21. AIR QUALITY

This chapter identifies air quality environmental values, describes existing conditions and assesses impacts to air quality associated with project construction, commissioning, operation and decommissioning. The measures Arrow Energy will implement through project design, construction, commissioning, operation and decommissioning to address impacts on these environmental values, are also described.

This chapter is based on the findings and information in the air quality impact assessment (Appendix 14, Air Quality Impact Assessment) prepared by Katestone Environmental Pty Ltd. The objectives for air quality are shown in Box 21.1 and are derived from the legislative policies described below.

Box 21.1 Objectives: Air quality

- To avoid or reduce potential adverse effects on air quality in sensitive receptor areas during project construction and operation.
- To achieve project air quality objectives during construction and operation.
- To identify mitigation strategies to reduce adverse effects on air quality environmental values to an acceptable level.

Impacts on civil aviation due to atmospheric turbulence caused by plume rise (from gas turbine exhaust stack and flare stack exhausts) are addressed in Chapter 29, Hazard and Risk.

21.1 Legislative Context and Standards

This section describes relevant international, Commonwealth and state legislation, guidelines, methods and policies designed to protect air quality environmental values during project construction and operation. The documents provide the framework within which the air quality impact assessment was performed.

A number of air pollutants that have been assessed for the project are not listed in Queensland regulations. Criteria for assessing these pollutants have therefore been taken from regulations and guidelines from other Australian states and international jurisdictions, as appropriate.

21.1.1 International Framework

Where Queensland and Australian regulations do not provide guidance for assessing and managing impacts on air quality through all project phases, the following international guidelines and treaties have been considered:

- Current methods in preparing mobile source port-relegated emission inventories (US EPA, 2009), which provide emission factors required to characterise emissions from LNG carriers and tug boats that will be used during LNG export activities.
- Compilation of air pollution emission factors (US EPA, 1995), which describes emission factors to be used for flaring activities at the LNG plant.
- Effects screening levels (TCEQ, 2008), which provide air quality objectives for a range of hydrocarbons that will be emitted by the project through the combustion of carbon-based fuels.

- Montreal Protocol on substances that deplete the ozone layer (UNEP, 2009), which is an international treaty designed to protect the ozone layer by prohibiting substances believed to be responsible for ozone depletion.

21.1.2 Commonwealth Guidelines and Measures

The following Commonwealth measures and guidelines are relevant to managing impacts on air quality through all project phases:

- National Environment Protection (Ambient Air Quality) Measure, which defines national ambient air quality standards and goals determined in consultation with all state governments. Compliance with these standards is assessed via air quality monitoring at sites representative of large urban populations.
- The emission estimation technique manual for combustion engines (DEWHA, 2008b), which provides procedures for estimating emissions for combustion gases emitted from engines.
- The emission estimation technique manual for marine operations (DEWHA, 2008c), which describes methods for estimating emissions to the atmosphere from equipment used during marine operations.

21.1.3 State Legislation, Policies and Guidelines

Queensland legislation, guidelines and policies relevant to project activities are described below. Where Queensland legislation, guidelines and policies do not provide guidance, New South Wales' methods and regulations have been considered:

- *Environmental Protection Act 1994*. This act provides for the protection of the air environment in Queensland while allowing for ecologically sustainable development. Subordinate to the act is the Environmental Protection (Air) Policy 2008 (EPP (Air), which identifies environmental values of the air environment to be enhanced or protected, thereby achieving the objectives of the act. The policy sets out indicators and air quality objectives aimed at protecting environmental values and provides a framework for making consistent, equitable and informed decisions about the air environment. Air quality objectives are based on goals set out in the National Environment Protection (Ambient Air Quality) Measure.
- Guidelines for the impact assessment of odour from developments (EPA, 2004). These define criteria for assessing annoyance from odours resulting from emissions from combustion equipment and flaring activities.
- Approved methods for the modelling and assessment of air pollutants in New South Wales (NSW DEC, 2005). The methods provide air quality objectives for pollutants that will be emitted by the project, but are not addressed in the EPP (Air).
- Protection of the Environment Operations (Clean Air) Regulation 2002. This is administered under the New South Wales *Protection of the Environment Operations Act 1997* and provides standards for emission concentrations of pollutants from equipment such as gas turbines, pumps and combustion equipment.

21.2 Assessment Method

This section describes the air quality impact assessment study methods, which apply the compliance assessment method. The legislation, regulations, guidelines, policies and methods described above have been used to establish air quality targets for the project. This approach allows impacts on air quality to be assessed in direct terms, i.e., if project air quality targets are met, impacts on environmental values in sensitive receptor areas will be acceptable.

The air quality impact assessment study area is shown in Figure 21.1 and encompasses all sensitive receptor areas relating to human health and wellbeing and aesthetics that may be

impacted by project activities, i.e., project-related impacts on air quality will be greatest within this area. Additional sensitive areas that may be impacted by the project relate to the health and biodiversity of ecosystems and protecting agricultural use. These areas are shown in Figure 17.3.

The air quality impact assessment included:

- Setting air quality targets for the project.
- Characterising atmospheric and air quality baseline conditions in the study area.
- Identifying project emission sources that may affect air quality and therefore require assessment.
- Dispersion modelling to determine the behaviour and fate of air pollutants emitted to the atmosphere from project activities.
- Assessing impacts on air quality using the compliance assessment method.

21.2.1 Baseline Assessment

This section describes the approach to establishing existing conditions in the study area though direct measurements, data modelling and analysis.

Direct Measurements

The Queensland Government Department of Environment and Resource Management (DERM) operates a network of ambient air quality monitoring stations in the Gladstone region. The location of these monitoring stations is shown in Figure 21.1.

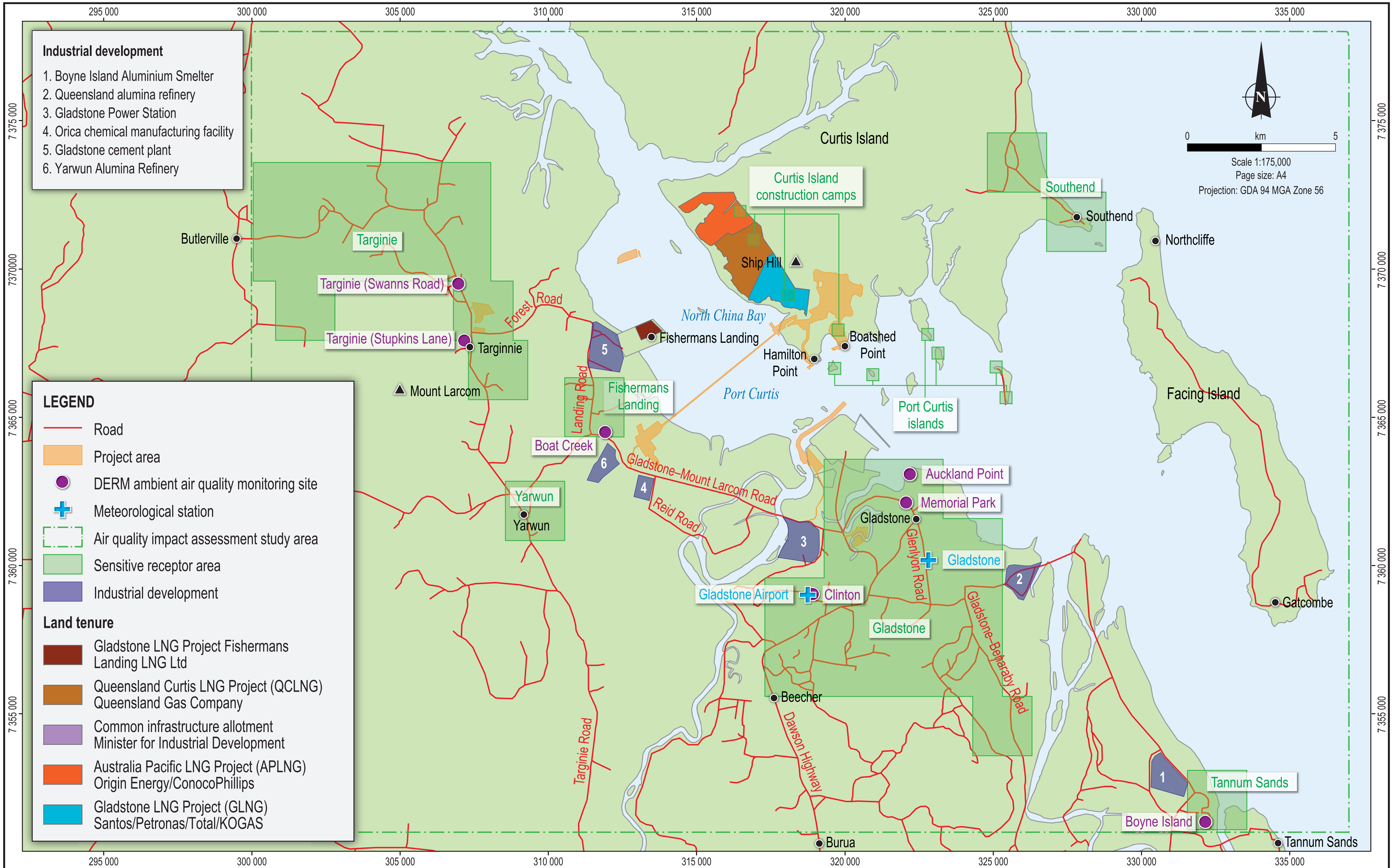
Table 21.1 shows the period of record at the monitoring stations, and the air pollutants (analysed at each location) that will be directly emitted from the LNG plant or subsequently formed via atmospheric photochemical reactions.

Table 21.1 DERM ambient air quality monitoring stations

Monitoring Station	Period of Record		Air Pollutants Monitored and Analysed[1]
	Start	End	
Boat Creek	June 2008	December 2010	NO_2, PM_{10}, $PM_{2.5}$
Clinton	February 2001	December 2010	NO_2, PM_{10}
Targinie (Swanns Road)	January 1997	December 2010	NO_2, PM_{10}, $PM_{2.5}$
Targinie (Stupkins Lane)	January 2001	December 2010	PM_{10}, O_3
Boyne Island	October 2008	December 2010	CO, NO_2, SO_2, PM_{10}, $PM_{2.5}$.
Auckland Point	July 2009	December 2010	O_3
Memorial Park	July 2009	December 2010	O_3

[1] NO_2 - nitrogen dioxide, O_3 - ozone, CO - carbon monoxide, SO_2 - sulfur dioxide, PM_{10} - particulate matter with an aerodynamic diameter less than 10 microns, $PM_{2.5}$ - particulate matter with an aerodynamic diameter less than 2.5 microns

Data from the monitoring stations was used to establish the baseline air quality conditions in the air quality impact assessment study area.



Source:
Place names and roads from DME.
Ambient air quality monitoring sites from DERM.
Sensitive receptor areas and existing industry from Katestone.
Meterological sites from BoM.
Project area and land tenure proponents from Coffey Environments. Coastline from GBRMPA.

coffey environments

Date: 16.11.2011
MXD: 7033CA_07_GIS195_v1_2
File Name: 7033_07_F21.01_GIS_GL

Arrow Energy
Arrow LNG Plant

arrow energy go further

Air quality impact assessment study area

Figure No: 21.1

Results from a monitoring program (Queensland Health, 2009) conducted as part of the Queensland Government Clean and Healthy Air for Gladstone Project was used to establish existing levels of volatile organic compounds likely to be emitted from the LNG plant.

The Bureau of Meteorology operates two meteorological stations in the region (see Figure 21.1), which record a number of parameters, including air temperature, wind speed and direction.

Data Modelling and Analysis

Data from the meteorological stations was incorporated into the Gladstone Airshed Modelling System version 3 (GAMSv3) computer dispersion model to characterise wind statistics in the air quality impact assessment study area.

The GAMSv3 model predicts atmospheric behaviour and ground-level concentrations of pollutants at a 250 m grid resolution. The model was developed for the Queensland Department of Local Government and Planning in 2008 for use in planning studies. The model has been calibrated for use in the air quality impact assessment study area by comparing model results with actual meteorological measurements. A detailed discussion of the model performance, accuracy and limitations is provided in Appendix B of Appendix 14, Air Quality Impact Assessment, and shows that model errors are within the recommended evaluation factors set out in the National Institute of Water and Atmospheric Research Good Practice Guide for Atmospheric Dispersion Modelling (NIWA, 2004).

Atmospheric stability and mixing height are parameters that describe the turbulent state of the atmosphere and, in combination with wind direction and wind speed, affect the dispersion of air pollutants emitted from an industrial source (e.g., the LNG plant). Atmospheric stability is the measure of the properties of the atmosphere that govern the vertical motion of air: the greater the instability, the greater the vertical motion of air and the generation of convective cells. Conversely, in a stable atmosphere, the vertical motion of air tends to be suppressed.

The US EPA-approved solar radiation/delta-T method was used to calculate atmospheric stability, and the Pasquill-Gifford scheme (US EPA, 1993) was used to classify these results as follows:

- Class A: highly unstable and convective.
- Class B: moderately unstable.
- Class C: slightly unstable.
- Class D: neutral conditions.
- Class E: slightly stable.
- Class F: stable.

Under stable atmospheric conditions (Classes E and F), ambient air temperature decreases as altitude increases. A plume released from an elevated stack will continue to rise until it cools to the temperature of the surrounding air.

During the night, atmospheric conditions are generally neutral or stable and, under very stable conditions, an inversion layer may develop where temperature increases with height. A plume, which lacks sufficient vertical momentum or thermal buoyancy, released below an inversion layer may not be able to penetrate the inversion layer and will be trapped beneath it, resulting in elevated ground-level concentrations. Conversely, a plume that is hotter than ambient air temperatures and emitted above an inversion layer (or has sufficient momentum to penetrate the inversion layer) will disperse relatively slowly and will not reach the ground unless it encounters elevated terrain.

Convective mixing is the dominant driving mechanism during unstable conditions (i.e., Classes A to C). A plume emitted from an elevated stack during unstable atmospheric conditions will reach the ground closer to the point of release than would occur under neutral (i.e., Class D) or stable (Classes E and F) atmospheric conditions.

The meteorological model CALMET was used to calculate temporal variations in mixing height above the LNG plant site and across the air quality impact assessment study area. Mixing height is the distance from the ground to the base of an inversion layer, within which pollutants emitted from an industrial source can freely mix with the ambient atmosphere. During the day, solar heating of the ground causes the air above it to warm, expand and rise, resulting in growth of the mixing height. In the absence of the sun at night, the ground cools and, in turn, cools the air above it, causing the mixing height to reduce.

21.2.2 Impact Assessment

A sensitivity analysis was undertaken to determine the configuration of the LNG plant that will cause greatest impacts on air quality. Results show that air quality impacts will be greatest when four LNG trains are operating and powered by mechanical drives operating at 100% capacity. This scenario, including the impacts on air quality from pilot flaring, LNG carriers and tug boats, was used as the basis for assessing impacts from routine operation.

Impacts on air quality from project operation have been assessed within the context of all existing industrial developments in the Gladstone region that affect air quality. Projects that are either under construction or have taken a final investment decision to proceed have also been included in the impact assessment. These are shown in Figure 21.1 and are listed below:

- The coal fired Gladstone Power Station operated by NRG Gladstone Operating Services.
- The alumina refinery in Gladstone operated by Queensland Alumina Ltd.
- The Boyne Island Aluminium Smelter operated by Boyne Smelters Ltd.
- The Yarwun Alumina Refinery (including the expansion project) operated by Rio Tinto Alcan.
- The Gladstone Cement Plant operated by Cement Australia.
- The chemical manufacturing facility at Yarwun operated by Orica Australia Pty Ltd.
- Australia Pacific LNG Project.
- Queensland Curtis LNG Project.
- Gladstone LNG Project.
- Gladstone LNG Project Fishermans Landing.

The major pollutants produced during operation will be oxides of nitrogen (NO_x) as NO_2 from LNG plant gas turbine generator emissions and SO_2 from LNG carriers (and tug boats used to assist LNG carriers). The GAMSv3 computer dispersion model was used to assess impacts on air quality from these pollutants.

Other pollutants associated with project operation include ozone, carbon monoxide, hydrocarbons (including volatile organic compounds), PM_{10}, $PM_{2.5}$, and odour. Ozone will not be directly emitted from the LNG plant but can potentially be generated as a result of chemical reactions between sunlight and pollutants emitted from existing industry and the LNG plant (i.e., nitrogen oxides and volatile organic compounds).

A conservative approach to assessing ozone formation was adopted where 100% of ground-level NO_2 emitted from the LNG plant was assumed to photochemically react and form ozone within a distance of 10 km from the site.

Impacts on air quality from emissions of ozone, carbon monoxide, PM_{10}, $PM_{2.5}$, hydrocarbons, and odour during routine operation and non-routine events (i.e., cold flaring during plant upsets and emergency situations) were assessed using the GAMSv3 computer dispersion model.

The air pollutant emission factors used in the impact assessment for various project components were based on Arrow Energy plant design specifications, equipment manufacturer specifications and emission factors and methods.

Impacts on air quality during construction have been qualitatively assessed, and impacts will be ameliorated by the management procedures described in this chapter.

Sensitive Receptor Areas

Sensitive receptor areas close to the LNG plant are shown in Figure 21.1. They include residences and community facilities on the mainland and Curtis Island, as well as residences on islands in Port Curtis:

- Tannum Sands.
- Gladstone.
- Yarwun.
- Fishermans Landing.
- Targinie.
- Port Curtis islands.
- Curtis Island construction camps.
- Southend.

The nearest single residence is located on Tide Island, approximately 1.6 km south of the LNG plant site. Gladstone city is located approximately 4.5 km southeast of the site.

Construction camps associated with the Queensland Curtis LNG Project, Australia Pacific LNG Project and Gladstone LNG Project have also been included as non-project sensitive receptor areas.

The Arrow Energy construction camp at Boatshed Point has been included as a sensitive receptor area. Temporary workers accommodation facilities for the project are located within mainland sensitive receptor areas, and impacts on air quality for these project components have also been included in the impact assessment.

Environmental Values and Impact Assessment Criteria

Environmental values are qualities or physical characteristics of the environment that are conducive to ecological health, public amenity or safety; and they are a measure of how we value the environment in which we live.

The EPP (Air) defines four environmental values to be enhanced or protected within sensitive receptor areas. These are the qualities of the air environment that are conducive to:

- Health and biodiversity of ecosystems (including terrestrial flora and fauna).
- Human health and wellbeing.
- The aesthetics of the environment, including the appearance of buildings, structures and other property, and nuisance caused by odours and dust.
- Agricultural use of the environment.

Ambient air quality criteria used in the assessment aim to protect these environmental values. The criteria are largely derived from those set out in the EPP (Air). Criteria for pollutants not specified in the policy are based on objectives set out in the following policies, guidelines and methods:

- Approved methods for the modelling and assessment of air pollutants in New South Wales (NSW DEC, 2005).
- Texas effects screening levels (TCEQ, 2008).
- Guideline for odour impact assessment from developments (EPA, 2004).

The air quality criteria are detailed in Table 21.2. A detailed explanation of how criteria were selected for each air quality indicator used in the assessment is provided in Appendix 14, Air Quality Impact Assessment.

Pollutant indicators, which can affect each environmental value, are cross referenced in Table 21.2. For example, the pollutants, which can impact the health and biodiversity of ecosystems environmental value, are limited to 1-year average NO_2 and 1-year average SO_2. Conversely, the human health and wellbeing environmental value can be affected by most of the pollutants listed in Table 21.2. If the project targets for each pollutant for human health and wellbeing are achieved at relevant sensitive receptor areas, the human health and wellbeing environmental values will also be protected in these areas.

Table 21.2 Air quality assessment criteria

Indicator	Environmental Value	Averaging Period	Project Target	Source
Nitrogen dioxide (NO_2)	Human health and wellbeing	1 hour (99.9th percentile)[a]	250 µg/m³	Environmental Protection (Air) Policy
		1 year	62 µg/m³	
	Health and biodiversity of ecosystems	1 year	33 µg/m³	
Sulfur dioxide (SO_2)	Human health and wellbeing	1 hour (99.9th percentile)[a]	570 µg/m³	
		24 hours[a]	230 µg/m³	
		1 year	57 µg/m³	
	Protecting agricultural use	1 year	32 µg/m³	
	Health and biodiversity of ecosystems	1 year	22 µg/m³	
Carbon monoxide (CO)	Human health and wellbeing	8 hours[a]	11,000 µg/m³	
Particles as PM_{10}	Human health and wellbeing	24 hours[b]	50 µg/m³	
Particles as $PM_{2.5}$	Human health and wellbeing	24 hours	25 µg/m³	
		1 year	8 µg/m³	
Ozone (O_3)	Human health and wellbeing	1 hour[a]	210 µg/m³	
		4 hours[a]	160 µg/m³	
Benzene	Human health and wellbeing	Annual	10 µg/m³	
1,3-Butadiene	Human health and wellbeing	Annual	2.4 µg/m³	
Formaldehyde	Human health and wellbeing	24 hours	54 µg/m³	
	Aesthetics (odour)	30 minutes	110 µg/m³	

Table 21.2 Air quality assessment criteria (cont'd)

Indicator	Environmental Value	Averaging Period	Project Target	Source
Toluene	Aesthetics (odour)	30 minutes	1,100 µg/m³	Environmental Protection (Air) Policy
	Human health and wellbeing	24 hours	4,100 µg/m³	
		Annual	410 µg/m³	
Xylene	Human health and wellbeing	24 hours	1,200 µg/m³	
		Annual	950 µg/m³	
Acetylene	Human health and wellbeing	1 hour	26,600 µg/m³	Texas Commission on Environmental Quality Effects Screening Levels
Ethane	Human health and wellbeing	1 hour	12,000 µg/m³	
Propane	Human health and wellbeing	1 hour	18,000 µg/m³	
Propylene	Human health and wellbeing	1 hour	8,750 µg/m³	
Acetaldehyde	Human health and wellbeing	1 hour (99.9th percentile)	42 µg/m³	Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales
Acrolein	Human health and wellbeing	1 hour (99.9th percentile)	0.42 µg/m³	
Dioxins and furans	Human health and wellbeing	1 hour (99.9th percentile)	2×10^{-6} µg/m³	
Ethylbenzene	Human health and wellbeing	1 hour (99.9th percentile)	8,000 µg/m³	
Odour for tall stacks	Aesthetics (odour)	1 hour (99.5th percentile)	0.5 Odour units[c]	Guideline-Odour Impact Assessment from Developments
Odour for ground-level sources and short stacks	Aesthetics (odour)	1 hour (99.5th percentile)	2.5 Odour units[c]	

[a] Target can be exceeded one day every year.
[b] Target can be exceeded five days every year.
[c] An odour unit is defined as the number of times a sample must be diluted to reach its detection threshold.

21.3 Existing Environment and Environmental Values

The terrain and local meteorological conditions influence the behaviour of air emissions and are described below, together with an overview of existing air quality in the region.

21.3.1 Air Temperature

The project is located in the subtropics, and long-term monthly average temperatures are typical of subtropical coastal climates. Mean monthly temperatures vary between 21°C and 23°C during the summer, and mean maximum temperatures are usually 30°C to 32°C. Temperatures exceed 35°C on average 4.4 days per year. The highest recorded temperature of 42°C occurred in March 2007.

During the winter months, mean monthly temperatures are between 12°C and 14°C, and mean maximum temperatures are between 22°C and 23°C. July is generally the coldest month, although, the lowest recorded temperature of 3.5°C was in August 2003.

During the day, temperatures are highest between midday and 2 p.m., and the coolest part of the day occurs immediately before sunrise (i.e., between 4 a.m. and 6 a.m.).

21.3.2 Wind Speed and Direction

The LNG plant site is located on relatively flat terrain on Curtis Island. This coastal, subtropical location is reflected in the meteorology, with strong land to sea interactions superimposed upon the dominant regional weather patterns that include the southeast trade winds.

The annual distribution of winds at the LNG plant site are shown in the wind rose in Figure 10.1. The southeast trade winds dominate, with winds from this direction accounting for 66% of the annual winds. Winds are strongest during the summer, when winds are dominated by southeasterly and, to a lesser extent, northeasterly breezes. Winds are lighter during spring and blow from the same direction as summer winds. Autumn and winter winds are dominated by southeasterly and southwesterly winds.

Wind patterns change over the course of a day and are strongest between the hours of 12.00 p.m. (noon) and 6.00 p.m. During the spring and summer months, the sea breeze tends to strengthen during the day, and changes from a southeasterly morning breeze to a northeasterly breeze in the late afternoon and evening. A small ridge to the north of the LNG plant site can generate light evening winds, which flow down the ridge to the coast.

The wind conditions at the LNG plant site provide for relatively good dispersion conditions for emissions sources. The prevailing southeasterly winds at the site will transport emission plumes away from Gladstone; and winds likely to carry emissions towards the city occur very infrequently.

21.3.3 Atmospheric Stability and Mixing Heights

Table 21.3 shows the percentage distribution of different classes of atmospheric stability at the LNG plant site. The high percentage of Class D stability is indicative of a coastal setting where the high heat capacity of water dampens the development of a strong convective boundary layer. A similar effect occurs at night, where the warmth of the water prevents the development of strong temperature inversions.

Table 21.3 Atmospheric stability at the LNG plant site

Atmospheric Stability Class	Frequency (%)
A – Extremely unstable	2
B – Unstable	12
C – Slightly unstable	15
D – Neutral	59
E – Slightly stable	5
F – Stable	7

The height above ground within which a plume can mix with ambient air is described as the mixing height and it can vary over the course of a day. The increase in the mixing height is dependent on how well the air can mix with the cooler upper levels of air, and therefore depends on meteorological factors such as the intensity of solar radiation and wind speed. Computer modelling for the site shows that, between the hours of 6.00 p.m. and 5.00 a.m., average mixing heights sit 350 m above ground level and do not generally change height.

During the day, solar radiation heats the air at ground level and causes the mixing height to rise and a boundary layer to develop. Average mixing heights increase to 1,000 m above ground level (maximum heights reach 2,000 m above the ground), and peak about 1.00 p.m.

21.3.4 Existing Air Quality

Gladstone is a major industrial centre with numerous chemical and mineral processing facilities located in the region, as well as a coal-fired power station and materials handling facilities. These facilities emit pollutants to the atmosphere and affect air quality in the region.

Existing ambient air quality in the air quality impact assessment study area has been monitored by DERM at a number of locations (see Figure 21.1) over the period January 1997 to December 2010 (see Table 21.1). A comparison with the air quality criteria set out in Table 21.2 shows that NO_2, SO_2, CO, O_3 did not exceed the targets over the period of record. Several exceedences of the 24 hour average project targets for PM_{10} and $PM_{2.5}$ and one exceedence of the annual average project target for $PM_{2.5}$ occurred in 2009. These exceedences were due to dust storms and bushfires, including a major dust storm in September of that year that affected much of eastern Australia and Queensland.

Monitoring data from the Clean and Healthy Air for Gladstone Project (Queensland Health, 2009) show that existing maximum concentrations of volatile organic compounds are well below project targets.

21.3.5 Environmental Values

Existing air quality in the air quality impact assessment study area is such that at present environment values, for the most part, are not being adversely affected by existing industry and activities in the region. The exception is the environmental value relating to human health and wellbeing, where PM_{10} and $PM_{2.5}$ (used as indicators for the condition of this environmental value) were adversely affected due to the dust storms and bushfires in 2009.

21.4 Issues and Potential Impacts

This section describes impacts on air quality during project construction, commissioning, operation and decommissioning. Project air quality assessment criteria used in this section are provided in Table 21.2.

21.4.1 Construction and Commissioning

Emissions to the atmosphere during the construction period will consist of fugitive dust generated during earthworks (due to vegetation and soil removal, and wind erosion of exposed surfaces, soil stockpiles and spoil), together with exhaust emissions (from construction vehicles and earthmoving equipment, operation of a concrete batching plant and minor emissions from welding fumes). These sources will temporarily increase the local concentrations of airborne particulate matter and combustion gases.

Compared with emissions in the operation phase, combustion gas emission rates during construction are low and short term in duration, and generation of fugitive dust will largely be restricted to site. Impacts during construction have not been assessed further and will be ameliorated by the management measures described in this chapter.

Disposal of feed gases via the flare system will be required during commissioning of the LNG plant. Flare emissions during these activities will produce fewer emissions to the atmosphere than those occurring during non-routine flaring events, which are assessed below. Emissions will be lower because the LNG plant will not be operating at full load during the commissioning phase; it will be operating at a lower pressure with resultant lower throughput in the LNG trains. Consequently, impacts on air quality during plant commissioning have not been assessed.

21.4.2 Operation

The major pollutants produced during operation are oxides of nitrogen (NO_x) as NO_2 from gas turbine generator emissions from the LNG plant and SO_2 from LNG carriers and the tugs used to assist these carriers. Emissions to the atmosphere associated with equipment, materials and personnel transfer at the materials offloading facility (MOF) and personnel jetty and mainland launch site are relatively minor; therefore, they have not been assessed.

Table 21.4 summarises all air pollutant compounds that will be emitted to the atmosphere during routine operation and non-routine events, along with their sources. The pollutants that can cause odours are acetaldehyde, NO_2, formaldehyde, toluene, benzene and SO_2.

Table 21.4 Routine operation and non-routine events air pollutants and emission sources

Pollutant Source	Pollutant Compound
Routine Operation	
30-MW gas turbine generators 100-MW gas turbine drives Flare pilot	NO_x, CO, PM_{10}, $PM_{2.5}$, 1,3-butadiene, acetaldehyde, acrolein, benzene, ethylbenzene, formaldehyde, toluene, xylene
LNG carriers and tug boats	NO_x, SO_2, CO, PM_{10}, $PM_{2.5}$, benzene, ethylbenzene, formaldehyde, toluene, xylene, dioxins and furans
Non-routine Events	
Cold flare	NO_x, CO, methane, acetylene, ethane, ethylene, propane, propylene

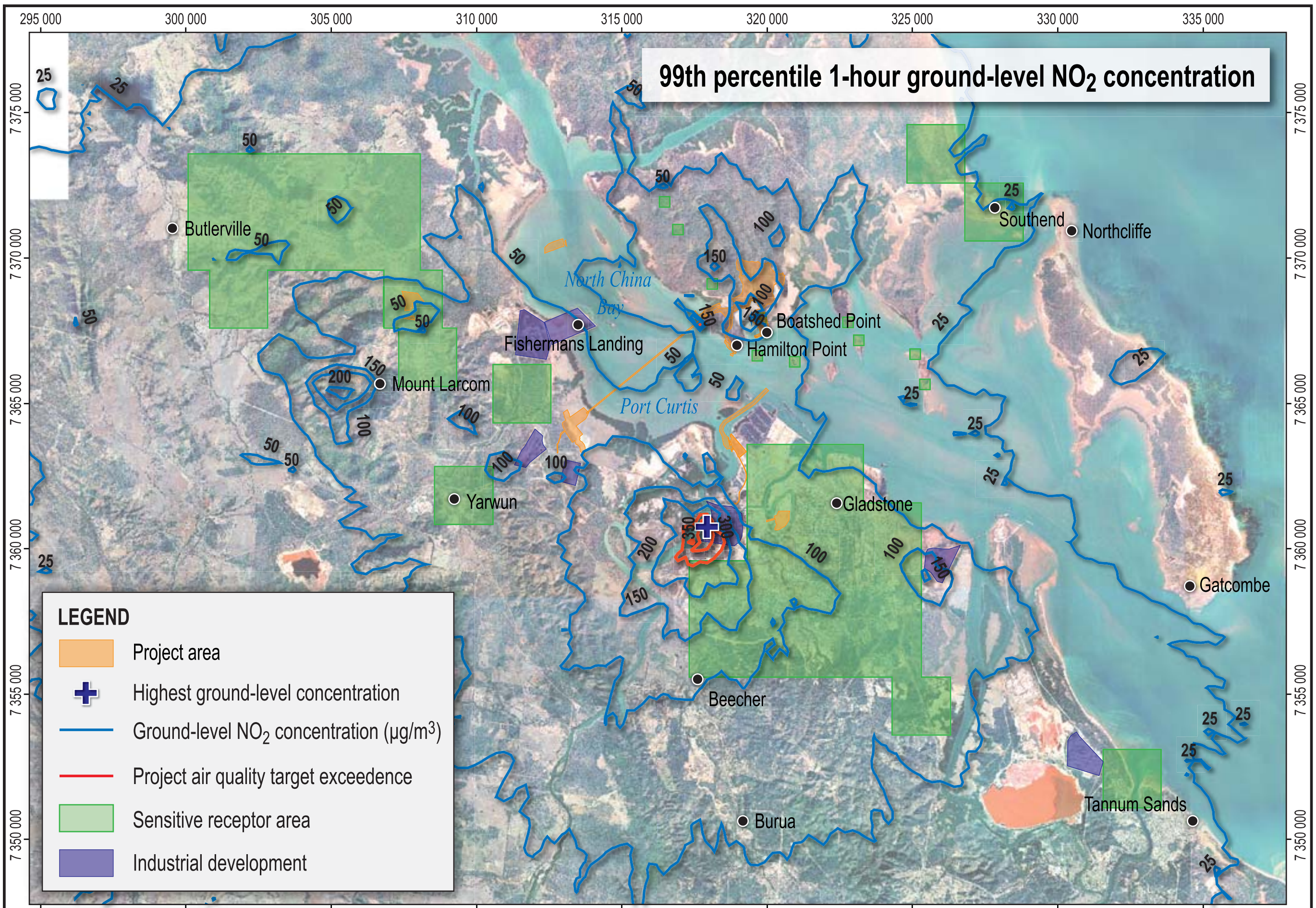
Emissions during routine operation and those that occur infrequently due to non-routine events can adversely affect air quality environmental values (i.e., the health and biodiversity of ecosystems, human health and wellbeing, aesthetics and agricultural use), particularly if air quality criteria are exceeded in sensitive receptor areas. The impacts in this section have been assessed in the context of the air quality criteria (see Table 21.2) for cumulative impacts associated with existing industry, those under construction and proposed future developments.

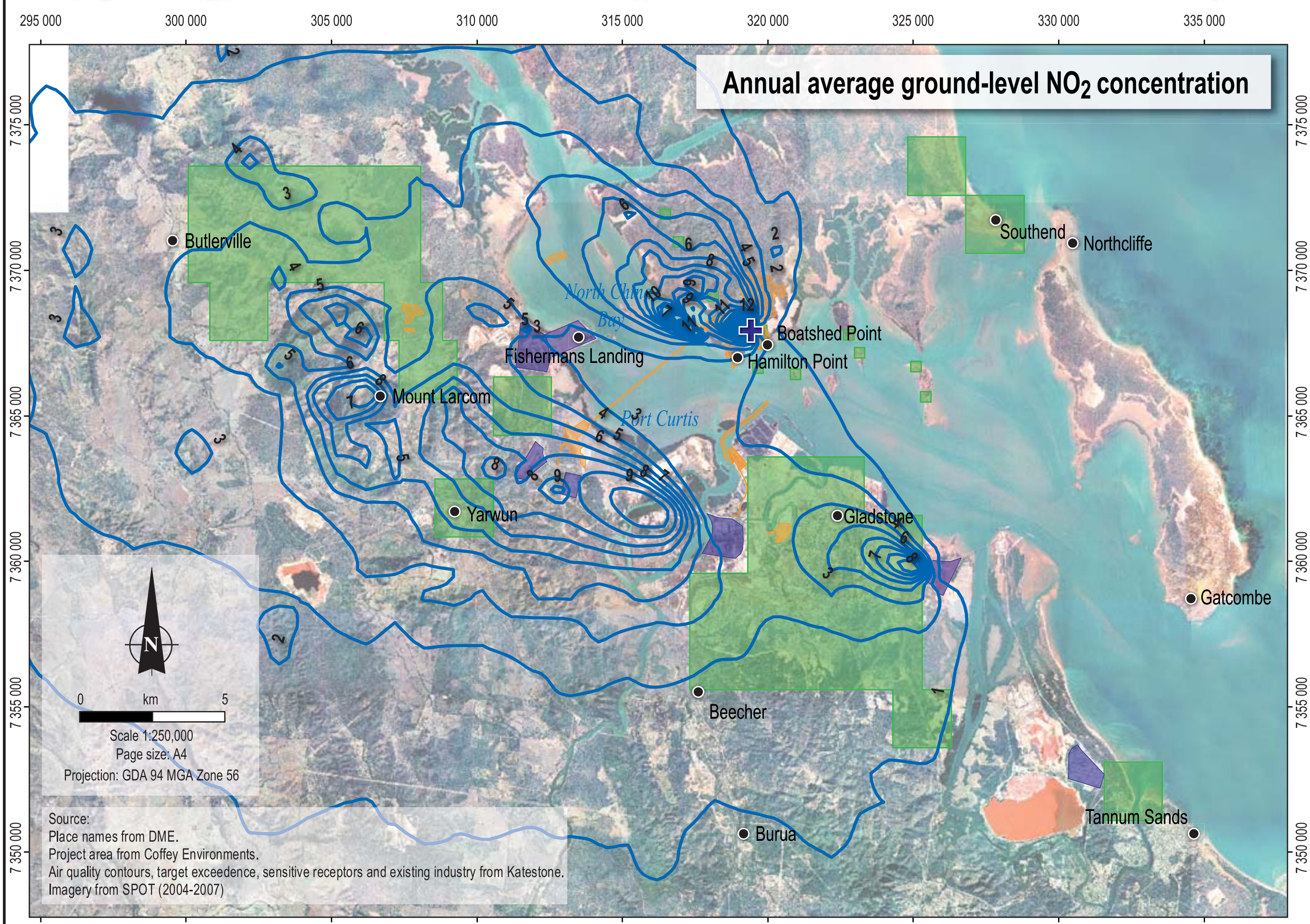
Routine Operation

The dispersion modelling results for NO_2 are provided in Figure 21.2 and predict that air quality criteria for the project will not be exceeded in any sensitive receptor areas. The criteria for 1-hour average NO_2 ground level concentrations is predicted to be exceeded outside of the sensitive receptor areas. This exceedence occurs immediately downwind of the coal-fired Gladstone Power Station and is due to operation of this facility, not the Arrow Energy LNG plant.

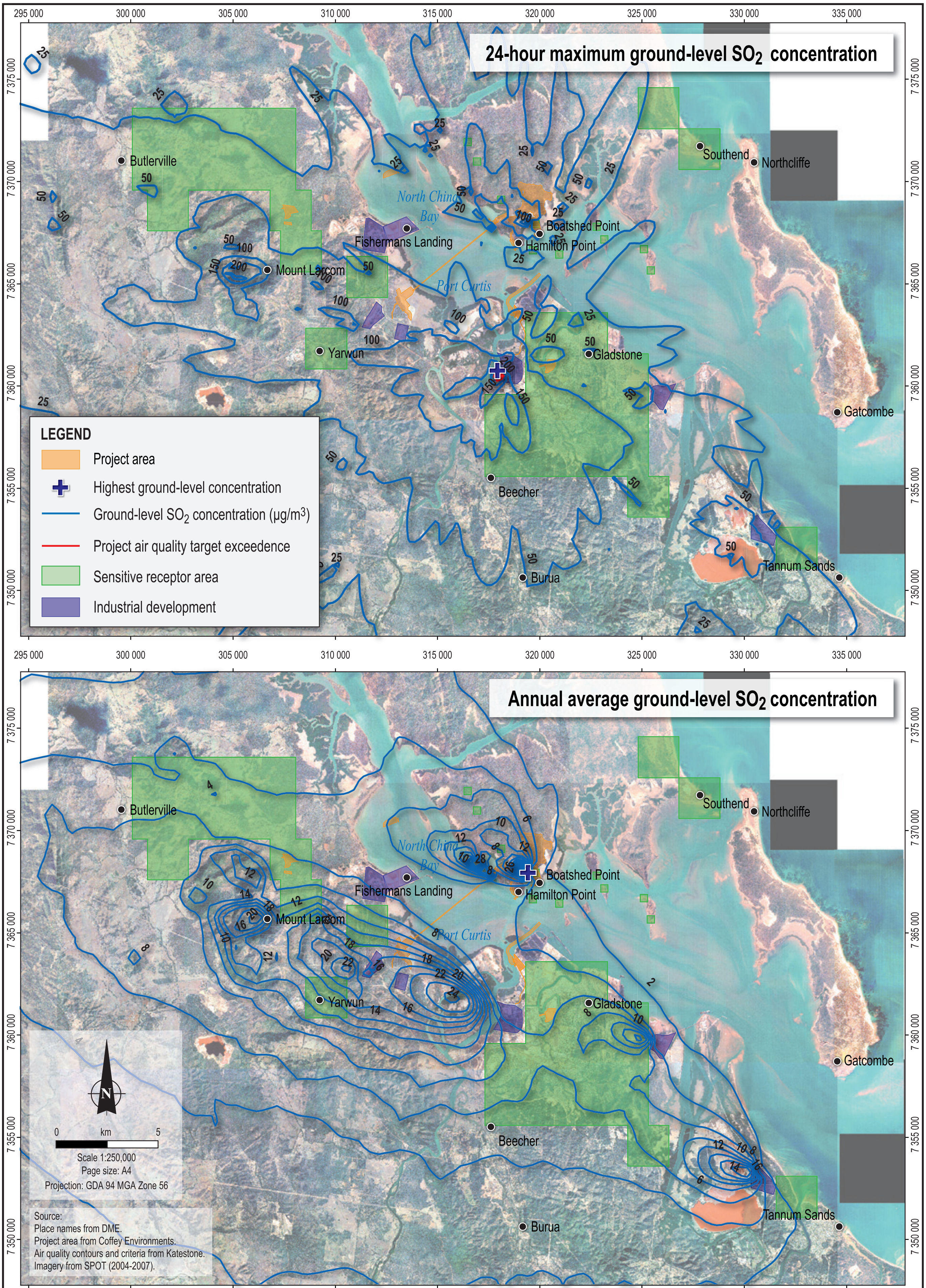
Environmentally sensitive areas within and adjacent to the air quality impact assessment study area are shown in Figure 17.2. Dispersion modelling shows that the NO_2 criteria for the protection of health and biodiversity of ecosystems (i.e., flora and fauna) are not exceeded anywhere.

The dispersion modelling results for SO_2 are provided in Figure 21.3. Predicted concentrations of CO during operation are provided in Table 21.5. The results show that criteria for both SO_2 and CO are not exceeded within any sensitive receptor areas or areas where essential habitat occur, including the area of vine thicket at the southern extent of Boatshed Point. SO_2 concentrations do exceed air quality criteria for the protection of health and biodiversity of ecosystems (but not for any other environmental value) within the boundary of the LNG plant site and offshore Curtis Island in North China Bay, where essential habitat does not occur (Figure 17.3).





coffey environments	Date: 13.02.2011 MXT: 7033CA_07_GIS126_v1_6 File Name: 7033_07_F21.02_GIS_GL	Arrow Energy Arrow LNG Plant	arrow energy go further	Predicted 99th percentile 1-hour and annual average ground-level concentrations of NO_2 due to emissions from the LNG plant and industry during operations	Figure No: 21.2



coffey environments	Date: 17.11.2011 MXT: 7033CA_07_GIS197_v1_4 File Name: 7033_07_F21.03_GIS_GL	Arrow Energy Arrow LNG Plant	arrow energy go further	Predicted maximum 24-hour and annual average ground-level concentrations of SO_2 due to emissions from the LNG plant and industry during operations	Figure No: 21.3

Exceedences of SO_2 relating to the protection of health and biodiversity of ecosystems that occur on the mainland outside of sensitive receptor areas but within the study area are found immediately downwind of the coal fired Gladstone Power Station and are due to emissions from this facility and not the Arrow Energy LNG plant.

Table 21.5 Predicted 8-hour average ground-level concentrations of CO during routine operation and non-routine events due to project activities and industry

Sensitive Receptor Area	Predicted CO Concentration (µg/m³)
Gladstone	487.6
Tannum Sands	121.4
Targinie	861.6
Yarwun	203.4
Fishermans Landing	343.8
Southend	446.8
Port Curtis islands	368.7
Curtis Island construction camps	276.0

The dispersion modelling results for ground-level concentrations of PM_{10} and $PM_{2.5}$ are provided in Table 21.6 and show that relevant criteria will not be exceeded in any of the sensitive receptor areas. Similarly, predicted maximum ground-level concentrations for hydrocarbons in sensitive receptor areas (provided in Table 21.7) will be well below air quality criteria.

Table 21.6 Predicted maximum 24-hour average ground-level concentrations of PM_{10} and $PM_{2.5}$ and annual average ground-level concentrations of $PM_{2.5}$ during routine operation due to project activities and industry

Sensitive Receptor Area	Predicted Concentration (µg/m³)		
	PM_{10}	$PM_{2.5}$	
	24-hour		Annual
Gladstone	24.9	10.4	5.5
Tannum Sands	18.5	5.4	3.4
Targinie	36.8	16.1	4.5
Yarwun	25.2	12.4	7.0
Fishermans Landing	23.9	11.2	7.0
Southend	28.5	7.6	4.1
Port Curtis islands	33.1	12.1	4.4
Curtis Island construction camps	28.6	7.2	4.9

The method for converting NO_2 to ozone is described in Section 21.2.2, Impact Assessment. The predicted highest concentration of NO_2 from project activities 10 km from the emission source is 54 µg/m³ resulting in a maximum increase in ozone levels of 54 µg/m³.

The maximum ozone level recorded by DERM (see Table 21.1) was 120 µg/m³ at Targinie (Stupkins Lane). This maximum recorded ozone concentration, combined with project contributions, results in a maximum ozone concentration of 174 µg/m³ in this sensitive receptor area, and is below the relevant air quality criteria.

Table 21.7 Predicted maximum ground-level concentrations of hydrocarbons during routine operation due to project activities and industry

Sensitive Receptor Area	Predicted Concentration (µg/m³)												
	1,3 Butadiene	Acetaldehyde	Acrolein	Benzene	Ethylbenzene	Formaldehyde		Toluene			Xylenes		Dioxins and Furans
	Annual	1-hour	1-hour	Annual	1-hour	30-minute	24-hour	30-minute	24-hour	Annual	24-hour	Annual	1-hour
Gladstone	0.0000007	0.008	0.001	0.00002	0.006	0.3	0.03	0.05	0.006	0.0002	0.003	0.0001	$6.56x10^{-11}$
Tannum Sands	0.000001	0.03	0.004	0.00004	0.02	3.4	0.2	0.6	0.03	0.0004	0.02	0.0002	$1.41\ x10^{-11}$
Targinie	0.000004	0.04	0.006	0.0001	0.03	1.2	0.1	0.2	0.03	0.001	0.01	0.0006	$7.75\ x10^{-11}$
Yarwun	0.000003	0.03	0.005	0.00008	0.03	2.0	0.2	0.4	0.03	0.0008	0.02	0.0004	$7.28\ x10^{-11}$
Fishermans Landing	0.000008	0.07	0.01	0.0002	0.05	2.2	0.3	0.4	0.05	0.002	0.03	0.001	$4.45\ x10^{-11}$
Southend	0.000002	0.02	0.003	0.00006	0.02	1.2	0.08	0.2	0.02	0.0007	0.007	0.0003	$4.35\ x10^{-11}$
Port Curtis islands	0.000003	0.02	0.004	0.00008	0.02	0.7	0.1	0.1	0.02	0.0009	0.01	0.0004	$8.91\ x10^{-11}$
Curtis Island construction camp	0.000009	0.02	0.003	0.0002	0.02	1.0	0.09	0.2	0.02	0.003	0.008	0.001	$6.35\ x10^{-11}$

Predicted odour concentrations occurring at sensitive receptor areas resulting from project activities are shown in Table 21.8. Odour concentrations do not exceed air quality criteria in any of these areas.

Table 21.8 Predicted maximum 1-hour average NO_2 and 8-hour average CO ground-level concentrations during non-routine events

Sensitive Receptor Area	Predicted Concentration (µg/m³)	
	NO_2	CO
Gladstone	258.0	491.0
Tannum Sands	35.0	134.0
Targinie	77.0	1,225.0
Yarwun	106.0	282.0
Fishermans Landing	83.0	431.0
Southend	39.0	603.0
Port Curtis islands	65.0	368.0
Curtis Island construction camps	103.1	276.0

Non-routine Events

The non-routine event resulting in the greatest impacts to air quality is associated with the flaring of feed gas in a LNG train during process upsets, emergencies, maintenance activities and shutdown conditions. Flaring under these conditions will be short term; therefore, long term project air quality targets for pollutants released during these non-routine events have not been assessed, i.e., only short-term targets have been assessed. Particulate emissions are not expected to occur during non-routine flaring events because smokeless flare technology will be used at the LNG plant. Therefore, particulate emissions have not been assessed.

Predicted 1-hour average ground-level concentrations of NO_2 and CO at sensitive receptor areas (resulting from non-routine flaring events) are shown in Table 21.9, and are well below the short-term air quality criteria.

Table 21.9 Predicted maximum 1-hour average ground-level concentrations of hydrocarbons during non-routine events

Sensitive Receptor Area	Predicted Concentration (µg/m³)				
	Methane	Ethane	Acetylene	Propane	Propylene
Gladstone	0.10	0.020	0.010	0.020	0.07
Tannum Sands	0.04	0.006	0.004	0.005	0.02
Targinie	5.60	0.800	0.500	0.700	2.50
Yarwun	0.06	0.009	0.006	0.008	0.03
Fishermans Landing	0.20	0.020	0.020	0.020	0.08
Southend	0.03	0.004	0.002	0.003	0.01
Port Curtis islands	0.04	0.006	0.004	0.005	0.02
Curtis Island construction camps	0.06	0.009	0.006	0.008	0.03

The predicted maximum 1-hour average ground-level concentrations of all hydrocarbons at sensitive receptor areas (released during non-routine events) are provided in Table 21.10. The results show that concentrations will be well below short-term air quality criteria.

Table 21.10 Predicted 1-hour average ground-level concentrations of odorous pollutants

Sensitive Receptor Area	Predicted Concentration												
	Acetaldehyde		NO_2		Formaldehyde		Toluene		Benzene		SO_2		Total
	µg/m^3	Odour Units	µg/m^3	Odour Units	µg/m^3	Odour Units	µg/m^3	Odour Units	µg/m^3	Odour Units	µg/m^3	Odour Units	Odour Units
Gladstone	0.005	0.000015	21.9	0.06	0.09	0.00008	0.02	0.0000028	0.002	0.00000026	31.8	0.0054	0.07
Tannum Sands	0.001	0.000003	4.0	0.01	0.02	0.00002	0.00	0.0000006	0.0003	0.00000006	5.1	0.0009	0.01
Targinie	0.01	0.000031	29.3	0.08	0.18	0.00017	0.03	0.0000057	0.003	0.00000053	41.1	0.007	0.09
Yarwun	0.003	0.00008	25.6	0.07	0.05	0.00004	0.01	0.0000015	0.0008	0.00000014	36.3	0.0062	0.08
Fishermans Landing	0.004	0.000013	19.4	0.05	0.08	0.00007	0.01	0.0000024	0.001	0.00000022	27.5	0.0047	0.06
Southend	0.002	0.000006	10.7	0.03	0.04	0.00003	0.01	0.0000012	0.0006	0.00000011	13.7	0.0023	0.03
Port Curtis islands	0.01	0.000015	39.9	0.11	0.09	0.00009	0.02	0.0000029	0.002	0.00000026	58.0	0.0098	0.12
Curtis Island construction camps	0.01	0.000034	76.8	0.22	0.20	0.00019	0.04	0.0000063	0.003	0.00000058	112.0	0.019	0.24

21.4.3 Decommissioning

Emissions to the atmosphere during decommissioning will be similar in type and duration as those occurring during construction activities, i.e., generation of fugitive dust and gaseous exhaust emissions, resulting in temporary localised elevations in concentrations of airborne particulate matter and combustion gases.

Combustion gas emission rates during decommissioning activities will be low and short term in duration when compared with emissions associated with LNG plant operation. The generation of fugitive dust will largely be restricted to project sites. Therefore, impacts from decommissioning activities do not require further assessment.

21.5 Avoidance, Mitigation and Management Measures

This section describes management measures to address the potential impacts on air quality. Mitigation measures proposed follow a hierarchy that first avoids the impact if possible (through project design), then reduces the impact through emission control and management.

This section details mitigation taking the form of avoidance (through design) and discusses mitigation measures applicable to the different phases of the project.

21.5.1 Design

Arrow Energy will employ a design philosophy based on the principle of minimising at source those air emissions that may adversely affect air quality environmental values. Measures will include:

- Design the LNG plant to comply with the air quality assessment criteria, which are based upon all relevant air quality standards and objectives. Compliance with these criteria will ensure protection of environmental values within the air quality impact assessment study area and all sensitive receptor areas. [C21.01]
- Where feasible, apply low-emission technology to equipment with high combustion rates (e.g., gas turbines). [C21.02]
- Fit compressors and boil-off gas recovery systems with dry gas seals and, where practical, hydrocarbon pumps will be fitted with double seals. [C21.03]
- Minimise fugitive emissions from sources such as pumps, seals, valves, connectors and pipe work via the application of the latest proven stage of development processes, facilities and methods of operation. These include using closed drainage, where practical, minimising the number of flanges, installing dry gas seals on compressors and vapour recovery systems and, where applicable, double seals for hydrocarbon pumps. [C21.04]
- Incorporate waste heat recovery units on the compressor drive gas turbine exhausts to provide process heat to use elsewhere in the LNG plant, thereby reducing operational requirements for gas-fired heaters. [C21.05]
- Fit all stacks with emissions monitoring ports suitable for continuous monitoring even if continuous monitoring is not currently required to facilitate future monitoring should the need arise. [C21.06]

21.5.2 Construction, Commissioning and Decommissioning

While no specific measures will be employed during commissioning to minimise impacts on the atmosphere (other than those incorporated into the design philosophy), measures to minimise impacts during construction and decommissioning activities will be included in the environmental management plan for the project. Measures will include the following:

- Reduce exposure time of bare soils on the ground surface as far as practicable, and undertake revegetation of bare surfaces as soon as practical following construction. [C21.07]
- Control speed limits on site via posted speed limit signs and confine vehicles generally to marked trafficable areas. [C11.20]
- Keep trafficked surfaces damp during construction with sprayed water when conditions are dry to suppress dust generation. Use water of a similar quality to that which is available in the locality and do not spray as concentrated flow. [C11.21]
- Maintain construction vehicles and equipment regularly to reduce exhaust emissions. [C21.08]
- Where practical, use low-sulfur diesel fuel in diesel-powered equipment (i.e., not more than 0.01% sulfur by mass). [C21.09]
- Do not use chlorofluorocarbons (CFC), halogens or related materials listed as banned under the Montreal Protocol in new installations. [C21.10]

21.5.3 Operation

Emissions to air from the operation of the LNG plant and ancillary facilities will be mitigated through engineered solutions that will be incorporated into operation as follows:

- Where practical, limit the volume of hydrocarbons flared or vented to the atmosphere from the LNG plant. Ensure that the flare is luminous and bright (i.e., show smokeless combustion at operating design gas flow rate) and the relative density of emitted smoke does not exceed No.1 Ringelmann Number. [C21.11]
- Do not vent boil-off gas to the atmosphere; instead route it to the feed gas inlet for reprocessing or sent to the end flash gas compressor for use in the high-pressure fuel gas system. [C21.12]
- Use low-sulfur fuel in diesel-powered generators will (not more than 0.01% sulfur by mass). [C21.13]
- Do not use chlorofluorocarbons (CFC), halogens or related materials listed as banned under the Montreal Protocol in new installations. [C21.10]
- Maintain equipment in accordance with manufacturer specifications to minimise fugitive emissions. [C21.14]

21.6 Residual Impacts

The avoidance, mitigation or management measures described above were implemented in the air quality impact assessment. Therefore residual impacts are the same as those described in Section 21.4, Issues and Potential Impacts, and the relevant air quality criteria will be achieved in all sensitive receptor areas.

21.7 Inspection and Monitoring

A leak detection and emissions monitoring plan will be prepared and implemented at the LNG plant site. It will include monitoring of pumps, piping and controls, vessels and tanks. Auditing, monitoring and recording of exhaust stack emissions will be in line with good industry practice and will provide data to assess performance against air quality criteria.

During construction and decommissioning, inspections and monitoring will occur in accordance with Arrow's Health, Safety and Environmental Management System and will reflect project approval requirements directed by government departments and be undertaken on an as-required basis.

Inspections will occur at regular intervals during construction and decommissioning to check that mitigation measures are effective in achieving performance criteria.

During operation, Arrow Energy will prepare a leak detection and emissions monitoring plan and implement the plan at the LNG plant site. The plan will include monitoring of pumps, piping and controls, vessels and tanks and ensure that auditing, monitoring and recording of exhaust stack emissions is in line with good industry practice and provides data to assess performance against air quality criteria.

21.8 Commitments

The measures (commitments) that Arrow Energy will implement to manage impacts on air quality are set out in Table 21.11.

Table 21.11 Commitments: Air quality

No.	Commitment
C21.01	Design the LNG plant to comply with the air quality assessment criteria, which are based upon all relevant air quality standards and objectives. Compliance with these criteria will ensure protection of environmental values within the air quality impact assessment study area and all sensitive receptor areas.
C21.02	Where feasible, apply low-emission technology to equipment with high combustion rates (e.g., gas turbines).
C21.03	Fit compressors and boil-off gas recovery systems with dry gas seals and where practical, hydrocarbon pumps will be fitted with double seals.
C21.04	Minimise fugitive emissions from sources such as pumps, seals, valves, connectors and pipe work via the application of the latest proven stage of development processes, facilities and methods of operation. These include using closed drainage, where practical, minimising the number of flanges, installing dry gas seals on compressors and vapour recovery systems and, where applicable, double seals for hydrocarbon pumps.
C21.05	Incorporate waste heat recovery units on the compressor drive gas turbine exhausts to provide process heat to use elsewhere in the LNG plant, thereby reducing operational requirements for gas-fired heaters.
C21.06	Fit all stacks with emissions monitoring ports suitable for continuous monitoring even if continuous monitoring is not currently required to facilitate future monitoring should the need arise.
C21.07	Reduce exposure time of bare soils on the ground surface as far as practicable, and undertake revegetation of bare surfaces as soon as practical following construction.
C11.20	Control speed limits on site via posted speed limit signs and confine vehicles generally to marked trafficable areas. Common with Chapter 11, Geology, Landform and Soils.
C11.21	Keep trafficked surfaces damp during construction with sprayed water when conditions are dry to suppress dust generation. Use water of a similar quality to that which is available in the locality and do not spray as concentrated flow. Common with Chapter 11, Geology, Landform and Soils.
C21.08	Maintain construction vehicles and equipment regularly to reduce exhaust emissions.
C21.09	Where practical, use low-sulfur diesel fuel in diesel-powered equipment (i.e., not more than 0.01% sulfur by mass).
C21.10	Do not use chlorofluorocarbons (CFC), halogens or related materials listed as banned under the Montreal Protocol in new installations.

Table 21.11 Commitments: Air quality (cont'd)

No.	Commitment
C21.11	Where practical, limit the volume of hydrocarbons flared or vented to the atmosphere from the LNG plant. Ensure that the flare is luminous and bright (i.e., show smokeless combustion at operating design gas flow rate) and the relative density of emitted smoke does not exceed No.1 Ringelmann Number.
C21.12	Do not vent boil-off gas to the atmosphere; instead route it to the feed gas inlet for reprocessing or sent to the end flash gas compressor for use in the high-pressure fuel gas system.
C21.13	Use low-sulfur fuel in diesel-powered generators will (not more than 0.01% sulfur by mass).
C21.14	Maintain equipment in accordance with manufacturer specifications in order to minimise fugitive emissions.