REPORT

SURAT GAS PROJECT IMPACT ASSESSMENT REPORT – AIR QUALITY

Coffey Environments Pty Ltd

Job No: 3568-2

16 September 2011

PROJECT TITLE:	Surat Gas Project Impact Assessment Report – Air Quality
JOB NUMBER:	3568-2
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DOCUMENT CONTROL

VERSION	DATE	PREPARED BY	REVIEWED BY
2-01	16.06.11	M Goodfellow and B Warren	Chaim Kolominskas
2-02	29.06.11	M Goodfellow and B Warren	Chaim Kolominskas
2-03	07.07.11	M Goodfellow and B Warren	Chaim Kolominskas
2-04	04.08.11	M Goodfellow and B Warren	Chaim Kolominskas
2-05	07.09.11	M Goodfellow and B Warren	Chaim Kolominskas
2-06 - Final	16.09.11	M Goodfellow and B Warren	Chaim Kolominskas

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Arrow Energy Pty Ltd proposes an expansion of its gas operations in the Surat Basin through the Surat Gas Project. The project development area covers approximately 8,600 km^2 and is located approximately 160 km west of Brisbane in Queensland's Surat Basin. The project development area extends from the township of Wandoan in the north towards Goondiwindi in the south, in an arc adjacent Dalby. The towns of Wandoan, Chinchilla, Kogan, Dalby, Cecil Plains, Millmerran, Miles and Goondiwindi are located within or in close proximity to the project development area. Project infrastructure including production wells and production facilities (including gas compression, water treatment and power generation facilities where applicable) will be located throughout the project development area but not in towns. Facilities supporting the petroleum development activities such as depots, stores and offices may be located in or adjacent to towns.

The air quality impact assessment is based on dispersion modelling that incorporates source characteristics and emission rates. The modelling incorporates the existing climate, meteorology, air quality and land use. The regional impacts were assessed using a photochemical model while the localised impacts were assessed with a steady state model for three meteorological regions of the project area. Background concentrations were determined and included in the cumulative impacts assessment. The main substances of concern in the regions were identified as the photochemically reactive substances nitrogen dioxide (NO_2) and ozone (O_3). The other substances assessed were shown to not have significant issues in the study area.

The presence of the project will cause a general increase of NO_2 and O_3 concentrations in the region, but the Air EPP objectives are not predicted to be exceeded. Elevated concentrations (although below the Air EPP objectives) occur in the areas where the project operations are occurring as well as west of the project area. If monitoring is requested, it is recommended that two regional impact monitoring stations for nitrogen oxides and ozone are established and located within the study area and another monitoring station located to the west of the study area in the region that is predicted to have the highest modelled concentrations. Monitoring will provide further validation of the study findings. It is also recommended that the monitoring stations be established prior to project commencement, for the collection of robust data sets of background concentrations. Data should be real-time (i.e. sub-hourly intervals) to enable comparison and validation with modelling predictions.

The localised assessment determined that the locations of integrated processing facilities and central gas processing facilities need to be constrained such that they maintain a separation of up to 225 m and 175 m respectively from the nearest sensitive receptors, depending on region. Mitigation in the form of increased stack heights or selective catalytic reduction may be considered. It should be noted that the predicted separation distances are based on a two-dimensional modelling localised assessment. It is recommended that once the facility locations and orientations are known three dimensional modelling should be conducted to further evaluate two dimensional study results.

1 INTRODUCTION

PAEHolmes has been commissioned by Coffey Environments to prepare the air quality assessment for the voluntary Environmental Impact Statement (EIS) for the proposed project in accordance with the project's final Terms of Reference. The air quality assessment describes the existing environmental values of the air quality project study area, and the project's potential impact on these values.

1.1 Proponent

Arrow Energy Pty Ltd (Arrow) is an integrated energy company with interests in coal seam gas field developments, pipeline infrastructure, electricity generation and proposed liquefied natural gas (LNG) projects.

Arrow has interests in more than 65,000 km^2 of petroleum tenures, mostly within Queensland's Surat and Bowen basins. Elsewhere in Queensland, the company has interests in the Clarence-Moreton, Coastal Tertiary, Ipswich, Styx and Nagoorin Graben basins.

Arrow's petroleum tenures are located close to Queensland's three key energy markets; Townsville, Gladstone and Brisbane. The Moranbah Gas Project in the Bowen Basin and the Tipton West, Daandine, Kogan North and Stratheden projects in the Surat Basin near Dalby comprise Arrow's existing coal seam gas production operations. These existing operations currently account for approximately 20% of Queensland's overall gas production.

Arrow supplies gas to the Daandine, Braemar 1 and 2, Townsville and Swanbank E power stations which participate in the National Electricity Market. With Arrow's ownership of Braemar 2 and the commercial arrangements in place for Daandine and Townsville power stations, Arrow has access to up to 600 MW of power generation capacity.

Arrow and its equity partner AGL Energy have access rights to the North Queensland Pipeline which supplies gas to Townsville from the Moranbah Gas Project. They also hold the pipeline licence for the proposed Central Queensland Gas Pipeline between Moranbah and Gladstone.

Arrow is currently proposing to develop the Arrow LNG Project, which is made up of the following aspects:

- Arrow LNG Plant – The proposed development of an LNG Plant on Curtis Island near Gladstone, and associated infrastructure, including the gas pipeline crossing of Port Curtis.
- Surat Gas Project – The upstream gas field development in the Surat Basin, the subject of this assessment.
- Arrow Surat Pipeline Project – (Formerly the Surat Gladstone Pipeline), the 450 km transmission pipeline connects Arrow's Surat Basin gas developments to Gladstone.
- Bowen Gas Project – The upstream gas field development in the Bowen Basin.
- Arrow Bowen Pipeline – The transmission pipeline which connects Arrow's Bowen Basin gas developments to Gladstone.

1.2 Surat Gas Project

Arrow proposes expansion of its gas operations in the Surat Basin through the Surat Gas Project. The need for the project arises from the growing demand for gas in the domestic and global markets and the associated expansion of LNG export markets.

The project development area covers approximately 8,600 km^2 and is located approximately 160 km west of Brisbane in Queensland's Surat Basin. The project development area extends from the township of Wandoan in the north towards Goondiwindi in the south, in an arc through Dalby. Townships within or in close proximity to the project development area include (but are not limited to) Wandoan, Chinchilla, Kogan, Dalby, Cecil Plains, Millmerran, Miles and Goondiwindi. Project infrastructure including production wells and production facilities (including gas compression, water treatment and power generation facilities where applicable) will be located throughout the project development area but not in towns. Facilities supporting the petroleum development activities such as depots, stores and offices may be located in or adjacent to towns.

The conceptual Surat Gas Project is premised upon an averaged sustained production from Arrow's Surat Basin gas fields of approximately 1,050 TJ/day. The averaged sustained gas production comprises 970 TJ/day for LNG production (including a 10% fuel gas requirement for facility operation) and a further 80 TJ/day for supply to the domestic gas market.

A project life of 35 years has been adopted for EIS purposes. Ramp-up to peak production is estimated to take between 4 and 5 years, and is planned to commence in 2014. Following ramp-up, gas production will be sustained at approximately 1,050 TJ/day for at least 20 years, after which production is expected to decline.

Infrastructure for the project is expected to comprise:

- Approximately 7,500 production wells drilled over the life of the project at a rate of approximately 400 wells drilled per year.
- Low pressure gas gathering lines to transport gas from the production wells to production facilities.
- Medium pressure gas pipelines to transport gas between field compression facilities and central gas processing and integrated processing facilities.
- High pressure gas pipelines to transport gas from central gas processing and integrated processing facilities to the sales gas pipeline.
- Water gathering lines to transport produced water from production wells to transfer, treatment and storage facilities.
- Approximately 18 production facilities across the project development area expected to comprise of six of each of the following:
    - Field compression facilities.
    - Central gas processing facilities.
    - Integrated processing facilities.
- A combination of gas powered electricity generation equipment that will be co-located with production facilities and/or electricity transmission infrastructure that may draw electricity from the grid (via third party substations).

It is envisaged that development of the Surat Gas Project will occur in five development regions: Wandoan, Chinchilla, Dalby, Kogan/Millmerran and Goondiwindi. Development of these regions will be staged to optimise production over the life of the project.

Arrow has established a framework to guide the selection of sites for production wells, production facilities, and routes for gathering lines and pipelines. The framework will also be used to select sites for associated infrastructure such as access roads and construction camps. Environmental and social constraints to development that have been identified through the EIS process coupled with the application of appropriate environmental management controls will ensure that protection of environmental values (resources) is considered in project planning. This approach will maximise the opportunity to select appropriate site locations that minimise potential environmental and social impacts.

Arrow has identified 18 areas that are nominated for potential facility development to facilitate environmental impact assessment (and modelling). These are based on circles of approximately 12 km radius that signify areas where development of production facilities could potentially occur.

Arrow intends to pursue opportunities in the selection of equipment (including reverse osmosis units, well site facilities, electrical generators and compressors) and the design of facilities that facilitates the cost effective and efficient scaling of facilities to meet field conditions. This flexibility will enable Arrow to better match infrastructure to gas production. It will also enable Arrow to investigate the merits of using template design principles for facility development, which may in turn generate further efficiencies as the gas reserves are better understood, design is finalised, or as field development progresses.

Further detail regarding the function of each type of production facility is detailed below.

1.2.1 Field compression facilities

Field compression facilities will receive gas from production wells and are expected to provide 30 to 60 TJ/day of first stage gas compression. Compressed gas will be transported from field compression facilities in medium pressure gas pipelines to multi-stage compressors at central gas processing facilities or integrated processing facilities where the gas will be further compressed to transmission gas pipeline operating pressure and dehydrated to transmission gas pipeline quality. Produced water will bypass field compression facilities.

1.2.2 Central gas processing facilities

Central gas processing facilities will receive gas both directly from production wells and from field compression facilities. Central gas processing facilities are expected to provide between 30 and 150 TJ/day of gas compression and dehydration. Produced water will bypass central gas processing facilities and be pumped to an integrated processing facility for treatment.

1.2.3 Integrated processing facilities

Integrated processing facilities will receive gas both from production wells and field compression facilities. Integrated processing facilities are expected to provide between 30 and 150 TJ/day of gas compression and dehydration. Produced water received at integrated processing facilities is expected to be predominantly treated using reverse osmosis and then balanced to ensure that it is suitable for the intended beneficial use. Produced water received from the field, treated water and brine will be stored in dams adjacent to integrated processing facilities.

1.3 Surat Gas Project Summary

The air quality impact assessment was conducted based on Arrow's preliminary field development plan for the Surat Gas Project, which is expected to include the following features:

- The 8600km^2 project development area, located 160km west of Brisbane is split into five development regions, Dalby, Wandoan, Milmerran/Kogan, Chinchilla and Goondiwindi as shown in Figure 1.1.
- For the purposes of understanding the preliminary field development plan each development region is considered to comprise a number of land parcels, each containing approximately 100 production wells summing to a total of approximately 7500 wells across the entire project development area.
- Each well is estimated to have an average operational life of 15-20 years.
- The project will produce an average sustained rate of approximately 1050 TJ/day of gas, with 97TJ/day used as fuel gas and 80TJ sold on the domestic market, leaving on average 873TJ/day for export.
- Eighteen production facilities are proposed to be constructed, including six integrated processing facilities (IPF) - gas compression and water processing facilities, six central gas processing facilities (CGPF) – gas compression and water transfer and six field compression facilities (FCF) – first stage compression only.
- On average, one production facility and 400 wells will be commissioned annually, see Table 1.1 for commissioning progression.
- A cumulative installed capacity of the production facilities, of 1530 TJ/day.

Table 1.1 below shows the sequencing of production facility and well commissioning, across the life of the project for the preliminary field layout case. For each year that the project is underway, new wells and one or two production facilities are commissioned (until a total of 18 facilities are installed). The commissioning of these wells and production facilities determines the corresponding cumulative installed gas production capacity.

Table 1.1: Production Facility Commissioning

Year	Facility Commissioned	Estimated Number of Wells Commissioned	Expected Installed Capacity (TJ/day)	Cumulative Installed Capacity (TJ/day)	Cumulative Total Gas Production (TJ/day)
2014	Wandoan IPF 1	174	120	120	0
2015	Dalby IPF 2	233	90	210	119
2016	Wandoan CGPF 1 and Dalby IPF 1	365	300 (150 + 150)	510	300
2017	Wandoan CGPF 2	386	150	660	490
2018	Dalby FCF 1	497	60#	660	676
2019	Dalby CGPF 1 and Milmerran FCF 2	196	210 (150 + 60#)	810	866
2020	Milmerran IPF 1	456	120	930	970
2021	Chinchilla IPF1	464	150	1080	970
2022	Chinchilla CGPF1	382	150	1230	970
2023	-	166	-	1230	970
2024	-	351	-	1230	970
2025	Milmerran FCF 3	311	60#	1230	970
2026	-	305	-	1230	970

Year	Facility Commissioned	Estimated Number of Wells Commissioned	Expected Installed Capacity (TJ/day)	Cumulative Installed Capacity (TJ/day)	Cumulative Total Gas Production (TJ/day)
2027	-	152	-	1230	970
2028	Milmerran CGPF 1	440	90	1320	970
2029	Milmerran FCF 4	361	30#	1320	970
2030	Milmerran FCF 1	733	30#	1320	970
2031	Goondiwindi IPF 1	308	120	1440	970
2032		-	-	1440	970
2033	Goondiwindi FCF 1	-	30#	1440	970
2034		-	-	1440	970
2035	Goondiwindi CGPF 1	-	90	1530	970

- FCFs are not included into the cumulative installed capacity as they feed gas into one of the larger IPFs or CGPFs, effectively bypassing the first stage of compression at these facilitates. Capacity of the larger CGPFs and IPFs currently account for this scenario.

Table 1.1 suggests that in years 2018 to 2020 total gas production is expected to exceed total installed capacity. Arrow have advised that in reality field development will be affected by the varying rates of gas production from each well as well as their decommissioning, which will affect total gas production. These factors are not considered in Table 1.1 and hence the scenario of producing more gas than there is capacity for has resulted in some years. In reality, total gas production will be managed over the life of the project in consideration of the total installed capacity and flow rates of wells such that total gas production will not exceed total installed capacity.

Project activities will include:

- Construction activities, including the installation of:
  - production well sites;
  - water and gas gathering lines;
  - medium and high pressure gas pipelines;
  - production facilities (including field compression facilities, central gas processing facilities, integrated processing facilities);
  - power generation;
  - water treatment facilities (reverse osmosis plants), dams and water transfer network;
  - associated office and workshop facilities; and
  - construction camps.
- Earthworks during construction using heavy earthmoving equipment such as excavators, scrapers, bulldozers, water trucks and a variety of ancillary support vehicles.
- Well flaring prior to facility commissioning. It is proposed that gas from wells will be flared at the nearest production facility.
- Operation and maintenance activities, involving regular inspections and maintenance of production wells, gathering lines and production facilities.
- Decommissioning and rehabilitation activities when the operation of wells, gathering lines and production facilities are no longer commercially viable.

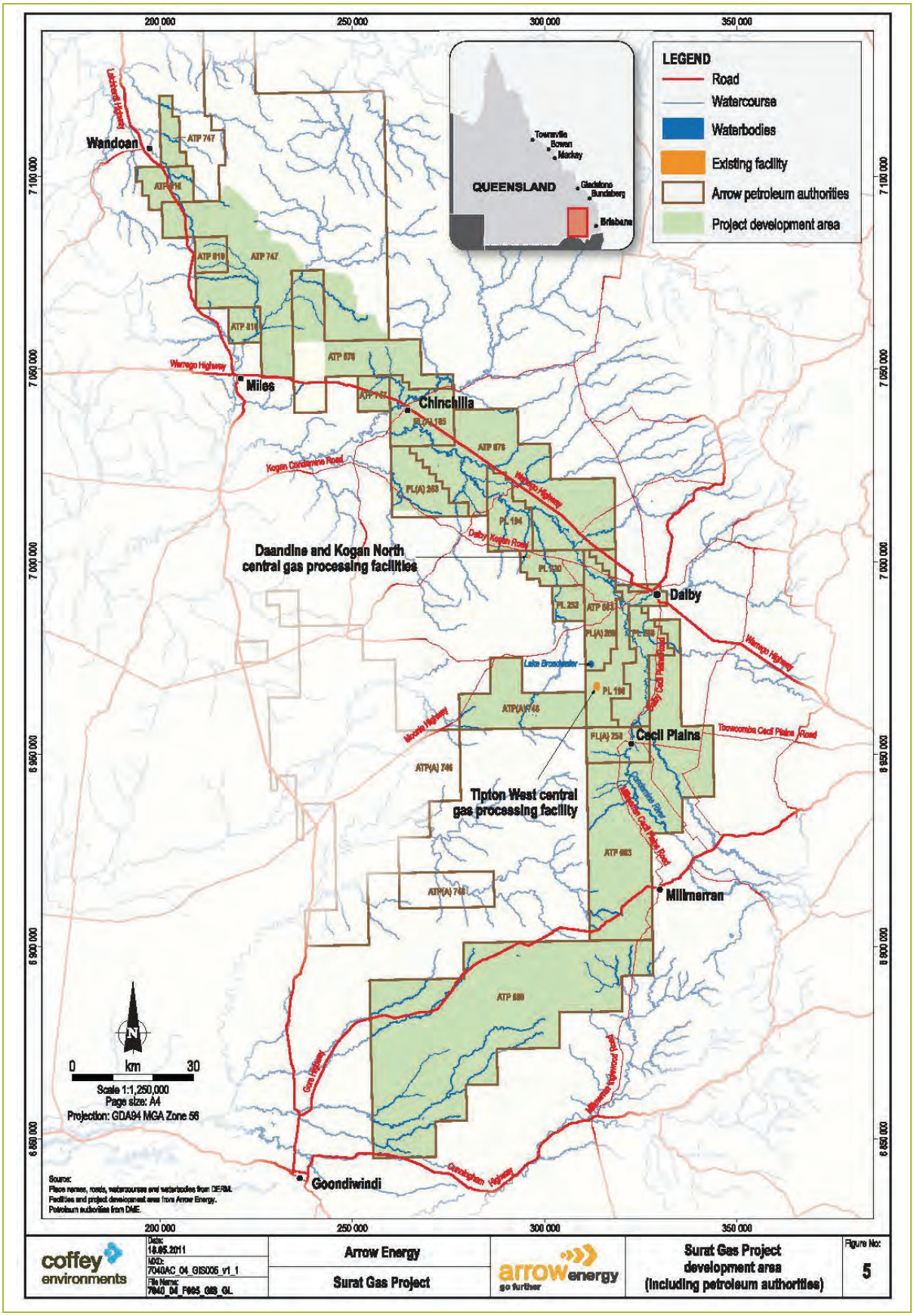


Figure 1.1: The project development area

2 LEGISLATIVE FRAMEWORK

Air discharges in Queensland are currently regulated through the:

- Queensland Environmental Protection Act 1994 (Qld EP Act 1994); and
- Environmental Protection Policy (Air) 2008 (Qld Air EPP 2008).

The framework for air quality legislation is governed by the Department of Environment and Resource Management (DERM) (formerly the Queensland Environment Protection Agency) and is shown in Figure 2.1.

Ambient air quality guidelines in Queensland are provided in the Environment Protection Policy for Air (Air EPP) 2008. These guidelines are consistent with guideline values published in the National Environment Protection Measure (NEPM) (Ambient Air Quality) and the NEPM (Air Toxics). Other guidelines used to assess the ambient air quality in Queensland are:

- Odour Impact Assessment Guideline; and
- Unratified guidelines, such as the dust deposition guideline of 120 mg/m²/day.

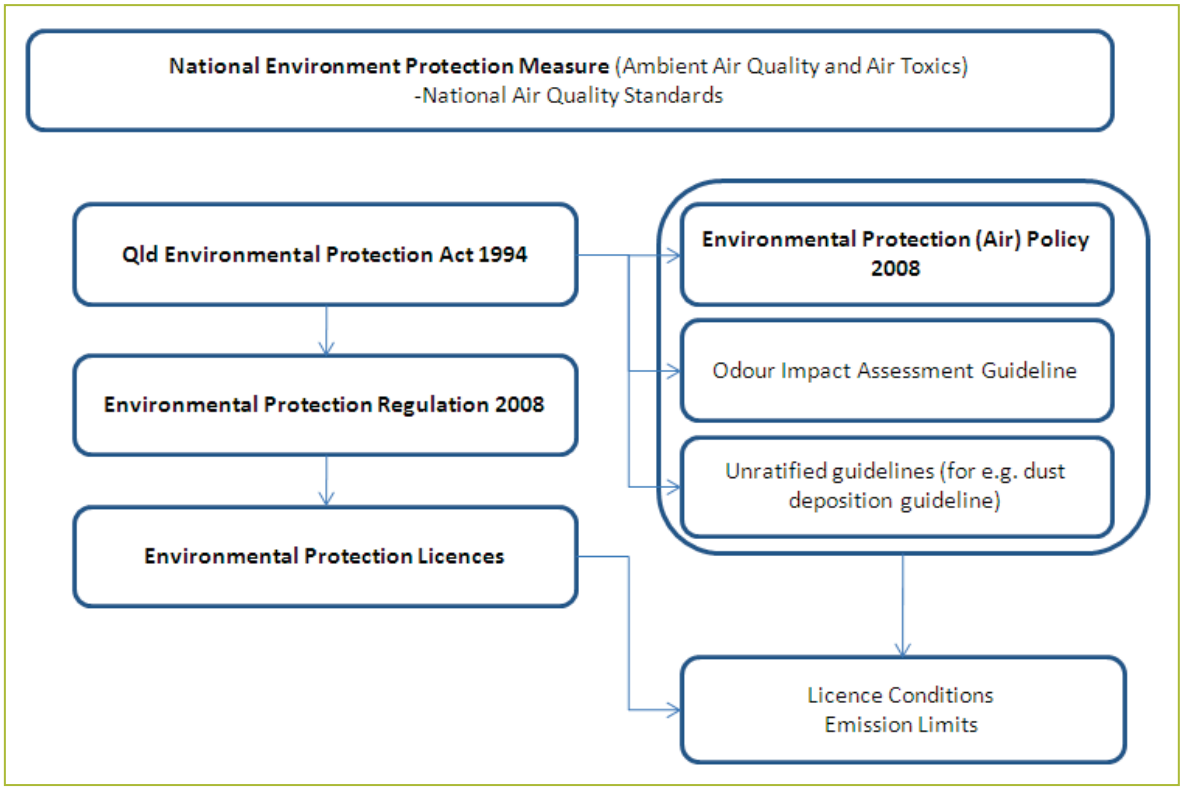


Figure 2.1: Structure of ambient air quality legislation in Queensland

Under the Qld EP Act 1994, Environmentally Relevant Activities that are listed in Schedule 2 of the Act require a licence to operate. DERM uses ambient air quality guidelines provided in the Air EPP 2008 and other guidelines to determine appropriate licence conditions and emission limits. The goal is to protect the ambient air quality surrounding a facility.

In Queensland, there are no specific performance standards for plant and equipment. Emission standards are often enforced on licence conditions and are intended to ensure that the ambient air quality guidelines presented in the Air EPP 2008 are achieved. The performance standards

for plant and equipment specified in the NSW DECCW's Protection of the Environment (Clean Air) Amendment (Industrial and Commercial Activities and Plant) Regulation 2005 are also often referenced in other jurisdictions. This regulation contains pollutant emission standards for specific units of industrial and commercial equipment for selected industry types, based on age.

The NPI (National Pollutant Inventory) requires Australian facilities to report their use, emissions and transfers of a list of 93 substances for the year (1 July to 30 June). This includes solid and liquid discharges as well as air emissions.

This study has complied with the DERM guideline Odour Impact Assessment from Developments (2004). Refer to Section 4.3.7 for further details on odour assessment.

The guideline sets out the following advice in relation to odour concentration guidelines:

Proponents of new facilities may undertake an impact assessment with relevant inputs of emissions and local meteorology to an air dispersion model to provide estimates of the likely odour impacts in the surrounding environment. The inputs should be as detailed as possible, reflecting any variation of emissions with time and including at least a full year of representative hourly meteorological data. The modelled odour concentrations at the "most exposed existing or likely future off-site sensitive receptors" should be compared with the following guideline values.

- 0.5 ou, 1-hour average, 99.5th percentile for tall stacks; and
- 2.5 ou, 1-hour average, 99.5th percentile for ground-level sources and down-washed plumes from short stacks.

For facilities that do not operate continuously, the 99.5th percentile must be applied to the actual hours of operation.

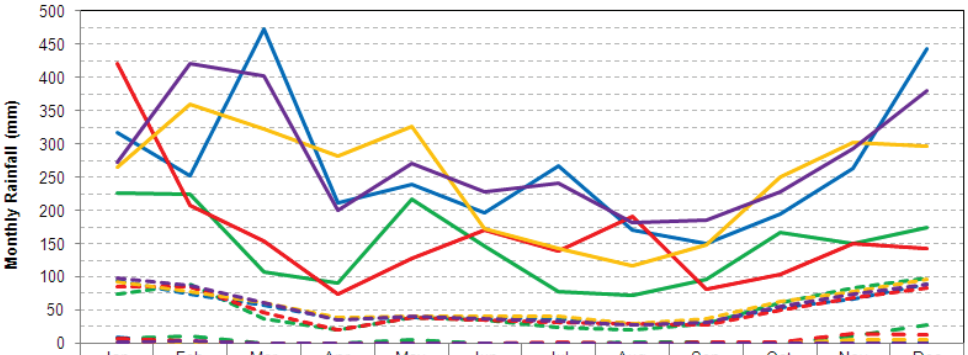
3 EXISTING ENVIRONMENT

3.1 Climate and Meteorology

This Section describes the climate and meteorology at selected points with the study area.

3.1.1 Rainfall

A summary of the long term monthly average rainfall at monitoring locations in the study area is presented in Figure 3.1**.** This summary shows a consistent pattern across the study area of 70-100 mm of rain, on average, during the summer months, dropping to average lows of 20-40 mm during winter.

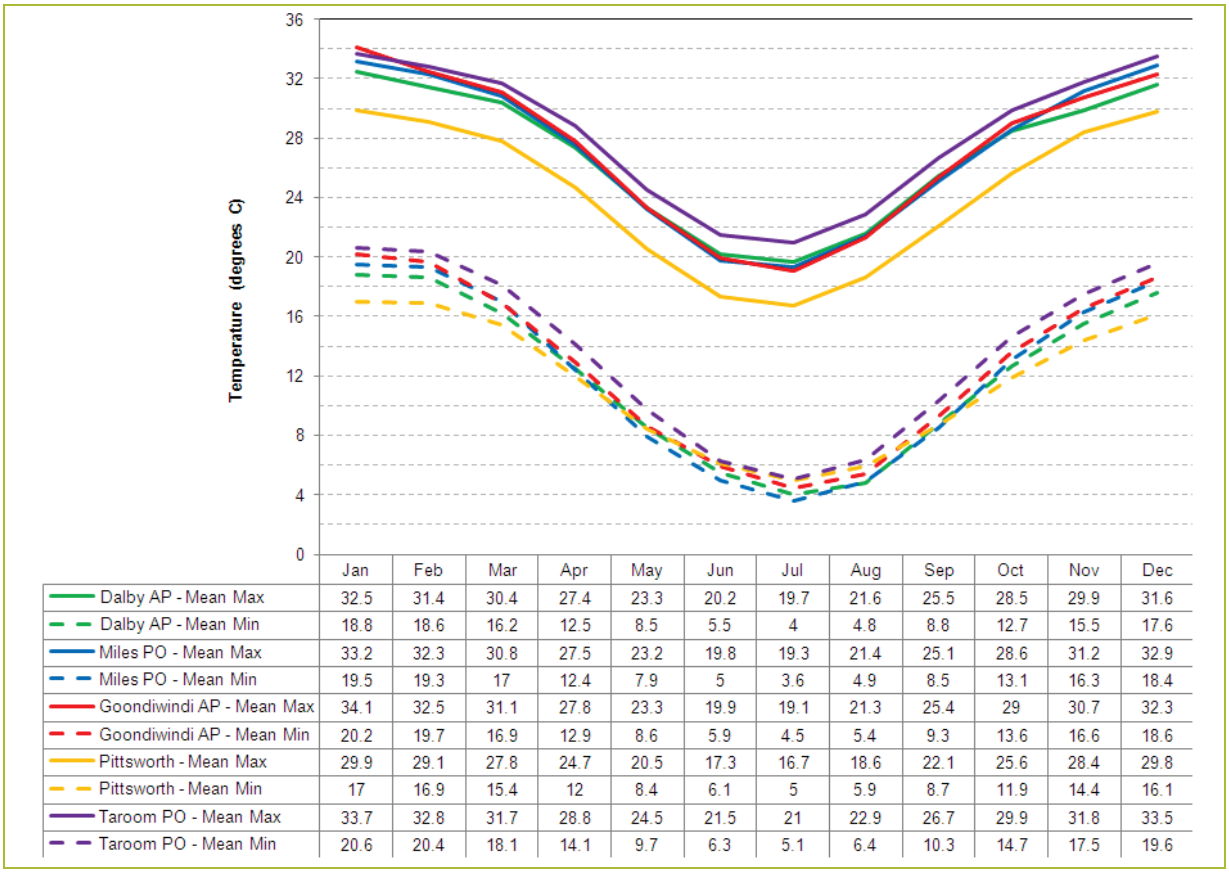


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dalby AP - Maximum	226.4	224.8	107.6	91.2	216.2	146.6	77.6	71.8	96.2	166.4	150.6	174.4
Dalby AP - Minimum	7.4	11.2	0.6	0	5.8	0.4	0	1.2	1.2	0.4	10.4	26.8
Dalby AP - Average	73.9	89	36.9	20.8	39.4	35.4	23.5	20	30.4	61.2	83.2	98.8
Miles PO - Maximum	317.5	251.8	472.9	211	239.6	195.6	267	170.6	150.6	194.4	262.6	442.5
Miles PO - Minimum	9.7	0.3	0	0	0	0	0	0	0	0.4	0	1.5
Miles PO - Average	95.1	74.9	58.2	36.6	39.1	39.6	37.3	29.1	31	54	66	89
Goondiwindi AP - Maximum	420	207	153.2	74.8	128.4	170	139.2	191	81.8	104.1	150.6	143.2
Goondiwindi AP - Minimum	7.4	2.8	0	0	0.4	0	1	0	1	2.2	14.6	12.4
Goondiwindi AP - Average	84.8	84.3	46.3	19.7	39	35.2	31.2	30	27.4	49.7	69.3	83.3
Pittsworth - Maximum	264.8	359.7	321.8	281.2	325.4	172.7	141.8	117.4	148.9	251	302	297.5
Pittsworth - Minimum	2.4	0.8	0	0	0	0	0	0	0	0	4.9	5.7
Pittsworth - Average	92.1	77	61.8	38.5	40.6	41	40.6	30	36.7	63.7	76.8	96.4
Taroom PO - Maximum	273.1	421.1	403.1	200	270.1	228.6	240.8	181.9	185.7	228.7	292	380.9
Taroom PO - Minimum	1.8	2.6	0	0	0	0	0	0	0	0	0.2	0
Taroom PO - Average	97.8	86.6	61.4	35.1	40.6	36.6	33.8	27.6	31.2	55.5	74.4	88.6

Figure 3.1: Long term average rainfall summary

3.1.2 Temperature

The long term monthly average temperatures within the study area display typical ranges for subtropical regions, as shown in Figure 3.2. Pittsworth, at a higher elevation, is generally cooler than the other monitoring stations in the region while at Taroom the temperatures are fractionally higher than the other monitoring stations. Mean monthly minimum temperatures range between 16 to 21°C in the summer and drop as low as 3.6°C in the winter. The mean maximum temperatures can range between 30 to 35°C in the hottest months and drop to between 17 and 21°C during the coldest part of the year.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dalby AP - Mean Max	32.5	31.4	30.4	27.4	23.3	20.2	19.7	21.6	25.5	28.5	29.9	31.6
Dalby AP - Mean Min	18.8	18.6	16.2	12.5	8.5	5.5	4	4.8	8.8	12.7	15.5	17.6
Miles PO - Mean Max	33.2	32.3	30.8	27.5	23.2	19.8	19.3	21.4	25.1	28.6	31.2	32.9
Miles PO - Mean Min	19.5	19.3	17	12.4	7.9	5	3.6	4.9	8.5	13.1	16.3	18.4
Goondiwindi AP - Mean Max	34.1	32.5	31.1	27.8	23.3	19.9	19.1	21.3	25.4	29	30.7	32.3
Goondiwindi AP - Mean Min	20.2	19.7	16.9	12.9	8.6	5.9	4.5	5.4	9.3	13.6	16.6	18.6
Pittsworth - Mean Max	29.9	29.1	27.8	24.7	20.5	17.3	16.7	18.6	22.1	25.6	28.4	29.8
Pittsworth - Mean Min	17	16.9	15.4	12	8.4	6.1	5	5.9	8.7	11.9	14.4	16.1
Taroom PO - Mean Max	33.7	32.8	31.7	28.8	24.5	21.5	21	22.9	26.7	29.9	31.8	33.5
Taroom PO - Mean Min	20.6	20.4	18.1	14.1	9.7	6.3	5.1	6.4	10.3	14.7	17.5	19.6

Figure 3.2: Long term average temperature summary

3.1.3 Wind Speed and Direction

Wind roses show the frequency of occurrence of winds by direction and strength. The bars correspond to the 16 compass points (N, NNE, NE, etc.). The bar at each wind direction in the wind rose diagram represents winds blowing from that direction, e.g. north. The length of the bar represents the frequency of occurrence of winds from that direction, and the widths of the bar sections correspond to wind speed categories, the narrowest representing the lightest winds. With the resulting figure it is possible to visualise how often winds of a certain direction and strength occur over a long period, either for all hours of the day, or for particular periods during the day.

Wind roses from three separate locations in the study area (one from the north, central and south of the study area) clearly show very different wind patterns across the study area. Dalby, shown in Figure 3.3, is centrally located within the study area and has winds that are very east to west oriented in the afternoons. The other two stations, including Miles in the northwest of the study area, and Goondiwindi in the south of the study area, show a more even spread around the compass points. All three stations (Figure 3.3, Figure 3.4 and Figure 3.5) present a high frequency of calm (<0.5 m/s) and very light winds. Calms form 19% and 18% of 9 AM winds and 9% and 13% of 3 PM winds at Dalby and Goondiwindi respectively. Miles Post Office, Figure 5.4, has a lower frequency of calms at 3% at 9 AM and 2% at 3 PM and there is a higher frequency of light wind speeds, close to 10% for most wind directions at 3 PM.

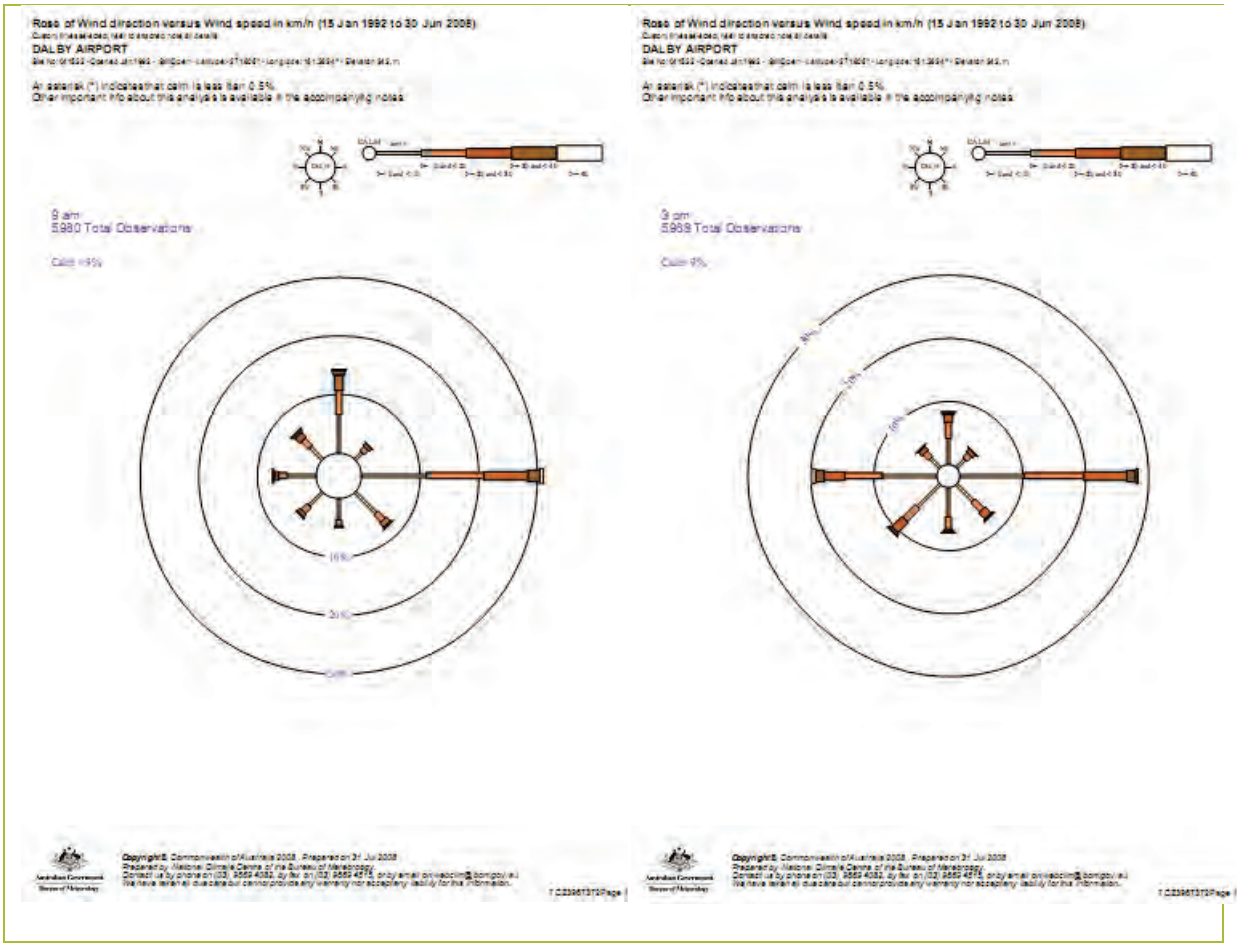


Figure 3.3: Long term average 9 AM (left) and 3 PM (right) wind roses from Dalby Airport

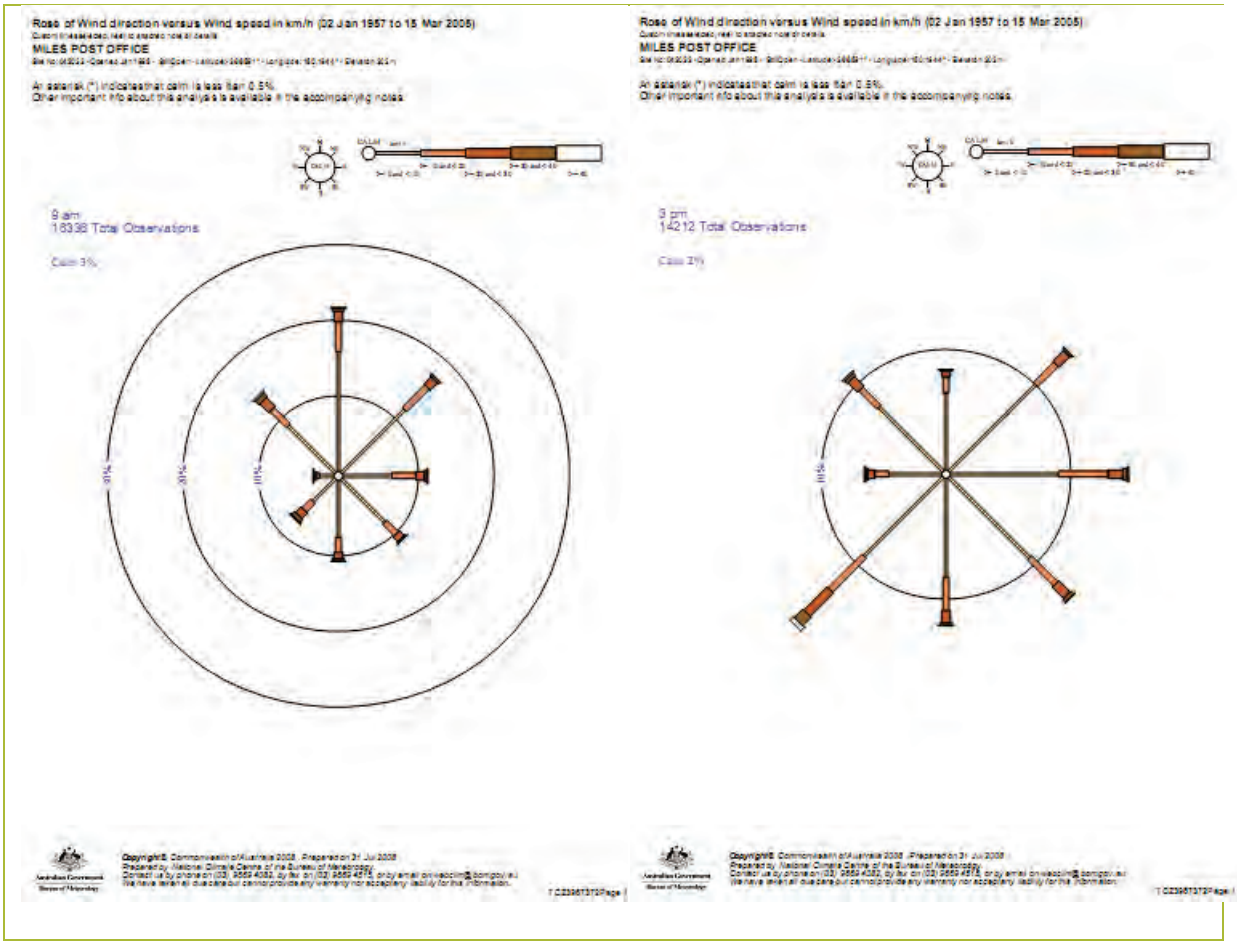


Figure 3.4: Long term average 9 AM (left) and 3 PM (right) wind roses from Miles Post Office

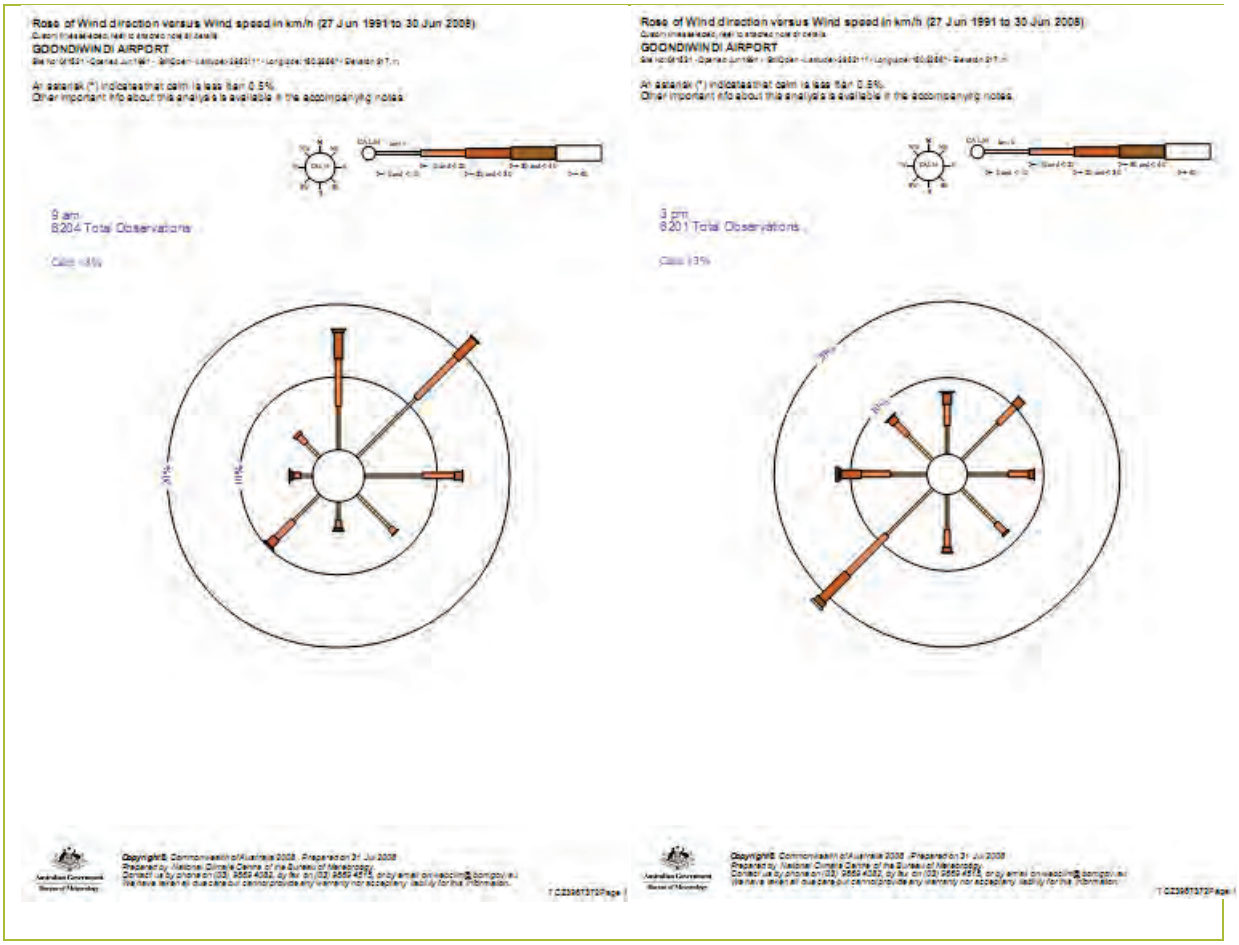
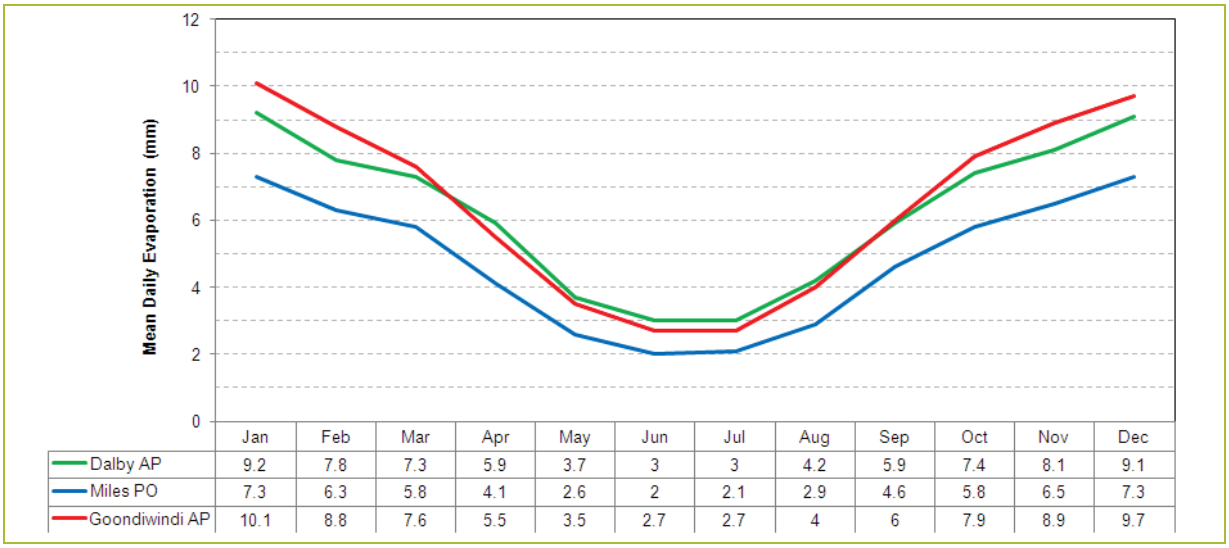


Figure 3.5: Long term average 9 AM (left) and 3 PM (right) wind roses from Goondiwindi Airport

3.1.4 Evaporation

During the summer months, longer hours of daylight, hotter temperatures and higher solar radiation results in evaporation rates that are five times higher than those experienced during the June to August cooler months. As can be seen in Figure 3.6, solar radiation is generally lower at Miles than at Goondiwindi or Dalby.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dalby AP	9.2	7.8	7.3	5.9	3.7	3	3	4.2	5.9	7.4	8.1	9.1
Miles PO	7.3	6.3	5.8	4.1	2.6	2	2.1	2.9	4.6	5.8	6.5	7.3
Goondiwindi AP	10.1	8.8	7.6	5.5	3.5	2.7	2.7	4	6	7.9	8.9	9.7

Figure 3.6: Mean daily evaporation

3.1.5 Temperature Inversions

A temperature inversion refers to a layer of air in the atmosphere in which the temperature cools at a much lower rate (or even warms) with height in comparison to other parts of the atmosphere. During night time the ground is cooled by radiating heat into space. Air in contact with the ground then becomes cooler than the air above it, suppressing convective mixing within the region close to the ground. A capping layer forms at the zone where the cool air below meets the warm air above. The lack of convective mixing results in stable meteorological conditions forming in the air layers below the top of temperature inversion. This phenomenon is much more pronounced over land than it is over water, as water holds its heat for longer than land.

This situation is expected to occur relatively frequently over the northern portion of the study area, especially when skies are clear and winds light.

3.1.6 Climate Extremes

The study area experiences approximately 20 thunder days per year, some of which can result in destructive winds, intense rainfall and flash flooding. In addition, in the past hundred years tropical cyclones have passed through the immediate vicinity (<200 km) 18 times (RGSQ, 2009).

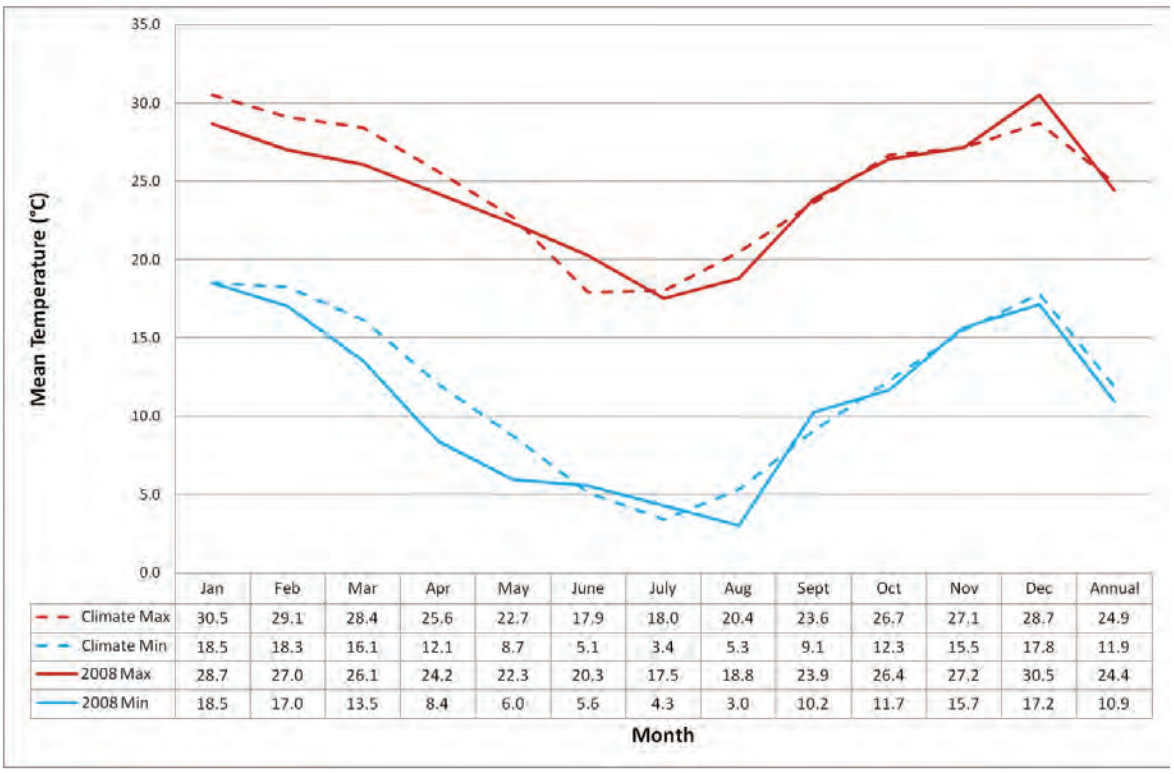
3.1.7 Selection of Representative Meteorological Year

Generally, a minimum of one year of meteorological data is acceptable for dispersion modelling studies. The data must, however, adequately represent worst-case meteorological conditions and the data should be considered representative with respect to climatic averages. Adequate representation of conditions likely to influence maximum plume impacts should be included in the year. Climate data over the last five years from the period of 2006 to 2010 has been used for comparison with the selected year of 2008. Oakey Aero was selected to determine the representative meteorological year as it centrally located in the project region.

A comparison of temperature (mean maximum and minimum) for 2008 and the last five years of data at Oakey Aero (2006-2010) is presented in Figure 3.7. In general, the average monthly temperatures for 2008 were within 1 to 2°C of long-term values.

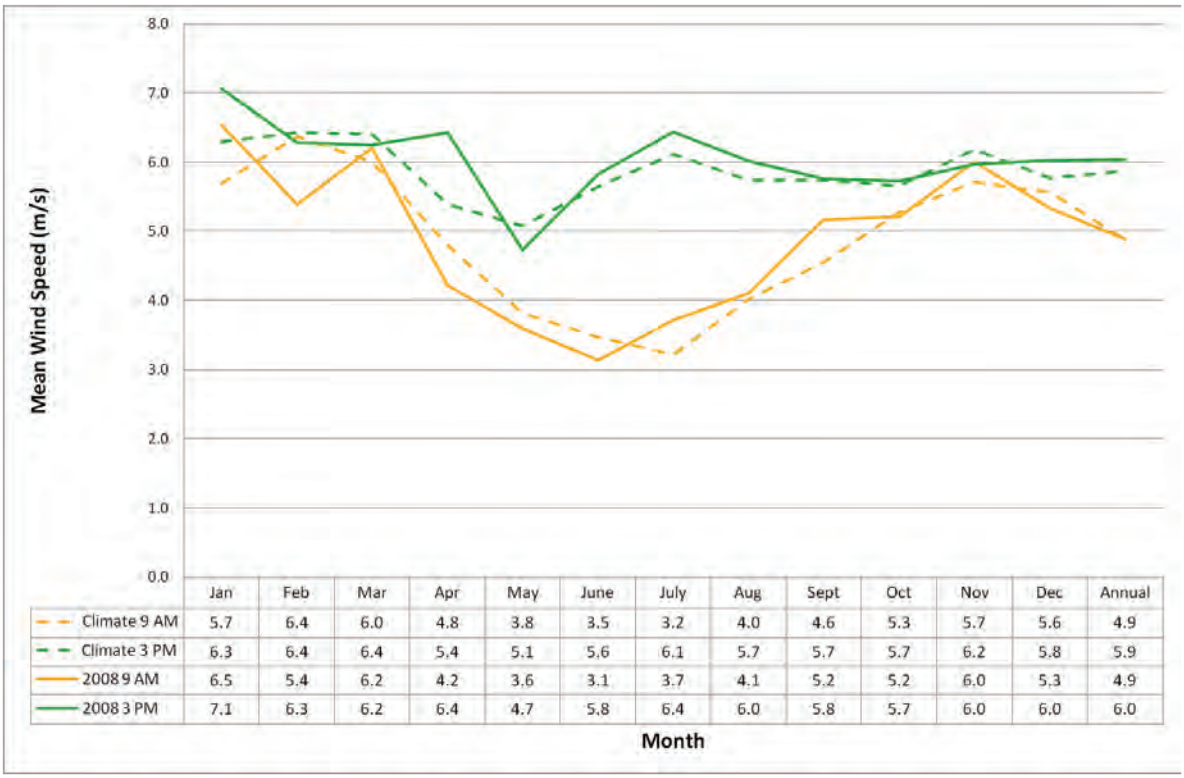
A comparison of wind speed (average of 9 AM/3PM) for 2008 and the last five years of data at Oakey Aero (2006-2010) is presented in Figure 3.8. Average wind speeds in 2008 are generally within approximately 1 m/s of the long-term averages. General patterns are similar for both the five year average and 2008 values.

The above findings suggest that given the highly variable nature of weather, the 2008 year to be modelled approximates long-term averages and can therefore be considered reasonably representative.



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Climate Max	30.5	29.1	28.4	25.6	22.7	17.9	18.0	20.4	23.6	26.7	27.1	28.7	24.9
Climate Min	18.5	18.3	16.1	12.1	8.7	5.1	3.4	5.3	9.1	12.3	15.5	17.8	11.9
2008 Max	28.7	27.0	26.1	24.2	22.3	20.3	17.5	18.8	23.9	26.4	27.2	30.5	24.4
2008 Min	18.5	17.0	13.5	8.4	6.0	5.6	4.3	3.0	10.2	11.7	15.7	17.2	10.9

Figure 3.7: Five Year Average vs 2008 maximum / minimum temperature for Oakey Aero



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Climate 9 AM	5.7	6.4	6.0	4.8	3.8	3.5	3.2	4.0	4.6	5.3	5.7	5.6	4.9
Climate 3 PM	6.3	6.4	6.4	5.4	5.1	5.6	6.1	5.7	5.7	5.7	6.2	5.8	5.9
2008 9 AM	6.5	5.4	6.2	4.2	3.6	3.1	3.7	4.1	5.2	5.2	6.0	5.3	4.9
2008 3 PM	7.1	6.3	6.2	6.4	4.7	5.8	6.4	6.0	5.8	5.7	6.0	6.0	6.0

Figure 3.8: Five Year Average vs 2008 9 AM/3PM Wind Speed at Oakey Aero

3.2 Existing Land Use and Air Quality

The study area primarily consists of undisturbed bushlands and agricultural operations. There is a presence of light industry including coal and gas fired power stations, coal/minerals mining, and industrial manufacturing. Small regional towns are sparsely located throughout the study area and are connected by a rural road transport network.

The existing air quality has been assessed using a photochemical dispersion model and known emission sources in the study area. Further information on the modelling methodology is in Section 4.4.2. Information on the sources considered in the existing air quality scenario are presented in Section 5.1. The resulting existing air quality ground level concentrations are in Section 5.3.

4 ASSESSMENT METHODOLOGY

The air quality impact assessment has been developed to meet the requirements of the Terms of Reference (TOR) (see Section 4.1) and is based on dispersion modelling that incorporates source characteristics and air pollutant emission rates. The modelling incorporates the existing climate, meteorology, air quality and land use as described in Section 3.

The air quality assessment utilised the following approach:

- Identify the extent of the geographical area required to appropriately assess the potential project impacts.
- Determine regulatory air quality standards/objectives.
- Identify potential project sources of emissions.
- Determine potential emission sources which require further assessment with regards to air quality. The assessment considers both regional and localised (near-field) impacts.
- Where appropriate, detail avoidance, management and mitigation measures.

4.1 Terms of Reference / Objectives

This assessment meets the requirements of the TOR with respect to air quality and provides additional material to support technical aspects associated with the dispersion modelling. Table 4.1 cross references each line item in the TOR to relevant section(s) within this assessment.

Table 4.1: Terms of Reference Cross-reference

Component of Terms of Reference	Relevant Sections
Description of Environmental Values (TOR Section 4.6.1)	
Description of the existing airshed with particular regard for particulates, gaseous and odorous compounds. Also, the background levels and sources of suspended particulates, NO_x, SO_x and other constituents that may be affected by the project	5
Meteorological data and ambient levels of contaminants to provide a baseline for air quality modelling – should include air temperature, wind speed and direction, atmospheric stability, mixing depth/height and others	3
The environmental values of the airshed for the affected area(s) should be described in terms of the Environmental Protection (Air) Policy 2008 (EPP (Air))	4.3
Potential Impacts and Mitigation Measures (TOR Section 4.6.2)	
Modelling should be done using a recognised atmospheric dispersion model	4.4
Air emission objectives should be stated and comparison made to the modelling results, in accordance with relevant standards, emission guidelines and relevant legislation	7
Description of any potential interaction between modelled and background emissions and any likely environmental harm which may result	7
Predicted ground level concentrations should be included, these should be made for both normal and maximum emission rates and worst-case meteorological conditions – the technique used should be explained, referenced and key assumptions identified	7
An accurate description of the activities carried out on the project area	1.3
Description of the impacts of emissions during construction on air environmental values and human health	6.2
Description of pollution control equipment and techniques used on the premises and features of the project designed to minimise emissions	9
Description of back-up measures that will minimise the likelihood of plant upsets and adverse air impacts, following the failure of primary measures	9
An air emission inventory should be included, detailing point, line, area and volume sources as well as fugitive emissions	6.3
A separate emission inventory for activities which occur offsite, including fugitive emissions	Appendix A
Provide a complete list of emissions to the atmosphere – present all concentrations of substances at standard temperature and pressure, mass emission rate, volume flow rate, exit temperature and velocity and flue gas oxygen content	6.3
Use emission rates from measurements taken at similar facilities where possible, otherwise use published emission factors or manufacturer data	Appendix A
Provide a comparison of emission rates with best practice national and international source emission standards	8
Using detailed model inputs, for significant emissions only, undertake an impact assessment on the surrounding environment, taking into account variation of emissions with time – include at least a full year of representative meteorological data - input parameters should be based on actual stack conditions	7
Estimate the ground level concentration, at the nearest sensitive receptors, based on 1-hour average for maximum (99.9^{th}) and 99.5^{th} percentile values – the results of the model should be presented as contour and contour frequency plots, under normal and maximum emission rates as well as worst case scenario meteorological conditions – the technique used should be explained, referenced and key assumptions identified	7
Evaluate cumulative impacts of the proposed emissions, considering existing and known future projects within the region – describe airshed management and capacity in view of existing and future users	7, 10
Identify 'worst case', emissions that may occur during start-up, shut-down and during 'upset' operating conditions and examine the worst-case impact	6
Averaging periods used to calculate ground level concentrations, should be in line with air quality indicators and goals in EPP (Air) Policy 2008, and NEPM Air	7

Component of Terms of Reference	Relevant Sections
Modelled air quality concentrations at the most exposed sensitive receptors should be compared with air quality standards including EPP (Air) Policy 2008 and NEPM Air	7
Assessment of chemical species not published in the EPP (Air), best practice design and criteria published in other jurisdictions could be used	7
The human health risk of all hazardous and toxic contaminants should be assessed regardless of whether they are covered by the National Environmental Protection Council (Ambient Air Quality) measure, or the EPP (Air) Policy 2008	4.3, 7
Where a single model is not sufficient to handle all atmospheric dispersion characteristics exhibited in the project area, a combination of acceptable models should be used	4.4
Description of the limitation and accuracy of the applied atmospheric dispersion models	4.5
Evaluate the extent of the potential of NO_x and Volatile Organic Compounds (VOCs) released by the project to generate photochemical smog	5.1
Evaluate the extent of the potential of SO_2 released by the project to generate acid rain or atmospheric acidification	4.3.4
Should the project not meet the guidelines given in the EPP (Air) Policy 2008, a risk assessment should be carried out to assess the adverse impacts off-site – risk management strategies should be put into place to minimise the risk of exposure of local communities, enabling the project to meet the objectives of the EPP (Air) Policy 2008	9

4.2 Study Area

The air quality study area encompasses all anticipated significant emission sources and allows for the modelling of synoptic scale meteorological events that may impact the project regions. The study area is provided in Figure 4.1.

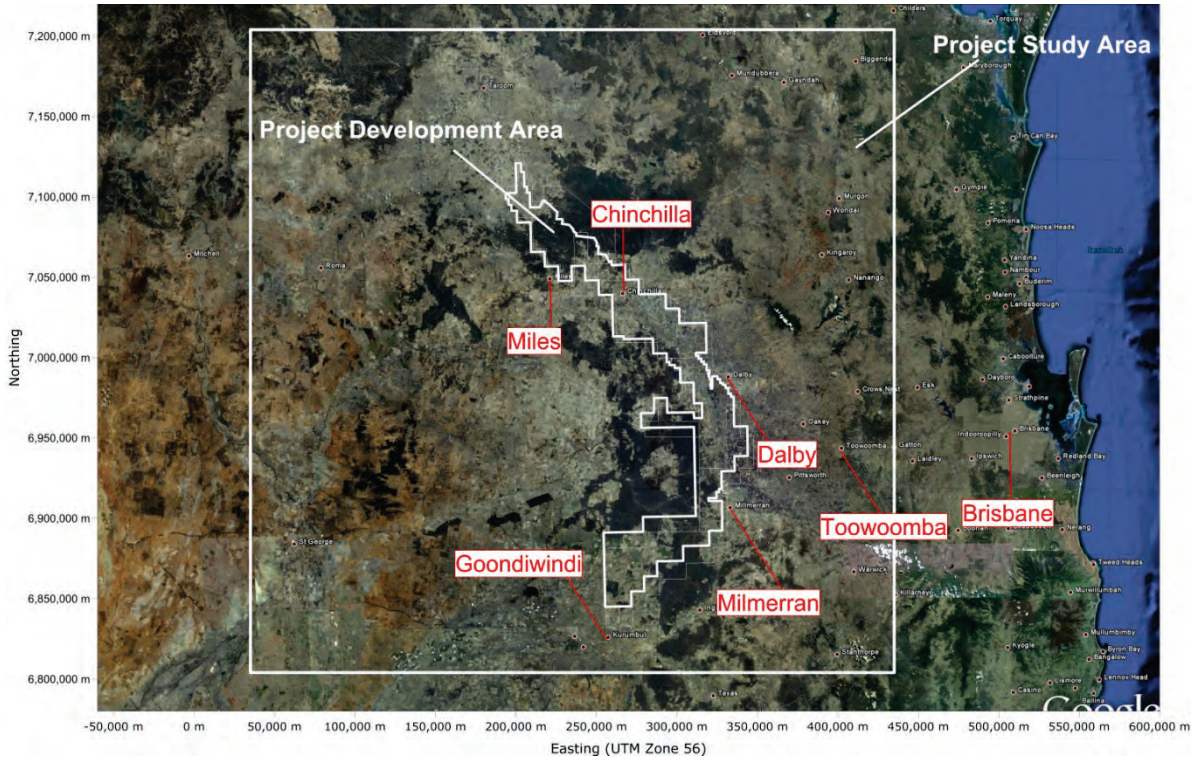


Figure 4.1: Surat Gas Project study area

4.3 Air Quality Criteria

The air quality criteria implemented in this project are outlined in Table 4.2. Discussion of specific substances to be assessed is provided below the table.

Table 4.2: Selected Substances and Regulatory Criteria

Substances		Objective		Purpose [a]	Time Period	Regulatory Agency	Allowable Exceedences
Carbon Monoxide (CO)		11,000	µg/m³	Health	8 hr	Air EPP/NEPM	1 day per annum
Nitrogen Dioxide (NO_2)		250	µg/m³	Health	1 hr	Air EPP/NEPM	1 day per annum
		62	µg/m³	Health	Annual	Air EPP/NEPM	
		33	µg/m³	Ecosystems	Annual	Air EPP	
Ozone (O_3)		210	µg/m³	Health	1 hr	Air EPP	1 day per annum
		160	µg/m³	Health	4 hr	Air EPP	1 day per annum
Total Suspended Particulate (TSP)		90	µg/m³	Health	Annual	Air EPP	
Particulate Matter <10 µm (PM10)		50	µg/m³	Health	24 hr	Air EPP/NEPM	5 days per annum
Particulate Matter <2.5 µm (PM2.5)		25	µg/m³	Health	24 hr	Air EPP	
		8	µg/m³	Health	Annual	Air EPP	
Sulfur Dioxide (SO_2)		570	µg/m³	Health	1 hr	Air EPP/NEPM	1 day per annum
		230	µg/m³	Health	24 hr	Air EPP/NEPM	1 day per annum
		57	µg/m³	Health	Annual	Air EPP/NEPM	
		33	µg/m³	Agriculture	Annual	Air EPP	
		22	µg/m³	Ecosystems	Annual	Air EPP	
Volatile Organic Compounds (VOCs)		-	µg/m³	-	-	-	
1,2-dichloroethane		750	µg/m³	Health	24 hr	Air EPP	
1.3-Butadiene		2.4	µg/m³	Health	Annual	Air EPP	
Benzene		10	µg/m³	Health	Annual	Air EPP	
Benzo(a)pyrene		0.0003	µg/m³	Health	Annual	Air EPP	
Dichloromethane		3200	µg/m³	Health	24 hr	Air EPP	
Formaldehyde		54	µg/m³	Health	24 hr	Air EPP	
		110	µg/m³	Nuisance	30 min	Air EPP	
Styrene		75	µg/m³	Nuisance	30 min	Air EPP	
Tetrachloroethylene		270	µg/m³	Health	Annual	Air EPP	
		8600	µg/m³	Nuisance	30 mins	Air EPP	
Toluene		4100	µg/m³	Health	24 hr	Air EPP	
		410	µg/m³	Health	Annual	Air EPP	
		1100	µg/m³	Nuisance	30 mins	Air EPP	
Xylene		1200	µg/m³	Health	24 hr	Air EPP	
		950	µg/m³	Health	Annual	Air EPP	
Dust deposition		120	mg/m 2/day	Nuisance	Monthly	Informal criterion	
Odour	Tall stacks	0.5	OU	Nuisance	1 hr	Qld guideline	44 per annum
	Ground level/short stacks [b]	2.5	OU	Nuisance	1 hr	Qld guideline	44 per annum

a. Health - Protection of health and wellbeing, Agriculture - Protection of agriculture, Ecosystems - Health and biodiversity of ecosystems (for forests and natural vegetation), Nuisance - Prevention of Nuisance.
b. Ground-level sources and down-washed plumes from short stacks

4.3.1 Nitrogen Dioxide

Nitrogen Dioxide (NO_2) is an oxide of nitrogen (NO_x). NO_x is defined as NO_2 and nitrogen oxide (NO). The NO_2 fraction of NO_x is associated with adverse health and is subject to regulatory criteria while NO is not regulated. NO_x is also associated with adverse impacts to the health and biodiversity of ecosystem.

Anthropogenic sources of NO_x are typically associated with combustion. At the point of release, the NO_x is predominantly NO (greater than 90%) with the remaining fraction as NO_2.

In the case of the Surat Gas Project, gas combustion from the power generation engine exhausts, wellhead engine exhausts and flares will produce NO_x during operation. NO_2 is the primary substance of concern associated with combustion of gas.

Biogenic sources of NO_x emissions include soils, plants, trees, crops, bushfires and lightning storms.

Both NO and NO_2 exist in a complex equilibrium in the atmosphere, predominantly influenced by the presence of atmospheric oxidants, VOCs, sunlight and other factors. The concentrations in the atmosphere at any time are determined by the rate of competing reactions. Reactions that form NO_2 from NO are reversible, the net concentration of each substance is determined by competition between the forward and reverse reactions and the rate of other reactions that involve NO and NO_2 in the atmosphere. This complex atmospheric chemistry and the prevalence of sources complicate the evaluation of NO_2.

NO_2 directly impacts human health with acuate impacts of ear, nose and throat irritation and long term impacts of impaired lung function, increased respiratory illness in children and increased asthma symptoms.

NO_x is associated with adverse impacts to the health of vegetation by influencing biochemical changes and causing growth reduction in plants from dry deposition. The Air EPP NO_2 objective for protecting ecology is based on the World Health Organisation (WHO) annual NO_x guideline for short term protection of vegetation (30 µg/m³ expressed as NO_2) (WHO, 2000). This WHO guideline has been developed from European research about the impacts of ambient NO_x concentration on the various foliage growth patterns.

Net releases of NO_x in the air are a potentially significant contributor to a number of environmental effects such as acid rain, eutrophication of watercourses and the formation of photochemical smog. Interactions between oxides of nitrogen and volatile organic compounds (VOCs) in the presence of sunlight are associated with ground level ozone (photochemical smog) and the formation of secondary particulate.

The regional impact of the project's NO_x emission sources on the existing air quality has been evaluated with the CSIRO Chemical Transport Model (CTM), as outlined in Section 4.4.2.2.

The localised impact of the NO_x emission sources has been evaluated with dispersion modelling and a regulatory approved method for estimating NO_x chemistry, as described in Section 4.4.3.3.

4.3.2 Volatile Organic Compounds

Volatile Organic Compounds (VOCs) is a collective term employed to describe organic carbon based compounds with the ability to enter the atmosphere as a vapour. Due to the ubiquitous nature of organic compounds emitted from natural and anthropogenic processes, there is a myriad of organic compounds that fall under the definition of VOC. Coal seam gas contains a limited mixture of VOCs.

From an air quality perspective, consideration of VOCs is important for the following reasons:

- Some VOCs are toxic. This diverse group of pollutants has characteristics such as toxicity or persistence such that they are hazardous to human, plant or animal life. Toxic VOCs relevant to this assessment include benzene, 1,3-butadiene, toluene and xylenes.

- VOCs can contribute to photochemical smog reactions to form ground level ozone (O_3) by reacting with NO_x in the presence of sunlight. These emissions have been considered in the Chemical Transport Model.
- The sense of odour often arises from the detection of particular combinations of VOCs.

VOCs are associated with combustion processes and fugitive gas leaks at the processing facilities. The toxicity, contribution to photochemical smog and odour associated with the release of these VOCs is considered in this assessment.

Ambient air quality guidelines do not typically consider methane as a VOC, as it contributes little to the formation of ground level ozone (described below). Methane is however, an active contributor to greenhouse gas emissions and has therefore been considered in depth in a separate greenhouse gas emissions study.

4.3.3 Photochemical Smog

Photochemical smog is a term used to describe the wide range of pollutants formed by a complex array of chemical reactions between oxides of nitrogen and VOCs in the presence of sunlight. The primary pollutant of concern within photochemical smog is ground level ozone (O_3). It is commonly used by environmental authorities as a key indicator of photochemical smog.

Ground level O_3 is a secondary[a] pollutant that is formed as a product of chemical reactions between primary pollutants (NO_x and VOCs). O_3 is a very strong oxidiser and is active in converting nitric oxide to the more hazardous nitrogen dioxide (NO_2). The oxidising nature of O_3 makes it toxic and significant exposure causes damage to living cells. In this assessment, the presence of O_3 is employed as an indicator of photochemical smog, along with nitrogen dioxide.

Typically, significant ground level O_3 formation occurs on hot, sunny, calm days, in broad areas with a ready supply of the precursor pollutants NO_x and VOC.

Due to the formation time (hours) and complex reaction mechanisms, O_3 is only evaluated on a regional scale. Peak ozone concentrations may occur up to 100 km or more from the primary emission source area because of the formation time (and associated wind transport) factor.

4.3.4 Sulfur Dioxide

Sulfur dioxide (SO_2) is the key member of a family of oxides of sulfur (SO_x). These gases are formed when substances containing sulfur are burnt – such as coal and oil.

The major health concerns associated with exposure to high concentrations of SO_2 include effects on breathing, respiratory illness, alterations in pulmonary defences, and aggravation of existing cardiovascular disease. SO_2 is also a major precursor to acid rain, which is associated with the acidification of lakes and streams, accelerated corrosion of buildings and monuments, and reduced visibility.

The emission of oxides of sulfur is directly dependent on the sulfur content of the fuels combusted. Coal seam gas only contains trace quantities of sulfur, unlike coal or some less refined grades of fuel oil. The combustion of diesel will produce emissions of oxides of sulfur, as will the operation of the large coal-fired power stations located in the study area.

[a] Primary pollutants are those that are emitted into the atmosphere at the point of release. Once in the atmosphere they may be transformed into secondary pollutants by a range of chemical and physical processes.

4.3.5 Carbon Monoxide

Carbon monoxide (CO) is produced from incomplete combustion of carbon-based materials, in conditions where carbon is only partially oxidised instead of being fully oxidised to form carbon dioxide (CO_2). CO can be harmful to humans because its affinity for haemoglobin is more than 200 times greater than that of oxygen (O_2). When it is inhaled it is taken up by the blood and therefore reduces the capacity of the blood to transport oxygen. Exposure to relatively high concentrations of CO is required before health impacts occur.

The assessment of CO usually only becomes significant if there is the presence of large volumes of motor vehicle activity such as would be found close to major motorways in large cities. Otherwise it is very unusual to find sources of CO that are sufficiently large to cause concern.

4.3.6 Particulate Matter

Suspended solids or liquids in air are referred to as Particulate Matter (PM). Concentrations of particles suspended in air are classified by aerodynamic diameter, i.e., a combination of the size and shape of a particle that determines its behaviour when suspended in air:

- Total Suspended Particulate (TSP) – refers to the total amount of the particulate matter suspended by air (regardless of size). Particles in air are subject to gravitational settling; particles larger than about 30 µm in aerodynamic diameter are likely to be removed by gravitational settling within a short time of being emitted (i.e., they settle to the ground or other surfaces fairly quickly).
- PM_{10} refers to the total of suspended particulate matter less than 10 µm in aerodynamic diameter. Particles in this size range can enter bronchial and pulmonary regions of the respiratory tract and can impact human health. Particles in this size range can remain suspended for many days.
- $PM_{2.5}$ refers to total of suspended particulate matter less than 2.5 µm in aerodynamic diameter. Epidemiological studies have shown that particles in this size range are associated with greater health impacts than other particle sizes.

The air quality impacts of particulate matter are complicated by the chemical makeup of the particles and by how these react when combined with other air pollutants.

In addition to the airborne concentration, deposited particulate matter can cause environmental impact to amenity (e.g., dust on laundry, cars and other surfaces). This is commonly referred to as dust deposition and is the process of particles, mostly greater than 10 µm in diameter, settling and accumulating on surfaces. Dust deposition is commonly an issue near operations that generate particulate matter via mechanical processes such as quarries, mines and construction sites.

Particulate matter is emitted from both anthropogenic and biogenic sources via the following mechanisms:

- Mechanical processes such as wind erosion of exposed soils, wheel generated dust from vehicle movement and dust associated with material movements.
- Combustion PM is formed as a product of incomplete combustion – it tends to be associated with fuels which are more difficult to burn such as coal and diesel. Combustion of gas will be associated with very low emissions of PM.
- As a secondary product of photochemical smog.

Combustion of gas due to facility power generation, flaring and wellhead engines will produce small quantities of very fine particles ($PM_{2.5}$). PM will also be associated with vehicles (both from combustion and mechanical processes).

4.3.7 Odour

Odour is a sensation that can be caused by a great variety of compounds, known as odorants. When their concentrations are high enough, they trigger odour responses in individuals who are exposed to them. The sensation of odour requires the action of a complex set of physiological and cognitive processes. Assessment of odour impacts is achieved using a process called dynamic olfactometry. Dynamic olfactometry provides controlled panels of observers with variable concentrations of an odorant to determine the concentration at which only half the panel can detect the odour. This concentration is referred to as the odour threshold or one odour unit (ou). The odour concentration of a sample reported in odour units is the number of dilutions (of a prescribed volume) required to achieve the odour threshold.

The main adverse effect of environmental odours is annoyance. People generally become annoyed by an odour that they regard as unpleasant and from which they cannot readily escape. Repeated exposure to annoying levels of odour results in nuisance. Long-term exposure to highly annoying odours may cause some physical symptoms that are related to stress, and the affected person may become particularly sensitive to the odour (QEPA, 2004). Typically odours impacts are described through the so-called FIDOL factors:

- Frequency of odour impacts;
- Intensity of odour impacts;
- Duration of odour impacts ;
- Offensiveness of the odour; and
- Location where the odour is detected.

The response to odours can also be strongly influenced by individual attitudes and experiences as well as social and economic factors (QEPA, 2004).

Odours can be made up of complex mixtures of odorants, or alternatively consist of a single odorant such as hydrogen sulphide (H_2S or rotten egg gas). Coal seam gas is known to consist of approximately 98.69% methane, 0.01% ethane, 0.22% carbon dioxide and 1.05% nitrogen. Trace amounts of various volatile organic carbons and hydrogen sulphide may be present in the gas stream.

Hydrogen sulphide is a critical odorant as its detection limit has been shown to be anywhere from 0.5 ppb to 130 ppb based on older studies (AIHA, 1989) with more recent studies publishing a detection threshold of 8 ppb (WA Health, 2009). There is reported to be the potential for annoyance and some health impacts such as headaches, nausea and fatigue at levels above 8 ppb. The difference between the data published in the two documents is likely to be associated with the methodology used to derive the data in the AIHA document, which was derived between 1930 and 1980. Since this time, more accurate methods of determining odour thresholds have been implemented.

As hydrogen sulphide may only be present in trace quantities the potential emissions impacts from coal seam gas flaring or through unexpected uncontrolled releases are difficult to quantify. However, given that they are expected to be infrequent events PAEHolmes does not anticipate they would cause a nuisance issue.

4.3.8 Dust Deposition

Deposition is the process by which particles settle by the action of gravity and collect or deposit on solid surfaces. Deposition rate is defined as the mass of deposited material across a defined area over a specified time period.

The deposition of dust is normally not a human health concern, but a nuisance to humans. The dust can settle on material objects, such as cars and laundry, which as a result of excess dust deposition will have to be cleaned more often.

The deposition rate of particles depends on the particles' deposition velocity and atmospheric properties. The deposition velocity is the distance a particle travels toward the ground in a unit of time. It depends on the particle size, particle density and properties of the atmosphere including density and viscosity. Particle sizes greater that 30 µm in aerodynamic diameter are primarily associated with dust deposition issues.

For the Surat Gas Project, typical activities that can cause dust deposition will include earthmoving and vehicle activities on unpaved roads, and preparation of sites for construction activities.

4.3.9 Greenhouse Gases

The greenhouse effect is the heating of the atmosphere due to presence of gases that absorb and emit infrared radiation. Anthropogenic global warming refers to an enhanced greenhouse effect associated with the increased atmospheric concentrations of greenhouse gases released from human activities. Examples of these activities are land clearing and fossil fuel combustion.

Greenhouse gas emissions and the possible impacts of anthropogenic climate change have been covered in a separate greenhouse gas assessment.

4.4 Atmospheric Dispersion Modelling

Atmospheric dispersion modelling has been used to assess emission sources against air quality guideline values and to establish the existing environmental values of the regions (regional values).

Two separate modelling approaches have been used in this assessment, one to determine the existing air quality and regional impacts of the project, and another to determine the localised (near field) impacts.

Existing air quality and regional impacts have been assessed using:

- TAPM meteorological data (Section 4.4.2.1).
- TAPM dispersion modelling (Section 4.4.2.1).
- CTM chemical reaction mechanisms for photochemical reacting compounds (NO_2, O_3) (Section 4.4.2.2).

Localised impacts (i.e., relatively close to emission sources) have been assessed using:

- Two-dimensional meteorological data (Section 4.4.3.1) was used to represent worst-case conditions.
- Land uses are generally rural relatively flat with some areas of forest.
- AUSPLUME dispersion modelling (Section 4.4.3.1)

- With NO_2 impacts estimated by post-dispersion calculations (Section 4.4.3.3).

The localised assessment considers two-dimensional meteorology as the specific locations of the facilities have not been determined.

4.4.1 Overview of Modelling Methodology

Plume dispersion modelling has undergone significant refinement in recent years. Steady state Gaussian plume air dispersion models such as AUSPLUME and AERMOD have formed the basis of air dispersion assessment for many years and are now being replaced by a generation of more sophisticated three-dimensional models, such as CSIRO's TAPM-CTM. Gaussian models remain suitable for relatively simple and generic scenarios, where terrain and meteorological effects are not complex. The new models incorporate many additional algorithms that simulate influences ignored by the steady state Gaussian models, which are known to significantly impact plume dispersion in many situations, as described later in this section.

The steady state Gaussian plume models employ a relatively simple methodology. They assume that for each hour all meteorological conditions, most notably wind speed and direction, are fixed for that hour. They also assume that meteorological conditions do not vary from location to location, i.e., the wind field is assumed to be constant over the modelling domain. During any particular hour under consideration, the plume from the source is assumed to travel in the direction of the wind, and disperse at a rate determined by the current meteorological conditions. In the next modelled hour, the model assumes that the plume instantly changes direction to align itself with the new wind direction and the plume from the previous hour ceases to exist. In other words, all information about the previous hour of modelling is discarded. Therefore, variable plume trajectories caused by wind changes, or variable rates of plume diffusion, cannot be handled by this approach.

The key assumptions inherent in the steady-state Gaussian plume dispersion models may be summarised as follows:

- Meteorological parameters remain constant for the period of one hour.
- Meteorological parameters remain fixed over the entire modelling domain, which often includes all regions within 10 km or more of the source.
- In the vertical, most meteorological parameters either remain constant (e.g., wind direction) or vary according to generic formulae (e.g., wind speed, temperature) that are seldom, if ever, validated for the site.
- The height of the mixing layer remains constant for the entire region.

TAPM-CTM is a sophisticated model which is considered appropriate for large domains.

4.4.2 Selected Regional Impact Models and Methodology

Due to the lack of representative background monitoring data over the very large study area and the complexity of photochemical reactions, the existing concentrations of the photochemically reacting compounds, NO_2 and O_3, were estimated from modelling. Specifically, The Centre for Australian Weather and Climate Research (CAWCR) Chemical Transport Model (CTM) was used to produce background concentrations of NO_2 and O_3 on a regional scale as well as to assess the regional impacts of the project on NO_2 and O_3 concentrations. Technical details of the model equations, parameterisations, and numerical methods are described in the Chemical Transport Model Technical Description (Cope et al., 2009). CTM is coupled to the commonly used TAPM (The Air Pollution Model) that drives the meteorological component of the modelling. This model considers existing (major) pollutant sources that may impact upon the study area.

The air dispersion modelling conducted for this regional impact assessment has been based on the modelling approach outlined in Figure 4.2. The following sections describe the models employed in detail.

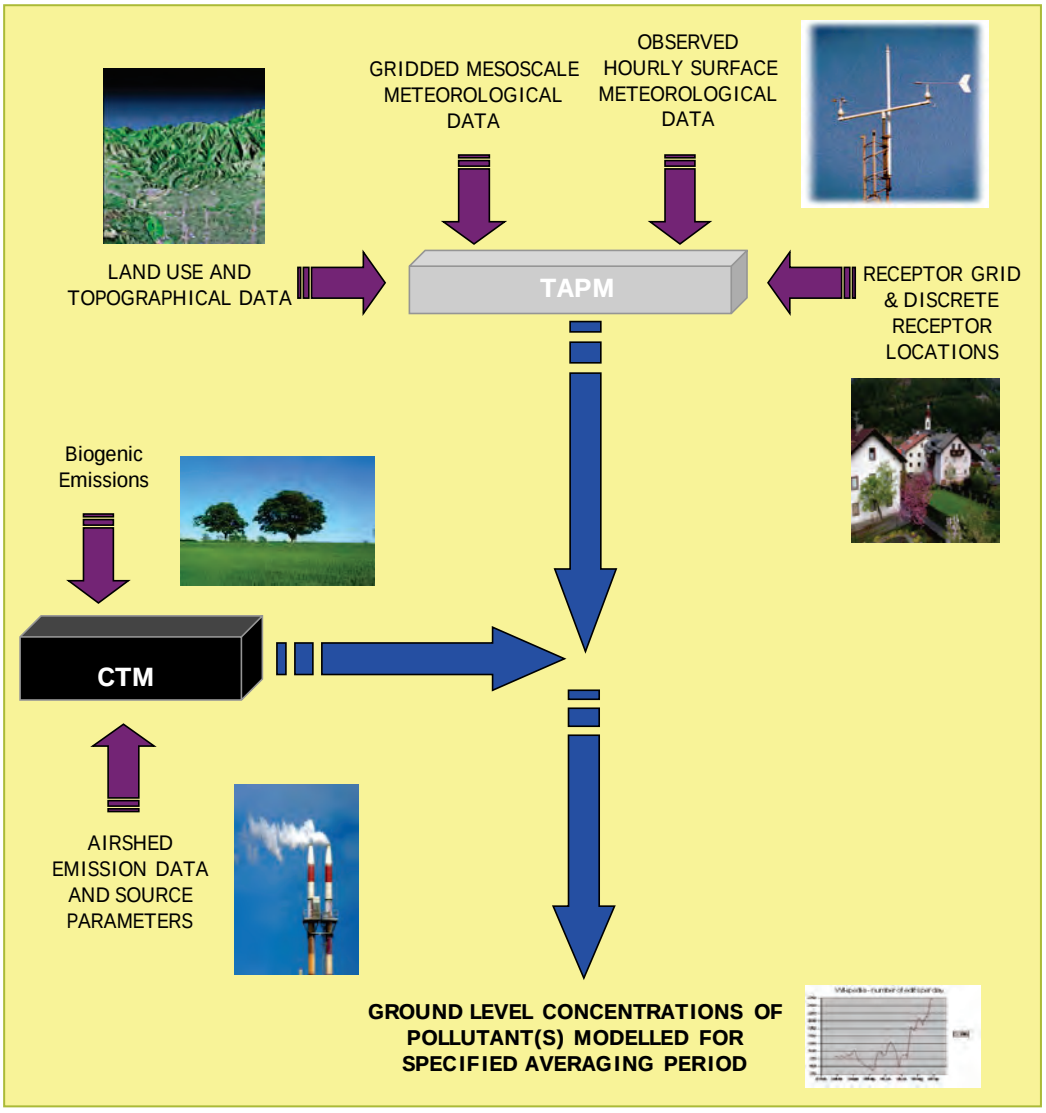


Figure 4.2: Modelling methodology used for regional impact assessments in this study

4.4.2.1 TAPM

The Air Pollution Model, or TAPM, is a coupled three dimensional meteorological and air pollution model produced by the CSIRO Division of Atmospheric Research. It was released in late 1999.

The meteorological component of TAPM is an incompressible, non-hydrostatic, primitive equation model. The model solves the momentum equations for horizontal wind components, the incompressible continuity equation for vertical velocity, and scalar equations for potential virtual temperature and specific humidity of water vapour, cloud water/ice, rain water and snow. Cloud microphysical processes, turbulence kinetic energy, eddy dissipation and radiative fluxes are also included (Hurley, 2008a). The model solution for winds, potential virtual temperature and specific humidity, are weakly nudged with synoptic-scale input values of these variables generated from meso-scale modelling.

TAPM may be used to generate meteorology for areas where there are no observations (NSW DECC, 2005a). Given the sparsity of meteorological monitoring stations in the modelling domain TAPM was used to generate surface meteorological data for areas where little or no data existed.

4.4.2.2 Chemical Transport Model (CTM)

CTM is designed to model the emission, transport, chemical transformation and deposition of a gas phase or a mixed gas and aerosol phase system. The CTM is typically used for modelling urban and regional scale photochemical smog production in combination with TAPM.

DERM is in the process of developing model guidelines for CTM-TAPM use within the state of Queensland. These guidelines were, however, not released at the time of this air quality assessment.

There are several CTM chemistry mechanisms that range from the very simple to the very complex. The generic reaction set (GRS) developed by Azzi et al. (1992) was chosen for this modelling study. While GRS is not the most complex or sophisticated chemistry mechanism available within CTM, it is the most practical based on the emissions data available for the study area.

The GRS chemistry mechanism is a highly condensed photochemical transformation mechanism used at a screening level analysis of photochemical smog formation. It is a gas-phase mechanism that consists of seven chemical reactions of seven compounds. The chemical reaction rates and variables are defined by Azzi et al. (1992). The necessary input chemical compounds are:

- NO;
- NO_2; and
- reactive organic carbon (ROC).

The other four chemically reacting compounds are O_3 and three theoretical reaction produced compounds. These theoretical compounds represent the numerous complex atmospheric chemical reactions that participate in O_3 and NO_2 formation, in a highly condensed fashion.

The GRS does not consider the atmospheric chemical reactions that form particulate matter nor does it have a direct input for commercial, domestic and motor vehicle sources.

While CTM contains far more complex chemistry mechanisms, the limited sophistication, confidence, and resolution of the available emission data for the study area does not warrant their use. The more complex chemistry mechanisms require the speciation of VOCs from emission sources that are not available within the public domain. Further work, including but not limited to the speciation of VOCs and speciation of NO_x, within the study area would be required to complete a more complex and detailed assessment. This work may be necessary to determine the precise conditions that O_3 and NO_2 exceedences will occur, if the airshed is deemed to be constrained for these pollutants.

4.4.3 Selected Localised Impact Models and Methodology

The air dispersion modelling conducted for this assessment has been based on the modelling approach outlined in Figure 4.3. The following sections describe the models employed in detail.

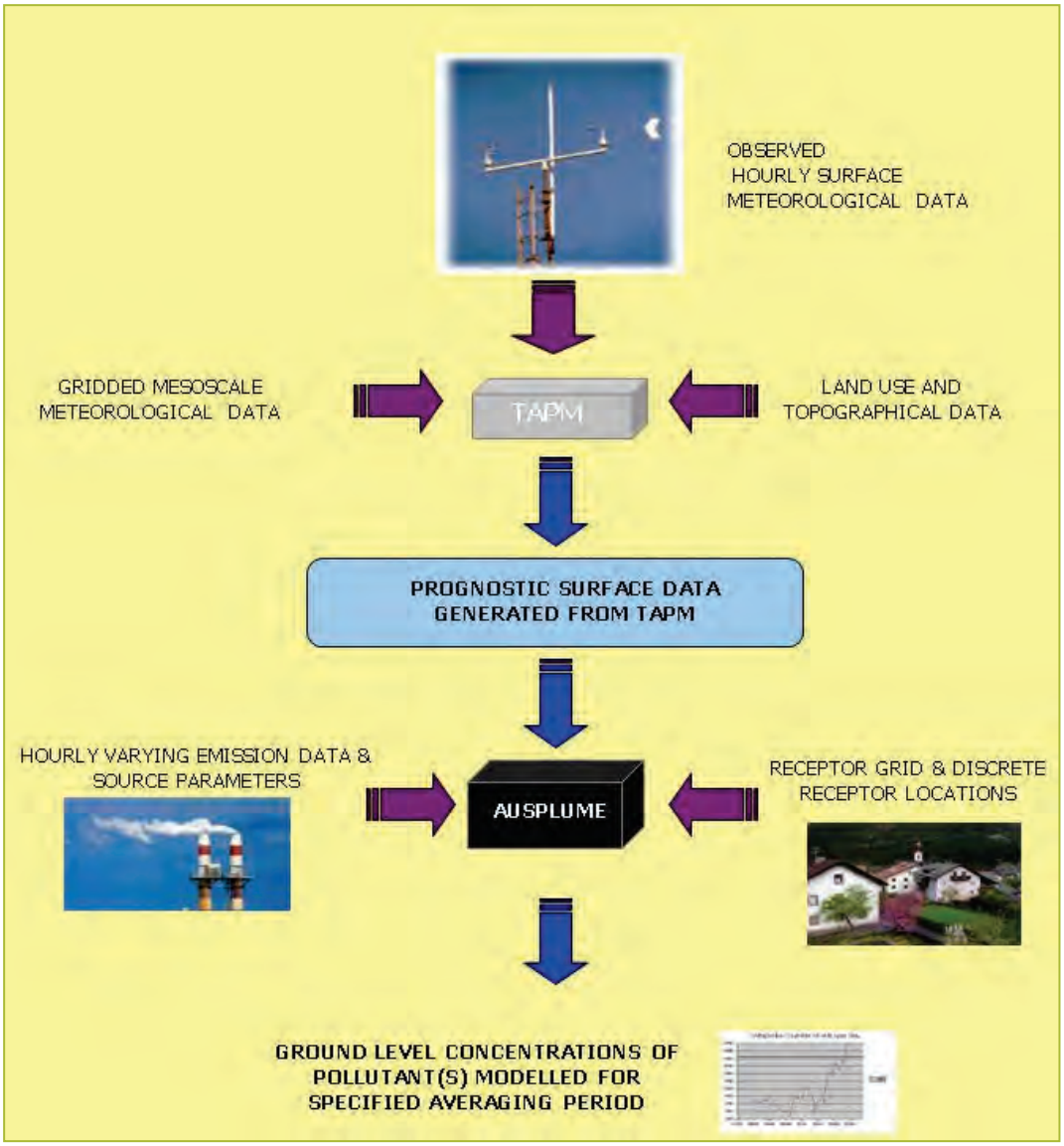


Figure 4.3: Modelling methodology used for localised impact assessments in this study

4.4.3.1 TAPM Meteorology Extracts

The hourly TAPM-generated meteorological data were extracted in the form of Ausplume meteorological files for the period of analysis and were used as input into Ausplume. This data represents a two-dimensional meteorological field. Three locations within the project development area were selected to represent the northern, central and southern sections regions. Meteorological data sourced from TAPM was used for the three locations in the localised modelling to provide a range of likely conditions experienced within the region. North, central and south regions were represented by extracted meteorological data from TAPM at locations presented in Table 4.3.

Table 4.3: Regional 2D Meteorological Extracts

Region	UTM Zone 56	
	Easting (km)	Northing (km)
North	224.521	7056.576
Central	308.521	6960.576
South	308.521	6888.576

4.4.3.2 Ausplume

AUSPLUME is a Gaussian plume dispersion model, which is widely used in Australia and New Zealand to predict the ground level concentrations of pollutants emitted from a variety of sources. The model is based on the Gaussian plume theory, which assumes that a plume is dispersed in a manner that enables the concentrations at a given time to be described in terms of a Gaussian statistical distribution, both vertically and horizontally about the centreline of the plume. The Gaussian assumption is widely used in dispersion modelling. There are some circumstances where it does not apply, however, for generic purposes such as those intended for this study, the assumption is usually an adequate approximation.

4.4.3.3 Modelling of Localised Impact NO_x Chemistry

One of the most common atmospheric chemistry issues regulatory modellers are required to address is estimating ground level NO_2 concentrations from modelled NO_x concentrations. The amount of NO_2 in the exhaust stream as it is released from combustion sources is typically in the order of 3 - 10% of total NO_x. After release, the ratio of NO_2 to NO_x in the plume increases as NO is oxidised, primarily in reaction with O_3. The rate of conversion is highly variable, depending on meteorological conditions and ambient ozone levels. In a dispersing plume, the following reactions (1 to 4) take place, effecting a NO_x-O_3 cycle. This cycle refers to the key set of chemical reactions that affect NO_2 within 20 km of a point source:

$NO + O_3 \rightarrow NO_2 + O_2$ (1)

$2NO + O_2 \rightarrow 2NO_2$ (2)

$NO_2 + O_2 + h\nu \rightarrow NO + O_3$ (3)

$NO_2 + O_3 \rightarrow NO_3 + O_2$ (4)

Each reaction conversion rate constant is dependent on temperature while reaction 3 is also dependent on UV light intensity (represented as *hv*). Reaction 4 will only occur at night as NO_3 rapidly photo-dissociates to NO and O_2 during the daytime. These rate constants highlight the fact that these reactions are time-dependent and therefore conversion of NO to NO_2 is never instantaneous.

To estimate the transformation of NO to NO_2 that occurs after the exhaust gases are discharged, the following common (and simplified) methods are available:

TOTAL CONVERSION METHOD (USEPA TIER 1 OR SCREENING):

- In this very conservative screening approach, predicted ground level concentrations of total NO_x are assumed to exist as 100% NO_2.

USEPA TIER 2 ANALYSIS:

- To be used when the NO_2 concentration exceeds guidelines when determined by the total conversion method above. This method assumes a 75% conversion of NO_x to NO_2 (USEPA, 2003), which is also conservative.

OZONE LIMITING METHOD (OLM):

- The OLM is based on the assumption that approximately 10% of the NO_X emissions are generated as NO_2 (AE, 2003). If the ozone concentration is greater than 90% of the predicted NO_X concentrations, all the NO_X is assumed to be converted to NO_2, otherwise $NO_2 = O_3 + 0.1 * NO_X$.

AMBIENT RATIO METHOD (ARM):

- If there is at least one year of monitoring data available for NO_X and NO_2 within the airshed, an empirical NO_x /NO_2 relationship can be derived and used as an alternative to the ozone limiting method (AE, 2003; USEPA, 2003). The Gladstone Airshed Modelling Study (GAMS) version 3 established an ambient ratio of 0.3 for the Gladstone area.

In this study the GAMS ambient ratio (0.3) method has been used to predict impacts from NO_X emissions. A 30% conversion is deemed appropriate due to the proximity to the source and the absence of appropriate representative data.

4.5 Limitations and Accuracy of Modelling

Atmospheric dispersion models represent a simplification of the many complex processes involved in determining ground level concentrations of pollutants. One of the crucial issues in obtaining good quality results is the data quality used for modelling and the correct application of an appropriate model for the site conditions.

Model uncertainty is composed of model chemistry/physics uncertainties, data uncertainties, and stochastic (random) uncertainties. In addition, there is inherent uncertainty in the behaviour of the atmosphere, especially on shorter time scales due to the effects of random turbulence. The main specific sources of uncertainty in dispersion models and their potential effects are summarised in Table 4.4.

Table 4.4: Summary of Main Sources of Modelling Uncertainty

Source of Uncertainty	Potential Effects
Oversimplification of physics in model code (varies with type of model)	A variety of effects that can lead to both under prediction and over prediction. However, errors are greater in Gaussian plume models, which do not include the effects of non-steady-state meteorology (i.e., spatially- and temporally-varying meteorology).
Oversimplification of chemistry in model code (varies with type of model)	A variety of effects that can lead to both under prediction and over prediction. Errors increase with increasing simplicity of the chemistry schemes employed. Assumptions such as all VOC being emitted as reactive organic compounds is an example of such simplification.
Errors in emissions data	Ground level concentrations are proportional to emission rate. Plume rise is affected by source dimensions, temperature and exit velocity.
Errors in wind data	Wind direction affects direction of plume travel. Wind speed affects plume rise and dilution of plume, resulting in potential errors in distance of plume impact from source, and magnitude of impact.
Errors in stability estimates	Gaussian plume models use estimates of stability class, and 3-D puff models use explicit vertical profiles of temperature and wind (which are used directly or indirectly to estimate stability class for Gaussian models). In either case, errors in these parameters can cause either under prediction or over prediction of ground level concentrations.
Errors in temperature	Usually the effects are small, but temperature affects plume buoyancy, with potential errors in distance of plume impact from source, and magnitude of impact.
Inherent uncertainty	Models predict 'ensemble mean' concentrations for any specific set of input data (say on a one hour basis), i.e. they predict the mean concentrations that would result from a large set of observations under the specific conditions being modelled. However, for any specific hour with those exact mean hourly conditions, the predicted ground level concentrations will never exactly match the actual pattern of ground level concentrations, due to the effects of random turbulent motions and random fluctuations in other factors such as temperature. The inherent uncertainty in concentrations downwind of an emission source has been estimated as 50-75% for a 1-hour average simulation.

5 EXISTING AIR QUALITY

Understanding the existing, or background, air quality to the study area is necessary to assess the cumulative impacts associated with this project. In completing this air quality assessment we have considered the existing concentrations in the study area of the following key pollutants NO_2, O_3, SO_2, CO, PM_{10}, and $PM_{2.5}$.

There are several methods for determining the existing air quality of a region. These methods consist of analysing ambient monitoring data, photochemical/dispersion modelling of existing sources, and the use of literature values of similarly characterised regions. For this analysis two methods were used to determine existing air quality concentrations. The SO_2, CO, PM_{10} and $PM_{2.5}$ were determined by analysing the DERM ambient monitoring data. The NO_2 and O_3 concentrations were determined using photochemical dispersion modelling of the existing major sources.

The DERM maintains a network of ambient pollutant monitoring stations[b] throughout South East Queensland (SEQ) and other major centres throughout the state. The closest monitoring station

[b]http://www.derm.qld.gov.au/environmental_management/air/air_quality_monitoring/air_monitoring_network/index.html

is located in Toowoomba[c] (as part of the SEQ network) about 45 km east of the Surat Gas Project development area. Toowoomba has a relatively large population, approximately 125,000, while the largest population centre in the area of interest is Dalby, with a population of approximately 13,000. Where data was not available at Toowoomba, data was taken from Flinders View approximately 135 km to the east of the Surat Gas Project development area.

The 90th percentile of the Toowoomba and Flinders View monitoring data was used as the existing concentrations of SO_2, CO, PM_{10} and $PM_{2.5}$. Toowoomba and Flinders View have different emission sources to those located within the study area. The land use surrounding the monitoring station in Toowoomba contains industrial facilities and general urban areas, whereas the land use within the study area is predominantly rural or small urban centres and the study area has several major power producing industries which impact the existing air quality. The Toowoomba and Flinders View monitoring station is likely to be a conservative representation of the existing concentrations in the study area, due to the surrounding land use which is typically associated with higher emission of the identified substances.

NO_2 and O_3 concentrations are heavily influenced by the photochemical reactions of an airshed as opposed to being heavily influenced by direct emission sources like the other identified substances. The photochemical reactions influencing the NO_2 and O_3 concentrations are dependent on concentration of NO_x and VOCs, type of VOCs as well as meteorological characteristics. It cannot be stated that NO_2 and O_3 concentrations as measured in Toowoomba are a conservative assessment of the existing air quality of the study area as the photochemical reactivity of regions are influence by different sources. For example, during certain times of the year the Toowoomba region is heavily impacted by VOC emissions from Brisbane city, while our study is not significantly impacted by these emissions. For these reasons the NO_2 and O_3 existing concentrations are estimated using a photochemical/dispersion model, the CSIRO developed Chemical Transport Model (CTM).

5.1 Photochemical Dispersion Modelling

The CTM modelling used to estimate background NO_2 and O_3 concentrations assesses photochemical reactions based on the regional emissions and meteorological characteristics. Further information on the CTM chemical mechanism is in Section 4.4.2.

The emissions considered in CTM modelling are:

- oxides of nitrogen (NO_X); and
- reactive VOCs (ROC).

The emission sources considered to affect the photochemical reactions in the study area are:

- Industrial:
  - oil and gas extraction;
  - coal mines;
  - electricity generation; and
  - other activities (agricultural facilities, petrol stations, etc.).
- Biogenic.

[c]http://www.derm.qld.gov.au/environmental_management/air/air_quality_monitoring/southeast_queensland_monitoring_stations.html#Toowoomba

The emissions sources not considered in CTM modelling due to insufficient emissions data and/or insufficient release parameters data include:

- commercial sources;
- domestic sources; and
- motor vehicles.

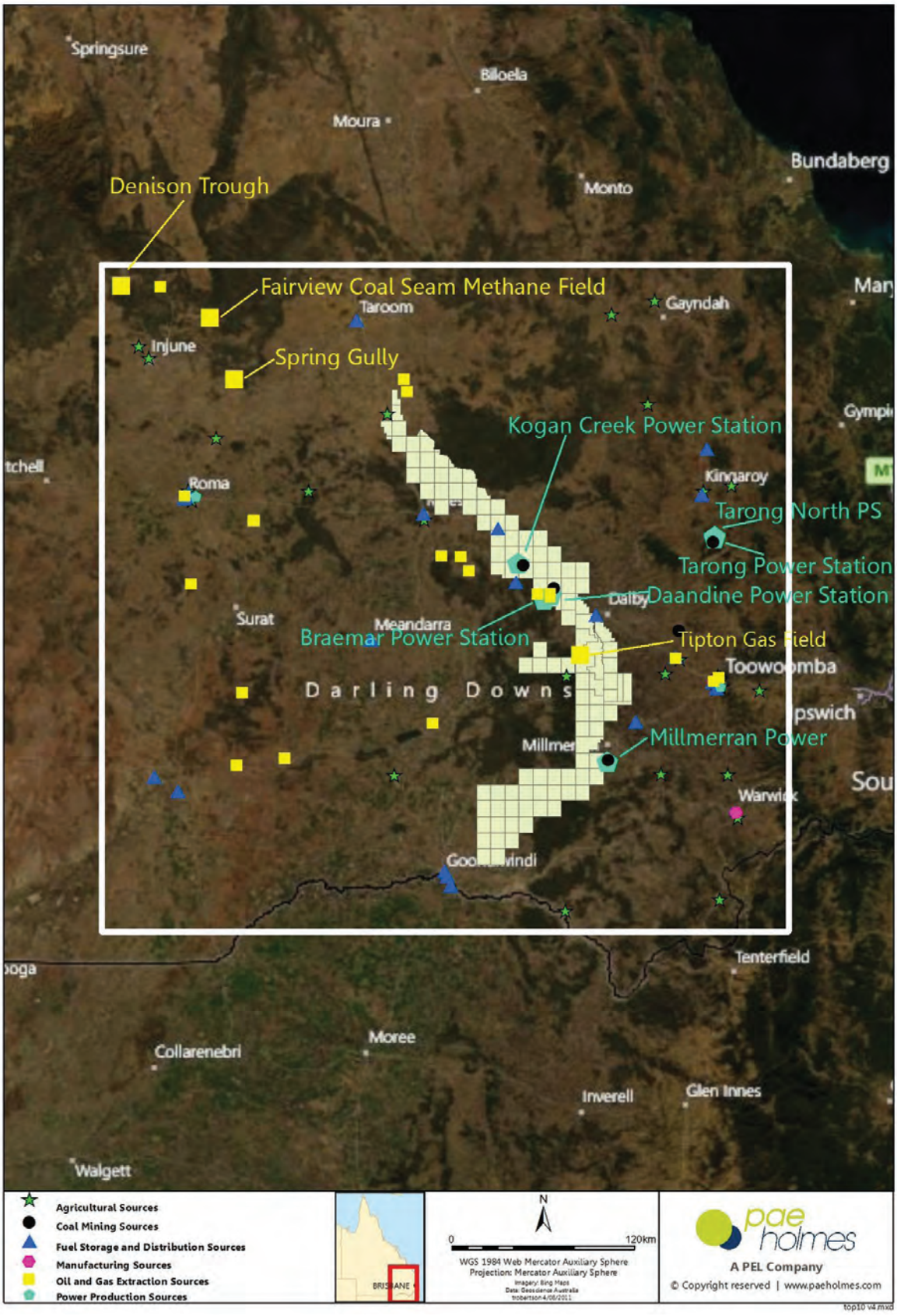


Figure 5.1: Locations of industrial emission sources in the existing air quality assessment

5.2 Model Inputs

5.2.1 Terrain and Land Use

Terrain for the modelling was taken for the United States Geological Service (USGS) Earth Resources Observational System (EROS) Data Center Distributed Active Archive Center (EDC DAAC). The data for terrain height and land use are determined on an approximate 1 km grid. The soil texture types and average leaf area index are determined on an approximate 4 m grid.

5.2.2 Meteorology

Data from seven monitoring stations (Dalby, Inglewood, Kingaroy, Miles, Oakey, Roma and Tamworth) around the modelling domain were incorporated into nudging files that were input into TAPM. Ausplume meteorological files extracted from TAPM were used in the localised assessment.

5.2.3 Emission Sources

A total of 96 industrial facilities have been included in the assessment of the existing air quality. These facilities include currently operating industries and future industries that have been approved for development. The future approved industries that have been included in this assessment are the Australia Pacific LNG Project (Katestone, 2010), GLNG (URS, 2009), and Spring Gully Power Station (URS, 2006). Further details of these facilities and the associated emissions considered in this assessment are provided in Appendix B and shown in Figure 5.1.

The current industrial emissions sources were based upon the 2009/2010 NPI emissions. The future approved industrial emissions sources have been determined based on a screening study of identified future projects and the emissions data available in the public domain. The model release parameters were assumed for each type of facility based on typical release mechanisms.

These industrial facilities were chosen to be included within this study based on significance of NO_X, and VOCs emissions - the pollutants that contribute to the formation of photochemical smog. A 'significant emission' has been defined as emitting a total mass of NO_X and VOCs over 100 kg/a. The NO_X emissions from industrial sources were assumed to be 5% NO_2 and 95% NO, which are fractions typical of combustion (US EPA, 2010). The portion of VOCs that are considered ROCs has been determined based on emission speciation data from the California Air Recourses Board (CARB) database (CARB 2010).

Emissions from motor vehicles and domestic activities were not considered in this assessment due to the lack of publicly available information. Communication with the Department of Environment and Resource Management has indicated that these emissions are insignificant contributors to the regional air quality (pers. communication with Dr Josef Ischtwan 12/1/2010).

Biogenic emissions are defined as emissions from non-man made sources. These emissions have been considered when determining the existing air quality and are estimated within the CTM-TAPM modelling scenarios based on TAPM land-use categories (Cope *et al*., 2009).

Biogenic sources included in the existing air quality assessment are:

- from vegetation; and
- microbial activity in the soils.

Emissions are released from soils, plants and trees in natural areas, crops, and urban vegetation. These emissions are functions of the species leaf mass, plant type, temperature, and light

conditions. Due to the heterogeneity of vegetation land cover, species composition, and leaf mass distribution in Australia, quantifying biogenic emissions requires a model with region-specific input database and a high degree of spatial and temporal resolution. TAPM-CTM provides this data in the form of gridded land-use categories as well as gridded leaf area index values. With this data, CSIRO determined temperature-dependent emission rates, and with the TAPM-derived meteorological data, biogenic emissions are calculated within the model (Cope *et al*., 2009).

Biogenic sources of air emissions not evaluated within the CTM are:

- emissions from bushfires and from controlled burning for fire hazard reduction;
- sea salt particulate matter; and
- windblown particulate matter.

These biogenic emission sources were not considered due to emission estimation limitations in the case of windblown dust, the transient nature of bush fire events and the distance from the ocean. Particulate matter is not considered to be a critical issue with this project and the background PM_{10} concentration were evaluated in the context of Toowoomba monitoring data.

5.3 Existing Air Quality Concentrations

The evaluation of the existing air quality concentrations are summarised in Table 5.1 along with the Air EPP health and well-being based objectives. Further information on these objectives can be found in Section 4.3.

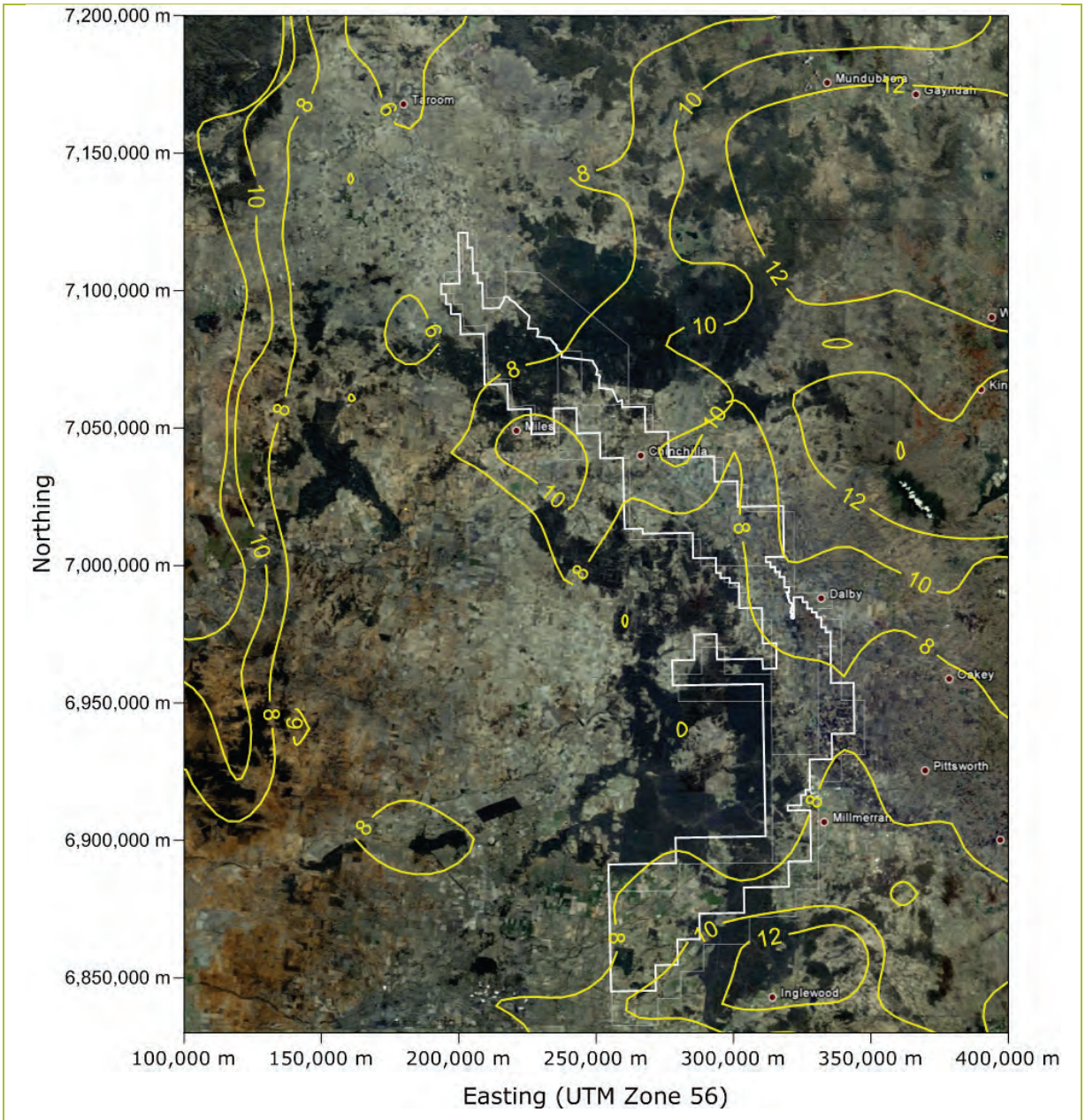
The evaluation of the existing air quality uses the TAPM-CTM modelling set-up as described in Section 4.4.2. Background concentrations for SO_2, CO and particulate matter were taken from DERM monitoring stations.

Contour plots of the maximum concentrations of the substances considered are contained in Figure 5.2, Figure 5.3, Figure 5.4, and Figure 5.5.

Table 5.1: Existing Maximum Ground Level Concentrations

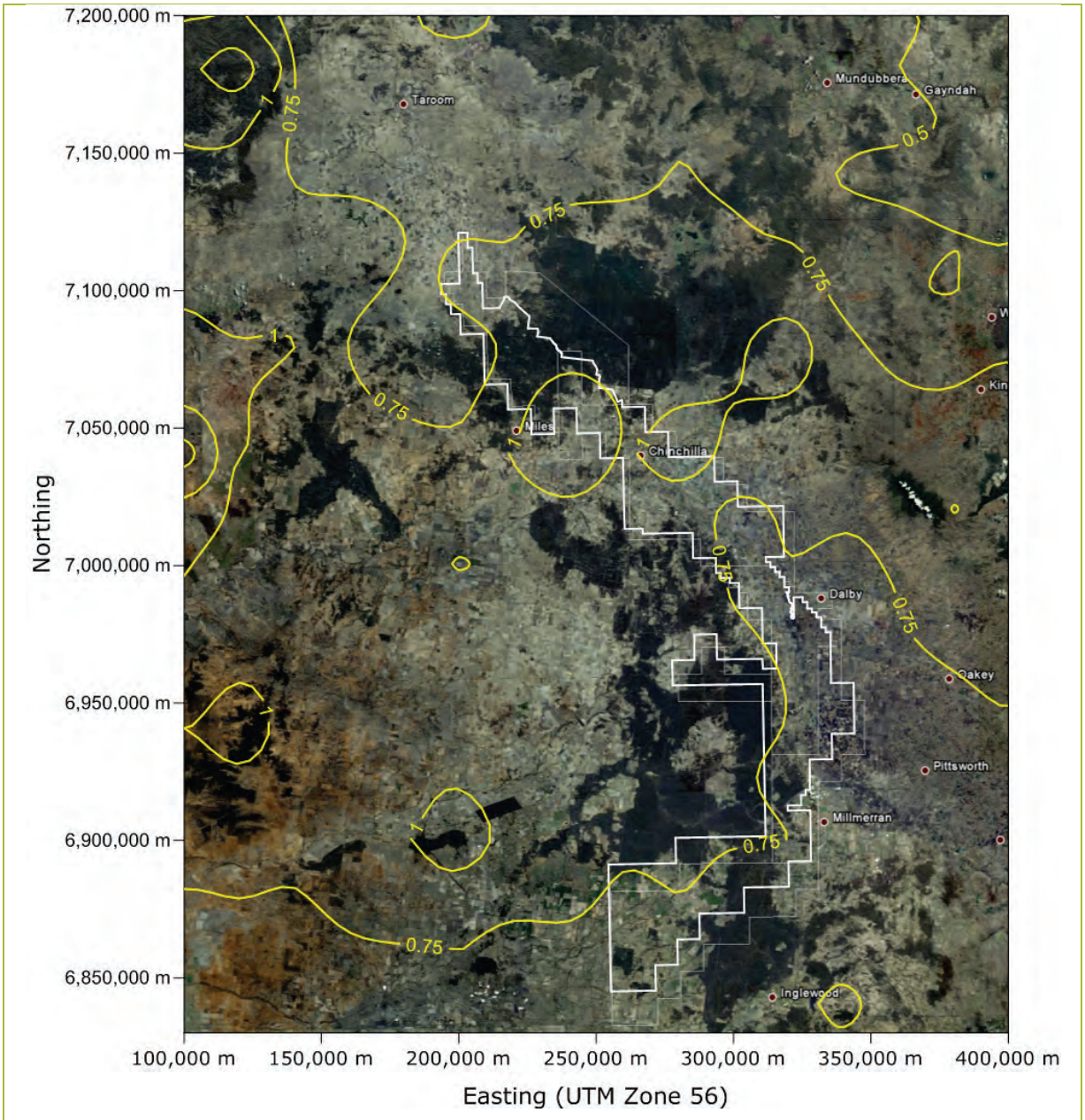
Pollutant	Air EPP Objectives (µg/m³) [a]	Averaging Period	Existing Concentration (µg/m³)
NO_2	250 [b]	1 hour	22 [c]
	62	Annual	2.2
O_3	210 [b]	1 hour	136 [c]
	160 [b]	4 hour	123 [c]
SO_2	570	1 hr	40.0 [d]
	230	24 hr	5.7 [d]
	57	Annual	2.9 [d]
CO	11,000	8 hr	750.1 [d]
PM_{10}	50	24 hr	25.7 [d]
$PM_{2.5}$	25	24 hr	6.8 [d]
$PM_{2.5}$	8	Annual	3.6 [d]

a. Health based objectives at standard temperature and pressure (0°C, 1atm).
b. Allowed 1 day exceedence per annum.
c. Second highest day per annum.
d. Average (DERM, 2007-2010) of DERM monitoring station results for Toowoomba with the exception of SO_2 which is taken from Flinders View. The 90th percentile of the data was taken for sub-annual averaging periods.



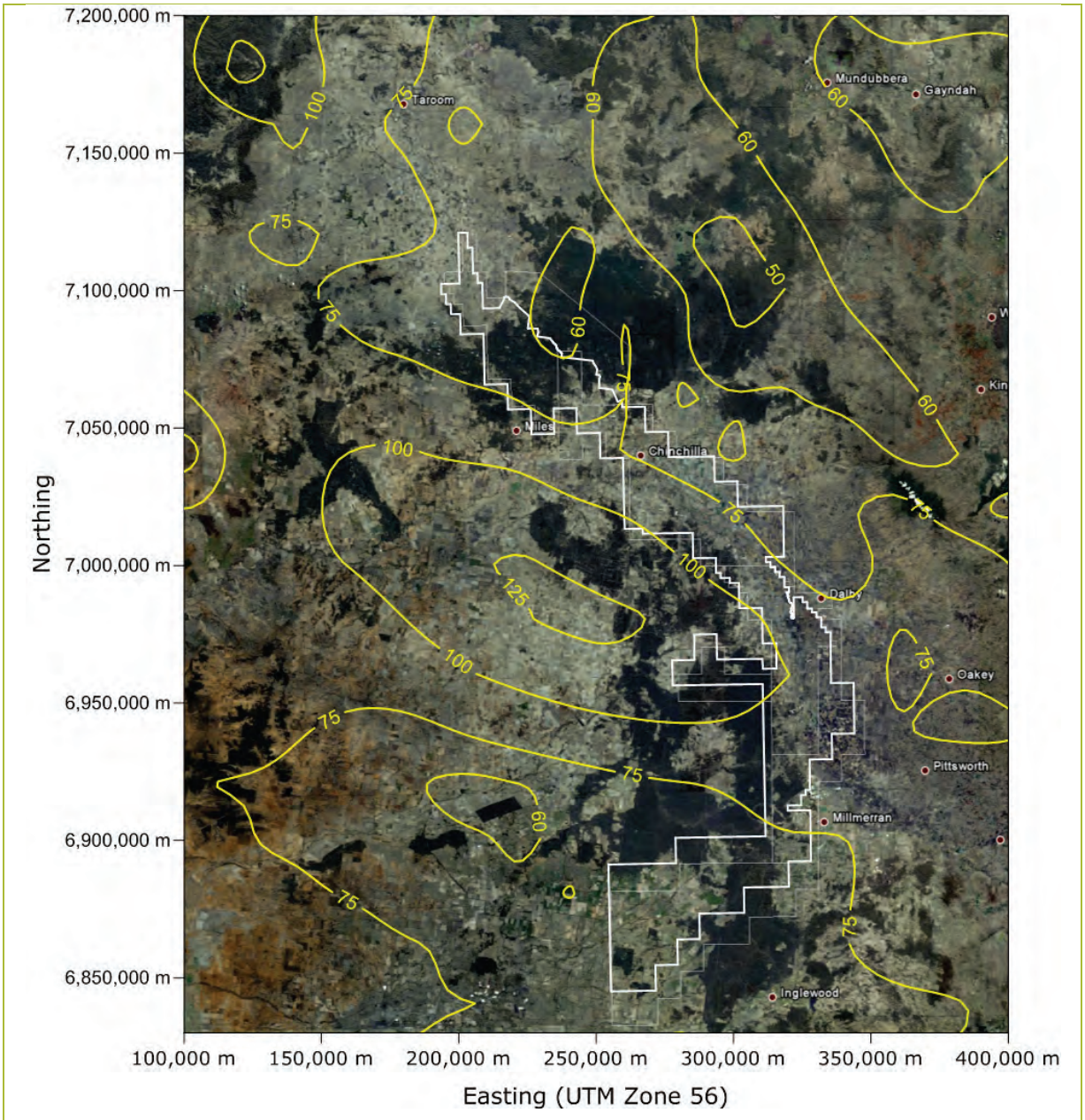
Species:	Location:	Scenario:	Percentile:	Averaging Time:
NO_2	Surat Basin	Existing Air Quality	Maximum	1 hr
Model Used:	**Units:**	**Guideline:**	**Met Data:**	**Plot:**
TAPM-CTM	$\mu g/m^3$	Air EPP 2008=250 $\mu g/m^3$ (not exceeded)	TAPM v. 4 Generated	B Warren

Figure 5.2: Existing maximum NO_2 (1 hr averaged) concentrations



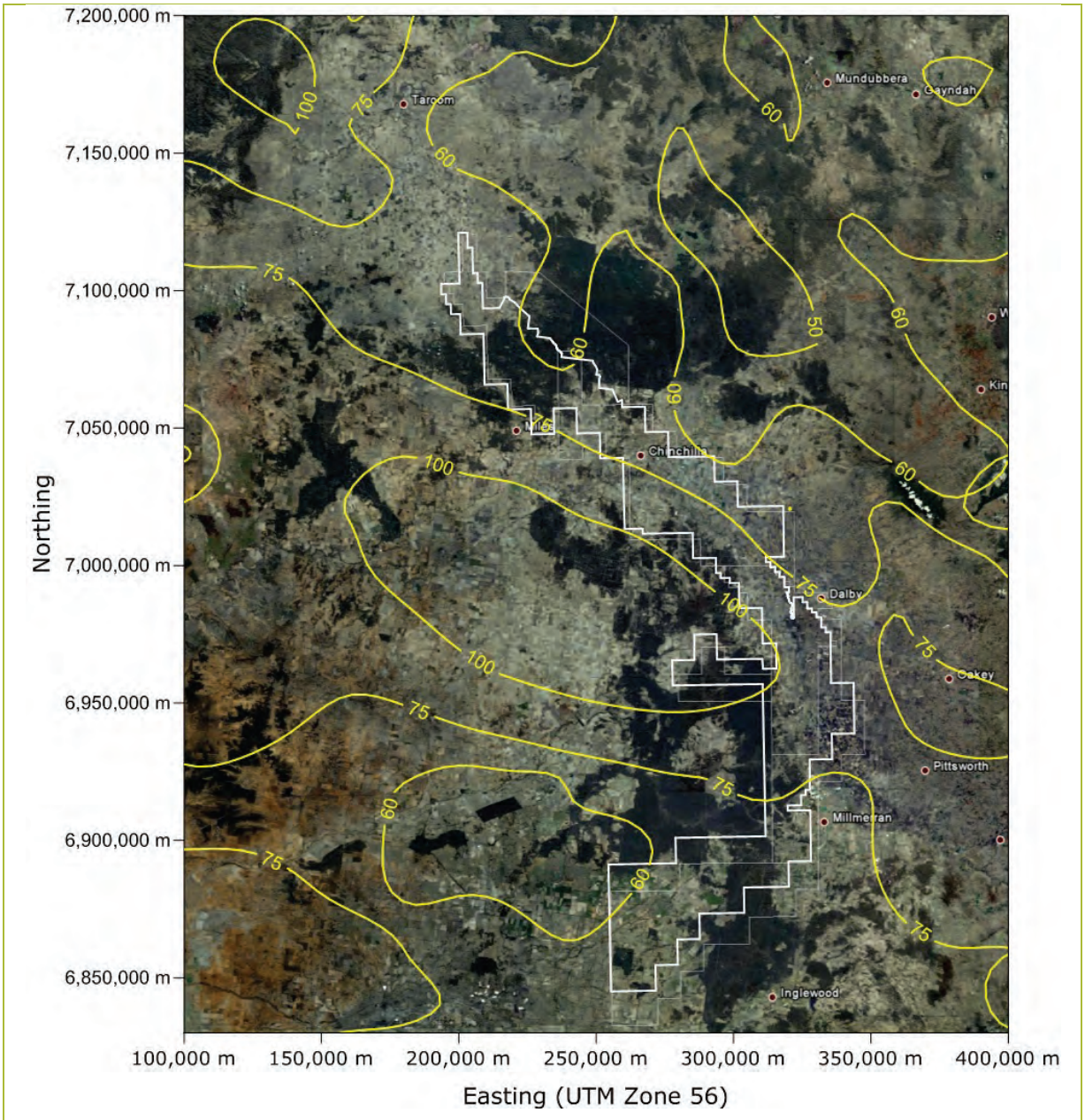
Species:	Location:	Scenario:	Percentile:	Averaging Time:
NO_2	Surat Basin	Existing Air Quality	Average	Annual
Model Used:	**Units:**	**Guideline:**	**Met Data:**	**Plot:**
TAPM-CTM	$\mu g/m^3$	Air EPP 2008=62 $\mu g/m^3$ (not exceeded)	TAPM v. 4 Generated	B Warren

Figure 5.3: Existing NO_2 (annual averaged) concentrations



Species:	Location:	Scenario:	Percentile:	Averaging Time:
O_3	Surat Basin	Existing Air Quality	Maximum	1 hr
Model Used:	**Units:**	**Guideline:**	**Met Data:**	**Plot:**
TAPM-CTM	$\mu g/m^3$	Air EPP 2008=210 $\mu g/m^3$ (not exceeded)	TAPM v. 4 Generated	B Warren

Figure 5.4: Existing maximum O_3 (1 hr averaged) concentrations



Species:	Location:	Scenario:	Percentile:	Averaging Time:
O_3	Surat Basin	Existing Air Quality	Maximum	4 hr
Model Used:	**Units:**	**Guideline:**	**Met Data:**	**Plot:**
TAPM-CTM	$\mu g/m^3$	Air EPP 2008=160 $\mu g/m^3$ (not exceeded)	TAPM v. 4 Generated	B Warren

Figure 5.5: Existing maximum O_3 (4 hr averaged) concentrations

6 EMISSIONS TO AIR

6.1 Sources of Emissions

Table 6.1 details all of the air quality emission sources likely to be generated by the Surat Gas Project. The project will create potential air quality impacts during each phase; construction, operation and decommissioning. Pollutants associated with each emission source are detailed in Table 6.2. Section 6.2 presents an assessment as to which of these emission sources (in Table 6.2) will be assessed further through modelling.

6.1.1 Construction

The Surat Gas Project differs from typical projects since some elements of construction (production well installation and associated gas and water gathering lines) will continue for a significant portion of the project lifespan. Construction air quality impacts are confined to combustion emissions associated with equipment, potential releases of unburnt gas, flaring of gas (during project ramp-up) and fugitive dust associated with material and vehicle movement.

Flaring of gas is expected to occur during the ramp up period of up to three months prior to facilities being online. Flaring will take place at the temporary flare site located adjacent the centralised facility locations, rather than adjacent to wells.

6.1.2 Operation

Key operational emission sources are associated with the different compression/processing facilitates and the operational wellheads. Some minor emissions associated with transport and maintenance and pilot flaring will be associated with ongoing operation of the gas fields. Air quality impacts are associated with combustion emissions which are as a result of power generation and fugitive leaks of unburnt gas.

It is understood that venting is not proposed during future operations; however, flaring may occur due to 'upset conditions' during the operational phase. Upset conditions depend on the associated activity, for example compressors may need to be shut down for maintenance. The expected maximum gas flow rates and frequencies per facility for flaring due to upset conditions (provided by Arrow) are as follows:

- One occurrence of flaring at a maximum rate of 150TJ/day (capacity of facility) for 24 hours per year.
- Two occurrences of flaring at a rate of 30TJ/day for eight hours per month.
- Four occurrences of flaring at a rate of 10TJ for eight hours per month

Expected gas flaring rates and frequencies are based on Arrow's existing operations in the Surat Basin, and are a best estimate based on experience in the gas project industry.

6.1.3 Decommissioning

Decommissioning air quality impacts will be confined to combustion emissions associated with equipment, potential releases of unburnt gas and fugitive dust associated with material and vehicle movement.

Table 6.1: Emission Sources associated with the Surat Gas Project

Project Activity and Emission Source	Phase	Source Characteristics	Type	Emissions
Production well installation	Construction	Once off at each well location	Fugitive /Point	Combustion emissions associated with drilling equipment, fugitive dust associated with vehicle and material movement.
Production well installation	Construction	Stationary sources	Point	Combustion emissions. Ramp-up flaring prior to facility commission. Flaring would occur at the nearest facility.
Gas and water gathering line installation	Construction	Once off associated with construction	Fugitive	Combustion emissions associated with construction equipment and fugitive dust associated with vehicle and material movement
Compression/ Processing facility installation (including construction camps)	Construction	Once off associated with construction	Fugitive	Combustion emissions associated with construction equipment, fugitive dust associated with construction.
Medium and high-pressure gas pipeline installation	Construction	Once off associated with construction	Fugitive	Combustion emissions associated with construction equipment and fugitive dust associated with vehicle and material movement
Production well operation (wellhead engines) – gas combustion - fugitive emissions	Operation	Continuous stationary sources	Point	Combustion emission Unburnt gas (e.g. from valves, periodic emissions from well workovers).
Processing facility operation – pilot flaring - flaring in the event of upset conditions	Operation	Continuous stationary sources	Point	Combustion emissions
Compression/ Processing facility operation – fugitive emissions	Operation	Continuous stationary sources	Fugitive	Unburnt gas (e.g. from valves, flanges, compressors and pumps).
Compression/ Processing facility operation – TEG reboiler	Operation	Continuous stationary sources	Point	Combustion emissions and unburnt gas
Compression/ Processing facility operation (power generation) – gas combustion	Operation	Continuous stationary sources	Point	Combustion emissions
Transport	Operation	Intermittent mobile sources	Fugitive	Combustion emissions and fugitive dust
Production well / gathering line / pipeline decommissioning	Decommissioning and Rehabilitation	Once off associated with decommissioning	Fugitive	Combustion emissions and unburnt gas, fugitive dust emissions associated with vehicle and material movement
Compression/ Processing facility decommissioning	Decommissioning and Rehabilitation	Once off associated with decommissioning	Fugitive	Combustion emissions and unburnt gas, fugitive dust emissions associated with vehicle and material movement

Compression/Processing facility – FCF, CGPF, IPF.
TEG – tri-ethylene glycol

Table 6.2: Pollutants in each Emission Type

Pollutant	Combustion Emissions	Unburnt Gas Emissions	Fugitive Dust Emissions
SO_x	No[a]	No	No
NO_x	Yes	No	No
VOC	Yes	Yes	No
CO	Yes	No	No
CO_2	Yes[b]	Yes[b]	No
TSP	Yes	No	Yes
PM_{10}	Yes	No	Yes
$PM_{2.5}$	Yes	No	No
Trace metals	No[a]	No	Yes
Odours	No[a]	Yes	No
Other toxic, persistent and/or hazardous substances	No[a]	No	No

a – Except in vehicles.
b – Covered in greenhouse gas assessment.

6.2 Evaluation of Emission Sources

The emission sources identified in Table 6.1 have been evaluated for potential to cause human health air quality impacts. Key sources that are considered to require further evaluation as part of this study are discussed below.

6.2.1 Construction Emissions

The majority of emission sources are transient and limited in duration with the exception of ramp-up flaring prior to facility commissioning. Further assessment of ramp-up flaring is proposed.

6.2.2 Operational

Operational emissions are ongoing sources which have the greatest potential to cause impacts. The following sources were evaluated further:

- Facility flaring due to upset conditions
- Project fugitive gas emissions
- Facility power generation
- Wellhead power generation

The emissions associated with the flaring of pilot gas and the tri-ethylene glycol reboiler are considered to be minor and are not considered further. Transport emissions have been estimated, as given in Appendix A, however, due to the minimal information around release characteristics, these emissions could not be represented in the regional modelling.

6.2.3 Summary of Emissions Assessment

Some construction and operational sources of emission require further assessment, and have been evaluated for inclusion into localised and regional assessments. The emission sources have been allocated based on emission characteristics and magnitude.

The following emission sources were assessed in the regional assessment:

- Project fugitive gas emissions
- Facility power generation

- Wellhead power generation

The following emission sources were assessed in the localised assessment:

- Ramp-up facility flaring
- Facility flaring due to upset conditions
- Facility power generation
- Wellhead power generation

Emission estimates are calculated for the above sources and the regional and localised modelling scenarios to address these emissions are presented in Section 6.3.

6.3 Emission Estimation

This section summarises the estimated emissions for the five main potential sources. Detailed calculations are presented in Appendix A. Based on information provided by Arrow these are taken to be maximum expected emission rates.

6.3.1 Ramp-up Flaring Emissions

Ramp-up gas flaring is proposed to occur prior to facility commissioning. PAEHolmes were advised by Arrow that ramp-up flaring would occur prior to the commissioning of facility power generation.

Ramp-up flaring is proposed to consume gas at a maximum rate as shown in Table 6.3. Only central gas processing facilities and integrated processing facilities are proposed to have flaring stacks.

Table 6.3: Maximum Ramp-Up Flaring Gas Consumption

Source	Value	Units
Ramp-up Flaring at CGPF/IPF	72.0	TJ/day per facility
	1,930,813	m^3/day per facility
	1,401,770	kg/day per facility

Emissions from flaring are based on the DEWHA Emission Estimation Technique Manual for Oil and Gas Exploration and Production Version 1.2 (DEWHA, 2010). Emission estimates are presented in Table 6.4.

Table 6.4: Ramp-up Flaring Emission Estimates

Pollutant	Emission Estimate (kg/day/facility)
CO	12,195
NO_x	2,103
TVOC	21,027
PM_{10}	168

The flaring stacks are subject to detailed design, however Arrow expect them to have similar physical parameters as shown in Table 6.5.

Table 6.5: Physical Flare Parameters

Sources	Height of Release (m)	Stack Diameter (m)	Exit Temperature (K)
Flare – Ramp-up	9.1	0.56	753

6.3.2 Upset Conditions Flaring Emissions

Flaring due to upset conditions may occur at central gas processing facilities and integrated processing facilities during the operational period, as discussed in Section 6.1.2.

Upset condition flaring is proposed to emit gas as shown in Table 6.6. Only central gas processing facilities and integrated processing facilities are proposed to have flaring stacks.

Table 6.6: Flaring Gas Consumption Due to Upset Conditions

Source	Consumption TJ/day	Duration/Frequency
Operational Flaring	Max. 150	A 24 hour event/year
	30	An 8 hour event/month
	10	An 8 hour event/month

Emissions from flaring are based on the DEWHA Emission Estimation Technique Manual for Oil and Gas Exploration and Production Version 1.2 (DEWHA, 2010). Emission estimates are presented in Table 6.7 based on the flaring of the consumption.

Table 6.7: Upset Condition Flaring Emission Estimates

Facility Consumption TJ/day	NO_x Emission Estimate g/s
150	50.7
30	10.1
10	3.4

The flaring stacks are subject to detailed design, however Arrow expect them to have similar physical parameters as per Table 6.5.

6.3.3 Fugitive Leaks

Fugitive VOC emissions of gas were estimated from water gathering lines, processing facilities, production well surface facilities and other gas production infrastructure. Emissions from fugitive gas leaks are based on a facility-level emission factor and mass-balance water gathering line losses (see Appendix A). Emission estimates are 12,414 kg/a of VOC.

6.3.4 Facility Power Generation Emissions

The most significant emission source from a facility is emissions from power generation. PAEHolmes have estimated emissions from each production facility for maximum compression/power requirements. Coffey Environments have supplied the maximum facility requirements expressed as total MW and number of 3 MW gas engine as shown in Table 6.8.

Table 6.8: Facility Power Generation Gas Engine Requirements

Facility	Gas Flow (TJ/day)	Total Power Requirement (MW)	No. of 3MW Units
Integrated Processing Facility	150	56	19
Central Gas Processing Facility	150	48	16
Field Compression Facility	50	9	3

Typical specifications were supplied for the 3 MW gas engine with parameters shown in Table 6.9.

Table 6.9: Required 3MW Gas Engine Specifications

Sources	Height of Release (m)	Stack Diameter (m)	Exit Velocity (m/s)	Gas Volume Flow Rate (Nm^3/s)	Exhaust Volume Flow Rate (m^3/s)	Exit Temperature (K)
3 MW gas engine	7.0	0.635	28.4	0.207	9.0	658

Emissions from the 3 MW gas engines are based on the US EPA AP 42 3.2 Natural Gas-fired Reciprocating Engines. Emission estimates are presented in Table 6.10.

Table 6.10: Facility Gas Engine Emission Estimates

Pollutant	Emission Rate (g/s)	Source	Emission Factor (kg/Sm^3)
CO	3.00	Arrow	NA
NO_x	1.50	Arrow	NA
NMHC	0.45	Arrow	NA
PM_{10}	0.035	AP-42	0.000159

6.3.5 Wellhead Power Generation Emissions

The most significant source of emissions for production well operations is from the wellhead engines. Emissions are based on each wellhead requiring a 60 kVA gas engine. Typical gas consumption values and physical stack parameters are shown in Table 6.11.

Table 6.11: Wellhead Gas Engine Stack Parameters

Sources	Height of Release (m)	Stack Diameter (m)	Exit Velocity (m/s)	Gas Volume Flow Rate (Nm^3/s)	Exhaust Volume Flow Rate (m^3/s)	Exit Temperature (K)
60 kva gas engine	2.5	0.08	29.1	0.0051	0.146	922

Emissions from gas engines are based on the US EPA AP 42 Section 3.2 'Natural Gas-fired Reciprocating Engines'. Emission estimates are presented in Table 6.12.

Table 6.12: Wellhead Gas Engine Emission Estimates

Pollutant	Emission Rate (g/s)	Source	Emission Factor (kg/Sm^3)
CO	0.3354	AP-42	0.062347
NO_x	0.2047	AP-42	0.038045
NMHC	0.0090	AP-42	0.001676
PM_{10}	0.0009	AP-42	0.000159

6.3.6 Total Emissions per Resource Area

Two emission scenarios were considered in the regional assessment of the project resource area emissions. Scenario 1 considered the emissions from all 18 production facilities operating at maximum compression across the entire project development area (a 'worst case' scenario given that field development will be staged), while Scenario 2 considers the emissions generated at maximum expected operations – year 2020, two years following the completion of ramp-up. At this point, nine production facilities will be operational across three of the five development regions.

Scenario 1 assessed the total emissions released over the lifetime of the project for each emission source in each resource area (Wandoan, Chinchilla, Dalby, Kogan/Milmerran and Goondiwindi) per annum as listed in Table 6.13. The area of the project operations are shown in Figure 6.1. The final locations of these resource area facilities have not yet been finalised. Random locations of these facilities have been selected by Coffey Environments and are shown in Figure 6.2. The number of wellhead engines are assumed to be those in use by the year 2020 (a total of 2,307). The regional assessment assumes that all facilities are operating at peak power capacity. In addition to these point sources the fugitive leaks ROC emissions were modelled. These emissions were assumed to be all NMHC releases from the fugitive leaks identified in Section 6.3.3 and determined in Appendix A. The fugitive emissions were modelled over the project in-use operational area, as shown in Figure 6.1, with an ROC emission rate of 0.005 g/s.

For Scenario 2, the emissions released from the resource areas consider emissions released from emission sources in operation in the year 2020. The emissions for set resource areas are contained in Table 6.14. The areas that are in operation for this scenario are shown in Figure 6.3.

For the regional impact assessment, the production facilities were modelled using the emission release characteristics given in Table 6.9. The wellhead engines were modelled using the emission release characteristic given in Table 6.11. The wellhead engines were spread evenly across the parcels in operation, as shown in Figure 6.1 and Figure 6.3, depending on model scenario.

In addition, all non-methane hydrocarbons (NMHC) emissions from the production facilities are assumed to be ROC. All VOC emissions from the wellhead engines are assumed ROC. All NO_X emissions from the recourse areas are assumed to be 5% NO_2 and 95% NO, which are fractions typical of combustion (US EPA, 2010). Further details of these facilities parameters considered in the regional modelling assessment are provided in Appendix B.

Transport emissions have been estimated, as given in Appendix A, however due to the minimal information around release characteristics and model configurations limitations, transport emissions have not been considered in the regional modelling.

Table 6.13: Summary of All Facilities Scenario in grams/second for each Resource Area

	Wandoan	Chinchilla	Dalby	Kogan/ Millmerran	Goondiwindi
Integrated Processing Facilities [a]					
Number	1	1	2	1	1
NO_x [b]	28.5	28.5	57	28.5	28.5
NMHC [c]	8.55	8.55	17.1	8.55	8.55
CO	57	57	114	57	57
PM	0.665	0.665	1.33	0.665	0.665
Central Gas Processing Facilities [a]					
Number	2	1	1	1	1
NO_x [b]	48	24	24	24	24
NMHC [c]	14.4	7.2	7.2	7.2	7.2
CO	96	48	48	48	48
PM	1.12	0.56	0.56	0.56	0.56
Field Compression Facilities [a]					
Number	0	0	1	4	1
NO_x [b]	0	0	4.5	18	4.5
NMHC [c]	0	0	1.35	5.4	1.35
CO	0	0	9	36	9
PM	0	0	0.105	0.42	0.105
Wellhead Engines [d]					
Number	984	152	756	415	0
NO_x [b]	201.4	31.1	154.8	85.0	0
VOCs [e]	8.9	1.4	6.8	3.7	0
CO	330.0	51.0	253.6	139.2	0
PM	0.9	0.1	0.7	0.4	0

a Emissions release characteristics given in Table 6.9.
b Assumed as 5% NO_2 and 95% NO for regional modelling.
c All NMHC assumed to be ROC for regional modelling.
d The emissions release characteristics given in Table 6.11.
e All VOCs assumed to be ROC for regional modelling.

Table 6.14: Summary of 2020 Facilities Scenario in grams/second for each resource area

	Wandoan	Chinchilla	Dalby	Millmerran	Goondiwindi
Integrated Processing Facilities [a]					
Number	1	0	2	1	0
NO_x [b]	28.5	0	57	28.5	0
NHMC [c]	8.55	0	17.1	8.55	0
CO	57	0	114	57	0
PM	0.665	0	1.33	0.665	0
Central Gas Processing Facilities [a]					
Number	2	0	1	0	0
NO_x [b]	48	0	24	0	0
NHMC [c]	14.4	0	7.2	0	0
CO	96	0	48	0	0
PM	1.12	0	0.56	0	0
Field Compression Facilities [a]					
Number	0	0	1	1	0
NO_x [b]	0	0	4.5	4.5	0
NHMC [c]	0	0	1.35	1.35	0
CO	0	0	9	9	0
PM	0	0	0.105	0.105	0
Wellhead Engines [d]					
Number	984	152	756	415	0
NO_x [b]	201.4	31.1	154.8	85.0	0
VOCs [e]	8.9	1.4	6.8	3.7	0
CO	330.0	51.0	253.6	139.2	0
PM	0.9	0.1	0.7	0.4	0

a Emissions release characteristics given in Table 6.9.
b Assumed as 5% NO_2 and 95% NO for regional modelling.
c All NMHC assumed to be ROC for regional modelling.
d The emissions release characteristics given in Table 6.11.
e All VOCs assumed to be ROC for regional modelling.

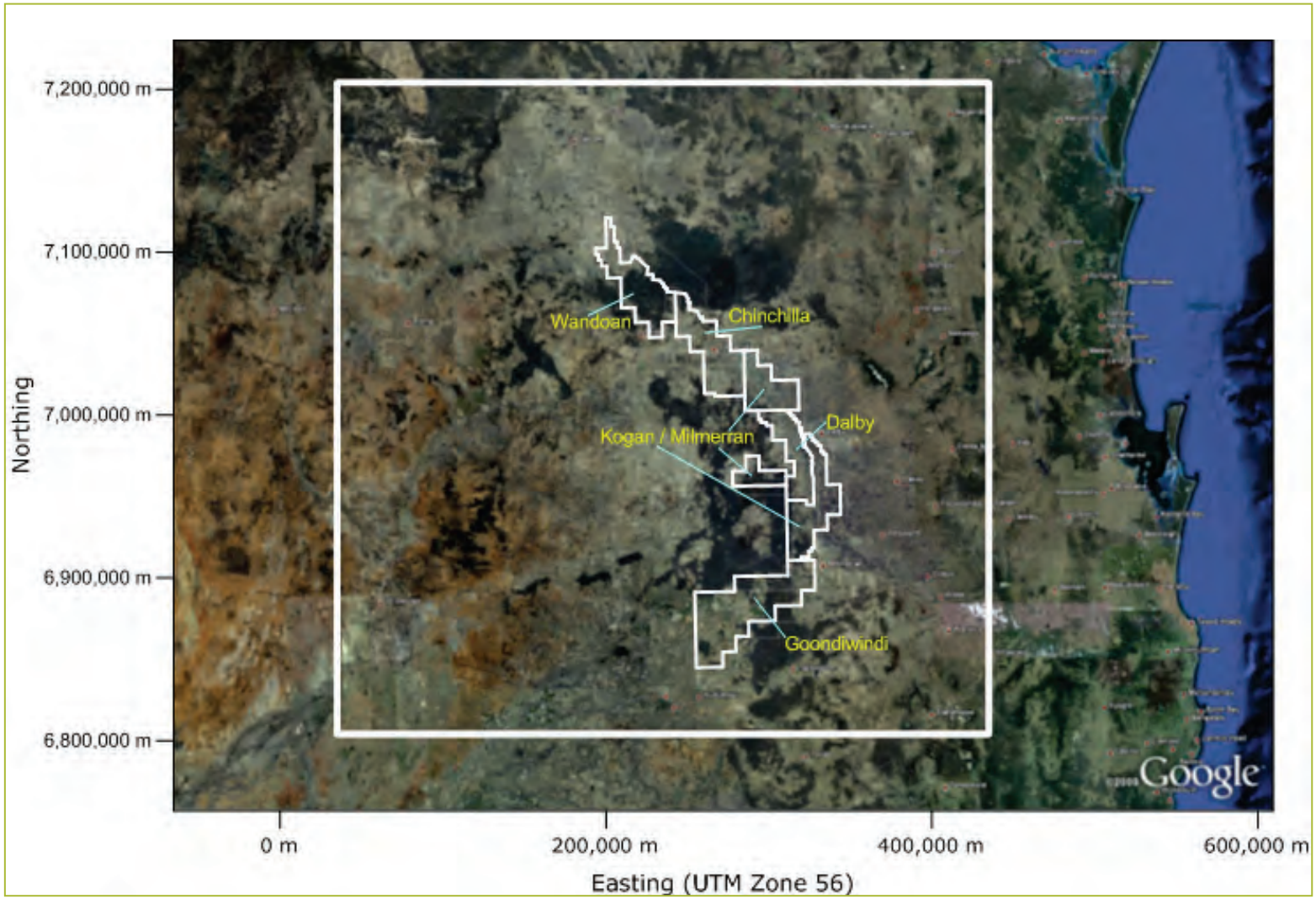


Figure 6.1: Project resource areas

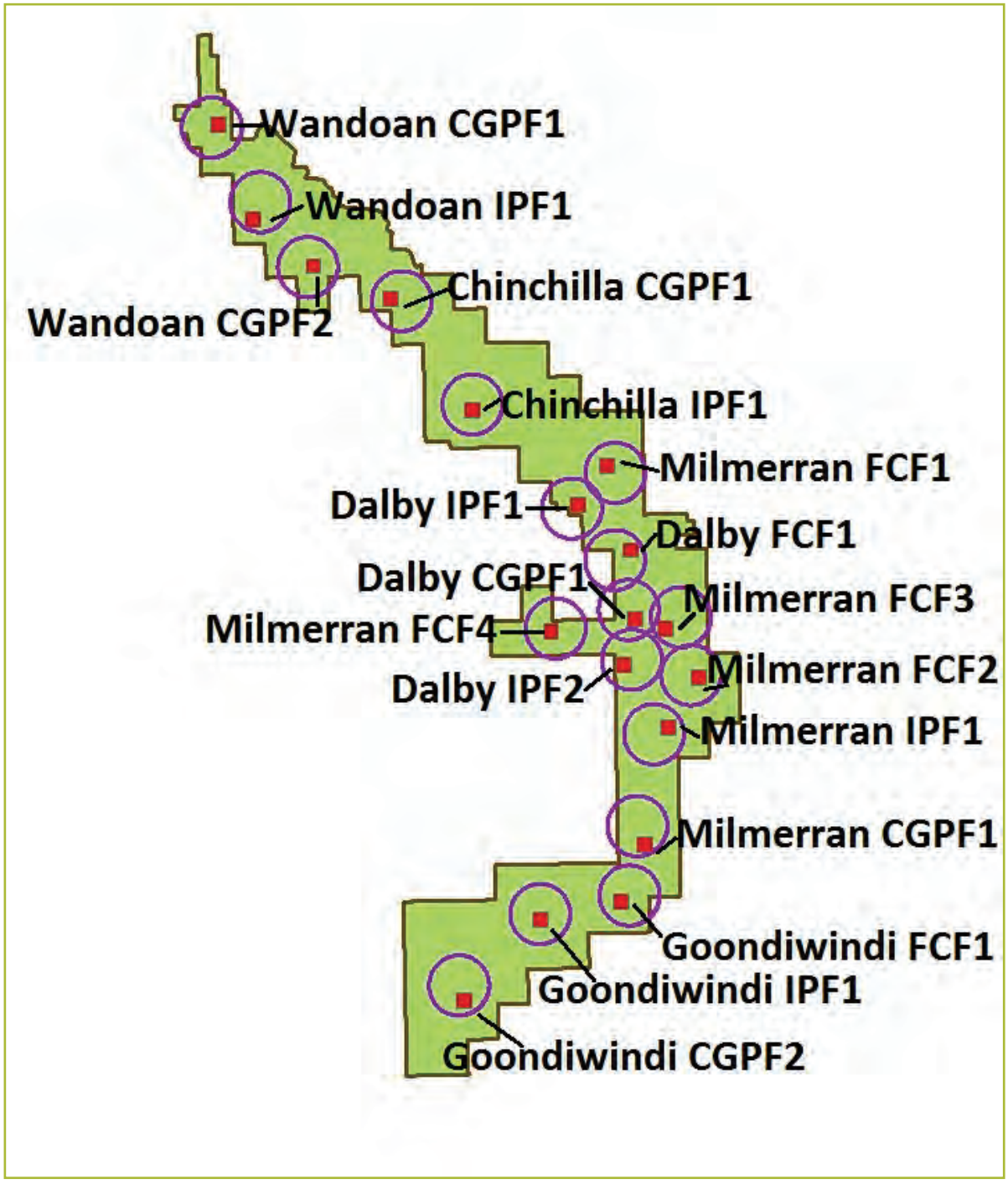


Figure 6.2: Random locations of conceptual production facilities for modelling purposes

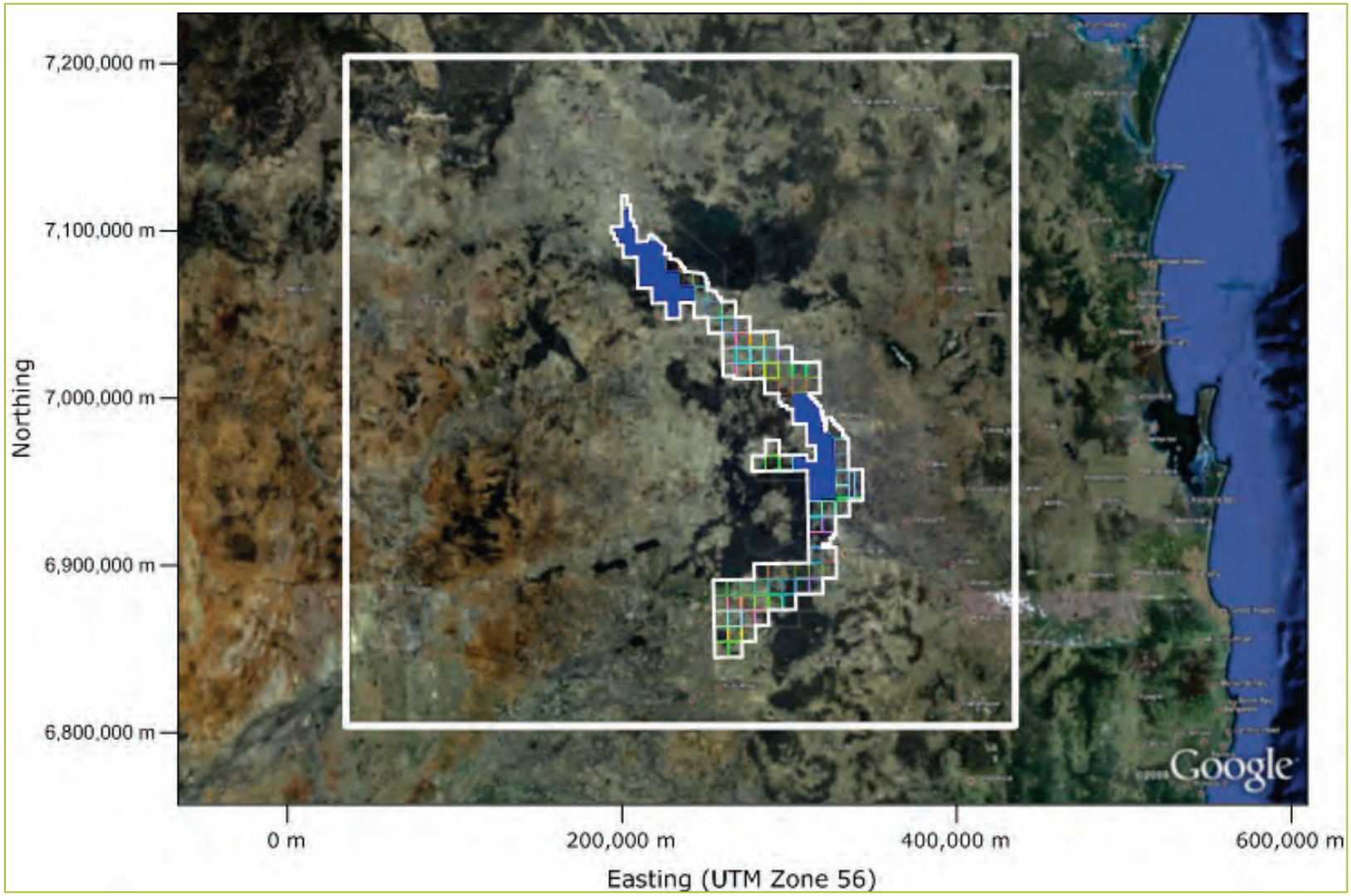


Figure 6.3: Locations of resource areas in operation up to year 2020 (shown in blue)

7 ASSESSMENT OF POTENTIAL IMPACTS

7.1 Regional Impacts

To evaluate the project's regional impacts on the photochemically reactive compounds, NO_2 and O_3, two scenarios have been considered. Scenario 1 considers all the projects facilities in operation, as summarised in Table 6.13. Scenario 2 considers the projects facilities emission as operating in year 2020, summarised in Table 6.14. The regional impacts of NO_2 and O_3 have been assessed using the photochemical/dispersion modelling methodology discussed in Section 4.4.2.

Each of these scenarios considers the existing air quality emission sources as described in Section 5.2.3.

SCENARIO 1 - ALL PROJECT FACILITIES IN OPERATION

This scenario considers the impact of the emissions from the operation of all project production facilities. This scenario assumes a select number of wellhead engines to be operating at full capacity continuously throughout the year. This scenario is further discussed in Section 6.3.6 and the emissions from the facilities and well head engines are summarised in Table 6.13.

This scenario is not representative of an actual operational year, but gives a worst-case scenario for total emissions released during a year. This scenario gives an indication of the maximum potential level of impact to areas within the study region.

SCENARIO 2 - PROJECT FACILITIES OPERATIONS IN 2020

This scenario considers the impact of the emissions from production facilities that begin operation up to and including year 2020. This scenario assumes a select number of wellhead engines to be operating at full capacity continuously for the year. This scenario is further discussed in Section 6.3.6 and the emissions from these facilities are summarised in Table 6.14.

This scenario gives realistic emission rates during an operational year with high production and will provide an indication of the realistic impacts from the projects operations on the study region. This scenario is still a conservative assessment as the emissions are determined based on a high production year activity.

7.1.1 NO_2 and O_3

The maximum estimated regional impact concentrations of NO_2 and O_3 for both scenarios are shown in Table 7.1 along with the Air EPP 2008 objective and the previously determined existing air quality concentrations. The contours plots for the substances considered in this assessment for Scenario 1 emissions are shown in Figure 7.1, Figure 7.2, Figure 7.3, and Figure 7.4. The contours plots for the substances considered in this assessment for Scenario 2 emissions are in Figure 7.5, Figure 7.6, Figure 7.7, and Figure 7.8.

The presence of the project will cause a general increase of NO_2 and O_3 concentrations in the region. These impacts are not limited to the localised areas where the project operations are occurring. Areas to the west of the project area are also impacted, as shown in the O_3 contours for both scenarios and more explicitly shown in Figure 7.9. . This formation is due to the photochemical reaction time, ambient air composition of photochemical reacting compounds from both current sources and the project sources, as well as the meteorological influences of the area. This location to the west of the study area is a slight valley that is subject to low mixing heights

allowing for the photochemical compounds to react resulting in increased NO_2 and O_3 concentrations

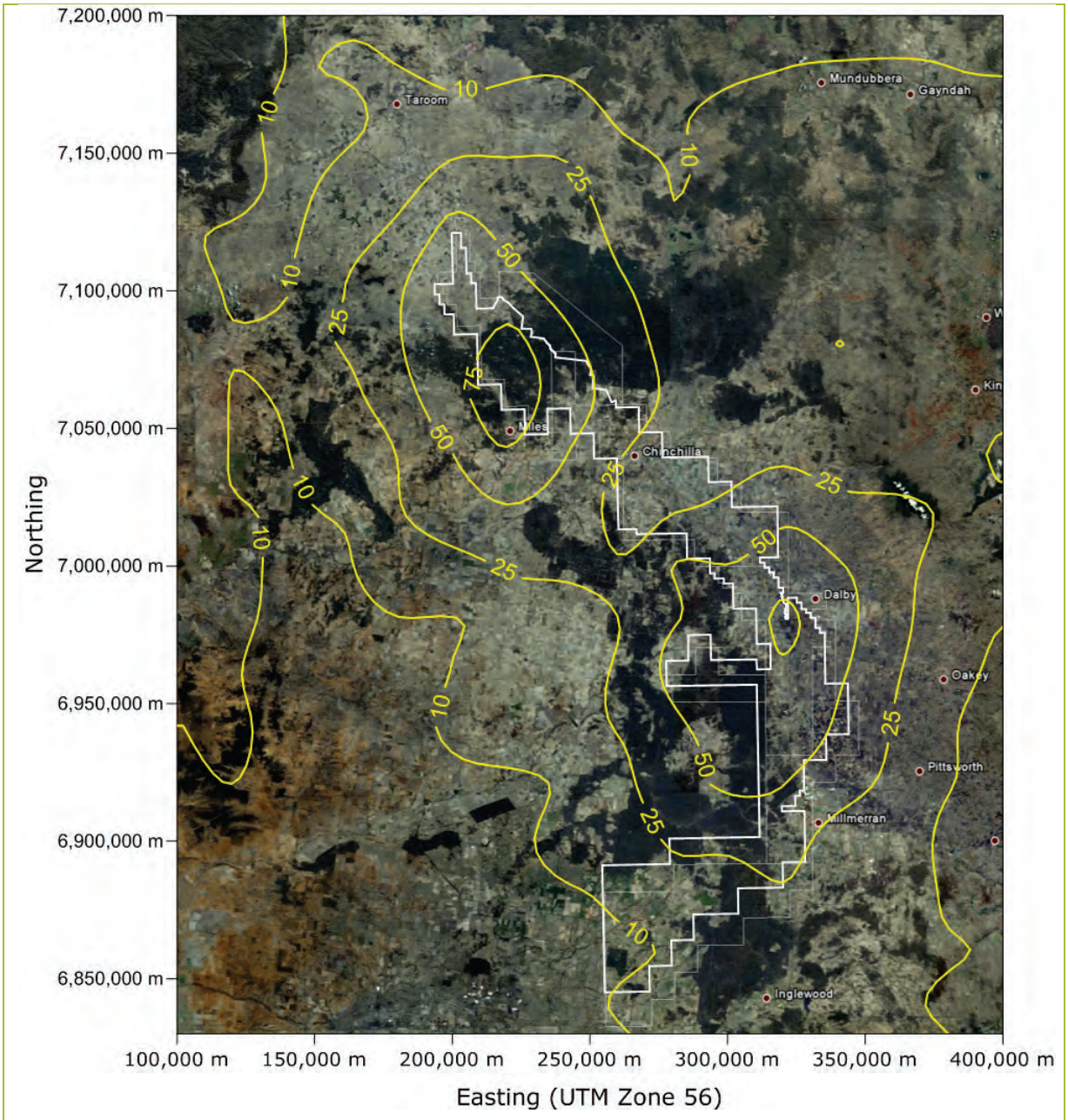
No Air EPP objective is predicted to be exceeded. In general, Scenario 1, where all the project facilities emissions are considered, has greater impacts than Scenario 2, which considers the emissions during operational year 2020.

As there is little data available on the air quality properties in this region of Queensland (i.e. used to configure the model in that region), the model results should not be considered as definitive predictions regarding future ground level concentrations. Rather, the results should be used more as an indication of relative concentrations, and therefore, of areas for prioritisation of air quality management initiatives for the region.

Table 7.1: NO_2 and O_3 Maximum Concentrations

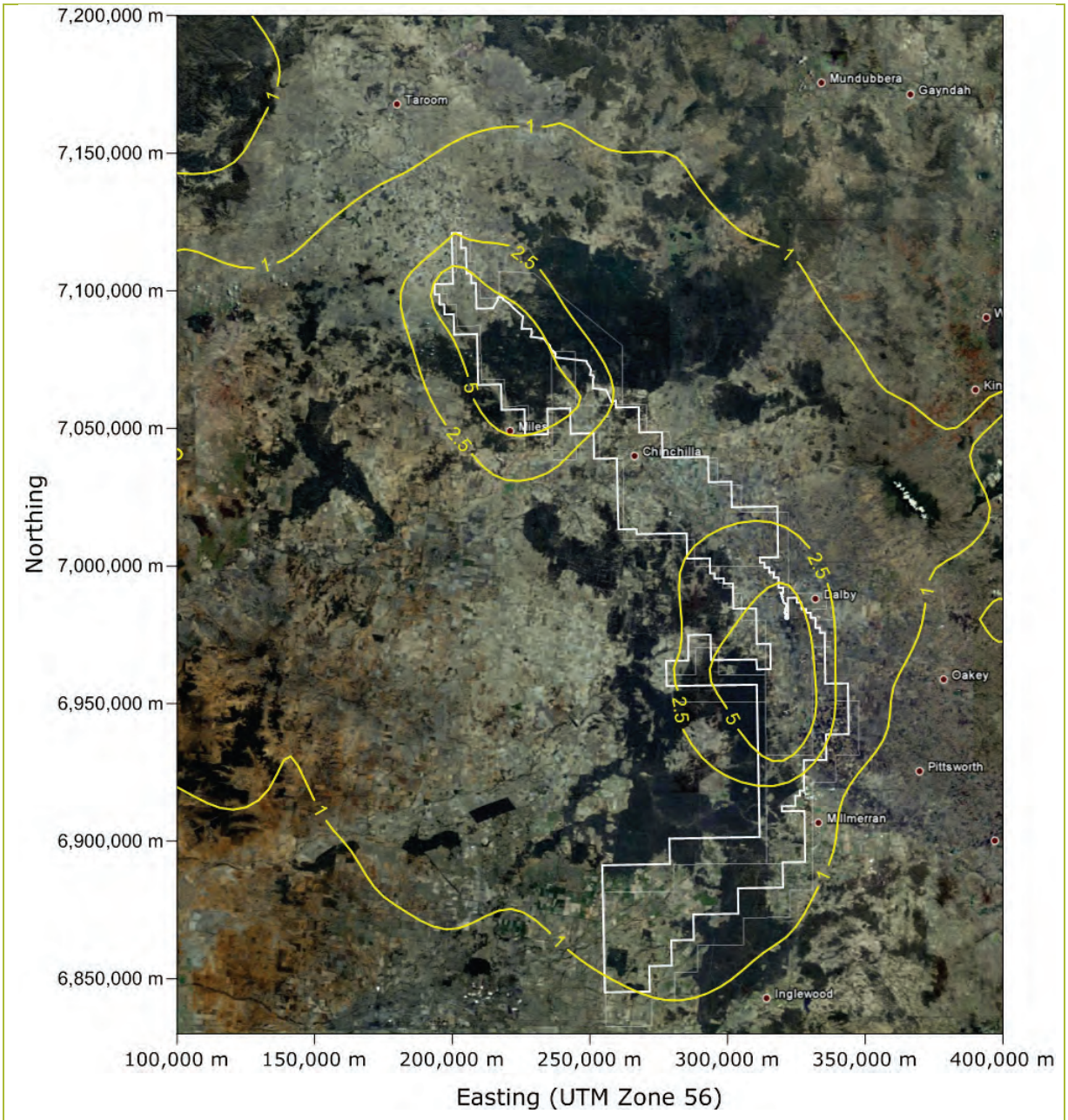
	Air EPP Objective (µg/m³) [a]	Averaging Time	Existing Air Quality [a] µg/m³	Scenario 1 All Project Facilities µg/m³	Scenario 2 Year 2020 Operations µg/m³
NO_2	250[b]	1 hr	22 [c]	85 [c]	86 [c]
	62	Annual	2.2	9	9
O_3	210 [b]	1 hr	136 [c]	160 [c]	160 [c]
	160 [b]	4 hr	123 [c]	154 [c]	154 [c]

a Heath based objectives at standard temperature and pressure (0°C, 1atm)
b Considering 1 day exceedence allowed per annum
c Second highest day model value



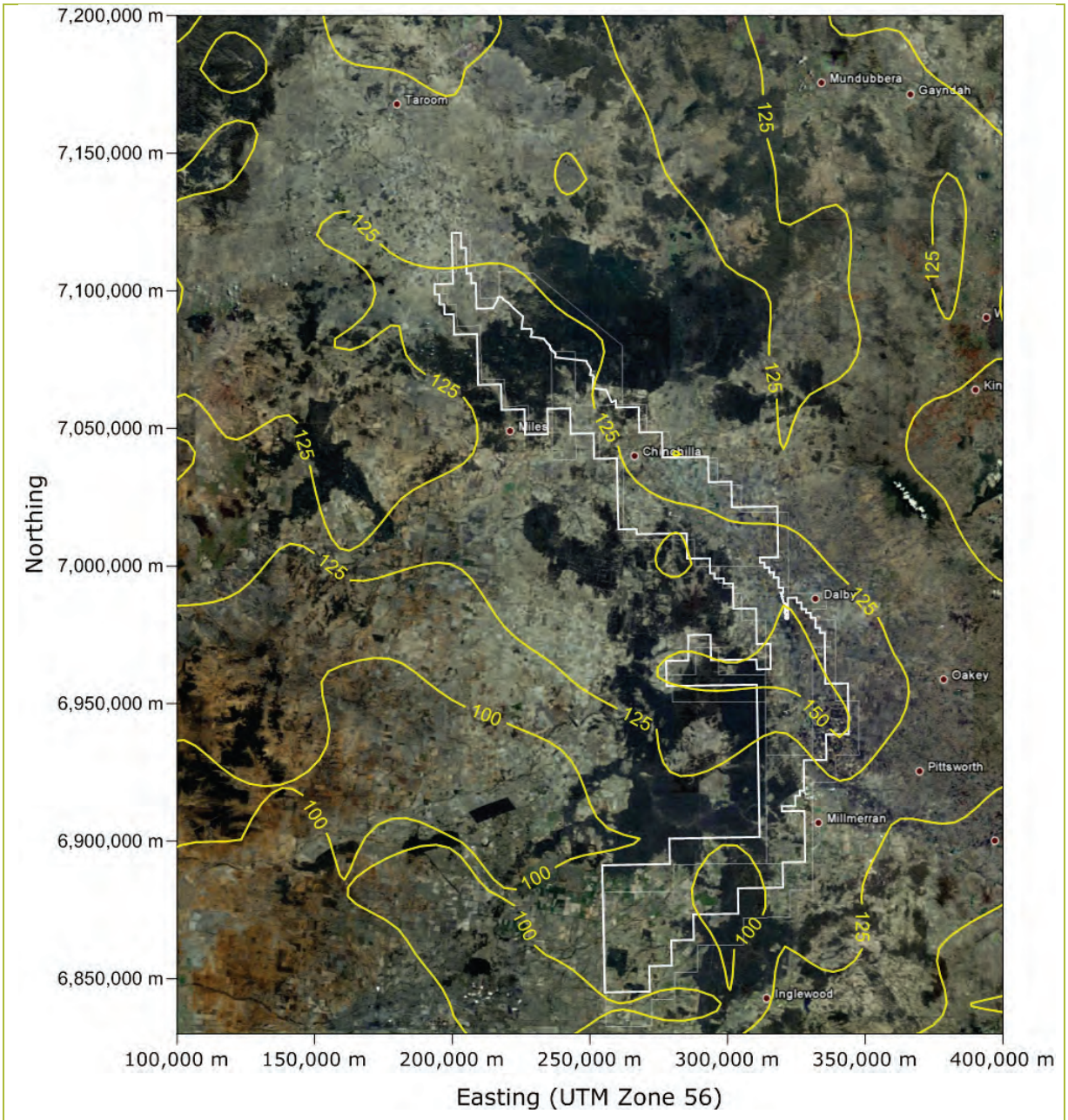
Species:	Location:	Scenario 1:	Percentile:	Averaging Time:
NO_2	Surat Basin	All Projects Facilities in Operation	Maximum	1 hr
Model Used:	**Units:**	**Guideline:**	**Met Data:**	**Plot:**
TAPM-CTM	$\mu g/m^3$	Air EPP 2008=250 $\mu g/m^3$ (no exceedences)	TAPM v. 4 Generated	B Warren

Figure 7.1: Scenario 1 – maximum NO_2 (1 hr averaged) concentrations



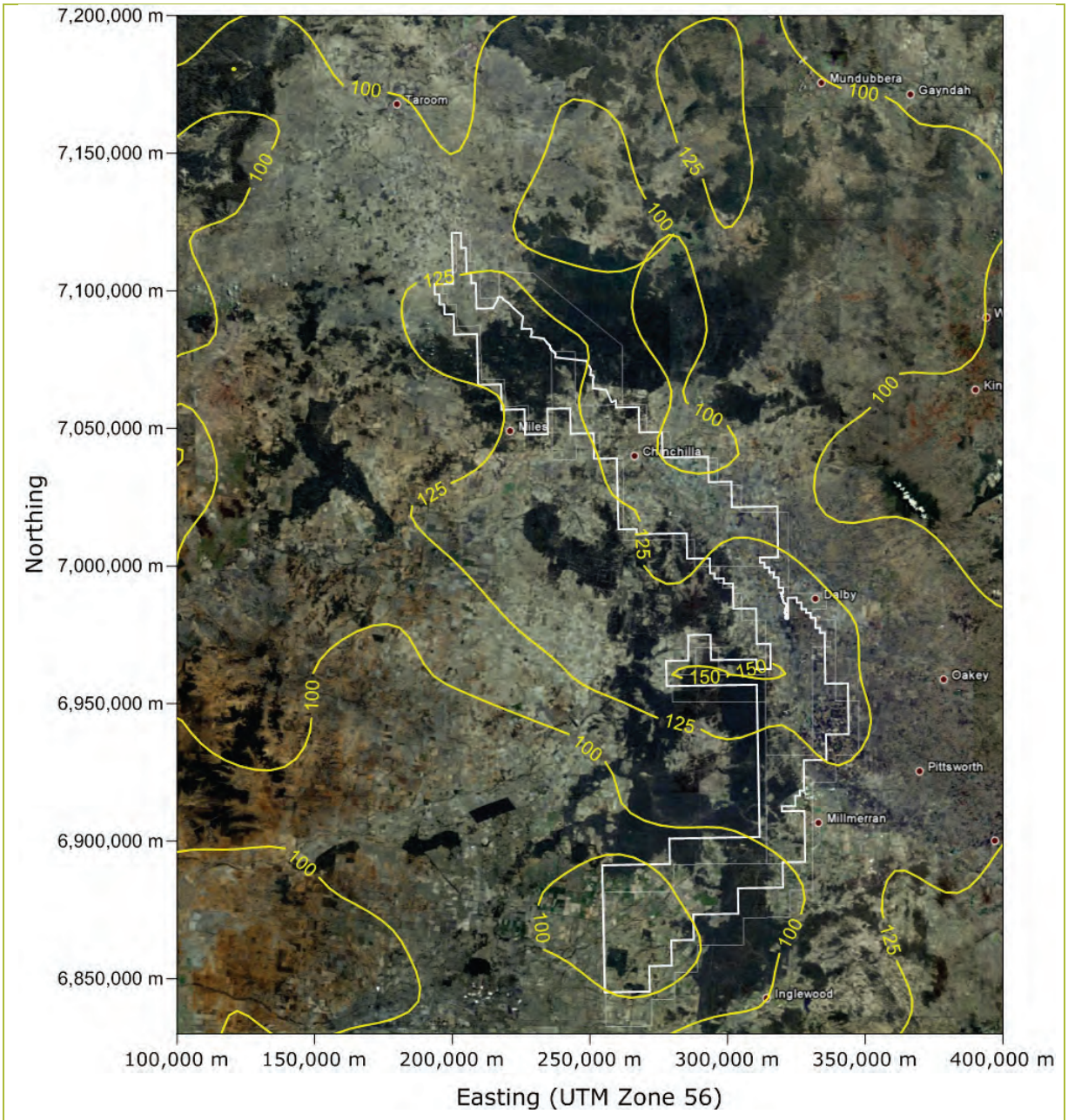
Species:	Location:	Scenario 1:	Percentile:	Averaging Time:
NO_2	Surat Basin	All Projects Facilities in Operation	Average	Annual
Model Used:	**Units:**	**Guideline:**	**Met Data:**	**Plot:**
TAPM-CTM	$\mu g/m^3$	Air EPP 2008=62 $\mu g/m^3$ (no exceedences)	TAPM v. 4 Generated	B Warren

Figure 7.2: Scenario 1 – annual average NO_2 concentrations



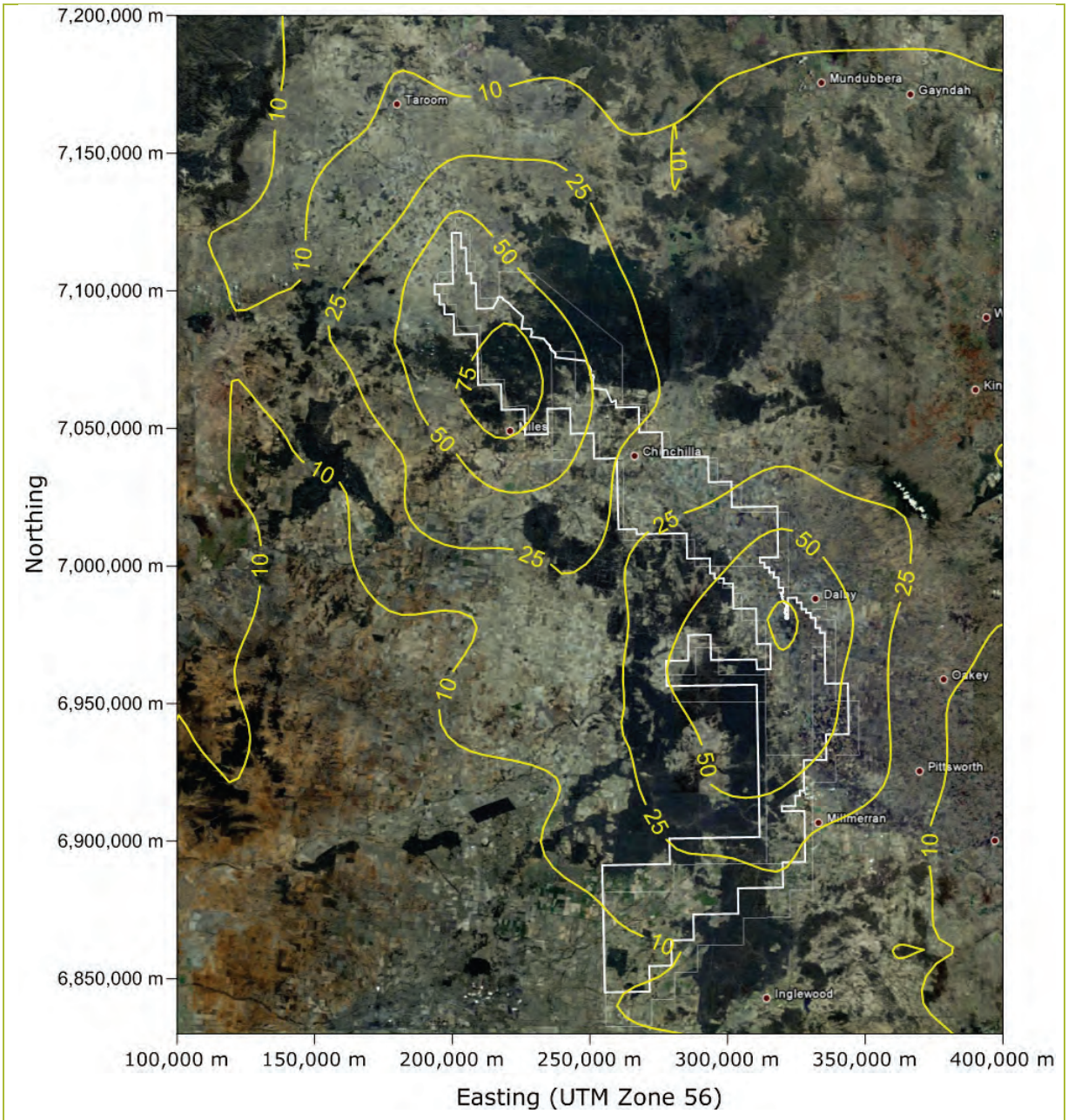
Species:	Location:	Scenario 1:	Percentile:	Averaging Time:
O_3	Surat Basin	All Projects Facilities in Operation	Maximum	1 hr
Model Used:	**Units:**	**Guideline:**	**Met Data:**	**Plot:**
TAPM-CTM	$\mu g/m^3$	Air EPP 2008=210 $\mu g/m^3$ (no exceedences)	TAPM v. 4 Generated	B Warren

Figure 7.3: Scenario 1 – maximum O_3 (1 hr averaged) concentrations



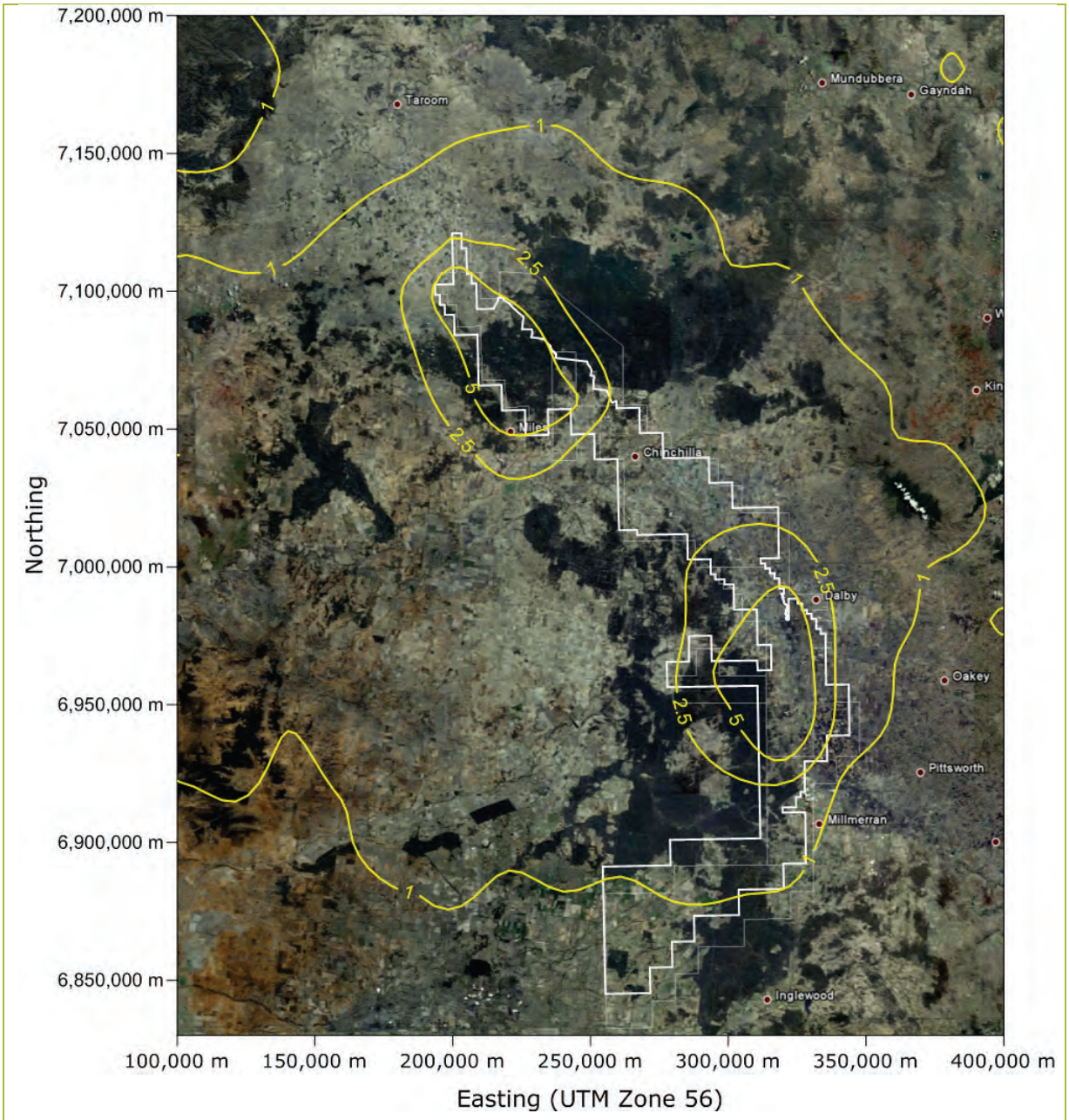
Species:	Location:	Scenario 1:	Percentile:	Averaging Time:
O_3	Surat Basin	All Projects Facilities in Operation	Maximum	4 hr
Model Used:	**Units:**	**Guideline:**	**Met Data:**	**Plot:**
TAPM-CTM	$\mu g/m^3$	Air EPP 2008=160 $\mu g/m^3$ (no exceedences)	TAPM v. 4 Generated	B Warren

Figure 7.4: Scenario 1 – maximum O_3 (4 hr averaged) concentrations



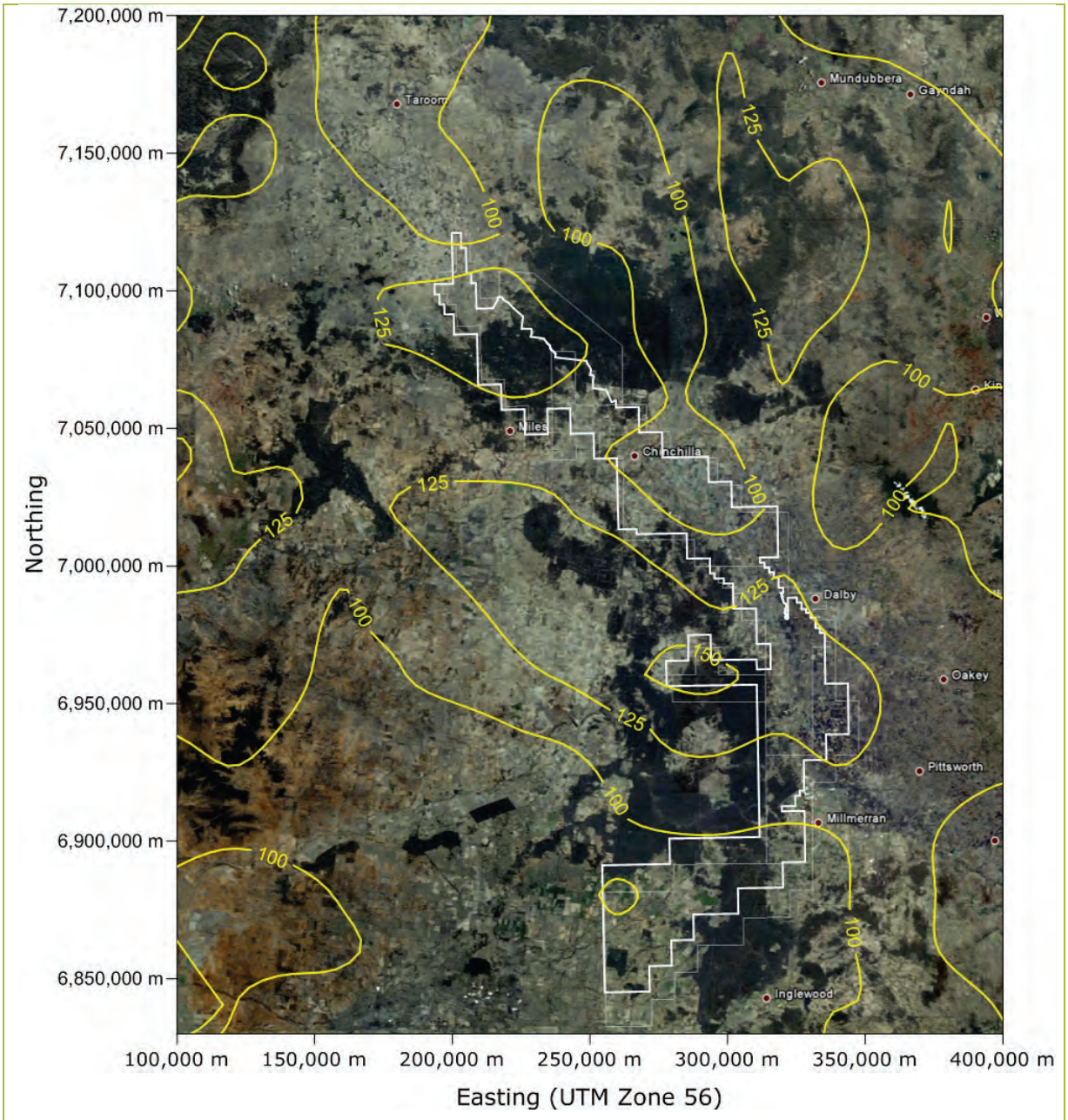
Species:	Location:	Scenario 2:	Percentile:	Averaging Time:
NO_2	Surat Basin	Facilities in Operation up to Year 2020	Maximum	1 hr
Model Used:	**Units:**	**Guideline:**	**Met Data:**	**Plot:**
TAPM-CTM	$\mu g/m^3$	Air EPP 2008=250 $\mu g/m^3$ (no exceedences)	TAPM v. 4 Generated	B Warren

Figure 7.5: Scenario 2 – maximum NO_2 (1 hr averaged) concentrations



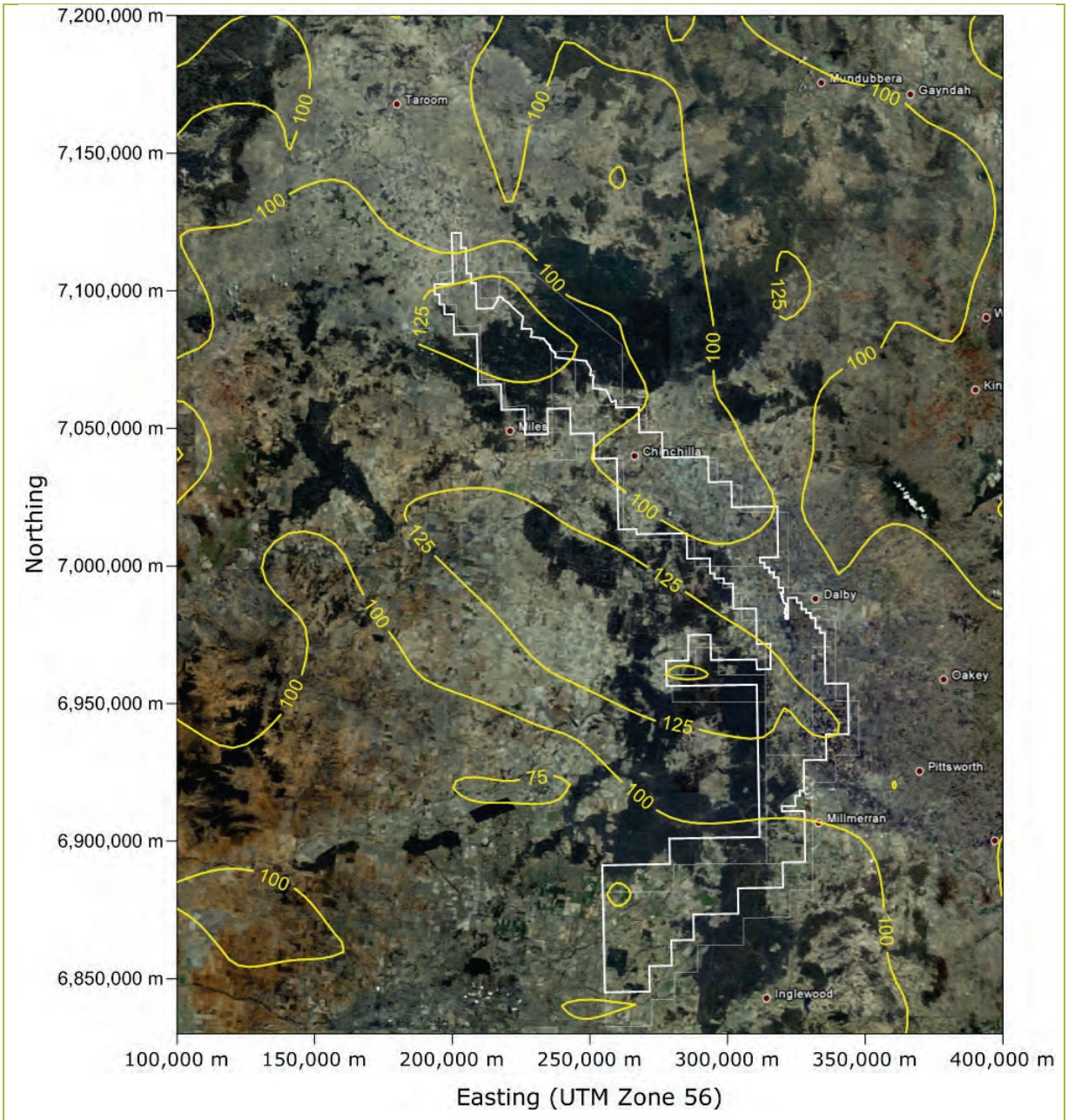
Species:	Location:	Scenario 2:	Percentile:	Averaging Time:
NO_2	Surat Basin	Facilities in Operation up to Year 2020	Average	Annual
Model Used:	**Units:**	**Guideline:**	**Met Data:**	**Plot:**
TAPM-CTM	$\mu g/m^3$	Air EPP 2008=62 $\mu g/m^3$ (no exceedence)	TAPM v. 4 Generated	B Warren

Figure 7.6: Scenario 2 – annual averaged NO_2 concentrations



Species:	Location:	Scenario 2:	Percentile:	Averaging Time:
O_3	Surat Basin	Facilities in Operation up to Year 2020	Maximum	1 hr
Model Used:	**Units:**	**Guideline:**	**Met Data:**	**Plot:**
TAPM-CTM	$\mu g/m^3$	Air EPP 2008=210 $\mu g/m^3$ (no exceedences)	TAPM v. 4 Generated	B Warren

Figure 7.7: Scenario 2 – maximum O_3 (1 hr averaged) concentrations



Species:	Location:	Scenario 2:	Percentile:	Averaging Time:
O_3	Surat Basin	Facilities in Operation up to Year 2020	Maximum	4 hr
Model Used:	**Units:**	**Guideline:**	**Met Data:**	**Plot:**
TAPM-CTM	µg/m^3	Air EPP 2008=160 µg/m^3 (no exceedences)	TAPM v. 4 Generated	B Warren

Figure 7.8: Scenario 2 – maximum O_3 (4 hr averaged) concentrations

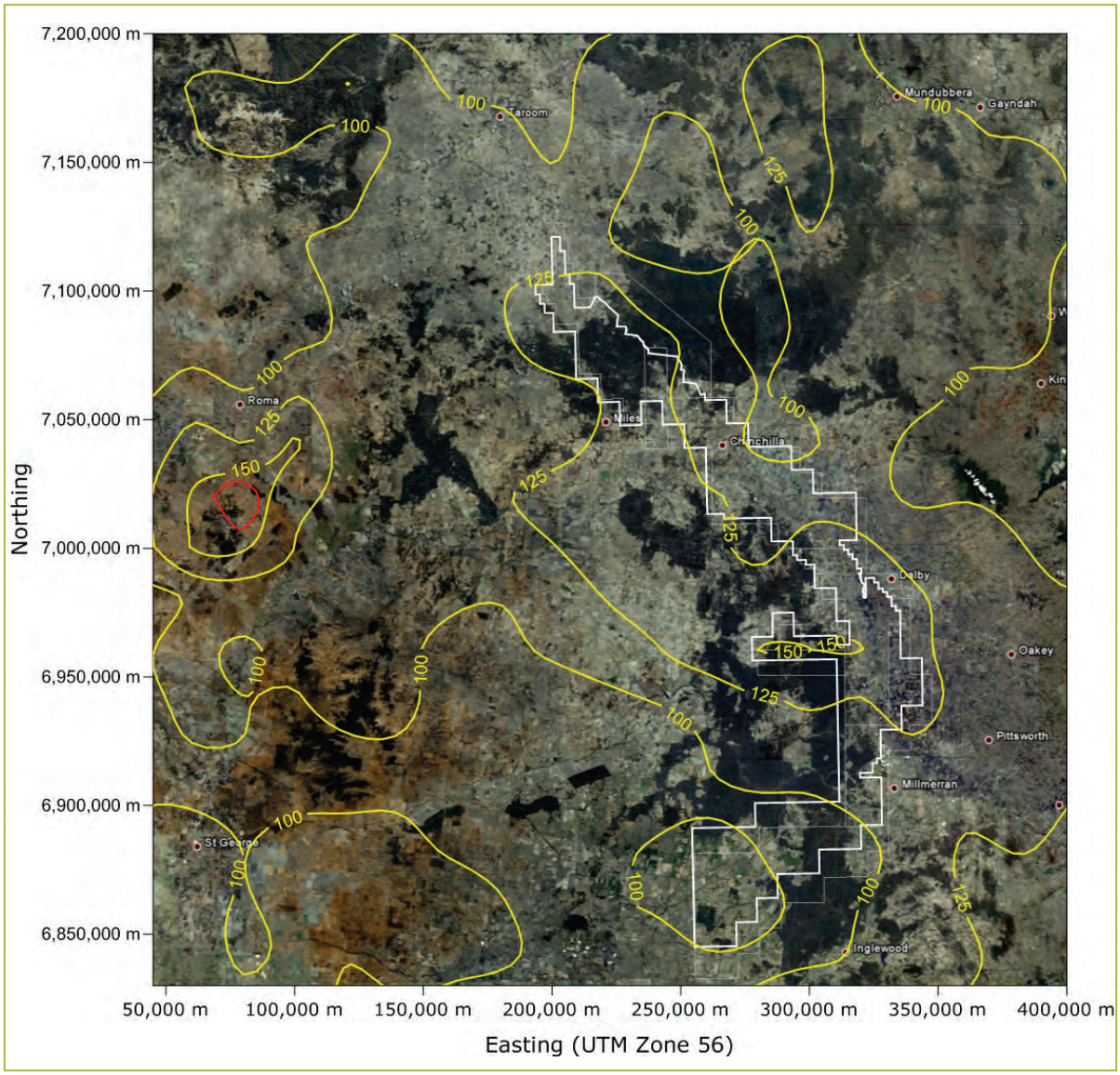


Figure 7.9: O_3 (4 hr averaged) contours showing high concentrations west of project area
Red contour indicates guideline value of 160 µg/m³

It should be noted that the 4 hour average ozone criterion allows for one day of exceedence. The results presented in Table 7.1 present the second highest day while the contours presented in Figure 7.9 are the maximum. Maximum contours are presented as CTM will not allow for gridded data for the second highest day to be extracted. Therefore the contours above should be considered in combination with the predictions presented in Table 7.1.

7.2 Localised Impacts

To evaluate the project's localised impacts the following emission sources were subject to localised assessment:

- Flaring
  - Ramp-up facility flaring; and
  - Facility flaring due to upset conditions.
- Power Generation
  - Facility power generation; and
  - Wellhead power generation.

Modelling was conducted using Ausplume for three meteorological regions (north, central and south) for rural land uses including flat and forested regions. Multiple regions were selected to account for the meteorological variability across the modelling domain. The results for each region are presented.

FLARING

The flaring assessment considers the flaring emissions from the maximum ramp-up flaring (72 TJ/day) emissions as well as the upset condition flaring rates (10, 30 and 150 TJ/day), as supplied by Arrow. The assessment considered meteorology of the northern, central and southern regions of the project. Flaring was assumed to be continuous during the modelling period. This is considered conservative as ramp-up is typically three months prior to facility commission and upset condition flaring is intermittent, during the operational phase.

POWER GENERATION

The power generation assessment considers the emissions from the maximum facility (field compression facility, central gas processing facility and integrated processing facility) power requirements as presented in Section 6.3.4 and typical wellhead power generation requirements, as supplied by Arrow. The assessment considered meteorology of the northern, central and southern regions of the project. Power generation was assumed to be continuous during the modelling period.

7.2.1 Nitrogen Oxides

NOx impacts were assessed and the resulting second highest concentrations within the modelling grid, including background levels, are presented. Localised impacts are assumed to have an ambient NO_X:NO_2 ratio of 0.3 as discussed in Section 4.4.3.3.

BACKGROUND NO_2

The existing NO_2 concentration for the localised assessment was determined from the regional air quality assessment Scenario 2 results. This scenario considered the project activities up to and including the year 2020. The 70th percentile daily 1-hour maximum concentrations were selected at a number of key locations within the project development area, as shown in Figure 1.1. The concentration ranges from 3 – 23 µg/m^3, and the maximum of the range was selected to represent background for the localised assessment.

Table 7.2: Localised Background NO_2 Concentration Values

UTM Zone 56		70th Percentile Daily Maximum 1-hr Concentration (µg/m³)
Easting (km)	Northing (km)	
200.5	7,080.8	16.4
220.5	7,060.8	23.2
260.5	7,040.8	4.6
300.5	6,900.8	4.8
280.5	6,880.8	3.9
280.5	6,760.8	3.3

FLARING

NOx impacts were assessed from flaring and the resulting maximum concentrations within the modelling grid (within 10 km), excluding background levels, are presented in Table 7.3.

Table 7.3: Maximum Predicted Flaring NO_2 Concentration

Flaring Rate (TJ/day)	Predicted NO_2 Concentration (µg/m³)
10	0.7
30	1.0
72	1.7
150	3.5

It can be seen in Table 7.3 that the second highest predicted 1 hour concentrations of NO_2 within 10 km of flaring, (excluding the background air quality) are well below the guideline concentration of 250 µg/m³. The second highest 1 hour concentration has been used in this assessment as it is in line with the model analysis for a New South Wales Level 2 assessments (NSW, 2005a) and US EPA short term steady state plume assessments (US EPA, 2005).

POWER GENERATION

NOx impacts were assessed from facility and wellhead power generation and the resulting second highest concentrations, including background levels are presented as follows:

- Integrated Processing Facility – Predicted concentrations presented in Figure 7.10.
- Central Gas Processing Facility – Predicted concentrations presented in Figure 7.11.
- Field Compression Facility – Predicted concentrations presented in Figure 7.12.
- Wellhead – Predicted concentrations presented in Figure 7.13.

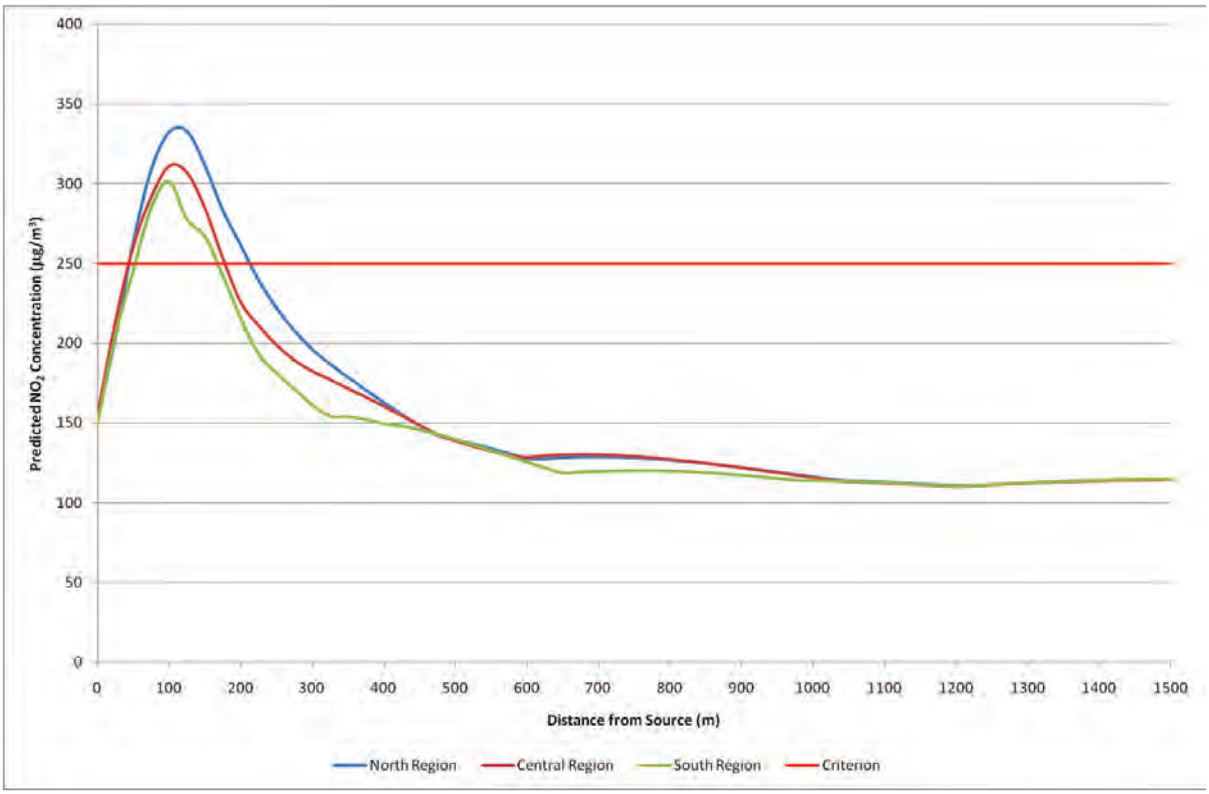


Figure 7.10: Maximum Predicted 1-hour NO_2 Concentrations at Distance from Integrated Processing Facility

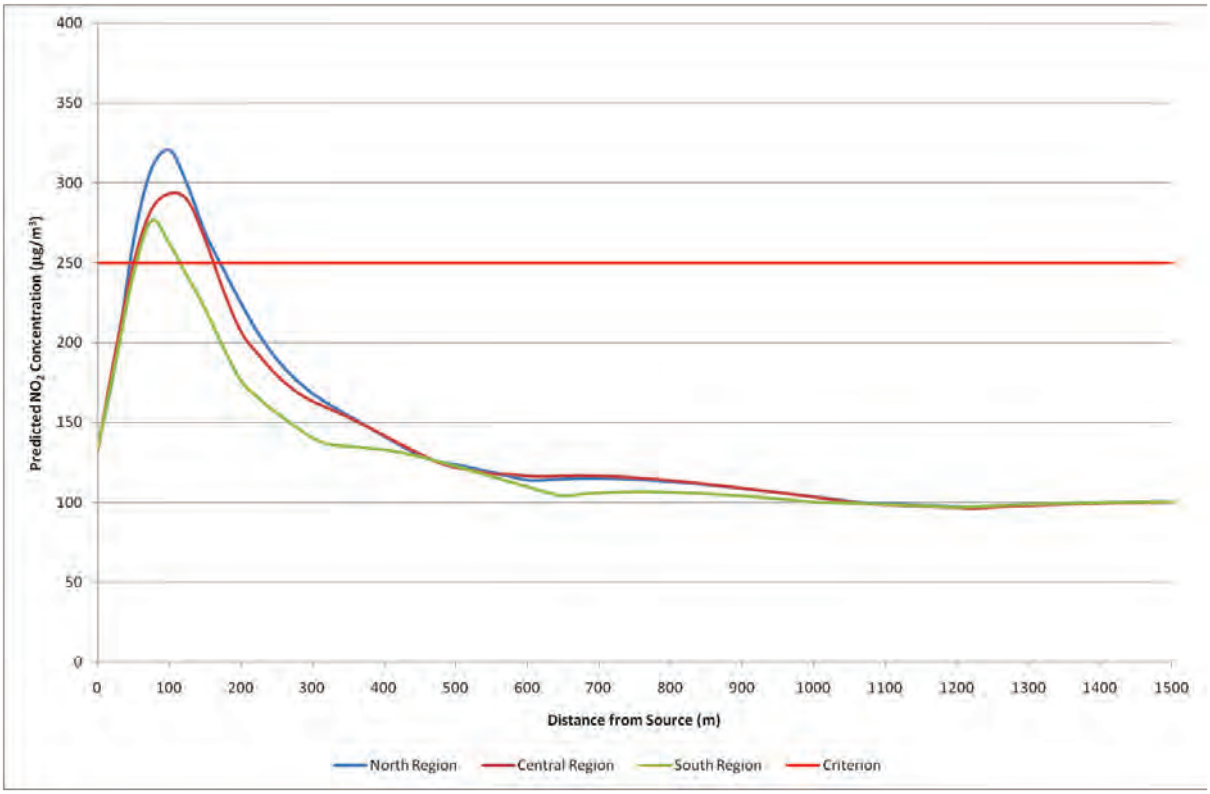


Figure 7.11: Maximum Predicted 1-hour NO_2 Concentrations at Distance from Central Gas Processing Facility

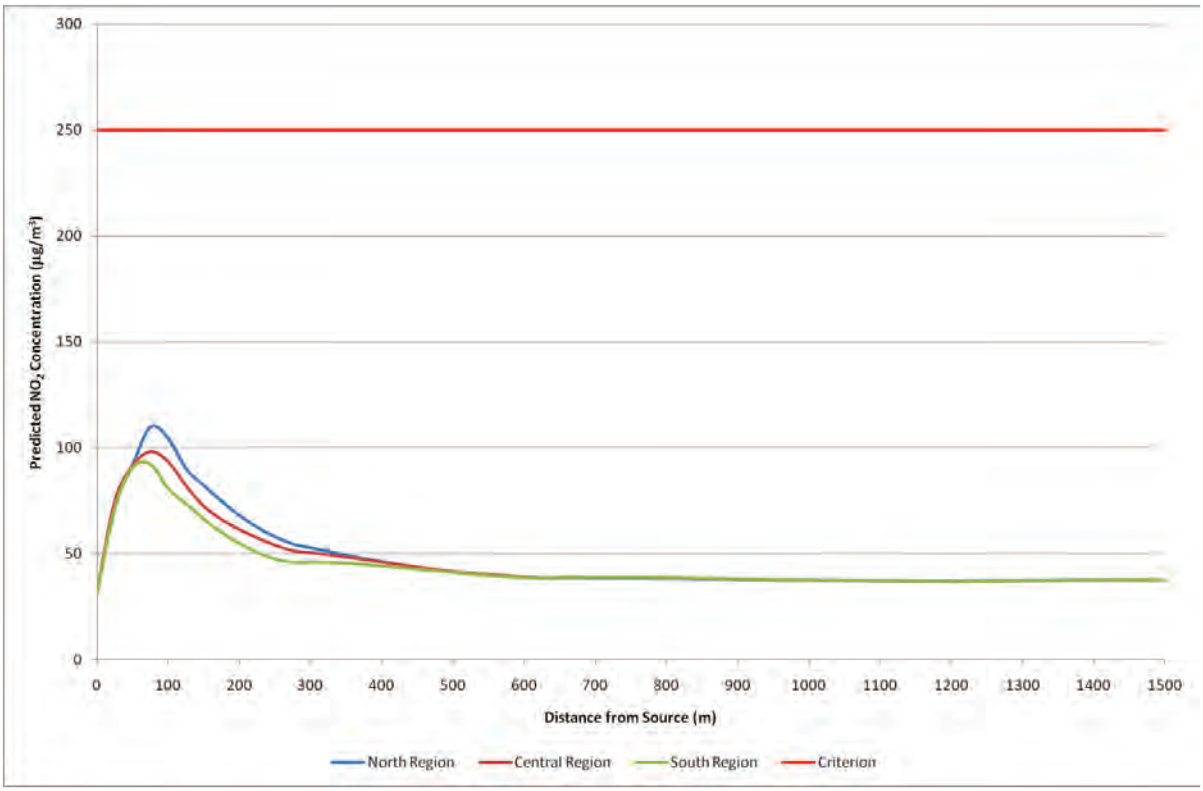


Figure 7.12: Maximum Predicted 1-hour NO_2 Concentrations at Distance from Field Compression Facility

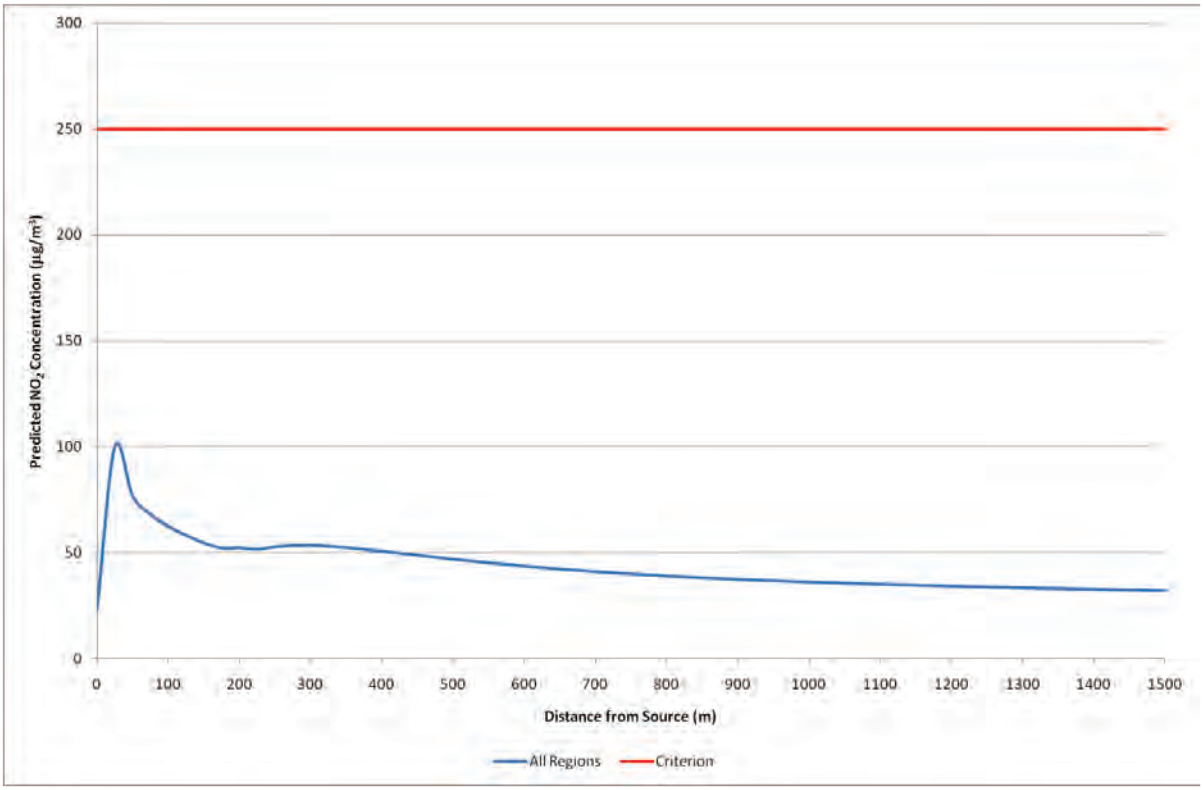


Figure 7.13: Maximum Predicted 1-hour NO_2 Concentrations at Distance from Well-head

It can be seen that the maximum predicted 1 hour concentrations of NO_2 close to the integrated processing facilities and central gas processing facilities are above guideline concentrations. The separation distance from the power generation gas engines to achieve compliance varies with facility as shown in Table 7.4

Table 7.4: Predicted Facility Separation Distances

Region	Required Separation (m)		
	Integrated Processing Facility	Central Gas Processing Facility	Field Compression Facility
North	225	175	-
Central	200	175	-
South	175	125	-

The separation distances required for both the integrated processing facility and central gas processing facility are due to the power requirements requiring 16 x 3 MW gas engines and 19 x 3 MW gas engines respectively while the field compression facility only requires 3 x 3 MW gas engines. If NOx emissions estimates were reduced then reductions in the required separation distances would be predicted. To achieve compliance and remove the need for separation distances estimated emissions would need to be reduced by approximately 73 % and 76 % of the reported integrated processing facility and central gas processing facility emissions respectively.

Wellhead generators are predicted to require no separation distance, since the maximum predicted 1 hour concentrations of NO_2 are below the guideline concentration.

7.2.2 VOCs

VOC emissions are typically associated with combustion and fugitive gas sources. Gas sampling information supplied by Arrow, indicated that no toxic VOCs were present in the gas above detection limits (Appendix A). Arrow has advised that gas combustion has limited speciation of toxic VOCs. Arrow has advised that combustion emissions of formaldehyde have not been identified and therefore has not been assessed further.

To determine if there is a possible issue surrounding toxic VOC emissions a theoretical analysis was conducted where the gas combustion toxic emissions are assumed to be equivalent to those reported in Table 57 of the NPI Combustion Engines Manual (NPI, 2008). Only the toxic VOC emissions reported under NPI from natural gas engines are assessed, and toxic VOCs not reported are assumed not to be emitted. By applying the NPI toxic percent VOC to the modelled output of total VOCs, PAEHolmes has predicted the maximum concentrations from an integrated processing facility to determine compliance with the Air EPP 2008 guidelines for each individual VOC species. Table 7.5 contains the results.

Table 7.5: Analysis of Toxic VOC Ambient Concentrations

VOC	Time Average	Air EPP Objective (µg/m³)	NPI % VOC [a]	Maximum Predicted Concentration (µg/m³)
1,2-dichloroethane	24-hour	750	0.04	0.07
1.3-Butadiene	annual	2.4	2.2	0.3
Benzene	annual	10	5.3	0.8
Benzo(a)pyrene	annual	0.0003	NR	-
Dichloromethane	24-hour	3200	NR	-
Styrene	30-min	75	0.04	0.14
Tetrachloroethylene	annual	270	NR	-
	30-mins	8600	NR	-
Toluene	24-hour	4100	1.9	3.25
	annual	410	1.9	0.27
	30-mins	1100	1.9	6.87
Xylene	24-hour	1200	0.7	1.20
	annual	950	0.7	0.10

a NPI, 2008 – Table 57

NR – not reported and assumed to not be emitted

No exceedences of Air EPP 2008 guidelines for VOCs were predicted.

7.2.3 SO_2

There are no significant sources of SO_2 emission from the production well gas engine exhausts or from the fugitive gas emissions. Since there are no predicted significant SO_2 sources within the project and there are currently no existing issues with ambient SO_2 concentrations, there will be no resulting adverse SO_2 impacts from the proposed project.

7.2.4 CO

Combustion emissions of CO are the only sources of CO emissions present within the project. These emission rates are minimal in comparison to emission rates necessary to cause adverse impacts. Typically, in industrialised nations, CO concentrations that are harmful to human health are only found near large volumes of motor vehicle activity. Due to these reasons, it has been determined that the proposed project will not cause any adverse CO impact.

7.2.5 Particulate Matter

Particulate matter was assessed at three locations throughout the project area for an integrated processing facility configuration. The resulting maximum concentrations within the modelling grid, excluding background levels, are presented in Table 7.6. It should be noted that both TSP and PM_{10} have been assumed to have the same concentration as $PM_{2.5}$ (i.e. assuming that 100% of the emitted particulate is $PM_{2.5}$) for the purposes of this assessment.

It is clear that the maximum concentrations within the modelling grid for PM (excluding background levels and the contribution from the production well gas engines exhausts) are below guideline concentrations. Even considering background data the predicted cumulative concentrations are not expected to exceed any of the DERM guidelines for particulate matter.

Table 7.6: Predicted Maximum Particulate Matter Impacts from an Integrated Processing Facilities

Pollutant	Averaging Period	Concentration (µg/m³)	Background (µg/m³)	Guideline (µg/m³)
PM_{10}	24 hour	13.3	25.7	50
$PM_{2.5}$	24 hour	13.3	6.8	25
$PM_{2.5}$	1 year	1.1	3.6	8
TSP	1 year	1.1	ND	90

ND = no data

7.2.6 Odour

The only odorant which may be within the project is hydrogen sulphide emissions from gas flaring and fugitive gas emissions. Data to date indicates that if present hydrogen sulphide would be in trace amounts making it difficult to quantify the potential impacts. However, given that flaring is expected to be an infrequent event, PAEHolmes does not anticipate these events would create a nuisance issue.

7.2.7 Dust Deposition

The PM emissions associated with the project are generally of a small size, < 10 µm in aerodynamic diameter. Particles in this size range tend to behave more like a gas than a particle and they are not usually associated with deposition issues. In addition there are very few PM emission sources and therefore additional dust deposition (above existing) will not be an issue with this project. As mentioned in Section 4.3.8, typical activities that can cause dust deposition will include earthmoving and vehicle activities on unpaved roads, and preparation of sites for construction. However, the emissions from these activities are expected to be localised, short term, and small in magnitude.

8 BENCHMARKING

This section provides a comparison of emission rates with best practice national and international source emission standards.

In the absence of specific Queensland emission source guidelines, the emission characteristics of power generation sources were be compared to the NSW DECC's Protection of the Environment Operations (POEO) (Clean Air) Regulation 2002 and its amendment (NSW, 2002 & NSW, 2005b).

Activities of the Surat Gas Project would most likely be represented by "Group 6" under the regulation, as the project is commencing after 2005. Table 8.1 presents the standards of concentration for Group 6, for activities relevant to the Surat Gas Project, while Table 8.2 presents the reference conditions for these standards.

It should be noted that the NSW POEO Group 6 standards (post 1/09/2005 facility) were used for comparison purposes only. It is noted that the motivation behind the NSW POEO is to allow NSW to adopt more innovative approaches to reducing pollution in constrained air-sheds.

Table 8.1: POEO Standards of Concentration Relevant to the Surat Gas Project

Air Impurity	Activity or Plant	Standard of Concentration
Solid particles (total)	Any activity or plant	50 mg/m³
Nitrogen dioxide (NO_2) or Nitric oxide (NO) or both, as NO_2 equivalent	Stationary reciprocating internal combustion engines	450 mg/m³
Sulfuric acid mist (H_2SO_4) or sulfur trioxide (SO_3) or both, as SO_3 equivalent	Any activity or plant	100 mg/m³
Hydrogen sulphide (H_2S)	Any activity or plant	5 mg/m³
Fluorine (F_2) and any compound containing fluorine, as total fluoride (HF) equivalent	Any activity or plant, other than the manufacture of aluminium from alumina	100 mg/m³
Chlorine (Cl_2)	Any activity or plant	200 mg/m³
Hydrogen chloride (HCl)	Any activity or plant	100 mg/m³
Type 1 substances and Type 2 substances (in aggregate) [antimony, arsenic, beryllium, cadmium, chromium, cobalt, lead, manganese, mercury, nickel, selenium, tin, vanadium]	Any activity or plant	1 mg/m³
Cadmium (Cd) or mercury (Hg) individually	Any activity or plant	0.2 mg/m³
Volatile organic compounds (VOCs), as n-propane	Any stationary reciprocating internal combustion engine using a liquid fuel	VOCs – 1140 mg/m³ or CO – 5880 mg/m³
	Any other activity or plant involving combustion	VOCs – 40 mg/m³ or CO – 125 mg/m³
Smoke	An activity or plant involving combustion	Ringelmann 1 or 20% opacity

(NSW, 2005b)

Table 8.2: Reference Conditions for POEO Standards of Concentration

Air Impurity	Activity or Plant	Reference Conditions
All air impurities (except smoke and dioxins or furans)	Any activity or plant (except as listed below)	Dry, 273 K, 101.3 kPa
	Any fuel burning equipment using solid fuel	Dry, 273 K, 101.3 kPa, 7% O_2
	Any fuel burning equipment using gas or liquid fuel	Dry, 273 K, 101.3 kPa, 3% O_2
	Gas turbines	Dry, 273 K, 101.3 kPa, 15% O_2
Smoke (if determining whether a specified standard of concentration of opacity has been exceeded)	Any activity or plant	Gas stream temperature above dew point. Path length corrected to stack exit diameter as per CEM-1

(NSW, 2005b)

The emission rate of NO_X also plays a large role in regional modelling, and as such benchmarking the emissions rate against relevant guidelines should be completed. The most directly relevant guidelines available for comparison are the Standards of Performance for Stationary Compression Ignition and Spark Ignition Internal Combustion Engines (US EPA, 20011), presented in Table 8.3.

Table 8.3: US EPA NO_x Emission Guidelines for Stationary Natural Gas Engines

Engine Type and Fuel	Maximum Engine Power	NO_x Emission Rate (g/HP-hr)	NO_x Emission Rate (g/kW-hr)	NO_x Concentration (ppmvd at 15% O_2)	NO_x Concentration (mg/m³ at 15% O_2)
Non-emergency SI natural gas	100≤HP<500 & HP≥500	2.0	2.68	160	305

ppmvd – Parts per million (volumetric dry) SI – Spark ignition HP – Horsepower

Converting the emission characteristics of the engines to the same units as the emission rate guideline (0.2 g/s NO_x -> 45 kW/hr output) results in an emission rate of NO_X from the wellhead engines of approximately 16.4 g/kW-hr. Converting the power generation engines from their characteristics (1.5 g/s NO_x -> 3 MW output) results in an emission rate of NO_x from the power generation engines of approximately 1.8 g/kW-hr.

Table 8.4 presents an overall comparison of the power generation and wellhead engines to the relevant standards and guidelines mentioned.

Table 8.4: Comparison of Power Generation and Wellhead Engines to Relevant Standards

Engine	Guideline/Standard NO_x Emission Rate (g/kW-hr)	NO_x Emission Rate (g/kW-hr)	Guideline/Standard NO_x Concentration (mg/m³)	NO_x Concentration (mg/m³)
Facility gas engines	2.68	1.8	450	167
Wellhead gas engines	2.68	**16.4**	450	**1402**

As shown in Table 8.4 the production facility power generation emission characteristics do not exceed the POEO standards. However, the concentration of NO_X for wellhead engine emissions exceeds the POEO standard and the US EPA guideline.

9 MITIGATION MEASURES

9.1 Constraints on Site Selection

The locations of resource area facilities have not been finalised as the integrated processing facility locations will be progressively planned over the life of the Surat Gas Project.

Arrow is committed to selecting sites for project infrastructure that will protect the environmental values of the project development area wherever practicable. The objectives of site selection are to:

- Ensure the selection of optimal, environmentally acceptable sites for infrastructure placement.
- Avoid or eliminate potential impacts to environmental values.
- Minimise, to the greatest extent practicable, potential impacts to environmental values unable to be avoided or eliminated during design.
- Identify environmental measures for low, moderate and highly constrained areas and 'No Go' areas.

Modelling of the facilities indicates that to ensure NO_2 emissions from the integrated processing facilities and central gas processing facilities meet the guideline concentrations; they should be

constructed up to approximately 225 m and 175 m respectively from sensitive receptors, depending on which region they are constructed in. To achieve compliance and remove the need for separation distances NOx emission concentrations for facility power generation would need to be reduced to 122 mg/m³ and 127 mg/m³ for integrated processing facilities and central gas processing facilities respectively. It should be noted that these separation distances and in stack concentration requirements are based on a two-dimensional modelling assessment. These requirements should be further evaluated with three-dimensional modelling once the facility locations are selected as site-specific terrain and meteorology may affect the predicted buffer distances.

The localised modelling results also indicate that individual production wells will not lead to exceedences of guidelines at any distance, and therefore no constraints on well placement are required.

Modelling undertaken in this assessment has been used to give an indication of areas within the project development area that may experience significant impacts. While Air EPP NO_2 and O_3 guidelines were not exceeded in the regional modelling exercise, the northern area of the project and the area west of project are predicted to impacts be impacted to a higher degree than other areas affected by the project.

This is due to the existing air quality of the resource area, and site selection should be undertaken with care, to ensure that sensitive receptors in the project area are not impacted upon by the project.

9.2 Project Activities

Arrow is committed to applying a hierarchy of controls in order to minimise environmental impact. Arrow has standard operating procedures determining how selection of equipment will be completed in regards to protecting environmental values. Equipment that results in environmental impact will be:

- avoided;
- substituted out; or
- have mitigations imposed to reduce the impact.

In order to determine what equipment should be installed for the project (and therefore what equipment should be avoided), equipment selection will consider as part of the assessment process:

- low source of noise emissions;
- low emissions to air (substances: NO_x, SO_x);
- high energy efficiency and fuel efficiency;
- low generation of waste;
- low greenhouse gas emissions;
- avoidance of ozone depleting substances;
- avoidance of particularly hazardous chemicals;
- low emissions of pollutants to water; and
- low water use.

Across all of Arrow's Surat Gas Project activities, Arrow has committed to the mitigation measures listed in Table 9.1 to minimise air quality impacts. These measures are recorded in standard operating procedures included in the Surat Gas Project Environmental Management Plan.

Table 9.1: Mitigation Commitments

Project Phase	Mitigation Measures
Construction activities (production well, gathering line, production facilities, pipeline installation)	Reassessment of facility air emission impacts as part of detailed design, utilising selected sites and equipment. The assessment should be completed utilising 3D modelling. Minimise land cleared for construction purposes (e.g. production well leases and equipment lay-down areas). The period of time surfaces are left bare will be minimised. Minimise the number and size of stockpiles, and water or cover as necessary. Progressively rehabilitate disturbed areas through revegetation or mulching. Undertake dust suppression during clearing and construction activities, especially in high wind conditions. Roads, access tracks and other areas may be watered to suppress dust. Vehicle travelling speeds will be restricted, and movements will be limited to approved access tracks. Dust generating activities in proximity to sensitive locations will be timed, when possible, to prevent dust nuisance at the receptor. Works upwind of receptors will be ceased, if dust cannot be controlled through standard mitigation options, during windy weather conditions. Selection of gaskets, seals and vehicle exhaust systems that are suitable for the task, and maintained according to manufacturer's recommendations. Manufacturer's recommendations and guidelines with respect to air emissions are followed at all times. Air pollution control technologies are to be maintained in good working order and kept in place at all times the equipment is operating. Air emissions will be monitored at the source in accordance with Environmental Authority conditions. Odours will be managed so that they do not cause environmental nuisance or harm to sensitive receptors.
Operational Phase	Implement a preventative maintenance program to ensure engines are operating efficiently to minimise NO_x, CO, methane and VOC emissions. Optimise gas turbine operation to minimise time of operation at low efficiency levels. Implement a quantifiable monitoring and measuring program. Roads, access tracks and other areas may be watered to suppress dust. Vehicle travelling speeds will be restricted, and movements will be limited to approved access tracks. Selection of gaskets, seals and vehicle exhaust systems that are suitable for the task, and maintained according to manufacturer's recommendations. Manufacturer's recommendations and guidelines with respect to air emissions are followed at all times. Air pollution control technologies are to be maintained in good working order and kept in place at all times the equipment is operating. Air emissions will be monitored at the source in accordance with Environmental Authority conditions. Odours will be managed so that they do not cause environmental nuisance or harm to sensitive receptors. Equipment that produces abnormal monitoring results will trigger maintenance /review procedures in order to return emissions to acceptable levels. Where practical, the equipment should not be brought back into service until normal operational emissions are achieved.

Project Phase	Mitigation Measures
Decommissioning Phase	Minimise the number and size of stockpiles. Rehabilitate disturbed areas to the maximum extent possible through revegetation or mulching. Undertake dust suppression during decommissioning and earthworks activities, especially in high wind conditions. Roads, access tracks and other areas may be watered to suppress dust. Vehicle travelling speeds will be restricted, and movements will be limited to approved access tracks. Dust generating activities in proximity to sensitive locations will be timed, when possible, to prevent dust nuisance at the receptor. Works upwind of receptors will be ceased, if dust cannot be controlled through standard mitigation options, during windy weather conditions. Odours will be managed so that they do not cause environmental nuisance or harm to sensitive receptors.
Vehicles and machinery	Ensure all vehicles and machinery are fitted with appropriate emission control equipment, maintained frequently and serviced to the manufacturer's specifications. Smoke from internal combustion engines should not be visible for more than ten seconds.

10 CUMULATIVE IMPACTS

The background air quality has been determined considering the currently present emission sources and the approved projects projected emissions, where data were available. The cumulative impacts of the presence of this project have shown to cause an increase of NO_2 and O_3 concentrations in the region. These impacts are not limited to the areas where the project operations are occurring, with areas to the west of the project area also shown to potentially be impacted. This formation is due to the photochemical reaction time, ambient air composition of photochemical reacting compounds from both current sources and the project sources, as well as the meteorological influences of the area. This location to the west of the study area is a low valley that is subject to low mixing heights (allowing for the photochemical compounds to react) resulting in increased NO_2 and O_3 concentrations. While impacts are projected to be increased, the regional modelling suggests that with the Air EPP objectives will not be exceeded with the presence of the projects operations.

11 MONITORING

The regional modelling predicted no exceedences of the NO_2 and O_3 Air EPP objectives. However, the predicted concentrations are higher than those predicted in the current emission scenario and the predicted concentrations are nearing the Air EPP objectives. If monitoring is requested by the administering authority, monitoring data could be used to verify the modelling results and ensure the region is meeting the Air EPP objectives. If monitoring is requested, it is recommended that two regional real-time monitoring stations for NO_2 and O_3 be established. One should be located within the study area and another to the west of the project area in the region that is predicted to have the highest modelled concentrations outside of the project area. The regional modelling has shown that the area to west of the project area is subject to the photochemical formation of NO_2 and O_3 from the contribution of the project's emissions. Figure 11.1 presents potential locations for the monitoring stations. The monitoring stations should be sited and maintained following the appropriate Australian standards. It is also recommended that the monitoring stations be established prior to project commencement, for the collection of robust data sets of background concentrations, and that the data be collected at sub-hourly intervals. Monitoring data would

enable long term comparisons to the model predictions allowing for validation of the predicted impacts.

If monitoring is requested by the administering authority then monitoring should be while the project is in operation. The monitoring station data (a minimum of six months) should be used to validate the regional modelling predictions for the operational phase of the project. Establishing a monitoring station at the southern end of the project area should also be considered if measurements at other locations indicate ambient values close to or above the Air EPP objectives.

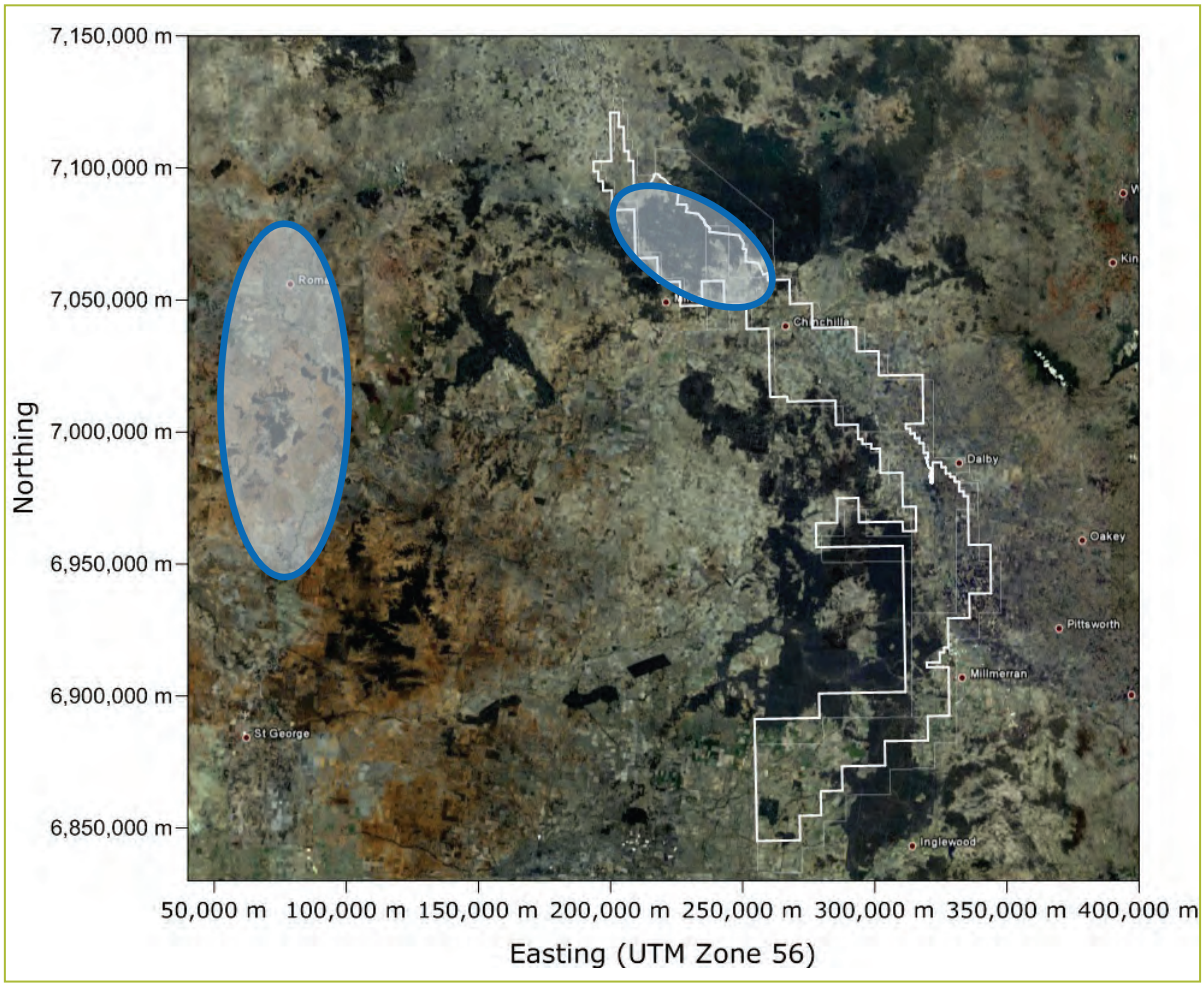


Figure 11.1: Recommended locations of NO_2 and O_3 monitoring stations (blue circles)

12 CONCLUSIONS

Air emission sources associated with the development of the Surat Basin have been identified and evaluated. Further assessment was conducted employing dispersion modelling to determine the nature and extent of air quality impacts in context of statutory ambient air quality goals.

The key substances of concern are oxides of nitrogen (NO_X) released during combustion processes. Oxides of nitrogen participate in photochemistry and significant background emission sources exist within the study area. The project's cumulative impacts on the regional air quality have been evaluated by modelling due to an absence of suitable background air quality data applicable over the large study area.

The Surat Gas Project will generally increase the concentrations of the photochemical compounds NO_2 and O_3. These impacts are not limited to the areas where the project operations are occurring but also to the areas to the west of the project area. While impacts are projected to be increased, the regional modelling suggests that with the Air EPP objectives will not be exceeded with the presence of the projects operations. If monitoring is requested, it is recommended that two regional monitoring stations for nitrogen oxides and ozone are established, one within the project area and the other to the west of the project area. Monitoring data would enable long term comparisons to the model predictions allowing for validation of the predicted impacts.

Wellhead gas engine emissions will not contribute significant levels of NO_2 in the immediate vicinity of the wells and thus no constraint on well placement is required based on emissions of this pollutant. However, due to the NO_X emissions released from the facility combustion processes, the locations of integrated processing facilities and central gas processing facilities need to be constrained such that they maintain a separation of approximately 225 m and 175 m respectively from the nearest sensitive receptors, depending on which region the facility is constructed in. Alternatively mitigation of some form may be considered, such as increasing stack height or selective catalytic reduction.

It should be noted that these separation distances and in-stack concentration requirements are based on a two-dimensional modelling localised assessment. It is recommended that once the facility locations and orientations are know three dimensional modelling should be conducted to further evaluate two dimensional study results.

VOCs are not emitted from the project in significant quantities, and therefore buffer distances are not required from facilities to remain below the VOC regulatory guidelines. As there are no significant impacts from SO_2, CO, particulate matter, odour, and dust deposition, no further constraints on the project are required.

13 REFERENCES

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Appendix A

Estimation of Emissions

A.1 ESTIMATION OF EMISSIONS

A.1.1 Composition and Molecular Weight of Arrow's Coal Seam Gas

Table A.1 presents the average composition and molecular weight of the coal seam gas produced by Arrow.

Table A.1: Composition and Molecular Weight of Arrow's Coal Seam Gas

Data Required	Forecast value	Unit
Methane composition of coal seam gas	98.69	mol%
Carbon dioxide composition of coal seam gas	0.22	mol%
Nitrogen composition of coal seam gas	1.05	mol%
Non-Methane VOCs composition of coal seam gas	0.04	mol%
Molecular weight of coal seam gas	16.24	kg/kmol

A.1.2 Fugitive Emissions

Fugitive emissions of coal seam gas were estimated from the following sources:

- water gathering lines;
- processing plants; and
- production well surface facilities and other gas production infrastructure.

A.1.2.1 Emissions from Water Gathering Lines

The amount of gas released from the water gathering lines of the wellheads has been estimated using the following separation efficiencies:

- 5% of the gas extracted leaves the wellhead via the water gathering lines.
- 80% of the gas in the water gathering lines is removed if a wellhead separator is required at the site.
- 99% of the gas in the water gathering lines is returned to gas production facilities through gathering systems in place at high point vents.

Based on these separation efficiencies, 0.05% of the gas extracted at the wellhead is lost in the water gathering lines if no separator is used at the wellhead, while 0.01% of the gas would be lost if a wellhead separator is present. Arrow plans to install wellhead separators on every well. As such, it is assumed that 0.01% of the gas produced at the wellhead is lost throughout the water gathering lines.

Once the volume of gas released has been determined (9.78×10^4 Sm^3/a), the mass of the VOCs emitted can be determined by using the composition and molecular weight of the gas indicated in Table A.1.

Using this methodology, the worst-case VOC emissions from water gathering lines is 670 kg/a for the year 2020.

A.1.2.2 Emissions from Process Plants and Production Wells

Fugitive VOC emissions from production and processing of gas can be estimated using facility-level emission factors for greenhouse gases presented in Table 6-1 of the American Petroleum Institute Compendium of Greenhouse Gas Emissions Methodologies for the Oil and Gas Industry (API Compendium) (API, 2009). The following equation can be used to calculate the greenhouse gas emissions:

$$E = Q \times EF_{S1}$$

where:

E	=	Emissions of methane	(t CH_4/a)
Q	=	Coal seam gas produced	(m^3/a)
EF_{S1}	=	Emission factor for fugitive emissions from production or processing	(t/m^3)

The emission factor for gas processing is 64.32 lb $CH_4/10_6$scf processed, with a basis of 87 mol% CH_4.

The coal seam gas industry is relatively new, and emission estimation techniques and factors specific to the industry have yet to be developed. The natural gas industry is a close analogue; hence the emission factors for the natural gas industry can be used to produce reasonable results from the coal seam gas industry. Facility-level emission factors are also useful, as the number and type of equipment to be used is subject to change.

The factor was scaled up by multiplying the original factor by the CH_4 composition of Arrow's coal seam gas (indicated in Table A.1), then dividing by the basis composition. It is also worthwhile to note that the emission factors in the source material presented in metric units have not been converted correctly.

The emission factor for gas processing was therefore calculated to be:

- Gas processing:
  - 1.17E-6 t CH_4/m^3 processed.

The emissions of methane are then converted to VOC emissions by using the gas composition data.

Using this methodology, the worst-case VOC emissions from gas processing are as follows:

- Processing:
  - 11,744 kg/a for the year 2020

A.1.3 Flaring

A.1.3.1 Ramp-up Flaring

Ramp-up flaring data was provided by Coffey Environment and contained a maximum gas consumption rate as shown in Table A.2. Only central gas processing facilities and integrated processing facilities are proposed to have flaring stacks.

Table A.2: Maximum Predicted Ramp-up Flaring Gas Consumption

Source	Value	Units
Ramp-up Flaring at CGPF/ IPF	72.0	TJ/d per facility
	1,930,813	m^3/d per facility
	1,401,770	kg/d per facility

Emissions from flaring are based on Worksheets 7 and 8 from the DEWHA Emission Estimation Technique Manual for Oil and Gas Exploration and Production Version 1.2 (NPI, 2010).

Emission estimates are presented in Table A.3.

Table A.3: Ramp-up Flaring Emission Estimates

Pollutant	Emission Factor kg/kg flared	Emission Estimate kg/d/facility
CO	8.7×10^{-3}	12,195
NO_x	1.5×10^{-3}	2,103
TVOC	1.5×10^{-2}	21,027
PM_{10}	1.2×10^{-4}	168.2

A.1.3.2 Flaring due to upset conditions

Flaring may occur from time to time due to upset conditions during the operational phase of the project. Table A.4 outlines proposed consumption of gas supplied by Coffey Environments during flaring due to upset conditions. Only central gas processing facilities and integrated processing facilities are proposed to have flaring stacks.

Table A.4: Flaring Gas Consumption

Source	Consumption TJ/day	Duration/Frequency
Flaring	Max. 150	24 hours/year
	30	8 hours/month
	10	8 hours/month

Screening assessment emissions from flaring are based on Worksheet 7 from the DEWHA Emission Estimation Technique Manual for Oil and Gas Exploration and Production Version 1.2 (NPI, 2010). Emission estimates are presented in Table A.5 based on the flaring scenarios indicated in Table A.4.

Table A.5: Operational Flaring Emission Estimates

Facility Consumption TJ/day	Facility Consumption kg/s	Emission Factor kg/kg flared	NO_x Emission Estimate g/s
150	33.8	1.5×10^{-3}	50.7
30	6.76		10.1
10	2.25		3.4

A.1.4 Power Generation

A.1.4.1 Wellhead Power Generation

Emissions are based on each wellhead requiring a 60 kVA gas engine. The gas consumption rate of the engines has been determined by using the 75th percentile of the maximum and minimum fuel consumption rates, 0.0051 Nm^3/s at normal temperature and pressure (15°C, 1 atm). This gas consumption rate at standard conditions (0°C, 1 atm) is calculated by multiplying by a conversion factor of 1.055, resulting in a rate of 0.0054 Sm^3/s. Emissions from gas engines are based on the US EPA AP 42 Section 3.2, 'Natural Gas-fired Reciprocating Engines' (US EPA, 1998). Emission estimates are presented in Table A.6.

Table A.6: Wellhead Power Generation Gas Engine Emission Estimates

Pollutant	Emission Factor kg/Sm^3	Emission Factor Source	Emission Rate g/s
CO	0.062347	AP-42	0.3354
NO_x	0.038045	AP-42	0.2047
NMHC	0.001676	AP-42	0.0090
PM_{10}	0.000159	AP-42	0.0009

A.1.4.2 Facility Compression

PAEHolmes have been advised that each facility (integrated processing facility, central gas processing facility and field compression facility) is to be modelled for maximum compression/power requirements for both the localised assessment and the regional assessment. Coffey Environments have supplied the maximum facility requirements expressed as total MW and number of 3 MW gas engine as shown in Table A.7.

Table A.7: Facility Power Generation Gas Engine Requirements

Facility	Gas Flow (TJ/d)	Total Power Requirement MW	No. of 3MW Units
IPF	150	56	19
CGPF	150	48	16
FCF	50	9	3

Gas consumption in these engines has been determined as 750 Nm^3/hr, or 0.218 Sm^3/s. Emissions from the 3 MW gas engines are based on information supplied by Arrow and the US EPA AP 42 Section 3.2, Natural Gas-fired Reciprocating Engines, where source emissions data was not available. Emission estimates are presented in Table A.8.

Table A.8: Facility Power Generation Gas Engine Emission Estimates

Pollutant	Emission Factor kg/Sm^3	Source	Emission Rate g/s
CO	NA	Arrow	3.00
NO_x	NA	Arrow	1.50
NMHC	NA	Arrow	0.45
PM_{10}	0.000159	AP-42	0.035

A.1.5 Transport

As the production wells, processing plants and other infrastructure required to be constructed for the extraction of gas are spread over large areas of land, the construction workforce will have to travel large distances. As a result, a significant quantity of diesel is expected to be used in passenger vehicles (i.e., light vehicles) for transport. Diesel will also be consumed in industrial vehicles (i.e., heavy vehicles) for construction, operation, maintenance and decommissioning of the facilities and associated infrastructure.

The activities likely to generate traffic and the specific types of vehicles selected for this project are summarised in Section 2 of the *Transport Assumptions Report* (Cardno Eppell Olsen, 2011). Light vehicles have been classified as sedans, wagons, vans, utilities, 4WDs and motorcycles while any other type of vehicle has been considered a HV (heavy vehicle) for the purposes of this estimate (Cardno Eppell Olsen, 2011). The estimated distances travelled by these vehicle classes are presented in Table A.9. In order to determine the emissions from the combustion of fuel in vehicles, the fuel consumption rates shown in Table A.10 have been used with the emission factors provided in Table A.11.

The estimated emissions from the combustion of diesel in light and heavy vehicles are presented in

Table A.12.

Table A.9: Distance Travelled by Light and Heavy Vehicles

Year	Distance Travelled by Light Vehicles (km / a)	Distance Travelled by Heavy Vehicles (km / a)
2013	279,000	539,000
2014	2,609,000	2,125,000
2015	4,305,000	2,675,000
2016	4,263,000	2,262,000
2017	6,784,000	3,439,000
2018	5,927,000	2,924,000
2019	5,311,000	2,027,000
2020	10,432,000	7,226,000
2021	6,844,000	2,821,000
2022	8,374,000	4,825,000
2023	7,736,000	2,530,000
2024	11,927,000	6,795,000
2025	8,726,000	4,193,000
2026	10,056,000	5,458,000
2027	9,170,000	5,223,000
2028	12,092,000	6,648,000
2029	12,517,000	7,544,000
2030	11,091,000	7,206,000
2031	13,617,000	9,531,000
2032	14,913,000	9,536,000
2033	16,345,000	9,488,000
2034	17,747,000	10,285,000
2035	18,880,000	10,250,000
2036	14,216,000	8,352,000
2037	13,942,000	8,192,000
2038	13,636,000	8,030,000
2039	12,338,000	6,953,000
2040	11,938,000	6,180,000
2041	10,939,000	6,627,000
2042	9,677,000	5,714,000
2043	9,725,000	6,176,000
2044	9,138,000	5,529,000
2045	8,582,000	5,121,000
2046	7,441,000	3,809,000
2047	6,997,000	3,787,000
2048	6,702,000	3,541,000

Table A.10: Fuel Consumption Rates in Light and Heavy Vehicles

Data Required	Value	Units
Average rate of diesel consumption of passenger vehicles (light vehicles) [a]	0.123	L/km
Average rate of diesel consumption of articulated trucks (heavy vehicles) [b]	0.559	L/km

a. ABS (2008) – PAEHolmes' assumption: The rate of fuel consumption for passenger vehicles was selected to represent the light vehicles. Passenger vehicles are defined as motor vehicles constructed primarily for the carriage of persons and containing up to nine seats (including the driver's seat). Included are cars, station wagons, four-wheel drive passenger vehicles, passenger vans or mini buses with fewer than 10 seats and campervans.

b. ABS (2008) – PAEHolmes' assumption: As a conservative approach, the rate of fuel consumption for articulated trucks was selected to represent the heavy vehicles (i.e., higher fuel consumption per kilometre).

Table A.11: Emission Factors (EF) for the Combustion of Diesel in Vehicles

	CO EF (kg/m^3)	NO_x EF (kg/m^3)	PM_{10} EF (kg/m^3)	TVOC EF (kg/m^3)
Light Goods Vehicle (LGV) [a]	19.4	8.89	2.39	0.423
Heavy Goods Vehicle (HGV) [b]	6.81	23.3	1.84	1.82

a. Table 15, NPI EET Manual for Combustion Engines v3.0

b. Table 21, NPI EET Manual for Combustion Engines v3.0

Table A.12: Emissions from the Combustion of Diesel in Light and Heavy Vehicles

Year	Emissions from Light Vehicles (kg/a)				Emissions from Heavy Vehicles (kg/a)			
	CO	NO_x	PM_{10}	TVOC	CO	NO_x	PM_{10}	TVOC
2013	666	305	82	15	2,052	7,020	554	548
2014	6,226	2,853	767	136	8,089	27,677	2,186	2,162
2015	10,273	4,707	1,266	224	10,183	34,841	2,751	2,721
2016	10,172	4,661	1,253	222	8,611	29,462	2,327	2,301
2017	16,188	7,418	1,994	353	13,092	44,792	3,537	3,499
2018	14,143	6,481	1,742	308	11,131	38,084	3,008	2,975
2019	12,673	5,807	1,561	276	7,716	26,401	2,085	2,062
2020	24,893	11,407	3,067	543	27,508	94,116	7,432	7,352
2021	16,331	7,484	2,012	356	10,739	36,743	2,902	2,870
2022	19,982	9,157	2,462	436	18,368	62,844	4,963	4,909
2023	18,460	8,459	2,274	402	9,631	32,952	2,602	2,574
2024	28,460	13,042	3,506	621	25,867	88,503	6,989	6,913
2025	20,822	9,542	2,565	454	15,962	54,613	4,313	4,266
2026	23,996	10,996	2,956	523	20,777	71,089	5,614	5,553
2027	21,881	10,027	2,696	477	19,883	68,028	5,372	5,314
2028	28,854	13,222	3,555	629	25,308	86,588	6,838	6,764
2029	29,868	13,687	3,680	651	28,718	98,258	7,759	7,675
2030	26,465	12,128	3,260	577	27,432	93,856	7,412	7,331
2031	32,493	14,890	4,003	708	36,283	124,138	9,803	9,697
2032	35,585	16,307	4,384	776	36,302	124,204	9,808	9,702
2033	39,002	17,873	4,805	850	36,119	123,578	9,759	9,653
2034	42,348	19,406	5,217	923	39,153	133,959	10,579	10,464
2035	45,051	20,645	5,550	982	39,020	133,503	10,543	10,428
2036	33,922	15,545	4,179	740	31,794	108,782	8,591	8,497
2037	33,268	15,245	4,099	725	31,185	106,698	8,426	8,334
2038	32,538	14,911	4,009	709	30,569	104,588	8,259	8,170
2039	29,441	13,491	3,627	642	26,469	90,561	7,152	7,074
2040	28,486	13,054	3,509	621	23,526	80,493	6,357	6,287
2041	26,103	11,961	3,216	569	25,228	86,315	6,816	6,742
2042	23,091	10,582	2,845	503	21,752	74,423	5,877	5,813
2043	23,206	10,634	2,859	506	23,511	80,441	6,352	6,283
2044	21,805	9,992	2,686	475	21,048	72,014	5,687	5,625
2045	20,478	9,384	2,523	447	19,495	66,699	5,267	5,210
2046	17,756	8,137	2,187	387	14,500	49,611	3,918	3,875
2047	16,696	7,651	2,057	364	14,416	49,325	3,895	3,853
2048	15,992	7,328	1,970	349	13,480	46,120	3,642	3,603

Appendix B

Existing Emission Sources

B.1 INDUSTRIAL EMISSION SOURCES

APPROVED FUTURE PROJECTS

A literature review was conducted to determine potential approved future projects that should be included in the cumulative assessment. The inclusion of approved future projects depends on the projects status, projects emissions, availability of data and the location of the project. Table B.1 lists the identified projects and the reasons for cumulative assessment inclusion status. The emissions for these projects are listed in the industry sections below.

Table B.1: Identified future projects and status in cumulative assessment

Project	Regional Assessment Status	Included
Arrow Surat Pipeline	Insufficient publically available data	-
Australia Pacific LNG Project (Gas Fields)	**Included with EIS emissions and emitted as per NPI sources**	√ [a]
Australia Pacific LNG Project (LNG Facility)	Not located in Assessment Domain	-
Bloodwood Creek Gas Production	NOx and VOC emissions were determined to be insignificant and were not included in the EIS assessment	-
Braemar 3 Power Station Project	Project is in the advanced stages of development and no EIS has been released	-
Cameby Downs Expansion	EIS is currently being conducted and emission data is not available	-
Darling Downs Power Station	EIS has been approved and emission data is not available	-
Kogan Creek Solar Boost	NOx and VOC emissions were determined to be insignificant	-
Elimatta Coal Project	EIS is currently being conducted and emission data is not available	-
Emu Swamp Dam Project	NOx and VOC emissions were determined to be insignificant	-
Felton Clean Coal Project	Project is currently being redesigned	-
GLNG	**Included with EIS emissions and emitted as per NPI sources**	√ [b]
Nathan Dam and Nathan Pipeline	EIS is currently being conducted and emission data is not available	-
New Acland Coal Mine Stage 3 Expansion Project	EIS is currently being conducted and emission data is not available	-
Queensland Curtis LNG	Not located in Assessment Domain	-
Spring Gully Power Station	**Included with EIS emissions and emitted as per NPI sources**	√ [c]
Queensland Hunter Gas Pipeline	Insufficient publically available data	-
Surat Basin Rail	Rail emissions have not been included in the regional assessment	-
Wandoan Coal Project	NOx and VOC emissions were determined to be insignificant and were not included in the EIS assessment	-

Bold – Included in Cumulative Assessment

a Katestone (2010)
b URS (2009)
c URS (2006)

OIL AND GAS EXTRACTION

Coal seam gas exploration involves locating highly productive areas. Initially, coal seam gas was mainly sought within the Permian coal seams of the Bowen and Sydney Basins. However, since the early 2000's, exploration has also targeted the relatively shallow depths of the lower rank coal seams of the Jurassic age Surat and Clarence-Moreton Basins in Queensland. Although these seams have less gas content than high rank Permian age coal, these lower rank coals at shallow depths (100 - 600 m) are more permeable and coal seam gas can be more easily extracted, resulting in higher recovery rates. The Bowen Basin remains the most actively explored and developed basin in Australia for coal seam gas and in 2004 over 80% of Australia's total coal seam gas drilling activity occurred in this area.

Companies actively exploring for coal seam gas in the Surat Basin include:

- Sunshine Gas Ltd
- Queensland Gas Company Ltd
- Pure Energy Resources Ltd
- Santos Ltd
- Origin Energy Ltd
- Arrow Energy Pty Ltd
- Blue Energy Pty Ltd

In 1995, Australian commercial production of coal seam gas was zero. In 2003, production was 40 PJ and by 2006 it had doubled to 80 PJ, with 73 PJ being produced in Queensland. In 2006, coal seam gas met 63% of the total Queensland gas demand of 117 PJ. Coal seam gas is predicted to supply 35 to 50% of the gas demand in eastern Australia by 2020 as the Cooper Basin gas reserves become depleted. Operations in the Surat Basin currently producing coal seam gas include:

- **Peat** (Origin Energy): Commenced in 2000 and located 14 km east of Wandoan. Produces about 6 PJ/a.
- **Scotia** (Santos Limited): Commenced in 2002 and located about 25 km north of Peat. Produces about 8 PJ/a.
- **Berwyndale South** (Queensland Gas Company): Commenced in 2006 and located 20 km east of Condamine. Produces about 8 PJ/a.
- **Kogan North** (Arrow Energy/CH4 Gas): Commenced in 2006 and located 40 km west of Dalby. Produces about 4 PJ/a.
- **Daandine** (Arrow Energy/CH4 Gas): Commenced supplying about 2 PJ/a to a 27 MW gas fired power station in 2006. Located 30 km west of Dalby.
- **Tipton West** (Arrow Energy/CH4 Gas): Commenced supplying about 6 PJ/a in 2007 to the Braemer Power Station. Located 20 km south of Dalby.

Santos are also proposing to develop their coal seam gas resources in the Bowen and Surat Basins in the area between Roma and Emerald as feed gas for a liquefied natural gas (LNG) liquefaction and export facility on Curtis Island, near Gladstone. The proposed coal seam gas fields for this project include Denison, Mahalo, Comet, Arcadia Valley, Fairview, Roma, Scotia and Eastern Surat Basin, among others. The total area of these fields is 33,000 km^2. The

Fairview, Arcadia Valley and Roma fields are proposed to be developed initially, with expansion into other areas to be dictated by the success of the initial development program.

Table B.2lists annual emissions of oxides of nitrogen (NOX, NO and NO_2), total volatile organic compounds (VOCs) and the modelled reaction organic carbon (ROC) emitted from the oil and gas extraction and processing operations currently located in the region and considered in the existing air quality analysis. The modelled release parameters and emission assumptions are detailed in Table B.7.

Table B.2: Emissions from oil and gas operations in existing air quality assessment

Site	Location (UTM 56)		Emissions (kg/a)				
	Northing (m)	Easting (m)	NO	NO_2	NO_x	VOCs	ROCs
Alton Gas Field (Santos)	137,208	7,184,640	0	0	0	206	170
Australia Pacific LNG Project – Coondabri East	237,757	7,034,015	37,677	1,983	39,660	258	230
Australia Pacific LNG Project – Coondabri East	142,113	7,088,140	22,606	1,190	23,796	155	138
Berwyndale South Compressor Station (QGC)	231,376	7,184,081	17,310	155,810	173,100	24,150	19,927
Daandine Gas Field (Arrow)	295,721	7,060,668	12,570	113,160	125,700	2,100	1,730
Denison Trough (APLNG)	45,152	7,009,170	75,000	675,000	750,000	1,000,000	1,156,073
Fairview Gas Field (Santos)	97,612	7,165,396	275,250	2,477,200	3,000,000	432,800	357,028
Fairview Meter Station (Jemena Asset Management)	97,933	7,166,023	0	0	0	2,300	1,889
Fairymount Field (Mosaic Oil)	109,254	7,128,461	0	0	0	1,500	1,231
GLNG	82,523	7,231,091	13,849	729	14,578	0	0
Kenya Compressor Station (QGC)	247,698	6,903,575	6,720	60,520	67,250	9,400	7,746
Kogan Gas Field (Arrow)	295,457	6,945,522	15,850	142,630	158,500	2,400	1,943
Kogan North (APT Petroleum)	288,370	7,045,395	48,140	433,240	481,380	14,000	11,513
Moonie (Santos)	228,487	7,045,961	7,070	63,630	70,700	95,300	78,607
Oakey Gas Gatestation (APT Allgas)	369,552	7,045,404	0	0	0	3,400	2,805
Peat (APLNG)	208,917	6,906,808	23,400	210,560	233,960	3,600	2,998
Roma (Santos)	81,220	7,127,312	0	0	0	2,060	1,704
Scotia (Santos)	206,775	7,119,905	57,930	521,340	579,260	61,000	50,558
Silver Springs Gasfield (Mosaic Oil)	113,208	6,926,453	20,340	183,050	203,400	12,200	10,031
Spring Gully (APLNG)	111,577	7,024,099	230,000	2,070,000	2,000,000	684,200	564,465
Surat (Origin)	84,402	7,024,099	37,000	333,000	370,000	14,000	11,550
Talinga (APLNG)	242,825	7,024,099	31,000	279,000	310,000	44,140	364,156
Tipton Gas Field (Arrow)	313,792	7,023,919	86,400	777,640	864,060	13,290	10,963
Toowoomba AC Plant (Pioneer Road Services)	392,015	7,015,779	272	2,440	2,720	2,030	1,675
Toowoomba Gas Gatestation (APT Allgas)	394,760	7,002,767	0	0	0	13,500	11,138
Wallumbilla LPG Plant (Santos)	122,053	7,003,208	43,520	391,680	435,200	45,260	37,336
Wallumbilla Terminal (Epic Energy)	121,677	6,967,774	2,859	25,730	28,590	340	760

Site	Location (UTM 56)		Emissions (kg/a)				
	Northing (m)	Easting (m)	NO	NO_2	NO_x	VOCs	ROCs
Westgrove Meter Station (Jemena Asset Management)	68,577	6,966,642	0	0	0	1,280	281
Windibri Field Compression Station (QGC)	231,376	6,953,306	13,380	120,430	133,810	18,660	1,056

Emissions estimated from the 2008/2009 NPI data – All sources directly quote online NPI data including site names, locations, registered owners

COAL MINES

Table B.3 lists annual emissions of oxides of nitrogen (NOX, NO and NO_2), total volatile organic compounds (VOCs) and the modelled reactive organic carbon (ROC) emitted from the existing coal mining operations currently located in the region and considered in the existing air quality analyses. The modelled release parameters and emission assumptions are detailed in Table B.7.

Table B.3 Emissions from coal mines in existing air quality assessment

Site	Location (UTM 56)		Emissions (kg/a)				
	Northing (m)	Easting (m)	NO	NO_2	NO_x	VOCs	ROCs
Commodore	330,876	7,019,504	26,227	236,046	262,273	23,897	21,333
Kogan Creek	279,488	7,006,480	17,734	159,608	177,342	16,973	15,152
New Acland	371,100	6,907,023	71,984	647,860	719,845	60,800	54,277
Tarong Coal	390,870	6,982,500	69,709	627,381	697,090	49,878	44,527
Wilkie Creek	297,664	7,034,635	38,197	343,772	381,969	34,388	30,699

Emission estimated from the 2009/2010 NPI data

ELECTRICITY PRODUCTION

Table B.4 lists annual emissions of oxides of nitrogen (NO_X, NO and NO_2), total volatile organic compounds (VOCs) and the modelled reactive organic carbon (ROC) emitted from the power stations currently located in the region and considered in the existing air quality analysis. The modelled release parameters and emission assumptions are detailed in Table B.7.

Table B.4 Emissions from power stations in existing air quality assessments

Site	Location (UTM 56)		Emissions (kg/a)				
	Northing (m)	Easting (m)	NO	NO_2	NO_x	VOCs	ROCs
Baillie Henderson Hospital	394,905	7,060,238	413	3,721	4,135	47	4
Braemar Power Station	292,345	7,020,715	294,396	2,649,566	2,943,962	20,635	1,651
Daandine Power Station	295,967	6,999,566	433,746	3,903,714	4,337,460	125,742	10,060
Kogan Creek Power Station	276,569	7,002,358	599,758	5,397,824	5,997,582	72,672	5,814
Millmerran Power Station	330,635	6,905,724	1,290,000	11,610,000	12,900,000	104,000	8,320
Oakey Power Station	369,477	6,966,179	8,019	72,172	80,191	339	27
Roma Power Station	87,898	7,036,752	43,357	390,216	433,574	2,818	225
Spring Gully Power Station	111,577	7,175,883	112,655	5,929	118,584	2,372	190
Tarong North Power Station	392,070	7,037,783	550,091	4,950,819	5,500,910	32,092	2,567
Tarong Power Station	392,058	6,955,073	2,300,530	20,704,770	23,005,300	110,440	8,835
Toowoomba Hospital	395,876	6,950,016	445	4,005	4,450	44	4

OTHER INDUSTRIAL EMISSIONS

Other industries located within the study area (as determined from a review of the National Pollutant Inventory) which will be sources of air pollutant emissions include:

- Agricultural Industries:
  - pig farms;
  - cattle feedlots;
  - poultry farms;
  - abattoirs;
  - sawmills; and
  - bird and animal food production.
- Fuel Storage and Distribution Depots.

Table B.5 lists annual emissions of oxides of nitrogen (NO_X, NO and NO_2), total volatile organic compounds (VOCs) and the modelled reactive organic carbon (ROC) emitted from the existing agricultural operations currently located in the region and considered in the existing air quality analyses. Table B.6 lists annual emissions of oxides of nitrogen (NO_X, NO and NO_2), total volatile organic compounds (VOCs) and the modelled reactive organic carbon (ROC) emitted from the existing fuel stations and distribution depots located in the region and considered in the existing air quality analyses. The modelled release parameters and emission assumptions are detailed in Table B.7.

Table B.5: Emissions from agricultural industries in existing air quality assessment

Site	Location (UTM 56)		Emissions (kg/a)				
	Easting (m)	Northing (m)	NO	NO_2	NO_x	VOCs	ROCs
Allora Landfill	400,271	7,148,988	0	0	0	570	510
Australian Country Choice ACC Feedlot, Roma	100,153	7,141,717	125	1,124	1,249	20	18
Beef City Abattoir, Purrawanda	363,357	7,063,812	1,000	9,000	10,000	822	734
Beef City Feedlot, Purrawanda	305,831	7,057,906	1,115	10,033	11,148	964	861
Cypress Supplies, Roma	85,236	7,094,261	664	5,978	6,642	498	445
Don KRC, Towoomba	395,754	7,062,063	110	990	1,100	67	59
Hornick Cypress, Roma	83,326	7,106,703	189	1,703	1,892	152	136
Injune Cypress	55,133	6,895,343	1,034	9,306	10,340	826	737
Lapunyah, Lundarva	206,376	7,044,790	3,478	31,303	34,781	2,610	2,330
Leyburn Landfill	361,606	6,819,506	0	0	0	273	243
Mauri Yeast, Toowoomba	395,862	6,955,136	154	1,388	1,542	6,211	5,545
Miamba Feedlot, Condamine	154,463	7,167,427	172	1,544	1,716	81	72
Mundubbera Green Mill	329,393	7,114,658	2,230	20,068	22,298	1,785	1,593
Oakey Abattoir	371,632	7,175,883	3,171	28,538	31,709	640	572
Peanut Company of Australia	384,556	6,898,998	285	2,566	2,851	128	114
Ridley AgriProducts, Toowoomba	393,147	6,957,421	0	0	0	227	203
Slack's Hardwood, Gayndah	354,860	6,965,755	216	1,941	2,157	166	149
Smithfield Feedlot, Proston	351,220	7,064,005	270	2,433	2,703	100	89
Stanthorpe Refuse Site	396,200	6,948,432	0	0	0	2,221	1,983
Swickers Bacon Factory, Kingaroy	401,379	6,956,299	533	4,793	5,325	58	52
Toowoomba Malthouse	395,757	6,826,899	403	3,631	4,034	15,501	13,838
Toowoomba Waste Management Centre	393,984	6,953,979	0	0	0	21,268	18,986
Valley Beef, Grantham	418,653	6,955,267	673	6,060	6,734	289	258
Wandoan Sawmill	201,730	6,949,761	226	2,037	2,263	182	163
Warwick Central Waste Facility	406,536	6,899,181	0	0	0	3,024	2,700
Whyalla Feedlot	307,124	7,067,516	1,477	13,295	14,772	1,131	1,010
Womblebank Sawmilling Company, Injune	61,121	6,874,059	415	3,737	4,153	330	295
Yuleba Cypress Sawmills, Miles	220,516	6,948,104	153	1,374	1,527	122	109

Emission estimated from the 2009/2010 NPI data

Table B.6: Emissions from fuel storage and distribution depots in existing air quality assessment

Site	Location (UTM 56)		Emissions (kg/a)				
	Easting (m)	Northing (m)	NO	NO2	NOx	VOCs	ROGs
AIR BP Roma	83,690	6,896,896	0	0	0	686	613
Reliance Petroleum Depot, Brookstead	346,697	6,888,400	0	0	0	14,638	13,068
Caltex Depot, Goondiwindi	238,631	7,058,826	0	0	0	5,740	5,125
Caltex Depot, Kingaroy	384,179	7,060,168	0	0	0	7,540	6,731
Caltex Depot, Roma	81,153	7,062,145	0	0	0	8,170	7,294
Caltex Depot, Toowoomba	391,201	7,161,730	0	0	0	14,400	12,855
APT Compressor Station, Dalby	322,555	6,974,291	3,130	28,172	31,302	205	183
Patdove Depot, Goondiwindi	237,251	7,047,953	0	0	0	11,302	10,090
APT Compressor Station, Kogan	275,252	6,840,838	2,604	23,437	26,042	170	152
Lowes Depot, Boggabilla	240,924	6,837,969	0	0	0	4,626	4,130
Reliance Petroleum Depot, Miles	220,087	6,832,335	0	0	0	10,657	9,514
Mobil Depot, Chinchilla	264,101	7,040,456	0	0	0	878	7,84
Mobil Depot, Meandarra	189,283	7,009,068	0	0	0	2,322	2,073
Mobil, St George	61,181	6,990,550	0	0	0	1,457	1,300
APT Compressor Station, Oakey	369,693	6,928,834	2,600	23,399	25,999	170	152
Reliance Petroleum Depot, Roma	81,974	6,966,733	0	0	0	7,199	6,427
Reliance Petroleum Depot, St George	74,897	7,061,946	0	0	0	12,305	10,985
Future Fuel Depot, Taroom	184,984	7,088,442	0	0	0	1,025	915
Reliance Petroleum Depot, Toowoomba	393,587	6,952,407	0	0	0	30,276	27,028
Reliance Petroleum Depot, Wondai	386,769	6,948,971	0	0	0	13,557	12,103

Emission estimated from the 2009/2010 NPI data

SUMMARY OF INDUSTRIAL EMISSIONS

The locations of the industrial emission sources are shown in Figure 5.1, with the ten most significant industrial emission sources identified. These sources were identified based on the highest total mass of NO_x and VOCs emitted (kg/a).

The industrial emission sources are all modelled as point sources in the CTM existing air quality assessment. Table B.7contains the generic modelling parameters associated with the industry category.

The NO_x emissions from industrial sources were assumed to be 5% NO_2 and 95% NO, which are fractions typical of combustion (US EPA, 2010).

The portion of VOCs that are considered ROCs has been determined based on emission speciation data from the CARB database (CARB 2010) and given in Table B.7.

Table B.7: Emission source parameters for CTM modelling

Industry	Stack Height (m)	Stack Diameter (m)	Stack Velocity (m/s)	Stack Temperature (K)	ROC/VOC Ratio
Oil and Gas Extraction	10	0.5	6	350	0.825
Coal Mine	10	0.5	6	350	0.893
Electricity Production	80	4.0	30	415	0.080
Other Industrial Emissions	10	0.5	6	350	0.893

Appendix C

Glossary

C.1 GLOSSARY

Term / Phrase	Definition
µg/m³	Microgram per cubic meter
µm	Micrometer
Acid rain	Rain containing acids that form in the atmosphere when industrial gas emissions (especially sulfur dioxide and nitrogen oxides) combine with water.
AIHA	American Industrial Hygiene Association
Air dispersion modelling	Mathematical simulation of how air pollutants disperse in the ambient atmosphere.
Air EPP	Air Environmental Protection Policy (Air EPP)
Airborne concentrations	Concentration moved or conveyed by or through air.
Airshed	An airshed is a part of the atmosphere that behaves in a coherent way with respect to the dispersion of emissions.
Alterations in pulmonary defences	Changes pertaining to the lungs or the respiratory system defences.
Ambient air quality	The state of quality and chemical characteristics of air as it exists in the environment.
Anthropogenic sources	Sources derived from human activities, as opposed to those occurring in biophysical environments without human influence.
API	American Petroleum Institute (API)
ARM	Ambient Ratio Method (ARM)
atm	Atmosphere (unit of pressure)
Biogenic	Produced by living organisms or biological processes.
Buffer distance	Distance that will ensure NO_2 emissions from the IPFs reach a maximum of 75% of the guideline concentrations.
CALPUFF	A multi-layer, multi-species, non-steady state puff dispersion model that can simulate the effects of time- and space-varying meteorological conditions on pollutant transport, transformation and removal.
Capping layer	A capping layer forms at the zone where the cool air below meets the warm air above.
Carbon Monoxide (CO)	Carbon Monoxide (CO) is a toxic, colourless, odourless gas produced by burning any fuel.
CAWCR	Centre for Australian Weather and Climate Research (CAWCR)
CGPF	Central Gas Processing Facility
CH_4	Methane (CH_4)
Coal seam gas (CSG)	Form of natural gas extracted from coal beds.
Combined-cycle gas turbine	Turbine in which the waste heat energy is used to produce electricity.
Convective mixing	The entrainment and deepening of the mixed layer in a lake due to heat loss generally in combination with wind forcing.
CTM	Chemical Transport Model (CTM)
Cyclical	Recurring at regular intervals.
DECCW	Department of Environment Climate Change and Water (DECCW)
Deposition velocity	The deposition velocity is the distance a particle travels toward the ground in a unit of time. It depends on the particle size, particle density and properties of the atmosphere including density and viscosity.
DERM	Department of Environment and Resource Management (DERM)
DEWHA	Department of the Environment, Water, Heritage and the Arts (now known as DSEWPC)
DSEWPC	Department of Sustainability, Environment, Water, Population and

Term / Phrase	Definition
	Communities
Dust deposition	The process of particles (mostly greater than 10 µm in diameter) settling and accumulating on surfaces.
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
Epidemiological studies	Studies of factors affecting the health and illness of populations.
Equilibrium	The condition of a system in which competing influences are balanced, resulting in no net change
Eutrophication of waterways	A process whereby water bodies receive excess nutrients that stimulate excessive plant growth (algae and nuisance plants weeds).
FCF	Field Compression Facility
FIDOL factor	Frequency Intensity Duration Offensiveness Location (FIDOL) factor
Fugitive emissions	Emissions of gases or vapours from pressurised equipment due to leaks and various other unintended or irregular releases of gases, mostly from industrial activities
Fugitive leaks	Uncontrolled releases not caught in a capture system.
GAMS	Gladstone Airshed Modelling Study (GAMS)
Gaussian models	It assumes that the air pollutant dispersion has a Gaussian distribution, meaning that the pollutant distribution has a normal probability distribution.
Ground level ozone	Formed by a chemical reaction between volatile organic pollutants (VOCs) and oxides of nitrogen (NO_x) in the presence of sunlight.
GRS	Generic Reaction Set (GRS)
Haemoglobin	Protein which carries oxygen in the blood.
Heterogeneity	Consisting of elements that are not of the same kind or nature.
IPFs	Integrated Processing Facilities (IPFs)
kg/a	Kilogram per annum
kVA	Kilo volt-ampere
LNG	Liquefied Natural Gas (LNG)
m/s	Meter per second
Mixing height	The height of the mixing.
Mixing layer	Layer where mixing activities occur.
MJ/m³	Megajoules per cubic meter
Mtpa	Mega tonnes per annum (Mtpa)
MW	Megawatt
Myriad	A large indefinite number.
NEPM	National Environment Protection Measure (NEPM)
Nitrogen Dioxide (NO_2)	Nitrogen dioxide (NO_2) is a reddish-brown gas. It is a lung irritant and is present in the highest concentrations among other oxides of nitrogen in ambient air. Nitric oxide (NO) and NO_2 are collectively known as NO_x.
Nm³/sec	Newton cubic metre per second
NMHC	Non Methane Hydrocarbons
NO_x	A generic term for mono-nitrogen oxides (NO and NO_2). The oxides of nitrogen are predominantly (greater than 90%) nitric oxide (NO).
NPI	National Pollutant Inventory (NPI)
O_3 concentrations	Ozone (O_3) concentrations
Open-cycle gas fired turbine	Turbine which the waste heat energy is not used for the production of electricity, it is released to the atmosphere.
Ou	Odour unit (Ou)
Oxidiser	An oxidising agent (also called an oxidant or oxidiser) can be defined as

Term / Phrase	Definition
	either, a chemical compound that readily transfers oxygen atoms, or a substance that gains electrons in a redox chemical reaction. In both cases, the oxidising agent becomes reduced in the process.
Ozone limiting method (OLM)	The ozone limiting method is based on the assumption that approximately 10% of the NO_X emissions are generated as NO_2 .If the ozone concentration is greater than 90% of the predicted NO_X concentrations, all the NO_X is assumed to be converted to NO_2
Particulate matter (PM)	Dust particles that are introduced or resuspended into the air through certain activities such as soil cultivation, or vehicles operating on open fields or dirt roadways.
Percentile	A value on a scale that indicates the percent of a distribution that is equal to it or below it. For example, a score at the 95th percentile is equal to or better than 95 % of the scores.
Photochemical reacting compounds	Chemical reactions that take place in the presence of sunlight. Photochemical reacting compounds are NO_2 and O_3.
Photochemical smog	Formed by chemical reactions that take place in the presence of sunlight between NO_x and VOC and which form ground-level O_3.
Physiological and cognitive processes	Physiological and mentally associated processes.
Pilot well programs	Part of the exploration program used to determine the location of pilot wells.
POEO	NSW DECC Protection of the Environment Operations
PJ	Petajoules (PJ)
PJ/a	Peta joules (PJ) per annum
$PM_{2.5}$	Total of suspended particulate matter less than 2.5 µm in aerodynamic diameter.
ppb	Parts per billion
Proponents	Organisation (private or public sector) or individual intending to implement a development proposal.
QEPA	Queensland Environmental Protection Agency (QEPA)
Qld EP Act 1994	Queensland Environmental Protection Act 1994
Respiratory illness	An illness affecting the respiratory system (system for taking in oxygen and giving off carbon dioxide).
RGSQ	Royal Geographical Society of Queensland (RGSQ)
ROC	Reactive organic carbon (ROC)
scf	Standard cubic foot
Screening level analysis	A gas-phase mechanism that consists of seven chemical reactions of seven compounds.
Seismic programs	Part of the exploration program used to determine the seismic data, thickness and depth of an area.
Sensitive receptors	Receptors sensitive to toxic VOC emissions.
SEQ	South East Queensland (SEQ)
Sm^3	Standard cubic metre
SRTM	Shuttle Radar Topography Mission (SRTM)
Stochastic uncertainties	Random uncertainties.
Sulphur Dioxide (SO_2)	A toxic gas found in the emissions of volcanos and from burning of coal or petroleum. Dissolves in water to form sulphurous acid and, in the presence of oxygen, sulphuric acid.
t	Tonnes
Temperature inversion	Refers to a layer of air in the atmosphere in which the temperature cools at a much lower rate (or even warms) with height than in other parts of the atmosphere.
Temporal	Limited by time.

Term / Phrase	Definition
Tenures	Allow the holder to undertake production and exploration activities.
TJ	Terajoule
tpd	Tonnes per day
Transient	Stationary for only a short time.
TSP	Total suspended particles (TSP)
TVOC	Total Volatile Organic Compounds
Ubiquitous	Nature of being everywhere at any given time.
US EPA	United States Environmental Protection Agency (US EPA)
USGS	United States Geological Service (USGS)
UTM	Universal Transverse Mercator (UTM)
Variable plume trajectories	Variable plume trajectories occur via wind changes or variable rates of plume diffusion.
Viscosity	Resistance of a liquid to shear forces and hence to flow.
Volatile Organic Compounds (VOCs)	Any organic compound which participates in atmospheric photochemical reactions (In this assessment methane is not included).
Wind roses	Show the frequency of occurrence of winds by direction and strength.