Australia Pacific LNG Project

Volume 5: Attachments

Attachment 28: Air Quality Impact Assessment – Gas Fields

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AUSTRALIA PACIFIC LNG GAS FIELDS PROJECT AREA - AIR QUALITY IMPACT ASSESSMENT

Prepared for

WORLEY PARSONS

KE0901668

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Draft

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Glossary

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

Term	Definition
kWe	kilowatts (electrical energy output)
MW	megawatts
bkW	brake kilowatts (mechanical energy output)
bkW-hr	brake kilowatt hours
bhp	brake horsepower
bhp-hr	brake horsepower hour
g/bkW-hr	grams per brake kilowatt hour
Btu	British thermal units
Btu/bhp-hr	British thermal units per brake horsepower hour
MJ/bkW-hr	megajoules per brake kilowatt hour

Air pollutants and chemical nomenclature

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

Other abbreviations

Australia Pacific LNG	Australia Pacific LNG
Origin	Origin Energy
ConocoPhillips	ConocoPhillips Australia LNG Pty Limited
QGC	Queensland Gas Company
CSG	coal seam gas
LNG	liquefied natural gas
GPF	Gas processing facility
WTS	Water transfer station

Other abbreviations

WTF	Water treatment facility
DERM	Department of Environment and Resource Management
NPI	National Pollutant Inventory
NEPM	National Environment Protection (Ambient Air Quality) Measure
Air Toxics NEPM	National Environment Protection (Air Toxics) Measure
EPP Air	Environmental Protection (Air) Policy
Approved Methods	Approved Methods for the Modelling and Assessment of Air Pollutants in NSW
VicSEPP	State Environmental Protection Policy of Victoria
TCEQ	Texas Commission on Environmental Quality Effects Screening Levels
Clean Air Regulation	NSW Protection of the Environment Operations (Clean Air) Regulation 2002
BoM	Bureau of Meteorology
ToR	Terms of Reference
CAT	Caterpillar engines
EMP	Environmental Management Plan
EIS	Environmental Impact Statement
EIA	Environmental Impact Assessment
NSCR	Non-Selective Catalytic Reduction (NO_X emission control technology)
RO	Reverse osmosis

Statistical terms

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

1. Executive Summary

Australia Pacific LNG Pty Limited (Australia Pacific LNG) proposes to produce liquefied natural gas (LNG) from its coal seam gas (CSG) resources in the Surat and Bowen Basins in Queensland. The Australia Pacific LNG Project (the Project) has been declared a 'significant project for which an environmental impact statement (EIS) is required' under the *State Development and Public Works Organisation Act 1971*. The Project consists of the following major elements, development of:

- CSG resources with the Surat Basin, also known as the Walloons gas fields ('the gas fields')
- a 450km high pressure gas transmission pipeline to transport the CSG to a LNG plant on Curtis Island near Gladstone ('the gas pipeline')
- a LNG plant and associated infrastructure to produce LNG for export ('LNG facilities')

Katestone Environmental has been commissioned by WorleyParsons to undertake an air quality impact assessment in preparation of an EIS for the gas fields and the gas pipeline elements of the Project. This report describes the following:

- sources and nature of air emissions associated with the gas fields development
- ambient air quality of the gas fields area that might be affected by the Project
- atmospheric dispersion modelling methodology applied to the study
- air quality impact assessment for both normal and abnormal (upset) operating conditions
- cumulative impacts of air emissions from the Project as well as other planned CSG developments over the central gas fields' area southwest of Chinchilla.

The primary source of air emissions within the gas fields' area include:

- gas-fired engines used to drive well-head pumps
- gas-fired engines used to drive the gas compressors at the gas processing facilities (GPF)
- gas-fired engines used to drive the water pumps at the water transfer stations (WTS) for the transfer of water from the well head to the water treatment facilities (WTF)
- gas-fired engines used to generate electrical power at the GPFs and WTFs
- gas-fired boilers used to regenerate the gas dehydration units.

The assessment has also considered the potential for impacts to air quality during abnormal or upset operating conditions when gas may be vented through the flares at the GPFs.

The assessment has identified the following key air pollutants are likely to be emitted within the gas fields:

- oxides of nitrogen (NO_X), as nitrogen dioxide (NO_2)
- sulphur dioxide (SO_2)

- carbon monoxide (CO)
- particulate matter with an aerodynamic diameter less than ten microns (PM_{10})
- hydrocarbons

Detailed studies of climate, meteorological and existing air quality were conducted to support and inform the study. The assessment of potential effects on air quality associated with the gas fields' operations has been carried out using atmospheric dispersion models and modelling techniques that are recognised as industry best practice.

The following conclusions can be drawn from the air quality assessment:

- Nitrogen dioxide was found to be the most important air pollutant. Predicted ground-level concentrations of nitrogen dioxide due to the operation of the gas fields are unlikely to exceed the Queensland Environmental Protection (Air) Policy 2008 (EPP Air) air quality objectives during normal operations accounting for existing sources of nitrogen dioxide in the region. This assumes that the current Talinga GPF (90 TJ/d) has non-selective catalytic converters fitted to six of the gas-fired reciprocating engines.
- Acrolein was found to be the next most important air pollutant. Predicted ground-level concentrations of acrolein due to the gas fields' operations are unlikely to exceed the air quality objectives during normal operations.
- Predicted ground-level concentrations of carbon monoxide and all other air pollutants due to the gas fields' operations are unlikely to exceed the EPP Air air quality objectives during normal operations.
- Predicted ground-level concentrations of carbon monoxide due to the gas fields' operations are unlikely to exceed the EPP Air air quality objective during normal operations accounting for existing sources of carbon monoxide in the region.
- The total cumulative impacts of the Australia Pacific LNG gas fields, the proposed Queensland Gas Company (QGC) gas plants and the power stations in the region have been assessed at the location where a cumulative impact is most likely to occur – the central gas fields' area southwest of Chinchilla, also known as the Undulla Nose. The maximum ground-level concentration of nitrogen dioxide predicted at any sensitive receptor location in this area is well below the EPP Air air quality objectives for the 1-hour and annual averages.
- The predicted ground-level concentrations of all air pollutants in the event of abnormal upset conditions requiring flaring are predicted to be below the air quality objectives during the operation of the gas flares. This is the case anywhere within the gas fields during any of the potential abnormal operating scenarios. This includes the use of all flares simultaneously while all other infrastructure is operating under normal conditions.

2. Introduction

Australia Pacific LNG Pty Limited (Australia Pacific LNG) proposes to produce liquefied natural gas (LNG) from its coal seam gas (CSG) resources in the Surat and Bowen Basins in Queensland. The Australia Pacific LNG Project (the Project) has been declared a 'significant project for which an environmental impact statement (EIS) is required' under the *State Development and Public Works Organisation Act 1971*. The Project consists of the following major elements, development of:

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- a LNG plant and associated infrastructure to produce LNG for export ('LNG facilities')

Katestone Environmental has been commissioned by WorleyParsons to undertake an air quality impact assessment in preparation of an EIS for the gas fields and the gas pipeline elements of the Project.

This report focuses on the methods and findings of an assessment of the potential for air quality issues relating to the operations of the Australia Pacific LNG gas fields. Air quality issues relating to project construction and development primarily relate to air emissions associated with major earthworks and land clearing, such as dust and combustion gas emissions from motor vehicles and earth moving equipment. These emissions will be short-term and highly transient. Notwithstanding this, they will be considered and managed in accordance with an environmental management plan (EMP).

This assessment has focussed on the primary source of air emissions for the gas fields during normal operations, including the:

- gas-fired engines used to drive the gas compressors at the gas processing facilities (GPF)
- gas-fired engines used to drive the water pumps at the water transfer stations (WTS) for the transfer of water from the well head to the water treatment facilities (WTF)
- gas-fired engines used to generate electrical power at the GPFs and WTFs
- gas-fired boilers used to regenerate the gas dehydration units.

The assessment has also considered the potential for impacts to air quality during abnormal or upset operating conditions when gas may be vented through the flares at the GPFs.

A variety of stationary gas-fired reciprocating internal combustion engine models will be selected for each operational purpose across the gas fields. Engines will be selected to meet specific project requirements such as production capacity, energy efficiency and environmental outcomes. The air quality assessment has investigated the potential impacts associated with all engines selected and operating at 100% capacity. The assessment has focused on the following key air pollutants:

- oxides of nitrogen (NO_X), as nitrogen dioxide (NO_2)

- sulphur dioxide (SO_2)
- carbon monoxide (CO)
- particulate matter with an aerodynamic diameter less than ten microns (PM_{10})
- hydrocarbons

The assessment of potential effects on air quality associated with emissions from combustion sources has been carried out using atmospheric dispersion modelling across the gas fields study area. The geographic location of each emission source is based on indicative locations for the major gas fields' infrastructure (GPFs, WTSs and WTFs) (see Figure 1). Consequently, the assessment's findings are indicative of the proposed gas fields' development and subject to minor changes as the final selection of plant locations is made as the Project develops. Notwithstanding this, the approach taken in the assessment is considered conservative, as all proposed project infrastructure and associated emission sources have been assumed to operate at their maximum load simultaneously. In reality, this scenario is unlikely to occur, as project infrastructure will be developed and decommissioned as gas reserves are depleted across the entire gas fields' area over a thirty year period. It is likely that a maximum of eight of the twenty three GPFs proposed would be operated across the region during any one year to deliver the quantity of CSG required for the LNG plant in Gladstone.

The assessment has been carried out at two scales. The first incorporates the entire gas fields' area to assess the potential cumulative effect of the entire project on air quality. This assessment incorporates three-dimensional meteorological patterns associated with wind flows over a vast region and incorporates the relevant terrain and land use patterns. The second assessment has been carried out at a local-scale, centred on the central gas fields' area southwest of Chinchilla, also known as the 'Undulla Nose' area. This area is densely populated with Australia Pacific LNG gas wells and processing facilities and is also in close proximity to gas fields operated by other proponents. The local-scale model provides more detailed information on the concentrations of pollutants that could occur in the near-field of Australia Pacific LNG infrastructure and provides a case study for the quantification of cumulative levels of air pollutants with neighbouring LNG producers.

The air quality impact assessment has been carried out in accordance with the EIS Terms of Reference, issued by the Coordinator-General (December 2009), including consideration of the following components relating to air quality:

- Discussion of local climate and meteorological conditions important to the dispersion of air pollutants
- Discussion of existing air quality including emission rates of air contaminants from major background sources within the region
- Discussion of gas-fired reciprocating engine characteristics, emissions and project plant and process design
- Methodology for the modelling of the regional and local meteorology using The Air Pollution Model (TAPM) and CALMET
- Methodology for the dispersion modelling of the gas fields' emission sources using CALPUFF on a regional and local scale

- Methodology for the dispersion modelling of regional background emission sources of NO_X such as power stations
- Selection of air pollutants to be assessed
- Review of relevant air quality objectives and criteria for the gas fields
- Assessment of predicted concentrations of air pollutants including NO_X, CO, SO_2, PM_{10}, hydrocarbons against air quality objectives

3. Overview of the Assessment Methodology

The air quality impact assessment is based on a dispersion modelling study that incorporates source characteristics and air pollutant emission rates based on the Project's pre-front end engineering and design (FEED) parameters and site-specific meteorology based on prognostic meteorological modelling with the assimilation of local observation of data. This section outlines the impact assessment methodology adopted for the study.

Air pollutants associated with gas-fired reciprocating engines and gas-fired boilers were identified and emission rates calculated from the following sources:

- technical specifications supplied by the manufacturer for individual engines selected for the Project Pre-FEED
- Part 4 of the *Protection of the Environment Operations (Clean Air) Regulation (2002)* – General standards of concentration for stationary reciprocating internal combustion engines and any boiler operating on gas
- The National Pollutant Inventory (NPI) handbooks for gas-fired reciprocating engines
- USEPA AP-42 Emission Factors, Chapter 3.2, Natural Gas-fired Reciprocating Engines.

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

- climate, including temperature, solar exposure, relative humidity, rainfall and atmospheric pressure
- meteorology, including wind speed and direction
- terrain and land use
- sensitive receptors
- emissions associated with the existing local industries
- ambient air quality, including NO_2, SO_2 and PM_{10} based on Department of Environment and Resource Management (DERM) monitoring data at Toowoomba
- ambient air quality for NO_2, based on the modelling of background NO_X sources such as existing power stations in the region

The impact assessment criteria were adopted from a review of the following sources:

- 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
- Texas Commission on Environmental Quality Toxicological section list of Effects Screening Levels

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

The atmospheric dispersion modelling included:

- the TAPM prognostic meteorological model to develop the three-dimensional site-specific meteorology for incorporation into the CALMET meteorological pre-processor
- meteorological data from Miles, Dalby and Applethorpe assimilated into TAPM to improve the simulation
- TAPM output as an 'initial guess' in the CALMET model
- CALMET inputs such as terrain and land use parameters, enhanced by the use of Geoscience Australia 9 second Digital Elevation Model (DEM) data and GIS and aerial image information
- CALMET modelling at a cell resolution of 3 km x 3 km across a 350 km x 350 km model domain
- CALMET modelling in the Undulla Nose area at a cell resolution of 300 m x 300 m across a 30 km x 30 km model domain, and
- emissions from existing industry such as coal- and gas-fired power stations in the region.

The assessment of air quality impacts considered the following:

- Assessment of criteria pollutants (including NO_2, SO_2, CO, PM_{10}, and $PM_{2.5}$) by comparison of the maximum (100th percentile) cumulative ground-level concentration (incremental plus background) at any location across the modelling domain with the EPP Air air quality objectives. Where the predicted concentration is insignificant compared with the air quality objectives, cumulative impact assessment has not been conducted.
- Calculation of the total cumulative ground-level concentration of NO_2 across the domain by modelling the emissions from the existing power stations in the region with the emissions from the gas fields.
- Assessment of all other air pollutants by comparison of the maximum (100th percentile) incremental ground-level concentration across the domain with the relevant air quality objectives.
- The application of NO_X emission controls using non-selective catalytic reduction (NSCR) technology on the existing rich-burn gas-fired reciprocating engines at the Talinga (90 TJ/day) GPF[1].

[1] Origin Energy commissioned Katestone Environmental in November 2009 to model air emissions associated with the existing Talinga GPF. The study determined that retro-fitting NSCR technology to 6 of the 12 Waukesha rich-burn gas fired engines could reduce NO_x emissions sufficiently to meet the EPP Air quality objectives and accommodate other proposed CSG developments in the area (see Section 4.1.3.3).

4. Development Proposal

4.1 Australia Pacific LNG Gas Fields Project Area

The Australia Pacific LNG gas fields are located in the Darling Downs region of central southern Queensland as illustrated in Figure 1. The Australia Pacific LNG CSG resource, known as the Walloons gas fields, cover an area of approximately 570,000 hectares, which, extends from Wallumbilla in the northwest to Millmerran in the southeast.

A staged development of the gas fields will be undertaken in order to optimise the extraction of CSG and the production of LNG throughout the proposed thirty-year life of the Project. However, the planning and selection of gas well and processing facility locations has not been finalised beyond the initial development.. Consequently, a conservative approach to the air quality assessment has been adopted by assuming all emission sources, including 23 GPFs and associated water handling infrastructure, will operate simultaneously over the life of the Project. It is likely that in reality up to only eight GPFs will operate across the gas fields at a time to maintain the proposed supply of CSG for the LNG facility at Curtis Island.

4.2 Composition of Coal Seam Gas

CSG is considered a relatively clean burning carbon-based gaseous fuel as its composition is primarily comprised of methane (CH_4). The composition of the CSG resource determined by chemical analysis is presented in Table 1.

Table 1 Composition of coal seam gas by analysis

Compound	Gas composition (mole %)	Gas composition (weight %)
Methane	97.87	96.02
Ethane	0.04	0.07
Propane	0.00	0.00
n-Butane	0.00	0.00
iso-Butane	0.00	0.00
n-Pentane	0.00	0.00
iso-Pentane	0.00	0.00
Hexane	0.00	0.00
Heptane	0.00	0.00
Octanes	0.00	0.00
Nitrogen	1.76	3.02
Carbon dioxide	0.33	0.89
Hydrogen	0.00	0.00

Compound	Gas composition (mole %)	Gas composition (weight %)
sulphide		

Table note:

Hydrogen sulfphide has been assumed to be one part per million for this assessment.

Pipeline gas analysis data provided by Origin.

4.3 Gas Field Processes and Infrastructure

This section describes the processes and infrastructure associated with the gas fields project area. The proposed total number of GPFs, WTSs and WTFs, and the number and types of engines to be used throughout the project area are summarised in Table 2.

4.3.1 Gas wells

The extraction of CSG will be carried out via a network of gas wells located within the Australia Pacific LNG exploration tenements. It is anticipated that gas wells will be developed at a rate of between 350 and 500 per year, depending on the available CSG supply in each tenement. A total of approximately 10,000 wells are anticipated to be developed over the life of the Project. Typically, well spacing will be based on a 750 metre grid.

The extraction of CSG from each gas well is expected to be carried out under free-flow once the pressure has been relieved on the resource deep underground through the removal of water in overlying aquifers. This process occurs in stages with the rate of gas flow not only different between gas fields but wells within each field. To achieve free-flow, a water pump driven by a small gas-fired engine will be operated at each well site until an adequate rate of gas free-flow occurs. This engine will not be operated for the entire duration of the gas extraction period from each well site.

It is expected that small quantities of gas will be released even at the initial stages of well dewatering, while small quantities of gas will be entrained in the water and water will be present in the gas. In order to prepare the gas for pipeline transmission to the GPF, both water and gas are passed through and wellhead separator, where the mixture is separated into separate gas and water streams. The two streams are separated and injected into the low pressure gas and water gathering network. The gas collected at each wellhead is then piped to the GPF located in a central position to the network of wells within the tenement.

Emissions associated with the water pump engines include NO_X, CO and trace amounts of SO_2 and hydrocarbons.

4.3.2 Gas processing facilities

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

Gas compression

Gas will arrive at the GPFs in a number of gas gathering trunklines from the nearby wells. Pipeline pressure will be as low as approximately 140kPag. At the GPF, gas is collected and diverted to a number of compression units operating in parallel where the pressure is raised to approximately 12,500kPag.

A combination of reciprocating and rotary screw compressor units will be used to compress the gas to the main pipeline pressure required for transmission to the LNG facility. Compressor units will be powered by gas-fired reciprocating engines using a small portion of the CSG as fuel.

Air pollutants emitted from the gas-fired reciprocating engines used to drive the gas compressors include NO_X and CO and trace amounts of PM_{10}, $PM_{2.5}$, SO_2 and hydrocarbons.

Gas dehydration

Some water is removed through condensation as the gas is compressed in the screw and reciprocating compressor units. The cooled compressed gas is then routed to a tri-ethylene glycol (TEG) dehydration unit to remove the remaining water in the gas in order to meet pipeline specifications, such as corrosion prevention.

Dehydration of the gas takes place through the TEG dehydration unit. The gas is contacted with TEG in a contactor column, extracting the water and allowing dry gas to be passed through. 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.

The dried gas is then routed to the high-pressure gas pipeline network. Water removed from the gas is treated before discharge.

Air pollutants emitted from the gas-fired boilers used to regenerate the TEG dehydration units include NO_X and CO and trace amounts of PM_{10}, $PM_{2.5}$, SO_2 and hydrocarbons.

Power generation

Electrical power for general use at the GPF will be generated on site using gas-fired reciprocating engines. The power capacity of the power generation engines is likely to be between that of the engines that drive the screw and reciprocating compressors. A small portion of the CSG extracted from the gas well will be consumed in the operation of the engines.

Air pollutants emitted from the gas-fired reciprocating engines used to drive the power generators include NO_X, CO, and trace amounts of PM_{10}, $PM_{2.5}$, SO_2 and hydrocarbons.

Gas flares

A gas flare will be used at the GPFs for pressure management, removing the need for individual vents at each wellhead. The flare will be used in the event that a compressor unit is not working or the downstream LNG processing facility ceases to process gas due to an upset.

The frequency of gas flaring will be very low and two nominal scenarios have been developed for the purposes of the air quality assessment. These scenarios include:

- Normal flaring: Normal GPF compressor and power generation engines and dehydration re-boilers plus flaring of 50% of the GPF feed gas. The frequency of this scenario is estimated to be for 3% of the time, e.g., once per month per GPF for 22 hours per occasion. Flaring under this scenario will not occur simultaneously from all GPFs.

- Shutdown flaring: During shutdown of all processing trains of the downstream LNG plant, continuous flaring may occur. This scenario assumes that flaring equivalent to 50% of the capacity of each GPF occurs at each location, with GPF compression off-line and emissions from power generation equivalent to 100% capacity. The frequency of this scenario is estimated to be for 0.5% of the time, e.g., once per month per GPF for 3.5 hours per occasion. Flaring may occur simultaneously from all GPFs.

To assess the worst-case flaring scenario, a conservative approach has been adopted. The assessment has been undertaken based on gas flaring occurring at all GPFs while operating under their normal operating scenario. While this scenario is extremely unlikely to occur, the approach has been undertaken to investigate the cumulative impacts associated with emissions released from GPFs that are closely located.

Air pollutants emitted from the gas flares include NO_X and CO and trace amounts of SO_2 and hydrocarbons. All flares have a Ringelmann value of less than one and are assumed to be smokeless. Consequently, particulate emissions are estimated to be zero.

4.3.3 Water transfer stations

Associated water refers to the water in underground aquifers overlying the CSG reserve that needs to be removed through the gas wells to relieve pressure and initiate the flow of gas. This water, generally described as brackish, is too saline to be discharged directly into the environment, and consequently, it is transferred to a nearby facility for desalination treatment. WTSs are isolated water pumping stations located across the gas fields project area to transmit the associated water from the wellheads to the WTFs.

Water pumps will be driven by electrical power generated using gas-fired reciprocating engines. A small portion of the CSG extracted from the gas well will be consumed in the operation of the engines.

Air pollutants emitted from the gas-fired reciprocating engines used to drive the water pumps at the WTSs include NO_X and CO and trace amounts of SO_2, PM_{10}, $PM_{2.5}$ and hydrocarbons.

4.3.4 Water treatment facilities

The associated water will be desalinated using the reverse osmosis (RO) process and stored at the WTF prior to re-use or discharge into local surface waters. RO is a common filtration process used in the water treatment industry and uses pressure to force a solution through a membrane. As the solution passes through the filter, the solute (in this case the concentrated salts) are retained in a brine solution on the upstream side of the filter while the purified solvent (in this case the water) is allowed to pass through to the other side.

Electrical power for general use and to drive the RO process will be generated using gas-fired reciprocating engines. A small portion of the gas will be consumed in the operation of the engines.

Air pollutants emitted from the gas-fired reciprocating engines used to generate electrical power at the WTF and drive the RO process include NO_X and CO and trace amounts of SO_2, PM_{10}, $PM_{2.5}$ and hydrocarbons.

4.3.5 Existing Origin gas processing facility at Talinga

At present Origin operate a 90 TJ/d GPF at Talinga in the Undulla Nose or central gas fields' area. This GPF comprises 12 Waukesha L7042GSI uncontrolled rich-burn gas-fired reciprocating engines that are used to drive the rotary screw compressors, and two other models of lean-burn engines used to drive the reciprocating compressors and for power generation. Dehydration boilers are also used. Lean-burn gas-fired reciprocating engines are also used for power generation and water pumping at the existing Talinga WTS and WTF. The emission sources at the existing Talinga GPF, WTS and WTF are summarised in

Table 3.

4.3.6 Proposed expansion of the Talinga gas processing facility

As part of the Australia Pacific LNG gas fields' project, it is proposed that the Talinga GPF will be expanded to 180 TJ/d, in addition to the development of a nodal gas plant nearby, to increase the CSG production rate in the Undulla Nose, which is a known gas 'sweet spot'. The additional emission sources proposed for the existing Talinga GPF, WTS and WTF and the proposed Talinga nodal plant are summarised in Table 4.

Table 2 Summary of the proposed Australia Pacific LNG gas fields processes and emission sources

Source location	Facility capacity	Engine application	Engine model	Number of engines	Facility identification
Gas processing facility	225 TJ/d	Gas compression – screw compressor	CAT G3520B	20	GPF_COM_03a
		Gas compression – reciprocating compressor	CAT G3616	10	
		Power generation	CAT G3516C	3	
		TEG Dehydration re-boiler	Gas-fired boiler	3	
	150 TJ/d	Gas compression – screw compressor	CAT G3520B	13	GPF_CNS_03, GPF_CON_01b, GPF_ORA_03b, GPF_MUG_06, GPF_CON_02b, GPF_RCK_04a, GPF_LUK_02a, GPF_GIL_02
		Gas compression – reciprocating compressor	CAT G3616	7	
		Power generation	CAT G3516C	2	
		TEG Dehydration re-boiler	Gas-fired boiler	2	
	75 TJ/d	Gas compression – screw compressor	CAT G3520B	7	GPF_OAN_04, GPF_CNN_04, GPF_KIA_01a, GPF_WOL_01, GPF_DAL_01b, GPF_CAR_01a, GPF_HCK_01a, GPF_NGA_02, GPF_BYM_03, GPF_CAS_05, GPF_WAA_04, GPF_ZIG_06,
		Gas compression –	CAT G3616	4	

Source location	Facility capacity	Engine application	Engine model	Number of engines	Facility identification
		reciprocating compressor			GPF_ZIG_06, GPF_WAA_03
		Power generation	CAT G3516C	1	
		TEG Dehydration re-boiler	Gas-fired boiler	1	
Water transfer station	N/A	Power generation	CAT G3406	1	WTS_COM_04, WTS_CMN_03, WTS_MEL_02, WTS_MEL_01, WTS_PHS_07, WTS_MUG_08, WTS_RCK_06, WTS_RCK_05, WTS_COM_04a, WTS_RAM_01, WTS_HCK_02, WTS_NGA_05, WTS_BYM_04, WTS_BYM_03, WTS_DAL_01, WTS_CAS_02, WTS_CAR_01, WTS_DAL_02, WTS_WOL_02, WTS_TAL_00, WTS_CNN_01, WTS_CON_02, WTS_CNS_03, WTS_OAN_01, WTS_OAN_02, WTS_ORA_02, WTS_ORA_01, WTS_KIN_01, WTS_KIA_02, WTS_HCK_03, WTS_CON_02a, WTS_GIL_01, WTS_WAA_02, WTS_ZIG_03
Water treatment facility	N/A	Power generation	CAT G3516C	4	WTF_MEL_01, WTF_HCK_01, WTF_RCK_01a, WTF_WOL_01, WTF_BYM_01, WTF_CON_01, WTF_GIL_01, WTF_GIL_01a
Treated water transfer station	N/A	Power generation	CAT G3516C	1	GPF_CON_02b, GPF_RCK_04a, GPF_WOL_01, GPF_GIL_02, GPF_BYM_03

Table 3 Summary of the existing Origin gas fields processes and emission sources at Talinga

Source location and identification	Existing facility capacity	Engine application	Engine model	Number of engines
Gas processing facility	90 TJ/d	Gas compression – screw compressor	Waukesha L7042GSI without NSCR controls	6
		Gas compression – screw compressor	Waukesha L7042GSI with NSCR controls	6
		Gas compression – reciprocating compressor	CAT G3612	5
		Power generation	CAT G3406	3
		TEG Dehydration re-boiler	Gas-fired boiler	2
Water transfer station (WTS_Talinga)	N/A	Power generation	CAT G3406	1
Water treatment facility (WTF_Talinga)	N/A	Power generation	CAT G3406	4

Table note:
The Waukesha L7042GSI is a rich-burn gas-fired reciprocating engine.

Table 4 Summary of the proposed Talinga expansion processes and emission sources

Source location and identification	Additional facility capacity	Engine application	Engine model	Number of additional engines	Total number of engines after expansion
Gas processing facility	90 TJ/d	Gas compression – screw compressor	Waukesha L7042GL	3	15
		Gas compression – reciprocating compressor	CAT G3612	4	9
		Power generation	CAT G3406	1	4
		TEG Dehydration re-boiler	Gas-fired boiler	1	3
Water transfer station (WTS_TAL_00)	N/A	Power generation	CAT G3406	1	2[1]
Water treatment facility	N/A	Power generation	CAT G3406	0	4
Nodal gas processing facility (GPF_TAL_02b)	N/A	Gas compression – screw compressor	Waukesha L7042GL	8	8

Table note:

The Waukesha L7042GL is a lean-burn gas-fired reciprocating engine.

[1] Total of two engines used for water pumping, located at WTS_Talinga and WTS_TAL_00.

5. Emissions

5.1 Normal Operations

The Australia Pacific LNG gas fields normal operating scenario refers to daily procedures relating to the extraction of CSG from the gas wells, the transmission of gas from the wellhead to the GPF, the processing and compression of gas for pipeline transmission, the generation of electrical power at the GPFs and WTF, and the handling of associated water such as pumping, transfer and treatment. Consequently, emission sources considered in this air quality assessment are associated with the gas-fired reciprocating engines and gas-fired dehydration boilers used in these operations.

5.1.1 Air Pollutants

The air pollutants considered in this assessment are associated with the combustion of CSG fuel in the gas-fired reciprocating engines and gas-fired dehydration boilers employed throughout the project. The pollutants considered include NO_X, SO_2, CO, PM_{10}, $PM_{2.5}$ and various hydrocarbon species. Where possible, air pollutant emission rates have been calculated using manufacturer technical specifications for each engine model. Pollutant emission rates typically described in manufacturer specifications include NO_X, CO and total hydrocarbons (THC) or non-methane hydrocarbons (NMHC), and are usually expressed in terms of the pollutant emission rate per (mechanical) energy output (g/bkW-hr).

To calculate the emission rate of SO_2 the feed gas composition and fuel flow rate have been used. Feed gas analysis has found that the concentration of hydrogen sulphide (H_2S) is less than one part per million. However, it should be noted that a concentration of one part per million represents the limit of detection for the analysis method used, and consequently, the concentration of H_2S may be between zero and one part per million. For this assessment, the concentration of H_2S is assumed to be one part per million. The combustion of H_2S in the gas-fired engines and boilers causes sulphur to oxidise and form SO_2. While it is likely that sulphur will only be present in the CSG in trace amounts, a conservative assumption has been made whereby all of the H_2S (i.e., 1 ppm) is converted to SO_2 and emitted from the exhaust stacks.

To calculate the emission rate of hydrocarbons, the method outlined in the USEPA AP-42 document Natural Gas-fired Reciprocating Engines (Chapter 3.1), while for the gas-fired dehydration boilers the AP-42 document Natural Gas Combustion (Chapter 1.4) has been used. In accordance with the AP-42 document, the engines are classified as uncontrolled four-stroke lean-burn or uncontrolled four-stroke rich-burn engines. For this approach, the emission rate for each hydrocarbon species is the product of an emission factor (in g/bkW-hr) and the energy output of the engine (bkW).

The AP-42 emission factors have been determined from emissions monitoring data 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 Australia Pacific LNG gas fields is likely to be different. The composition of the natural gas fuel combusted in AP-42 emission tests will likely be a mixture of methane, ethane and propane, with trace amounts of butane, pentane, hexane, sulphur and other hydrocarbons. Whereas, the CSG, is a cleaner burning fuel because it is primarily composed of CH_4 (see Table 1). Consequently, the emission rates of hydrocarbons will be overestimated by the use of the AP-42 emission factors.

Emission rates of PM_{10} and $PM_{2.5}$ have also been calculated using the AP-42 documents, and in a similar way to the hydrocarbon emissions estimation technique, the mass rate of particulate emitted is a function of the engine or boiler energy output. The AP-42 document assumes that the emission factor for PM_{10} is equal to the emission factor for $PM_{2.5}$. Consequently, the emission rate for both particle size fractions is equal. This suggests that all particles emitted with a diameter less than 10 microns are actually $PM_{2.5}$. The emission factors used for PM_{10} and $PM_{2.5}$ relate to the total filterable portion.

5.1.2 Standards of emission concentrations

The Department of Environment and Resource Management (DERM) has not set emission concentration standards for sources of air pollution such as fuel burning activities. However the ToR for the Australia Pacific LNG Project prescribes that the air quality impact assessment should include: 'A comparison of the predicted level of emissions with the best practice national source emission standards.'

In NSW, the *Protection of the Environment Operations (Clear Air) Regulation (2002)* provides standards of emission concentrations for scheduled premises. The standards for stationary reciprocating internal combustion engines and gas-fired boilers are provided in Table 5.

Table 5 NSW standards of emission concentrations (in mg/m³)

Air impurity	Activity or plant	Standard of concentration
Oxides of nitrogen (as NO_2)	Stationary reciprocating internal combustion engines	450
	Any boiler operating on gas	350
PM_{10}	Any activity or plant	50
Hydrogen sulphide	Any activity or plant	5
Carbon monoxide	Any activity or plant involving combustion, including any stationary reciprocating internal combustion engines using a gaseous fuel	125
Volatile organic compounds, as n-propane		40

Table note:
Source: NSW Clear Air Regulation (2002)
Reference conditions: Dry, 273 K, 101.3 kPa, 3% oxygen content

5.1.3 Gas-fired Engines

The performance characteristics of all gas-fired reciprocating engines considered in the air quality assessment are presented in Table 6, while the emission source characteristics are presented in Table 7. Performance information is presented for normal operating conditions with the engines operating at both minimum and maximum operating loads.

The stack concentration and mass emission rate of criteria air pollutants for each of the gas-fired reciprocating engines are presented in Table 9, while the stack concentration and mass emission rate of hydrocarbon species are presented in Appendix A.

Preliminary dispersion modelling was conducted using the AP-42 emission factors for individual hydrocarbon compounds. The preliminary dispersion modelling found some potential for elevated levels of acrolein. However, acrolein is unlikely to be produced in the exhausts of the gas-fired reciprocating engines when predominantly methane composed CSG is used as the fuel, 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 described in the EIS report by Katestone Environmental for QGC, 'Air Quality Impact Assessment of Upstream and Pipeline Gas Field Infrastructure for the QCLNG Project, June 2009'. Consequently, acrolein emission rates have been characterised in this study using sampling data published in the QGC report, rather than AP-42.

In order to calculate the emission rate of acrolein for each individual engine capacity, the emission rate was calculated from the product of the measured stack concentration reported in the QGC report and the volume flow rate of the Australia Pacific LNG project engines.

Comparison of impacts for engines operating under minimum and maximum loads

The dispersion modelling assessment has been carried out for the engines operating at maximum capacity. Maximum capacity represents the worst-case emissions load and, consequently, the highest ground-level concentrations. To illustrate this, a sensitivity analysis has been carried out by comparing the predicted ground-level concentrations of oxides of nitrogen from the main engine used to drive the screw compressors (the CAT G3520B) for the minimum and maximum loads. The results of this sensitivity analysis are presented in Appendix B and show that ground-level concentrations are slightly higher for the 100% load scenario. This illustrates that there is no value in setting a minimum emission velocity on the Project approval. The concentration limit is sufficient to cover all eventualities.

Small capacity engines at the wellhead

The emission source characteristics of the small gas-fired generator sets used to drive the wellhead water pumps are presented in Table 10, while the stack concentration and mass emission rates of criteria air pollutants for the small the gas-fired generator sets are presented in Table 11. These generators have a significantly lower engine capacity, at 50 kWe, than the compressor driver engines and power generation engines. This represents between 1.5% and 4.5% the capacity of the size of the other engines used throughout the Project. Consequently, they have not been considered in the assessment. Additionally, the location of each wellhead is not yet known and will develop throughout the life of the Project.

Mitigation controls for emissions of oxides of nitrogen on rich-burn engines

All of the gas-fired reciprocating engines proposed for use at the GPFs, WTSs and WTFs are lean-burn engines. Lean-burn engines may operate up to the lean flame extinction limit, with oxygen levels of 12% or greater. Lean-burn engines typically have lower NO_X emissions than rich-burn engines.

The proposed Australia Pacific LNG project also includes the expansion of the existing Talinga GPF from the current operational capacity of 90 TJ/d to 180 TJ/d. The existing Talinga 90 TJ/d GPF comprises 12 Waukesha L7042GSI rich-burn gas-fired reciprocating engines to drive the screw compressors. These rich-burn engines emit approximately ten times more NO_X than similar lean-burn engines; however, the lean-burn engines tend to emit greater amounts of hydrocarbon compounds (US EPA, 2000). While the proposed expansion of the Talinga GPF will employ an additional three Waukesha L7042GL lean-burn engines, and a further eight Waukesha L7042GL lean-burn engines at the nearby nodal GPF, mitigation measures to reduce the amount of NO_X emitted from the Waukesha L7042GSI rich-burn engines has been recommended and assessed in this air quality assessment. With the use of Non-selective Catalytic Reduction (NSCR) control technology, the following emission reductions can be achieved for the rich-burn reciprocating engines:

- NO_X – 90% reduction
- CO – 80% reduction, and
- Hydrocarbons – 50% reduction

The exhaust source characteristics remain unchanged with the implementation of the NSCR controls.

Table 6 Performance characteristics of gas-fired reciprocating engines used across Australia Pacific LNG gas fields

Parameter	Units	CAT G3520B	Waukesha L7042GSI	Waukesha L7042GL	CAT G3616	CAT G3612	CAT G3516C	CAT G3406
Engine use		Screw compressor	Screw compressor	Screw compressor	Reciprocating compressor	Reciprocating compressor	Power generation	Power generation
Engine type		Lean-burn	Rich-burn	Lean-burn	Lean-burn	Lean-burn	Lean-burn	Lean-burn
Engine power at maximum load	bhp	1,725	1,480	1,480	4,735	3,550	2,221	171
	bkW	1,286[1]	1,104[1]	1,104[1]	3,531[1]	2,647[1]	1,656[1]	128[1]
Engine power at minimum load	bkW	960[2]	643[3]	919[4]	2,805[2]	2,083[2]	N/A	N/A
Heat rate	MJ/bkW-hr	9.75	10.83	10.09	9.53	9.56	8.60	11.15
Heat rate	Btu/bhp-hr	6,892	7,675	7,135	6,736	6,761	6,078	7,880

Table note:
[1] Maximum operating load at 100% capacity.
[2] Minimum operating load at 75% capacity.
[3] Minimum operating load at 58% capacity.
[4] Minimum operating load at 83% capacity.
The Waukesha L7042GSI, CAT G3612 and CAT G3406 engines are currently in use at the Talinga 90 TJ/day GPF.
N/A: Not available.

Table 7 Emission source characteristics of the gas-fired engines used across the Australia Pacific LNG gas fields at maximum load

Parameter	Units	CAT G3520B	Waukesha L7042GSI	Waukesha L7042GSI with NSCR[3]	Waukesha L7042GL	CAT G3616	CAT G3516C	CAT G3612	CAT G3406
Number of stacks per engine	-	1	1	1	1	2	1	2	1
Stack height	m	9.0	7.2	7.2	7.2	9.0	4.5	11.1	5.0
Stack diameter	m	0.36	0.355	0.355	0.355	0.457	0.36	0.457	0.127
Stack cross-sectional area	m^2	0.10	0.10	0.10	0.10	0.16	0.10	0.16	0.01
Exhaust gas velocity	m/s	49.1	33.2	33.2	33.2	45.6	54.9	34.3	29.2
Temperature	°C	537	607	607	607	469	477	459	593
Actual volume flow rate[1]	Am^3/hr	18,000	11,830	11,830	11,830		20,110	40,452	1,332
Actual volume flow rate[2]	Am^3/s	5.00	3.29	3.29	3.29	7.49	5.59	5.62	0.37
Normalised volume flow rate[2]	Nm^3/s	1.69	1.02	1.02	1.02	2.76	2.03	2.10	0.12
Plume buoyancy flux factor[4]	m^4/s^3	10.11	6.93	6.93	6.93	14.38	10.81	10.72	0.77

Table note:

[1] Volume flow per engine unit

[2] Volume flow per stack. Flow from the CATG3616 and CAT G3612 engines is assumed to be equally split between two 50% exhaust stacks.

[3] NSCR refers to the addition of Non-selective Catalytic Reduction NO_X controls of the Waukesha L7042GSI rich-burn engines.

[4] Plume buoyancy flux factor calculated based on annual average minimum daily temperature (night time) at Miles of 12.2 °C.

Maximum operating load for all engines is assumed to be 100% capacity.

The Waukesha L7042GSI, CAT G3612 and CAT G3406 engines are currently in use at the Talinga 90 TJ/day GPF. The Waukesha L7042GSI engines are categorised as rich-burn.

Table 8 Emission source characteristics of the gas-fired engines used across the Australia Pacific LNG gas fields at minimum load

Parameter	Units	CAT G3520B	Waukesha L7042GSI	Waukesha L7042GSI with NSCR[3]	Waukesha L7042GL	CAT G3616	CAT G3516C	CAT G3612	CAT G3406
Number of stacks per engine	-	1	1	1	1	2	1	2	1
Stack height	m	9.0	7.2	7.2	7.2	9.0	4.5	11.1	5.0
Stack diameter	m	0.36	0.355	0.355	0.355	0.457	0.36	0.457	0.127
Stack cross-sectional area	m^2	0.10	0.10	0.10	0.10	0.16	0.10	0.16	0.01
Exhaust gas velocity	m/s	39.3	18.0	18.0	27.0	36.7	N/A	27.0	N/A
Temperature	°C	537	523	523	359	470	N/A	480	N/A
Actual volume flow rate[1]	Am^3/hr	14,413	6,507	6,507	9,464	21,643	N/A	16,189	N/A
Actual volume flow rate[2]	Am^3/s	4.00	1.81	1.81	2.63	6.01	N/A	4.50	N/A
Normalised volume flow rate[2]	Nm^3/s	1.35	0.62	0.62	1.14	2.21	N/A	1.63	N/A
Plume buoyancy flux factor[4]	m^4/s^3	8.09	3.57	3.57	4.58	11.58	N/A	8.59	N/A

Table note:
1 Volume flow per engine unit
2 Volume flow per stack
3 NSCR refers to the addition of Non-selective Catalytic Reduction NOX controls of the Waukesha L7042GSI rich-burn engines.
4 Plume buoyancy flux factor calculated based on annual average minimum daily temperature (night time) at Miles of 12.2 oC.
The Waukesha L7042GSI, CAT G3612 and CAT G3406 are currently in use at the Talinga 90 TJ/day GPF. The Waukesha L7042GSI engines are categorised as rich-burn.
N/A – Data not available from engine technical specifications.

Table 9 Exhaust gas concentrations and emission rates of criteria pollutants for the gas-fired reciprocating engines used across the Australia Pacific LNG gas fields at maximum load

Pollutant	Load	Units	CAT G3520B	Waukesha L7042GSI	Waukesha L7042GSI NSCR	Waukesha L7042GL	CAT G3616	CAT G3516C	CAT G3612	CAT G3406
Oxides of nitrogen	Max	mg/Nm^3	280	6,455	646	681	333	328	1,643	14,760
		g/s	0.47	6.58	0.66	0.69	0.92	0.67	3.44	1.72
	Min[1]	mg/Nm^3	268	6,226	627	514	327	N/A	341	N/A
		g/s	0.36	3.86	0.39	0.58	0.72	N/A	0.56	N/A
Carbon monoxide	Max	mg/Nm^3	758	5,230	1,046	1,198	1210	656	5,964	952
		g/s	1.28	5.33	1.07	1.22	3.33	1.33	12.50	0.11
Sulphur dioxide	Max	mg/Nm^3	0.16	0.27	0.27	0.27	0.28	0.16	0.28	0.14
		g/s	0.00028	0.00028	0.00028	0.00028	0.00078	0.00033	0.00058	0.00002
PM_{10}	Max	mg/Nm^3	0.069	13.33	13.33	0.10	0.056	0.064	0.056	0.11
		g/s	0.00012	0.014	0.014	0.00010	0.00031	0.00013	0.00023	0.000013
$PM_{2.5}$	Max	mg/Nm^3	0.069	13.33	13.33	0.10	0.056	0.064	0.056	0.11
		g/s	0.00012	0.014	0.014	0.00010	0.00031	0.00013	0.00023	0.000013
Reference oxygen content	%	%	N/A	5.0	5.0	5.0	N/A	10.3	N/A	2.0

Table note:
1NOX concentrations and emission rates shown for minimum loads

Pollutant	Load	Units	CAT G3520B	Waukesha L7042GSI	Waukesha L7042GSI NSCR	Waukesha L7042GL	CAT G3616	CAT G3516C	CAT G3612	CAT G3406

2Assumes NSCR reduces emissions from rich-burn engines as follows NOx = 90%, CO = 80% and VOCs = 50%.

Exhaust gas concentrations (mg/Nm3) and emission rates (g/s) are based on total emissions per engine unit.

Reference oxygen conditions at 0oC, 1 Atm.

The Waukesha L7042GSI, CAT G3612 and CAT G3406 are currently in use at the Talinga 90 TJ/day GPF.

N/A – Data not available from engine technical specifications.

Table 10 Emission source characteristics for the wellhead water pump gas-fired generator sets

Parameter	Units	Value
Engine power	kWe	50
Number of stacks per engine	-	1
Stack height	m	2.6
Stack diameter	m	0.08
Stack cross-sectional area	m^2	0.01
Exhaust gas velocity	m/s	41.0
Temperature	°C	649
Actual volume flow rate[1]	Am^3/hr	744
Actual volume flow rate	Am^3/s	0.21
Normalised volume flow rate[2]	Nm^3/s	0.06
Plume buoyancy flux factor[3]	m^4/s^3	0.44

Table note:

1 Volume flow per engine unit

2 Volume flow per stack

3 Plume buoyancy flux factor calculated based on annual average minimum daily temperature (night time) at Miles of 12.2 oC.

Table 11 Exhaust gas concentrations and emission rates of criteria pollutants for the wellhead water pump gas-fired generator sets

Pollutant	Units	Value
Oxides of nitrogen	mg/Nm^3	3,312
	g/s	0.20
Carbon monoxide	mg/Nm^3	2,405
	g/s	0.15
Sulphur dioxide	mg/Nm^3	0.23
	g/s	0.000014

Table note:

Exhaust gas concentrations (mg/Nm3) and emission rates (g/s) are based on total emissions per unit at 100% operating load.

Exhaust oxygen content not provided.

Concentrations provided at stack conditions.

5.1.4 Gas-fired boilers

The emission source characteristics of the gas-fired boilers used to regenerate the TEG dehydration units are presented in Table 12. The stack concentration and mass emission rate of criteria air pollutants for each of the gas-fired reciprocating engines are presented in Table 13, while the stack concentration and mass emission rate of hydrocarbon species are presented in Appendix A.

Table 12 Emission source characteristics of the gas-fired boilers used for the regeneration of the TEG Dehydration Units

Parameter	Units	Value
Number of stacks per engine	-	1
Stack height	m	7.0
Stack diameter	m	0.20
Stack cross-sectional area	m^2	0.03
Exhaust gas velocity	m/s	4.4
Temperature	°C	500
Actual volume flow rate[1]	Am^3/hr	495
Actual volume flow rate	Am^3/s	0.14
Normalised volume flow rate[2]	Nm^3/s	0.05
Plume buoyancy flux factor[3]	m^4/s^3	0.27

Table note:
1 Volume flow per engine unit
2 Volume flow per stack
3 Plume buoyancy flux factor calculated based on annual average minimum daily temperature (night time) at Miles of 12.2 oC.

Table 13 Exhaust gas concentrations and emission rates of criteria pollutants for the gas-fired boilers

Pollutant	Units	Value
Oxides of nitrogen	mg/Nm^3	229
	g/s	0.01
Carbon monoxide	mg/Nm^3	N/A
	g/s	N/A
Sulphur dioxide	mg/Nm^3	0.80
	g/s	0.00004
PM_{10}	mg/Nm^3	8.26

Pollutant	Units	Value
	g/s	0.0004
$PM_{2.5}$	mg/Nm^3	8.26
	g/s	0.0004
Reference oxygen content	%	N/A

Table note:

Exhaust gas concentrations (mg/Nm^3) and emission rates (g/s) are based on total emissions per boiler unit at 100% operating load.

N/A – Data not available from engine technical specifications.

5.2 Non-normal Operations

5.2.1 Gas Flares

Process flares at the GPFs will be used to manage the pressure in the gas pipelines. The flares will be used in the event of the GPFs being shut down for either maintenance or an emergency, or if an upset occurs at the LNG facility at Curtis Island and the flow of feed gas in the gas pipeline is shutdown. The process flare system will not be used during normal operations.

The emission source characteristics of each gas flare for the 75 TJ/d, 150 TJ/d and 225 TJ/d capacity plants are presented in Table 14. The stack concentration and mass emission rate of criteria air pollutants for each of the flares are presented in Table 15, while the composition and percentage distribution of hydrocarbon species are presented in Table 16. The flare Ringelmann value is less than one indicating that there would be no visible smoke emissions. Therefore, particulate emissions are assumed to be zero.

Due to the large amount of heat, heat loss due to radiation and buoyancy that is 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 of the flare accounting for the above factors. 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 Origin.

Table 14 Emission source characteristics of the gas flares at the gas processing facilities

Parameter	Units	75 TJ/d	150 TJ/d	225 TJ/d
Energy release rate	GJ/hr	149	298	447
Stack height	m	20.0	40.0	46.0
Effective stack height[1]	m	26.9	49.6	57.6
Stack diameter	m	0.469	0.692	0.813
Effective stack diameter[1]	m	2.09	2.95	3.61
Exhaust gas velocity[2]	m/s	20	20	20

Parameter	Units	75 TJ/d	150 TJ/d	225 TJ/d
Temperature[2]	°C	1,000	1,000	1,000
Actual volume flow rate	Am^3/hr	45,766	91,531	137,297
Actual volume flow rate	Am^3/s	12.71	25.43	38.14

Table note:
Data provided by Origin
1 Effective stack height and diameter calculated using US EPA Screen 3 method
2 Screen 3 method assumption

Table 15 Exhaust gas concentrations and emission rates of the gas flares at the gas processing facilities

Pollutant	Units	75 TJ/d	150 TJ/d	225 TJ/d
Oxides of nitrogen[1]	**g/s**	**1.21**	**2.42**	**3.63**
Sulphur dioxide[2]	g/s	36.29	72.58	108.88
Carbon monoxide[1]	g/s	6.58	13.17	19.75
Total hydrocarbons[1]	g/s	2.49	4.98	7.47
PM_{10} and $PM_{2.5}$[1]	g/s	No particulate emissions with a smokeless flare		

Table note:
1 Calculated using Screen 3 method.
2 Calculated from mass balance of assumed concentration of 1 ppm of H2S in CSG fuel.

Table 16 Composition and distribution 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 concentrations of individual hydrocarbon species have been determined from the average percentage distribution of each as listed in Table 16 and the predicted maximum ground-level concentration for total hydrocarbons.

5.2.2 Inventory of emissions of oxides of nitrogen at the gas processing facilities

A summary of the total emissions of NO_X by GPF is presented in Table 17.

Table 17 Summary of emissions of oxides of nitrogen by gas processing facility capacity and engine model

GPF Capacity (TJ/d)	Facility ID	Engine model	No. of engine units per GPF	Total NOx emission rate per engine model (g/s)	Total NOx emission rate per GPF (g/s)
225	GPF_COM_03a	CAT G3520B	20	9.4	20.64
		CAT G3616	10	9.2	
		CAT G3516C	3	2.01	
		Gas-fired boiler	3	0.03	
150	GPF_CNS_03 GPF_CON_01b GPF_ORA_03b GPF_MUG_06 GPF_CON_02b GPF_RCK_04a GPF_LUK_02a GPF_GIL_02	CAT G3520B	13	6.11	13.91
		CAT G3616	7	6.44	
		CAT G3516C	2	1.34	
		Gas-fired boiler	2	0.02	
75	GPF_OAN_04 GPF_CNN_04 GPF_KIA_01a GPF_WOL_01 GPF_DAL_01b GPF_CAR_01a GPF_HCK_01a GPF_NGA_02 GPF_BYM_03 GPF_CAS_05 GPF_WAA_04	CAT G3520B	7	3.29	7.65
		CAT G3616	4	3.68	
		CAT G3516C	1	0.67	
		Gas-fired boiler	1	0.01	

GPF Capacity (TJ/d)	Facility ID	Engine model	No. of engine units per GPF	Total NOx emission rate per engine model (g/s)	Total NOx emission rate per GPF (g/s)
	GPF_ZIG_06 GPF_ZIG_05 GPF_WAA_03				
180	Talinga	Waukesha L7042GSI - Existing without NSCR	6	39.48	58.63
		Waukesha L7042GSI - Existing with NSCR	6	3.96	
		Waukesha L7042GL Expansion	3	2.07	
		CAT G3612	9	6.21	
		CAT G3406	4	6.88	
		Gas-fired boiler	3	0.03	
Talinga Nodal	GPF_TAL_02b	Waukesha L7042GL	8	5.52	5.52

6. Air Quality Criteria

6.1 Queensland Environmental Protection Policies

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

The object of the EP Act is summarised as follows:

> *"The object of the Environmental Protection Act 1994 is to protect Queensland's environment while allowing for development that improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends." (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 EPP Air is to identify the environmental values of the air environment to be enhanced or protected and to achieve the object of the EP Act, 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 -*
>
> - *Identifying environmental values to be enhanced or protected; and*
> - *Stating indicators and air quality objectives for enhancing or protecting the environmental values; and*
> - *providing a framework for making consistent, equitable and informed decisions about the air environment (EPP Air Part 2, Section 6).*
>
> *The environmental values to be enhanced or protected under the EPP Air are –*
>
> - *the qualities of the air environment that are conducive to protecting the health and biodiversity of ecosystems; and*
> - *the qualities of the air environment that are conducive to human health and wellbeing; and*

- *the qualities of the air environment that are conducive to protecting the aesthetics of the environment, including the appearance of buildings structures and other property; and*
- *the qualities of the air environment that are conducive to protecting agricultural use of the environment.*

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.

6.2 National Environment Protection Measure

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

6.3 Relevant Ambient Air Quality Objectives for the Project

A summary of the relevant EPP Air ambient air quality objectives for criteria pollutants adopted for this assessment are presented in Table 18.

Table 18 Ambient air quality objectives for criteria air pollutants

Indicator	Environmental value	Averaging period	Air quality objective [1] ($\mu g/m^3$)	Number of days of exceedence allowed
Nitrogen dioxide	Health and wellbeing	1-hour	250	1
		Annual	62	-
	Health and biodiversity of ecosystems	Annual	33	-
Sulphur dioxide	Health and wellbeing	1-hour	570	1
		24-hour	230	1
		Annual	57	-
	Protecting agriculture	Annual	32	-
	Health and biodiversity of ecosystems (for forests and natural	Annual	22	-

Indicator	Environmental value	Averaging period	Air quality objective [1] (µg/m³)	Number of days of exceedence allowed
	vegetation)			
Carbon monoxide	Health and wellbeing	8-hour	11,000	1
Ozone	Health and wellbeing	1-hour	210	1
		4-hour	160	1

Table note:
[1] Air quality objective at 0°C

In addition to the air pollutants detailed above, the combustion of coal seam gas in the gas-fired reciprocating engines and flares is also likely to produce small quantities of hydrocarbons. The full list of hydrocarbons likely to be emitted from the gas-fired reciprocating engines and boilers are presented with their relevant air quality objective in Appendix C, while the top five compounds in terms of the highest concentrations predicted as a percentage of their objective are presented in Table 19. Where an air quality objective for a particular pollutant is not published in the EPP Air, an appropriate objective from another jurisdiction has been adopted. These include:

- NSW Department of Environment, Climate Change and Water (NSW DECCW) 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 2009.

Table 19 Ambient air quality objectives and standards for the top five hydrocarbons

Indicator	Environmental value	Averaging period	Air quality objective or standard (µg/m³)	Source of standard or goal
Acetaldehyde	Odour	1-hour	42	NSW DECCW
Acrolein	Health (Extremely toxic - USEPA)	1-hour	0.42	NSW DECCW
Ethyl Chloride (Chloroethane)	Health and wellbeing	1-hour	0.048	NSW DECCW
Formaldehyde	Health and wellbeing	24-hour	54	EPP Air
Phenanthrene	Health	1-hour	0.5	TCEQ

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 20.

Table 20 Summary of percentile values used for comparison to air quality objectives

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

7. Existing Environment

The existing environment in the region surrounding the Australia Pacific LNG gas fields is discussed here in terms the geographical, meteorological and climatic conditions that are likely to influence the dispersion of air pollutants released by the gas fields' operations. A summary of the existing air quality in the region used in cumulative air quality assessment is also presented.

7.1 Terrain and Land Use

The Australia Pacific LNG gas fields' area extends across the Surat Basin from Wallumbilla to Millmerran on the Darling Downs, and cover an area of approximately 570,000 hectares. The Surat Basin covers an area of 27,000 km² across southern Queensland and northern New South Wales. The Walloons Gasfields are between 200 km and 400 km inland from the Queensland coastline.

The terrain in the north-western gas fields' area, west of Miles and to the north of the Warrego Highway comprises of predominantly slight to moderately undulating hills that tend to be used for livestock grazing. Conversely, the south-eastern gas fields area east of Miles and to the south of the Warrego Highway comprises of predominantly very flat agricultural land used for food crops and cotton.

This relatively flat geomorphology tends to result in a uniform wind field across the Darling Downs 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 relatively high proportion of moderate to strong wind speeds.

7.2 Climate

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

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

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

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

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

7.2.1 Meteorological data from the gas fields area

Meteorological data from the Bureau of Meteorology (BoM) monitoring stations located at Roma, Dalby and Miles have been used to characterise the climate in the Australia Pacific LNG gas fields. The Roma, Dalby and Miles monitoring stations have been selected for their close proximity to the proposed gas fields and processing facilities and the availability of data. These monitoring stations have been selected to provide a summary of the regional climate, where data collection has been carried out for between 12 – 114 years. The meteorological parameters that are measured at the Roma, Dalby and Miles monitoring stations include long-term temperature, solar exposure, atmospheric pressure, rainfall, relative humidity and wind speed and direction. The parameters used from each site are summarised in Table 21.

Table 21 Bureau of Meteorology monitoring stations and meteorological parameters used in the climate summary

Region	Location	Latitude/longitude	Record period	Parameters
Roma	**Airport**	**26.54 °S**	**1985 - 2009**	Temperature, solar exposure,

Region	Location	Latitude/longitude	Record period	Parameters
		148.78 °E		relative humidity, rainfall, surface pressure, wind speed and wind direction
Miles	**Post Office**	**26.66 °S** 150.18 °E	**1885 – 2009**	Temperature, solar exposure, relative humidity and rainfall
	Constance St	**26.66 °S** 150.18 °E	**1997 – 2009**	Surface pressure, wind speed and wind direction
Dalby	**Airport**	**27.16 °S** 151.26 °E	**1992 – 2009**	Temperature, solar exposure, relative humidity and rainfall

Temperature and solar exposure

The average daily minimum and maximum temperature at Roma, Miles and Dalby is presented in Table 22 for each season. A histogram of the average daily maximum and minimum temperature in each region is presented in Figure 2. The analysis identifies a seasonal temperature profile typical of the sub-tropical Queensland climate, with cooler winter months of June, July and August and warmer summer months of December, January and February.

The average maximum daily temperature recorded at the sites during summer ranges from 31.8 °C at Dalby to 33.4 °C at Roma. The average minimum daily temperature recorded at the sites during winter ranges from 4.5 °C at Miles to 4.8 °C at Dalby. On average, daily temperatures tend to increase to the west across the gas fields, with Roma typically recording higher temperatures throughout the year than Miles to the east, and Dalby further to the east.

Table 22 Average daily temperature ranges by season across the Australia Pacific LNG gas fields (in °C)

Location	Spring		Summer		Autumn		Winter	
	Min	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
Roma	13.5	29.2	20.2	33.4	12.6	27.8	4.7	20.8
Miles	12.6	28.3	19.1	32.8	12.4	27.2	4.5	20.2
Dalby	12.3	28.0	18.3	31.8	12.4	27.1	4.8	20.5

Table notes:
Averages based on recording periods for:
Roma: 1992 – 2009
Miles: 1908 – 2009

Location	Spring		Summer		Autumn		Winter	
	Min	Max	Min	Max	Min	Max	Min	Max

Dalby: 1992 – 2009

As described above, the amount of solar radiation at the surface is a primary driver for the weather patterns and climatic cycles that influence the Darling Downs and central Queensland region. Average daily solar exposure, measured in megajoules per square metre (MJ/m²) at Roma, Miles and Dalby for the period 1990 - 2009 is presented in a time series chart in Figure 3. The analysis illustrates the seasonal pattern whereby summertime solar exposure is twice that of the wintertime. Solar exposure at Roma is marginally higher than at Miles and Dalby, as evident in the higher temperatures at Roma.

Rainfall

The annual pattern of rainfall illustrates the sub-tropical climate in the region, where the percentage of annual precipitation occurring during the monsoonal months of November to February is 50% for Roma, 51% for Miles and 57% for Dalby. The average and highest recorded monthly rainfall at Roma, Miles and Dalby is presented in Table 23 and illustrated graphically in Figure 4.

Table 23 Average and highest monthly rainfall at Roma, Miles and Dalby (in millimetres)

Average rainfall													
Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Roma	72	83	42	36	38	30	24	23	22	57	63	71	558
Miles	95	75	58	37	39	40	37	29	31	54	66	89	649
Dalby	74	89	37	21	39	35	24	20	30	58	83	99	604
Highest rainfall													
Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Roma	265	204	154	189	114	116	77	86	90	202	167	175	824
Miles	318	252	473	211	240	196	267	171	151	194	263	443	1,179
Dalby	226	225	108	91	216	147	78	72	96	166	151	174	847

Table note:
Averages based on recording periods for:
Roma: 1985 – 2009
Miles: 1885 – 2009
Dalby: 1992 – 2009

The annual average rainfall across the region ranges between 558 millimetres at Roma and 649 millimetres at Miles, with the maximum monthly average rainfall occurring in December, January and February for Dalby (99 mm), Miles (95 mm) and Roma (83 mm), respectively. While rainfall predominantly occurs during the monsoonal summer period illustrating its sub-tropical climate, the relatively low amount of annual rainfall shows that the region is still quite dry due to its inland, semi-arid setting, when compared to the tropical north of Australia. On average, the total rainfall during the monsoonal months is slightly more than twice that of the drier months. In comparison in Darwin, approximately ten times as much rainfall occurs during the monsoonal months (November-March) that in the drier months (April – October).

Relative humidity

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

Relative humidity has been analysed from long-term averages based on daily measurements collected at 9am and 3pm at Roma, Miles and Dalby. The monthly average relative humidity at 9am and 3pm at each location is presented in Table 24 and Figure 5.

Table 24 Average daily relative humidity ranges at 9am and 3pm across the Australia Pacific LNG gas fields (in %)

Location	Time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Roma	9am	55	61	56	56	65	73	69	57	47	46	49	51	57
	3pm	34	40	33	33	37	42	38	30	26	28	33	34	34
Miles	9am	60	64	63	64	71	75	72	63	55	53	53	56	62
	3pm	41	42	40	41	46	48	44	38	34	34	35	37	40
Dalby	9am	68	71	67	68	76	81	76	68	63	60	61	63	68
	3pm	46	49	41	40	47	49	45	39	37	38	42	44	43

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

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

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

Surface pressure

As discussed above, long- and short-term fluctuations in atmospheric pressure are important when describing climatic patterns across the region. Monitoring data from Roma and Miles have been used to characterise the mean sea-level pressure (MSLP) in the region during the period 2002 – 2009. Longer term seasonal cycles in MSLP at Roma and Miles are shown graphically in Figure 6, while shorter term daily fluctuations at Roma are presented in Figure 7.

The longer term cycles are evident in the seasonal fluctuations of MSLP, which fluctuates around an average pressure of 1020 hPa during the drier winter months (May – August), and 1010 hPa during the wetter summer months (November – February) (Figure 6). Within this seasonal cycle, MSLP fluctuates on a diurnal basis between 3 - 4 hPa, with solar heating of the ground during the midday-afternoon period reducing the atmospheric pressure above the ground (Figure 7). At night when the temperature falls, atmospheric pressure increases again. The distributions of MSLP during the winter and summer months, presented in Figure 7, show the average pressure during the winter around 1020 hPa and around 1010 hPa in the summer.

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

Wind speed and direction

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

The distributions of wind speed and direction observed at Roma and Miles have been used to characterise the wind fields in the Australia Pacific LNG gas fields. The annual distribution of winds at Roma, for the period January 1999 to June 2009, are presented as a wind rose diagram in Figure 8, while the seasonal and diurnal distributions are presented in Figure 9. Frequency distributions of wind direction and wind speeds at Roma are shown in Figure 10 and Figure 11.

Similar annual, seasonal and diurnal distributions of winds at Miles are presented in Figure 12, Figure 13, Figure 14 and Figure 15. A summary of the main wind field characteristics at Roma and Miles are also presented in Table 25 and Table 26.

The analysis of the distribution of winds across the Australia Pacific LNG gas fields has identified two dominant features of the regional wind fields:

- A large proportion of the winds blow from the northeastern quadrant (between the north and east). These winds tend to be moderate for 29% of the time or strong for 13% of the time.
- There are a significant amount of hours where calms are recorded across the region, particularly at Miles.

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

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

Table 25 Summary of the distribution of wind speed and direction at Roma

Wind direction	Distribution of wind speeds (% of total winds)			
	Light Calm to <2 m/s	Moderate 2 – 5 m/s	Strong >5m/s	Total
All directions	22%	54%	24%	100%
North-eastern sector (350° to 100°)	7%	29%	13%	49%
South-western sector (180° to 220°)	1%	7%	3%	11%

Note: Statistics based on a 97.9% data recovery during the 1999 – 2009 monitoring period

Table 26 Summary of the distribution of wind speed and direction at Miles

Wind direction	Distribution of wind speeds (% of total winds)			
	Light Calm to <2 m/s	Moderate 2 – 5 m/s	Strong > 5m/s	Total
All directions (100%)	40%	55%	5%	100%
North-eastern sector (350° to 100°)	7%	32%	3%	41%
South-western sector (180° to 220°)	3%	8%	1%	12%

Note: Statistics based on a 97.6% data recovery during the 2004 – 2008 monitoring period

7.2.2 Summary

The analysis of meteorological monitoring data at Roma, Miles and Dalby in the gas fields' area indicates that, while the area is geographically vast, the climate across the region does not vary significantly as it is largely driven by synoptic scale patterns with minor perturbations as a result of local and meso-scale influences.

In summary, the climate across the gas fields' area can be described as follows:

- Sub-tropical with warm and wetter summers relative to mild and drier winters
- Average daily maximum temperatures range between 20 – 33°C.
- Average daily minimum temperatures range between 4 – 20°C.
- Average annual rainfall ranges between 558 – 668mm.
- The highest average monthly rainfall occurs during the wet season of December to February.
- Average annual rainfall tends to slightly increase to the north of the gas fields.
- Relative humidity tends to be higher during the late autumn and winter months than the spring and summer, and is likely to be due to the relatively sparsely vegetated, semi-arid conditions across the region.
- Average relative humidity tends to slightly increase to the north of the gas fields. This coupled with the increase in rainfall indicates the climate becomes wetter closer to the tropical north and closer to the Queensland coast.
- The climate, particularly in the summer, is largely driven by synoptic pressure systems such as the Queensland trough and the Cloncurry heat low. This leads to average MSLP of approximately 1020hPa in the winter and 1010hPa in the summer. Consequently, weather patterns are dominated by the daily deepening of the trough

that, during the summer, leads to the generation of afternoon thunderstorms. During winter, the relatively higher pressure leads to dry, clear weather conditions.

- The dominant wind direction across the gas fields is from the north to northeast all year round, with significant winds from the south to southwest during autumn and winter.
- Moderate winds between 2 – 5m/s dominate the gas fields with Roma and Miles recording wind speeds in this range for 54% and 55% of the time, respectively. There are also a significant amount of calm winds across the gas fields with Roma and Miles recording calms approximately 10% and 25% of the time, respectively.
- Moderate and strong wind speeds will assist the dispersion of air pollutants from gas engines and boilers but increase dust emissions from erodible surfaces. However, calm conditions coupled with a stable atmosphere at night, such as during temperature inversions, are likely to create poor dispersion conditions and lead to higher ground-level concentrations of air pollutants in close proximity to the source.

7.3 Existing Ambient Air Quality

7.3.1 Existing industries and regional sources of oxides of nitrogen

The primary air pollutant of concern for the Project is NO_2. There is currently no ambient air quality monitoring for NO_2, particles or other air pollutants carried out by DERM in the Surat Basin area. Notwithstanding this, the existing air quality in the region is likely to be fairly good due to the nature of land use. Industries identified through a review of the National Pollutant Inventory include:

- coal mining
- electricity generation
- gas supply
- log sawmilling and timber dressing
- meat and meat product manufacturing
- mineral, metal and chemical wholesaling
- oil and gas extraction
- sheep, beef cattle, poultry, pig and grain farming
- waste treatment, disposal and remediation services

The most significant sources of air pollutants likely to affect regional air quality, are associated with Kogan Creek, Millmerran, Tarong, and Tarong North coal-fired power stations and the Braemar, Daandine, Oakey, Condamine and Darling Downs gas-fired power stations. Due to the significant distances between, and geographical locations of, these industries, their affect is likely to be relatively minor at sensitive places within the gas fields.. Plumes associated with emissions from the Australia Pacific LNG gas fields' activities are likely to affect areas in the gas fields at different times and during different meteorological conditions to that which may be associated with the power station plumes.

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 effects are expected to be minimal. This is because the distance between gas extraction and processing infrastructure, and consequently emission sources, is considerable, as for Australia Pacific LNG's Australia Pacific LNG production areas. Hence, any effects are likely to be highly localised. A cumulative impact assessment has been carried out in the Undulla Nose area, where there is a relatively high density of gas processing infrastructure and the Australia pacific LNG gas fields are in close proximity to the gas fields operated by the Queensland Gas Company (QGC).

7.3.2 Existing background concentrations

The nearest ambient air quality monitoring station to the gas fields, which is operated by the DERM, is located at Toowoomba. This monitoring station has been operating since July 2003, and records ambient concentrations of NO/NO_2, CO, O_3, PM_{10} and $PM_{2.5}$. The Toowoomba monitoring station observations have been used to characterise the existing air quality in the gas fields for NO_2, CO and O_3.

The nearest and most representative monitoring station that measures SO_2 is at Flinders View, west of Ipswich. This monitoring station is located approximately four kilometres from the Swanbank coal-fired power station, and is considered to be a conservative representation of the eastern gas field areas that are slightly closer to the Tarong, Tarong North, Kogan Creek and Millmerran coal-fired power stations. These coal-fired power stations are likely to be the dominant sources of SO_2 in the Darling Downs region.

Both Toowoomba and Flinders View monitoring stations are influenced by urban activities and industrial emission sources that tend to emit a higher proportion of fine particles to total suspended particles (TSP) than occurs in the natural environment. Consequently, measurements of PM_{10} and $PM_{2.5}$ from Toowoomba and Flinders View are not considered representative of the gas fields, which is a significant distance from any industrialised, urban environments. Background concentrations for PM_{10} and $PM_{2.5}$, have been based on data published in the EIS for the Wandoan Coal Project (Xstrata, 2009). This data was collected by Xstrata to provide background concentrations for use in the EIS air quality assessment. The town of Wandoan is located near the gas fields in the north of the Australia Pacific LNG gas fields' area. The 70th percentile concentration has been used to represent the 24-hour average concentration of PM_{10} and $PM_{2.5}$.

A summary of existing background levels of NO_2, SO_2, CO, PM_{10} and $PM_{2.5}$ is presented in Table 27.

Table 27 Regional background air quality (in µg/m³)

Pollutant	Source	Averaging period	Concentration[1]	Objective	Percent of guideline
Nitrogen dioxide	Toowoomba	1-hour	11.3	250	4.5
		Annual [2]	13.9	62	22.4
Carbon monoxide	Toowoomba	8-hour	54.7	11,000	0.5

Pollutant	Source	Averaging period	Concentration[1]	Objective	Percent of guideline
Ozone	Toowoomba	1-hour	56.8	210	27.0
Sulphur dioxide	Flinders View	1-hour	2.9	570	0.5
		24-hour	4.5	230	2.0
		Annual [2]	6.6	57	11.6
PM_{10}	Wandoan	24-hour	14.0	50	28.0
$PM_{2.5}$	Wandoan	24-hour	5.1	25	20.4
		Annual [3]	5.1	8	63.8

Table note:

[1] The 70th percentile has been used to represent background concentrations of NO_2.

[2] The annual average is the highest annual average concentration from the monitoring period.

[3] The annual average for $PM_{2.5}$ is the same as the 24-hour average as the monitoring period is less than one year (March to July 2009). This is considered very conservative.

Toowoomba is a relatively large town at the eastern edge of the Darling Downs region with a mixture of agricultural and industrial activities. While some of the sources of air pollutants in the Toowoomba region that are identified in the National Pollutant Inventory (NPI) are similar to those in the gas fields, the higher density of industrial activity and the greater concentration of motor vehicles and heavy mobile machinery in the Toowoomba region, in comparison to the gas fields, means ambient concentrations of NO_2 recorded at the DERM monitoring station are likely to be higher than in the gas fields.

Power stations have been included in the CALPUFF dispersion modelling assessment to quantify an appropriate ambient background concentration that represents the spatial distribution of NO_2. The approach used for the quantification of background concentrations of NO_2 for the cumulative assessment is summarised in Section 7.3.3

7.3.3 Modelled background sources of oxides of nitrogen

To assess the spatial distribution of ambient ground-level concentrations of NO_2 associated with NO_X emissions from the various coal- and gas-fired power stations in the Darling Downs region, and to assess the cumulative impacts in conjunction with the Australia Pacific LNG gas fields. The power stations have been included in the dispersion modelling study. The source characteristics and emission rates for the existing and approved power stations that have been included in the assessment are summarised in Table 28, while their locations are illustrated in Figure 1.

Table 28 Source characteristics and emissions of oxides of nitrogen for power stations included in the dispersion modelling for background air quality

Background Source	Fuel and station type	Number of stacks	Stack Height (m)	Stack Diameter (m)	Velocity (m/s)	Temp (°C)	NO_X Emission Rate (g/s)
Braemar	Gas-fired	6	30	6.1	37.5	536	19.2

Background Source	Fuel and station type	Number of stacks	Stack Height (m)	Stack Diameter (m)	Velocity (m/s)	Temp (°C)	NO_X Emission Rate (g/s)
	open cycle	2	30	10.2	19.5	587	29.1
Condamine	Gas-fired open cycle	2	34	3.7	13.7	127.3	6.9
Daandine	Gas-fired open cycle	11	8	6.1	32	425	1.71
		1	30	1.2	18	150	0.7
Darling Downs including Stage 2	Gas-fired combined cycle	4	30	5.7	38	541	9.69
Oakey	Gas- and diesel fired open cycle	2	35	6.2	38.9	562.2	40.5
Kogan A	Coal-fired	1	160	8.8	24.4	120	542
Millmerran	Coal-fired	1	141	7.98	24.4	143	443.9
Tarong	Coal-fired	1	210	10	27	137	1014.7
Tarong North	Coal-fired	1	210	5.16	26	128	250.5

8. Atmospheric Dispersion Modelling Methodology

Air dispersion modelling was conducted using a two-stage approach. Firstly, the CSIRO's meteorological model, TAPM (The Air Pollution Model) Version 4 (Hurley 2005), was used to simulate the regional meteorology in the Walloons development area of the Surat Basin. The wind field was then refined using the CALMET Version 6.3 meteorological pre-processor. Secondly, the CALPUFF plume dispersion model was used to predict ground-level concentrations of air pollutants emitted from the Australia pacific LNG gas fields..

8.1 TAPM Prognostic Meteorological Model

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, Southeast Asia and 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 effectively simulates meso-scale (regional) and micro-scale (local) wind patterns. 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 that 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 analysis. TAPM solves the fundamental fluid dynamics equations to predict meteorology at a meso-scale (20 kilometres to 200 kilometres) and at a micro-scale (down to a few hundred metres). TAPM includes parameterisations for cloud/rain micro-physical processes, urban/vegetation canopy and soil, and radiative fluxes.

Analysis of BoM monitoring station data found that the region experiences calm to very light wind conditions for up to 22% of the year at Roma and 40% of the year at Miles. These calm wind episodes are generally linked to cool clear nights predominant during winter. These events are initiated by the rapid cooling of the earth's surface after sunset, the subsequent lowering of the boundary layer and the development of an inversion layer. Due to the large amount of time that these conditions were observed within the modelling domain it was imperative that the frequency of calm wind conditions be well represented in the development of the meteorological fields for inclusion in the air dispersion model. As such three BoM sites, as identified in Table 29, were selected as being representative of the regional-scale wind patterns and indicative of the frequency of calm wind conditions expected in the region.

Table 29 BoM monitoring stations and parameters assimilated into TAPM

Location	Latitude	Longitude	Height (m)	Radius of influence (km)	Data quality indicator
Applethorpe	28.62°S	151.95°E	10	50	0.4
Miles	26.66°S	150.18°E	10	50	0.6
Dalby	27.16°S	151.26°E	10	50	0.5

TAPM was configured with the following parameters:

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

8.2 CALMET Diagnostic Meteorological Pre-processor

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

CALMET Version 6.3 was used to simulate meteorological conditions in the Australia Pacific LNG gas fields. The modelling domain was setup to be nested within the coarse resolution TAPM domain. CALMET treats the prognostic model output as the initial guess field for the diagnostic model wind fields. CALMET then adjusts the initial guess field for the kinematic effects of terrain, slope flows, blocking effects and 3-dimensional divergence minimisation. The coupled approach unites the meso-scale prognostic capabilities of TAPM with the refined capabilities of CALMET to account for terrain and land use.

The use of the three-dimensional wind field provides a complete set of meteorological variables for every grid point and vertical level for each hour of the simulation period. This is a significant improvement in modelling approach to the method of data assimilation from discrete surface stations, which are limited in their ability to represent local scale wind patterns across large distances.

CALMET was configured with the following parameters:

- Grid domain area of 360km by 360km
- Horizontal grid cell resolution of 3km by 3km

- 12 vertical levels with heights at 20m, 60m, 100m, 150m, 200m, 250m, 350m, 500m, 800m, 1600m, 2600m and 4600m
- 1-year time scale (1 January – 31 December 2008)
- The terrain and land use were refined from those used in the TAPM model to account for the increased resolution, with the terrain generated from the Geosciences Australia 9-second arc DEM dataset at a resolution of 3 km
- Prognostic wind fields input as MM5/2D.dat "initial guess" field only (as generated from TAPM)
- All default options and factors were selected with the exception of the following:
- Step 1 wind field options include kinematic effects, divergence minimisation, Froude adjustment to a critical Froude number of 1, and slope flows
- Terrain radius of influence set at 2 km
- Cloud cover calculated from prognostic relative humidity.

8.3 Meteorological Model Evaluation

A comprehensive model evaluation should include assessments of the models technical algorithms, statistical measures against observational data and operational assessments by users in real world applications. A review of various model evaluation techniques is described in Chang and Hanna (2004). TAPM and CALMET/CALPUFF are both currently maintained and updated by their respective developers and have been extensively validated for dispersion modelling in Australia and overseas (Hurley 2005 and Earth Tech 2006).

The meteorological component of the air dispersion model has been evaluated by a suite of different performance measures, following Wilmot et al. (1982) and Emery (2001). To ascertain the effectiveness of the meteorological model in capturing the dynamic interactions between meteorological parameters important to dispersion, a systematic approach was employed following Gilliam et al (2006).

Model evaluation must be treated with care as a numerical model is a closed system where the solutions are governed by physical constants and assumptions (parameterisations), while natural systems are unique open systems, where the random nature of a process such as turbulence cannot be explicitly resolved. The parameterisation of natural phenomena is an approximation of reality and as such will introduce a certain amount of inherent error into the model solutions (Oreskes et al 1994). Another source of uncertainty is the fact that observations represent a single realisation in space and time of an infinite number of possibilities (ASTM, 2000), while numerical models solve the average value for an area equal to the finest resolution of the model. Therefore errors in the parameterisation of meteorological variables and processes are inherently passed on to the dispersion model iteratively and introduce significant perturbations that are artefacts of the modelling approach itself and not a result of natural processes (Piekle et al, 1998).

Performance statistics are used to judge the performance of a model. In general, a good model will display a small amount of error with most of the variability in model solutions being explained by the natural variability found in the observations. A model that performs well should have the majority of its solutions fall within a factor of 2 (± 33%) of the observations. Table 30 presents a set of benchmarks for good model performance.

The meteorological component of the air dispersion model has been assessed for its performance in accurately simulating the distribution of wind speed, wind direction and temperature at four sites within the modelling domain. The predictions (C_p) were then paired with the observations (C_o) and statistical measures calculated. C_p and C_o can be paired separately in time and in space or in time and space together. Pairing in both time and space simultaneously being the strictest of all pairings, where the prediction is accurate at the right location at the right time.

The statistical measures used to evaluate the model's performance are described in Appendix D.

Table 30 Benchmarks for good model performance

Parameter	Wind Speed, U and V wind vectors	Temperature	Source
IOA	> 0.6	> 0.8	Emery 2001
MAE	< 2 m/s	< 2 °C	Emery 2001
RMSE	Small relative to units	Small relative to units	Chang & Hannah 2004
RMSE_s	≈ MAE	≈ MAE	Chang & Hannah 2004
RMSE_u	≈ MAE	≈ MAE	Chang & Hannah 2004
SE	< 1	< 1	Hurley 2008
SR	≈ 1	≈ 1	Hurley 2008
SV	< 1	< 1	Hurley 2008
Vector correlation (magnitude, phase)	> 0.6, < 15	-	Crosby & Gemmil 1992
Differential (C_p-C_o)	< factor of 2 (± 33%)		Chang & Hannah 2004

8.4 Analysis of Dispersion Meteorology

The relatively flat to slightly undulating terrain results in a relatively uniform wind field across the gas fields. The areas of shrubby, low vegetation present a low surface roughness and result in a higher proportion of moderate wind speed between 3 - 5m/s, while areas of dense, tall vegetation present a higher surface roughness resulting in a higher proportion of lower wind speeds less than 2m/s. The rate of plume dispersion and the resulting ground-level concentrations of air pollutants associated with emissions from the gas fields' operations is a function of wind speed, with higher concentrations tending to occur during periods of lighter winds and often coupled with a relatively stable atmosphere. Consequently, it was important that the meteorological model accurately simulated the frequency and directional patterns of light to moderate winds across the gas fields, to provide confidence in the prediction of ground-level concentrations.

8.4.1 Wind Speed and Direction

The model showed good skill with a small amount of error in developing an accurate wind field across the modelling domain (Appendix E). Observational data from the BoM monitoring sites located at Dalby and Miles have been assimilated into the final wind field and are shown to perform very well with IOAs greater than 0.8 for wind speed and U and V wind components and greater than 0.9 for temperature and a small amount of error (MAE < 2m/s and < 2°C). The vector correlations for these sites were also very high with a magnitude correlation greater than 0.9 and a phase of less than 5.

To determine the models accuracy outside of the radius of influence from the assimilated sites, the BoM monitoring stations at Roma and Oakey were used as benchmarks for model performance. The model was found to perform well at Roma with an IOA of greater than 0.75 for wind speed and U and V wind vectors and greater than 0.9 for temperature. The model's MAE was below 2 m/s for the meteorological variables, but showed an MAE of 2.4 for temperature. This is probably due to several very cold evenings (– 3°C observed) not being fully represented in the model (- 1°C predicted).

Overall though, the differential between predicted and observed varied by less than 10%. The vector correlation was also within the bounds proposed for good model performance (0.76, 10). Indeed, the annual distribution of winds from this site are seen in the observations to be predominantly (41%) from the northern quadrant (NW to NE). The model predicted that 32% of the winds would be from this quadrant. The majority of the model's error was seen to be in the underestimation of the frequency of high winds experienced at this site and the over estimation of winds between 1 and 2m/s.

The model did not perform as well at Oakey. However, it still complied with the benchmarks proposed for good model performance. The model scored an IOA of 0.65 for wind speed and approximately 0.8 for the U and V wind vectors. The model's MAE was approximately 2 for both the meteorological variables and temperature. This is due to the model's underestimation of the frequency of high wind speeds. However, the model showed a good vector correlation (0.79, 0.4) indicating that the predicted magnitude and direction of the wind was accurate for the majority of the time. For example, the observational data for Oakey indicates that 6% of the time winds are below 1m/s. The model also predicted that 6% of the time winds would be below 1m/s. The observational data also indicated that 50% of all winds come from the eastern quadrant (NE to SE). This is also well presented in the model where 45% of all winds are form this quadrant.

Although the model did not represent the frequency of high wind speeds (> 7m/s) within the modelling domain, Katestone Environmental is confident that the meteorology important for the dispersion of pollutants in relation the Project and the conservative assessment of air quality impacts is well represented in this model.

8.4.2 Atmospheric stability

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, a plume released from a 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 in the layer beneath the inversion 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 nocturnal inversion, will remain relatively undiluted, and will not reach the ground unless it encounters elevated terrain.

The reciprocating engine stacks are quite short (generally less than ten metres), and while the exhaust gas temperature is hot (between 359°C and 593°C) and the vertical velocity is quite substantial (between 18m/s and 55m/s), the small volumetric flow rate means the plume does not possess the necessary thermal and mechanical buoyancy to penetrate the low nocturnal inversion layer, resulting in relatively poor plume dispersion during inversion conditions. This is illustrated by the very low night time buoyancy flux parameters for each engine of between $0.77m^4/s^3$ and $14.38m^4/s^3$.

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 exposure (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 locations are presented in Table 31. The high proportion of E and F class stability is due to the high frequency of light winds, particularly during the night time. It is these light wind stable conditions that generate the poor dispersion conditions.

Table 31 Percentage frequency distribution for atmospheric stability under the Pasquil-Gifford stability classification scheme

Pasquill-Gifford Stability class	Classification	Frequency (%)			
		Roma	Miles	Dalby	Oakey
A	Extremely unstable	3.7	4.6	2.7	2.6
B	Unstable	15.3	19.2	13.3	13.8
C	Slightly unstable	17.1	15.7	18.2	18.5
D	Neutral	27.2	21.6	42.5	34.8
E	Slightly stable	10.5	9.9	9.0	10.1

Pasquill-Gifford Stability class	Classification	Frequency (%)			
		Roma	Miles	Dalby	Oakey
F	Stable	26.3	29.0	14.3	20.4

8.4.3 Mixing Height

The mixing height refers to the height above ground within which particulates or other pollutants released at or near ground can mix with ambient air. During stable atmospheric conditions, the mixing height is often quite low dispersion is limited to within this layer. 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 cooler. The growth of the mixing height is dependent on how well the air can mix with the cooler upper level 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 and generally good dispersion characteristics.

Mixing height information has been extracted from CALMET and is presented in Figure 16 for Roma and Miles and Figure 17 for Dalby and Oakey. The data show that at all locations the mixing height develops around 6 am, increases to a peak at 2-3 pm (2500m to 3000m) before descending rapidly at 4 pm. The average and minimum night time mixing heights are quite low at all sites (≈ 50 m). The large variation in daytime and night time mixing heights and the rapid decrease of the boundary layer around sunset indicates that the mixing height in these locations is dominated by solar heating of the ground surface with very little terrain or mesoscale features (such as sea breezes) influencing the development of the boundary layer.

8.5 CALPUFF Dispersion Model

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

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

Key features of CALPUFF used to simulate dispersion:

- Domain area of 66 by 66 grids at a horizontal resolution of 3 km by 3 km
- 1-year time scale (1 January – 31 December 2008)

- Gridded three-dimensional hourly-varying meteorological conditions as generated by CALMET
- Partial plume path adjustment for terrain modelled
- Transitional plume rise modelled
- Stack tip downwash modelled
- ISC method used to simulate building downwash (Undulla Nose case study model)
- Dispersion coefficients calculated internally from sigma v and sigma w using micrometeorological variables
- Minimum sigma v set to 0.2m/s
- Minimum wind speed set to 0.2m/s

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

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

8.7 Odour

The generation of odorous air emissions is not generally associated with the operation of gas-fired reciprocating engines and gas-fired boilers. As discussed above, the primary gaseous air pollutants emitted from these sources are NO_X and CO, with trace quantities of hydrocarbons.

The assessment was based on the primary air pollutant emitted from the engines associated with the GPFs and other water handling infrastructure, NO_X, and hydrocarbon species identified as being odorous, and with a predicted maximum ground-level concentration on the grid of greater than ten percent of their air quality objective.

Impacts associated with CO have not been assessed with regard for odour as CO is an odourless gas. For hydrocarbons, not all species identified in the air emissions are considered odorous. However, the air quality objective for many of the odorous compounds has been based on their odour threshold or detection level in the ambient environment.

No assessment of the potential synergistic effects of gaseous mixtures has been made. No source odour emission rate information was available for LNG facilities.

In addition to this assessment, Katestone Environmental conducted an ambient odour assessment during a site investigation of the existing Origin GPF at Spring Gully. During the visit, all emission sources were inspected and an ambient odour survey was performed around the site, and at and beyond the site boundary. No significant odours were detected on the site and beyond the boundary.

9. Air Quality Impact Assessment Scenarios for the Assessment of the entire gas field

This section describes the operational scenarios considered for the assessment of air quality for the entire Australia Pacific LNG gas fields.

9.1 General Site Layout

While the spatial and temporal development of the Australia Pacific LNG gas fields will change over the life of the thirty year project, an estimation of the location of gas field infrastructure has been made in order to assess the maximum likely impact the Project will have on air quality in the Darling Downs region. As discussed in Section 4.1, a conservative assessment approach has been adopted whereby all of the infrastructure, and therefore emission sources, required to carry out the Project over its lifetime have been modelled and assessed as though operating concurrently. In reality this will not occur, as gas well and GPF development will be staged to meet the demand for LNG. However, in order to assess the cumulative effect of closely co-located emission sources on ground-level concentrations, this method provided the simplest assessment approach, as it was not feasible to model each development scenario over thirty years. The approximate location of each of the GPFs, WTSs and WTFs in the north-western, central and south-eastern gas fields, which were included in the air quality assessment, are illustrated in Figure 18, Figure 19 and Figure 20, respectively.

9.2 Modelling Scenarios

The air quality impact assessment has considered the following scenarios as summarised in Table 32. A summary of the impact assessment criteria and format for results presentation is presented in Table 33.

Table 32 Air quality impact assessment scenarios modelled

Scenario	Typical Operations	Operations modelled	Source	Source type
Australia Pacific LNG - normal	Continuous	Continuous	GPF, WTS, WTF	Gas-fired reciprocating engines
				Gas-fired boilers
Australia Pacific LNG - abnormal	Intermittent	Continuous	GPF	Flares
Background	Continuous	Continuous	Power stations	Coal-fired boilers
				Open-cycle gas turbines
				Combined-cycle gas turbines
				Diesel-fired

Scenario	Typical Operations	Operations modelled	Source	Source type
				turbines

Table 33 Summary of impact assessment criteria for all air pollutants

Pollutant	Averaging period	Determination of background concentrations	Impact assessment		
			Assessment	Percentile	Results Presentation
Nitrogen dioxide	1-hour	Modelled	Incremental impact and cumulative	100^{th}	1, 2, 3, 4
	Annual				1, 2, 3, 4
Sulphur dioxide	1-hour	Monitoring data from Flinders View (70^{th} percentile)	Incremental and cumulative impact	100^{th}	1, 2
	24-hour				1, 2
	Annual				1, 2
Carbon monoxide	8-hour	Monitoring data from Toowoomba (70^{th} percentile)	Incremental impact	100^{th}	1, 2, 3, 4
PM_{10}	24-hour	Monitoring data from Wandoan (70^{th} percentile)	Incremental and cumulative impact	100^{th}	1, 2
	Annual				1, 2
$PM_{2.5}$	24-hour	Monitoring data from Wandoan (70^{th} percentile)[6]	Incremental and cumulative impact	100^{th}	1, 2
	Annual				1, 2
Volatile Organic Compounds	1-hour	Background not assessed	Incremental impact	100^{th}	1, 3[5]
Photochemical smog	1-hour	Calculated from NO_2 modelling results	Incremental and cumulative impact	100^{th}	1, 2

Table note:
Results presentation

Pollutant	Averaging period	Determination of background concentrations	Impact assessment		
			Assessment	Percentile	Results Presentation

[1] Impact assessment presented as a table of maximum Australia Pacific LNG incremental impact across modelling domain

[2] Impact assessment presented as a table of maximum Australia Pacific LNG incremental impact plus background across modelling domain

[3] Impact assessment presented as a contour plot of Australia Pacific LNG incremental impact

[4] Impact assessment presented as a contour plot of Australia Pacific LNG incremental impact plus background

[5] Formaldehyde only

[6] Background concentration used for the annual average of $PM_{2.5}$ is the 24-hour average due to less than one year of data available

10. Air Quality Impact Assessment Scenarios for the Undulla Nose case study

This section describes the operational scenarios assessed for the cumulative air quality assessment of NO_2 at the Undulla Nose.

10.1 General Site Layout

The local-scale modelling assessment has focussed on the central Australia Pacific LNG gas fields' area known as the Undulla Nose. In particular, the assessment has investigated the potential for localised cumulative impacts associated with emissions of NO_X from the following sources:

- proposed Australia Pacific LNG gas fields
- existing Talinga GPF, WTS and WTF
- Talinga expansion infrastructure
- Talinga nodal plant – GPF_TAL_02b
- power stations in the region
- emissions from potential QGC gas processing plants located in the QGC exploration leases adjacent to the Australia Pacific LNG tenements.

The area and sources assessed in the Undulla Nose case study model are illustrated in Figure 21.

10.2 Modelling methodology

For CALMET, the Undulla Nose model has been configured by nesting a 1 km by 1 km grid within the regional-scale model's 3 km by 3 km grid. Additional refinement of the terrain and land use was carried in order to resolve these geophysical characteristics at the local-scale.

For CALPUFF, improvements were made to the spatial distribution of emission sources at each facility and the profiles of buildings close to each stack were included to account for building wake turbulence in the model. This has the effect of increasing ground-level concentrations close to the source and reducing them further away from the source. The resolution of the CALPUFF model runs were also improved by further nesting the computational grid by a factor of two. This resulted in a CALPUFF grid with a cell resolution of 500 m by 500 m.

10.3 QGC source characteristics and emissions

In order to assess the potential cumulative impacts associated with emissions from the proposed QGC operations in the Undulla Nose area, Origin provided Katestone Environmental with conservative estimates of the quantity, location and capacity of potential gas processing plants that may be developed by QGC during the life of the Australia Pacific LNG Project.

Based on the production capacity information provided by Origin, emission sources and characteristics were pro-rated according to the information presented in the EIS report by Katestone Environmental for QGC, 'Air Quality Impact Assessment of Upstream and Pipeline Gas Field Infrastructure for the QCLNG Project, June 2009'. The quantity and type of sources assessed are presented in Table 34, while the source characteristics and emission rates or NO_X are presented in Table 35.

Table 34 Quantity and type of engines assessed based on Australia Pacific LNG assumptions and QGC EIS data

Processing facility	Australia Pacific LNG assumed capacity (TJ/d)	Based on QGC EIS	Number of engines pro-rated from QGC Project plant capacities			
			Screw Comp.	Recip. Comp.	Power Generator	Dehydration Re-boilers
QGC engine types	-	-	CAT G3512	CAT G3608	CAT 3516C1	Boilers
QGC number of engines	-	-	8	10	-	-
QGC - Facility A	40	FCS (8 TJ/d)	40	-	1	1
QGC - Facility B	40	FCS (8 TJ/d)	40	-	1	1
QGC - Facility C	100	CPP (18 TJ/d)	-	56	1	1
QGC - Facility D	100	CPP (18 TJ/d)	-	56	1	1
QGC - Berwyndale South	100	CPP (18 TJ/d)	-	56	1	1

Table 35 Source characteristics and emission rates oxides of nitrogen based on Australia Pacific LNG assumptions and QGC EIS data

Parameters	Units	Sources			
QGC engines		CAT G3512	CAT G3608	CAT 3516C1	Boilers
Stack height	(m)	7.2	8	4.5	7
Stack diameter	(m)	0.2603	0.5968	0.36	0.2

Parameters	Units	Sources			
Stack exhaust gas velocity	(m/s)	48.7	26.9	54.9	4.4
Temperature	(K)	733.15	743.15	750.15	773.15
NO_X emission rate per source	(g/s)	0.558	0.461	0.67	0.01
Total NO_X emission rate per plant	(g/s)	22.32	25.61	0.67	0.01

10.4 Modelling scenarios

The air quality impact assessment has considered the following scenarios as summarised in Table 36. A summary of the impact assessment criteria and format for results presentation is presented in Table 37.

Table 36 Air quality impact assessment scenarios modelled

Scenario	Typical Operations	Operations modelled	Source	Source type
Australia Pacific LNG - normal	Continuous	Continuous	GPF, WTS, WTF	Gas-fired reciprocating engines
				Gas-fired boilers
QGC - normal	Continuous	Continuous	GPF	Gas-fired reciprocating engines
				Gas-fired boilers
Background	Continuous	Continuous	Power stations	Coal-fired boilers
				Open-cycle gas turbines
				Combined-cycle gas turbines
				Diesel-fired turbines

Table 37 Summary of impact assessment criteria for all air pollutants

Pollutant	Averaging period	Determination of background concentrations	Impact assessment		
			Assessment	Percentile	Results Presentation

Pollutant	Averaging period	Determination of background concentrations	Impact assessment		
			Assessment	Percentile	Results Presentation
Nitrogen dioxide	1-hour	Modelled	Incremental impact and cumulative	100th	1, 2, 3, 4
	Annual				1, 2, 3, 4

Table note:

Results presentation

[1] Impact assessment presented as a table of maximum Australia Pacific LNG incremental impact at sensitive receptors

[2] Impact assessment presented as a table of maximum Australia Pacific LNG incremental impact plus background at sensitive receptors

[3] Impact assessment presented as a contour plot of Australia Pacific LNG incremental impact

[4] Impact assessment presented as a contour plot of Australia Pacific LNG incremental impact plus background

11. Dispersion model results – entire gas field

This section presents the results of the air quality impact assessment for NO_2, SO_2, CO, ozone, PM_{10}, $PM_{2.5}$ and all identified hydrocarbons for the normal and abnormal operating scenarios.

11.1 Normal Operations – criteria air pollutants

The predicted maximum incremental and cumulative ground-level concentrations of criteria air pollutants are presented in Table 38. Values presented in Table 38 represent the maximum ground-level concentration anywhere within the Australia Pacific LNG gas fields based on assessment of all emissions under normal operating conditions. Cumulative ground-level concentrations of NO_2 include existing power stations in the region.

Table 38 Predicted maximum incremental and cumulative ground-level concentrations of criteria air pollutants for the Australia Pacific LNG gas fields

Pollutant	Averaging period	Objective	Predicted maximum incremental concentration		Predicted maximum with background	
			Maximum on grid (µg/m³)	Percent of objective (%)	Maximum on grid (µg/m³)	Percent of objective (%)
Nitrogen dioxide	1-hour	250	241.2	96.5%	241.2	96.5%
	Annual	62	4.0	6.5%	4.2	6.8%
Carbon monoxide	8-hour	11,000	536.0	4.9%	591.0	5.4%
Sulphur dioxide	1-hour	570	0.3	0.04%	-	-
	24-hour	230	0.02	0.01%	-	-
	Annual	57	0.001	0.00002%	-	-
PM_{10}	24-hour	50	0.2	0.4%	14.2	28.4%
$PM_{2.5}$	24-hour	25	0.2	0.9%	5.3	21.3%
	Annual	8	0.01	0.1%	5.1	63.9%

For the purpose of plotting contours of ground-level concentrations of air pollutants, the Australia Pacific LNG gas fields has been divided into three regions, namely, the north-western region, the central region and the south-western region. The contour plots for all air pollutants consistently show that the north-western and south-eastern regions have substantially lower ground-level concentrations than the central.

Figure 22, Figure 23 and Figure 24 present maximum 1-hour average ground-level concentrations of NO_2 due to project activities and accounting for the influence of existing sources of NO_2, such as power stations.

Figure 25, Figure 26 and Figure 27 present annual average ground-level concentrations of NO_2 due to project activities and accounting for the influence of existing sources of NO_2, such as power stations.

Figure 28, Figure 29 and Figure 30 present 8-hour average ground-level concentrations of carbon monoxide due to project activities and accounting for background levels of carbon monoxide.

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 Australia Pacific LNG project activities, under normal operating conditions, assessed in isolation and including background concentrations. Further consideration of ground-level concentrations of NO_2 is included below.
- The results for NO_2 indicate that the contribution to ground-level concentrations from NO_X emissions associated with the existing power stations is insignificant. The maximum 1-hour average ground-level concentration of NO_2 was predicted to be to the northeast of the Talinga/Undulla Nose area at night, during light winds blowing from the southwest and towards the power stations. The predicted maximum 1-hour average ground-level concentration of NO_2 for the background only, at the same location where the maximum impact associated with the Australia Pacific LNG gas fields occurred, is less than 9μg/m^3, and occurred during the day when the wind was blowing from the northwest.
- Ground-level concentrations of carbon monoxide, PM_{10} and $PM_{2.5}$ are predicted to be very low and well below the EPP Air objectives across the Australia Pacific LNG gas fields with the addition of background levels of air pollutants.
- Ground-level concentrations of sulphur dioxide are predicted to be negligible and well below the EPP Air objectives for the Australia Pacific LNG gas fields in isolation.

Further analysis of the spatial distribution of NO_2 across the Australia Pacific LNG gas fields with respect to the location of the GPFs and other infrastructure has been conducted. As the exact location of all gas plants has not been determined, the spatial relationship between plant and local sensitive receptors is unknown. The predicted maximum 1-hour average and annual average ground-level concentrations of NO_2 within three kilometres of each of the GPFs have been calculated and are presented in Table 39.

Table 39 Predicted maximum 1-hour and annual average ground-level concentrations of nitrogen dioxide within three kilometres of each GPF in isolation and with background (in μg/m^3)

Location	GPF Capacity (TJ/d)	Predicted maximum incremental concentration		Predicted maximum with background	
		1-hour average	Annual average	1-hour average	Annual average
GPF_COM_03a	225	79.3	1.0	79.3	1.0
GPF_CNS_03	150	146.5	1.6	146.5	1.7

Location	GPF Capacity (TJ/d)	Predicted maximum incremental concentration		Predicted maximum with background	
		1-hour average	Annual average	1-hour average	Annual average
GPF_CON_01b	150	219.8	1.6	219.8	1.8
GPF_ORA_03b	150	161.9	1.0	161.9	1.3
GPF_MUG_06	150	40.4	0.8	40.7	0.9
GPF_CON_02b	150	117.1	1.0	117.1	1.2
GPF_RCK_04a	150	39.5	1.2	39.5	1.3
GPF_LUK_02a	150	65.6	1.1	66.1	1.2
GPF_GIL_02	150	84.6	0.7	84.6	0.8
GPF_OAN_04	75	43.3	0.7	43.3	0.9
GPF_CNN_04	75	157.1	1.3	157.1	1.5
GPF_KIA_01a	75	44.9	0.3	44.9	0.6
GPF_WOL_01	75	28.6	0.6	28.7	0.8
GPF_DAL_01b	75	115.4	1.3	115.4	1.5
GPF_CAR_01a	75	50.2	0.7	50.2	0.8
GPF_HCK_01a	75	30.3	0.8	31.1	0.9
GPF_NGA_02	75	31.3	0.6	31.3	0.7
GPF_BYM_03	75	89.2	0.8	89.2	0.9
GPF_CAS_05	75	87.8	0.7	87.8	0.9
GPF_WAA_04	75	36.4	0.2	36.4	0.3
GPF_ZIG_06	75	90.2	0.5	90.2	0.6
GPF_ZIG_05	75	19.9	0.2	19.9	0.4
GPF_WAA_03	75	95.0	0.6	95.0	0.8

The results show the following:

- The predicted maximum 1-hour average and annual average ground-level concentrations within 3 km of all gas plants is less than the EPP Air objective of 250µg/m³
- The maximum 1-hour average ground-level concentration of NO_2 adjacent to all but one gas plant is less than 65% of the objective with the inclusion of background sources of NO_2.

11.2 Normal Operations – hydrocarbons

The predicted maximum incremental ground-level concentrations of the highest five hydrocarbons in terms of the percentage of the air quality objective are presented in Table 40. The results for the full suite of hydrocarbons are presented in Appendix F. Values presented in Table 40 represent the maximum ground-level concentration anywhere within the gas fields based on assessment of all emissions under normal operating conditions.

Table 40 Predicted maximum incremental ground-level concentrations of the five most important hydrocarbons for the Australia Pacific LNG gas fields

Pollutant	Averaging period	Objective	Predicted maximum incremental concentration	
			Maximum on grid (µg/m³)	Percent of objective (%)
Acrolein	1-hour	0.42	0.32	76
Acetaldehyde	1-hour	42	22.5	54
Formaldehyde	24-hour	54	9.3	17
Chloroethane	1-hour	0.048	0.005	10
Phenanthrene	1-hour	0.5	0.03	6

The hydrocarbon that has a predicted maximum ground-level concentration that is the greatest percentage of the objective is acrolein.

Figure 31, Figure 32 and Figure 33 present maximum 1-hour average ground-level concentrations of acrolien across the Australia Pacific LNG gas fields.

The dispersion modelling results show that the maximum1-hour average ground-level concentration of acrolien is predicted to be below the objective throughout the Australia Pacific LNG gas fields.

11.3 Normal Operations – Odour

An assessment of the potential for odour impacts has been conducted based on odour thresholds of the individual compounds contained in the exhausts of the gas fields' plant. The assessment was based on the 1-hour average ground-level concentration predicted in the Australia Pacific LNG gas fields. Pollutants considered were NO_2 and those odorous hydrocarbons with the potential to influence the ground-level concentration of odour.

By definition, one odour unit (1ou) is equivalent to the odour threshold of a mixture of substances. Consequently, the DERM odour guideline of 2.5ou (for a wake affected stack) is equivalent to a factor of two and half times the substance's odour threshold. Therefore, if the predicted ground-level concentration of the substance is below two and half times the substance's odour threshold, it is unlikely that the odour associated with the substance would exceed the odour guideline. This assessment does not account for any synergistic effects that may alter the odour character or odour threshold of the substance. The assessment is made for the ground-level concentration of each individual compound in the gas mixture at the odour guideline of 2.5ou, 1-hour average (99.5th percentile). Predicted ground-level odour concentrations of potentially odorous compounds are presented in Table 41.

Table 41 Predicted 1-hour average 99.5th percentile ground-level odour concentration for identified pollutants

Pollutant	Odour threshold[2] (µg/m[3])	Predicted 99.5th percentile ground-level concentration[4] (µg/m[3])	Predicted 99.5th ground-level odour concentration[4] (ou)	Percent of odour guideline (%)
Nitrogen dioxide	100[5]	142.9	1.4	57.2
Formaldehyde	36[6]	13.4	0.37	14.9
Acetaldehyde	27[7]	2.1	0.19	7.8
Acrolein	50[8]	0.03	0.15	0.1
Total	-	-	2.1	84%

[1] Air quality objective expressed as a 1-hour average
[2] Odour threshold in micrograms per cubic metre is equivalent to one odour unit
[3] Equivalent pollutant concentration in comparison to EPA odour guideline of 2.5ou
[4] Predicted maximum is for the 99.5th percentile
[5] Odour threshold for nitrogen dioxide 0.05-0.22ppm (WHO, 2000b)
[6] Odour threshold for formaldehyde 0.027-1.9ppm (CCOHS, 2006)
[7] Odour threshold for acetaldehyde 27 - 7,420µg/m³ at 25°C (Buttery *et al*., 1988, Flatch *et al*., 1967, Fors, 1988, Hartung *et al*., 1971, Mulders *et al*., 1973, Teranishi, 1974)
[8] Odour threshold for acrolein 50 - 4,122µg/m³ (OMoE, 2005)

The results show the following:

- The maximum (99.5th percentile) 1-hour average ground-level odour concentration across the Australia Pacific LNG gas fields, associated with emissions from the Australia Pacific LNG Project, is predicted to be below the odour guideline of 2.5ou, and
- Odour associated with the operation of the Australia Pacific LNG Project is unlikely to evident at sensitive receptors.

11.4 Abnormal operations - operation of gas flares

The predicted maximum incremental and cumulative ground-level concentrations of criteria air pollutants and the predicted maximum incremental ground-level concentrations of hydrocarbons for the Australia Pacific LNG gas fields during abnormal upset conditions are presented in Table 42.

Figure 34, Figure 35 and Figure 36 present maximum 1-hour average ground-level concentrations of NO_2 due to the operation of gas flares across the Australia Pacific LNG gas fields and accounting for the influence of existing sources of NO_2, such as power stations.

The results show that the ground-level concentrations of all air pollutants are predicted to be below the air quality objectives during the operation of the gas flares. This is the case anywhere within the Australia Pacific LNG gas fields during any of the potential operating scenarios. This includes the use of all flares simultaneously while all other infrastructure is operating under normal conditions.

Table 42 Predicted maximum incremental and cumulative ground-level concentrations for criteria air pollutants and hydrocarbons for the Australia Pacific LNG Project during abnormal upset conditions

Pollutant	Averaging period	Objective	All flares only		All flares plus power generation engine only		All flares plus Australia Pacific LNG normal operating scenario	
			Incremental	With background	Incremental	With background	Incremental	With background
Nitrogen dioxide	1-hour	250	18.9	108.7	230.6	230.6	241.2	241.2
	Annual	62	0.1	0.8	3.3	3.5	4.1	4.2
Carbon monoxide	8-hour	11,000	45.0	99.7	370.1	424.8	536.0	590.6
Methane	1-hour	-	71.2	N/A	N/A	N/A	N/A	N/A
Ethane	1-hour	12,000	10.4	N/A	N/A	N/A	N/A	N/A
Ethylene	1-hour	-	10.4	N/A	N/A	N/A	N/A	N/A
Acetylene	1-hour	26,600	6.5	N/A	N/A	N/A	N/A	N/A
Propane	1-hour	18,000	9.1	N/A	N/A	N/A	N/A	N/A
Propylene	1-hour	8,750	32.4	N/A	N/A	N/A	N/A	N/A

Table note:

N/A: Not assessed. There is no background monitoring for hydrocarbons in the region and, consequently, a cumulative assessment has not been carried out. The background associated with hydrocarbon emissions from the engines and boilers has not been conducted as these sources emit different hydrocarbons and the concentrations predicted are a very small fraction of the ambient air quality objectives.

12. Dispersion model results – Undulla Nose case study

The predicted maximum 1-hour and annual average ground-level concentrations of NO_2 at a sensitive receptor location, for the Australia Pacific LNG Project with background including QGC plants are presented Table 43.

Table 43 Predicted maximum cumulative ground-level concentrations of nitrogen dioxide at the most affected sensitive receptor for the Australia Pacific LNG gas fields with background including QGC plants

Pollutant	Averaging period	Objective	Maximum at a sensitive receptor (µg/m³)	Percent of objective (%)
Nitrogen dioxide	1-hour	250	154.1	61.6
	Annual	62	1.1	1.8

Figure 37 and Figure 38 present maximum 1-hour average and annual average ground-level concentrations of NO_2 due to project activities and accounting for the influence of existing sources of NO_2, such as power stations and the operations of the QGC plants that are proposed nearby.

The results show the following:

- The total cumulative impacts for the Australia Pacific LNG gas fields, the proposed QGC gas plant and the power stations in the region have been assessed. The maximum ground-level concentration of NO_2 predicted at any sensitive receptor location in the Undulla Nose area is not expected to exceed the EPP Air air quality objectives for the 1-hour and annual averages.

13. Conclusions

The assessment of potential effects on air quality associated with emissions from combustion sources has been carried out using atmospheric dispersion modelling across the Australia Pacific LNG gas fields. The following conclusions can be drawn from the air quality assessment:

- Nitrogen dioxide was found to be the most important air pollutant. Predicted ground-level concentrations of nitrogen dioxide due to the gas fields' operations are unlikely to exceed the EPP Air air quality objectives during normal operations accounting for existing sources of nitrogen dioxide in the region. This assumes that NOx emissions from rich-burn gas-fired engines at the existing Talinga GPF (90TJ/d) are significantly reduced through the application of non-selective catalytic converter technology to at least 6 of the engines.
- Acrolein was found to be the next most important air pollutant. Predicted ground-level concentrations of acrolein due to the gas fields' operations are unlikely to exceed the air quality objectives during normal operations.
- Predicted ground-level concentrations of carbon monoxide and all other air pollutants due to the gas fields' operations are unlikely to exceed the EPP Air air quality objectives during normal operations.
- Predicted ground-level concentrations of carbon monoxide due to the gas fields' operations are unlikely to exceed the EPP Air air quality objective during normal operations accounting for existing sources of carbon monoxide in the region.
- The total cumulative impacts of the Australia Pacific LNG gas fields, the proposed QGC gas plants and the power stations in the region have been assessed at the location where a cumulative impact is most likely to occur, which is the central gas fields or Undulla Nose area. The maximum ground-level concentration of nitrogen dioxide predicted at any sensitive receptor location in the Undulla Nose area is well below the EPP Air air quality objectives for the 1-hour and annual averages.
- The predicted ground-level concentrations of all air pollutants in the event of abnormal upset conditions requiring flaring are predicted to be below the air quality objectives during the operation of the gas flares. This is the case anywhere within the Australia Pacific LNG gas fields during any of the potential abnormal operating scenarios. This includes the use of all flares simultaneously while all other infrastructure is operating under normal conditions.

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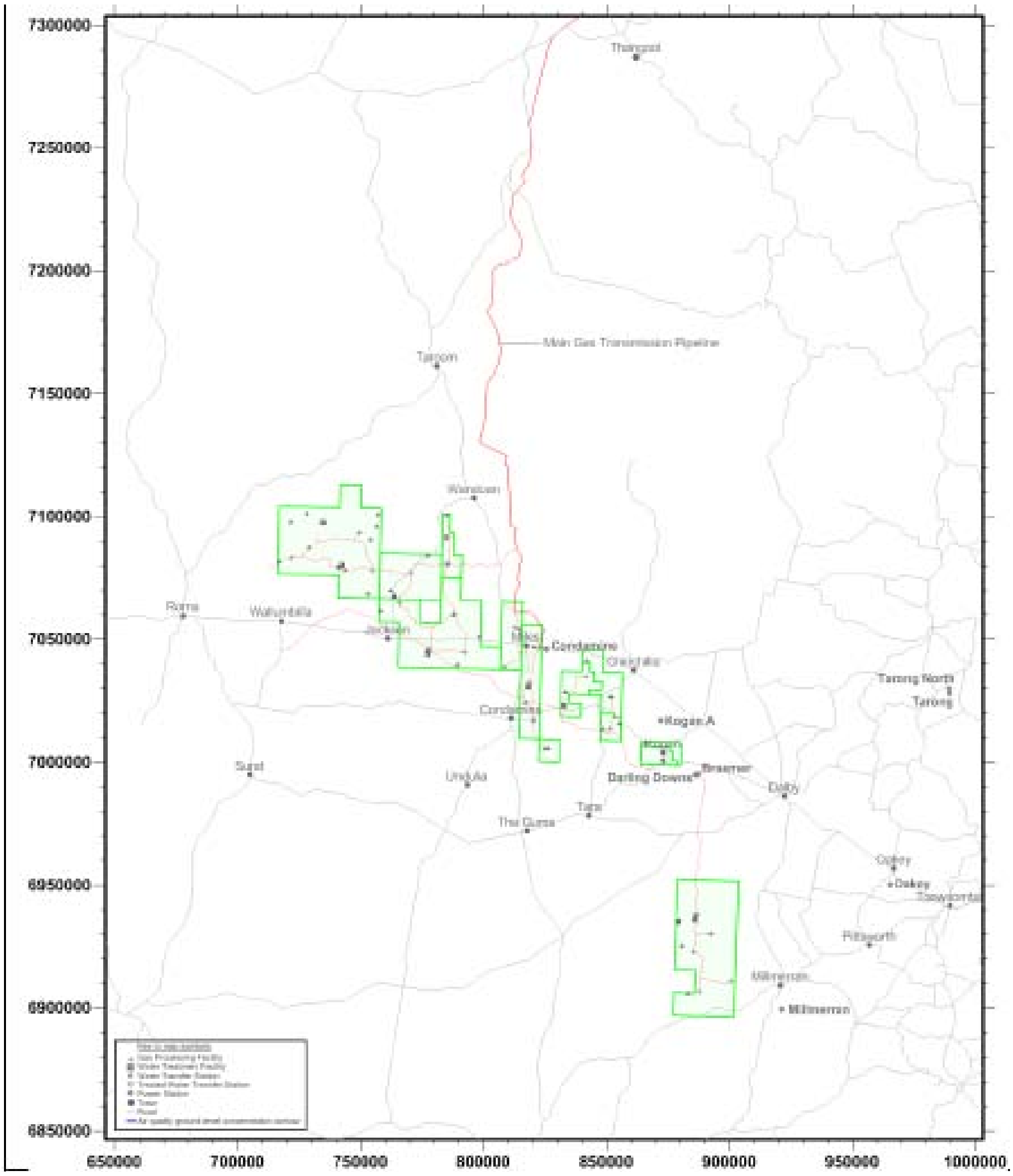


Figure 1 Map showing the Australia Pacific LNG gas fields and southern portion of the gas transmission pipeline

Location:	**Data source:**	**Units:**
Darling Downs, south central Queensland	GIS data supplied by WorleyParsons	Australian Map Grid coordinates – MGA94 1994 AMG Zone 55 (in metres)
Type:	**Prepared by:**	**Date:**
Site map	A. Balch	December 2009

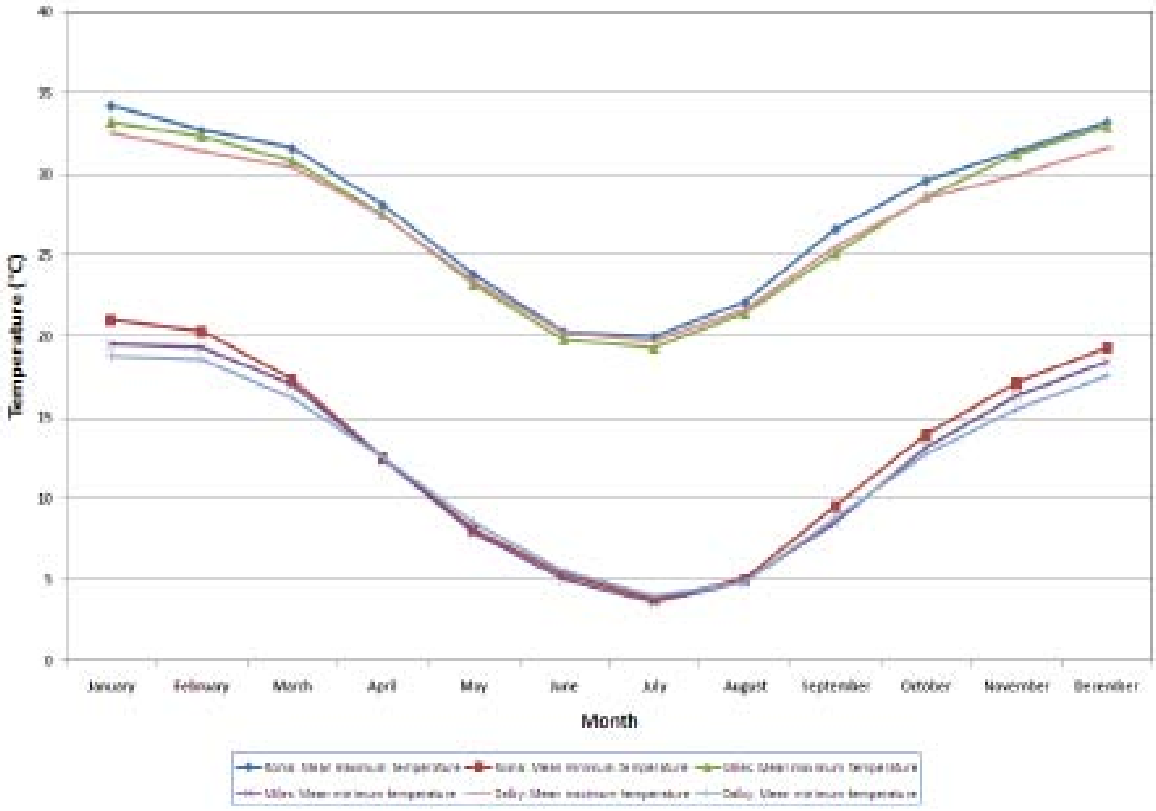


Figure 2	**Average daily maximum and minimum temperatures (°C) for Roma, Miles and Dalby**	
Location: Roma, Miles and Dalby	**Data source:** BoM	**Units:** Degrees Celsius
Type: Histogram	**Prepared by:** S. Menzel	**Date:** October 2009

Figure 3 Mean daily solar exposure (MJ/m²) for Roma, Miles and Dalby

Location: Roma Aero, Miles PO and Dalby Aero	**Data source:** BoM	**Units:** MJ/m²
Type: Histogram	**Prepared by:** S. Menzel	**Date:** October 2009

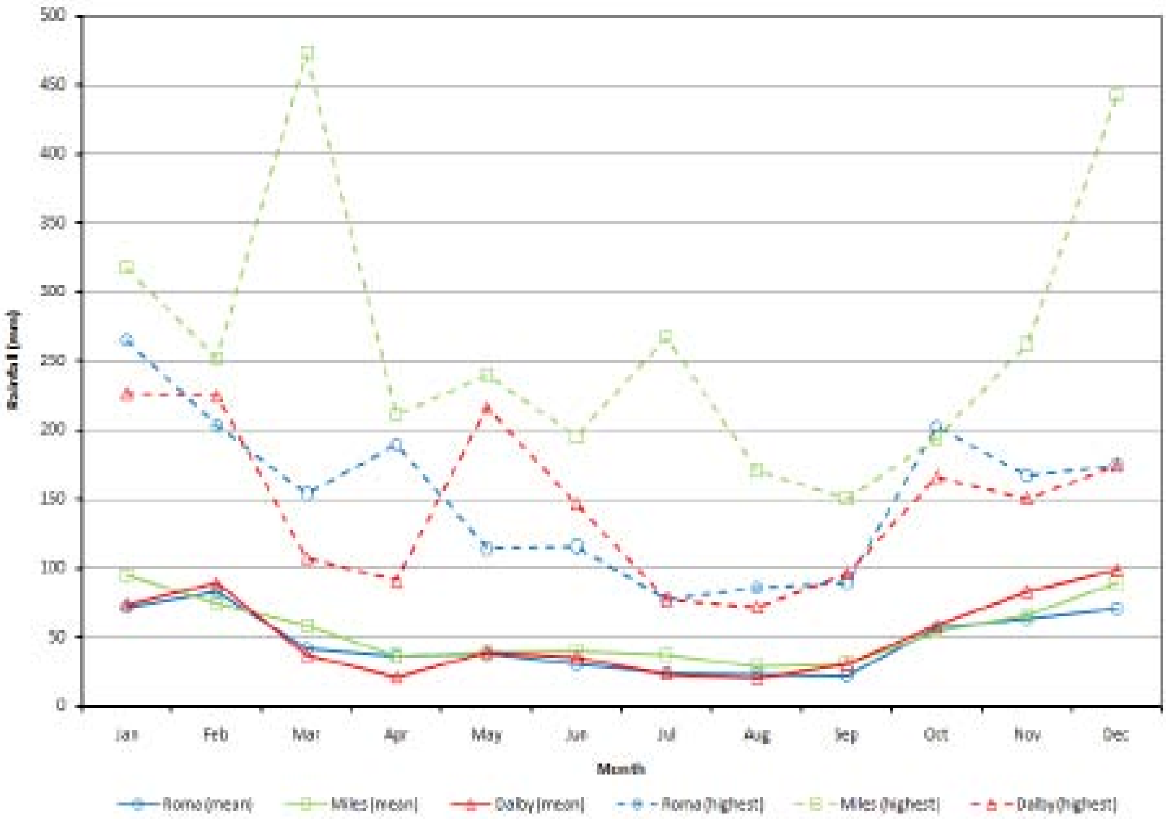
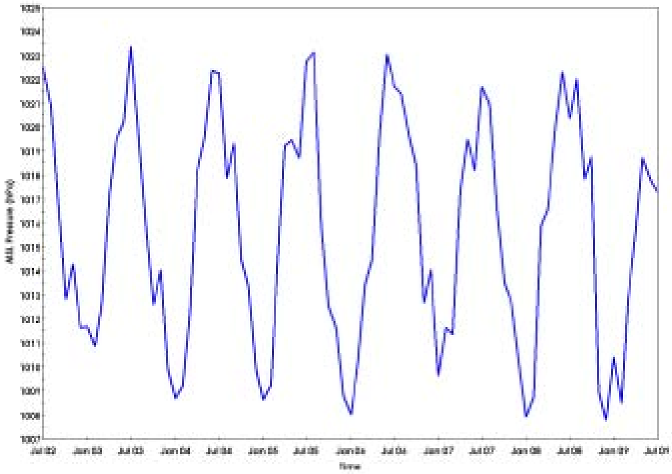


Figure 4 **Average and highest monthly rainfall at Roma, Miles and Dalby**

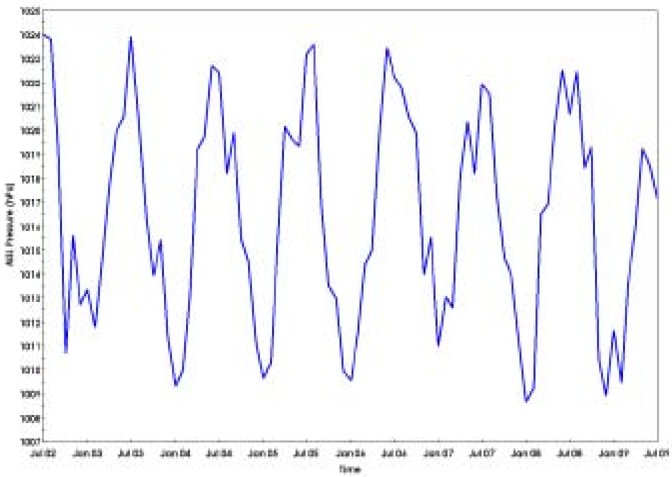
Location: Roma, Miles and Dalby	**Data source:** BoM	**Units:** Millimetres per month
Type: Histogram	Prepared by: A. Balch	**Date:** November 2009

Figure 5 **Monthly averaged 9am and 3pm measurements of relative humidity (%) for Roma, Miles and Dalby**

Location: Roma, Miles and Dalby	**Data source:** BoM	**Units:** Percentage
Type: Histogram	Prepared by: A. Balch	**Date:** October 2009



a)



b)

Figure 6 **Monthly averaged mean sea-level pressure at Roma (a) and Miles (b)**

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

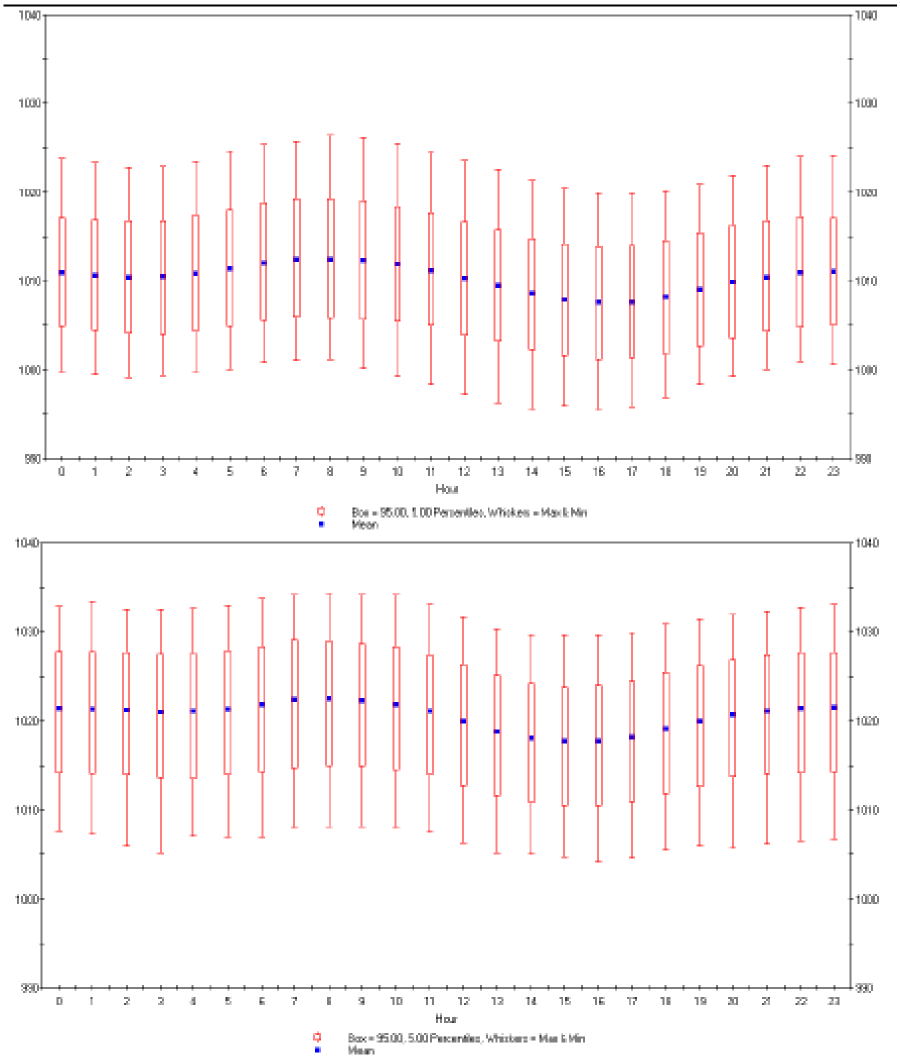


Figure 7	**Hourly distribution of surface pressure at Roma during the wet season (top) (November to February) and the dry season (bottom) (May to August)**	
Location: Roma	**Data source:** BoM	**Units:** hPa
Type: Box and whisker plot	**Prepared by:** A. Balch	**Date:** November 2009

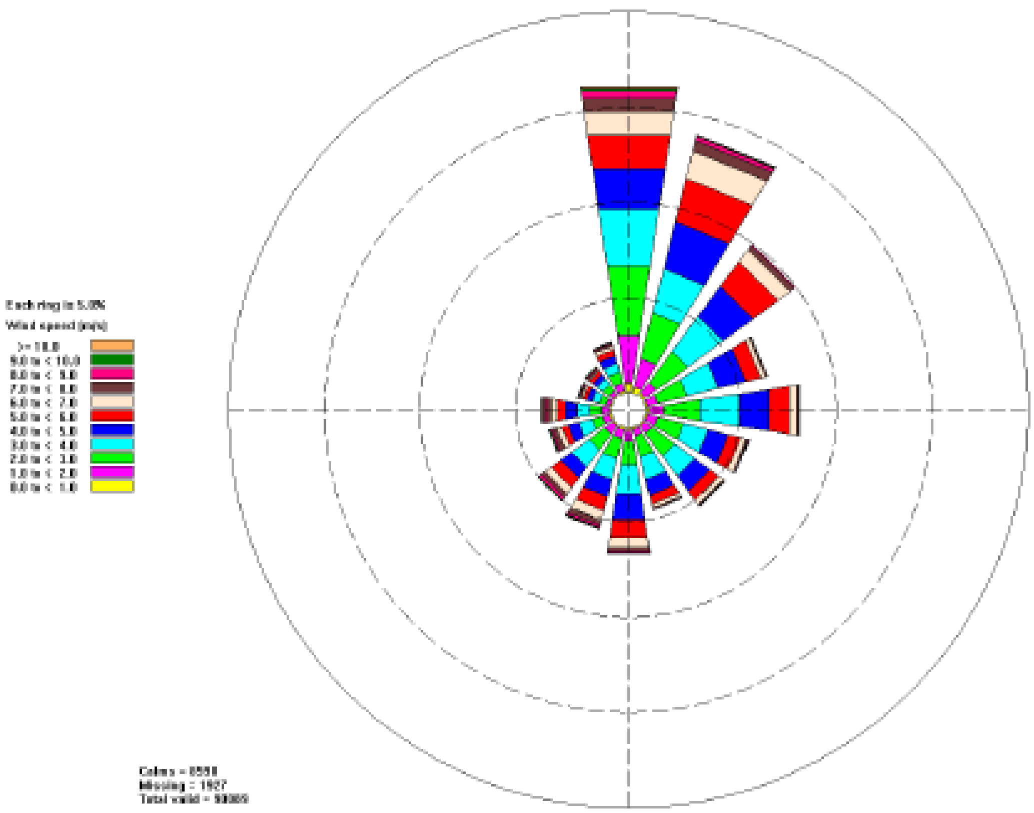


Figure 8 **Annual distributions of winds at Roma**

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

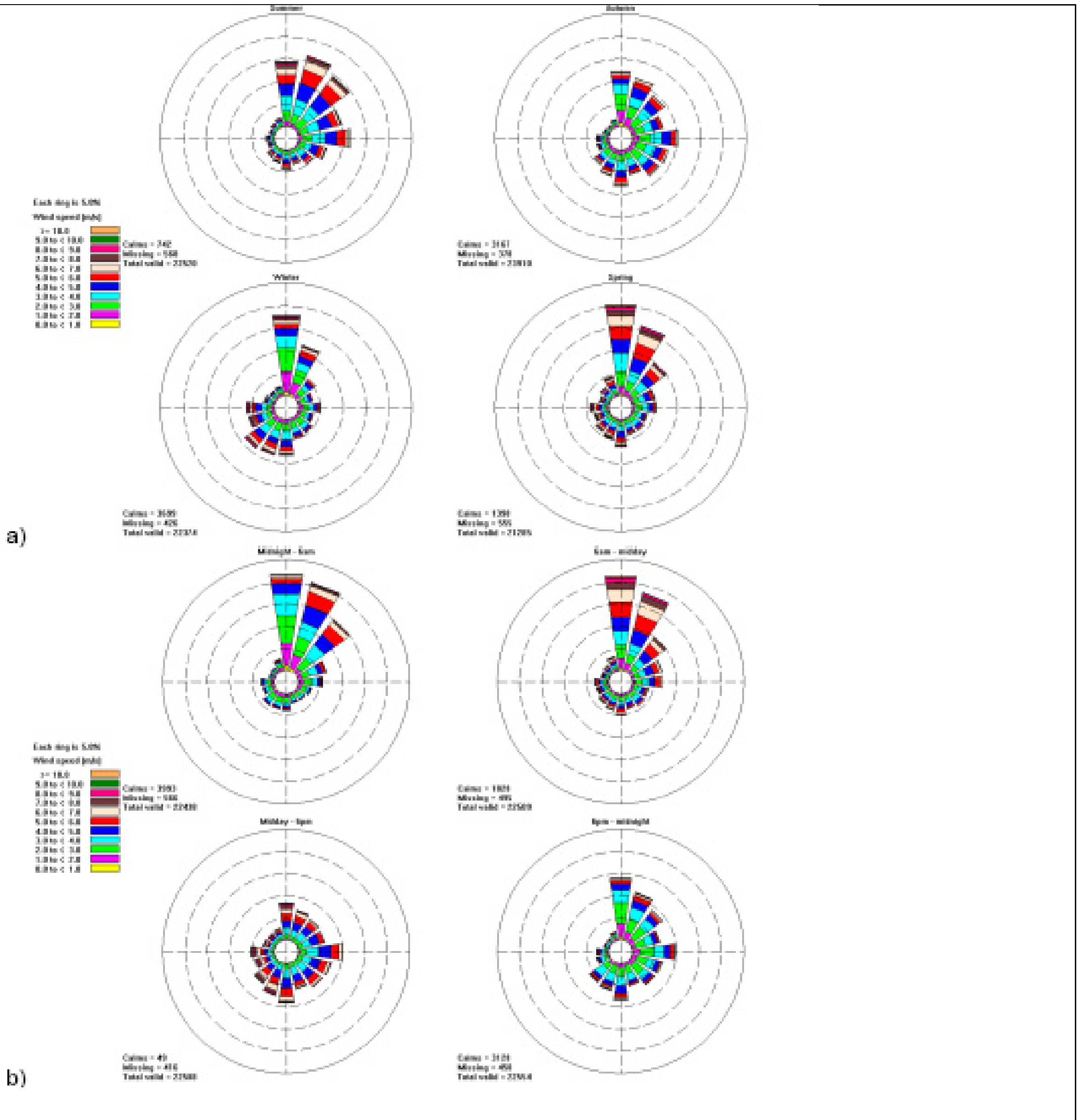


Figure 9 Seasonal (a) and diurnal (b) distributions of winds at Roma

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

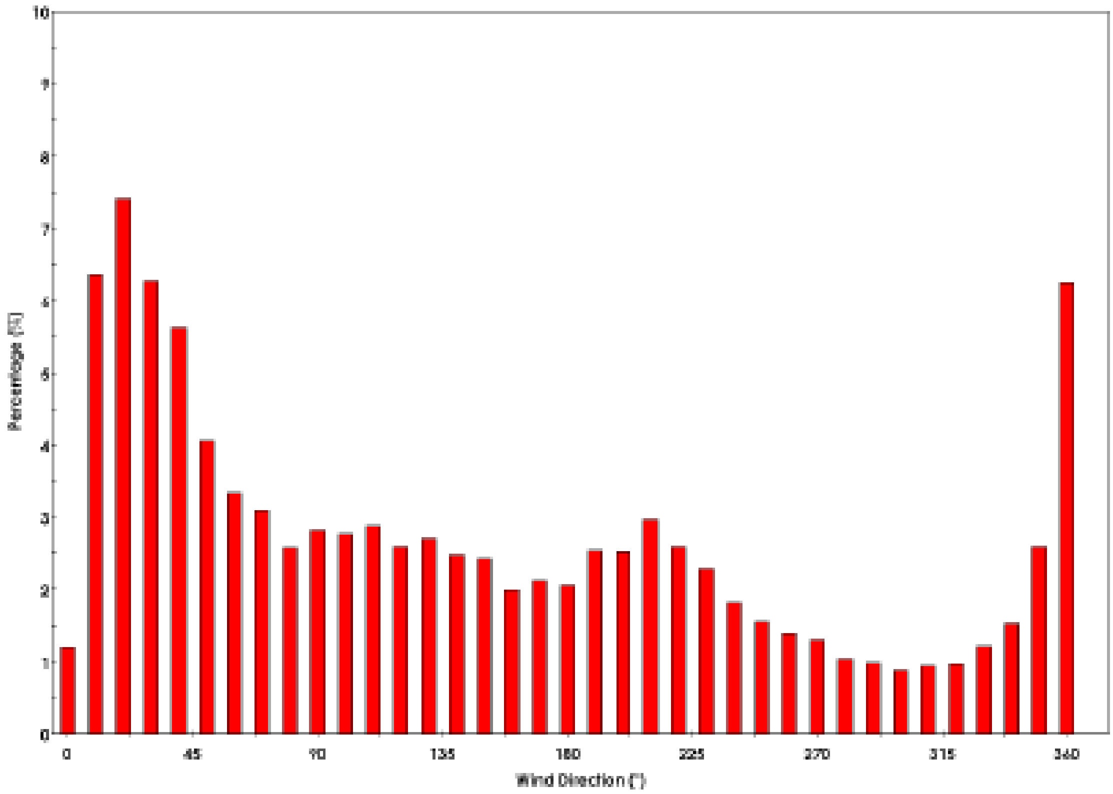


Figure 10 Annual frequency distribution of wind direction at Roma

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

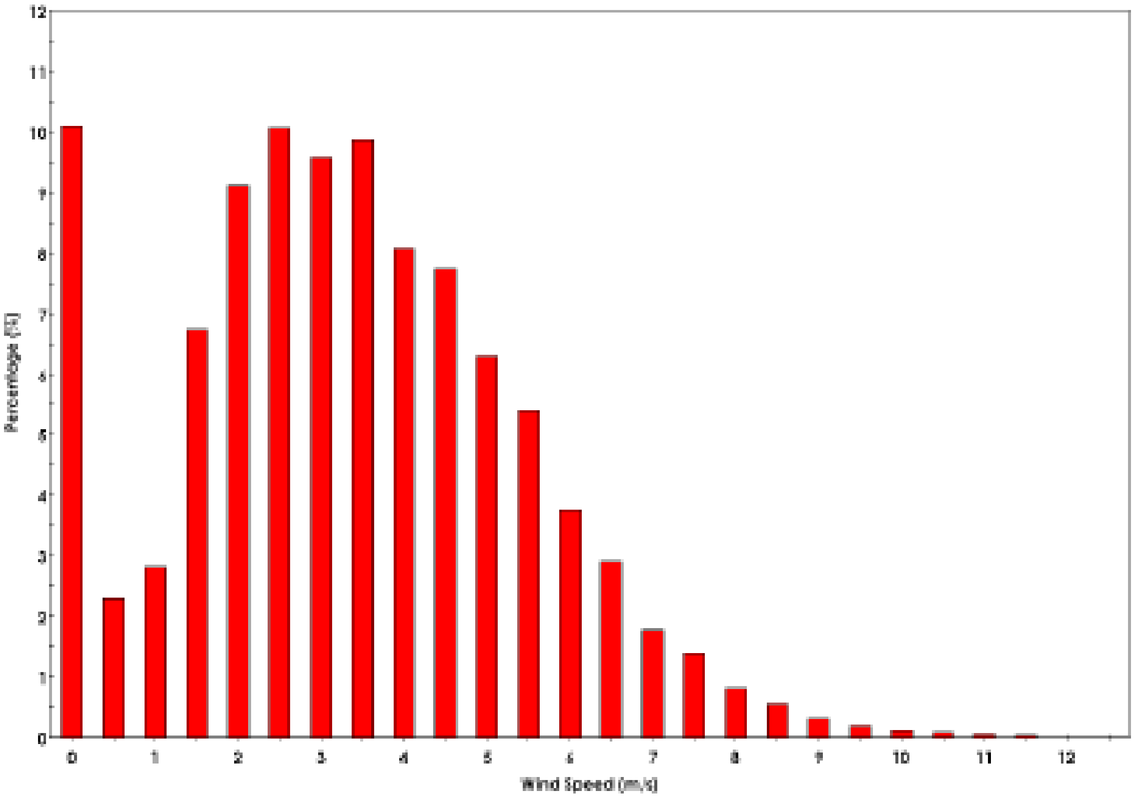


Figure 11 Annual frequency distribution of wind speeds at Roma

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

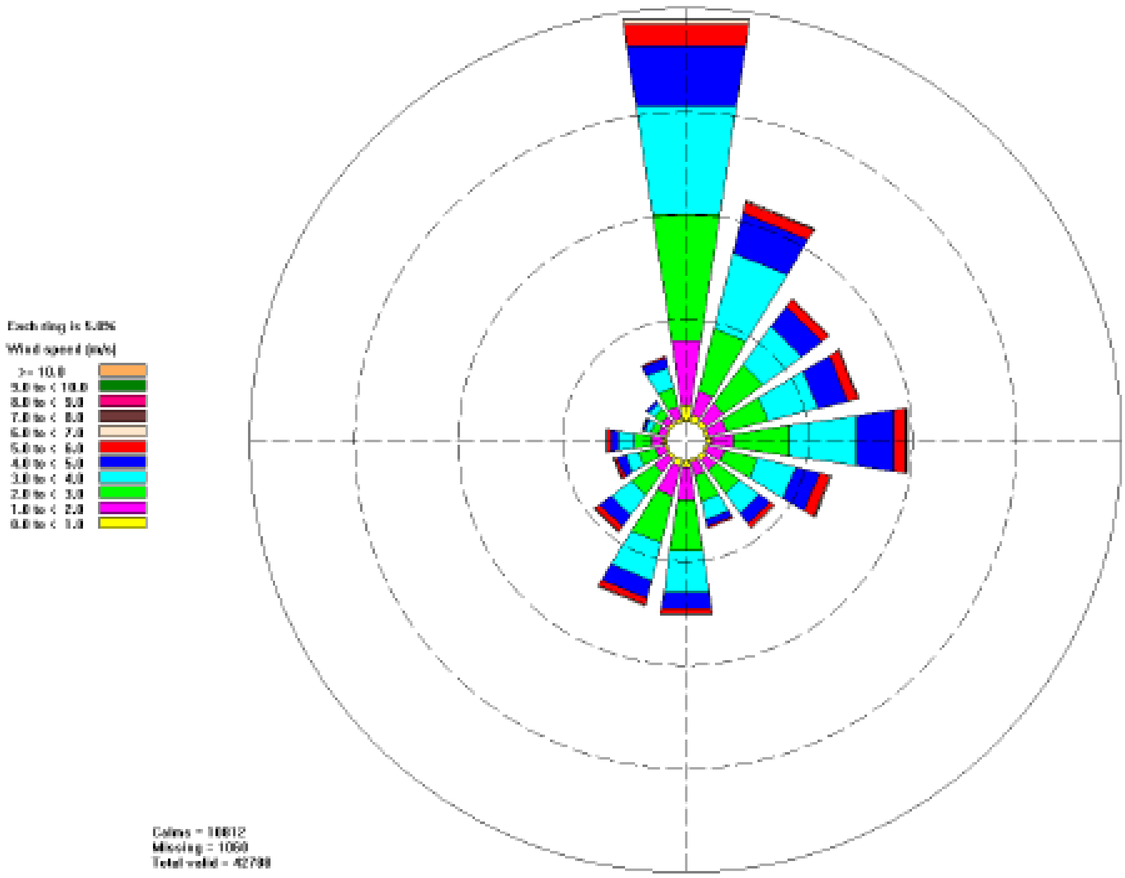


Figure 12 Annual distribution of winds at Miles

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

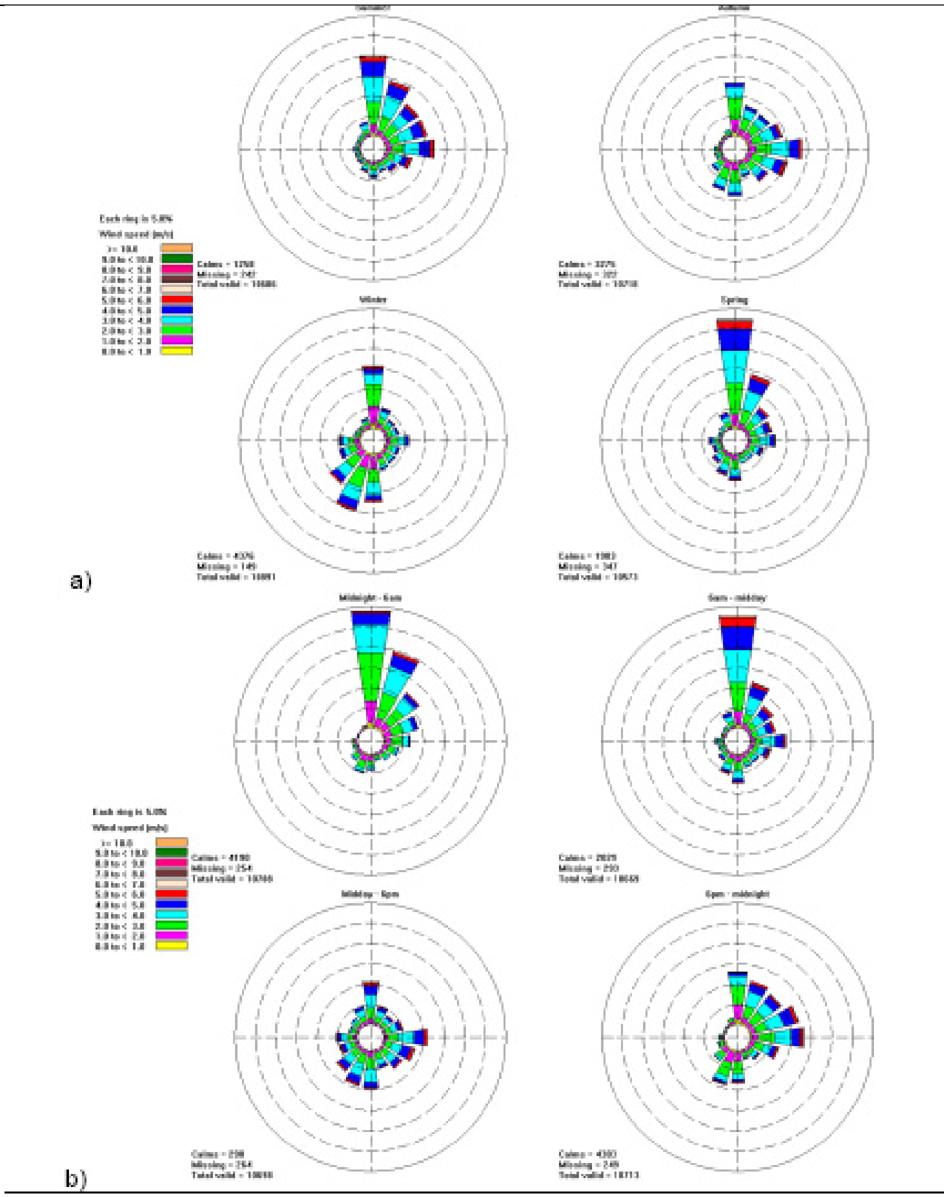


Figure 13 **Seasonal (a) and diurnal (b) distributions of winds at Miles**

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

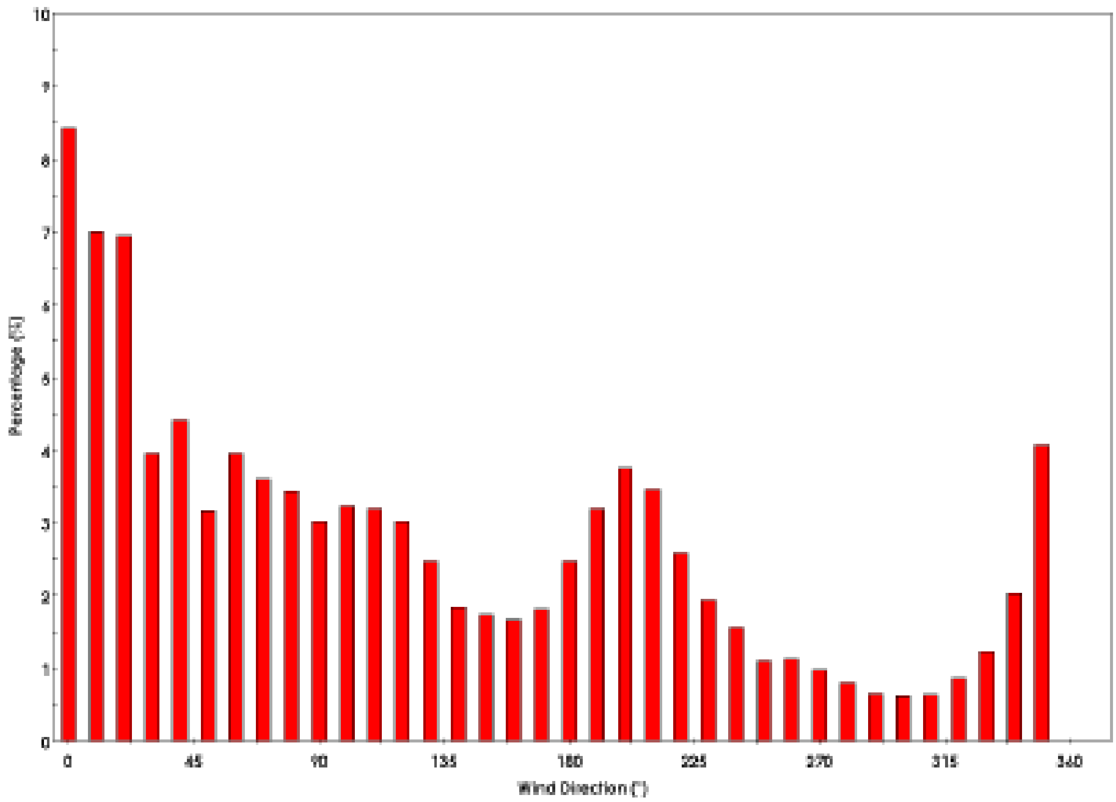


Figure 14 Annual frequency distribution of wind direction at Miles

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

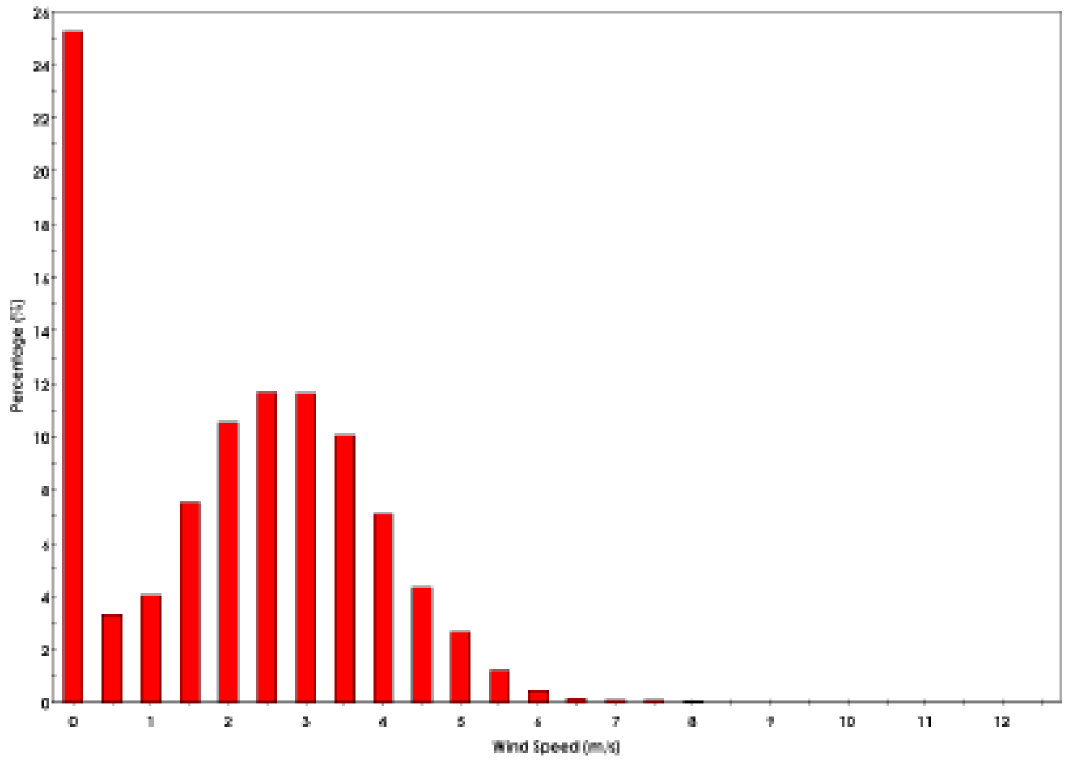
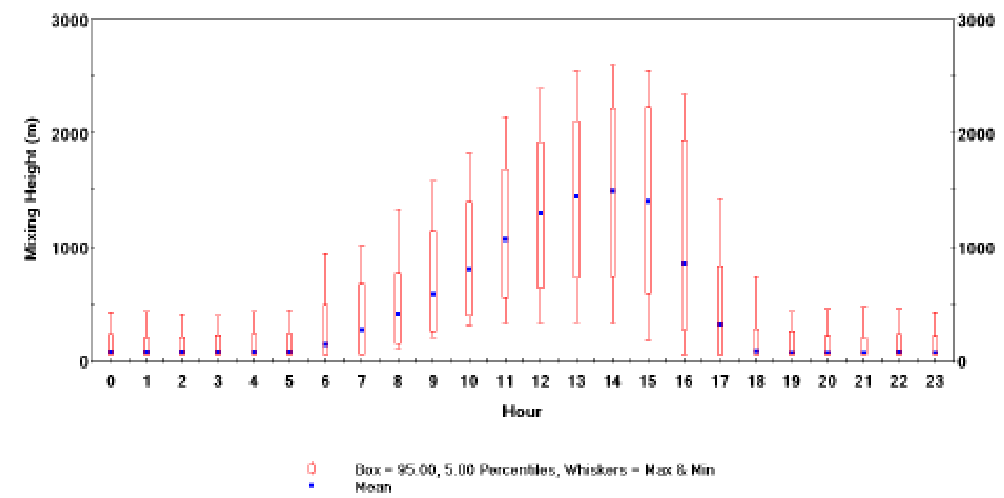
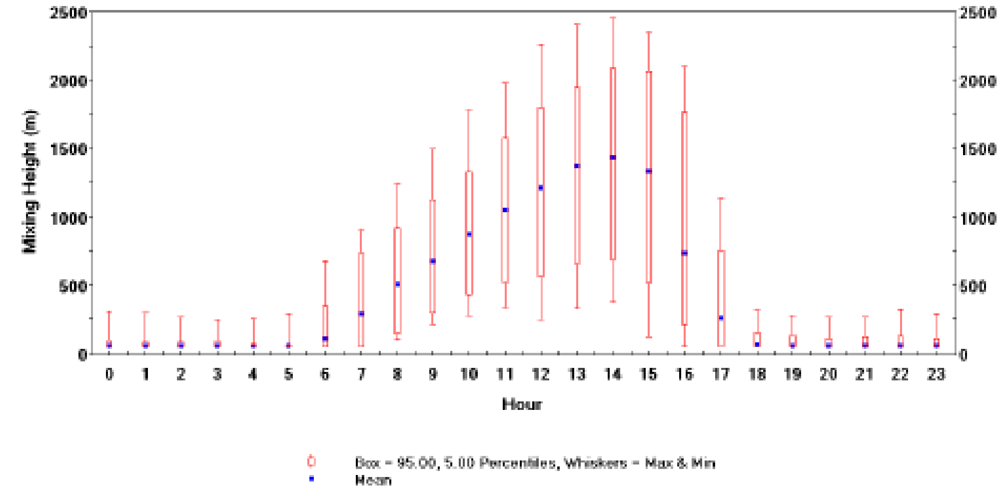


Figure 15 Annual frequency distribution of wind speeds at Miles

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



a)



b)

Figure 16 Mixing height for a) Roma and b) Miles

Location: Roma Miles	**Data source:** CALMET	**Units:** Metres above surface
Type: Box and whisker plot	**Prepared by:** A. Wiebe	**Date:** December 2009

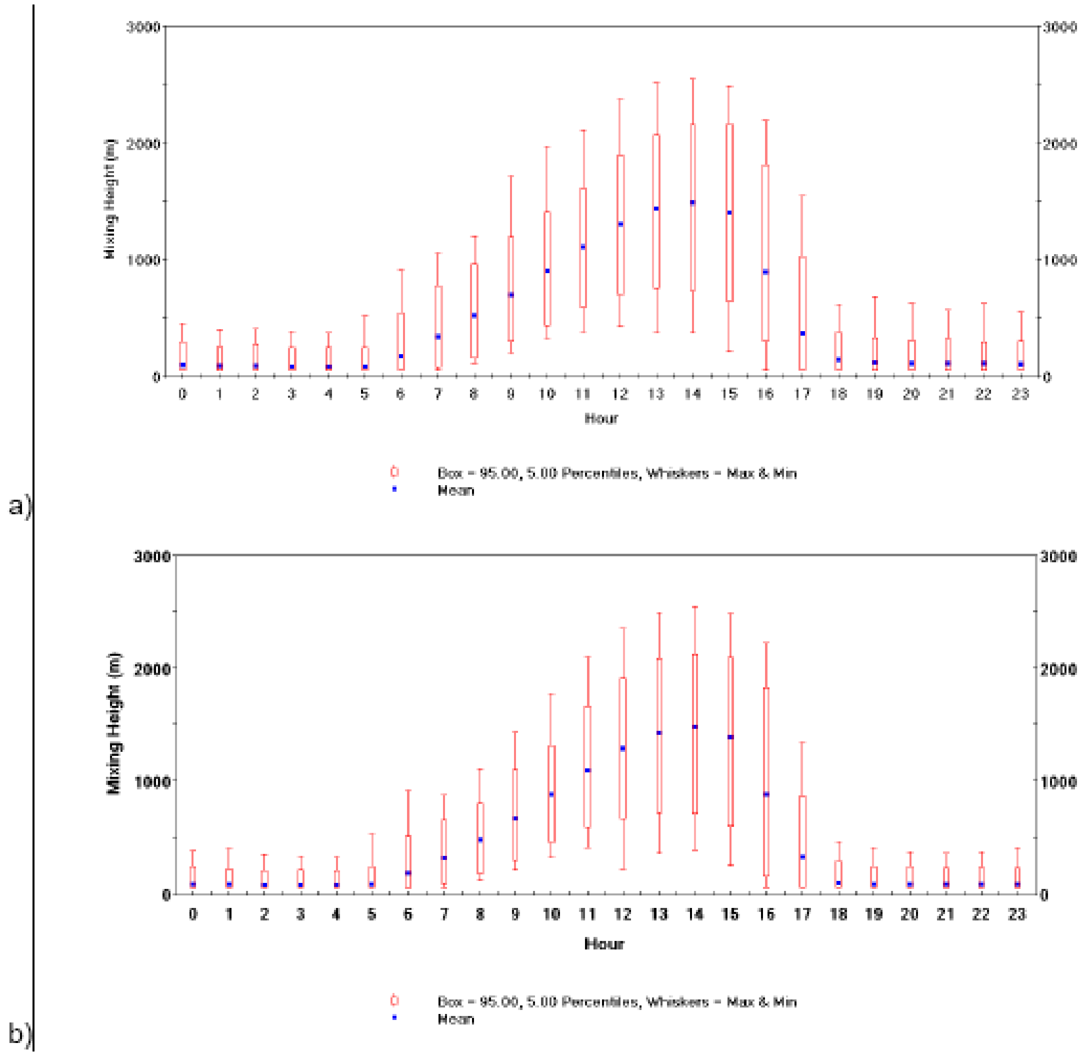


Figure 17 Mixing height for a) Dalby and b) Oakey

Location: a) Dalby b) Oakey	**Data source:** CALMET	**Units:** Metres above surface
Type: Box and whisker plot	**Prepared by:** A. Wiebe	**Date:** December 2009

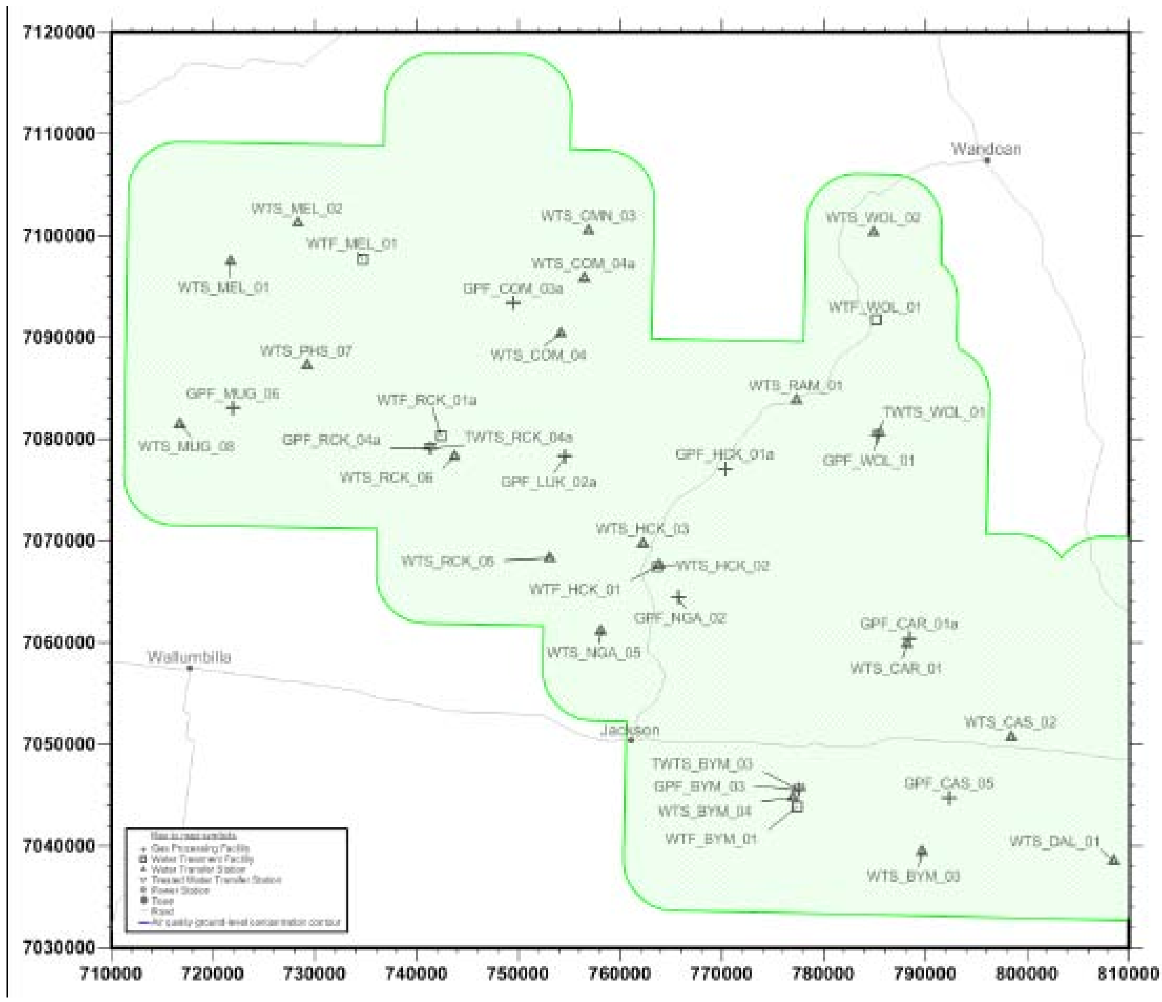


Figure 18 Map showing the north-western region of the Australia Pacific LNG gas fields including the location GPF, WTS, WTF infrastructure included in the modelling study

Location: Darling Downs, south central Queensland	**Data source:** GIS data and plant locations supplied by WorleyParsons and Origin	**Units:** Australian Map Grid coordinates – MGA94 1994 AMG Zone 55 (in metres)
Type: Site map	**Prepared by:** A. Balch	**Date:** December 2009

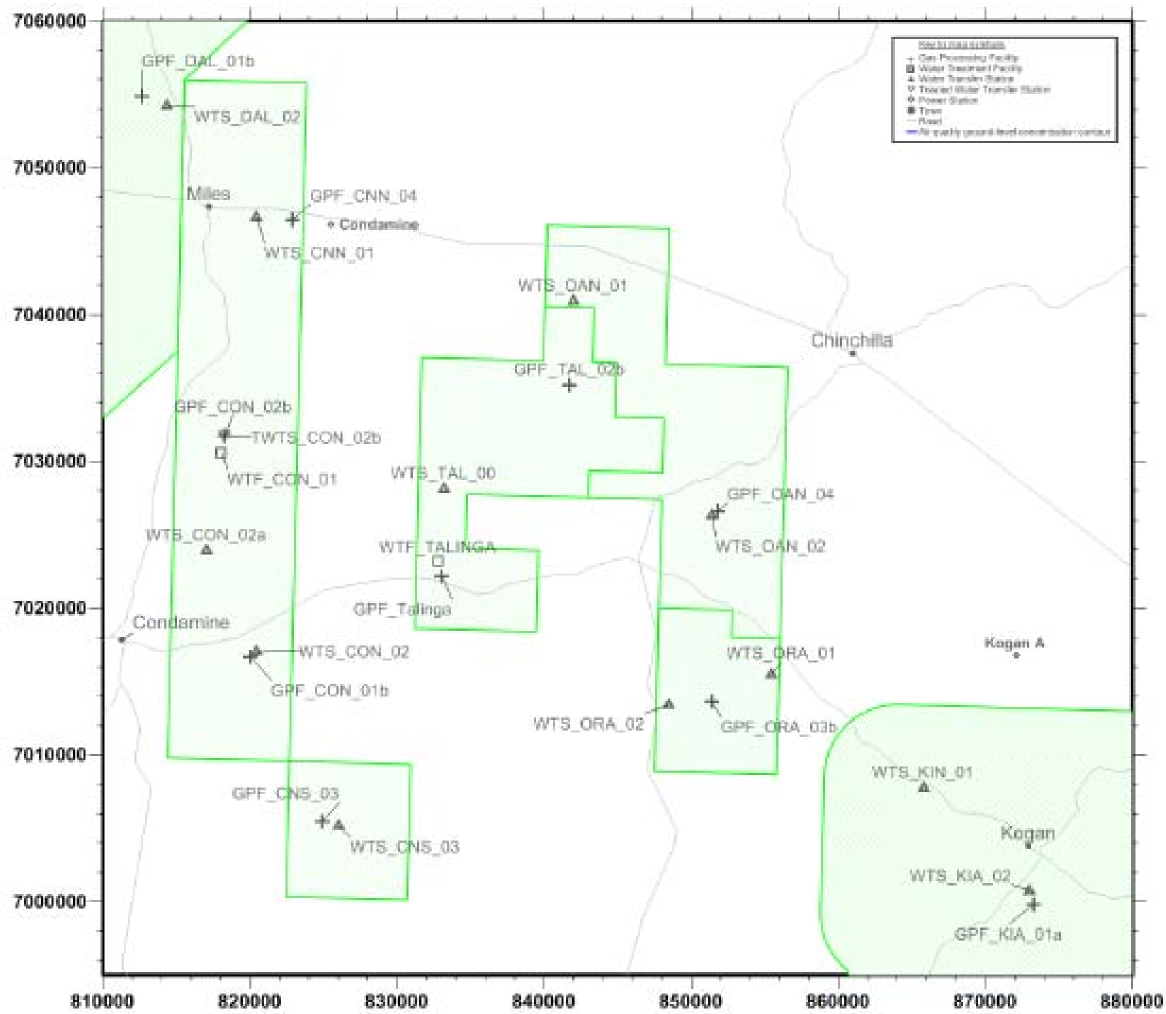


Figure 19 Map showing the central region of the Australia Pacific LNG gas fields including the location GPF, WTS and WTF infrastructure included in the modelling study

Location: Darling Downs, south central Queensland	**Data source:** GIS data and plant locations supplied by WorleyParsons and Origin	**Units:** Australian Map Grid coordinates – MGA94 1994 AMG Zone 55 (in metres)
Type: Site map	**Prepared by:** A. Balch	**Date:** December 2009

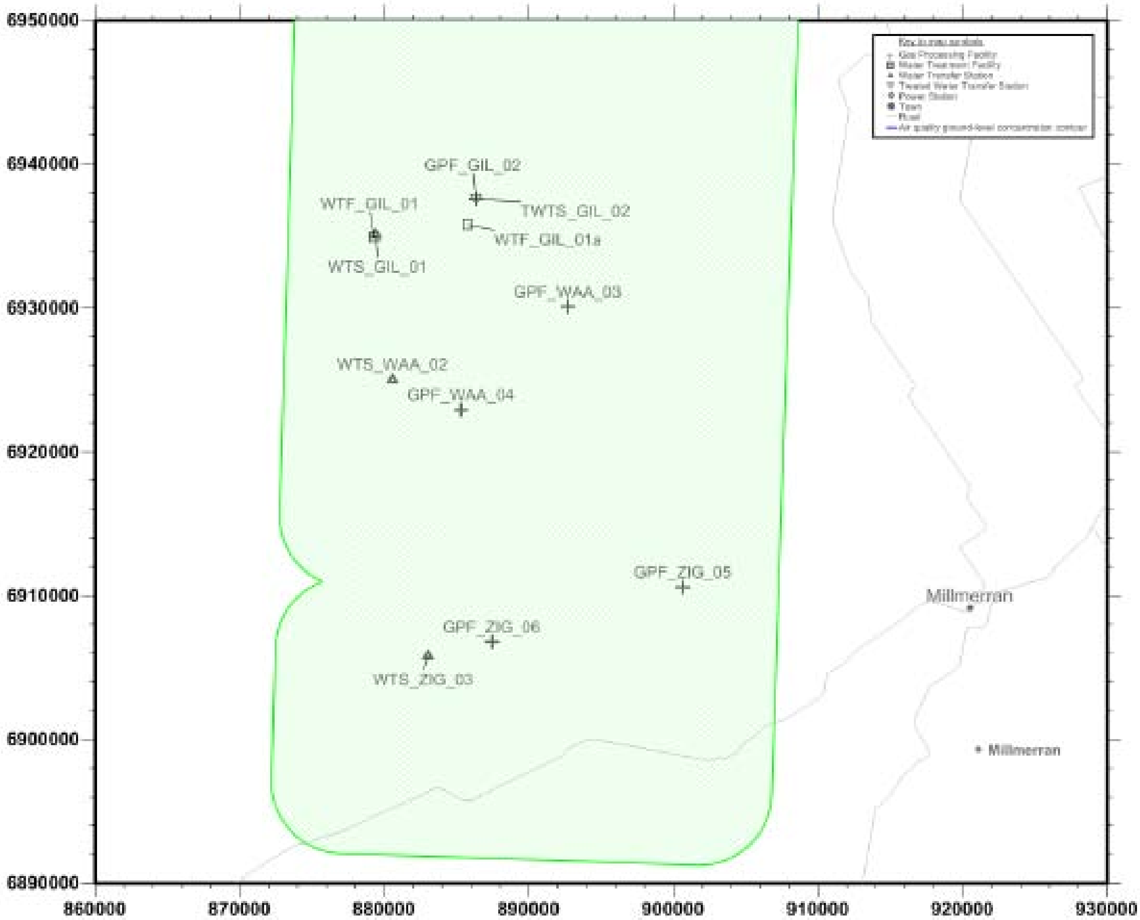


Figure 20 Map showing the south-eastern region of the Australia Pacific LNG gas fields including the location GPF, WTS and WTF infrastructure included in the modelling study

Location: Darling Downs, south central Queensland	**Data source:** GIS data and plant locations supplied by WorleyParsons and Origin	**Units:** Australian Map Grid coordinates – MGA94 1994 AMG Zone 55 (in metres)
Type: Site map	**Prepared by:** A. Balch	**Date:** December 2009

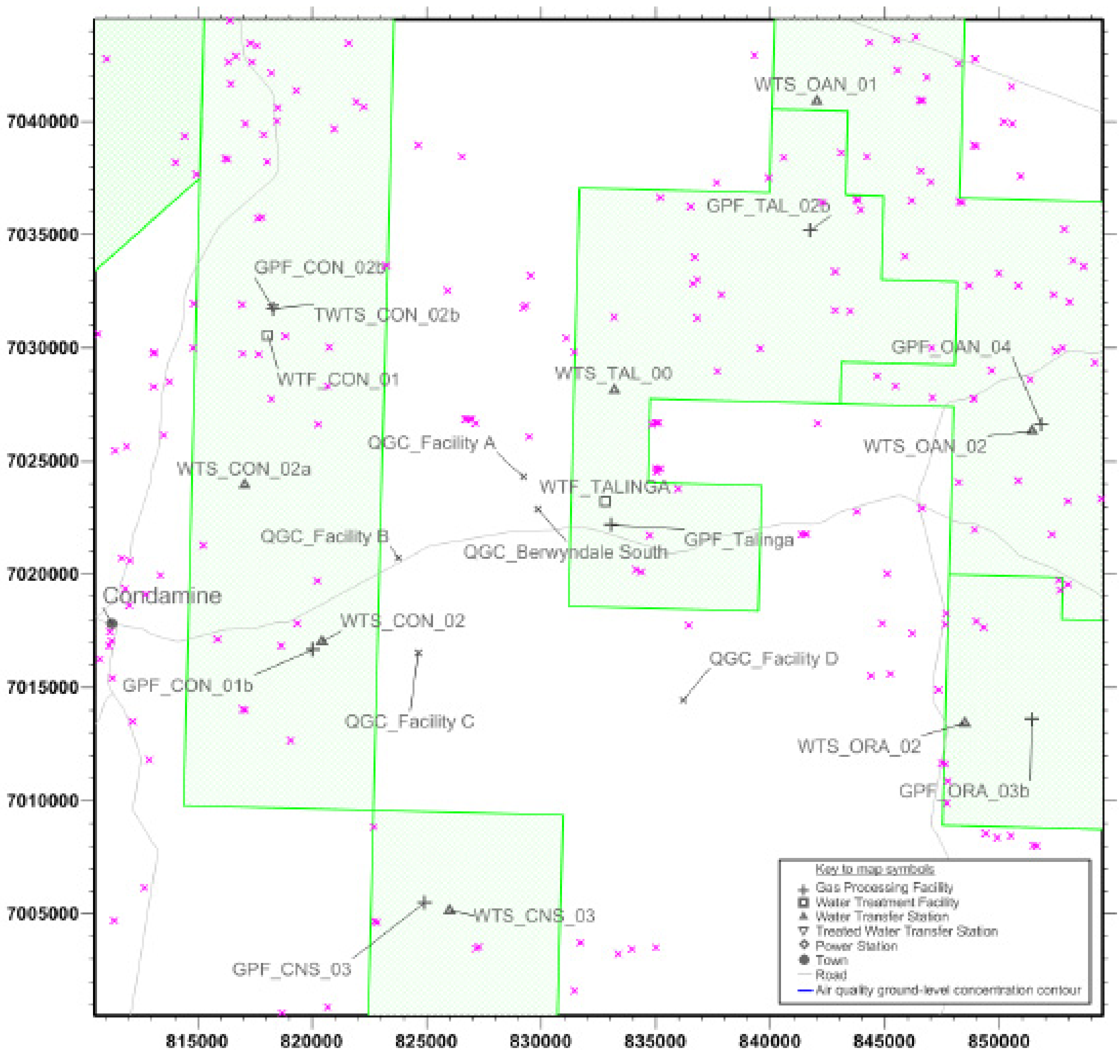


Figure 21 Map showing the gas fields area assessed in the Undulla Nose case study dispersion model including the location GPF, WTS and WTF infrastructure and QGC sources. Locations of identified sensitive receptors are also shown.

Location:	**Data source:**	**Units:**
Darling Downs, south central Queensland	GIS data and plant locations supplied by WorleyParsons and Origin	Australian Map Grid coordinates – MGA94 1994 AMG Zone 55 (in metres)
Type:	**Prepared by:**	**Date:**
Site map	A. Balch	December 2009

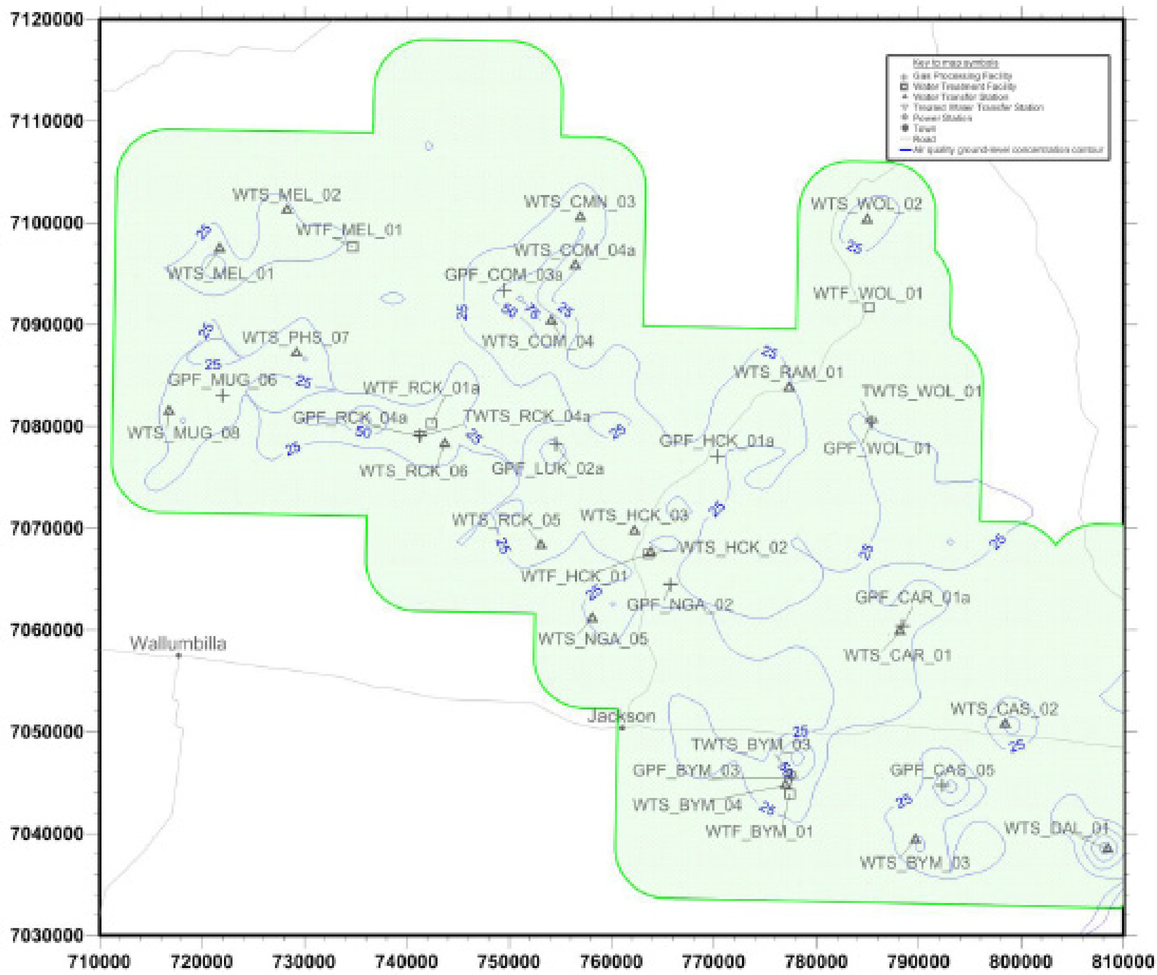


Figure 22 Normal operating scenario north-western region – Predicted maximum 1-hour average ground-level concentrations of nitrogen dioxide for the Australia Pacific LNG gas fields with background

Location:	**Averaging period:**	**Data source:**	**Units:**
Darling Downs, south central Queensland	1-hour	CALPUFF	µg/m³
Type: Maximum contour plot	Air quality objective: Health and wellbeing: 250 µg/m³	**Prepared by:** S. Menzel	**Date:** December 2009

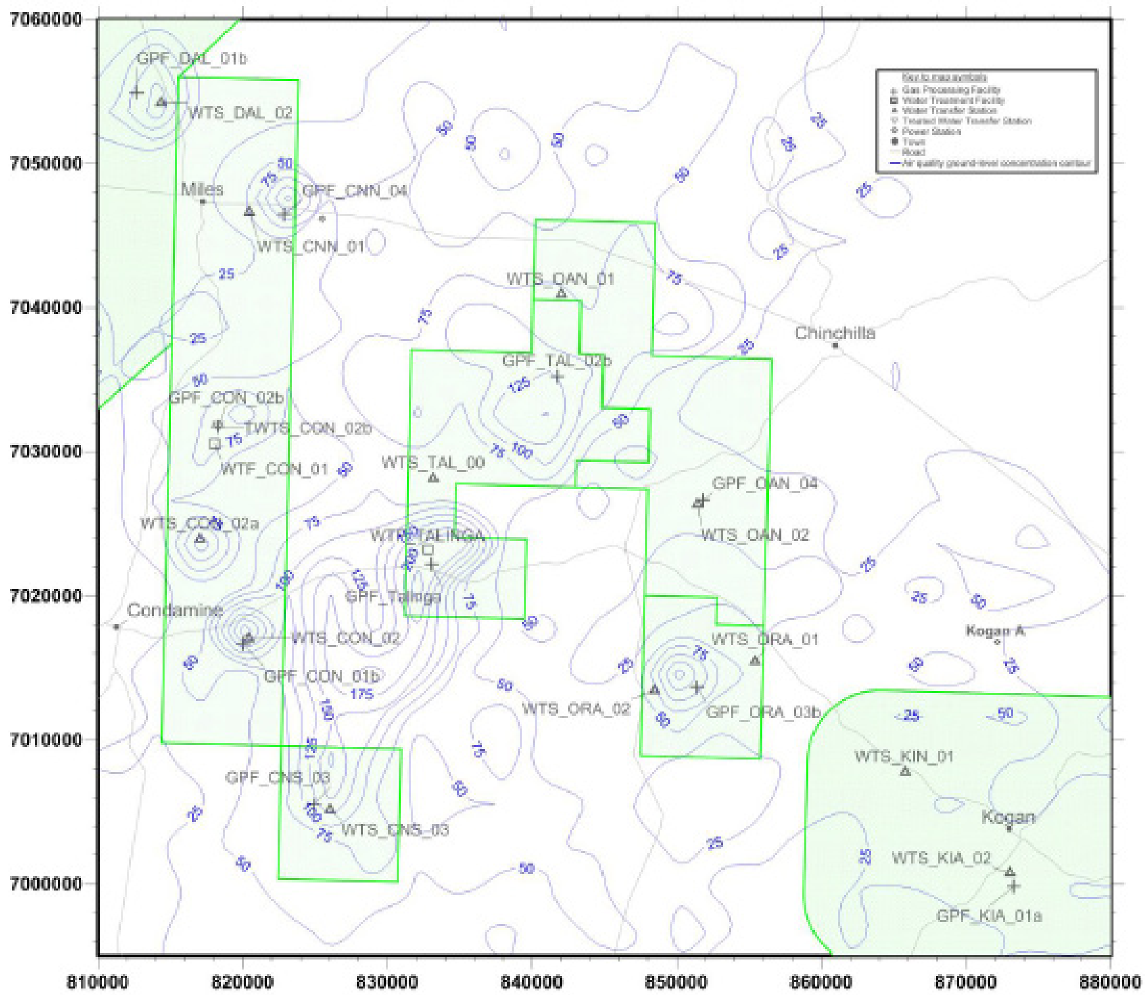


Figure 23 Normal operating scenario central region – Predicted maximum 1-hour average ground-level concentrations of nitrogen dioxide for the Australia Pacific LNG gas fields with background

Location:	**Averaging period:**	**Data source:**	**Units:**
Darling Downs, south central Queensland	1-hour	CALPUFF	µg/m³
Type: Maximum contour plot	Air quality objective: Health and wellbeing: 250 µg/m³	**Prepared by:** S. Menzel	**Date:** December 2009

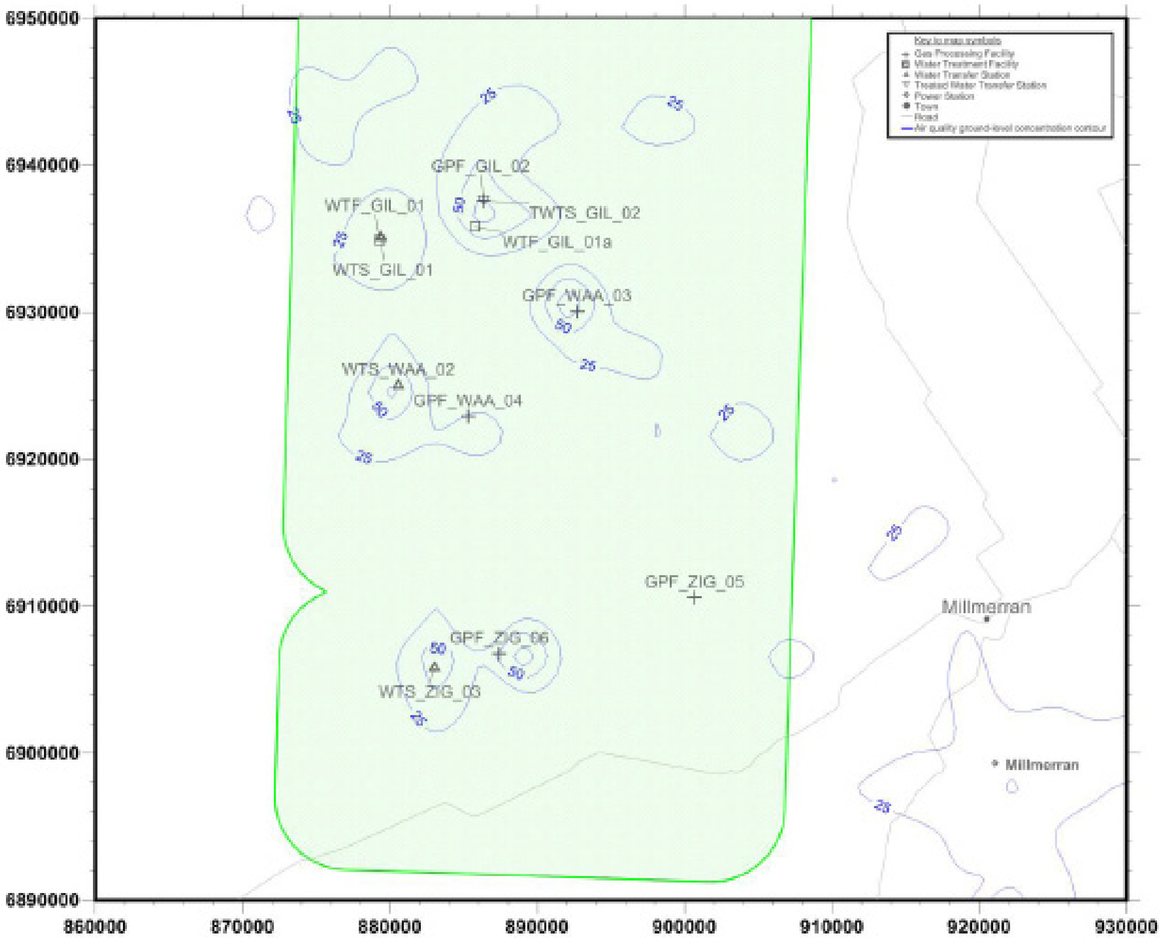


Figure 24 Normal operating scenario south-eastern region– Predicted maximum 1-hour average ground-level concentrations of nitrogen dioxide for the Australia Pacific LNG gas fields with background

Location: Darling Downs, south central Queensland	**Averaging period:** 1-hour	**Data source:** CALPUFF	**Units:** µg/m³
Type: Maximum contour plot	Air quality objective: Health and wellbeing: 250 µg/m³	**Prepared by:** S. Menzel	**Date:** December 2009

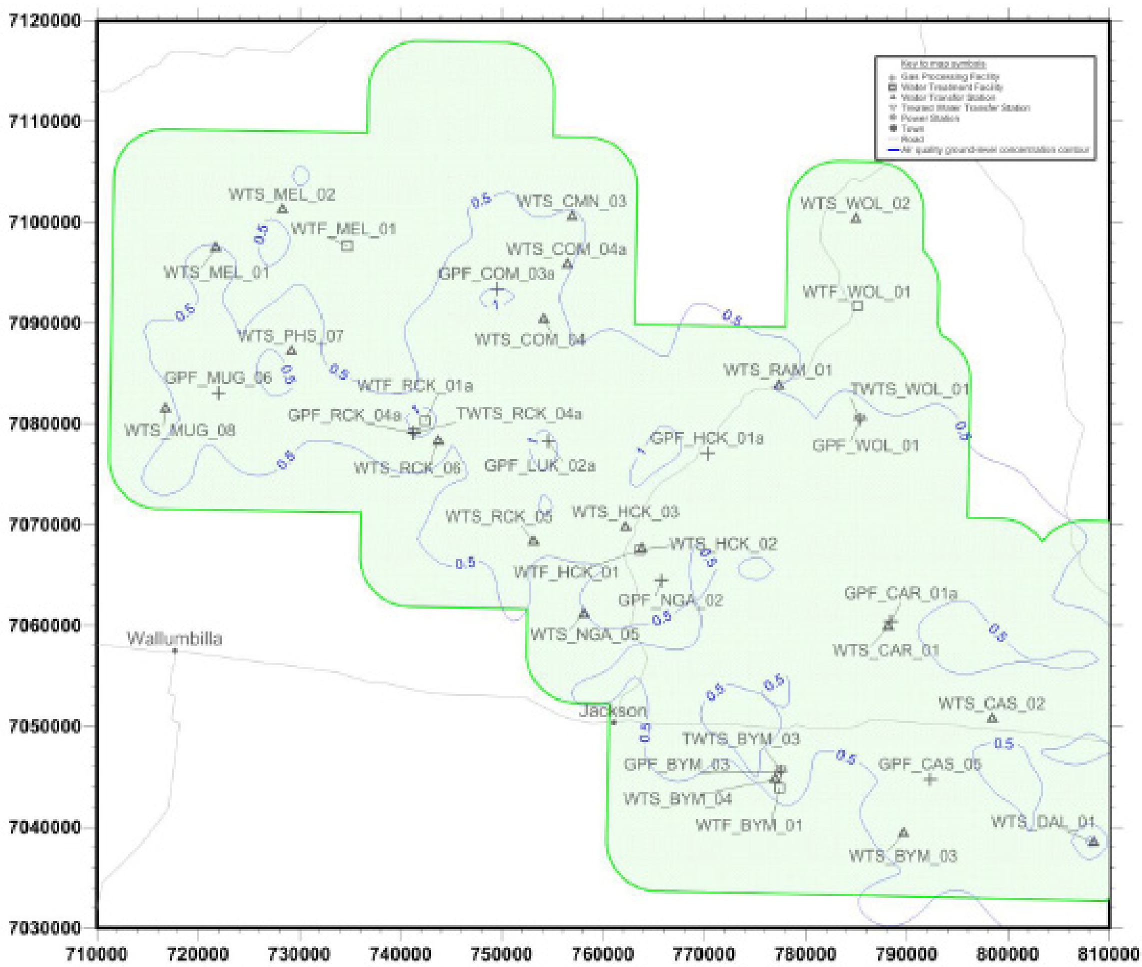


Figure 25 Normal operating scenario north-western region– Predicted annual average ground-level concentrations of nitrogen dioxide for the Australia Pacific LNG gas fields with background

Location: Darling Downs, south central Queensland	**Averaging period:** Annual	**Data source:** CALPUFF	**Units:** µg/m³
Type: Contour plot	Air quality objective: Health and wellbeing: 62 µg/m³	**Prepared by:** S. Menzel	**Date:** December 2009

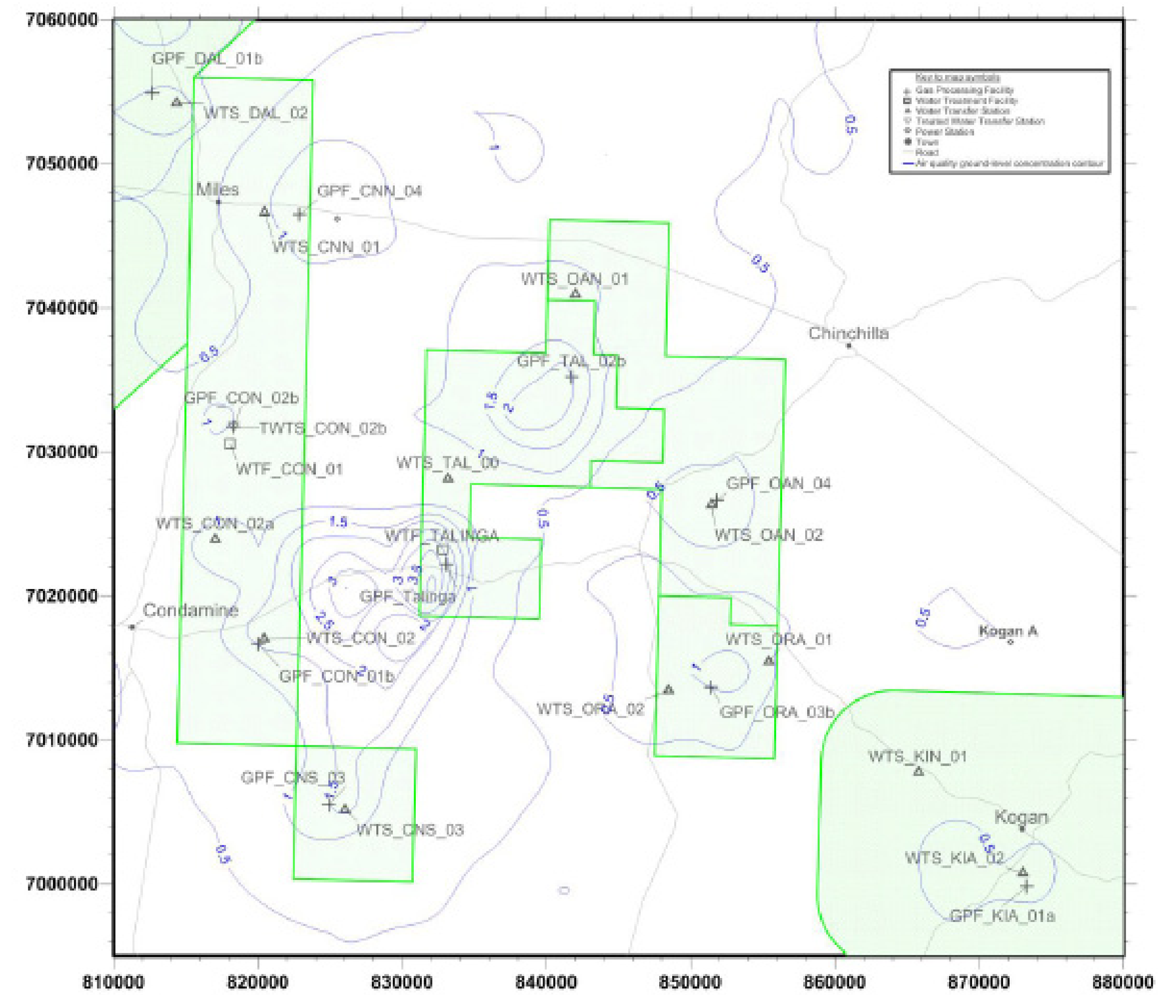


Figure 26 Normal operating scenario central region – Predicted annual average ground-level concentrations of nitrogen dioxide for the Australia Pacific LNG gas fields with background

Location: Darling Downs, south central Queensland	**Averaging period:** Annual	**Data source:** CALPUFF	**Units:** µg/m³
Type: Contour plot	Air quality objective: Health and wellbeing: 62 µg/m³	**Prepared by:** S. Menzel	**Date:** December 2009

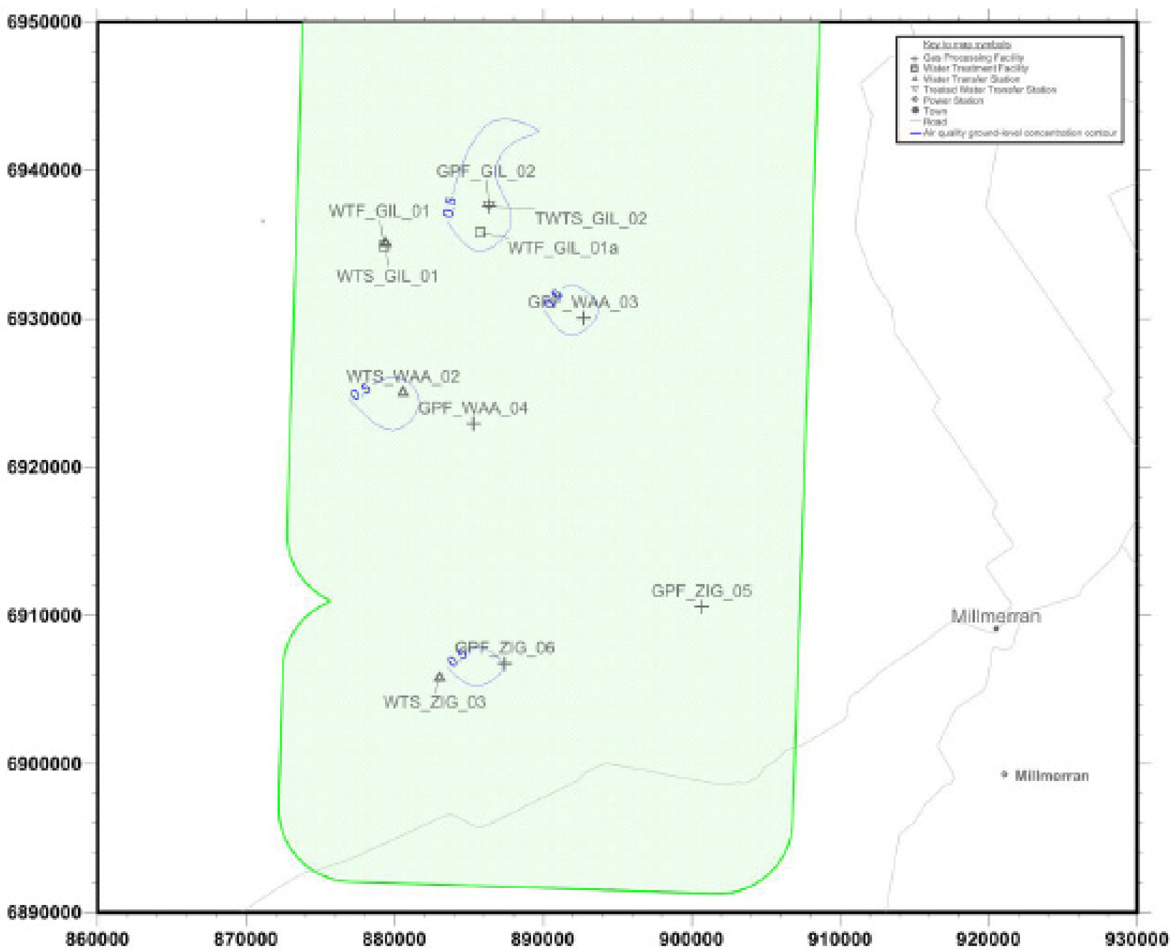


Figure 27 Normal operating scenario south-eastern region – Predicted annual average ground-level concentrations of nitrogen dioxide for the Australia Pacific LNG gas fields with background

Location: Darling Downs, south central Queensland	**Averaging period:** Annual	**Data source:** CALPUFF	**Units:** µg/m³
Type: Contour plot	Air quality objective: Health and wellbeing: 62 µg/m³	**Prepared by:** S. Menzel	**Date:** December 2009

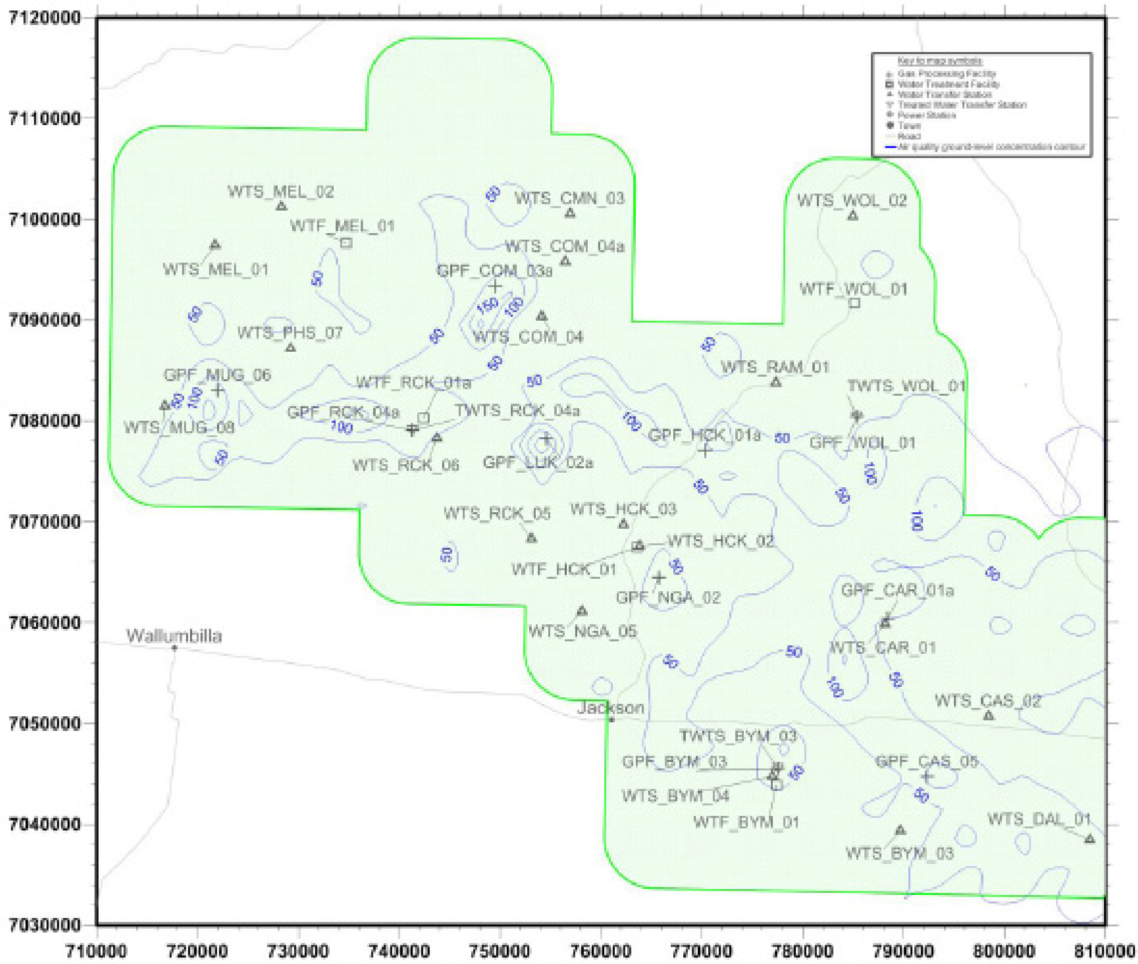


Figure 28 Normal operating scenario north-western region – Predicted maximum 8-hour average ground-level concentrations of carbon monoxide for the Australia Pacific LNG gas fields with background

Location: Darling Downs, south central Queensland	Averaging period: 8-hour	**Data source:** CALPUFF	**Units:** µg/m³
Type: Maximum contour plot	Air quality objective: Health and wellbeing: 11,000 µg/m³	**Prepared by:** S. Menzel	**Date:** December 2009

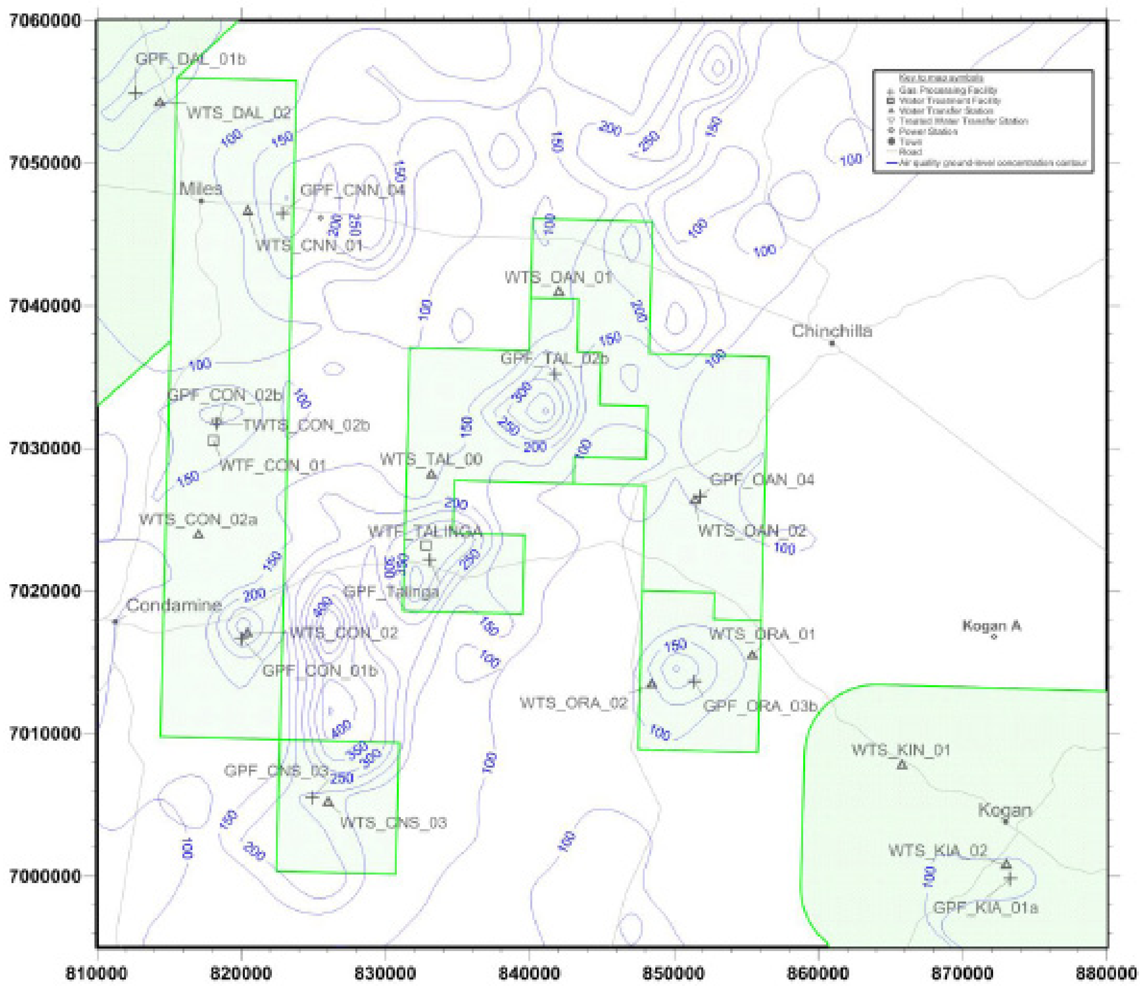


Figure 29 Normal operating scenario central region – Predicted maximum 8-hour average ground-level concentrations of carbon monoxide for the Australia Pacific LNG gas fields with background

Location:	Averaging period:	Data source:	Units:
Darling Downs, south central Queensland	8-hour	CALPUFF	µg/m³
Type: Maximum contour plot	Air quality objective: Health and wellbeing: 11,000 µg/m³	**Prepared by:** S. Menzel	**Date:** December 2009

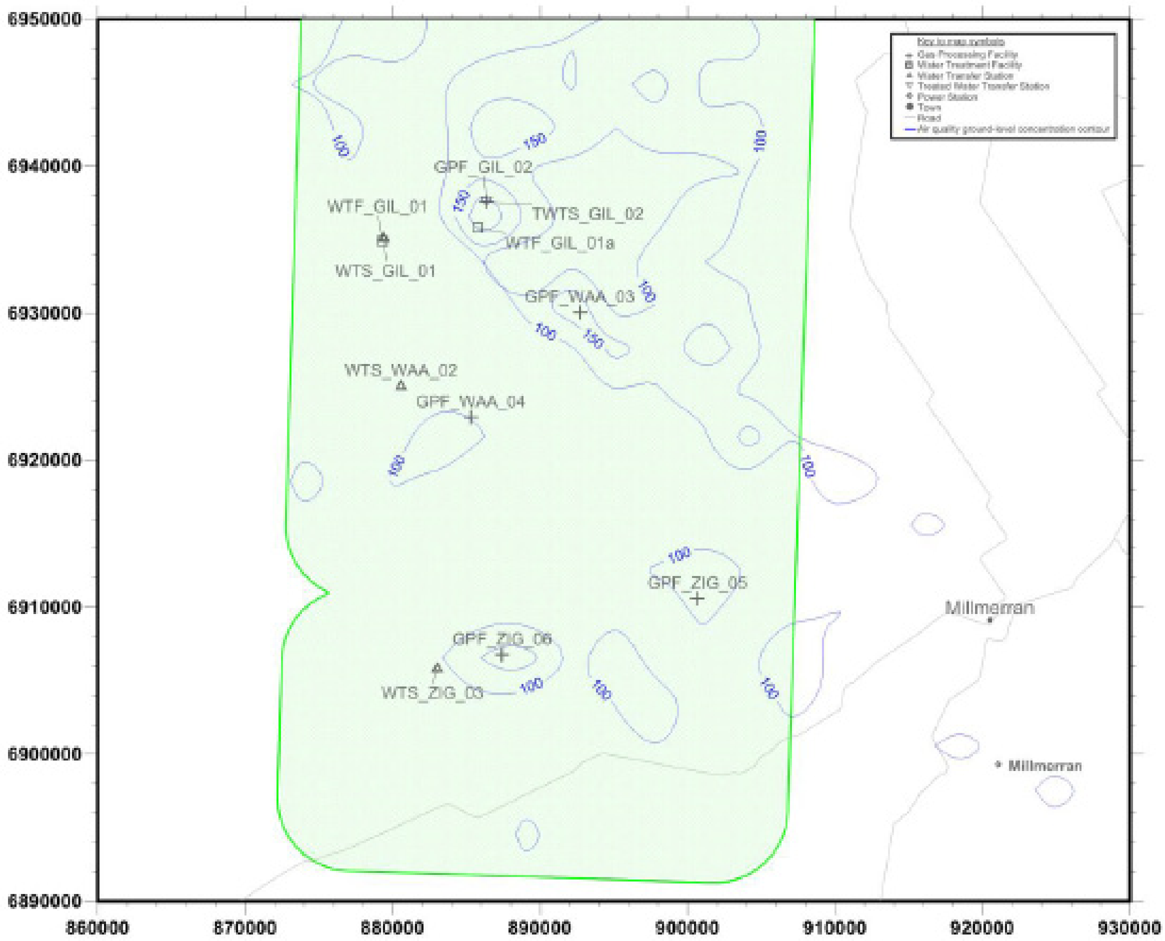


Figure 30 Normal operating scenario south-eastern region – Predicted maximum 8-hour average ground-level concentrations of carbon monoxide for the Australia Pacific LNG gas fields with background

Location: Darling Downs, south central Queensland	Averaging period: 8-hour	**Data source:** CALPUFF	**Units:** µg/m³
Type: Maximum contour plot	Air quality objective: Health and wellbeing: 11,000 µg/m³	**Prepared by:** S. Menzel	**Date:** December 2009

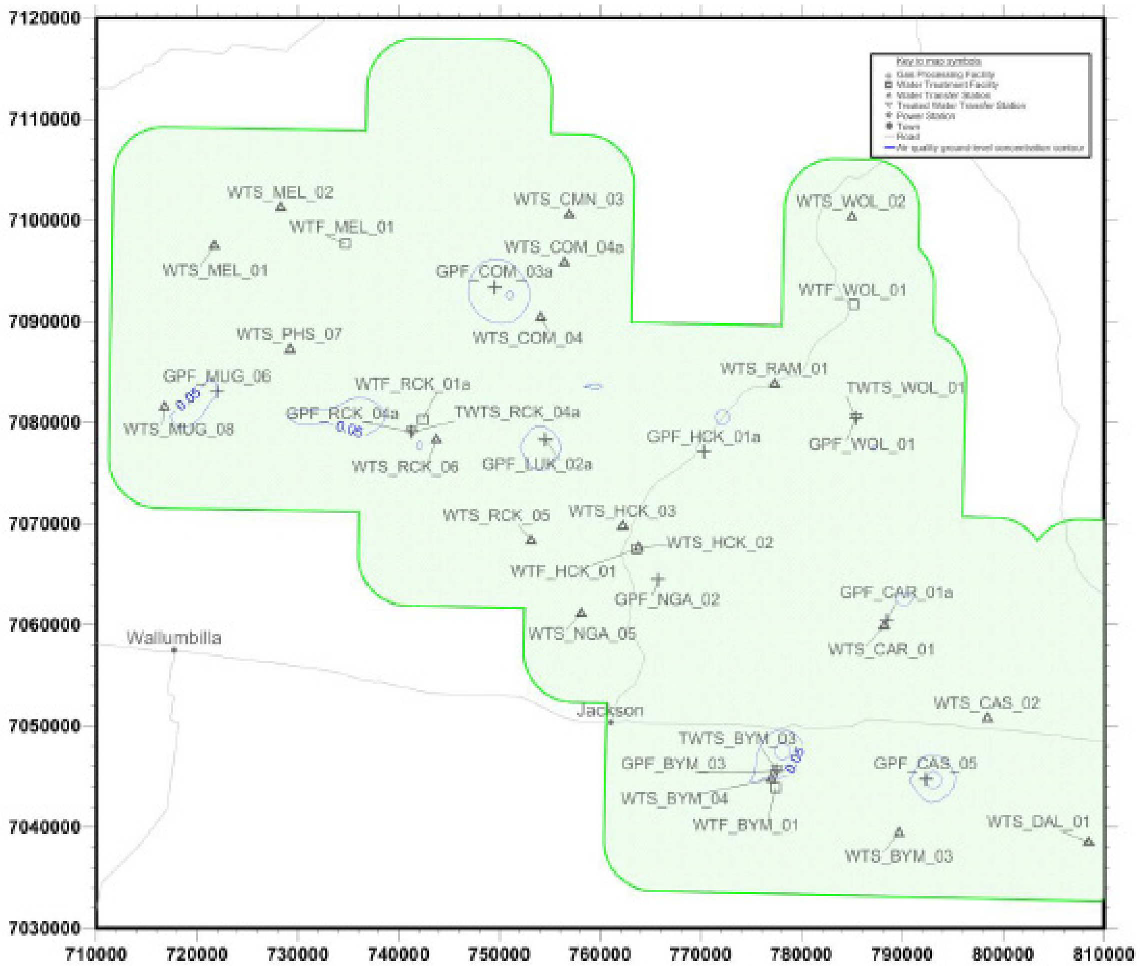


Figure 31 Normal operating scenario north-western region – Predicted maximum 1-hour average ground-level concentrations of acrolein for the Australia Pacific LNG gas fields in isolation

Location: Darling Downs, south central Queensland	Averaging period: 1-hour	**Data source:** CALPUFF	**Units:** µg/m³
Type: Maximum contour plot	Air quality objective: NSW DECCW: 0.42 µg/m³	**Prepared by:** S. Menzel	**Date:** December 2009

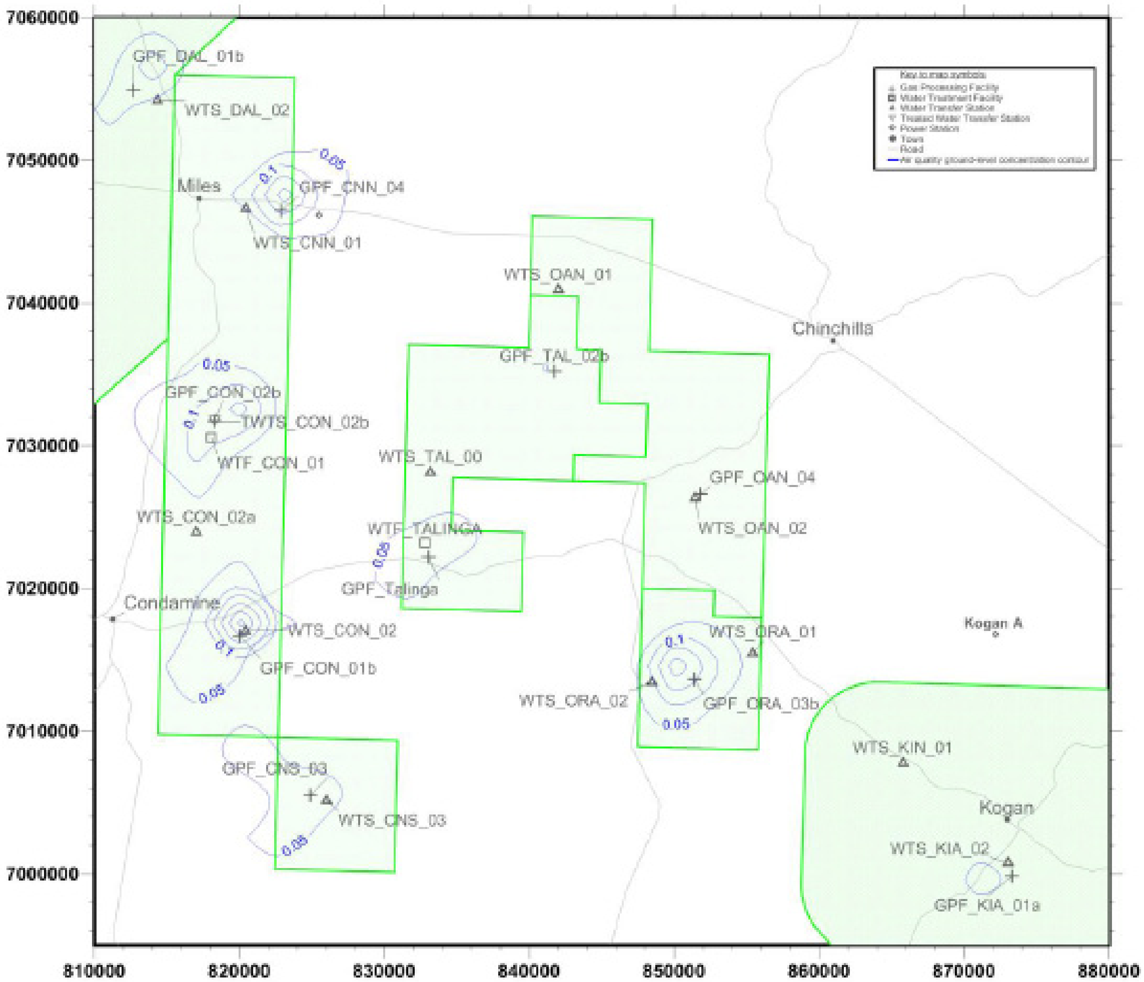


Figure 32 Normal operating scenario central region – Predicted maximum 1-hour average ground-level concentrations of acrolein for the Australia Pacific LNG gas fields in isolation

Location: Darling Downs, south central Queensland	Averaging period: 1-hour	**Data source:** CALPUFF	**Units:** µg/m³
Type: Maximum contour plot	Air quality objective: NSW DECCW: 0.42 µg/m³	**Prepared by:** S. Menzel	**Date:** December 2009

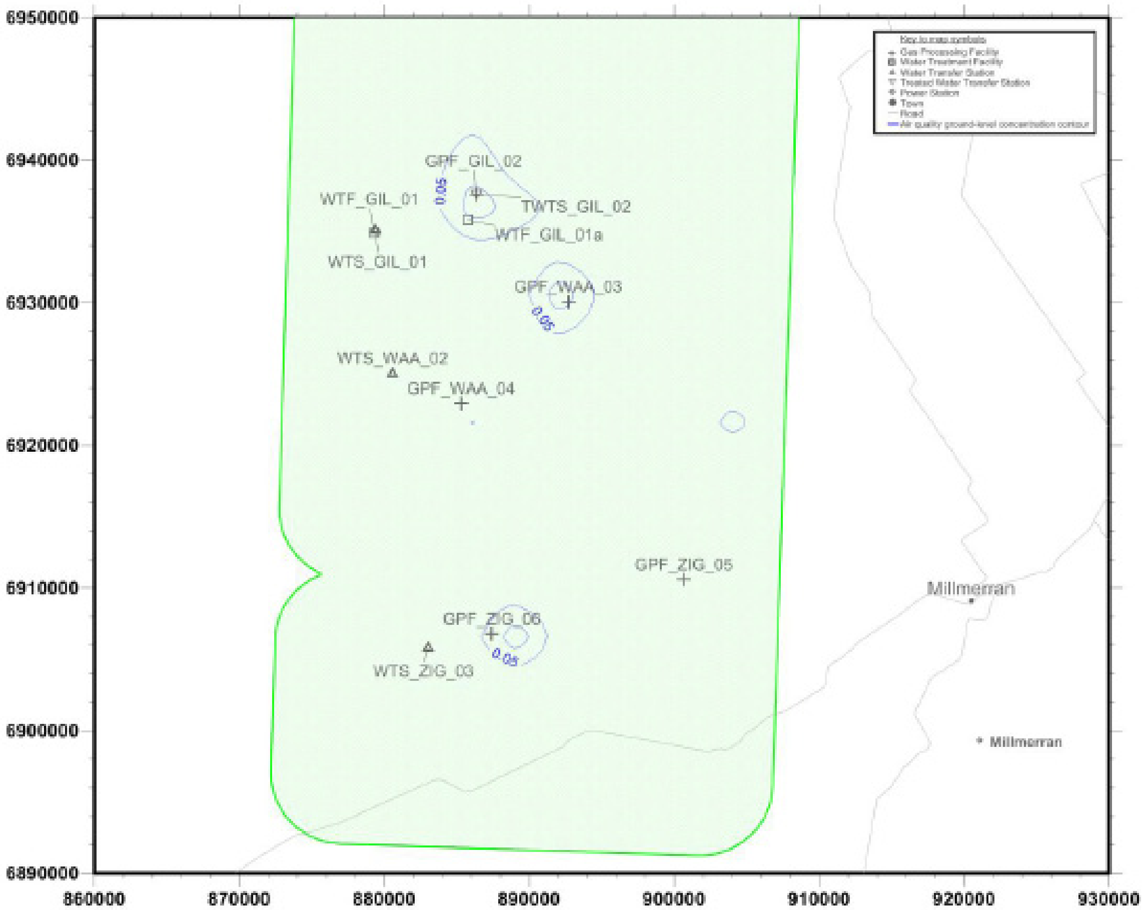


Figure 33 Normal operating scenario south-eastern region – Predicted maximum 1-hour average ground-level concentrations of acrolein for the Australia Pacific LNG gas fields in isolation

Location: Darling Downs, south central Queensland	Averaging period: 1-hour	**Data source:** CALPUFF	**Units:** µg/m³
Type: Maximum contour plot	Air quality objective: NSW DECCW: 0.42 µg/m³	**Prepared by:** S. Menzel	**Date:** December 2009

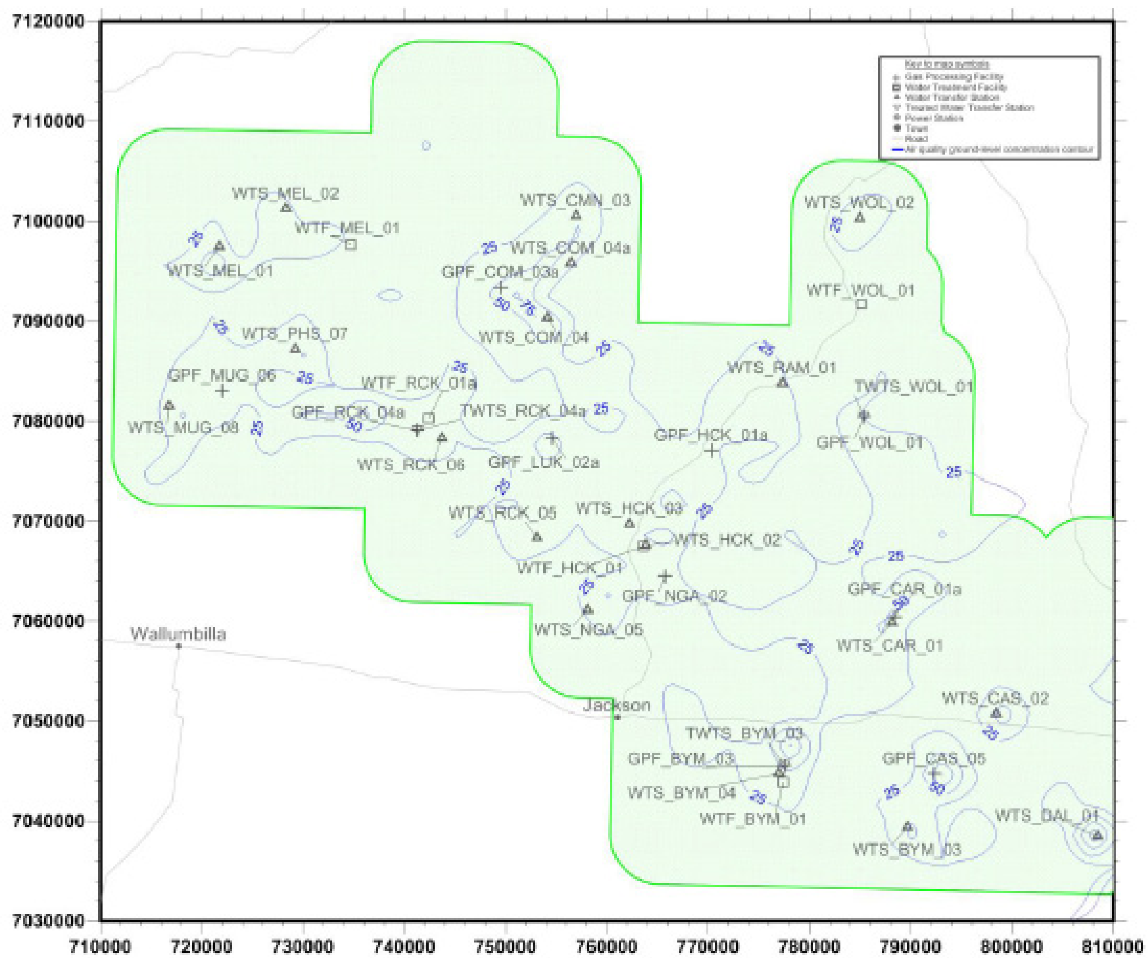


Figure 34 Abnormal/upset operating scenario north-western region: All flares plus normal operating scenario – Predicted maximum 1-hour average ground level concentrations of nitrogen dioxide for the Australia Pacific LNG gas fields with modelled background			
Location: Darling Downs, south central Queensland	Averaging period: 1-hour	**Data source:** CALPUFF	**Units:** µg/m³
Type: Maximum contour plot	Air quality objective: Health and wellbeing: 250 µg/m³	**Prepared by:** S. Menzel	**Date:** December 2009

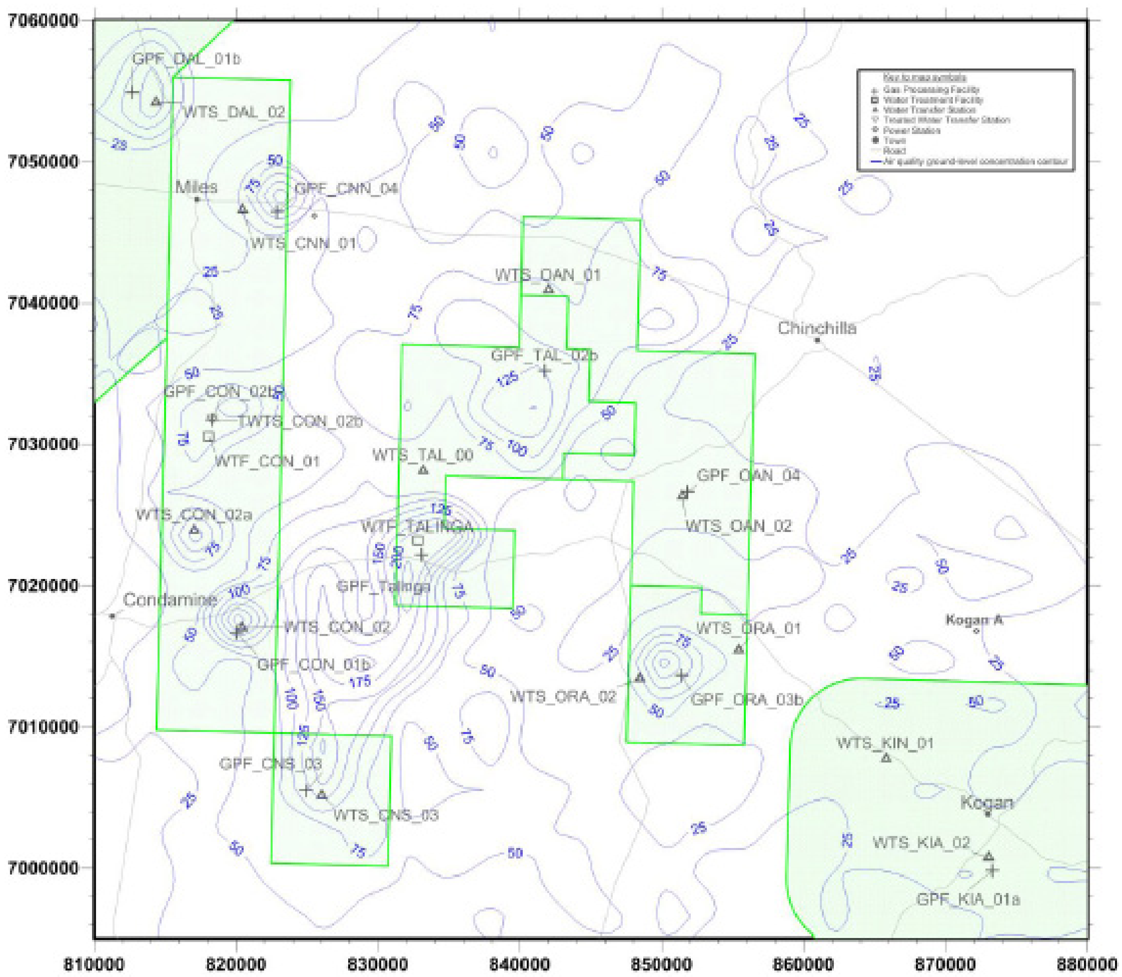


Figure 35 Abnormal/upset operating scenario central region: All flares plus normal operating scenario – Predicted maximum 1-hour average ground level concentrations of nitrogen dioxide for the Australia Pacific LNG gas fields with modelled background			
Location: Darling Downs, south central Queensland	Averaging period: 1-hour	**Data source:** CALPUFF	**Units:** µg/m³
Type: Maximum contour plot	Air quality objective: Health and wellbeing: 250 µg/m³	**Prepared by:** S. Menzel	**Date:** December 2009

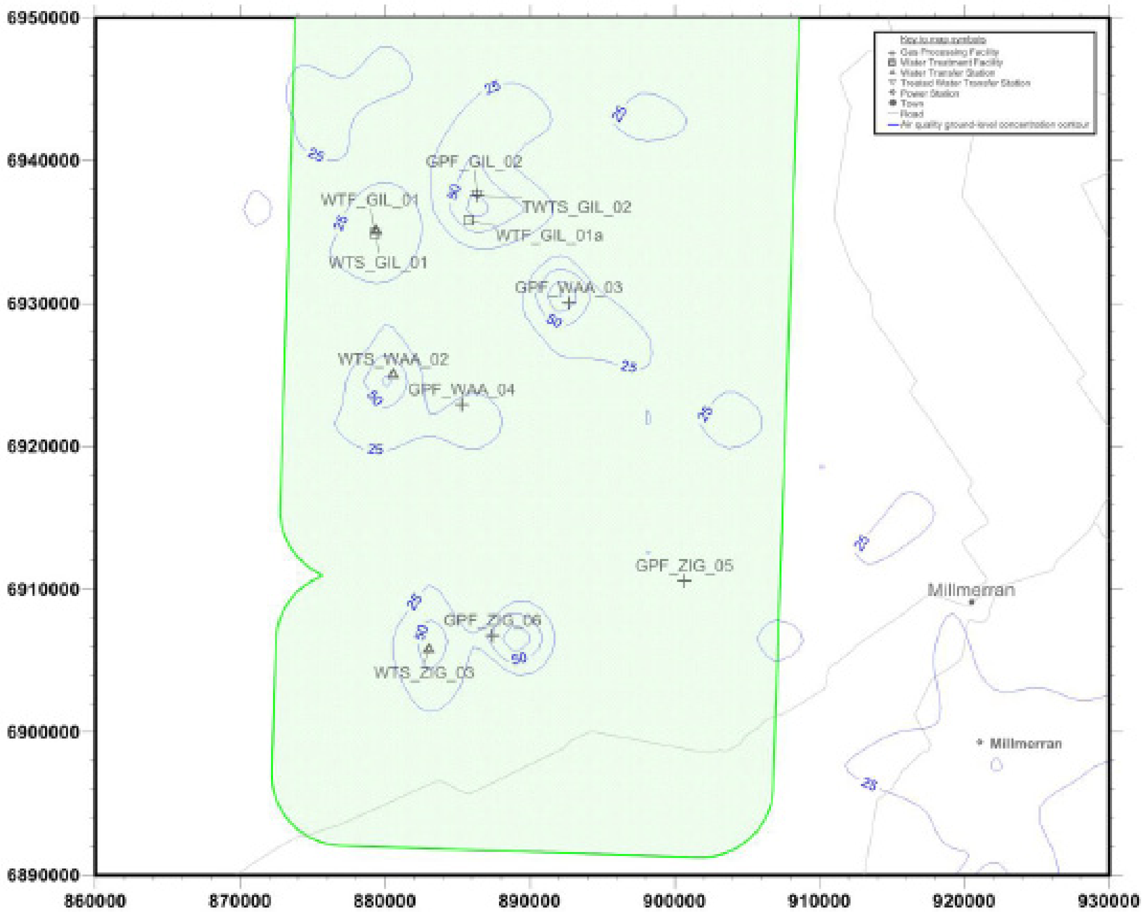


Figure 36 Abnormal/upset operating scenario south-eastern region: All flares plus normal operating scenario – Predicted maximum 1-hour average ground level concentrations of nitrogen dioxide for the Australia Pacific LNG gas fields with modelled background

Location: Darling Downs, south central Queensland	Averaging period: 1-hour	**Data source:** CALPUFF	**Units:** µg/m³
Type: Maximum contour plot	Air quality objective: Health and wellbeing: 250 µg/m³	**Prepared by:** S. Menzel	**Date:** December 2009

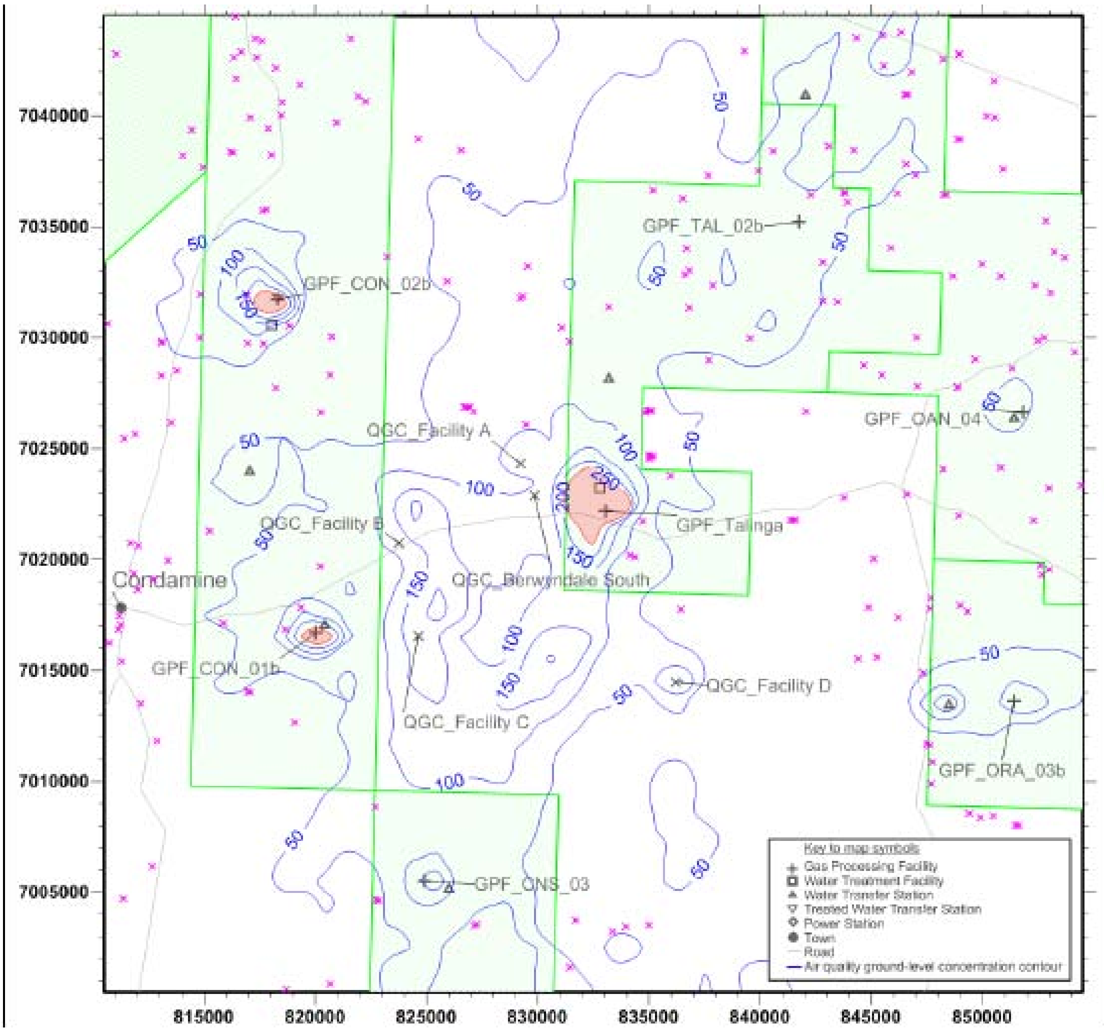


Figure 37 Normal operating scenario – Predicted maximum 1-hour average ground-level concentrations of nitrogen dioxide for the Australia Pacific LNG gas fields with background including QGC (Undulla Nose case study model)

Location: Darling Downs, south central Queensland	Averaging period: 1-hour	**Data source:** CALPUFF	**Units:** µg/m³
Type: Maximum contour plot	**Air quality objective:** Health and wellbeing: 250 µg/m³	**Prepared by:** A. Balch	**Date:** December 2009

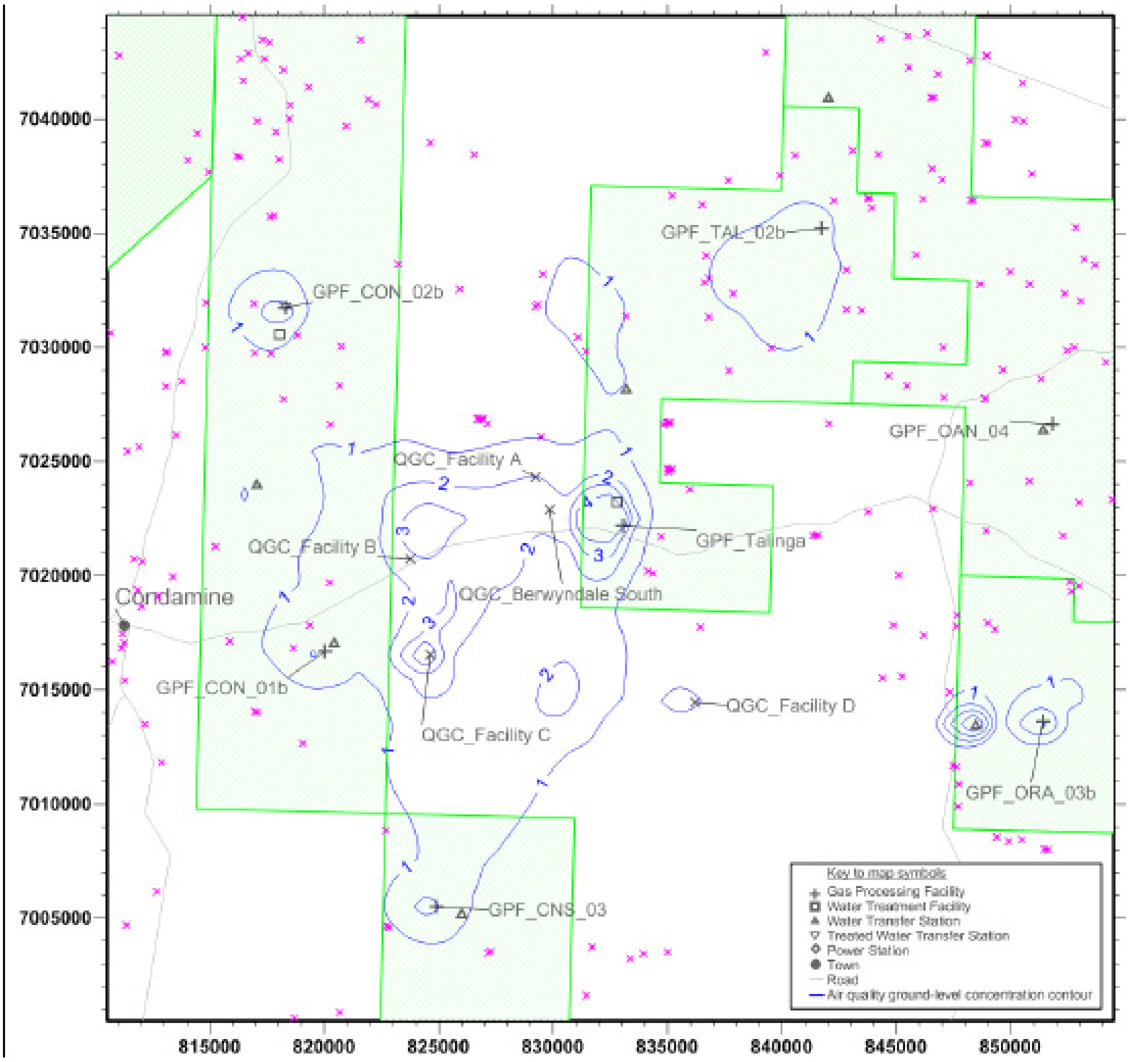


Figure 38 Normal operating scenario – Predicted annual average ground level concentrations of nitrogen dioxide for the Australia Pacific LNG gas fields with QGC modelled background (fine scale model)

Location: Darling Downs, south central Queensland	**Averaging period:** Annual	**Data source:** CALPUFF	**Units:** µg/m³
Type: Contour plot	**Air quality objective:** Health and wellbeing: 62 µg/m³	**Prepared by:** A Balch	**Date:** December 2009