AIR QUALITY IMPACT ASSESSMENT OF UPSTREAM AND PIPELINE GAS FIELD INFRASTRUCTURE FOR THE QCLNG PROJECT

Prepared for

QUEENSLAND GAS COMPANY

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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

Term	***Definition***
CO	Carbon monoxide
PM	Particulate matter (fine dust)
$PM_{2.5}$ and PM_{10}	Particulate matter less than 2.5 or 10 microns, respectively
SO_2	sulphur dioxide
VOC	Volatile organic compounds
PAH	Polycyclic aromatic hydrocarbons
CO_2	Carbon dioxide
CO_2-e	Carbon dioxide equivalents
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 an Air Quality Impact Assessment in preparation of an Environmental Impact Statement (EIS) 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 gas field extraction infrastructure and the associated compressor stations will link into a transmission pipeline that will pump gas to a proposed LNG processing facility to be located at Curtis Island near Gladstone.

The proposed transmission pipeline stretches 380 km between the QCLNG production leases situated near Miles in the Surat Basin and the QCLNG facility on Curtis Island. The pipeline will be buried to a depth of at least 750 mm and comprise a single compressor station near the pipeline midpoint to regulate the gas transmission pressure. The pipeline network will also include 200 km of interconnected pipelines branching out from the main line to connect with production leases in the Surat Basin, and a 220 km collection lateral that will connect additional CSG fields to the main trunk gas pipeline.

The objective of the assessment is to investigate the potential for all air emissions to adversely impact on the air quality in the region. A variety of engines will be used across the project area for power generation and CSG processing. This assessment has focussed on the primary source of air emissions for the project, the gas-fired reciprocating engines that drive the two types of compressors that are proposed for the project, reciprocating compressors at the Central Processing Plants (CPPs) and screw compressors at the Field Compressor Stations (FCSs). The air quality assessment has investigated the impacts associated with both compressor types running at 100% engine capacity. The assessment has focused on the following key air pollutants:

- Oxides of nitrogen (NO_X), as nitrogen dioxide (NO_2)
- Carbon monoxide (CO)
- Hydrocarbons (VOC)

The configuration and location of the CSG extraction wells and compressor station infrastructure is yet to be finalised, and will develop as further resource exploration continues through the lifetime of the project. Notwithstanding this, the dispersion modelling for the impact assessment has been carried out using a nominal compressor station layout.

Modelling of air pollutants from background sources has been carried out using the CSIRO's TAPM (The Air Pollution Model) dispersion model to predict contributions to air quality levels. TAPM has also been used to derive meteorological information at three nominal site locations spread across the proposed project footprint. The TAPM generated meteorological information has then been incorporated into the AUSPLUME dispersion model to predict the impacts of NO_X, CO and VOC from the compressor stations.

The predicted ground-level concentrations of air pollutants have been compared with the relevant 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)*
- EPA Victoria (Vic SEPP) *State Environment Protection Policy (Air Quality Management)*
- World Health Organisation (WHO) Guidelines for Air Quality (Chapter 3) 2000
- National Exposure Standards for Atmospheric Contaminants in the Occupational Environment (NOHSC:1003(1995))
- Texas Commission on Environmental Quality Toxicological section list of Effects Screening Levels

The air quality impact assessment 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
- Reciprocating compressor and screw compressor station process emissions and plant design
- Methodology for the AUSPLUME dispersion modelling of the QCLNG stations
- Methodology for the TAPM dispersion modelling of background sources
- Assessment of predicted impacts of air pollutants including NO_X, CO and VOC by comparison to relevant guidelines

2. Development Proposal

2.1 Project Area

The project area for upstream infrastructure comprises the current QCLNG gas field 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 Upstream and Pipeline components comprise a network of CSG extraction, processing and transmission infrastructure designed to deliver gas to the proposed LNG facility at Curtis Island, in preparation for export. Table 1 presents a summary of the emissions sources across the project area.

Table 1 Summary of processes, engines types and number of engines to be used across the QCLNG Project

Process	Application	Engine model or type	Engine capacity (kW)	Number of engines across project
Well head pumps[1]	CSG/water flow pump	Oil Lift G2000 pump	36	10-156
Field compressor stations	CSG compression	Caterpillar G3512 gas engines	2,097	216
Central Processing Plants	CSG compression	Caterpillar G3608 gas engines	4,696	90
Tri-ethylene glycol dehydration units	CSG dehydration	Vortec 8100 gas engine	240	9
Export pipeline midpoint compressor station	CSG compression	Caterpillar G3512 gas engines	2,097	8
Camp sites	Power generation	Gas engine model to be advised	360	5
Field office	Power generation	Gas engine model to be advised	288	2

[1] Well head pumps are required for approximately 6 months per well and number value represents the annual range of pumps required over the lifetime of the project

QCLNG propose that CSG will be extracted from a network of 6,000 gas wells, required for the minimum 20-year life of the project, and situated throughout the QCLNG production leases in the Surat Basin. In order to optimise production, wells will be located approximately 750 m apart. Well development will grow organically and not necessarily in a complete grid pattern, initially. Approximately 65% of CSG extraction wells are expected to require well head pumps for the removal of water from the well, and duration of pumping is six months. The well head pumps to be used are Oil Lift G2000 pumps driven by a 36 kW gas-fired engine.

CSG extracted from each well will then be transmitted via pipeline to the nearest Field Compressor Station (FCS) where eight screw compressors will be employed 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 ten reciprocating compressors will further compress the gas and remove moisture in the Tri-ethylene Glycol (TEG) dehydration units to a pressure suitable for transmission in the Main Export Pipeline that will carry the CSG from the gas fields to the QCLNG facility at Curtis Island. Table 2 presents the composition of coal seam gas as extracted from the resource and as received at the QCLNG plant. The CSG does not comprise any sulfur compounds.

Table 2 Composition of coal seam methane gas pre- and post-processing at the Field Compressor Stations and Central Processing Plants

Compound	Gas composition at extraction well pre-processing (mole %)	Gas composition post-compressor station for delivery to the QCLNG plant (mole %)
Methane	97.51	97.80
Nitrogen	2.23	2.00
Ethane	0.01	0.02
Carbon Dioxide	0.22	0.16

For the purpose of modelling, the configuration of the gas processing infrastructure will comprise one CPP and three associated FCS as illustrated in Figure 2. Located evenly throughout the production leases in close proximity to gas well clusters, the CPP will be situated at the centre of three FCSs at each corner of a triangle and at a distance of approximately five kilometres from the CPP. This configuration comprises a single production unit with gas processed in the CPP feeding the Main Export Pipeline for transmission to Curtis Island. Nine production units are proposed in total, including a total of nine CPPs and 27 FCSs. This capacity has been designed to meet the initial CSG demand associated with a two train LNG facility at Curtis Island.

At present, the proposed location of the nine production units has not been selected, and further exploration is being conducted to fully develop the QCLNG CSG resource in the Surat Basin. Consequently, the location of the proposed 6,000 gas extraction wells and production units have not been finalised. Additionally, the site layout for each of the CPPs and FCSs has not been determined and therefore a generic site layout has been adopted for the dispersion modelling assessment. The layout of the CPPs and FCSs are presented in Figure 3, with compressor engine stack locations nominally situated 50 m apart. The final arrangement of compressors at each station is likely to change as the project develops.

2.2.1 Field Compressor Stations

The FCS will comprise compression facilities, a vent for pressure management, power generation using gas engines and a water management system.

Low pressure (approximately 200 kPa) gas from the wells will be received at the FCS. This gas will contain free water that arises from the condensation in the flow lines as well as some carryover from the well head separator.

Gas compression will be performed by eight Caterpillar G3512 gas-fired reciprocating engines with single stage Ariel screw compressors. Each compressor will have a throughput capacity of approximately 8 TJ/d. Free water will then be removed and the gas compressed to about 1200-1500 kPa.

A gas flare will be used at the FCSs for pressure management, removing the need for individual vents at each well head. The flare will be used in the event that a compressor unit is not working, resulting in the combustion of CSG product, comprising primarily of methane (CH_4) and small quantities of nitrogen (N_2) and carbon dioxide (CO_2). The capacity of the flare at the FCS will not be greater than the flare at the CPP. The frequency of gas flaring will be very low (approximately 3.5 occurrences per year on average) and of short duration (less than one hour), and will only occur in the event of a compressor breakdown or other emergency situation.

Power for the FCS will be provided by the gas engines with a diesel generator for backup. The fuel for the gas engines will be tapped off from the inlet supply of CSG to the FCS.

2.2.2 Central Processing Plants

The CPPs will comprise compression facilities, gas dehydration and regeneration units, a flare, power generation, metering facilities and offices and a control room.

At the CPP the gas will be dried and pressurised to its export pressure of approximately 10 MPa. Gas compression will be performed by 10 Caterpillar G3608 gas-fired reciprocating engines with two stage Ariel compressors. Each compressor will have a throughput capacity of 18 TJ/d.

Dehydration and regeneration of the gas will be through a Tri-ethylene Glycol (TEG) dehydration unit. It is estimated that there will be 45 TEG units. The gas is contacted with TEG in a contactor column, extracting the water and allowing dry gas to be passed to the compressor units. The water-enriched TEG is then regenerated in a gas-fired boiler. A single rectification stage is used to reduce TEG loss in the overhead water vapour, and stripping gas is used to achieve the TEG purity required for use in the contactor. The TEG is circulated using dual electrically-powered pumps.

In contrast to the FCSs, each CPP will include a flare capable of managing 85 TJ/d of gas flow. Any gas vented from the units will be directed to the flare and combusted.

Flow from each CPP will be metered as part of the process of transferring the gas to market. Metering assists in the identification of any losses occurring within the pipeline network.

3. Emissions

3.1 Normal Operations

3.1.1 Air Pollutants

The air pollutants considered in this assessment are associated with the combustion of CSG fuel in the gas engines employed throughout the project. The primary focus of emission sources for the dispersion modeling assessment are the gas-fired reciprocating engines associated with the compression and transmission of CSG at the compressor stations. This is due to the large number of units and their engine capacity in comparison to the other engines used across the project for power generation and small pumps.

The pollutants assessed include NO_X, CO and various hydrocarbon species. Sulfur is not present in the CSG resource, 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, CO, total hydrocarbons and formaldehyde have been supplied by the proponent from gas engine specification technical data. Further chemical speciation of the hydrocarbons that could be found in the exhaust emissions from the gas-fired reciprocating engines is 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).* The Caterpillar G3512 and G3608 gas-fired reciprocating engines are classified as four-stroke lean-burn engines according to the AP-42 emission factors.

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, and therefore the composition of the CSG being used as fuel across the QCLNG project area is likely to be different. The composition of the natural gas fuel combusted in AP-42 emission tests will likely be a composition of methane, ethane and propane, with trace amounts of sulfur and other hydrocarbons. Consequently, the composition of hydrocarbons in the engine exhaust gas across the QCLNG project may differ from that outlined in the AP-42 documents due to the combustion of CSG, which is primarily CH_4 in its composition (see Table 2).

Preliminary dispersion modelling was conducted using the AP-42 emission factors individual hydrocarbon compounds. The preliminary dispersion modelling found some potential for elevated levels of acrolein. However, acrolein is unlikely to occur in the exhausts of the Caterpillar 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.

3.1.2 Screw Compressor Gas-fired Engines

The performance characteristics of the Caterpillar G3512 gas engines with single stage Ariel screw compressors, to be located at the FCSs, is presented in Table 3. Performance information is presented for normal operating conditions with the gas engines operating at 100% capacity. Each FCS will comprise eight screw compressors with a total of 216 screw compressors to be employed across the project area at 27 FCSs. In addition to the FCSs, eight screw compressors and associated gas-fired reciprocating engines will be employed at a midline compressor station along the export pipeline to the LNG facility at Curtis Island. Table 4 presents the concentrations and emission rates for NO_X, CO and total hydrocarbons, while Table 5 presents the likely contribution to total hydrocarbon emissions for all hydrocarbons identified in the US EPA AP-42 emission factors document for natural gas-fired reciprocating engines.

Table 3 Performance and source characteristics for the Caterpillar G3512 gas engines with single stage Ariel screw compressors under normal operating conditions at 100% capacity

Parameter	Units	Value[1]
Engine power	bkW	705
LHV input	kW	2,097
Nominal engine efficiency	%	33.6
Nominal fuel consumption	MJ/bkW-hr	10.71
Stack height	m	7.2
Stack diameter	m	0.2603
Exhaust gas temperature	^oC	460
Exhaust gas velocity	m/s	48.7
Exhaust mass flow rate (0^oC, 1 Atm, wet)	kg/bkW-hr	6.11
Exhaust gas flow rate (0^oC, 1 Atm, wet)	Nm^3/bkW-hr	4.86
Exhaust gas flow rate (actual stack conditions)	m^3/s	2.6
Normalised exhaust gas flow rate (0^oC, 1 Atm)	Nm^3/s	0.96

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

Table 4 Concentration and emission rate for oxides of nitrogen, carbon monoxide and total hydrocarbons for the Caterpillar G3512 gas engines with single stage Ariel screw compressors

Parameter	Concentration[1] (g/bkW-hr)	Emission rate[1] (g/s)
Oxides of nitrogen (as NO_2)	2.68	0.558
Carbon monoxide	2.41	0.489
Total Hydrocarbons[2]	4.16	0.814
Formaldehyde	0.34	0.066
Acrolein[3]	-	9E-5

Note:
[1] Information obtained from Catepillar gas engine technical data sheet.
[2] Total hydrocarbons as non-methane hydrocarbons and presented as methane equivalents.
[3] Measured by Leeder Consulting, 7 May 2009, in G3512 screw compressor fuelled with CSG.

Table 5 Breakdown of emission rates for hydrocarbons from the Caterpillar G3512 gas engines with single stage Ariel screw compressors

Pollutant	Molecular weight	Emission Factor (lb/MMBtu)	Composition (mole%)	Stack Concentration (mg/Nm^3)	Emission Rate (g/s)
1,1,2,2-Tetrachloroethane	167.85	4.00E-05	0.00028	2.29E-02	2.21E-05
1,1,2-Trichloroethane	133.40	3.18E-05	0.00028	1.82E-02	1.76E-05
1,1-Dichloroethane	98.96	2.36E-05	0.00028	1.35E-02	1.30E-05
1,2,3-Trimethylbenzene	120.20	2.30E-05	0.00023	1.32E-02	1.27E-05
1,2,4-Trimethylbenzene	120.20	1.43E-05	0.00014	8.18E-03	7.89E-06
1,2-Dichloroethane	99.00	2.36E-05	0.00028	1.35E-02	1.30E-05
1,2-Dichloropropane	110.98	2.69E-05	0.00029	1.54E-02	1.48E-05
1,3,5-Trimethylbenzene	120.20	3.38E-05	0.00033	1.93E-02	1.87E-05
1,3-Butadiene	54.10	2.67E-04	0.00582	1.53E-01	1.47E-04
1,3-Dichloropropene	96.90	2.64E-05	0.00032	1.51E-02	1.46E-05
2-Methylnaphthalene	142.19	3.32E-05	0.00028	1.90E-02	1.83E-05
2,2,4-Trimethylpentane	114.22	2.50E-04	0.00258	1.43E-01	1.38E-04
Acenaphthene	154.20	1.25E-06	0.00001	7.15E-04	6.90E-07
Acenaphthylene	152.18	5.53E-06	0.00004	3.16E-03	3.05E-06
Acetaldehyde	44.10	8.36E-03	0.22358	4.78E+00	4.61E-03
Benzene	78.10	4.40E-04	0.00664	2.52E-01	2.43E-04
Benzo(b)fluoranthene	252.32	1.66E-07	0.00000	9.50E-05	9.16E-08
Benzo(e)pyrene	252.31	4.15E-07	0.00000	2.37E-04	2.29E-07
Benzo(g,h,i)perylene	276.32	4.14E-07	0.00000	2.37E-04	2.29E-07
Biphenyl	154.22	2.12E-04	0.00162	1.21E-01	1.17E-04
Butane	58.12	5.41E-04	0.01098	3.10E-01	2.99E-04
Butyr/Isobutyraldehyde	72.11	1.01E-04	0.00165	5.78E-02	5.57E-05
Carbon Tetrachloride	153.24	3.67E-05	0.00028	2.10E-02	2.03E-05
Chlorobenzene	112.56	3.04E-05	0.00032	1.74E-02	1.68E-05
Chloroethane	64.52	1.87E-06	0.00003	1.07E-03	1.03E-06
Chloroform	119.38	2.85E-05	0.00028	1.63E-02	1.57E-05
Chrysene	228.00	6.93E-07	0.00000	3.97E-04	3.83E-07
Cyclopentane	70.10	2.27E-04	0.00382	1.30E-01	1.25E-04
Ethane	30.07	1.05E-01	4.11826	6.01E+01	5.80E-02
Ethylbenzene	106.20	3.97E-05	0.00044	2.27E-02	2.19E-05
Ethylene Dibromide	187.86	4.43E-05	0.00028	2.53E-02	2.45E-05
Fluoranthene	202.26	1.11E-06	0.00001	6.35E-04	6.13E-07
Fluorene	166.22	5.67E-06	0.00004	3.24E-03	3.13E-06
Formaldehyde	30.03	5.28E-02	2.07365	3.02E+01	2.91E-02
Methane	16.00	1.25E+00	92.13984	7.15E+02	6.90E-01
Methanol	32.04	2.50E-03	0.09202	1.43E+00	1.38E-03
Methylcyclohexane	98.19	1.23E-03	0.01477	7.04E-01	6.79E-04
Methylene Chloride (Dichloromethane)	84.93	2.00E-05	0.00028	1.14E-02	1.10E-05

Pollutant	Molecular weight	Emission Factor (lb/MMBtu)	Composition (mole%)	Stack Concentration (mg/Nm^3)	Emission Rate (g/s)
n-Hexane	86.18	1.11E-03	0.01519	6.35E-01	6.13E-04
n-Nonane	128.20	1.10E-04	0.00101	6.29E-02	6.07E-05
n-Octane	114.23	3.51E-04	0.00362	2.01E-01	1.94E-04
n-Pentane	72.15	2.60E-03	0.04250	1.49E+00	1.44E-03
Naphthalene	128.20	7.44E-05	0.00068	4.26E-02	4.11E-05
PAH	252.31	2.69E-05	0.00013	1.54E-02	1.48E-05
Phenanthrene	178.23	1.04E-05	0.00007	5.95E-03	5.74E-06
Phenol	94.11	2.40E-05	0.00030	1.37E-02	1.32E-05
Propane	44.10	4.19E-02	1.12055	2.40E+01	2.31E-02
Pyrene	202.25	1.36E-06	0.00001	7.78E-04	7.51E-07
Styrene	104.15	2.36E-05	0.00027	1.35E-02	1.30E-05
Tetrachloroethane	167.85	2.48E-06	0.00002	1.42E-03	1.37E-06
Toluene	92.10	4.08E-04	0.00522	2.33E-01	2.25E-04
Vinyl Chloride	62.50	1.49E-05	0.00028	8.53E-03	8.22E-06
Xylene	106.20	1.84E-04	0.00204	1.05E-01	1.02E-04

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

3.1.3 Reciprocating Compressor Gas-fired Engines

The performance characteristics of the Caterpillar 3608 gas engines with two stage Ariel reciprocating compressors, located at the CPPs, are presented in Table 6, while pollutant concentrations and emission rates are presented in Table 7. Performance information is presented for normal operating conditions with the gas engines operating at 100% capacity. Each CPP will comprise ten reciprocating compressors with a total of 90 compressors to be employed across the project area at 9 CPPs. Table 6 presents the concentrations and emission rates for NO_X and CO, while Table 8 presents the likely contribution to total hydrocarbon emissions for all VOCs identified in the US EPA AP-42 emission factors document for natural gas-fired reciprocating engines.

Table 6 Performance and source characteristics for the Caterpillar 3608 gas engines with two stage Ariel reciprocating compressors under normal operating conditions at 100% capacity

Parameter	Units	Value[1]
Engine power	bkW	1,767
LHV input	kW	4,696
Nominal engine efficiency	%	37.6
Nominal fuel consumption	MJ/bkW-hr	9.56
Stack height	m	8
Stack diameter	m	0.5968
Exhaust stack temperature	^oC	470
Exhaust gas velocity	m/s	26.9
Exhaust mass flow rate (0^oC, 1 Atm, wet)	kg/bkW-hr	7.04
Exhaust gas flow rate (0^oC, 1 Atm, wet)	Nm^3/bkW-hr	5.57
Exhaust gas flow rate (actual stack conditions)	m^3/s	7.53
Normalised exhaust gas flow rate (0^oC, 1 Atm)	Nm^3/s	2.77

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

Table 7 Concentration and emission rate for oxides of nitrogen, carbon monoxide and total hydrocarbons for the Caterpillar G3608 gas engines with two stage Ariel reciprocating compressors

Parameter	Concentration[1] (g/bkW-hr)	Emission rate[1] (g/s)
Oxides of nitrogen (as NO_2)	0.94	0.461
Carbon monoxide	3.35	1.646
Total Hydrocarbons[2]	8.06	3.957
Formaldehyde	0.54	0.26
Acrolein[3]	-	1.3E-5

Note:
[1] Information obtained from Catepillar gas engine technical data sheet.
[2] Total hydrocarbons as non-methane hydrocarbons and presented as methane equivalents.
[3] Measured by Leeder Consulting, 7 May 2009, in G3608 screw compressor fuelled with CSG.

Table 8 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)	Total hydrocarbon composition (mole %)	Stack concentration (mg/Nm^3)	Emission rate (g/s)
1,1,2,2-Tetrachloroethane	167.85	4.00E-05	0.00028	3.88E-02	1.07E-04
1,1,2-Trichloroethane	133.40	3.18E-05	0.00028	3.08E-02	8.53E-05
1,1-Dichloroethane	98.96	2.36E-05	0.00028	2.29E-02	6.33E-05
1,2,3-Trimethylbenzene	120.20	2.30E-05	0.00023	2.23E-02	6.17E-05
1,2,4-Trimethylbenzene	120.20	1.43E-05	0.00014	1.39E-02	3.84E-05
1,2-Dichloroethane	99.00	2.36E-05	0.00028	2.29E-02	6.33E-05
1,2-Dichloropropane	110.98	2.69E-05	0.00029	2.61E-02	7.22E-05
1,3,5-Trimethylbenzene	120.20	3.38E-05	0.00033	3.28E-02	9.07E-05
1,3-Butadiene	54.10	2.67E-04	0.00582	2.59E-01	7.16E-04
1,3-Dichloropropene	96.90	2.64E-05	0.00032	2.56E-02	7.08E-05
2-Methylnaphthalene	142.19	3.32E-05	0.00028	3.22E-02	8.91E-05
2,2,4-Trimethylpentane	114.22	2.50E-04	0.00258	2.42E-01	6.71E-04
Acenaphthene	154.20	1.25E-06	0.00001	1.21E-03	3.35E-06
Acenaphthylene	152.18	5.53E-06	0.00004	5.36E-03	1.48E-05
Acetaldehyde	44.10	8.36E-03	0.22358	8.11E+00	2.24E-02
Benzene	78.10	4.40E-04	0.00664	4.27E-01	1.18E-03
Benzo(b)fluoranthene	252.32	1.66E-07	0.00000	1.61E-04	4.45E-07
Benzo(e)pyrene	252.31	4.15E-07	0.00000	4.02E-04	1.11E-06
Benzo(g,h,i)perylene	276.32	4.14E-07	0.00000	4.01E-04	1.11E-06
Biphenyl	154.22	2.12E-04	0.00162	2.06E-01	5.69E-04
Butane	58.12	5.41E-04	0.01098	5.25E-01	1.45E-03
Butyr/ Isobutyraldehyde	72.11	1.01E-04	0.00165	9.79E-02	2.71E-04
Carbon Tetrachloride	153.24	3.67E-05	0.00028	3.56E-02	9.85E-05
Chlorobenzene	112.56	3.04E-05	0.00032	2.95E-02	8.16E-05
Chloroethane	64.52	1.87E-06	0.00003	1.81E-03	5.02E-06
Chloroform	119.38	2.85E-05	0.00028	2.76E-02	7.65E-05
Chrysene	228.00	6.93E-07	0.00000	6.72E-04	1.86E-06
Cyclopentane	70.10	2.27E-04	0.00382	2.20E-01	6.09E-04
Ethane	30.07	1.05E-01	4.11826	1.02E+02	2.82E-01
Ethylbenzene	106.20	3.97E-05	0.00044	3.85E-02	1.07E-04
Ethylene Dibromide	187.86	4.43E-05	0.00028	4.30E-02	1.19E-04
Fluoranthene	202.26	1.11E-06	0.00001	1.08E-03	2.98E-06
Fluorene	166.22	5.67E-06	0.00004	5.50E-03	1.52E-05
Formaldehyde	30.03	5.28E-02	2.07365	5.12E+01	1.42E-01
Methane	16.00	1.25E+00	92.13984	1.21E+03	3.35E+00
Methanol	32.04	2.50E-03	0.09202	2.42E+00	6.71E-03
Methylcyclohexane	98.19	1.23E-03	0.01477	1.19E+00	3.30E-03
Methylene Chloride (Dichloromethane)	84.93	2.00E-05	0.00028	1.94E-02	5.37E-05
n-Hexane	86.18	1.11E-03	0.01519	1.08E+00	2.98E-03
n-Nonane	128.20	1.10E-04	0.00101	1.07E-01	2.95E-04
n-Octane	114.23	3.51E-04	0.00362	3.40E-01	9.42E-04
n-Pentane	72.15	2.60E-03	0.04250	2.52E+00	6.98E-03
Naphthalene	128.20	7.44E-05	0.00068	7.21E-02	2.00E-04
PAH	252.31	2.69E-05	0.00013	2.61E-02	7.22E-05
Phenanthrene	178.23	1.04E-05	0.00007	1.01E-02	2.79E-05
Phenol	94.11	2.40E-05	0.00030	2.33E-02	6.44E-05
Propane	44.10	4.19E-02	1.12055	4.06E+01	1.12E-01
Pyrene	202.25	1.36E-06	0.00001	1.32E-03	3.65E-06

Pollutant	Molecular weight	Emission factor[1] (lb/MMBtu)	Total hydrocarbon composition (mole %)	Stack concentration (mg/Nm^3)	Emission rate (g/s)
Styrene	104.15	2.36E-05	0.00027	2.29E-02	6.33E-05
Tetrachloroethane	167.85	2.48E-06	0.00002	2.40E-03	6.66E-06
Toluene	92.10	4.08E-04	0.00522	3.96E-01	1.09E-03
Vinyl Chloride	62.50	1.49E-05	0.00028	1.44E-02	4.00E-05
Xylene	106.20	1.84E-04	0.00204	1.78E-01	4.94E-04
Note: [1]Source: US EPA AP-42					

3.1.4 Well Head Pumps

Well head pumps are expected to be required to extract excess water from the CSG wells for approximately 65% of production wells and the duration of use is typically six months. The pumps used across the project area are Oil Lift G2000 pumps and each is driven by a single 36 kW gas-fired reciprocating engine.

CSG extraction wells will be developed across a grid pattern throughout the production leases at an approximate distance of 750 m apart. Consequently, well head pumps will be situated at least 750 m apart but commonly at a greater distance, possibly several kilometres, as wells are likely to be spread out through the leases to maximise the efficiency of CSG extraction. This will result in the small Oil Lift G2000 pump gas-fired reciprocating engines being significantly isolated from one another, and therefore minimising the impact to air quality.

Table 9 outlines the proposed annual development schedule for CSG extraction wells across the entire QCLNG development leases for the lifetime of the project between 2007 and 2032, and presents the total annual number of well head pumps required. Due to the small number of pumps required across the geographically large project area, the comparatively low NO_X emission rate due to the lower engine capacity (1.7% and 0.8% of the screw and reciprocating compressor engines, respectively) and the short duration of use for each pump at each location (approximately 6 months), the impacts for the well head pump engines have not been assessed in the dispersion modelling assessment.

Table 9 Proposed annual development schedule for CSG extraction wells and associated well head pumps and engines

Year of project	Annual incremental gas well count	Annual cumulative well count	Annual number of well head pumps required
2007	74	74	24
2008	71	145	23
2009	115	260	37
2010	334	594	109
2011	454	1,047	147
2012	479	1,527	156
2013	441	1,968	143
2014	329	2,297	107
2015	360	2,657	117
2016	375	3,032	122
2017	355	3,387	115
2018	360	3,747	117
2019	265	4,012	86
2020	340	4,352	111
2021	310	4,662	101
2022	245	4,907	80
2023	185	5,092	60
2024	175	5,267	57
2025	210	5,477	68
2026	205	5,682	67
2027	130	5,812	42
2028	105	5,917	34
2029	105	6,022	34
2030	30	6,052	10
2031	30	6,082	10
2032	0	6,082	-

3.1.5 Tri-Ethylene Glycol Dehydration Units

At the CPPs, further processing is performed to reduce the moisture content of the CSG in order to obtain the necessary conditions for export to the LNG plant. This process requires dehydration of the CSG using TEG Dehydration Units.

Glycol dehydration is a liquid desiccant system commonly used in the removal of water from natural gas prior to transmitting and processing. The TEG Dehydration Units operate by feeding the wet natural gas stream into an absorber where it is contacted with the lean, water-free glycol. The water is then removed by physical absorption. The rich glycol is subsequently regenerated by removing hydrocarbons in a flash vessel and through the removal of water by passing through boiler tubes. Emissions associated with the TEG Dehydration process are primarily associated with the gas-fired boiler used to heat the TEG and include NO_X, CO and hydrocarbons.

There will be approximately one TEG Dehydration Unit for every two compressor units at the CPPs, resulting in a total of five TEG units per CPP. A single 240 kW Vortec 8100 gas-fired engine will be used to power all five TEG Dehydration Units. The capacity of a single 240 kW Vortec 8100 engine is approximately 5% of a single Caterpillar G3608 gas engine and there will be 10 Caterpillar 3608 gas engines at each CPP. Due to the small incremental increase in emissions from the single 240 kW Vortec 8100 gas-fired engine, when used in conjunction with 10 Caterpillar G3608 gas-fired reciprocating engines (0.5% engine capacity of 10 Caterpillar G3608 engines), the TEG generator has not been included in the assessment.

3.1.6 Camp Site Power Generation

QCLNG propose to develop five camp sites across the project area with these locations yet to be determined. Each site will generate its own electrical power through a single 360 kW gas-fired generator, which is 7.7% and 17.2% of the Caterpillar G3608 (0.77% of the engine capacity of 10 G3608 engines), and Caterpillar G3512 (2.1% of the engine capacity of 8 G3512 engines), gas-fired reciprocating engines, respectively. Consequently, impacts from a single 360 kW gas-fired generator have not been assessed due to their small incremental increase in air emissions in comparison to the compressor stations. Camp sites will not be located within five kilometres of the compressor stations.

3.1.7 Field Office Power Generation

QCLNG propose to develop a single field office site within the project area with the location yet to be determined. The site will generate its own electrical power through a single 288 kW gas-fired generator. Similarly to the camp sites, the field office will not be located in close proximity to compressor stations and the engine capacity of a single 288 kW gas-fired generator is 6.1% and 13.7% of the Caterpillar G3608 (0.61% of the engine capacity of 10 G3608 engines) and Caterpillar G3512 (1.7% of the engine capacity of 8 G3512 engines) gas-fired reciprocating engines, respectively. Consequently, impacts from the single 288 kW gas-fired generator have not been assessed.

3.2 Non-normal Operations

In the event of an emergency, such as a fire, or for maintenance purposes where the gas compressors need to be shutdown, coal seam gas will be combusted in a flare at the FCSs and CPPs.

3.2.1 Field Compressor Stations and Central Processing Plants

As discussed in Section 2.2, in the event of the FCSs and CPPs being shut down for either maintenance or an emergency, a process gas flare will operate to combust coal seam gas prior to its release to the atmosphere. The process flare system will not be used during normal operations.

QCLNG estimates that the frequency of flaring at either a FCS of CPP due to emergency shutdowns is likely to be approximately 3.5 times per year for a duration of 30–60 minutes. Additionally, minor flaring events for compressor shut downs and maintenance may occur approximately 570 times per year (based on 70 TJ/d production), for the short duration it takes to blowdown the volume of gas contained in the CPP or individual equipment within a station. For this dispersion modelling study, the flare operating at a single CPP has been assessed. The peak flow rate of gas to the flare has been used for this assessment and is likely to be the standard operating condition of the flare emergency shutdowns. Gas flaring is likely to be a short term event of less than one hour duration, therefore only short averaging periods have been assessed.

Due to the large amount of heat, and subsequent buoyancy, generated by the flare, it cannot be simply modelled as a stack source. To model the flare emissions appropriately, the US EPA Screen 3 methodology was used to generate the stack characteristics for the flare. Only limited information is available for flare emissions and consequently emission factors have been employed based on US EPA AP-42 documents (Chapter 13.5, Industrial Flares) in conjunction with information supplied by QCLNG. Emission characteristics for the flare during maintenance and emergency shutdowns are presented in Table 10.

Table 10 Emission characteristics of the proposed process system flare, located at each Central Processing Plant, during plant maintenance and emergency shutdowns

Parameter	Units	Maintenance and emergency shutdowns
Nominal stack height	m	22.0[1]
Nominal flare tip diameter	m	0.45[1]
Temperature	°C	1,000[2]
Gas exit velocity (modelled)	m/s	20.0[2]
Effective stack height (modelled)	m	23.1[3]
Effective flare tip diameter (modelled)	m	0.32[3]
Energy output	GJ/hr	4[1]
Exhaust gas mass rate	g/s	18,517[1]
Exhaust Gas flow rate	m^3/s	10.7[1]

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

The USEPA AP-42 emission factors for industrial flares and the emission rates used in the assessment for each of the pollutants, NO_X, CO, and total hydrocarbons, are presented in Table 11. The USEPA AP-42 emission factors for industrial flares also consider particulate emissions for a range of flare types. QGC propose to use the same flares currently employed in their gas fields in the Surat Basin. These flares have a Ringelmann value of less than one and are therefore classified as smokeless flares with a particulate emission rate near to zero.

Table 11 Emission factors and emission rates for the proposed process system flare during facility maintenance and emergency shutdowns

Parameter	Oxides of nitrogen	Carbon monoxide	Total hydrocarbons
Emission factor (g/GJ)	29.24[1]	159.07[1]	60.19[1]
Emission Rate (g/s)	0.03[3]	0.16[3]	0.06[3]

[1] From AP-42 Emission Factors.
[2] From AP-42 Emission Factors and flare energy output data supplied by QCLNG.

The AP-42 emission factors document for industrial flares (chapter 13.5) provides an average distribution by volume for the total hydrocarbon fraction, and is reproduced here as Table 12.

Table 12 Composition of hydrocarbon emissions from the flare based on US EPA AP-42 emission factors

Composition	Volume (%)	
	Average	Range
Methane	55	14 - 83
Ethane/Ethylene	8	1 - 14
Acetylene	5	0.3 - 23
Propane	7	0 - 16
Propylene	25	1- 65
Note: The composition presented is an average of a number of test results obtained under the following sets of test conditions: steam-assisted flare using high-Btu-content feed; steam-assisted using low-Btu-content feed; and air assisted flare using low-Btu-content feed. In all tests, “waste” gas was a synthetic gas consisting of a mixture of propylene and propane.		

The predicted ground-level concentration for individual hydrocarbon species have been determined from the average percentage distribution for each as listed in Table 12 and the predicted maximum ground-level concentration for total hydrocarbons.

3.2.2 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.

Control strategies to minimise the impacts from construction activities such as the generation of dust from vehicle movements and earthworks will be discussed as part of the project’s environmental management plan.

3.3 Summary of Emission Sources

Table 13 presents a summary of the emission sources during both normal and non-normal operations across the QCLNG project area.

Table 13 Summary of emission sources for the project

Unit	No. of process units	Type of source at each unit								Total no. of sources
		Cat G3512 engines	Cat G3608 engines	300 kVA engine - Vortec 8100	450 kVA engine - Camp site power generation	360 kVA engine - Field office power generation	100 kVA engine - FCS power generation	Oil Lift G2000	Flare	
Power (kW)	N/A	2097	4696	240	360	288	80	36	N/A	N/A
FCS	27	8	0	0	0	0	1	0	0	243
CPP	9	0	10	1	0	0	0	0	1	108
Export pipeline midpoint CS	1	8	0	0	0	0	1	0	0	9
Well heads	Variable	0	0	0	0	0	0	1	0	Variable
Field Office	1	0	0	0	0	1	0	0	0	1
Camp sites	5	0	0	0	1	0	0	0	0	1

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

Table 14 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
Ozone	Health and wellbeing	1-hour	210	1
		4-hour	160	1

[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. As discussed in Section 3.1.1, the hydrocarbon emissions likely to be emitted from the gas-fired reciprocating engines used to power the CSG compressors are presented in Table 15 with their relevant air quality objective. For air quality assessments, it is common practice to consider, and where appropriate adopt, an air quality objective for a specific substance from another jurisdiction if information is not available in the EPP(Air). As a result, air quality objectives from the following guidelines and standards have been adopted where the EPP(Air) does not provide any assessment criteria for the hydrocarbons identified in this study:

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

Table 15 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
Acetaldehyde	Toxicity (odour based)	3-minute	5,900	Vic SEPP
Acetylene	Health	1-hour	26,600	TCEQ
Acrolein (2-propenal)	Toxicity (Class 3)	3-minute	0.77	Vic SEPP
	Health (Extremely toxic - USEPA)	1-hour	0.42	NSW DECC
	Health	30-minute	50	WHO
	Health (Extremely toxic - USEPA)	1-hour	2.3	TCEQ
	Health (Extremely toxic - USEPA)	1-year	0.23	TCEQ
Benzene	Health and wellbeing	1-hour	29	NSW DECC
		1-year	10	EPP(Air)
Biphenyl	Health and wellbeing	1-hour	24	NSW DECC
1,3 Butadiene	Health and wellbeing	1-year	2.4	EPP(Air)
Butane	Occupational environment	8-hour	1,900,000	NOHSC:1003
Butyr/Isobutyraldehyde	Odour	1-hour	14	TCEQ
Carbon Tetrachloride (Tetrachloromethane)	Health and wellbeing	1-hour	12	NSW DECC
Chlorobenzene	Toxicity (odour based)	3-minute	1,500	Vic SEPP
1,1-Dichloroethane	Odour	1-hour	4,000	TCEQ
1,2-Dichloroethane	Health and wellbeing	1-hour	70	NSW DECC
	Health and wellbeing	24-hour	750	EPP(Air)

Indicator	Environmental value	Averaging period	Air quality objective or standard ($\mu g/m^3$)	Source of standard or goal
1,2-Dichloropropane	Odour	1-hour	1,150	TCEQ
1,3-Dichloropropene	Occupational environment	8-hour	4,500	NOHSC:1003
Ethyl Chloride (Chloroethane)	Health and wellbeing	1-hour	0.048	NSW DECC
Chloroform (Trichloromethane)	Health and wellbeing	1-hour	900	NSW DECC
Cyclopentane	Occupational environment	8-hour	1,720,000	NOHSC:1003
Ethane	Health	1-hour	12,000	TCEQ
Ethylbenzene	Health and wellbeing	1-hour	8,000	NSW DECC
Ethylene (Ethene)	Health	Simple Asphyxiant		NOHSC:1003 / TECQ
Ethylene Dibromide	Health	1-hour	4	TCEQ
Formaldehyde	Health and wellbeing	24-hour	54	EPP(Air)
	Protecting aesthetic environment	30-minute	110	EPP(Air)
Methane	Health	Simple Asphyxiant		NOHSC:1003 / TECQ
Methanol	Toxicity (odour based)	3-minute	8,700	Vic SEPP
	Toxicity (odour based)	1-hour	3,000	NSW DECC
Methylcyclohexane	Occupational environment	8-hour	1,610,000	NOHSC:1003
Methylene Chloride (Dichloromethane)	Health and wellbeing	3-minute	5,800	Vic SEPP
2-Methylnaphthalene	Odour	1-hour	60	TCEQ
n-Hexane	Health and wellbeing	1-hour	3,200	NSW DECC
n-Nonane	Occupational environment	8-hour	1,050,000	NOHSC:1003
n-Octane	Occupational environment	8-hour	1,400,000	NOHSC:1003

Indicator	Environmental value	Averaging period	Air quality objective or standard (µg/m³)	Source of standard or goal
n-Pentane	Health and wellbeing	1-hour	33,000	NSW DECC
Naphthalene	Occupational environment	8-hour	52,000	NOHSC:1003
Phenol	Toxicity (odour based)	3-minute	130	Vic SEPP
Propane	Health	1-hour	18,000	TCEQ
Propylene	Health	1-hour	8,750	TCEQ
Pyrene	Health	1-hour	0.5	TCEQ
Styrene	Health and wellbeing	1-week	280	EPP(Air)
	Protecting aesthetic environment	30-minutes	75	EPP(Air)
Toluene	Health and wellbeing	24-hour	4,100	EPP(Air)
		1-year	410	EPP(Air)
	Protecting aesthetic environment	30-minutes	1,100	EPP(Air)
1,1,2,2-Tetrachloroethane	Occupational environment	8-hour	6,900	NOHSC:1003
1,1,2-Trichloroethane	Health and wellbeing	3-minute	1,800	Vic SEPP
1,2,3-Trimethylbenzene	Health and wellbeing	3-minute	4,000	Vic SEPP
1,2,4-Trimethylbenzene	Health and wellbeing	3-minute	4,000	Vic SEPP
1,3,5-Trimethylbenzene	Health and wellbeing	1-hour	2,200	NSW DECC
2,2,4-Trimethylpentane	Health	1-hour	3,500	TCEQ
Vinyl Chloride (monomer)	Health and wellbeing	24-hour	28	EPP(Air)
Xylenes	Health and wellbeing	24-hour	1,200	EPP(Air)
		1-year	950	EPP(Air)

Compliance has been assessed by comparison of the relevant air quality objectives against the predicted maximum concentration in the modelling domain. Comparison of air quality objectives from each jurisdiction to the predicted maximum is based on a specific percentile of the distribution of predicted ground-level concentrations. The percentile used for each is presented in Table 16.

Table 16 Summary of percentile values used for comparison to air quality objectives

Standard or goal	Percentile
Environment Protection (Air) Policy	100
EPA Victoria State Environmental Protection Policy (Air)	99.9
NSW Department of Environment and Climate Change	100
World Health Organisation	100
Texas Commission on Environmental Quality	100

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 shrubland.

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 (see Section 5.3.1).

5.2 Location of Sensitive Receptors

It is important to consider the proximity of project infrastructure, such as CSG extraction wells, compressor stations, field offices and camp sites that employ gas engines for power generation, to sensitive receptors and land uses in the region. However, as the specific locations of the project infrastructure have not yet been determined, identification of the sensitive receptors likely to be impacted by air emissions could not be determined for this assessment. Notwithstanding this, the dominant annual, seasonal and diurnal wind patterns in the region have been analysed in order to identify the likely directions for plume transport from the proposed project area. This analysis has been presented in the Section 5.3.1.

5.3 Climate

This section is an overview of the climate in the Surat Basin in south central Queensland based on long term monitoring information. Meteorological monitoring data from the Bureau of Meteorology (BoM) station at Miles Post Office (-26.6569 latitude and 150.1819 longitude) and the and BoM automated weather station (AWS) have been used to characterise long term wind speed and direction, temperature and solar radiation, surface pressure, rainfall and relative humidity in the region. While the precise location of project infrastructure has not yet been determined, the town of Miles is centrally located within the project exploration and leasehold area.

The location of Miles and the three project areas assessed in the dispersion modelling study are illustrated in Figure 4.

5.3.1 Wind Speed and Direction

Wind speed and direction are important parameters for the transport and dispersion of air pollutants. The winds in the Surat Basin are influenced by the regions relatively flat terrain, dry conditions and the absence of land and sea breezes. Annual wind roses for the 1-hour average measurements of wind speed and direction from the Miles site have been presented for the April 2003 to April 2008 period in Figure 5, while a frequency distribution of the annual wind speed is presented in Figure 6. The seasonal and diurnal distributions are also presented in Figure 7 and Figure 8.

Table 17 presents a summary of the distribution of wind speed and direction at Miles for the period April 2003 to April 2008, indicating the predominant wind direction sectors and the frequency. The predominant annual wind flows at Miles are from the north to northeast with 38% of winds blowing from this direction. A further 24% of winds are from the east-northeast to east-southeast, while 18% of winds are from the south to southwest sector. The diurnal distribution of winds indicates that the evening, night time and morning wind flows are dominated by winds from the northern and eastern sectors, with winds during the afternoon period more evenly distributed from all directions. Seasonally, winds from the north-eastern quadrant tend to dominate spring, summer and autumn months, while the winter is dominated by winds from the opposite direction, the south-western quadrant.

A frequency distribution of wind speeds observed at the Miles meteorological station is presented in Figure 6, while the predominant wind speeds are also summarised in Table 17. The analysis indicates that moderate wind speeds between 2-5 m/s dominate the region with 74% of the winds being in this range. Light winds account for 20% of the time, while strong winds greater than 5 m/s occur for 6% of the time.

Table 17 Summary of the distribution of wind speed and direction at Miles for the period 1998-2008

Wind direction	Distribution of Wind speed (% of total winds)			
	Light winds 0 – 1.99 m/s	Moderate winds 2.0 – 4.99 m/s	Strong winds > 5.0 m/s	Total winds 0 - >10.0 m/s
All sectors	20%	74%	6%	100%
North-eastern sector (N, NNE, NE)	7%	29%	3%	38%
Eastern sector (ENE, E, ESE)	4%	19%	2%	24%
South-southwestern sector (S, SSW, SW)	5%	13%	1%	18%

Note: Only 71.9% of valid data was retrieved from the Miles BoM meteorological station during the period 1998-2008.

5.3.2 Temperature and Solar Radiation

The annual mean maximum daily temperature recorded at Miles for the period 1908-2005 is 27.1°C, with a mean minimum daily temperature of 12.2°C. The warmest month is January with an average maximum daily temperature of 33.2°C and a mean minimum daily temperature of 19.5. February, March, November and December also average above 30°C (maximum). In contrast, the coolest month is July with an average maximum daily temperature of 19.3°C and a mean minimum daily temperature of 3.6°C. The average monthly distribution of maximum and minimum temperatures for Miles is illustrated in Figure 9.

Figure 10 presents the mean daily solar exposure (in MJ/m^2) recorded at Miles during 1990 to 2008. This figure illustrates the typical monthly pattern of solar exposure, with the annual solar exposure 2.5 times greater during the summer than the winter.

5.3.3 Rainfall

Rainfall information has been analysed from data provided by the Bureau of Meteorology at the Miles monitoring station (1885-2008) and indicates that the annual average is 650.2 mm. Consistent with a sub-tropical climate, the summer months are wetter with 39.8% of annual average rainfall, and the winter months are drier with 16.4% of the annual average, while the autumn and spring has 20.6% and 23.2% respectively. The monthly distribution of rainfall is presented in Table 18 and Figure 11.

Table 18 Minimum, average and maximum, monthly average rainfall at the BoM monitoring station at Miles (1885-2008)

Month	Minimum (mm)	Maximum (mm)	Average (mm)	Average Rainfall (%)
January	9.7	317.5	95.2	14.6
February	0.3	251.8	75	11.5
March	0	472.9	58.6	9.0
April	0	211	36.6	5.6
May	0	239.6	39.1	6.0
June	0	195.6	39.6	6.1
July	0	267	37.6	5.8
August	0	170.6	29.3	4.5
September	0	150.6	31	4.8
October	0.4	194.4	54	8.3
November	0	262.6	66	10.1
December	1.5	442.5	88.6	13.6

5.3.4 Relative Humidity

The monthly averaged relative humidity at 9am and 3pm at the BoM site at Miles for the period 1961 to 2005 is presented in Figure 12. This figure shows that the spring months (September to November) tend to be less humid, ranging from 53% to 55% humidity at 9am. A higher relative humidity was measured during the winter months of May through to July with measurements ranging from 71% to 75% at 9am. The relative humidity during the summer and autumn months (December to April) ranged from 56% to 64% at 9am. The data also shows that, on average, the relative humidity is 56% higher at 9am than at 3pm.

5.3.5 Surface pressure

The monthly averaged surface pressure at Miles is presented in Figure 13. The biannual pattern of peaks and troughs in the monthly averaged pressure field indicates that the months of December through February are dominated by low pressure synoptic conditions that are typically associated with wetter summer conditions, while the months of April through October are dominated by high pressure synoptic conditions that are typically associated with clear, drier conditions.

5.4 Ambient Air Quality in the Region

5.4.1 Existing Industries and Sources of Oxides of Nitrogen

There is currently no monitoring of ambient air quality performed in the QCLNG project area or Surat Basin. Notwithstanding this, the existing air quality in the region is likely to be fairly good due to the nature of land use and the operation of low impact industries within the Dalby Regional Council. Industries identified through a review of the National Pollutant Inventory include:

- Log sawmilling and timber dressing
- Mineral, metal and chemical wholesaling
- Oil and gas extraction
- Pasture and cropping

Further afield and within the southern central Queensland region 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 include Condamine and Darling Downs will also provide a cumulative impact in the region in the future. Due to the significant distances between, and geographical locations of these sources, the impacts are likely to be relatively minor as sensitive receptors situated in the QCLNG project area will be impacted by individual plumes differently from each source depending on wind patterns and regional flows.

Coal seam gas extraction and exploration is currently being conducted by several gas producers in the Surat Basin and southern Queensland region. While emissions from production activities conducted by these producers have not been included in this air quality impact assessment, the cumulative impacts are expected to be minimal as, similarly to the QCLNG production areas, the distance between gas extraction and processing infrastructure, and consequently emissions sources, is considerable, any impacts are highly localised.

5.4.2 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 19 presents the source characteristics and emission rates for the existing and approved power stations assessed, their location in the region are illustrated in Figure 14. The primary background air pollutant for this air quality assessment is NO_X. While other air pollutants emitted by the QCLNG project include CO and various VOCs and PAHs, emissions data and ambient air monitoring data for these substances are not available, and consequently their cumulative impact has not been assessed.

The methodology employed for the dispersion modelling of background levels of NO_X is described in detail in Section 6.1. Regional transport and dispersion of NO_X emissions (described in Table 19) from the power stations was modelled using a regional airshed model (TAPM), with the maximum 1-hour average and annual average ground-level concentrations of NO_X determined across a gridded domain that covered the QCLNG project area. Three sites were selected for the assessment of QCLNG operations that were centred on primary CSG extraction and processing areas, including:

- Region 1: -26.9183 S and 150.3567 E
- Region 2: -26.2858 S and 149.7227 E
- Region 3: -27.1653 S and 150.7862 E

The maximum 1-hour average and annual average ground-level concentrations of NO_X were then determined within a 50 km radius of the assessment site for the background concentration. This provided a highly conservative ambient background concentration for the cumulative assessment.

Table 19 Source characteristics of power stations in south central Queensland included in the dispersion modelling for background air quality

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

Note: Due to the regional nature of this assessment some stations consisting of multiple units were combined into a single unit with the total station emission rate assumed.

5.4.3 Measured Background Levels for Ozone

Background levels for ozone have been determined from EPA's monitoring station at Toowoomba, the nearest monitoring station to the QCLNG project area. These levels are likely to be a slightly conservative estimate of the ozone levels in the Surat Basin due to industry and the number of motor vehicles in the Toowoomba area in comparison to that in the more rural project area.

Table 20 Measured concentrations of ozone from the EPA's monitoring station at Toowoomba, July 2003 to August 2007

Air pollutant	Averaging period	Concentration ($\mu g/m^3$)		Objectives ($\mu g/m^3$)
		Maximum	95th percentile	
Ozone	1-hour	192	84	210
	4-hour	148	82	160

6. Atmospheric Dispersion Modelling Methodology

Air dispersion modelling was conducted using a two stage approach. Firstly, the CSIRO's meteorological and plume dispersion model, TAPM (The Air Pollution Model) Version 4 (Hurley 2005), was used to simulate the regional meteorology in the Surat Basin and further afield in south central Queensland and to predict ground-level concentrations of NO_X associated with background emissions from several existing and approved power stations within the region of the proposed QCLNG project area.

Secondly, the AUSPLUME v6.0 plume dispersion model was used to predict ground-level concentrations of NO_X, CO and a suite of hydrocarbons associated with the emissions from the gas-fired reciprocating engines used to extract and process CSG across the project area, for transmission to the LNG facility at Curtis Island.

For NO_X, predicted ground-level concentrations could then be added to the predicted background and assessed in terms of the cumulative impacts. For CO and hydrocarbons, background ambient information was not available and, consequently, the background for each specific compound could not be determined. Therefore the assessment has been conducted based on the QCLNG project's incremental impact to the region.

6.1 TAPM Modelling Methodology

The meteorological model, TAPM v4, 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.dar.csiro.au/TAPM/ for more details on the model and validation results from the CSIRO). Katestone Environmental has used the TAPM model throughout Australia as well as in parts of New Caledonia, the United States of America, Bangladesh and Vietnam. This model generally has performed well for simulating winds in a region. TAPM has proven to be a useful model for simulating meteorology in locations where detailed 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 kilometres to 200 kilometres) and at a local scale (down to a few hundred meters). TAPM includes parameterisations for cloud/rain micro-physical processes, urban/vegetation canopy and soil, and radiative fluxes.

6.1.1 Development of Site-Specific Meteorology using TAPM

TAPM uses synoptic meteorological information for the Surat Basin region as input into the model. 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 kilometres, and at elevations of 100 metres to 5 kilometres above the ground. TAPM uses this synoptic information, along with specific details of the location such as surrounding terrain, land-use, soil moisture content and soil type to simulate the likely meteorology of a region as well as at a specific location.

TAPM was setup as follows:

- 55 x 65 grid point domain with an outer grid of 15 kilometres and nesting grids of 6 kilometres and 3 kilometres (with a 3000 metre grid for the background dispersion modelling)
- 25 vertical levels
- Grid centred in a location capturing the location of the proposed gas fields (latitude – 26° 56.5’, longitude 150°19.5’)
- Geoscience Australia 9 second DEM terrain data
- The TAPM defaults for sea surface temperature
- Default options selected for advanced meteorological inputs
- The synoptic data used in the simulation is for the year 2007
- No surface station observed data was assimilated
- Background power stations modelled in Eularian mode

The regional land use was mainly defined as low sparse shrubland surrounding the site, with moderately dense forest to the north east. Small patches of pastural land, not interconnected, are spread throughout the domain. The soils were defined as a mix of clay and sandy clay loams.

6.1.1.1 Wind Speed and Direction

An analysis of the correlation between TAPM predicted and BoM observed wind fields at Miles indicates the model has performed reasonably well in simulating the general distribution of wind direction and speeds. Table 21 presents the correlation statistics for TAPM predicted and BoM observed wind fields at Miles. A description of the statistical methods used in the analysis is provided in Appendix A.

Due to the large area of CSG extraction and processing for the project, and the preliminary stage of infrastructure planning and locating, three regions were assessed based on the primary production lease areas (see Figure 4). Three meteorological datasets centred on each of the production leases were extracted from TAPM in AUSPLUME format in order to assess the impacts from a production unit setup to be located within each region. As discussed in Section 5.1, the terrain and land use is relatively uniform across the project area with regard to dispersion meteorology with no significant features to divert or influence wind flows. Consequently, an assessment of the sources at this specific location can be considered representative of a larger area across each of the three regions, as general wind patterns are unlikely to change significantly.

Table 21 Correlation statistics for TAPM predicted and BoM observed wind fields at Miles for the diurnal profile

Time of day	Parameter	Statistics			
		RCOR	IOA	MAE	Magnitude, Phase[1]
00:00-05:59	Wind Speed	0.44	0.67	0.96	N/A
	Wind Direction	n/a	n/a	n/a	0.84, 0.3
	U vector	0.76	0.87	0.78	N/A
	V vector	0.78	0.88	0.96	N/A
06:00-11:59	Wind Speed	0.67	0.75	1.04	N/A
	Wind Direction	n/a	n/a	n/a	0.87, 7.6
	U vector	0.83	0.89	1.10	N/A
	V vector	0.85	0.91	1.13	N/A
12:00-17:59	Wind Speed	0.56	0.69	1.17	N/A
	Wind Direction	n/a	n/a	n/a	0.80, 12.8
	U vector	0.83	0.89	1.31	N/A
	V vector	0.74	0.84	1.51	N/A
18:00-23:59	Wind Speed	0.39	0.63	1.10	N/A
	Wind Direction	n/a	n/a	n/a	0.80, 4.1
	U vector	0.76	0.87	0.98	N/A
	V vector	0.70	0.82	1.20	N/A

Note:
[1] Complex Vector Correlation Coefficient
RCOR: Pearson Correlation Coefficient
IOA: Index of Agreement
MAE: Mean Absolute Error
N/A – Not applicable

The annual distribution of winds for the three regions predicted by TAPM are presented in wind rose diagrams in Figure 15 - Figure 17 and show the predominant wind direction is from the north-eastern quadrant, with some further significant contributions from south-westerly flows. The TAPM predicted winds for each of the three regions are in reasonable agreement with the observed wind field at Miles, except for an under prediction by TAPM of the frequency of winds from the north and north-northeast. The BoM observations at Miles indicate that 25% of all winds are from the north and north-northeast at greater than 2 m/s. For the Region 2 location, the closest to the Miles monitoring station, TAPM predicted these wind conditions occur for only 12% of the time. Miles is situated between the Region 1 and 2 assessment locations. While the under-prediction of winds from this sector will likely result in an under-prediction of impacts to the south and south-southwest, the strength of the winds (>2 m/s) is likely to generate good dispersion conditions resulting in lower ground-level concentrations.

The seasonal distribution of winds at Region 2 is presented in Figure 18 and indicates that north-easterly flows dominate the spring, summer and autumn months, while the south-westerly winds are predominantly winter flows. The diurnal distribution of winds at Region 2, presented in Figure 19, do not indicate any particular directional pattern such as development of sea breezes or nocturnal katabatic drainage flows, as dominant north-easterly and south-westerly flows tend to occur in similar proportions during the morning, afternoon, evening and night time periods.

In conclusion, the correlation statistics used in the analysis of TAPM's performance in simulating the wind field in the Miles region indicate the following:

- The index of agreement shows a good agreement, with the U vector components between 0.87 and 0.89, and the V vector component between 0.82 and 0.91 during each diurnal period of morning, afternoon, evening and night time
- The complex vector correlation indicates a correlation of between 0.80 - 0.87, with the variability in wind direction phase angle between 0.3 and 12.8. This outcome is reasonable as the natural variability in wind direction fluctuations is typically between 5 – 20 degrees and dependent on wind speed. The higher the wind speed the greater the variability. This is shown in the higher phase angle during the afternoon period when winds are likely to be stronger and the lower angle during clamer periods at night.

6.1.1.2 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.

Atmospheric stability class has been calculated using the USEPA approved Solar Radiation/Delta-T (SRDT) method (EPA, 2000). This method utilises the TAPM modelled wind speeds and solar radiation (W/m^2) to determine daytime stability, while nocturnal stability is determined by wind speeds and the vertical temperature gradient between the surface and the adjacent vertical sigma level at the site location. This approach has been found to provide a more robust and verifiable classification scheme than the one produced internally in TAPM. The percentage frequency distribution of stability classes at the four assessment sites are presented in Table 22.

Table 22 Percentage frequency distribution for atmospheric stability under the Pasquill-Gifford stability classification scheme

Pasquill-Gifford Stability Class	Frequency (%)		
	Region 1	Region 2	Region 3
A	2.8	2.1	2.4
B	13.4	13.2	11.9
C	18.7	20.1	18.9
D	35.6	41.2	42.8
E	10.7	12.2	12.5
F	18.7	11.2	11.5

There is a high percentage of D class or neutral stability. This is due to the high frequency of winds speeds greater than 2 m/s. 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 Region 2 has been extracted from TAPM and is presented in Figure 20. The data shows the mixing height tends to develop around 9am, peaks around mid afternoon (2-3pm) before decreasing again around sunset (6pm). The figure also indicates the mixing height's diurnal profile with the 95th percentile extending to approximately 1,400 m around early afternoon, and collapsing below 50 m during the night.

6.1.2 Determination of Background Concentrations for Oxides of Nitrogen using TAPM

As discussed in Section 5.4.2, the TAPM dispersion model was used to predict background concentrations for NO_X across the project area, based on emissions for NO_X from eight existing and approved power stations in the region. Predictions were made at a grid resolution of three kilometres. The maximum 1-hour and annual average ground-level concentration for NO_X anywhere within a 50 km radius of the centre of each assessment region was then determined and used as the background level for each of the three regions assessed. This is likely to result in a very conservative estimate of the average background concentration in the region for the air quality impact assessment. The predicted maximum 1-

hour (99.9th percentile) and annual average ground-level concentrations of NO_2 for the background in each region are presented in Table 23, with contour plots illustrating the distribution of NO_2 across the project area presented for the 1-hour (99.9th percentile) and annual average in Figure 21 and Figure 22, respectively.

Table 23 Background concentrations of nitrogen dioxide for each region used in the air quality impact assessment

Region	Averaging Period	Predicted maximum (99.9th percentile) background concentration (µg/m³)
1	1-hour	9.9
	Annual	0.4
2	1-hour	41.3
	Annual	3.4
3	1-hour	41.3
	Annual	3.4

6.2 AUSPLUME Modelling Methodology

Atmospheric dispersion modelling was carried out using the AUSPLUME Version 6.0 dispersion model. AUSPLUME is a Gaussian, steady-state dispersion model, and is accepted for use by the EPA for application in environments where wind patterns and plume dispersion is not strongly influenced by complex terrain and the land-sea interface. AUSPLUME was found suitable as the local terrain is relatively flat, and there are no significant impediments to wind flows such as tall buildings and dense forests.

The AUSPLUME dispersion model is used to project downwind ground-level concentrations of air contaminants by taking into consideration:

- Air pollutant emissions data - emission rate and source characteristics
- Site specific meteorology
- Terrain elevation information
- Building wake effects

The preliminary nature of this assessment mean final compressor station locations have yet to be confirmed and therefore site-specific meteorology, terrain and land use could not be incorporated into the model and impacts to air quality at specific sensitive receptor locations could not be assessed as their proximity to compressor stations is not yet determined. Additionally, due to the lack of significant building structures within the compressor station sites in close proximity to the engine exhaust stacks, building wakes were not modelled for this assessment. This is discussed in detail in Section 6.3.1.

The following input parameters have been used for the plume dispersion modelling:

- Site-specific meteorological data developed using TAPM with no local observations assimilated. Meteorological parameters include hourly averaged:
    - Wind direction
    - Wind speed
    - Temperature
    - Stability class (developed using US EPA solar radiation/deltaT method)
    - Mixing height

- Terrain effects ignored
- Gridded receptors positioned over a Cartesian grid -
  - East-west dimensions: 20,000 m
  - North-south dimensions: 20,000 m
  - Grid spacing: 200 m
- Surface roughness land use (Z_0) of 0.4 to reflect slightly undulating (rolling rural) terrain with low vegetation and occasional forests
- Pasquill-Gifford horizontal and vertical dispersion curves for sources less than 100 m tall
- Default options for other model parameters

6.3 Air Quality Impact Assessment Scenarios

6.3.1 General Site Layout

The configuration and location of the CSG extraction wells and compressor station infrastructure is yet to be finalised, and will develop as further resource exploration continues through the lifetime of the project. Notwithstanding this, the dispersion modelling for the impact assessment has been carried out using a nominal compressor station layout.
It is proposed that each of the nine CPPs will be located in a centralised position within each gas field lease area with a connecting pipeline to the three FCSs situated approximately five kilometres away, as illustrated in Figure 2. The FCSs will be situated adjacent to clusters of gas wells to minimise the transmission distances with the CSG at low pressure. Gas wells will be situated across a Cartesian grid arrangement approximately 750 m apart.

The arrangement of the ten gas-fired reciprocating engines to drive the CSG compressors at the CPPs and the eight gas-fired reciprocating engines at the FCSs have also been nominally arranged for the dispersion modelling assessment in two parallel lines with each stack 50 m apart, as shown in Figure 3. The final design for gas-fired reciprocating engines at the compressor stations may be a straight line arrangement evenly spaced over a distance of approximately 125 m, however a change in layout will not significantly alter the ground-level impacts in the far field. As each station primarily consists of production equipment and infrastructure with no significant building structures close by, building wakes have not been included in the dispersion model. Notwithstanding this, the short design of the engine exhaust stacks (<8 m) and moderate exhaust exit velocities (9.95 and 25.02 m/s) is likely to result in the stacks being affected by mechanical turbulence to a minor degree. Consequently, the dispersion model is likely to slightly under predict ground-level concentrations in the near field (within 100-200 m of the stacks), while slightly over predicting ground-level concentrations in the far field. As compressor stations are likely to be situated within a cleared area of land with a significant separation distance isolating them from any sensitive receptors due to safety precautions, any near-field impacts are likely to be within the site boundary. This will result in a conservative assessment of impacts beyond the site boundary.

6.3.2 Modelling Scenarios – Normal Operations

The impact assessment has then been carried out for this arrangement of compressor stations for three nominal regions, in order to account for variable wind fields across the QCLNG project area. The three regions selected for the production lease areas were central to the proven gas reserves and the current extraction infrastructure. For each region, meteorology was extracted from TAPM for application in the AUSPLUME dispersion model.

The modelling scenarios for the normal operations are outlined as follows:

- Region 1 (centre at 26.2858 S and 149.7227 E): single CSG production unit comprising
    - 1 x CPP (10 x Caterpillar 3608 gas engines with two stage Ariel reciprocating compressors)
    - 3 x FCS (8 x G3512 gas-fired reciprocating engines with single stage Ariel screw compressors)
- Region 2 (centre at 26.9183 S and 150.3567 E): single CSG production unit comprising
    - 1 x CPP (10 x Caterpillar 3608 gas engines with two stage Ariel reciprocating compressors)
    - 3 x FCS (8 x G3512 gas-fired reciprocating engines with single stage Ariel screw compressors)
- Region 3 (centre at 27.1653 S and 150.7862 E): single CSG production unit comprising
    - 1 x CPP (10 x Caterpillar 3608 gas engines with two stage Ariel reciprocating compressors)
    - 3 x FCS (8 x G3512 gas-fired reciprocating engines with single stage Ariel screw compressors)

As the final location of the CSG compressor station production units (1xCPP and 3xFCS) are yet to be confirmed, there is a potential for the clustering of CSG process infrastructure in regions of high gas yield. Consequently, the plumes associated with multiple CSG production units located within close proximity to one another, have the potential to accumulate under certain meteorological conditions and lead to higher ground-level concentrations than predicted in this assessment. Notwithstanding this, the large area associated with the QCLNG production and exploration leases is likely to result in the CSG production units being situated at least 10-15 km apart, and result in only a small increase in the background concentration of air pollutants at emission points downwind. Further assessment of cumulative impacts from all emission sources will be required once infrastructure locations have been confirmed. Additionally, impacts associated with emissions from other CSG producers in the region have not been included in the assessment of background concentrations.

6.3.3 Modelling Scenarios – Non-normal Operations

The modelling scenarios for non-normal operations are outlined as follows:

- Region 1 (centre at 26.2858 S and 149.7227 E): single flare situated at the CPP
- Region 2 (centre at 26.9183 S and 150.3567 E): single flare situated at the CPP
- Region 3 (centre at 27.1653 S and 150.7862 E): single flare situated at the CPP

The assessment of the flare has been conducted for all hours of the year in order to determine the worst case impact resulting from the combination of all likely meteorological conditions. In reality, a flaring event is likely to be for the duration of less than one hour at a frequency of approximately 3.5 per year. Consequently, only short term averaging periods have been assessed.

6.3.4 Air Pollutants and Averaging Periods

6.3.4.1 Oxides of Nitrogen

The assessment of the impacts of NO_X associated with emissions from the QCLNG project has been made for the four-stroke lean-burn gas-fired reciprocating engines operating concurrently at a 100% capacity.

As discussed in 5.4.2, background concentrations of NO_X have been assessed based on emissions from coal- and gas-fired power stations in the south central Queensland region. However, emissions from other CSG producers in the region and other minor industrial and motor vehicle emissions are not included. The assessment has therefore been designed to determine the incremental increase from the CSG compressor gas-fired reciprocating engines and the cumulative impacts of the region's major emitters, the coal- and gas-fired power generation plants. While only a single CSG production unit has been assessed in isolation, the planned spatial distribution of production units across the large project area is aimed at maximising the efficiency of CSG extraction and processing, and consequently, will minimise the potential of plumes converging and producing cumulative impacts.

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

Table 24 presents the modelled scenarios, averaging periods and percentiles used for the assessment of NO_X and comparison with the EPP(Air) air quality objectives.

Table 24 Modelled scenarios and averaging periods for oxides of nitrogen

Operating condition	Source	Averaging period	Percentile assessed[1]	Cumulative background assessed[2]
Normal	CPP, FCS (gas-fired reciprocating engines)	1-hour Annual	100th N/A	99.9th N/A
Non-normal	Flare	1-hour	100th	99.9th

[1] The predicted maximum ground-level concentration across the modelled domain was assessed

[2] The predicted maximum ground-level concentration within the region was determined and used for the background concentration

N/A – Not applicable

6.3.4.2 Carbon Monoxide

There is no ambient air monitoring for concentrations of CO in the project area, and representative emission rates for CO for the power stations was not available for inclusion in the background dispersion modelling. With the exception of areas that are close to major roadways, background levels of CO are expected to be low in comparison with the EPP(Air) air quality objective. Emissions of CO from the gas-fired reciprocating engines have been modelled for this air quality impact assessment and are presented in isolation.

Table 25 presents the modelled scenarios, averaging periods and percentiles used for the assessment of CO and comparison with the EPP(Air) air quality objectives.

Table 25 Modelled scenarios and averaging periods for carbon monoxide

Operating condition	Source	Averaging period	Percentile assessed[1]	Cumulative background assessed
Normal	CPP, FCS (gas-fired reciprocating engines)	8-hour	100th	No background
Non-normal	Flare	8-hour	100th	No background
[1] The predicted maximum ground-level concentration across the modelled domain was assessed				

6.3.4.3 Hydrocarbon Compounds

There is no ambient air monitoring for concentrations of various hydrocarbons in the project area, and representative emission rates for these substances released from the power stations was not available for inclusion in the background dispersion modelling. Consequently, the air quality impact assessment for all hydrocarbon emissions has been conducted in isolation. Notwithstanding this, background levels of hydrocarbons are expected to be extremely low in comparison with the relevant air quality objectives due to the largely rural nature of the project area.

As discussed in Section 3, total hydrocarbon emissions from the gas-fired reciprocating engines have been modelled as methane equivalents, with the emission rate subsequently scaled according to the breakdown of potential hydrocarbons emitted from four-stroke lean-burn gas-fired reciprocating engines as documented in US EPA AP-42 (Chapter 3).

Table 26 presents the modelled scenarios, averaging periods and percentiles used for the assessment of hydrocarbons and comparison with the EPP(Air) air quality objectives.

Table 26 Modelled scenarios and averaging periods for hydrocarbons

Operating condition	Source	Averaging period	Percentile assessed[1]	Cumulative background assessed
Normal	CPP, FCS (gas-fired reciprocating engines)	3-minute average 15-minute average 30-minute average 1-hour average 24-hour average 7-day average Annual average	99.9th 100th 100th 100th 100th 100th N/A	No background
Non-normal	Flare	1-hour average	100th	No background

[1] The predicted maximum ground-level concentration across the modelled domain was assessed

6.3.4.4 Photochemical Smog

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

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

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

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

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

The first investigation of the chemical transformations in industrial plumes was undertaken in 1986 around Gladstone Power Station, a major emitter of nitrogen oxides (over 2000 g/s at full load, or more than 100 times the emission rate of the proposed QCLNG project). An aerial survey was conducted to measure NO_X and ozone concentrations at distances out to 200 kilometres for a set of late winter conditions. These studies have been very useful to determine the relatively slow rate of transformation of emitted nitric oxide into NO_2. However, there were no events when an ozone generation stage was encountered.

Due to the proportionally low emissions of NO_X from the gas-fired reciprocating engines in comparison to the background emissions from the power stations, photochemical modelling has not been conducted for this assessment. In order to assess the potential of the QCLNG project to cause air quality impacts in relation to ozone, an extremely conservative method has been applied. The method assumes that 100% of the ground-level concentration of NO_2 at a distance of approximately 10 km downwind of the source is converted to ozone. The modelling domain for each of the three regions is centred on the centre of the CPPs. The ground-level concentration of NO_2 at and beyond a distance of 10 km from the centre point of the CPP (which is the largest source of NO_X in the domain), has been predicted. The mean, minimum and maximum concentrations of NO_2 have been calculated and converted to ozone for each of the 1-hour averaging period for comparison with the air quality objectives.

7. Interpretation of Air Quality Impacts

This section presents the results of the air quality impact assessment for NO_2, CO, ozone and all identified hydrocarbons for the normal and non-normal operating conditions.

7.1 Normal Operations

As discussed in Section 3.1 and 6.3, normal operations refer to emissions from the gas-fired reciprocating engines used for the compression and transmission of CSG at the CPPs and FCSs.

7.1.1 Nitrogen Dioxide

Figure 23 and Figure 24 present the predicted maximum 1-hour and annual average ground-level concentrations of NO_2 respectively, for Region 1, in isolation, during normal operations. Figure 25 to Figure 28 present similar contours for Region 2 and Region 3.

Table 27 presents the predicted maximum 1-hour and annual average ground-level concentrations within the modelling domain for each region in isolation and including background concentrations.

Table 27 Predicted maximum 1-hour and annual average ground-level concentrations of nitrogen dioxide for each region in isolation and including background

Region	Averaging Period	Incremental predicted maximum concentration (µg/m³)	Predicted maximum background concentration (µg/m³)	Cumulative concentration (µg/m³)	Air quality objective (µg/m³)	Percent of air quality objective (%)
1	1-hour	35.0	9.9	44.9	250	17.9
	Annual	3.8	0.4	4.2	62[1] / 33[2]	6.8/12.7
2	1-hour	35.7	41.3	77.0	250	30.8
	Annual	4.0	3.4	7.4	62[1] / 33[2]	11.9/22.4
3	1-hour	33.8	41.3	75.1	250	30.0
	Annual	4.3	3.4	7.7	62[1] / 33[2]	12.4/23.3

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 the proposed QCLNG project, under normal operating conditions, assessed in isolation and including background concentrations.
- The predicted maximum 1-hour average ground-level concentration of NO_2 at any location within the Regions for the operation of a single CSG production unit (including one CPP and three FCSs) in isolation is 35.7 µg/m^3 or 77 µg/m^3 including background which is 31% of the EPP(Air) air quality objective of 250 µg/m^3.

- The predicted annual average ground-level concentration of NO_2 at any location within the regions for the operation of a single CSG production unit (including one CPP and three FCSs) in isolation is 4.3 µg/m^3 or 7.7 µg/m^3 including background which is 12.4% of the EPP(Air) air quality objective of 62 µg/m^3

While only a single production unit has been assessed, due to the assumption that production units will not be co-located within a distance of 10-15km, the assessment indicates that a doubling of the emission rates, associated with the co-location of the production units in the same position, would not generate an exceedence of the air quality objective for NO_2 at any location within the modelled domain. Based on Region 2, the highest predicted cumulative impact for the 1-hour average, the incremental impact from two production units co-located would be 71.4 µg/m^3. With the background of 41.3 µg/m^3 added, the cumulative impact would be 112.7 µg/m^3, which is 45% of the air quality objective of 250 µg/m^3.

7.1.2 Carbon Monoxide

Figure 29 to Figure 31 present the predicted maximum 8-hour average ground-level concentrations of CO for Regions 1, 2 and 3 respectively during normal operations in isolation.

Table 28 presents the predicted maximum 8-hour average ground-level concentrations within the modelling domain for each region in isolation.

Table 28 Predicted maximum 8-hour average ground-level concentrations of carbon dioxide for each region in isolation

Region	Predicted maximum concentration (µg/m³)	Air quality objective (µg/m³)	Percent of air quality objective (%)
1	140	11,000	1.4
2	135	11,000	1.3
3	140	11,000	1.4

The results show the following:

- There are no exceedances predicted of the EPP(Air) air quality objectives for the 8-hour average ground-level concentration of CO due to the proposed QCLNG project, under normal operating conditions, and assessed in isolation

- The predicted maximum 8-hour average ground-level concentration of CO at any location within the Regions for the operation of a single CPP and three FCSs in isolation is 140 µg/m^3, which is 1.4% of the EPP(Air) air quality objective of 11,000 µg/m^3

7.1.3 Hydrocarbons

Table 29 presents a summary of the top ten highest predicted ground-level concentrations of hydrocarbons in terms of their percentage of the air quality objective for any location across the modelling domain and based on a single CSG production unit (1 x CPP and 3 x FCS), in isolation. A comprehensive list of predicted maximum ground-level concentrations for all hydrocarbons likely to be emitted from the gas-fired reciprocating engines is presented in Appendix B.

Table 29 Summary of the top ten predicted maximum ground-level concentrations of hydrocarbons for each region in isolation and their air quality objective

Indicator	Source of Air quality objective or standard	Averaging period	Air quality objective or standard	Predicted maximum ground-level concentration (µg/m^3)			Percentage of air quality objective (%)		
			(µg/m^3)	Region 1	Region 2	Region 3	Region 1	Region 2	Region 3
Formaldehyde	EPP(Air)	24-hour	54	14.3	15.6	17.3	26.5	28.9	32.1
	EPP(Air)	30-minute	110	27.7	29.5	31.1	25.2	26.8	28.3
Chloroethane	NSW DECC	1-hour	0.05	0.0005	0.001	0.001	0.97	1.05	1.11
Phenanthrene	TCEQ	1-hour	0.5	0.003	0.003	0.003	0.52	0.56	0.59
Acrolein	NSW DECC	1-hour	0.42	0.0019	0.0020	0.0021	0.45	0.49	0.50
Benzene	NSW DECC	1-hour	29	0.11	0.12	0.13	0.38	0.41	0.43
1,3-Butadiene	EPP(Air)	1-year	2.40	0.007	0.007	0.008	0.29	0.31	0.33
Fluorene	TCEQ	1-hour	0.5	0.001	0.002	0.002	0.28	0.31	0.32
Ethylene Dibromide	TCEQ	1-hour	4.00	0.011	0.012	0.013	0.28	0.30	0.32
Biphenyl	NSW DECC	1-hour	24	0.053	0.057	0.061	0.22	0.24	0.25
Ethane	TCEQ	1-hour	12,000	26.1	28.2	30.0	0.22	0.24	0.25

The tabulated results indicate that none of the 52 identified hydrocarbon species associated with emissions from the gas-fired reciprocating engines, used to drive the CSG compressors, was found to exceed the ambient air quality objectives.

7.1.4 Photochemical Smog

The assessment of photochemical smog impacts has been conducted based on 100% conversion of NO_2 to ozone. This is an extremely conservative assumption. Table 30 presents the predicted mean, minimum and maximum 1-hour average ground-level concentrations for NO_2 at a distance of 10 km downwind of the CPP for each Region, and the conversion of NO_2 to ozone.

Table 30 Predicted range of 1-hour average ground-level concentrations of ozone downwind of the compressor stations for each region (µg/m^3)

Location	Predicted ozone		Background ozone	Cumulative ozone concentration range	Air quality objective
	Mean	Range			
Region 1	37.4	17.3 – 78.5	84	101.3 – 162.5	210
Region 2	33.3	14.7 – 77.4		98.7 – 161.4	
Region 3	32.5	15.4 – 76.6		99.4 – 160.6	

The predicted range of maximum ozone concentrations is well below the EPP(Air) objective of 210 µg/m^3.

7.2 Non-normal Operations

As discussed in Section 3.2 and 6.3.3, non-normal operations refer to emissions from the gas flare situated at the CPPs. Emission releases from the flare are expected to be of low frequency and short duration and initiated by emergency conditions at the CPPs.

7.2.1 Nitrogen Dioxide

Table 31 presents the predicted maximum 1-hour average ground-level concentrations of NO_2 within the modelling domain, associated with emissions from the gas flare during non-normal operations for each region in isolation and with a background included. Figure 32 presents the predicted maximum 1-hour average ground-level concentrations of NO_2 for Region 1, in isolation, during non-normal operations.

Table 31 Predicted maximum 1-hour average ground-level concentrations of nitrogen dioxide for each region in isolation for the gas flare during non-normal emergency operations

Region	Averaging Period	Incremental predicted maximum concentration (µg/m³)	Background concentration	Combined impact	Air quality objective (µg/m³)	Percent of air quality objective (%)
1	1-hour	0.21	9,9	10.1	250	4
2	1-hour	0.20	41.3	41.5	250	17
3	1-hour	0.18	41.3	41.5	250	17

The results show the following:

- There are no exceedances predicted of the EPP(Air) air quality objective for the 1-hour average ground-level concentration of NO_2 due to the proposed QCLNG project, during non-normal operating conditions, assessed in isolation.
- The predicted maximum 1-hour average ground-level concentration of NO_2 at any location within the Regions during non-normal operations; in isolation, is 0.21 µg/m^3, or 42 µg/m3 including a background which is 17% of the EPP(Air) air quality objective of 250 µg/m^3

7.2.2 Carbon Dioxide

Table 32 presents the predicted maximum 8-hour average ground-level concentrations of CO within the modelling domain, associated with emissions from the gas flare during non-normal operations for each region in isolation. It should be noted that while the 8-hour average has been assessed for comparison with the EPP(Air) air quality objective, and the modelling has been conducted for a full year of meteorological conditions, gas flaring at the CPP is likely to be of less than one hour in duration and therefore the 8-hour average ground-level concentrations of CO will be significantly lower than the value presented in Table 32.

Table 32 Predicted maximum 1-hour and annual average ground-level concentrations of carbon monoxide for each region in isolation and including background

Region	Averaging Period	Incremental predicted maximum concentration (µg/m³)	Air quality objective (µg/m³)	Percent of air quality objective (%)
1	1-hour	1.75	11,000	0.016
2	1-hour	1.72	11,000	0.016
3	1-hour	1.74	11,000	0.016

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 the proposed QCLNG project, during non-normal operating conditions, assessed in isolation.
- The predicted maximum 8-hour average ground-level concentration of CO at any location within the Regions during non-normal operations and in isolation is 1.75 µg/m^3, which is 0.016% of the EPP(Air) air quality objective of 11,000 µg/m^3

7.2.3 Hydrocarbons

As described in Section 3.2.1 emissions of hydrocarbons from the gas flare during non-normal operations have been determined from the manufacturers design specifications of total hydrocarbon releases and the breakdown of specific hydrocarbons as outlined in the US EPA's AP-42 Industrial Flares (Chapter 13.5) document.

7.2.3.1 Issue Identification

The proposed QCLNG Project is anticipated to emit a suite of hydrocarbons. The available published information about these hydrocarbons suggests that they are recognised asphyxiants. The risk to persons living and working in the surrounding area that could be associated with exposure to these hydrocarbons due to their release from the QCLNG Project needs to be assessed.

The following hydrocarbons have been identified as being likely to be emitted from the flare of the QCLNG Project:

- Methane
- Ethane/ethylene
- Acetylene
- Propane
- Propylene

7.2.3.2 Hazard Identification/Dose Response Assessment

A summary of health and safety data relating to each of the hydrocarbons is included in Table 33. It is noted that whilst there are no design standards for these hydrocarbons that are published by the Victorian EPA, the NSW Department of Environment and Climate Change or the National Environment Protection Council (NEPC), the Texas Commission on Environmental Quality has published air quality guidelines for some of the organic species. These are also shown in Table 33.

The National Occupational Health and Safety Commission of Worksafe Australia publishes HSIS exposure standards for atmospheric contaminants in the occupational environment. Each of the compounds that are likely to be emitted from the QCLNG flare situated at the CPPs is characterised as non-irritating to eyes and skin and non-irritating if inhaled. However, inhalation of each at elevated concentrations can act as an asphyxiant. The HSIS exposure standards do not make recommendations as to the concentration of each compound that could cause asphyxiation, rather, the reader is referred to Chapter 10 of the Guidance Note on the Interpretation of Exposure Standards for Atmospheric Contaminants in the Occupational Environment NOHSC 3008(1995) 3rd Edition. That document states:

10. SIMPLE ASPHYXIANTS

10.1 Simple asphyxiants are gases which, when present in an atmosphere in high concentrations, lead to a reduction of oxygen concentration by displacement or dilution. It is not appropriate to recommend an exposure standard for each simple asphyxiant, rather it should be required that a sufficient oxygen concentration be maintained.

10.2 The minimum oxygen content in air should be 18 per cent by volume under normal atmospheric pressure. This is equivalent to a partial pressure of oxygen (PO2) of 18.2 kPa (137 mm Hg). At pressures significantly higher or lower than the normal atmospheric pressure, expert guidance should be sought.

7.2.3.3 Exposure Assessment

The dispersion modelling predicted that the maximum 1-hour average combined concentration of total hydrocarbons across the modelling domain would be 1.4 µg/m³, 1.3 µg/m³ and 1.2 µg/m³ (as methane), for Regions 1, 2 and 3 respectively. Table 34 provide estimates of ground-level concentrations of each of the speciated hydrocarbons identified above based on the maximum predicted ground-level concentration across the modelling domain. These predictions are presented as a mass concentration for comparison with the TCEQ air quality standards. The predictions are also presented as a volume percentage in air.

Table 33 Health and Safety data relevant to speciated VOCs likely to be emitted from the CPP Emergency Flare

Compound	CAS Number	Mass relative to air	Lower explosive limit (%)	HSIS Exposure Standards (TWA, STEL)	Victorian EPA/NSW DECC design standards	Texas (TCEQ) 1-hour average (µg/m³)	BOC MSDS		
							Eye	Inhalation	Skin
Methane	74-82-8	0.55	5	No values assigned.	-	-	Non-irritating	Non-irritating - Asphyxiant. Effects are proportional to oxygen displacement	Non-irritating
Ethane	74-84-0	1.04	3	No values assigned.	-	12,000	Non-irritating	Non-irritating - Asphyxiant. Effects are proportional to oxygen displacement	Non-irritating
Ethylene	74-85-1	0.97	2.7	No values assigned.	-	-	Non-irritating	Non-irritating - Asphyxiant. Effects are proportional to oxygen displacement	Non-irritating
Acetylene	74-86-2	0.90	2.5	No values assigned.	-	26,600	Non-irritating	Non-irritating - Asphyxiant. Effects are proportional to oxygen displacement	Non-irritating
Propane	74-98-6	1.52	2.2	No values assigned.	-	18,000	Non-irritating	Non-irritating - Asphyxiant. Effects are proportional to oxygen displacement	Non-irritating
Propylene	115-07-1	1.45	2.4	No values assigned.	-	8,750	Non-irritating	Non-irritating - Asphyxiant. Effects are proportional to oxygen displacement	Non-irritating

Table 34 Maximum ground-level concentrations of methane, ethane, ethylene, acetylene, propane and propylene across the modelling domain due to flare emissions

Compound	MW	% v/v of total VOCs emitted	Texas (TCEQ) 1-hour average (µg/m³)	Predicted maximum concentrations across modelling domain								
				Region 1			Region 2			Region 3		
				ppb	% v/v in air	µg/m³	ppb	% v/v in air	µg/m³	ppb	% v/v in air	µg/m³
Methane	16.04	55	-	1.174	1.2E-07	0.8	1.090	1.1E-07	0.7	1.006	1.0E-07	0.7
Ethane	30.07	8	12000	0.171	1.7E-08	0.2	0.159	1.6E-08	0.2	0.146	1.5E-08	0.2
Ethylene	28.05	8	-	0.171	1.7E-08	0.2	0.159	1.6E-08	0.2	0.146	1.5E-08	0.2
Acetylene	26.04	5	26600	0.107	1.1E-08	0.1	0.099	9.9E-09	0.1	0.091	9.1E-09	0.1
Propane	44.09	7	18000	0.149	1.5E-08	0.3	0.139	1.4E-08	0.3	0.128	1.3E-08	0.2
Propylene	42.08	25	8750	0.534	5.3E-08	0.9	0.496	5.0E-08	0.9	0.457	4.6E-08	0.8

7.2.3.4 Risk Characterisation

The findings of the dispersion modelling assessment summarised in Table 34 indicates that the predicted ground-level concentration of each hydrocarbon is very low. None of these hydrocarbons is likely to be present in sufficient quantities to displace oxygen to the extent that asphyxiation could occur. At most, these hydrocarbons combined could displace $2.31\text{x}10^{-7}$%, $2.14\text{x}10^{-7}$% and $1.98\text{x}10^{-7}$% of oxygen at the most affected location on the modelled domain in Regions 1, 2 and 3, respectively. This is a negligible amount given that the recommendation for the occupational environment is to ensure that the oxygen level remains above 18% (note: average content of oxygen in air is 20.9%). This indicates a negligible risk of asphyxiation.

The predicted maximum concentration of each hydrocarbon is also very low compared to the TCEQ standards (maximum of 0.01%).

The predicted concentration of each hydrocarbon is very low when compared with its lower explosive limit, indicating a very low risk of explosion. Whilst two of the hydrocarbons are heavier than air, all are emitted in very low concentrations and at an elevated temperature. Hence, there is a negligible risk that these compounds could concentrate in low lying areas and cause an explosion or asphyxiation.

8. Conclusions

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

The assessment was conducted using a combination of CSIRO's TAPMv4.0.1 dispersion model to determine background levels of pollutants and to derive meteorological files for use in AUSPLUME modelling of compressor stations in three Regions across the project area, in the absence of definitive final locations. Analysis of the meteorology at these three locations has been performed for the one year simulated together with analysis of longer term climate statistics from the BoM site located at Miles.

The air quality assessment focussed on the impacts to air quality associated with the emission of criteria air pollutants such as oxides of nitrogen and carbon monoxide and also included an assessment of various hydrocarbon species with the potential to be generated from the combustion of CSG in the gas-fired reciprocating engines used to drive the CSG compressors.

The following conclusions can be drawn from the air quality assessment for the proposed QCLNG project:

- For the three site locations assessed:
  - There are no exceedances predicted of the EPP(Air) air quality objectives for the 1-hour and annual average ground-level concentration of nitrogen dioxide due to the proposed QCLNG project during normal operations, 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.
  - There are no exceedances predicted of the EPP(Air) air quality objectives for the 8-hour average ground-level concentration of carbon monoxide due to the proposed QCLNG project during normal operations, assessed in isolation, at any location within the modelled domain.
  - None of the 52 identified hydrocarbon species associated with emissions from the gas-fired reciprocating engines, used to drive the CSG compressors, was found to exceed the ambient air quality objectives.
  - There are no exceedances of the EPP(Air) objectives for ozone due to the proposed QCLNG project during normal operations.
  - There are no exceedances predicted of the EPP(Air) air quality objectives for the 1-hour average ground-level concentration of nitrogen dioxide due to the proposed QCLNG project during non-normal operations when the gas flare is initiated at the CPP at any location within the modelled domain.
  - There are no exceedances predicted of the EPP(Air) air quality objectives for the 8-hour average ground-level concentration of carbon monoxide due to the proposed QCLNG project during non-normal operations when the gas flare is initiated at the CPP, assessed in isolation, at any location within the modelled domain

- There are no exceedances predicted of the TCEQ air quality objectives for the 1-hour average ground-level concentration of any hydrocarbon species emitted by the gas flare at the CPP due to the proposed QCLNG project during non-normal operations, assessed in isolation, at any location within the modelled domain.

- All hydrocarbon species likely to be emitted by the gas flare are simple asphyxiants and consequently, have the potential to deplete oxygen in the local environment. This is primarily of concern in a confined space and unlikely to be an issue in the ambient environment. The total amount of oxygen predicted to be displaced by all of the hydrocarbon species combined is 2.31×10^{-7}%. This is a negligible amount given that the recommendation for the occupational environment is to ensure that the oxygen level remains above 18% (note: average content of oxygen in air is 20.9%). This indicates a negligible risk of asphyxiation.

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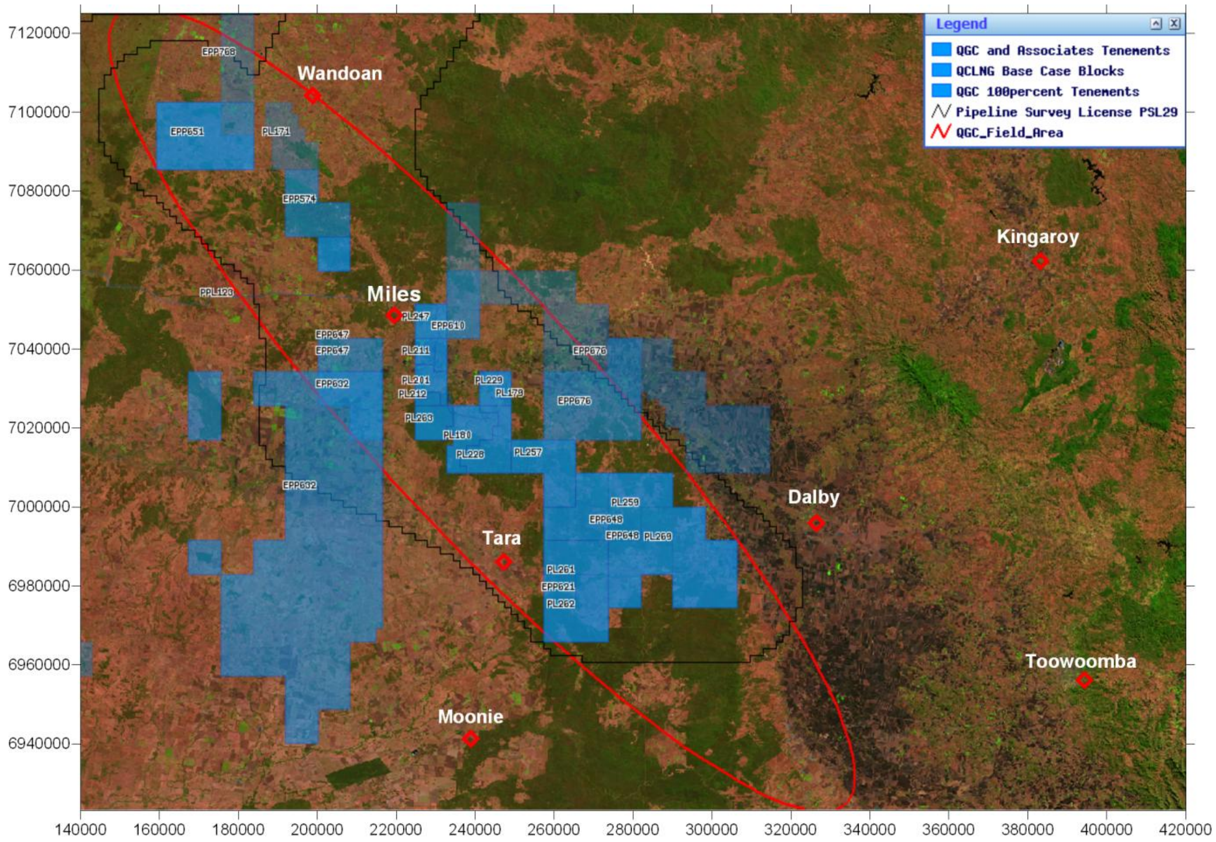

Figure 1 **The QCLNG gas field exploration and development project area**

Location: Surat Basin region, QLD			
Type: Project area map	**Prepared by:** A. Schloss	**Date:** 27/01/09	

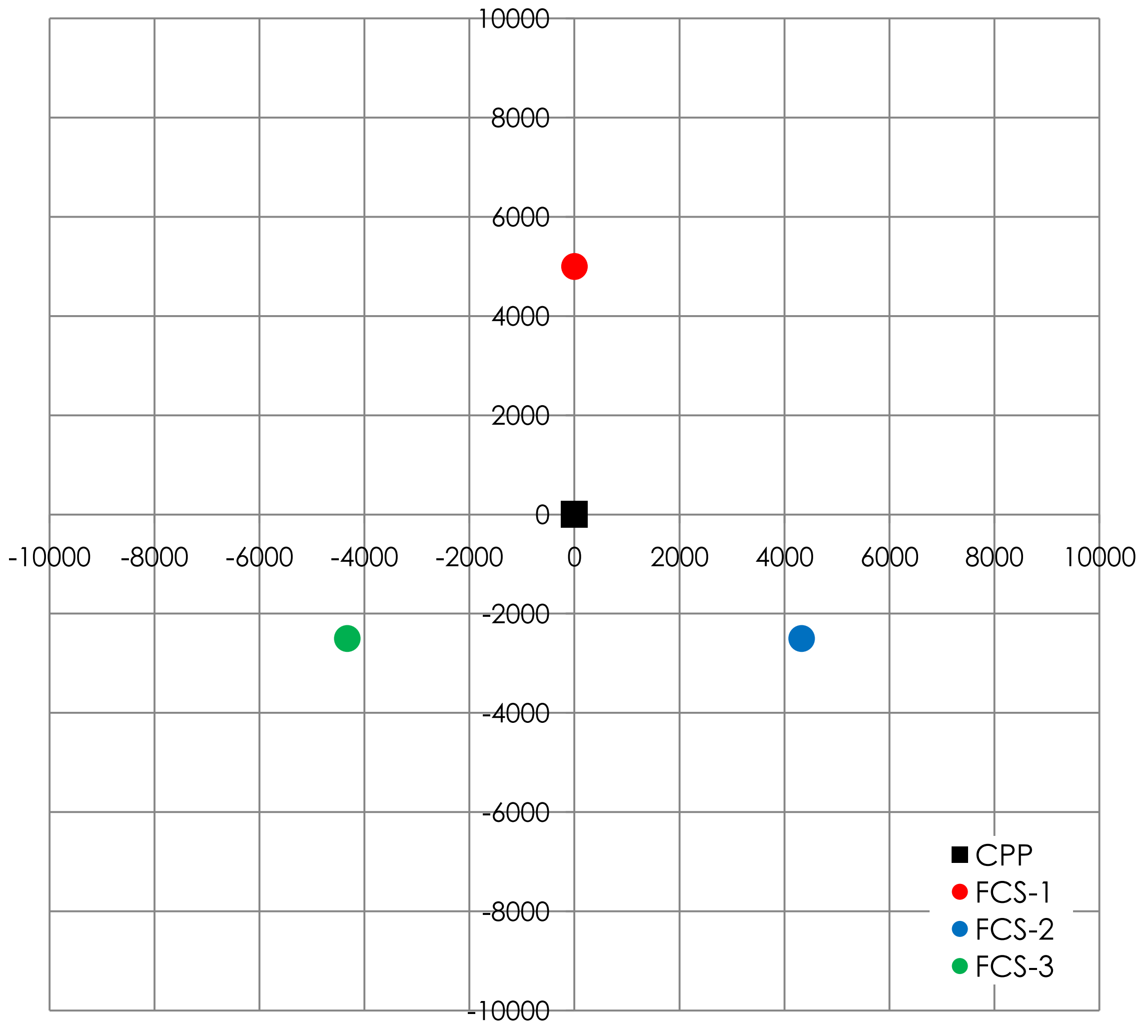

Figure 2 Configuration of the Central Processing Plant (CPP) and three Field Compressor Stations (FCS) developed for the dispersion modelling

Location: Surat Basin region, QLD	**Units:** Metres		
Type: Compressor station location map	**Prepared by:** A. Balch	**Date:** 16/12/08	

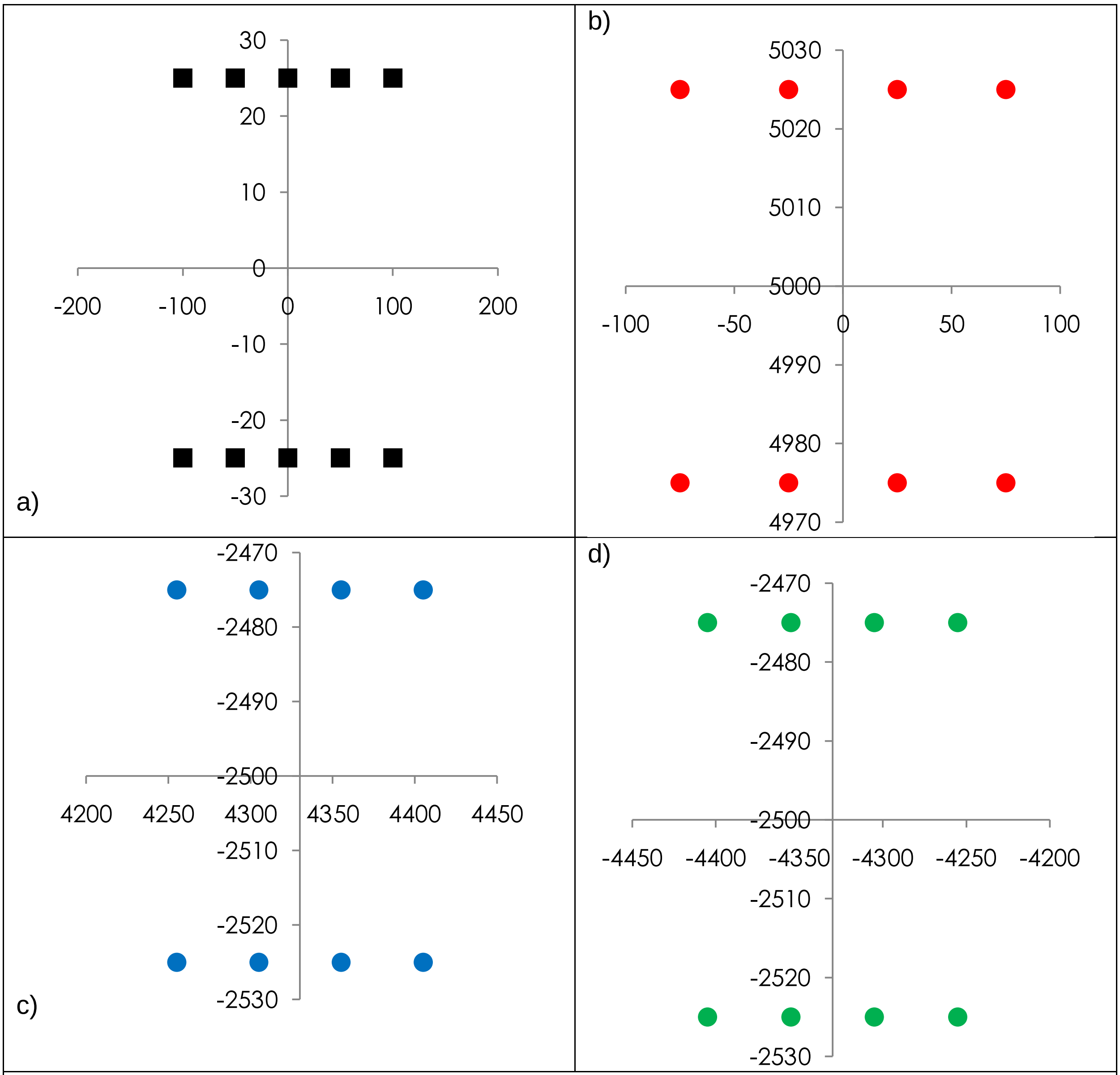

Figure 3 **Emission source locations for each of the gas compressor station stacks, as modelled**

Location: Nominal site locations	**Units:** Metres		**Key** a) Central Processing Plant (CPP) b) Field Compressor Station 1 (FCS-1) c) Field Compressor Station 2 (FCS-2) d) Field Compressor Station 3 (FCS-3)
Type: Compressor station location map	**Prepared by:** A. Balch	**Date:** 16/12/08	

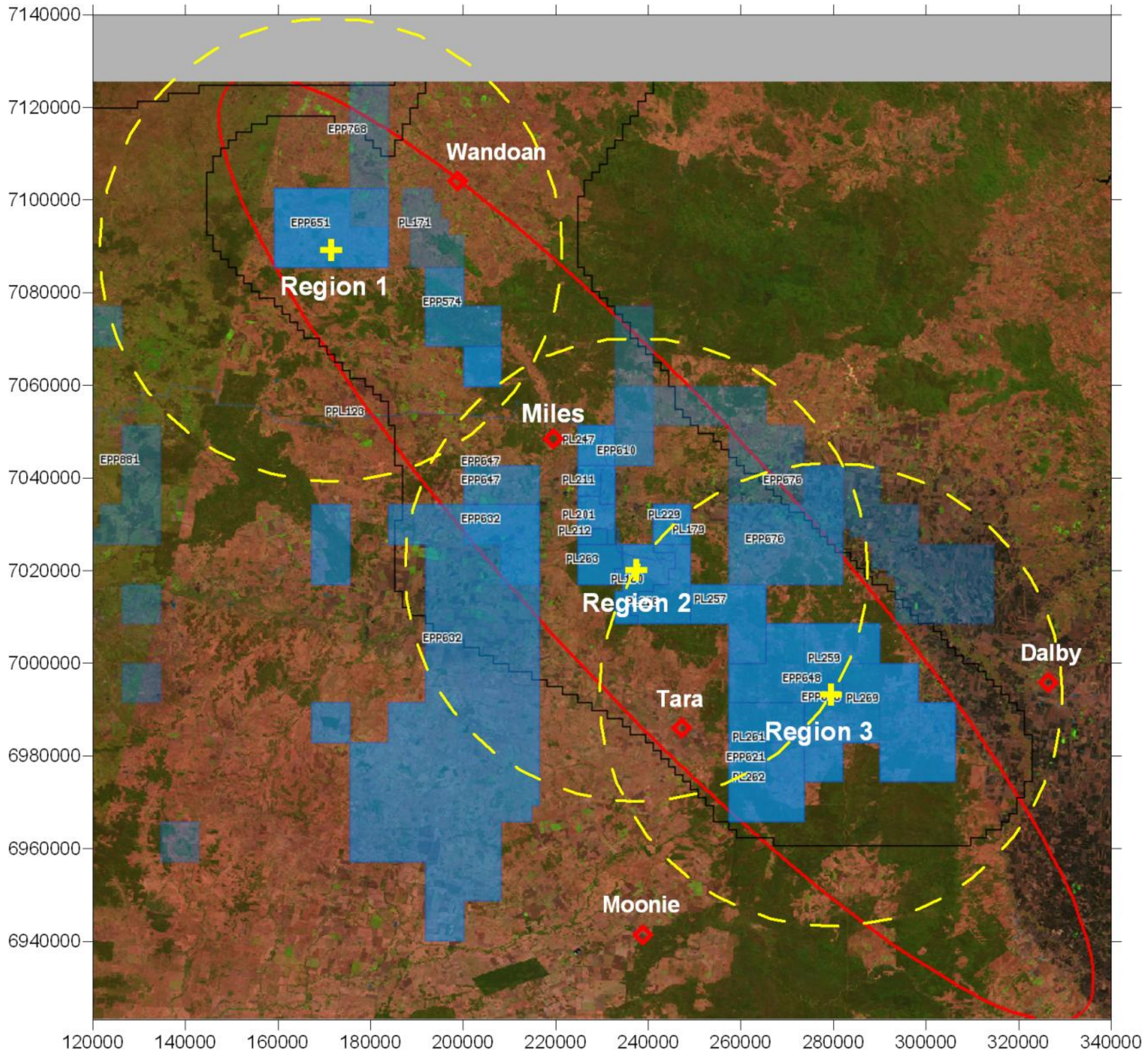

Figure 4 QCLNG project exploration and production leases in the Surat Basin. The three regions indicate the centre of gas extraction well clusters and the nominal air quality impact assessment locations

Location: Surat Basin region, QLD		**Units:** Australian Map Grid coordinates – MGA94
Type: Site location map	**Prepared by:** A. Schloss and A. Balch	**Date:** 27/01/09

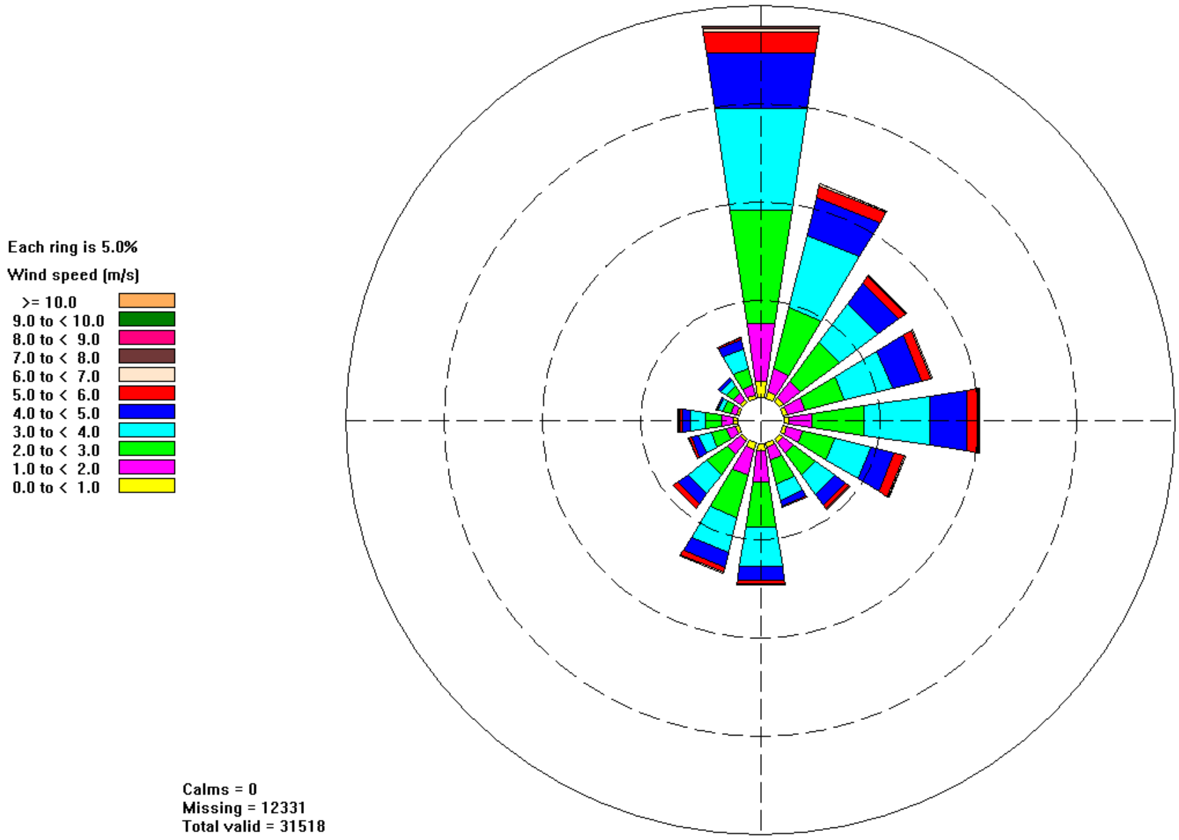

Figure 5 Annual distribution of wind speed and direction at Miles

Location: Miles	**Period:** April 2003 – April 2008	**Data source:** Bureau of Meteorology	**Units:** Degrees and metres per second
Type: Annual wind rose		**Prepared by:** A. Schloss	**Date:** 23/01/09

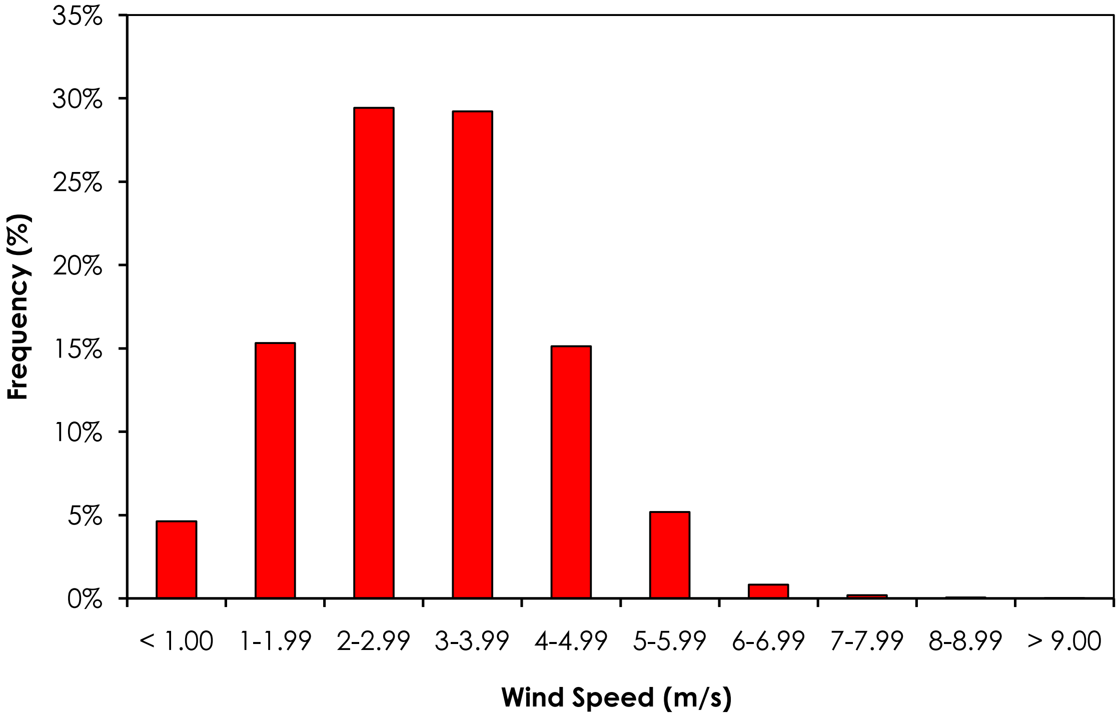

Figure 6 Frequency distribution of wind speed at Miles

Location: Miles	**Period:** April 2003 – April 2008	**Data source:** Bureau of Meteorology	**Units:** Percentage and metres per second
Type: Frequency distribution of annual wind speed		**Prepared by:** A. Balch	**Date:** 23/01/09

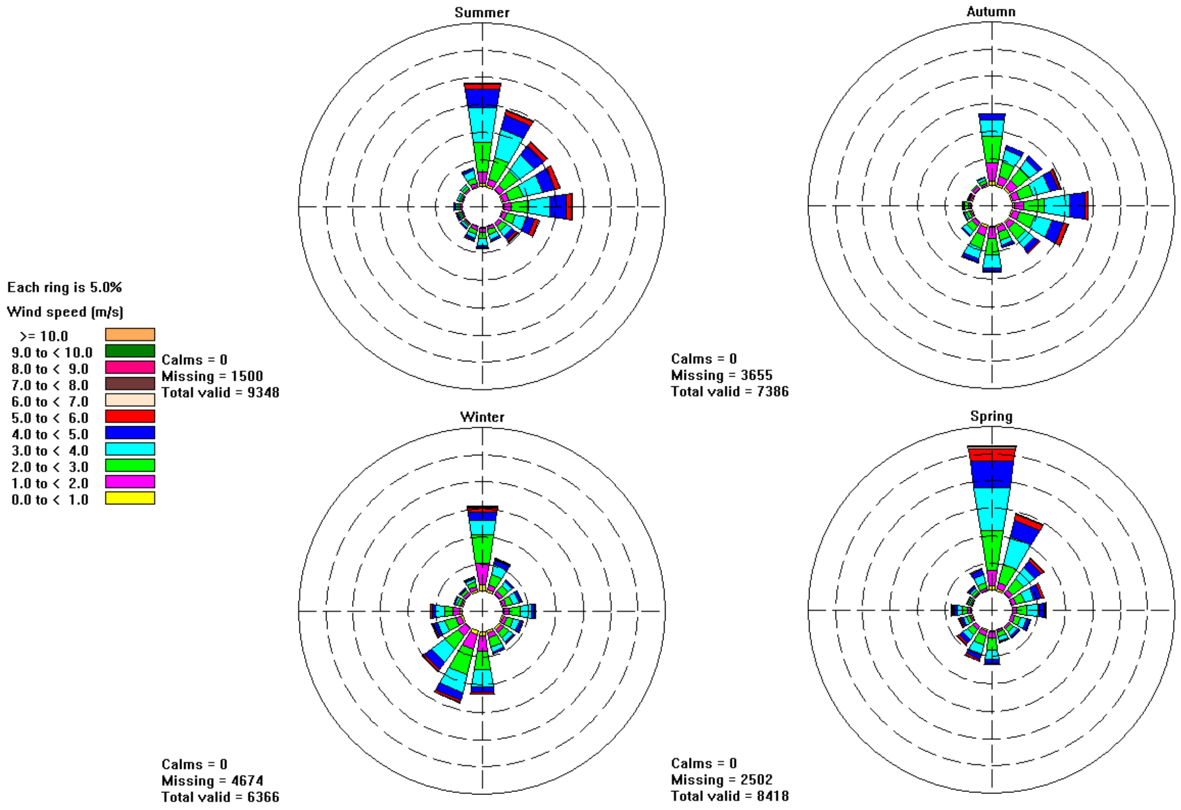

Figure 7 Seasonal distribution of wind speed and direction at Miles

Location: Miles	**Period:** April 2003 – April 2008	**Data source:** Bureau of Meteorology	**Units:** Degrees and metres per second
Type: Seasonal wind rose		**Prepared by:** A. Schloss	**Date:** 23/01/09

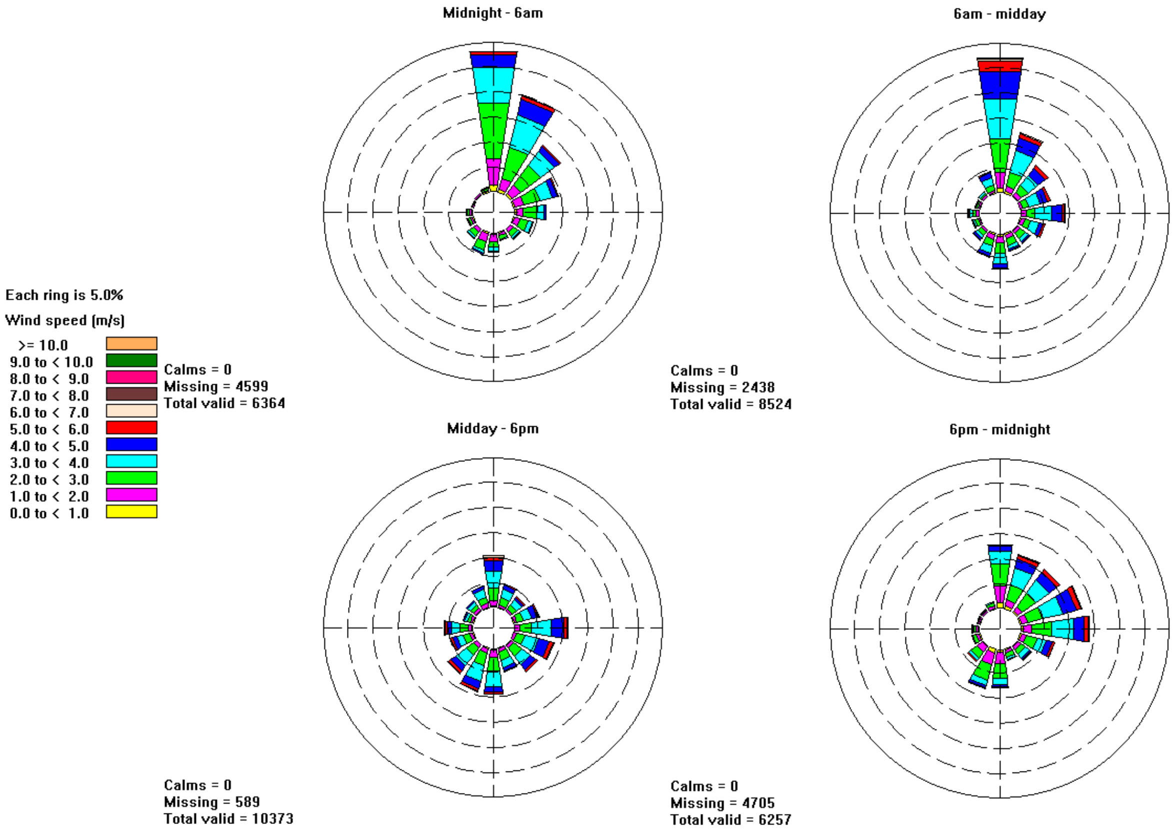

Figure 8 **Diurnal distribution of wind speed and direction at Miles**

Location: Miles	**Period:** April 2003 – April 2008	**Data source:** Bureau of Meteorology	**Units:** Degrees and metres per second
Type: Diurnal wind rose		**Prepared by:** A. Schloss	**Date:** 23/01/09

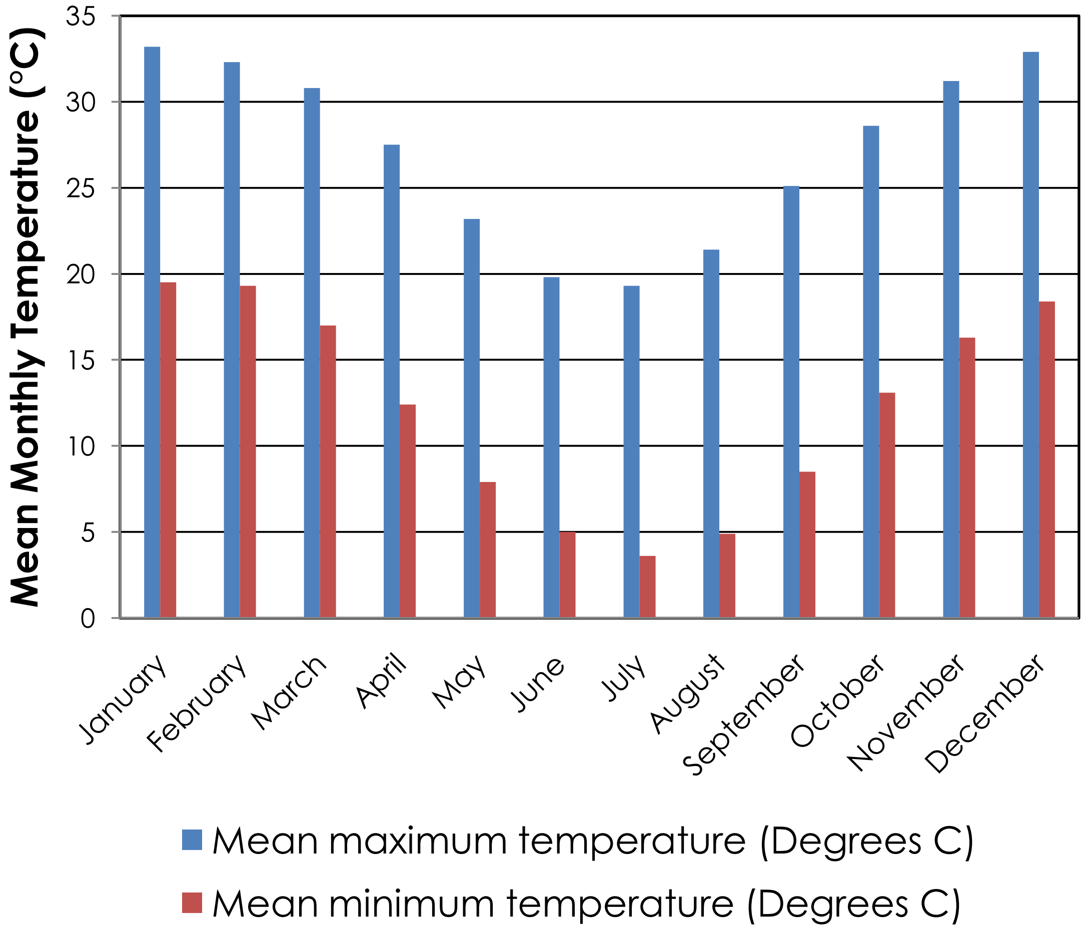

Figure 9 Average daily maximum and minimum temperatures for Miles

Location: Miles	**Period:** 1908-2005	**Data source:** Bureau of Meteorology	**Units:** Celsius
Type: Histogram		**Prepared by:** S. Menzel	**Date:** 15/12/2008

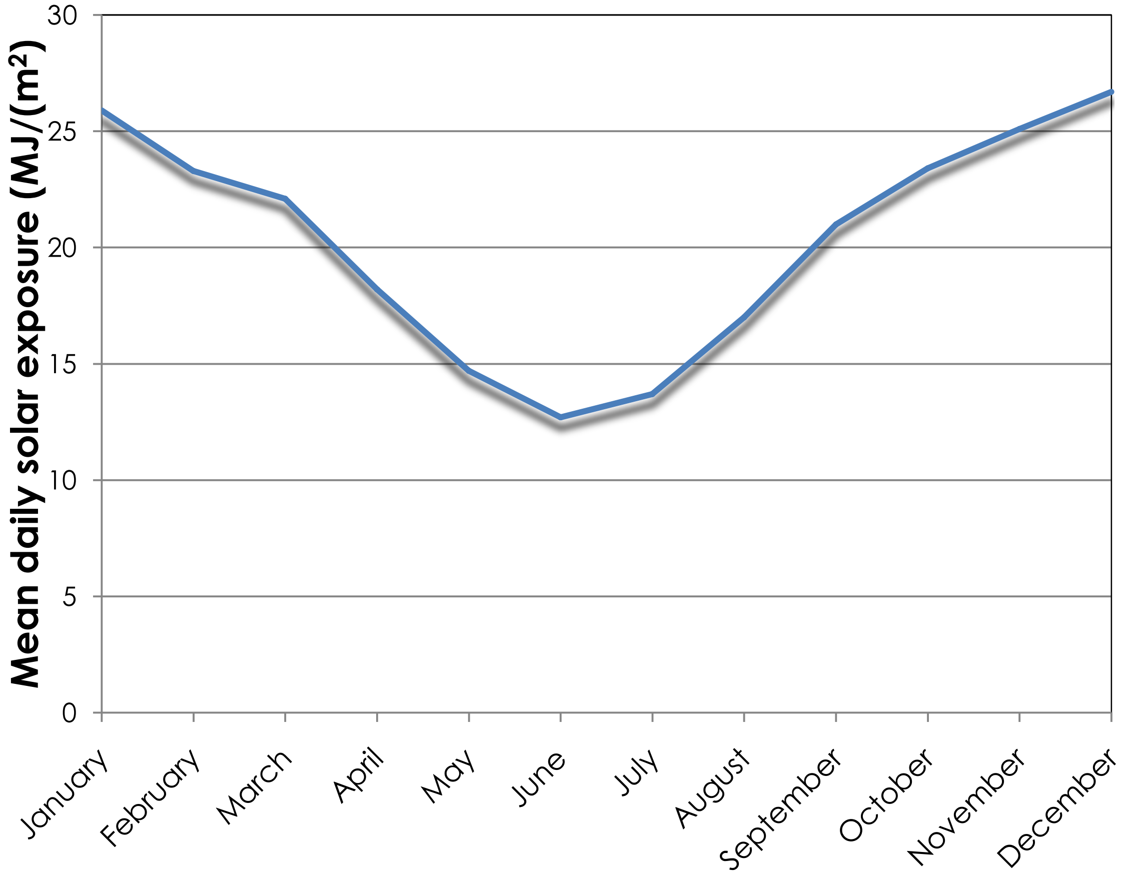

Figure 10 Mean daily solar exposure for Miles

Location: Miles	**Period:** 1990-2008	**Data source:** Bureau of Meteorology	**Units:** Megajoules per square metre
Type: Histogram		**Prepared by:** S. Menzel	**Date:** 15/12/2008

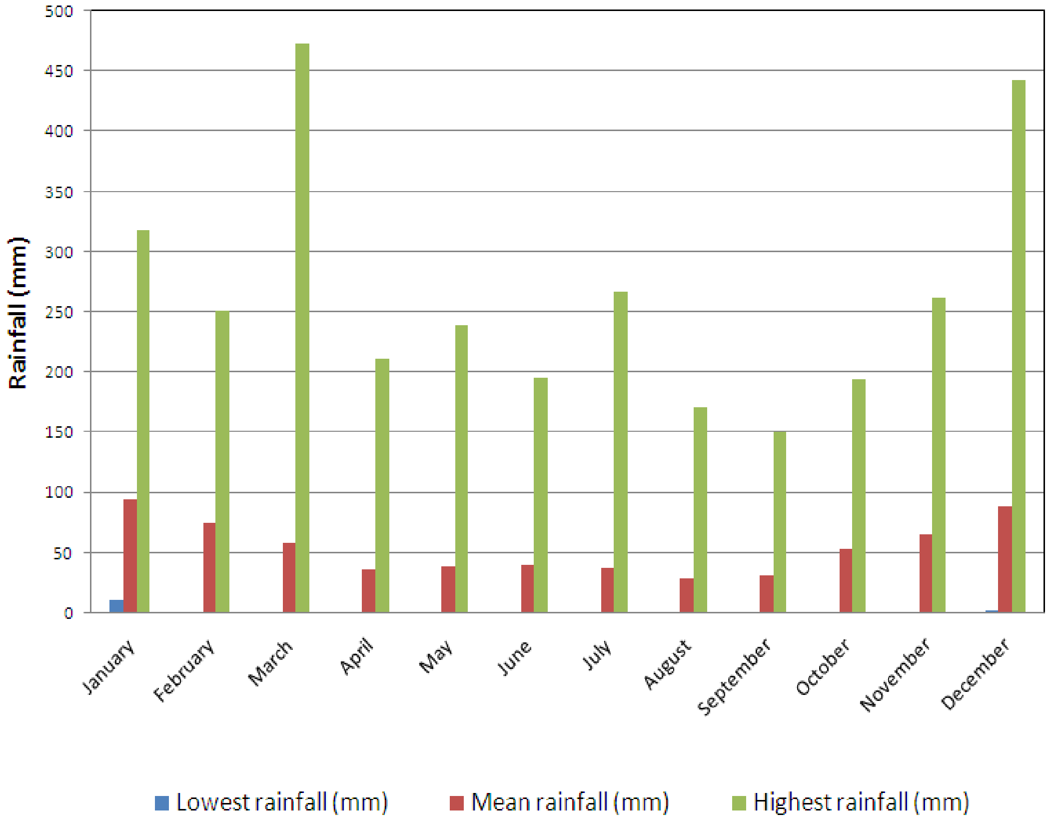

Figure 11 Range of lowest, average and highest monthly rainfall for Miles

Location: Miles	**Period:** 1885-2008	**Data source:** Bureau of Meteorology	**Units:** Millimetres
Type: Histogram		**Prepared by:** S. Menzel	**Date:** 15/12/2008

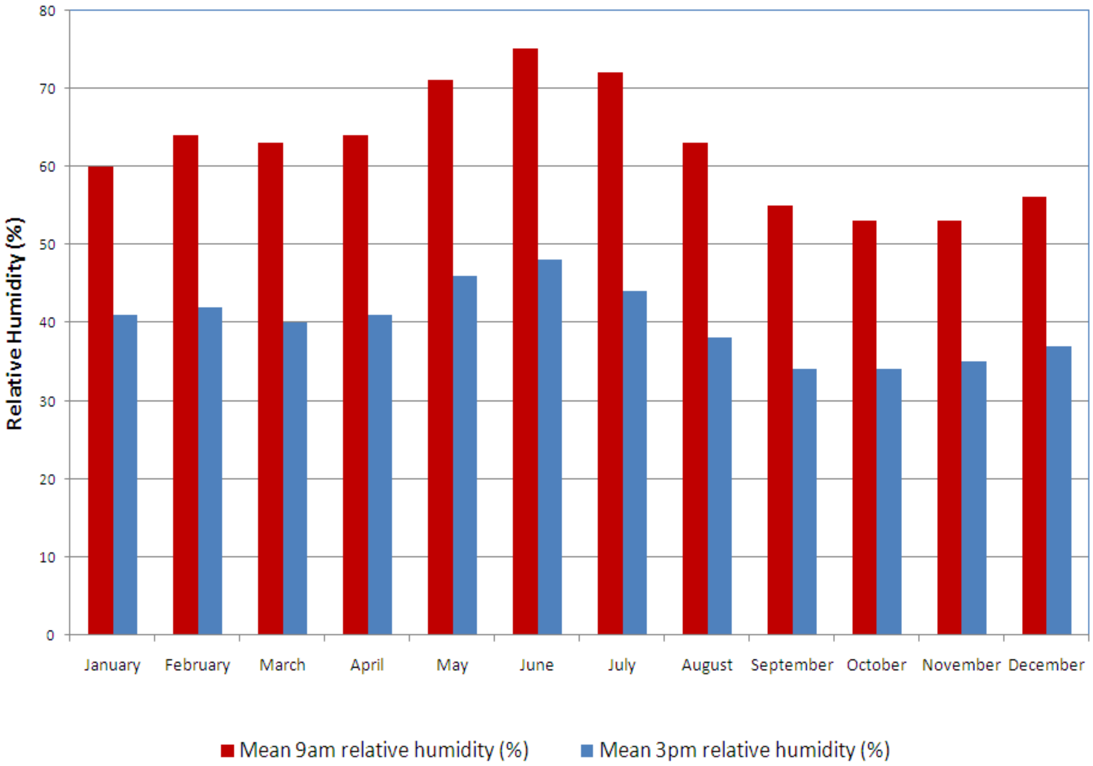

Figure 12 Mean 9am and 3pm relative humidity for the BoM station located at Miles

Location: Miles	**Period:** 1961-2005	**Data source:** Bureau of Meteorology	**Units:** Percentage
Type: Histogram		**Prepared by:** S. Menzel	**Date:** 15/12/2008

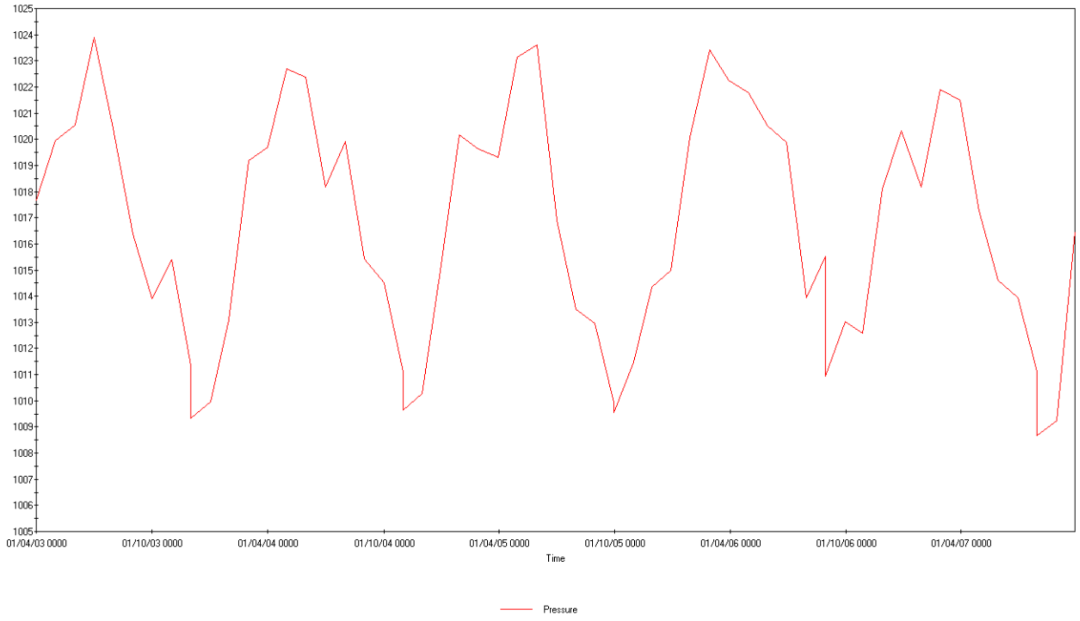

Figure 13 Monthly averaged surface pressure for Miles

Location: Miles	**Period:** 2000 – 2007	**Data source:** Bureau of Meteorology	**Units:** Pascals
Type: Time series		**Prepared by:** S. Menzel	**Date:** 15/12/2008

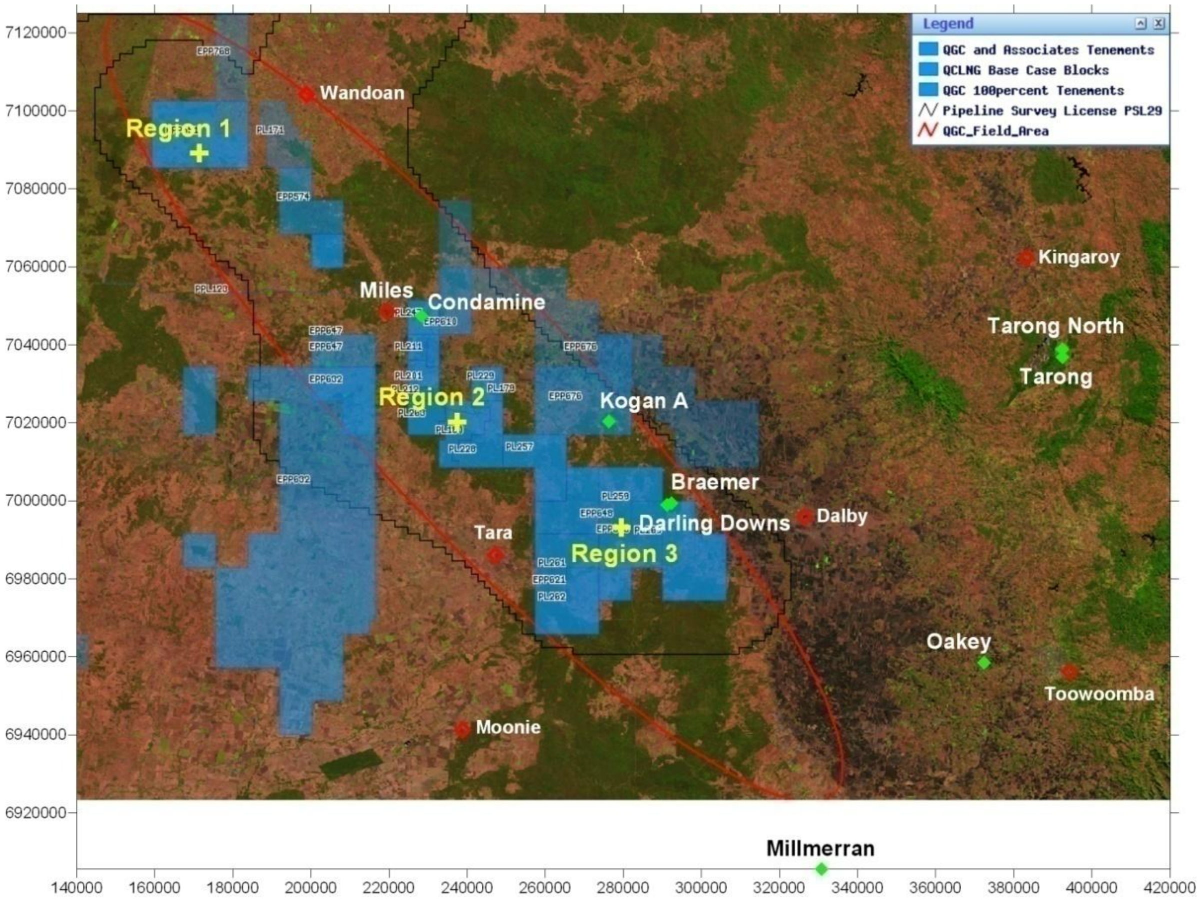

Figure 14 QCLNG exploration and production leases and the location of the existing and approved power stations included in the assessment of background concentrations of oxides of nitrogen in the region

Location: Surat Basin, QLD	**Prepared by:** A. Schloss and A. Balch		
Type: Project area map	**Date:** 27/01/09		

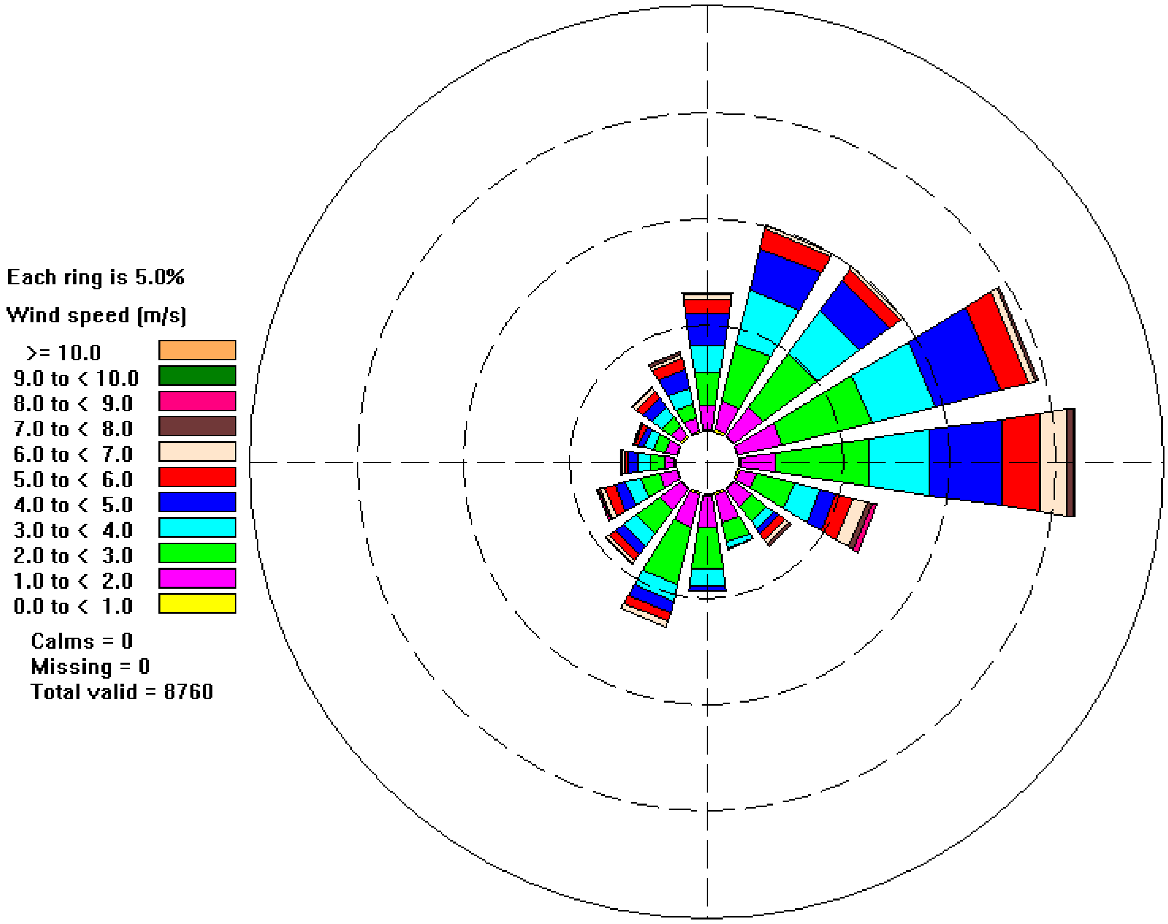

Figure 15 Predicted annual wind rose for the QCLNG project Region 1

Location: QCLNG project area Region 1	**Period:** 1 January 2007 – 31 December 2007	**Data source:** Generated by TAPM	**Units:** Metres per second and degrees
Type: Wind rose		**Prepared by:** A. Schloss and S. Menzel	**Date:** 23/01/09

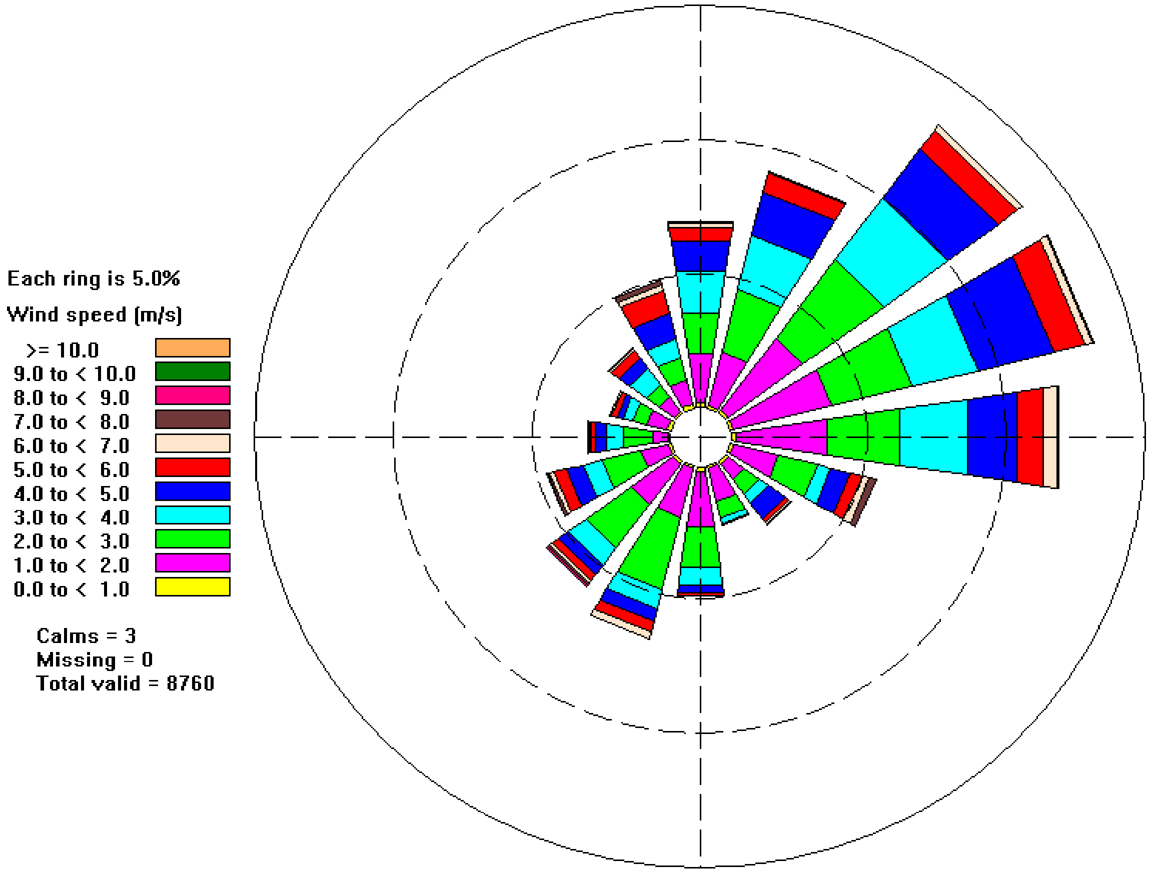

Figure 16 Predicted annual wind rose for the QCLNG project Region 2

Location: QCLNG project area Region 2	**Period:** 1 January 2007 – 31 December 2007	**Data source:** Generated by TAPM	**Units:** Metres per second and degrees
Type: Wind rose		**Prepared by:** A. Schloss and S. Menzel	**Date:** 23/01/09

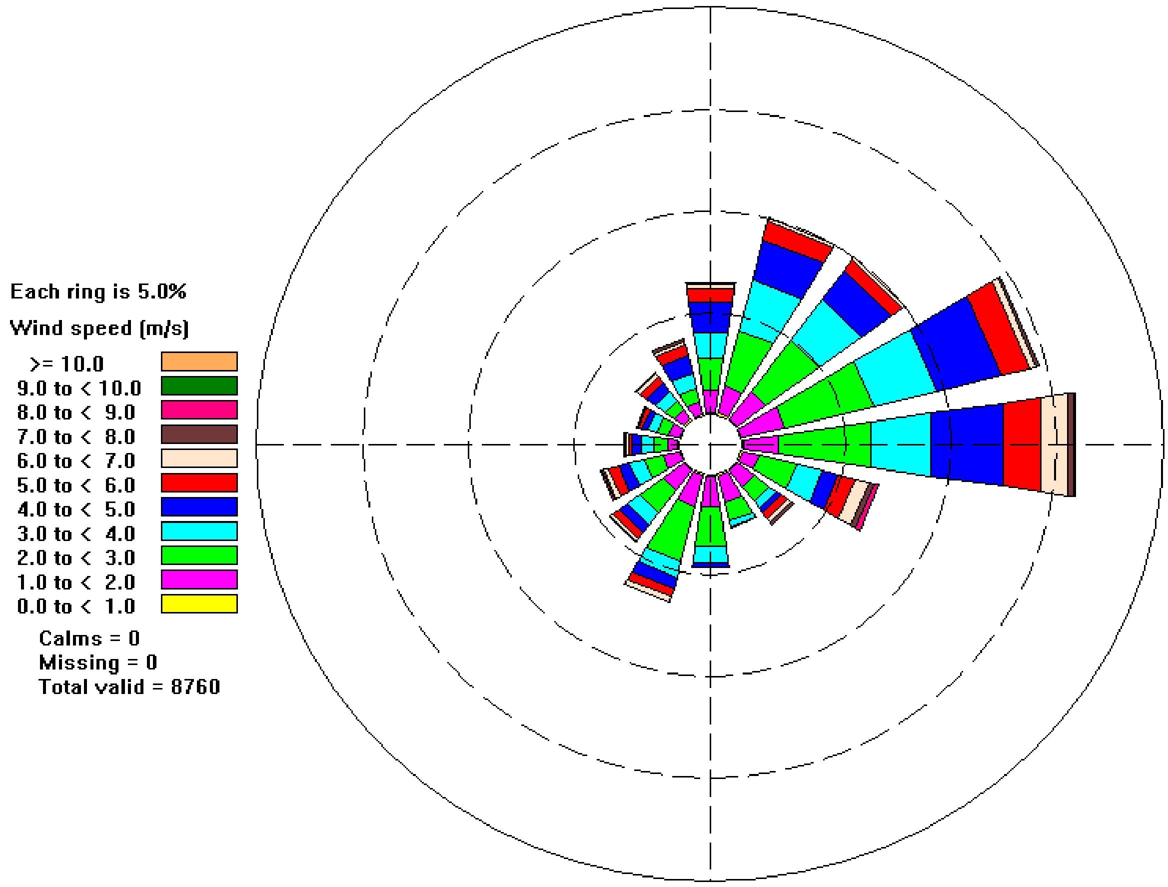

Figure 17 Predicted annual wind rose for the QCLNG project Region 3

Location: QCLNG project area Region 3	**Period:** 1 January 2007 – 31 December 2007	**Data source:** Generated by TAPM	**Units:** Metres per second and degrees
Type: Wind rose		**Prepared by:** A. Schloss and S. Menzel	**Date:** 23/01/09

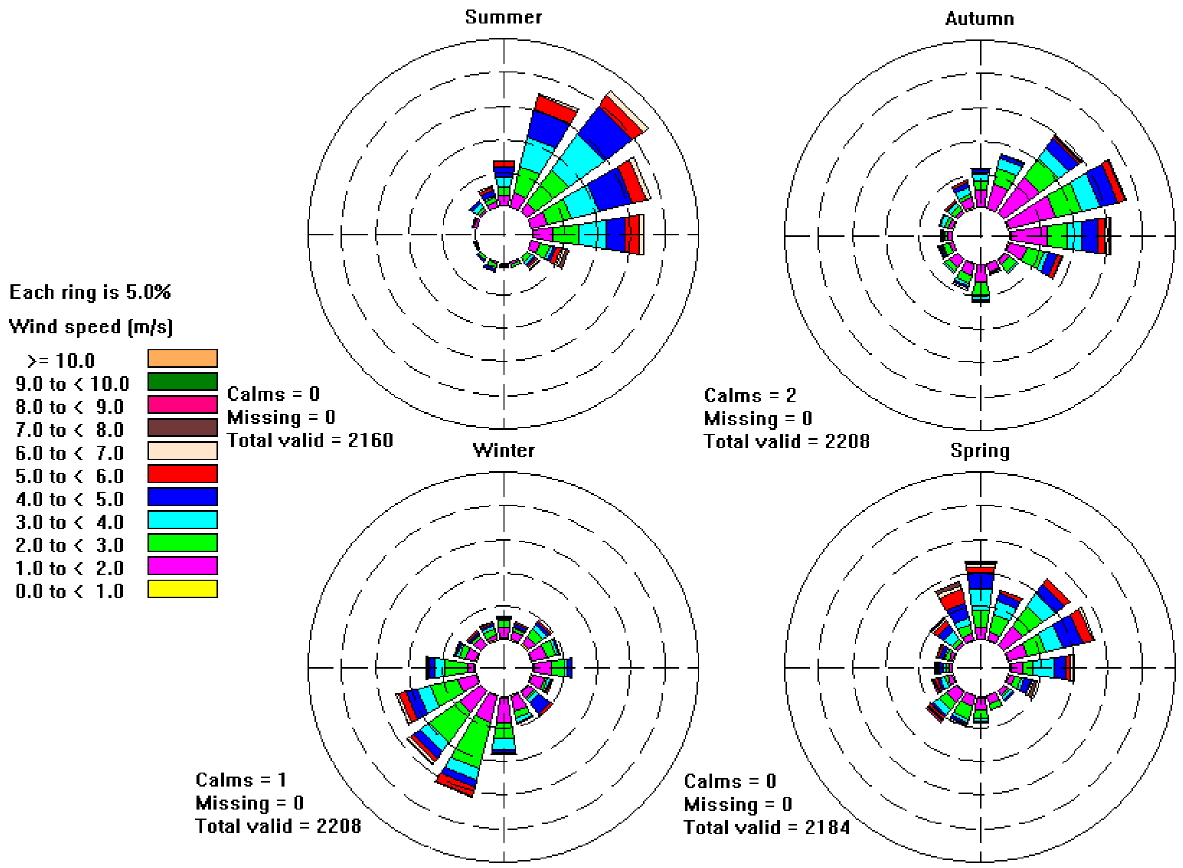

Figure 18 Predicted seasonal wind rose for the QCLNG project Region 2

Location: QCLNG project area Region 2	**Period:** 1 January 2007 – 31 December 2007	**Data source:** Generated by TAPM	**Units:** Metres per second and degrees
Type: Wind rose		**Prepared by:** A. Schloss and S. Menzel	**Date:** 23/01/09

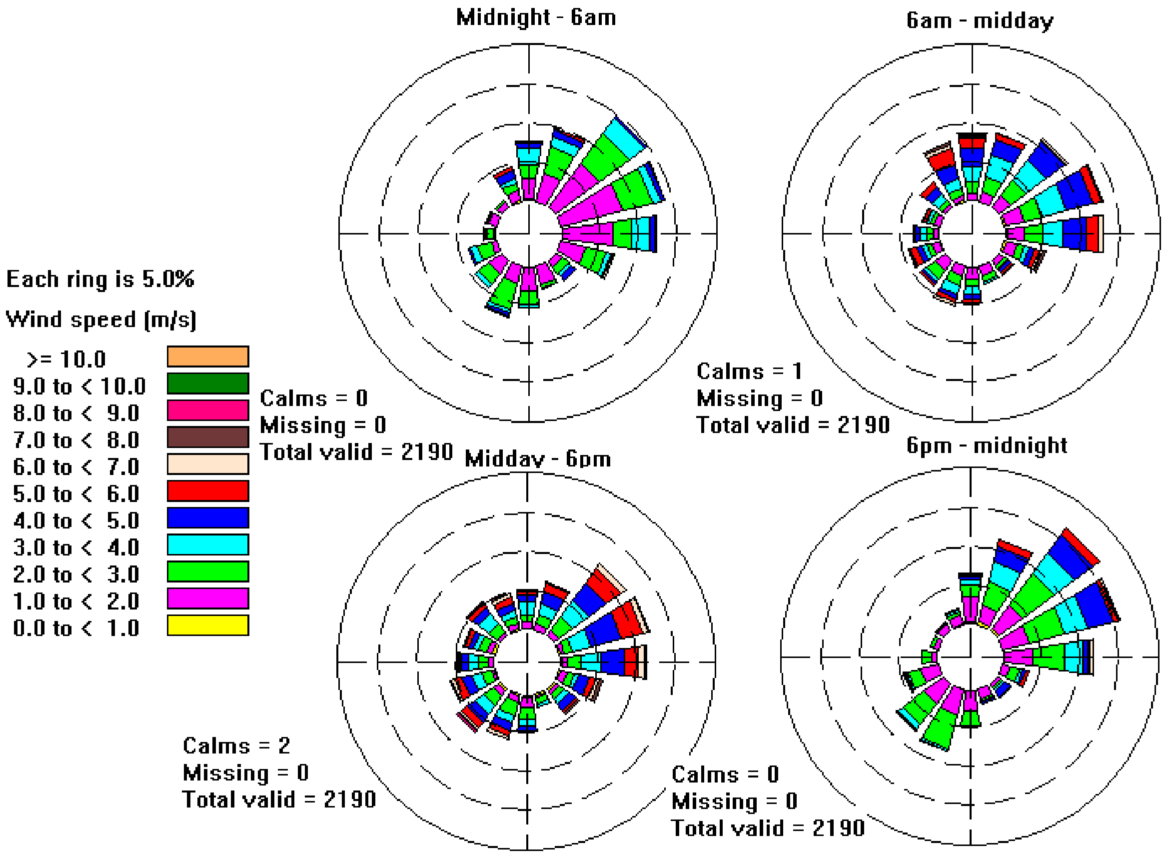

Figure 19 Predicted diurnal wind rose for the QCLNG project Region 2

Location: QCLNG project area Region 2	**Period:** 1 January 2007 – 31 December 2007	**Data source:** Generated by TAPM	**Units:** Metres per second and degrees
Type: Wind rose		**Prepared by:** A. Schloss and S. Menzel	**Date:** 23/01/09

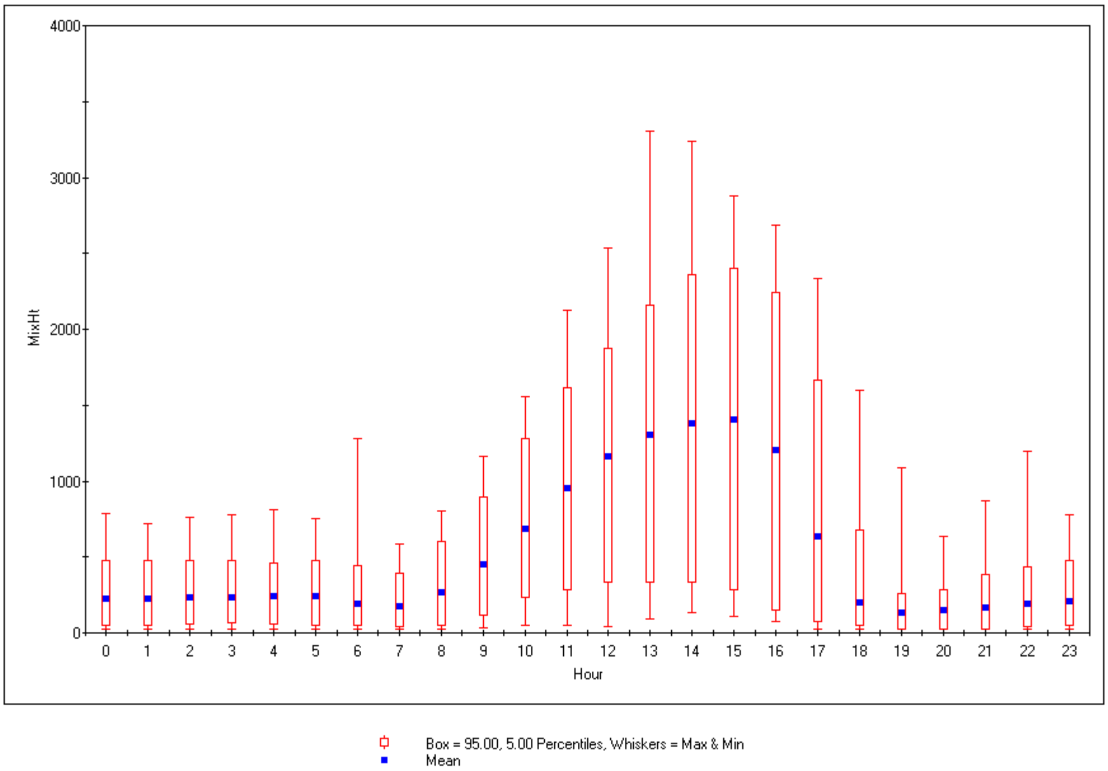

Figure 20 Daily profile for mixing height above ground at Region 2

Location: QCLNG project area Region 2	**Period:** 1 January 2007 – 31 December 2007	**Data source:** Generated by TAPM	**Units:** Metres
Type: Box and whisker plot		**Prepared by:** A. Schloss and S. Menzel	**Date:** 15/12/08

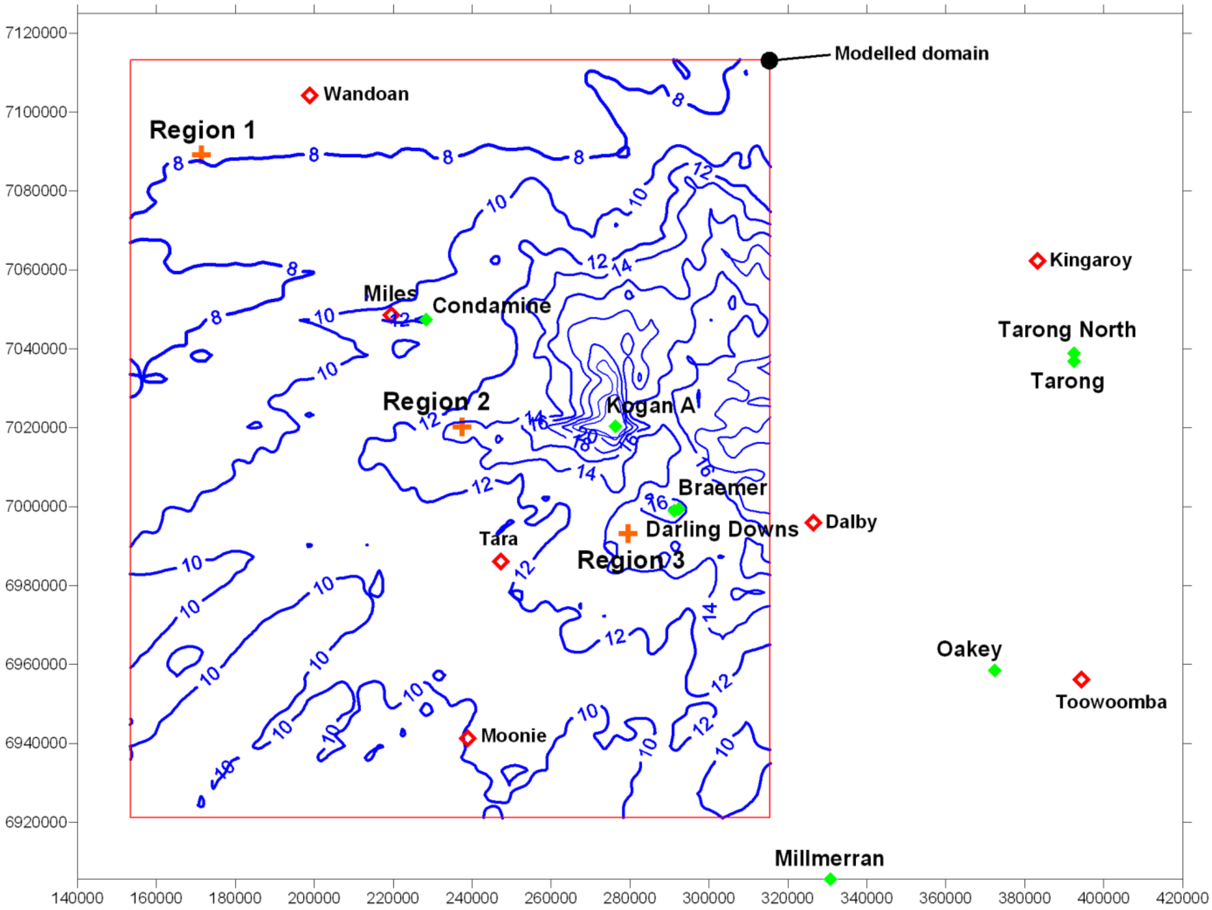

Figure 21 Predicted maximum 1-hour average ground-level concentrations of nitrogen dioxide for the existing background in the QCLNG project area, based on modelling of existing and approved sources of oxides of nitrogen in the region

Location: QCLNG project area, Surat Basin	**Averaging period:** 1-hour	**Data source:** TAPM modelling	**Units:** µg/m³ and AMG coordinates in metres
Type: NO_2 1-hour average contour plot	**Air quality objective:** 250 µg/m³	**Prepared by:** A. Schloss and A. Balch	**Date:** 27/01/09

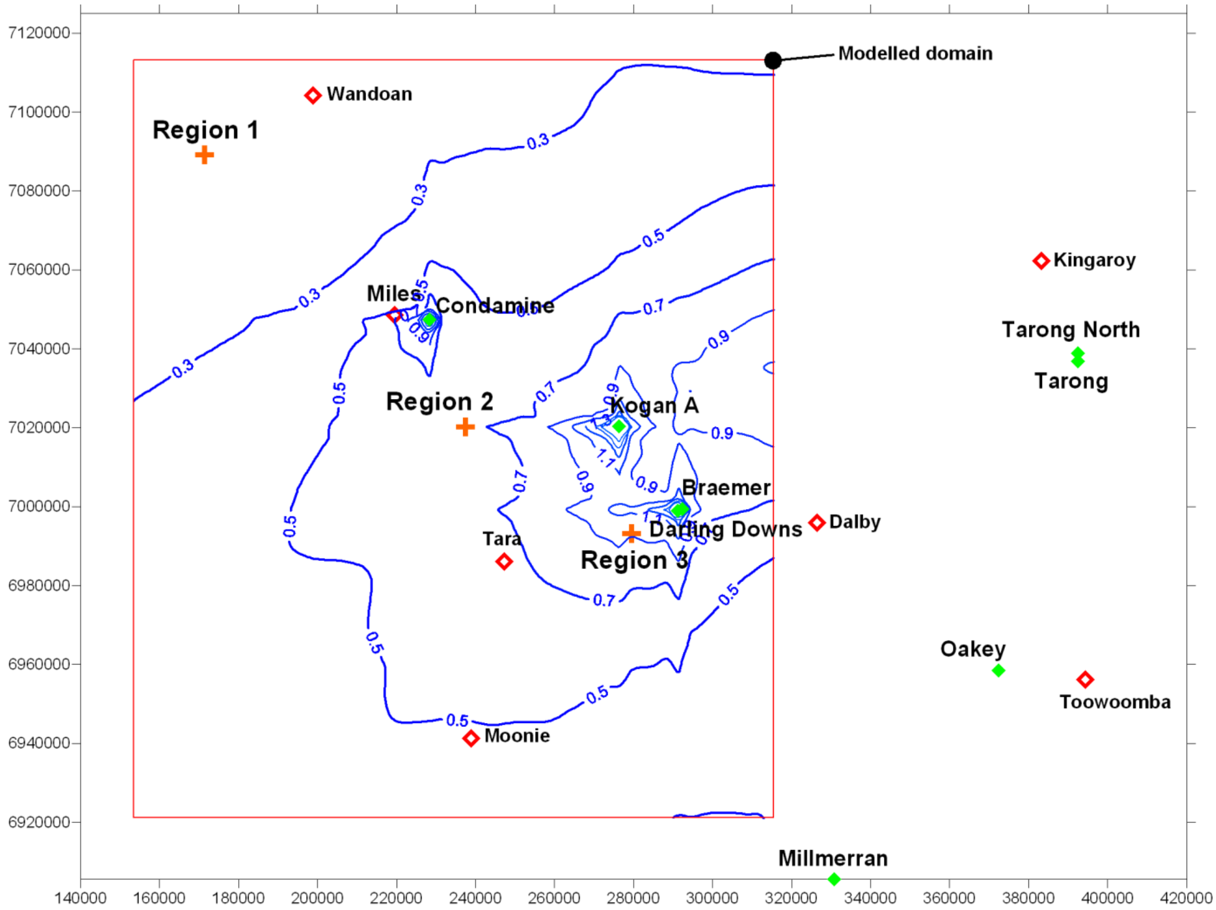

Figure 22 Predicted annual average ground-level concentrations of nitrogen dioxide for the existing background in the QCLNG project area, based on modelling of existing and approved sources of oxides of nitrogen in the region

Location: QCLNG project area, Surat Basin	**Averaging period:** Annual	**Data source:** TAPM modelling	**Units:** µg/m³ and AMG coordinates in metres
Type: NO_2 annual average contour plot	**Air quality objective:** 62 µg/m³	**Prepared by:** A. Schloss and A. Balch	**Date:** 27/01/09

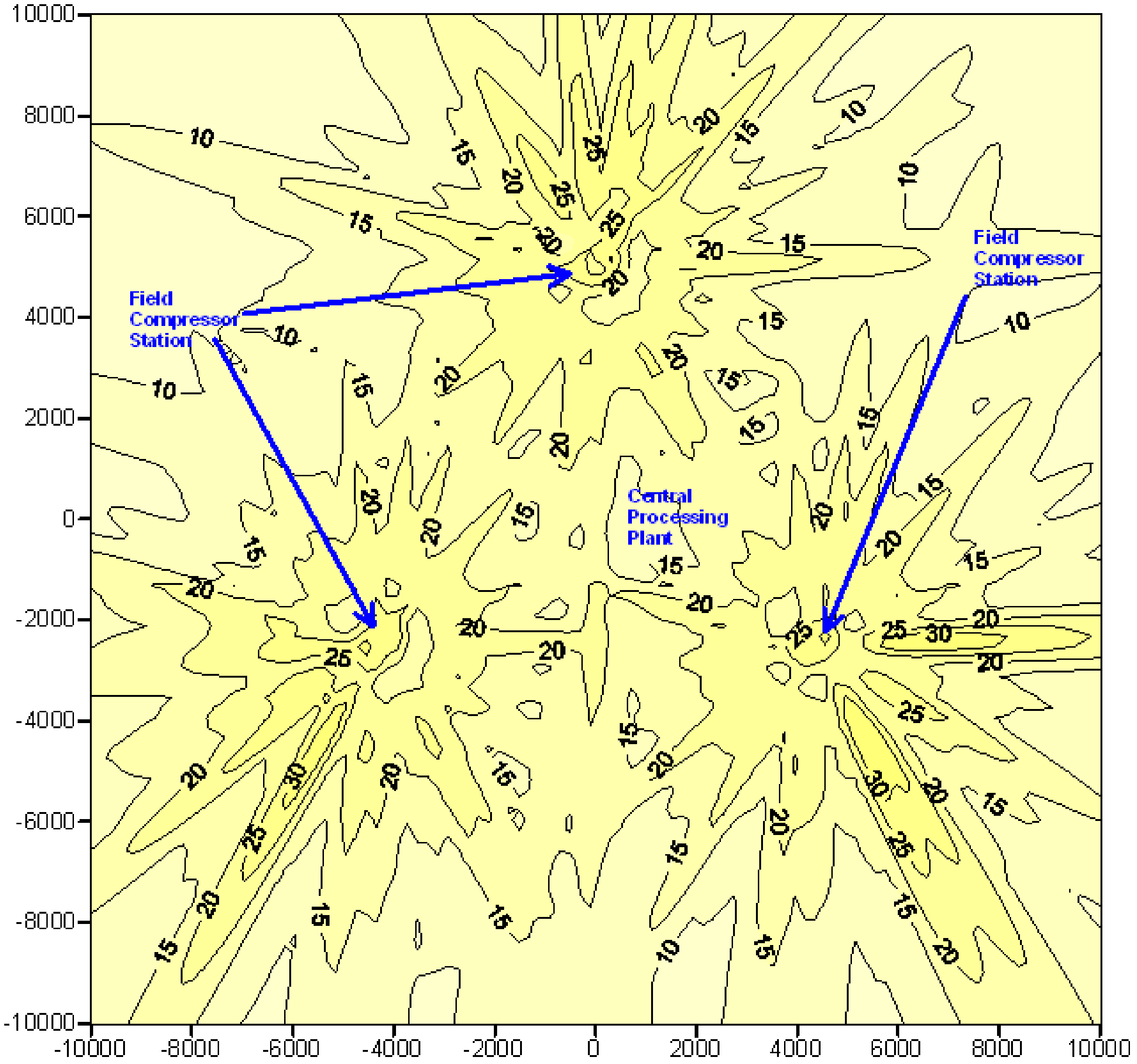

Figure 23 **Predicted maximum 1-hour average ground-level concentrations of nitrogen dioxide for the 1 x CPP and 3 x FCS compressor station setup in isolation for Region 1**

Location: QCLNG project area, Surat Basin	**Averaging period:** 1-hour	**Data source:** Ausplume modelling	**Units:** µg/m³ and metres
Type: NO_2 (100th percentile) contour plot	**Air quality objective:** 250 µg/m³	**Prepared by:** S. Menzel	**Date:** 28/05/09

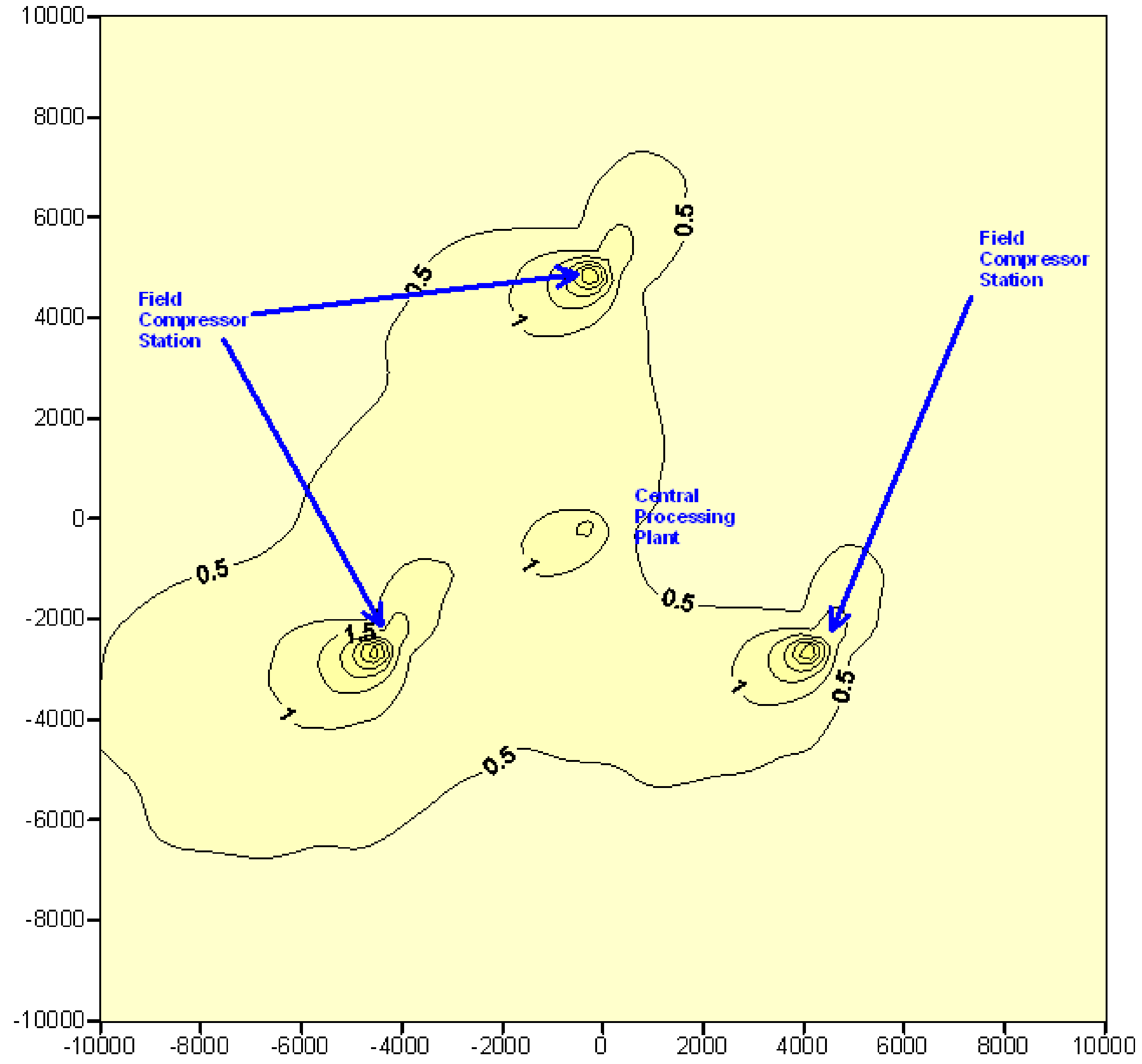

Figure 24 Predicted annual average ground-level concentrations of nitrogen dioxide for the 1 x CPP and 3 x FCS compressor station setup in isolation for Region 1

Location: Region 1	**Averaging period:** Annual	**Data source:** Ausplume modelling	**Units:** µg/m³ and metres
Type: NO_2 (100th percentile) contour plot	**Air quality objective:** Health and wellbeing 62 µg/m³	**Prepared by:** S. Menzel	**Date:** 28/05/09

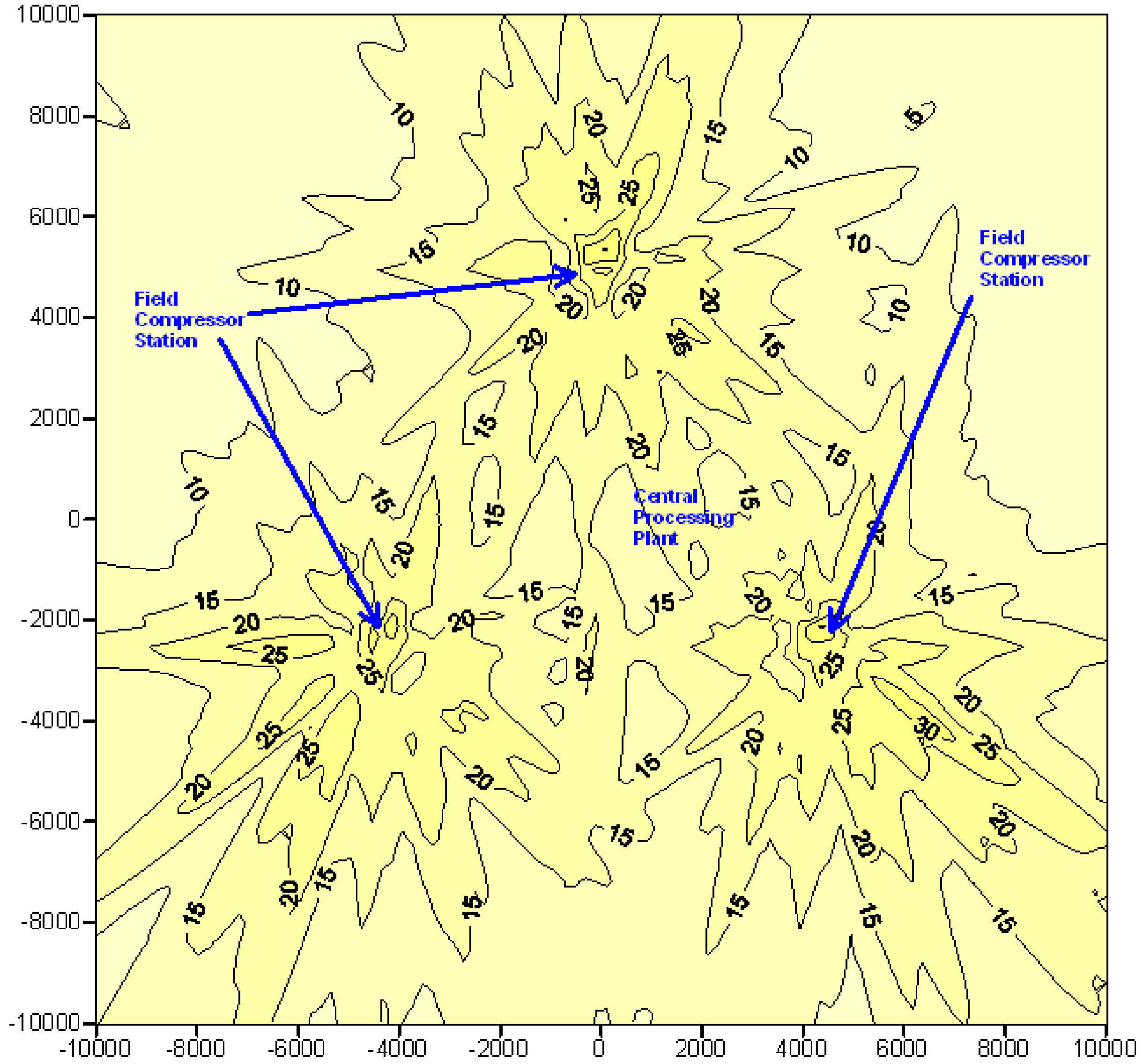

Figure 25 **Predicted maximum 1-hour average ground-level concentrations of nitrogen dioxide for the 1 x CPP and 3 x FCS compressor station setup in isolation for Region 2**

Location: Region 2	**Averaging period:** 1-hour	**Data source:** TAPM met, AUSPLUME Modelling	**Units:** µg/m³ and metres
Type: NO_2 (100th percentile) contour plot	**Air quality objective:** 250 µg/m³	**Prepared by:** S. Menzel	**Date:** 28/05/09

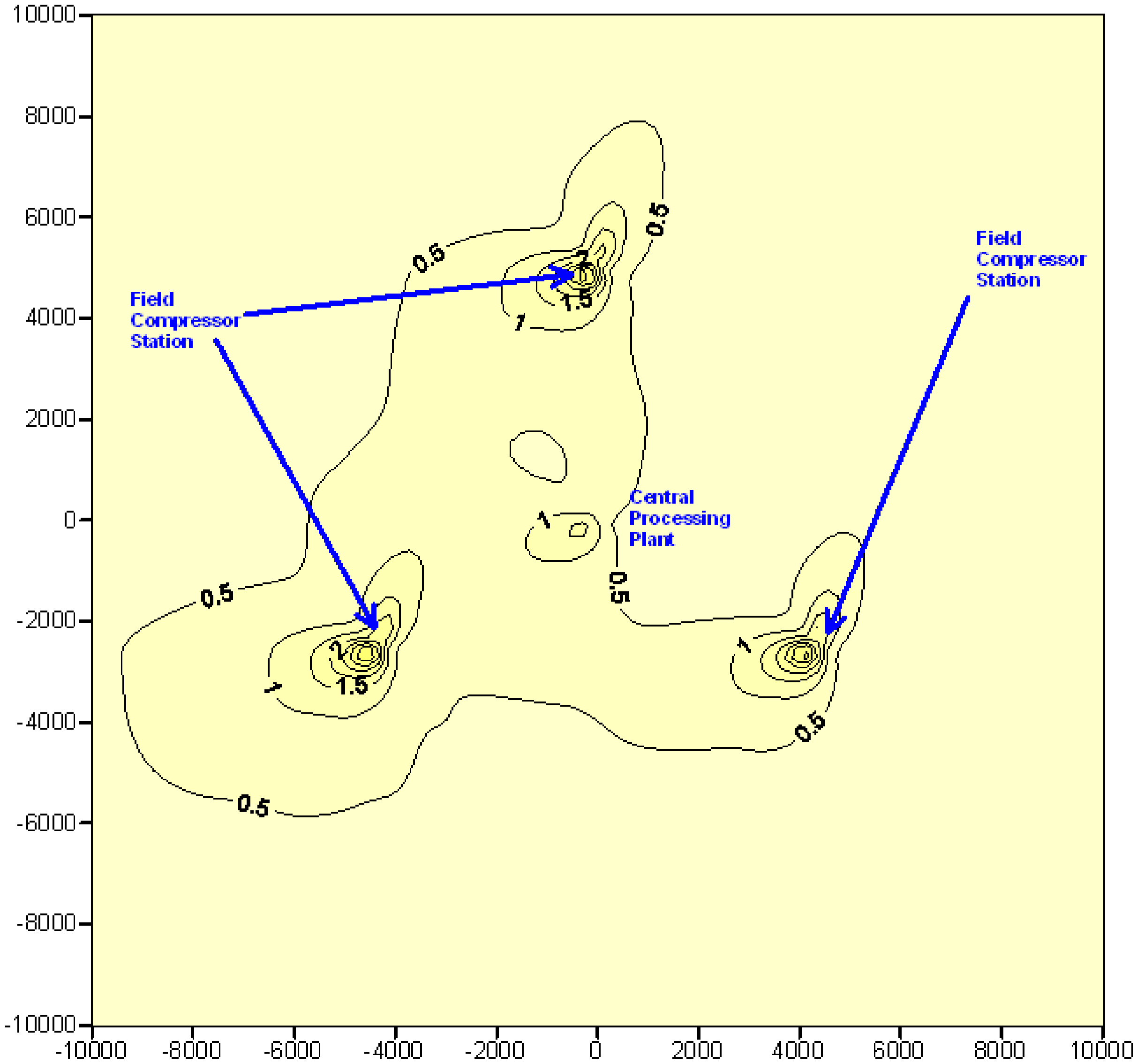

Figure 26 Predicted annual average ground-level concentrations of nitrogen dioxide for the 1 x CPP and 3 x FCS compressor station setup in isolation for Region 2

Location: Region 2	**Averaging period:** Annual	**Data source:** TAPM met, AUSPLUME Modelling	**Units:** µg/m³ and metres
Type: NO_2 (100th percentile) contour plot	**Air quality objective:** Health and wellbeing 62 µg/m³	**Prepared by:** S. Menzel	**Date:** 28/05/09

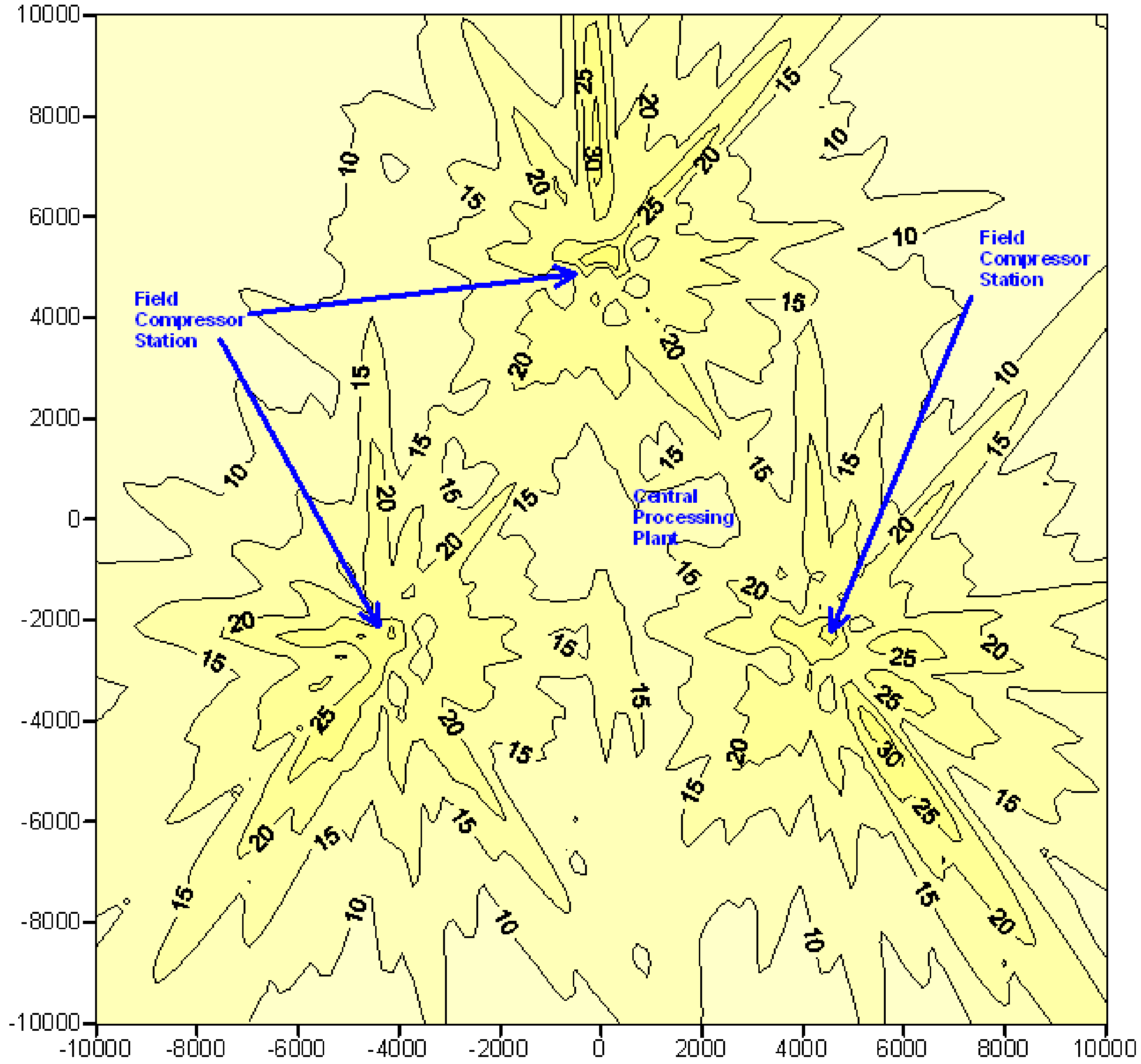

Figure 27	Predicted maximum 1-hour average ground-level concentrations of nitrogen dioxide for the 1 x CPP and 3 x FCS compressor station setup in isolation for Region 3		
Location: Region 3	**Averaging period:** 1-hour	**Data source:** TAPM met, AUSPLUME Modelling	**Units:** µg/m³ and metres
Type: NO_2 (100th percentile) contour plot	**Air quality objective:** 250 µg/m³	**Prepared by:** S. Menzel	**Date:** 28/05/09

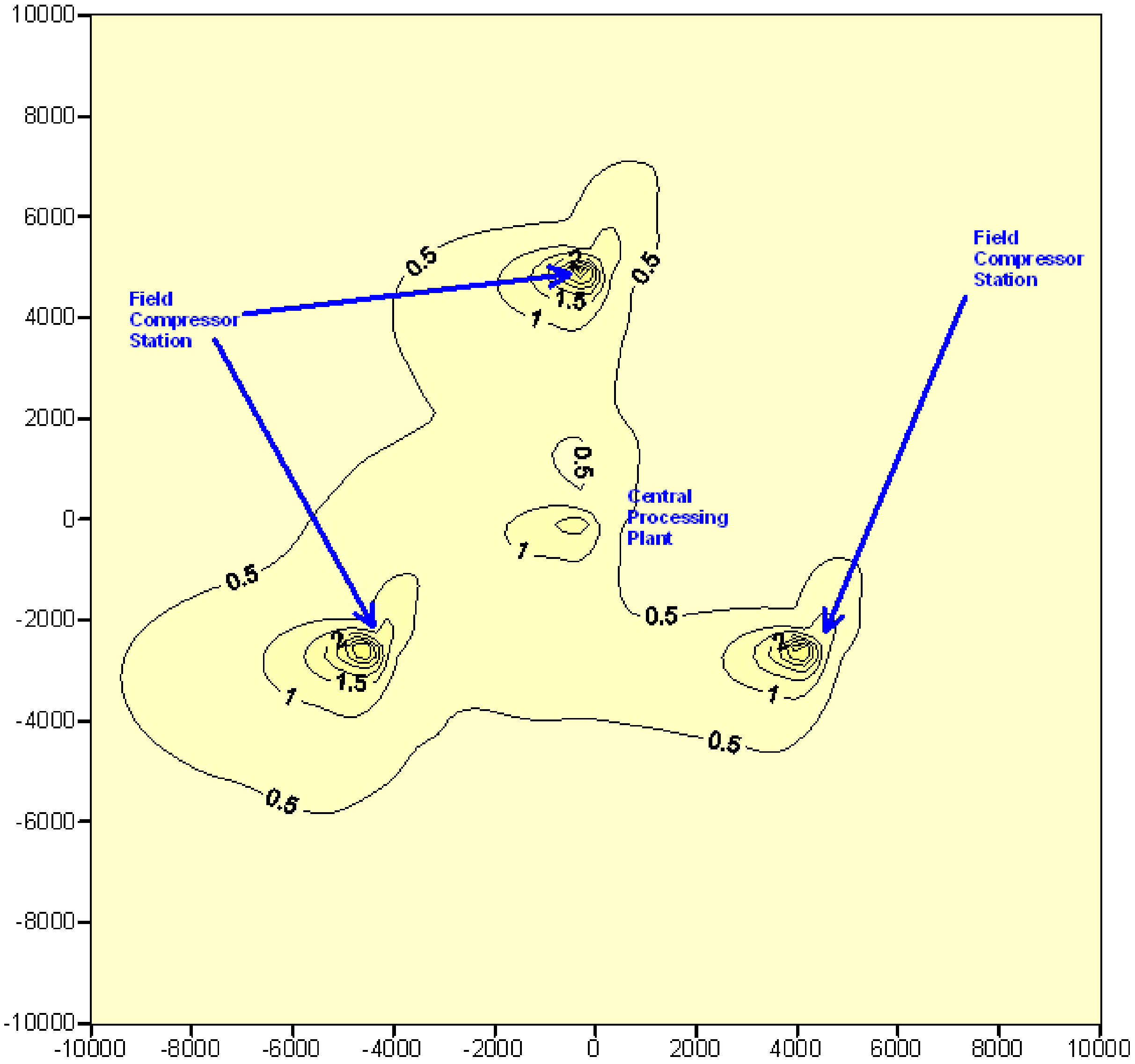

Figure 28 Predicted annual average ground-level concentrations of nitrogen dioxide for the 1 x CPP and 3 x FCS compressor station setup in isolation for Region 3

Location: Region 3	**Averaging period:** Annual	**Data source:** TAPM met, AUSPLUME Modelling	**Units:** µg/m³ and metres
Type: NO_2 (100th percentile) contour plot	**Air quality objective:** Health and wellbeing 62 µg/m³	**Prepared by:** S. Menzel	**Date:** 28/05/09

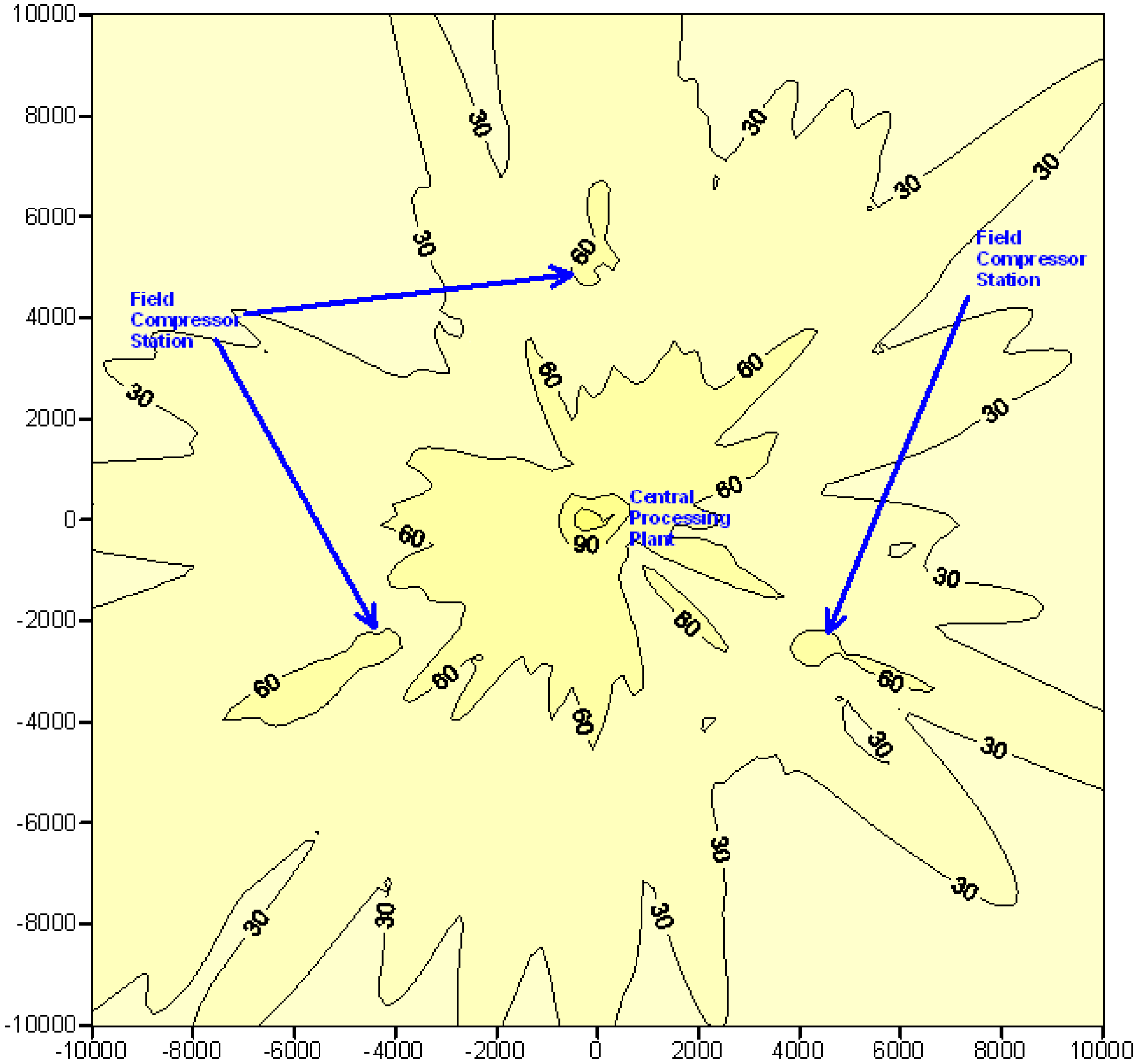

Figure 29 **Predicted maximum 8-hour average ground-level concentrations of carbon monoxide for the 1 x CPP and 3 x FCS compressor station setup in isolation for Region 1**

Location: Region 1	**Averaging period:** 8-hour	**Data source:** TAPM met, AUSPLUME Modelling	**Units:** µg/m³ and metres
Type: CO (100th percentile) contour plot	**Air quality objective:** 11 000 µg/m³	**Prepared by:** S. Menzel	**Date:** 28/05/09

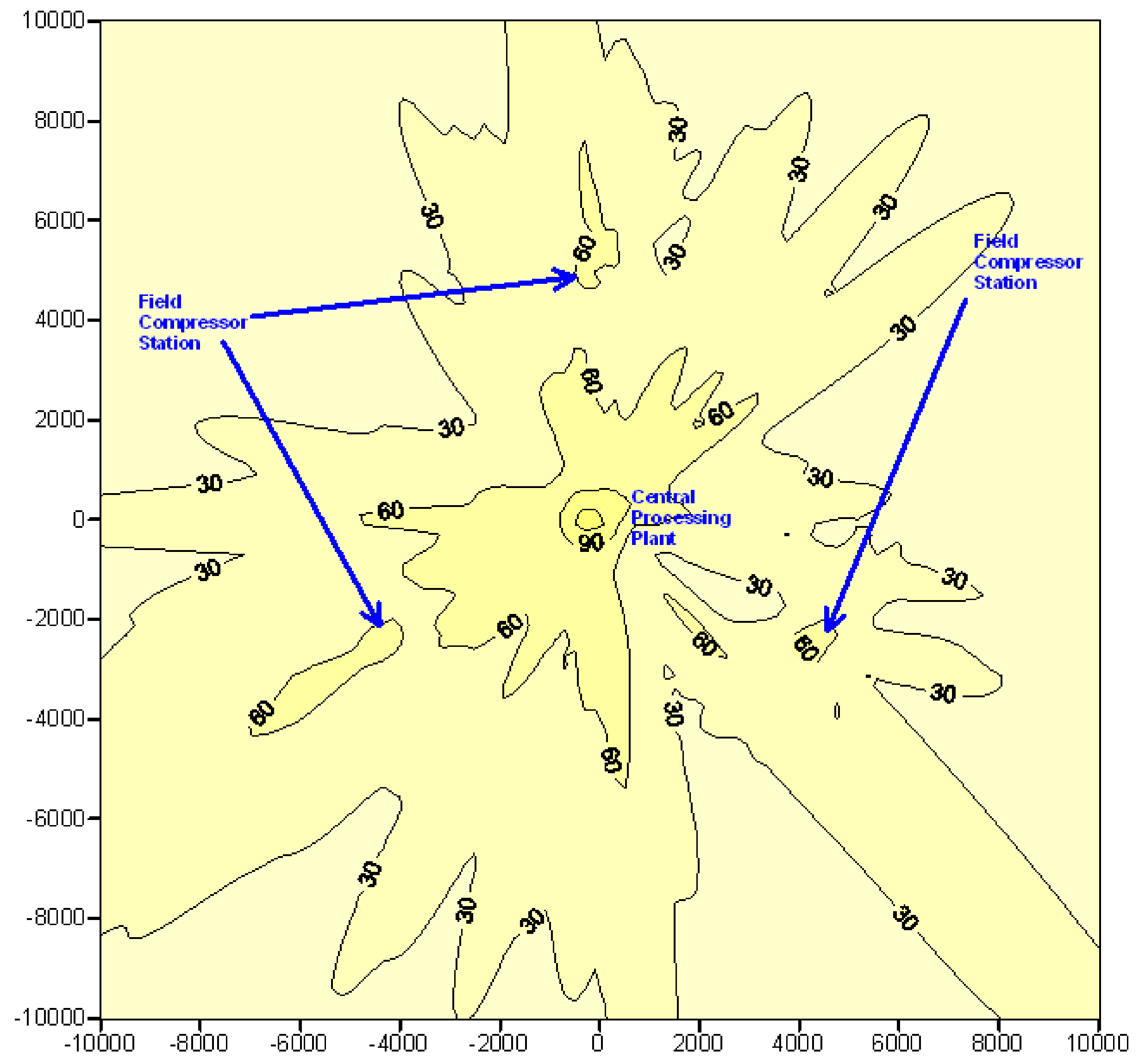

Figure 30 **Predicted maximum 8-hour average ground-level concentrations of carbon monoxide for the 1 x CPP and 3 x FCS compressor station setup in isolation for Region 2**

Location: Region 2	**Averaging period:** 8-hour	**Data source:** AUSPLUME Modelling	**Units:** µg/m³ and metres
Type: CO (100th percentile) contour plot	**Air quality objective:** 11 000 µg/m³	**Prepared by:** S. Menzel	**Date:** 28/05/09

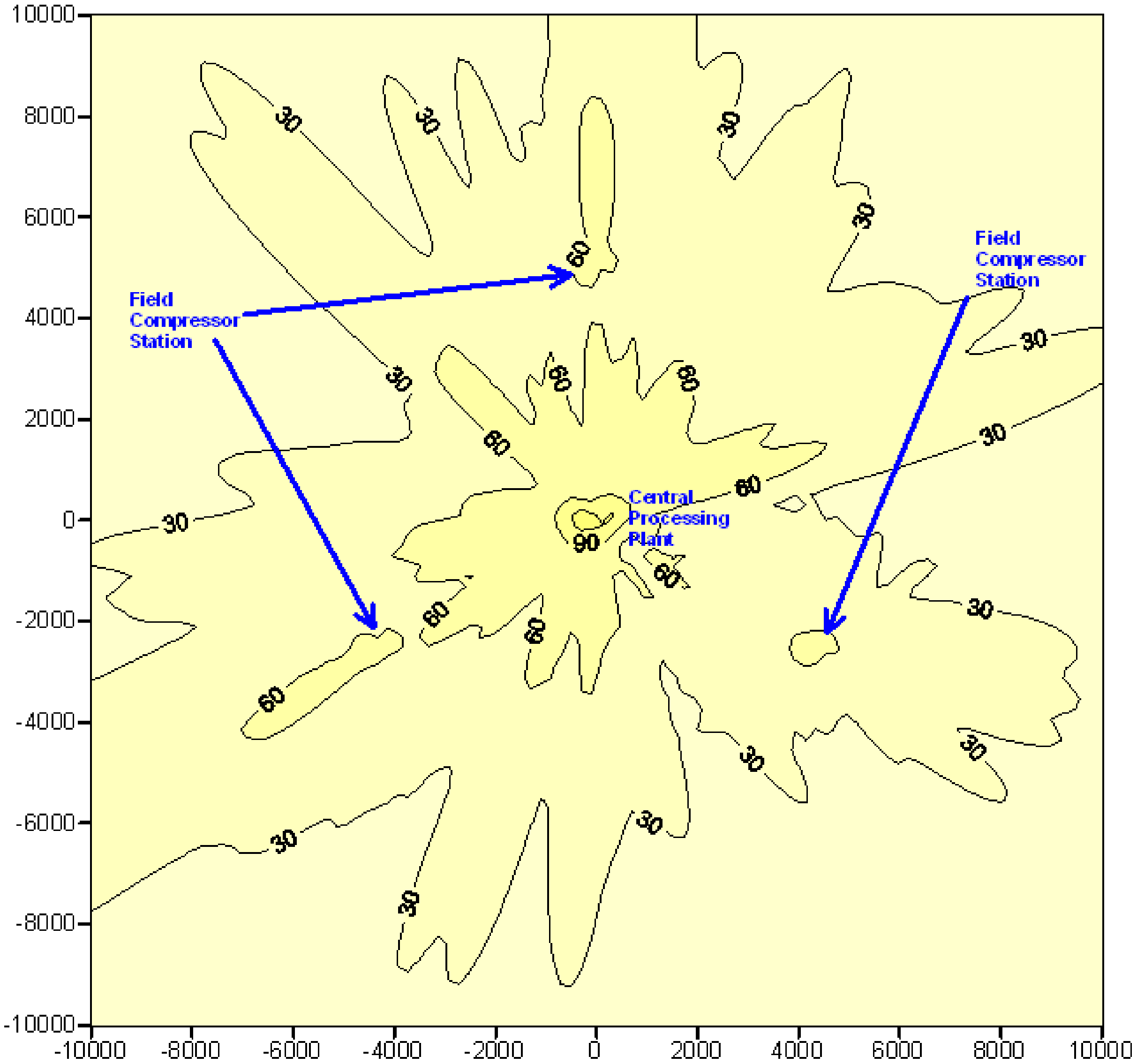

Figure 31 **Predicted maximum 8-hour average ground-level concentrations of carbon monoxide for the 1 x CPP and 3 x FCS compressor station setup in isolation for Region 3**

Location: Region 3	**Averaging period:** 8-hour	**Data source:** AUSPLUME Modelling	**Units:** µg/m³ and metres
Type: CO (100th percentile) contour plot	**Air quality objective:** 11 000 µg/m³	**Prepared by:** S. Menzel	**Date:** 28/05/09

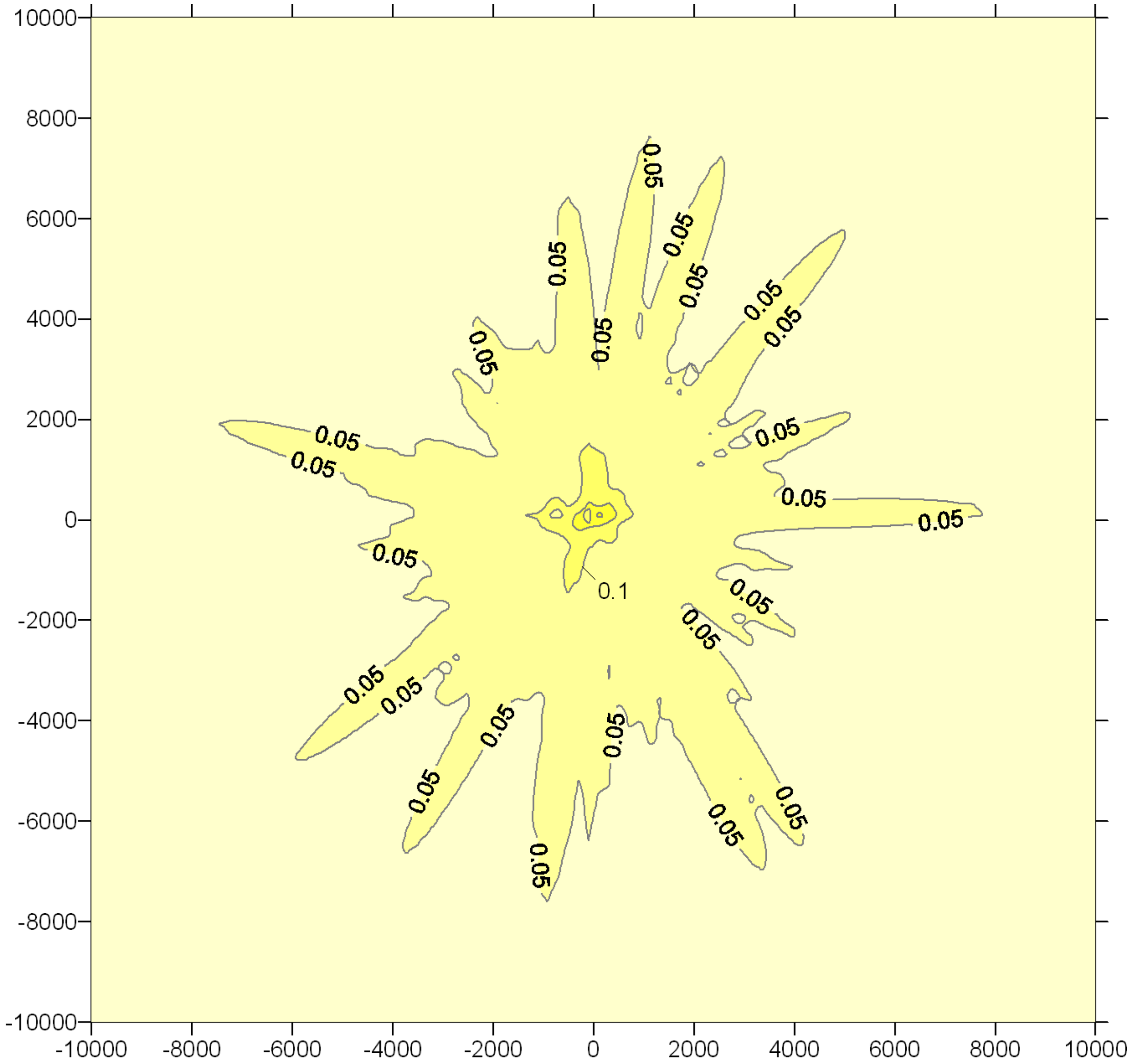

Figure 32 Predicted maximum 1-hour average ground-level concentrations of nitrogen dioxide for the gas flare at the CPP during non-normal emergency operations, in isolation, for Region 1

Location: QCLNG project area, Surat Basin	**Averaging period:** 1-hour	**Data source:** Ausplume modelling	**Units:** µg/m³ and metres
Type: NO_2 (100th percentile) contour plot	**Air quality objective:** 250 µg/m³	**Prepared by:** A. Schloss and A. Balch	**Date:** 13/02/09

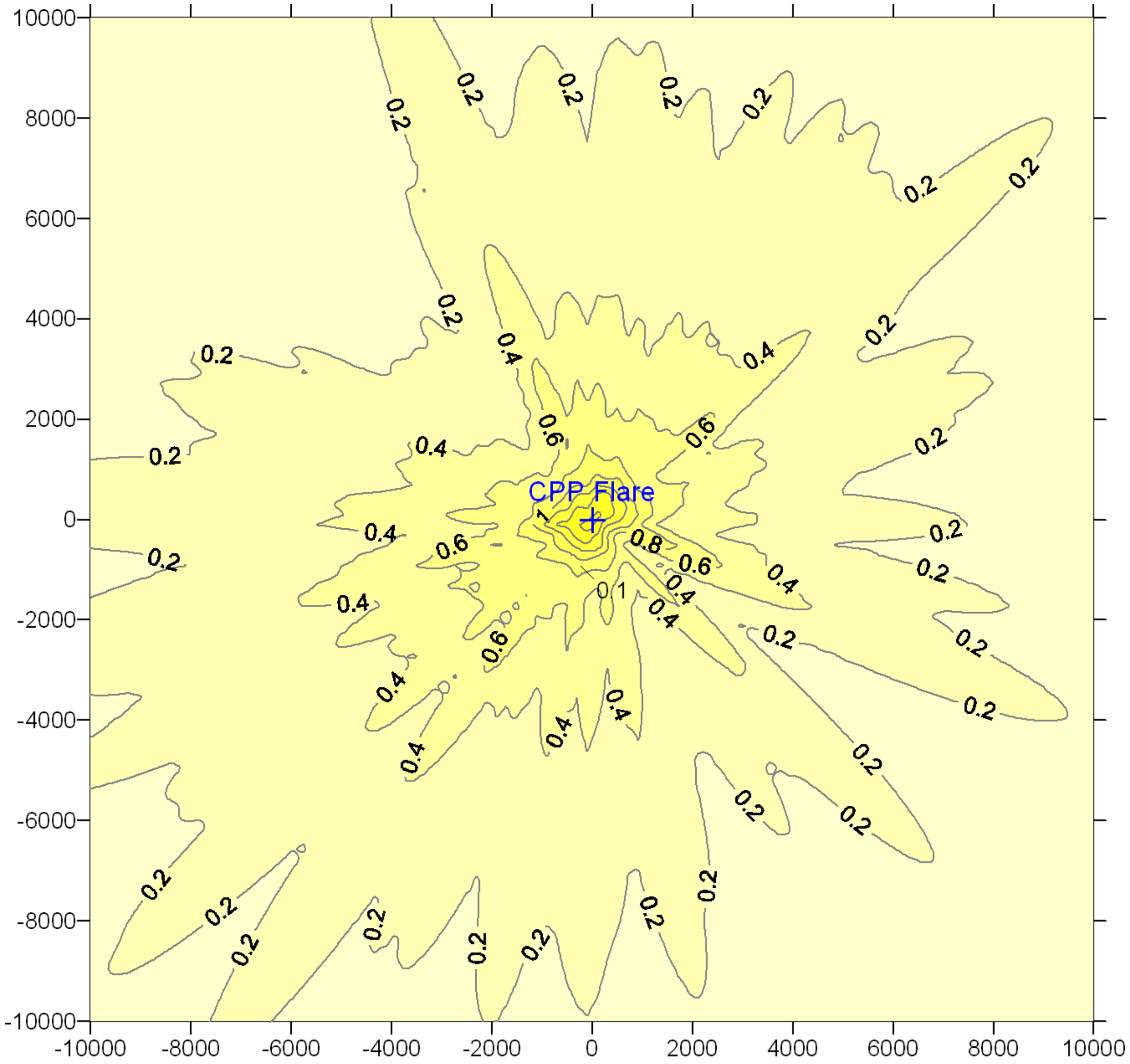

Figure 33 Predicted maximum 1-hour average ground-level concentrations of carbon monoxide for the gas flare at the CPP during non-normal emergency operations, in isolation, for Region 1

Location: QCLNG project area, Surat Basin	**Averaging period:** 8-hour	**Data source:** Ausplume modelling	**Units:** µg/m³ and metres
Type: CO (100th percentile) contour plot	**Air quality objective:** 11,000 µg/m³	**Prepared by:** A. Schloss and A. Balch	**Date:** 13/02/09

APPENDIX A
STATISTICAL METHODS

Prepared for

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KE0810650
June 2009

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APPENDIX A – STATISTICAL METHODS

Pearson Correlation Coefficient

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

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

Equation 1. Pearson Correlation Coefficient

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

Index of Agreement

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

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

Equation 2. Index of Agreement

Where O_{mean} is the observed mean

Mean Absolute Error

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

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

Equation 3. Mean Absolute Error

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

Complex Vector Correlation

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

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

Equation 4. Complex Correlation Coefficient

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

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

Equation 5. Phase Angle

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

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APPENDIX B
IMPACT ASSESSMENT FOR HYDROCARBONS

Prepared for

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KE0810650

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Indicator	Source of Air quality objective or standard	Averaging period	Air quality objective or standard	Predicted maximum ground-level concentration (µg/m³)			Percentage of air quality objective (%)		
			(µg/m³)	Region 1	Region 2	Region 3	Region 1	Region 2	Region 3
1,1,2,2-Tetrachloroethane	NOHSC:1003	8-hour	6,900	0.018	0.018	0.018	<0.000	<0.000	<0.000
1,1,2-Trichloroethane	Vic SEPP	3-minute	1,800	0.032	0.035	0.033	0.002	0.002	0.002
1,2,3-Trimethylbenzene	Vic SEPP	3-minute	4,000	0.023	0.025	0.024	0.001	0.001	0.001
1,2,4-Trimethylbenzene	Vic SEPP	3-minute	4,000	0.014	0.016	0.015	<0.000	<0.000	<0.000
1,1-Dichloroethane	TCEQ	1-hour	4,000	0.014	0.015	0.015	<0.000	<0.000	<0.000
1,2-Dichloroethane	NSW DECC	1-hour	70	0.014	0.015	0.015	0.020	0.022	0.021
	EPP(Air)	24-hour	750	0.009	0.010	0.010	0.001	0.001	0.001
1,2-Dichloropropane	TCEQ	1-hour	3,500	0.016	0.017	0.017	<0.000	<0.000	<0.000
1,3,5-Trimethylbenzene	NSW DECC	1-hour	2,200	0.020	0.022	0.022	0.001	0.001	0.001
1,3-Butadiene	EPP(Air)	1-year	2.40	0.020	0.021	0.019	0.816	0.868	0.790
1,3-Dichloropropene	NOHSC:1003	8-hour	4,500	0.012	0.012	0.012	<0.000	<0.000	<0.000
2,2,4-Trimethylpentane	TCEQ	1-hour	3,500	0.145	0.161	0.159	0.004	0.005	0.005
Acetaldehyde	Vic SEPP	3-minute	5,900	8.284	9.129	8.704	0.140	0.155	0.148
Acrolein	NSW DECC	1-hour	0.42	2.990	3.304	3.274	712.0	786.7	779.6
	Vic SEPP	3-minute	0.77	5.093	5.613	5.351	661.5	728.9	695.0
	WHO	30-minute	50	3.643	4.417	4.002	7.286	8.834	8.004
	TCEQ	1-hour	2.3	2.990	3.304	3.274	130.0	143.7	142.3
	TCEQ	1-year	0.23	0.377	0.401	0.365	163.8	174.3	158.7
Benzene	NSW DECC	1-hour	29	0.256	0.283	0.280	0.883	0.975	0.967
	EPP(Air)	1-year	10	0.032	0.034	0.031	0.323	0.343	0.312
Biphenyl	NSW DECC	1-hour	24	0.123	0.136	0.135	0.514	0.568	0.563
Butane	NOHSC:1003	8-hour	1,900,000	0.244	0.242	0.243	<0.000	<0.000	<0.000
Butyr/Isobutyraldehyde	TCEQ	1-hour	14	0.059	0.065	0.064	0.420	0.464	0.460
Carbon Tetrachloride	NSW DECC	1-hour	12	0.021	0.024	0.023	0.178	0.197	0.195
Chlorobenzene	Vic SEPP	3-minute	1,500	0.030	0.033	0.032	0.002	0.002	0.002

Indicator	Source of Air quality objective or standard	Averaging period	Air quality objective or standard	Predicted maximum ground-level concentration (µg/m^3)			Percentage of air quality objective (%)		
			(µg/m^3)	Region 1	Region 2	Region 3	Region 1	Region 2	Region 3
Chloroethane	NSW DECC	1-hour	0.05	0.001	0.001	0.001	2.267	2.504	2.482
Chloroform	NSW DECC	1-hour	900	0.017	0.018	0.018	0.002	0.002	0.002
Cyclopentane	NOHSC:1003	8-hour	1,720,000	0.103	0.101	0.102	<0.000	<0.000	<0.000
Ethane	TCEQ	1-hour	12,000	61.087	67.499	66.887	0.509	0.562	0.557
Ethylbenzene	NSW DECC	1-hour	8,000	0.023	0.026	0.025	<0.000	<0.000	<0.000
Ethylene Dibromide	TCEQ	1-hour	4.00	0.026	0.028	0.028	0.644	0.712	0.705
Formaldehyde	EPP(Air)	24-hour	54	21.014	23.012	21.723	38.915	42.615	40.228
	EPP(Air)	30-minute	110	37.423	45.373	41.111	34.021	41.248	37.374
Methane	TCEQ	1-hour	Asphyxiant						
Methanol	Vic SEPP	3-minute	8,700	2.477	2.730	2.603	0.028	0.031	0.030
	NSW DECC	1-hour	3,000	1.454	1.607	1.593	0.048	0.054	0.053
Methylcyclohexane	NOHSC:1003	8-hour	1,610,000	0.556	0.549	0.553	0.000	0.000	0.000
Methylene Chloride (Dichloromethane)	Vic SEPP	3-minute	5,800	0.020	0.022	0.021	<0.000	<0.000	<0.000
2-Methylnaphthalene	TCEQ	1-hour	60	0.019	0.021	0.021	0.032	0.036	0.035
n-Hexane	NSW DECC	1-hour	3,200	0.646	0.714	0.707	0.020	0.022	0.022
n-Nonane	NOHSC:1003	8-hour	1,050,000	0.050	0.049	0.049	<0.000	<0.000	<0.000
n-Octane	NOHSC:1003	8-hour	1,400,000	0.159	0.157	0.158	<0.000	<0.000	<0.000
n-Pentane	NSW DECC	1-hour	33,000	1.513	1.671	1.656	0.005	0.005	0.005
Naphthalene	NOHSC:1003	8-hour	52,000	0.034	0.033	0.033	<0.000	<0.000	<0.000
Phenol	Vic SEPP	3-minute	130	0.024	0.026	0.025	0.018	0.020	0.019
Propane	TCEQ	1-hour	18,000	24.377	26.935	26.691	0.135	0.150	0.148
Pyrene	TCEQ	1-hour	0.50	0.001	0.001	0.001	0.158	0.175	0.173
Styrene	EPP(Air)	7-day	280	0.006	0.006	0.006	0.002	0.002	0.002
	EPP(Air)	30-minute	75	0.017	0.020	0.018	0.022	0.027	0.025
Toluene	EPP(Air)	24-hour	4,100	0.162	0.178	0.168	0.004	0.004	0.004

Indicator	Source of Air quality objective or standard	Averaging period	Air quality objective or standard (µg/m^3)	Predicted maximum ground-level concentration (µg/m^3)			Percentage of air quality objective (%)		
				Region 1	Region 2	Region 3	Region 1	Region 2	Region 3
	EPP(Air)	1-year	410	0.030	0.032	0.029	0.007	0.008	0.007
	EPP(Air)	30-minute	1,100	0.289	0.351	0.318	0.026	0.032	0.029
Vinyl Chloride	EPP(Air)	24-hour	28	0.006	0.006	0.006	0.021	0.023	0.022
Xylene	EPP(Air)	24-hour	1,200	0.073	0.080	0.076	0.006	0.007	0.006
	EPP(Air)	1-year	950	0.013	0.014	0.013	0.001	0.002	0.001
Benzo(b)fluoranthene	TCEQ	1-hour	0.5	0.000	0.000	0.000	0.019	0.021	0.021
Chrysene	TCEQ	1-hour	0.5	0.000	0.000	0.000	0.081	0.089	0.088
Acenaphthene	TCEQ	1-hour	1	0.001	0.001	0.001	0.073	0.080	0.080
Acenaphthylene	TCEQ	1-hour	1	0.003	0.004	0.004	0.322	0.355	0.352
Benzo(e)pyrene	TCEQ	1-hour	0.5	0.000	0.000	0.000	0.048	0.053	0.053
Benzo(g,h,i)perylene	TCEQ	1-hour	0.5	0.000	0.000	0.000	0.048	0.053	0.053
Fluoranthene	TCEQ	1-hour	0.5	0.001	0.001	0.001	0.129	0.143	0.141
Fluorene	TCEQ	1-hour	0.5	0.003	0.004	0.004	0.660	0.729	0.722
Phenanthrene	TCEQ	1-hour	0.5	0.006	0.007	0.007	1.210	1.337	1.325