model utilises the three-dimensional wind fields developed from the coupled TAPM/CALMET meteorological model to simulate the dispersion of air pollutants and predict ground-level concentrations across a gridded domain. CALPUFF is a non-steady-state Lagrangian, Gaussian, puff model containing parameterisations for complex terrain effects, overwater transport, coastal interaction effects, building downwash, wet and dry removal, and simple chemical transformations.

CALPUFF employs the three dimensional meteorological fields generated from CALMET by simulating the effects of temporal and spatial variability of meteorological conditions on pollutant transport, transformation and removal. CALPUFF contains algorithms that can resolve near-source effects such as building downwash, transitional plume rise, partial plume penetration, sub-grid scale terrain interactions, as well as the long range effects of removal, transformation, vertical wind shear, overwater transport and coastal interactions. Emission sources can be characterised as arbitrarily-varying point, area, volume and lines or any combination of those sources within the modelling domain.

Key features of CALPUFF used to simulate dispersion:

- Domain area of 66 by 66 grids at a horizontal resolution of 3 km by 3 km
- 1-year time scale (1 January – 31 December 2008)
- Gridded three-dimensional hourly-varying meteorological conditions as generated by CALMET
- Partial plume path adjustment for terrain modelled
- Transitional plume rise modelled
- Stack tip downwash modelled
- Dispersion coefficients calculated internally from sigma v and sigma w using micrometeorological variables
- Minimum sigma v set to 0.2 m/s
- Minimum wind speed set to 0.2 m/s