Climate, natural hazards and climate change

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Climate, natural hazards and climate change

Santos GLNG Gas Field Development Project

AUGUST 2014

Prepared for

Santos GLNG

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Abbreviations

Abbreviation	Description
ARI	Average recurrence interval
BoM	Bureau of Meteorology
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCC	Department of Climate Change, Commonwealth Government
DLGP	Department of Local Government and Planning, Queensland Government
EIS	Environmental Impact Statement
GCM	Global Climate Model
GFD Project	Santos GLNG Gas Field Development Project
GHG	Greenhouse gas
GLNG	Gladstone Liquefied Natural Gas
HSHS	Health Safety Hazard Standard
IPCC	Intergovernmental panel on climate change
km	kilometre
km^2	square kilometre
MJ/m^2	Mega joules per square metre
mm	millimetre
ToR	Terms of Reference
WMO	World Meteorological Organisation

Glossary

Term	Definition
Coal seam water	Groundwater produced at the surface by the depressurisation of coal seams during gas production.
Gas compression facility	A facility that houses multiple compressor units, either nodal or hub compressors or a mixture of both used to increase the pressure of gas for the purpose of transmission; may be collocated with a gas treatment facility and/or water management facility.
Gas gathering lines	High-density polyethylene pipelines through which natural gas flows from a wellhead to gas compression facility under low pressure.
Gas treatment facility	A facility within a gas compression facility that uses various treatment technologies to remove heavy hydrocarbon gases (e.g. ethane, propane, butane, pentane, hexane and heptane), moisture, and other impurities from the gas to meet supply specifications.
Production well	A well that is designed to extract gas from one or more natural underground reservoirs.
Transmission pipelines	Engineered pipelines used to transmit gas or water under pressure downstream of gas compression or water pumping process.
Water gathering line	High-density polyethylene lines through which coal seam water flows from a wellhead under low or medium pressure to water transfer, storage and/or treatment infrastructure.
Water management facility	The collective term to refer to the major infrastructure components involved in water storage and treatment.

Glossary

Term	Definition
Water storage	Water storage is a regulated or unregulated structure that provides temporary storage and balancing of flow rates and quality characteristics between various points of water management infrastructure. To refer to a specific type of water storage facility, preface the descriptor before storage. For example: Brine storage; water management storage, coal seam water storage.
Wells	A structure that is designed to bore through the earth's surface in order to extract resources.

Introduction

This report has been prepared in response to Section 4.1 of the terms of reference (ToR) for the Santos GLNG Gas Field Development Project (the GFD Project) environmental impact statement (EIS). It describes the existing regional and local climate in the GFD Project area and assesses the potential for extreme climatic events to occur and how these events may impact on the GFD Project. Preferred and alternative mitigation strategies to address potential impacts on the GFD Project from extreme climatic events such as floods, severe storms, temperature extremes and bushfires are described.

Climate change projections for the GFD Project area are assessed and a climate change risk assessment for the GFD Project is presented. Adaptation strategies are proposed to reduce unacceptable climate change risks to environmental and social values. The management of climatic impacts on the GFD Project and co-operative opportunities for government, industry and other sectors are described.

Project Description

Santos GLNG intends to further develop its Queensland gas resources to augment supply of natural gas to its existing and previously approved Gladstone Liquefied Natural Gas (GLNG) Project.

The GFD Project is an extension of the existing approved gas field development and will involve the construction, operations, decommissioning and rehabilitation of production wells and the associated supporting infrastructure needed to provide additional gas over a project life exceeding 30 years.

Specifically, the GFD Project will expand the GLNG Project's gas fields from 6,887 km^2 to 10,676 km^2 and develop an additional 6,100 production wells beyond the currently authorised 2,650 wells; resulting in a maximum of up to 8,750 production wells.

The GFD Project will continue to progressively develop the Arcadia, Fairview, Roma and Scotia gas fields across 35 Santos GLNG petroleum tenures in the Surat and Bowen basins, and associated supporting infrastructure in these tenures and in adjacent areas. The location of the GFD Project area and primary infrastructure is shown on Figure 2-1.

This GFD Project will include the following components:

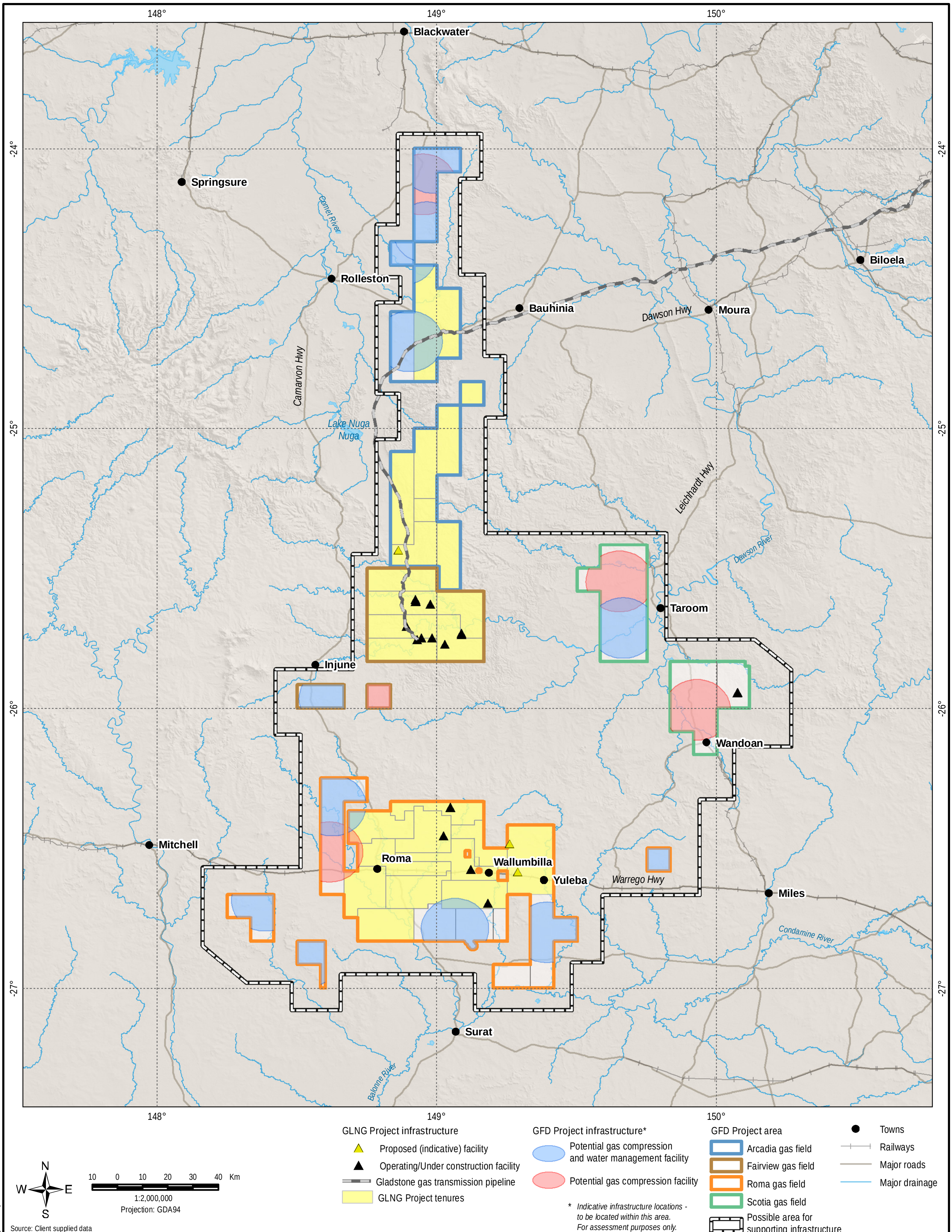
- Production wells
- Fluid injection wells, monitoring bores and potentially underground gas storage wells
- Gas and water gathering lines
- Gas and water transmission pipelines
- Gas compression and treatment facilities
- Water storage and management facilities
- Access roads and tracks
- Accommodation facilities and associated services (e.g. sewage treatment)
- Maintenance facilities, workshops, construction support, warehousing and administration buildings
- Utilities such as water and power generation and supply (overhead and/or underground)
- Laydown, stockpile and storage areas
- Borrow pits and quarries
- Communications.

The final number, size and location of the components will be determined progressively over the GFD Project life and will be influenced by the location, size and quality of the gas resources identified through ongoing field development planning processes, which include consideration of land access agreements negotiated with landholders, and environmental and cultural heritage values.

Where practicable, the GFD Project will utilise existing or already approved infrastructure (e.g. accommodation camps, gas compression and water management facilities) from the GLNG Project or other separately approved developments. The GFD Project may also involve sourcing gas from third-party suppliers, as well as the sharing or co-location of gas field and associated facilities with third parties.

For the purposes of transparency this EIS shows an area off-tenure that may be used for infrastructure such as pipelines and temporary camps (supporting infrastructure area). While not assessed specifically in this EIS, any infrastructure that may be located within this area would be subject to further approval processes separate to this EIS.

Approved exploration and appraisal activities are currently underway across the GFD Project's petroleum tenures to improve understanding of the available gas resources. As the understanding of gas resources improves, investment decisions will be made about the scale, location and timing of the next stages of field development.



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GFD PROJECT EIS

GFD PROJECT AREA AND PRIMARY INFRASTRUCTURE

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CLIMATE

Figure: **2-1**

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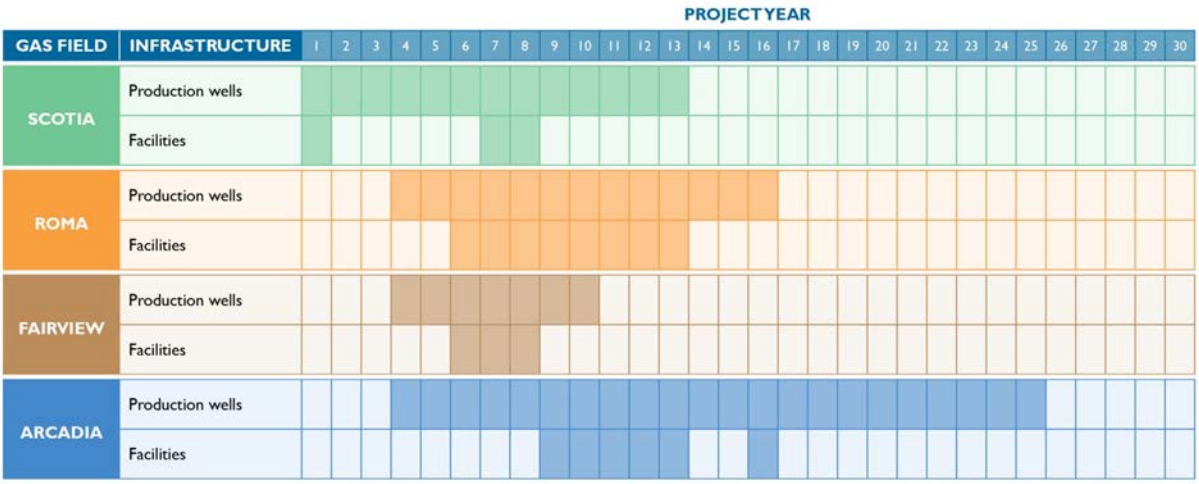
2 Project Description

For the purposes of this EIS, a scenario based on the maximum development case was developed at the approval of the ToR. This scenario assumed that production from the wells and upgrading of the gas compression facilities in the Scotia gas field would commence in 2016, followed by the GFD Project wells in the Roma, Arcadia and Fairview gas fields in mid-2019. This schedule is indicative only and was used for the purpose of the impact assessment in this EIS. The proposed GFD Project schedule is outlined in Figure 2-2. This schedule provides an overall field development scenario for the purposes of assessment in this EIS.

Figure 2-2 Proposed GFD Project development schedule



Decommissioning and rehabilitation will occur progressively throughout the life of the GFD Project as construction activities cease and exhausted gas wells are decommissioned. However, final decommissioning and rehabilitation will occur at the end of gas production in accordance with relevant approvals and regulatory requirements.

Regulatory and policy framework

3.1 Climate change regulatory framework

The *National Climate Change Adaptation Framework* (Council of Australian Governments, 2007) sets out Australia's approach to long-term climate change adaptation. The framework covers a range of actions to address key demands from business and the community for targeted information on climate change impacts and adaptation options.

The Commonwealth Government's position paper *Adapting to Climate Change in Australia* (Department of Climate Change (DCC), 2010) outlines the Commonwealth Government's role in adaptation, which includes building community resilience and establishing the right conditions for people to adapt; taking climate change into account in the management of Commonwealth assets and programs; providing sound scientific information; and leading national reform (Department of the Environment (DOTE), 2014).

Consistent with the Commonwealth Government's initiatives, the Queensland Government has committed to responsibly and cost-effectively manage the impacts of climate change on the State economy, communities, infrastructure and environmental assets by supporting climate adaptation measures that will focus on building community resilience, protecting ecosystems and enhancing industry productivity.

Climatic hazards such as bushfires, flooding and landslides are among the State interests addressed in the Queensland State Planning Policy (Department of State Development, Infrastructure and Planning (DSPIP), 2013). Design standards developed and implemented by regional councils, government agencies, and other recognised sources provide further guidance to ensure that proposed infrastructure such as roads or water pipelines can withstand local extremes of temperature, wind and surface water flow.

3.2 Santos GLNG corporate policy and standards

3.2.1 Environmental policy

Santos GLNG's environmental policy commits the GFD Project to continuously seek to find new ways to minimise its environmental impact across the lifecycle of its activities. To do this, Santos GLNG will comply with relevant legal and other requirements, continuously improve the corporate Environment, Health and Safety Management System and proactively identify environmental hazards, assess their risk and eliminate or, if not practical, manage the risk to as low as reasonably practicable.

3.2.2 Climate change policy

Climate change is a long-term issue, requiring urgent but informed action to stabilise atmospheric greenhouse gas concentrations. As a global stakeholder in the energy business, Santos GLNG recognises that one of their key social and environmental responsibilities is to pursue strategies that address the issue of climate change.

3.2.3 EHSMS19 Climate change

Santos GLNG has adopted the corporate-wide Environment, Health and Safety Management System that provides a structured framework for effective environmental, and health and safety practices across its activities and operations. The environment, health and safety management system is the basis for plans and procedures and will also apply to the proposed GFD Project.

The key environment, health and safety management system standard (EHSMS) related to managing the impacts of climate change to the GFD Project is EHSMS19: Climate Change. The standard describes Santos GLNG's management approach to climate change, carbon pricing and greenhouse gas emissions.

One the key element of EHSMS19 is climate change risk and adaptation. Santos GLNG recognises that climate change can pose different risks to its activities and Santos GLNG considers these when undertaking risk assessments. In particular, incremental changes in climate variables such as ambient temperature, and changes in the occurrence and intensity of extreme events (e.g. number of days >35ºC, cyclones, floods and drought) have the potential to significantly impact on Santos' operations and workforce. Adaptation to physical aspects of climate change is to be factored into Santos GLNG's risk management process which is guided by EHSMS09 Managing Environmental Health and Safety Risks.

3.2.4 Post-environment impact statement field planning and development process

The constraints approach is based upon the *GFD Project environmental protocol for constraints planning and field development* (Constraints protocol). The Constraints protocol applies to all gas field related activities. The scope of the Constraints protocol is to:

- Enable Santos GLNG to comply with all relevant State and Federal statutory approvals and legislation
- Support Santos' environmental policies and the General Environmental Duty (GED) as outlined in the *Environmental Protection Act 1994* (Qld) (EP Act)
- Promote the avoidance, minimisation, mitigation and management of direct and indirect adverse environmental impacts associated with land disturbances
- Minimise cumulative impacts on environmental values.

The c Constraints protocol) details the process that Santos GLNG will use to identify, assess and manage potential impacts to the environment during field planning and development. This process has been successfully used for the approved GLNG Project, which increases the certainty of GFD Project environmental outcomes.

The general principles of the Constraints protocol, in order of preference, are to:

- Avoid — avoid direct and indirect impacts
- Minimise — minimise potential impacts
- Mitigate — implement mitigation and management measures to minimise adverse impacts
- Remediate and rehabilitate — actively remediate and rehabilitate impacted areas
- Offset — offset residual risk in accordance with regulatory requirements.

3 Regulatory and policy framework

Consistent with Santos GLNG's environmental management hierarchy, the Constraints protocol prioritises avoidance of environmental impact during field planning by identifying those areas that are not amenable to development. This includes areas of high environmental value as identified in regulatory frameworks and Santos GLNG's baseline surveys. For areas that are considered appropriate to develop, Santos GLNG will identify impacts to environmental values that could potentially occur due to the construction, operations and decommissioning activities of the GFD Project, and determine pre-mitigated impacts (i.e. those that would occur without mitigation).

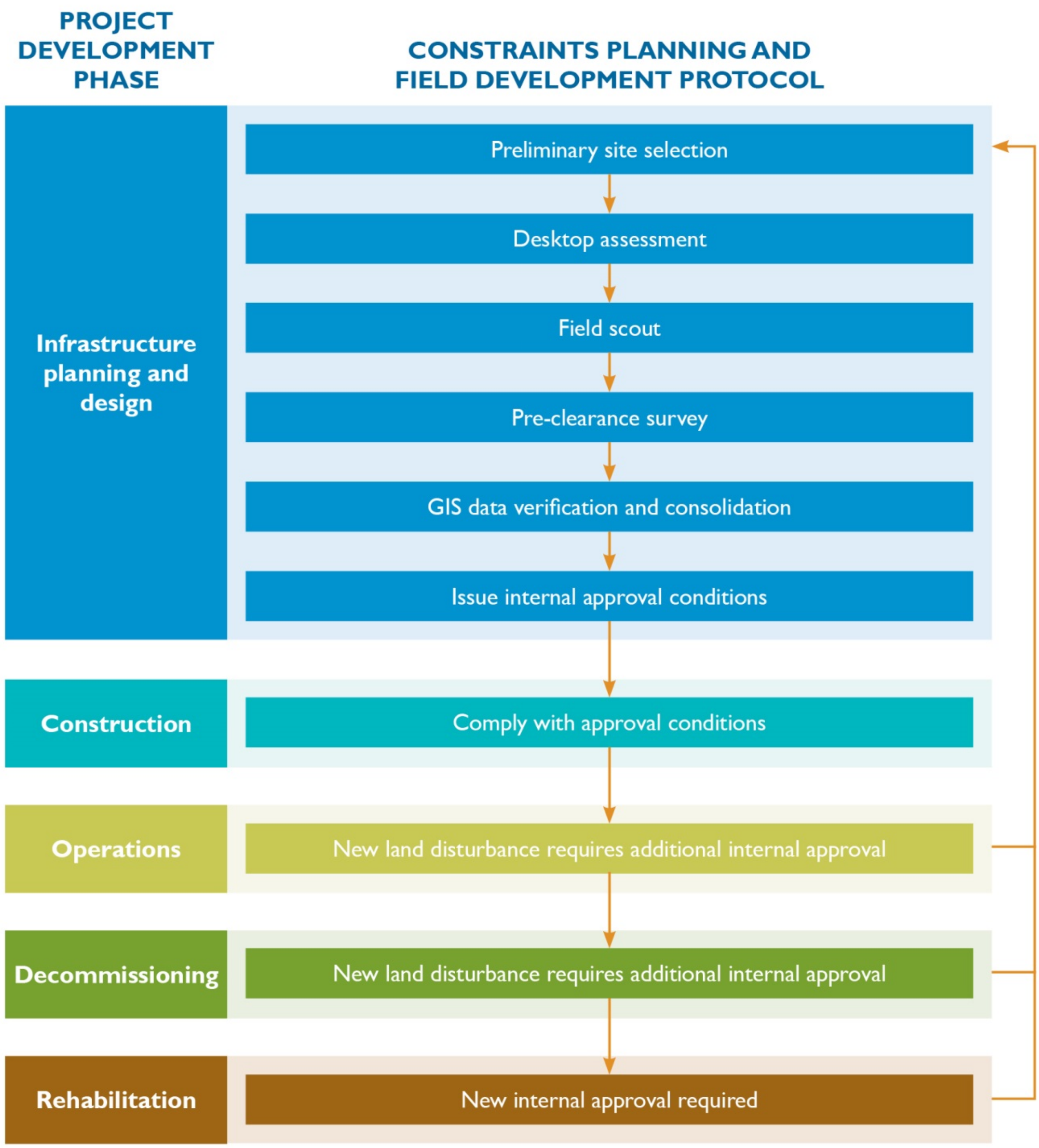
Relevant mitigation and management measures based on the approved environmental management framework already implemented for the GLNG Project are then applied to the pre-mitigated impacts to identify the mitigated (residual) impacts. This process increases certainty about potential impacts by identifying those areas that are not amenable to development, and for those areas where development could occur, how development should proceed.

The post-EIS field development process is a continuation of the field planning process and will be ongoing throughout the life of the GFD Project. The field development process will inform the GFD Project's design, together with a range of other factors including technical feasibility, cost and risk as required by standards applicable to the design, construction, operations, decommissioning and rehabilitation of gas developments. This information will be used to support the subsequent approvals process such as environmental approval application and the plan of operations.

The tasks involved in the field development process are summarised in Figure 3-1.

3 Regulatory and policy framework

Figure 3-1 Field development process



Existing climate

4.1 Overview

This section provides a description of relevant Bureau of Meteorology (BoM) datasets and a summary of meteorological data in the region and GFD Project area. It also includes an assessment of the potential for extreme climatic events to occur in the GFD Project area and how these events may impact on the GFD Project.

4.2 Data sources

4.2.1 Bureau of Meteorology gridded datasets

BoM gridded climate datasets were derived for data collected between 1961 and 1990 and are used to describe regional climate. The observation station data used to generate the gridded datasets were extracted from BoM's national climate database, the *Australian Data Archive for Meteorology*. To develop the database, BoM extracted rainfall from approximately 6,000 stations and temperature from 600 stations. The data collected conformed to the World Meteorological Organisation (WMO) guidelines for the quality and continuity of data used in climatological analyses (WMO, 1989).

The resolution of the gridded meteorological and terrain data is approximately 2.5 km and input station data conform to the WMO guidelines.

4.2.2 Bureau of Meteorology observation stations

The BoM operates eight meteorological observation stations in the region. The meteorological observations include rainfall, temperature, evaporation, solar exposure, relative humidity, and wind. The datasets have been graphed and plotted for each observation station. Monthly climate statistics based on these data were used to characterise long-term rainfall, temperature, evaporation, solar exposure, and relative humidity in the study area.

The observation stations used are described in Table 4-1.

Table 4-1 BoM observation stations

Station	Station number	Latitude	Longitude	Elevation (m)	Operational period
Rolleston Airport	35129	24°27'36''S	148°37'48''E	219	2010-2012
Rolleston	35059	24°27'36''S	148°37'47''E	214	1987-2010
Taroom Post Office	35070	25°38'27''S	149°47'45''E	199	1870-2012
Injune Post Office	43015	25°50'34''S	148°34'01''E	390	1925-2012
Roma Airport	43091	26°32'39''S	148°46'40''E	307	1985-2012
Miles Post Office	42023	26°39'36''S	150°10'48''E	302	1885-2011
Miles Constance Street	42112	26°39'36''S	150°10'48''E	305	1998-2013
Surat	43035	27°09'36''S	149°04'11''E	246	1885-2012

4.3 Regional climate

The region is predominantly rural and characterised by a variety of landscapes including steep hills and mountains, undulating hills, floodplain, creeks, riparian areas and townships. The north of the region, in proximity to Arcadia gas field, is dominated by steep hills and mountains, which are connected to and are part of the Expedition Range. In proximity to the Scotia gas field, the terrain is undulating and dominated by grazing land in the east, and steep ridgelines are separated by creeks in the south. In the south, the region consists of rolling hills, small valleys and riparian areas, which are cropped and grazed. It can be expected that the variability in terrain will contribute to local climate variability across the region.

4.3.1 Climate classification

BoM uses a modified version of the Köppen climate classification scheme to classify Australia's climate. The Köppen classification is based on the concept that native vegetation is the best expression of climate. BoM uses mean monthly and annual rainfall as well as maximum and minimum temperature data to determine the Köppen classification.

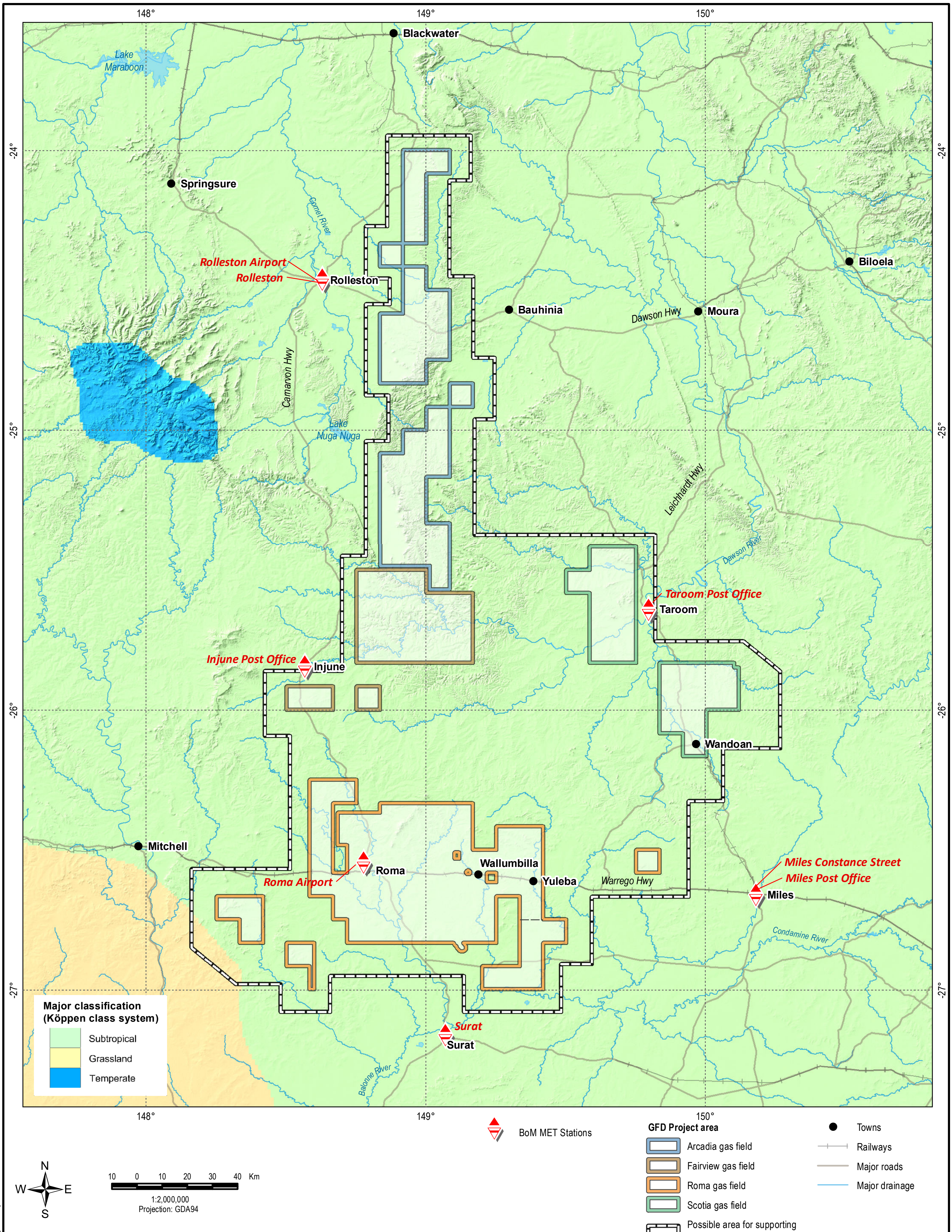
The BoM also classifies the climate according to thermal zones, using temperature and humidity data, accounting for the effect of elevation. This method of classification identifies six key zones across Australia, based on a set of definitions relating to summer and winter conditions:

- Hot humid summer
- Warm humid summer
- Hot dry summer, mild winter
- Hot dry summer, cold winter
- Warm summer, cold winter
- Mild/warm summer, cold winter (BoM, 2012).

Köppen and thermal climate classification scheme maps, which are based on temperature and humidity data collected over the period 1961 to 1990, are presented in Figure 4-1 and Figure 4-2.

Figure 4-1 shows that the majority of the region is classified as subtropical, which BoM describes as a moderately dry winter and dry summer. The median rainfall is lowest (500- 600 millimetres (mm) per annum) in the southwest of the region.

Figure 4-2 shows that the thermal classification for most of the region is hot dry summer, cold winter with mean temperatures around 21°C and median rainfall less than 800 mm a year. In the north and northwest of the region, the climate is classed as hot dry summer, mild winter with the average temperature approximately 24°C. To the north and northeast, the climate is classified as hot humid summer with mean temperature of approximately 24°C and median rainfall of 1,000 mm.



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KÖPPEN CLIMATE CLASSIFICATION

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Figure: **4-1**

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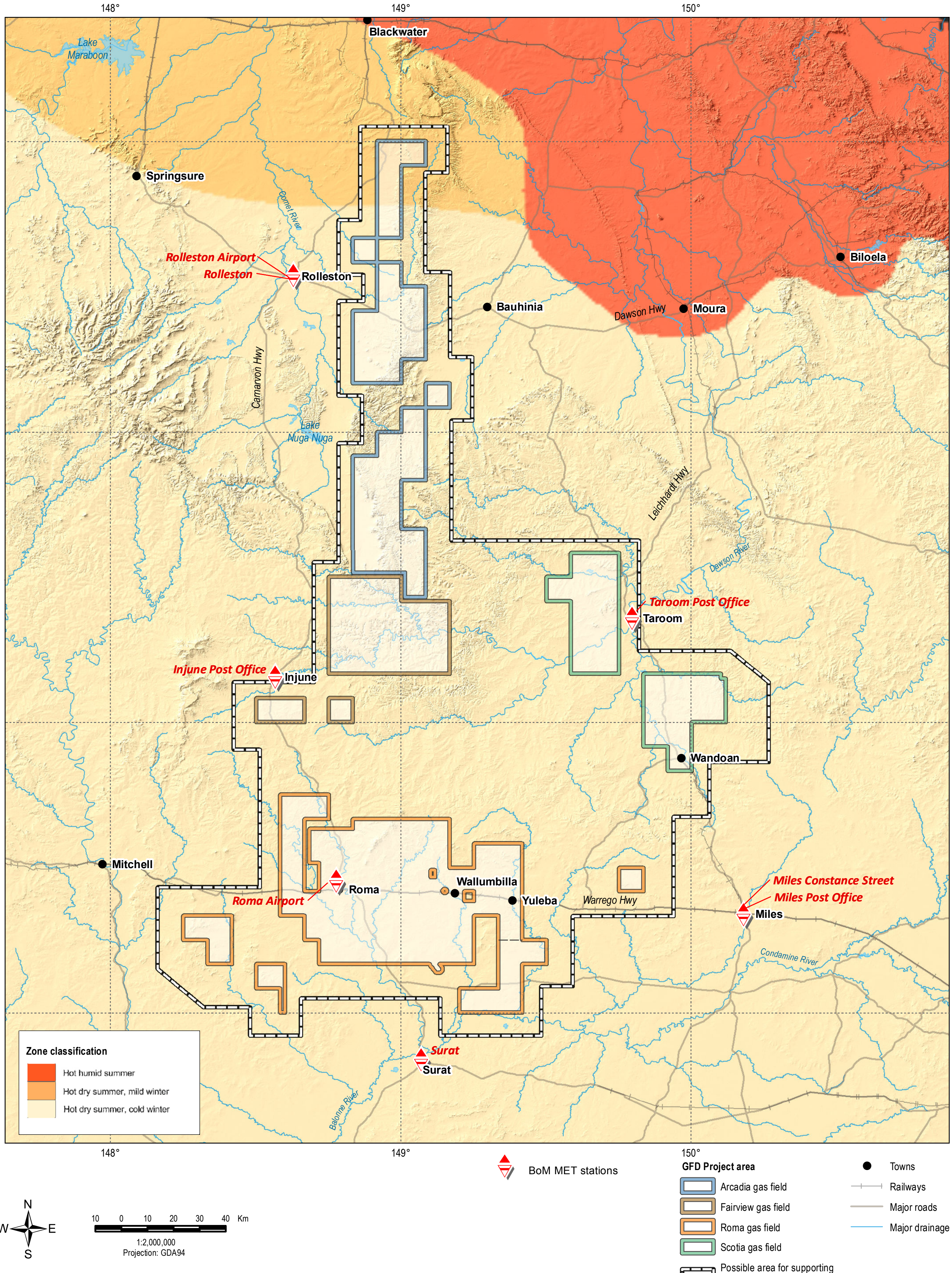

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THERMAL CLIMATE CLASSIFICATION

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Figure: 4-2

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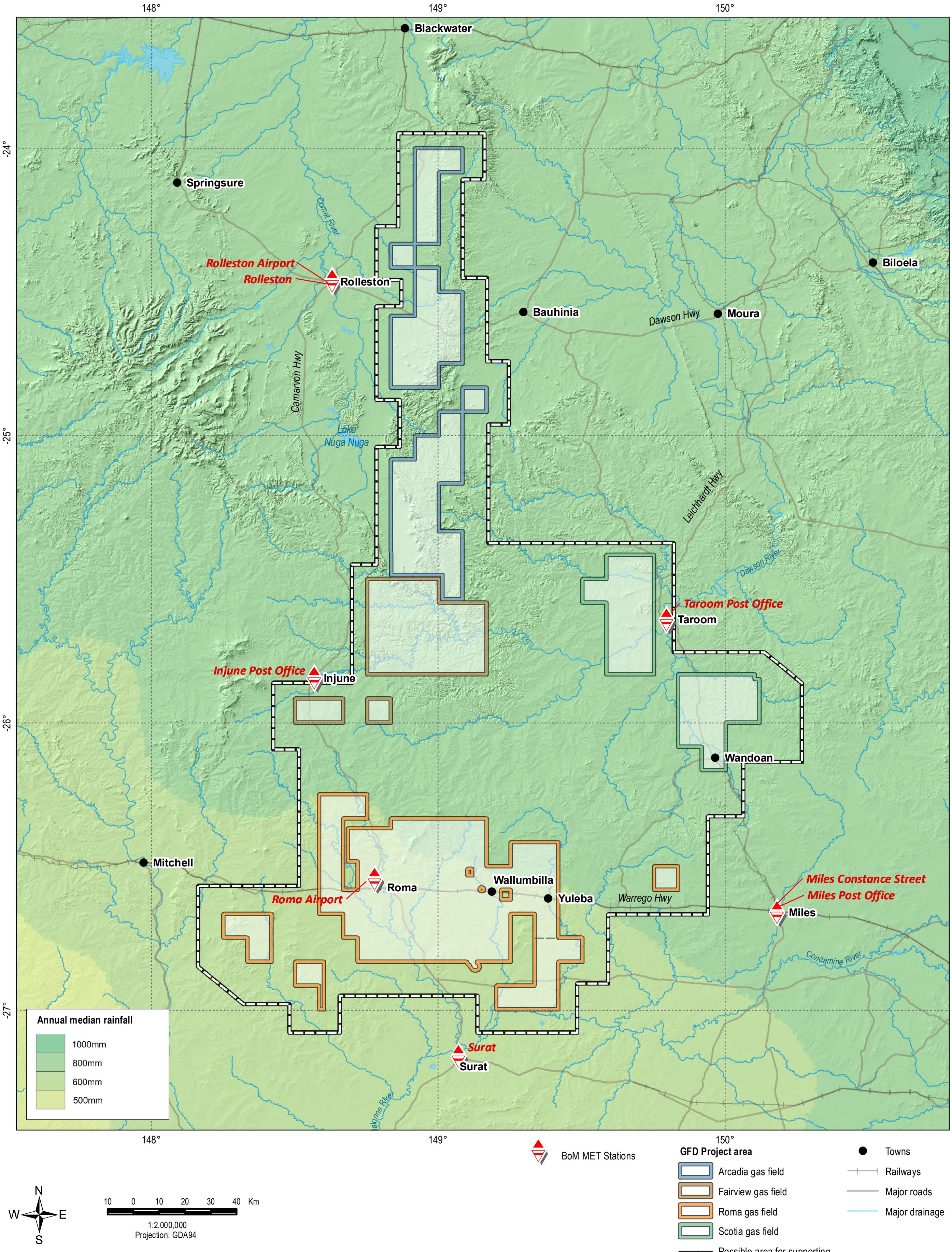
4.3.2 Annual median rainfall

The annual median rainfall for the region is above 500 mm per year and the majority of the region is above 800 mm. The driest area is to the southwest and the wettest to the northeast where the rainfall is more than 1,000 mm a year. For most of the GFD Project area, the annual median rainfall is more than 800 mm, except for southern tenures where it is 600-800 mm. Figure 4-3 shows the variation in regional annual median rainfall for the period 1961 to 1990 across the region.

4.3.3 Annual mean temperature

The annual mean temperature for the majority of the region is 21°C. However, in the upland areas of Carnarvon National Park and to the west of Injune, it is lower (18°C). The highest temperatures in the region can be found in the north around Rolleston, Moura and Biloela, where the mean is 24°C. The Arcadia gas field tenures in the north are located on higher ground to the west of the Blackdown Tablelands and to the east of Rolleston where the annual mean temperature is 21°C. Figure 4-4 shows the regional annual mean temperature for the period 1961 to 1990 and shows that the annual mean temperature varies across the region.



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REGIONAL ANNUAL MEDIAN RAINFALL

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Figure: 4-3

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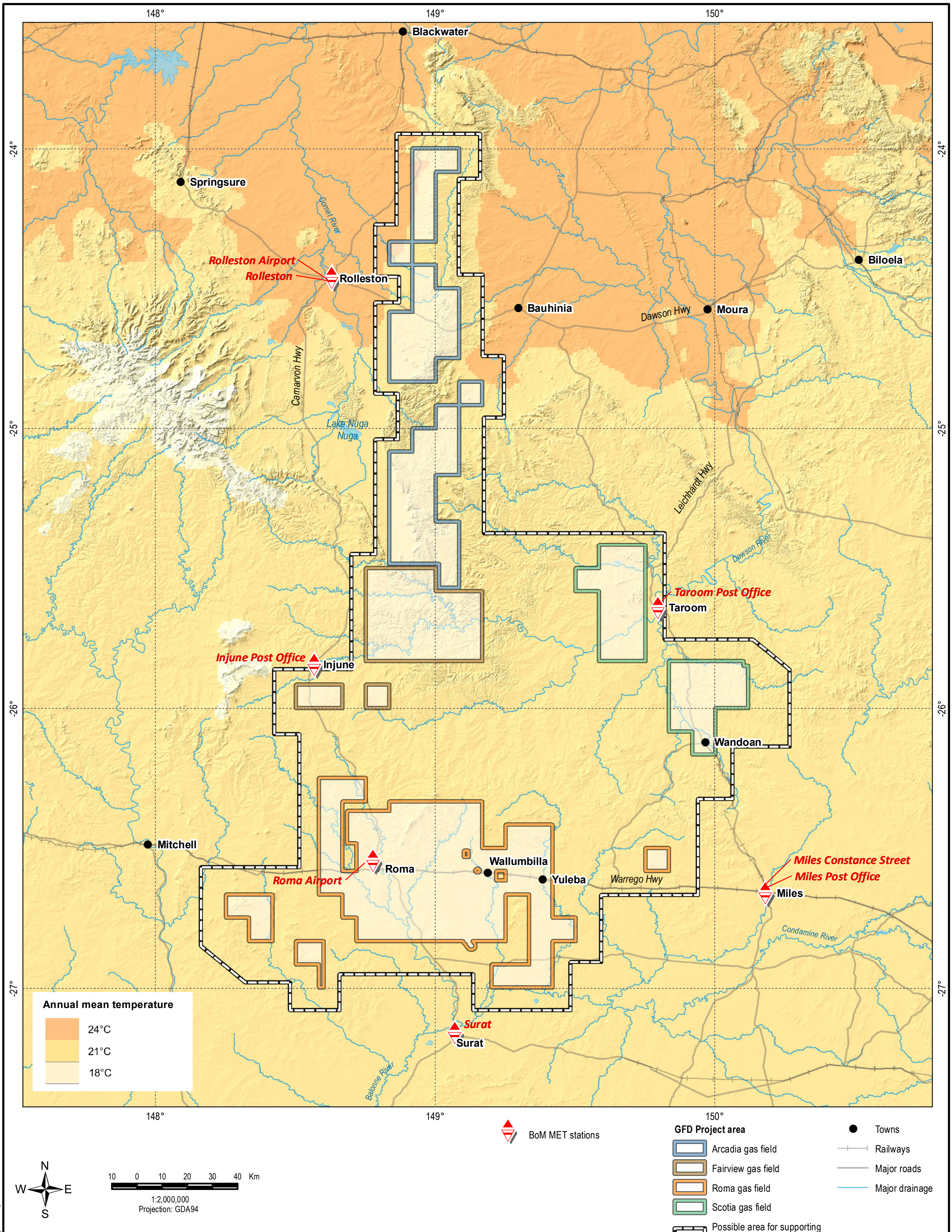

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GFD PROJECT EIS

REGIONAL ANNUAL MEAN TEMPERATURE

URS

CLIMATE

Figure: 4-4

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4.4 Local climate

This section reports on the local climate conditions observed at the eight BoM observation stations described in Section 4.2.2. While available data from the BoM have been presented, there are differences in meteorological variables recorded at each station; as a result, some data sets are incomplete and of different durations.

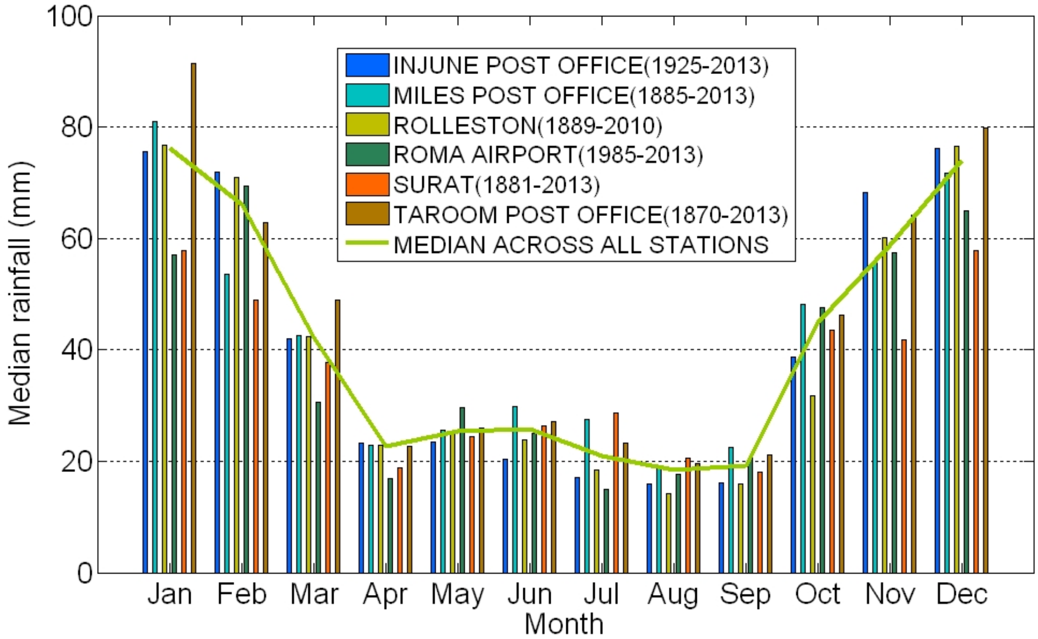
4.4.1 Rainfall

Monthly median rainfall represents the 50th percentile of total monthly rainfall and is reported instead of the mean value, which is skewed by extreme events.

Monthly median

Monthly median rainfall is monitored at six stations, which are Injune Post Office, Miles Post Office, Rolleston, Roma Airport, Surat and Taroom Post Office[1]. Monthly median rainfall is shown in Figure 4-5.

Figure 4-5 Monthly median rainfall



Rainfall is at its highest from late spring through to summer. The wettest month is January, with a median rainfall of 98 mm measured at Taroom Post Office. The driest months of the year are April to September. In these months, median rainfall is between 14.2 mm at Rolleston in August and 29.8 mm at Miles Post Office in June.

Annual total

Annual median rainfall is shown in Figure 4-6.

[1] Rainfall is not monitored at Rolleston Airport and Miles Constance Street.

Figure 4-6 Median annual total rainfall

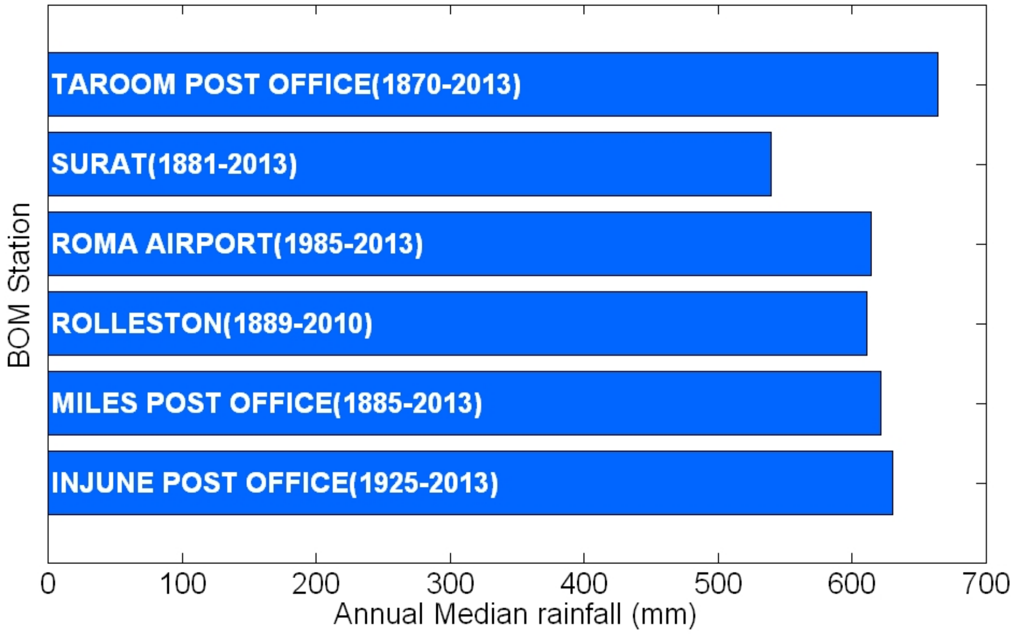


Figure 4-6 shows that annual median rainfall is over 580 mm at the different stations. The highest annual rainfall is a Taroom Post Office, with a median of 674 mm between 1870 and 2013 and the lowest at Surat in the south, with a median of 581 mm between 1881 and 2013.

4.4.2 Temperature

Figure 4-7 shows the maximum and minimum monthly average temperature.

Figure 4-7 Mean maximum and minimum temperature

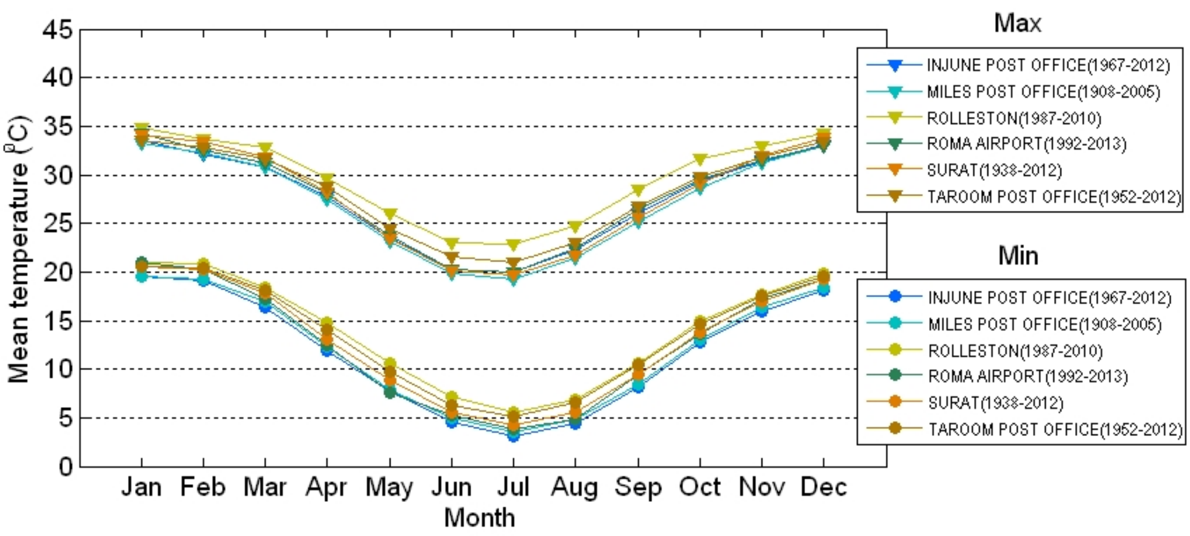


Figure 4-7 shows that the monthly mean maximum and minimum temperature is similar for the BoM stations. The variation in temperature is seasonal, being warmer in summer and cooler in winter.

Rolleston in the north experiences slightly higher maximum temperatures than other sites. The mean maximum monthly temperatures in Rolleston are at their highest during the summer months (December to February). The mean monthly maximum temperature ranges from 19.3°C in July (Miles Post Office) to 34.8°C in January (Rolleston).

The lowest mean minimum temperatures are experienced in June, July and August. The mean minimum temperature is below 3.1°C in July at Injune Post Office. In summer, the lowest mean minimum temperature recorded at Injune Post Office was 18.1°C (December).

4.4.3 Evaporation

Mean daily evaporation rates for each month at Roma Airport and Miles Post Office are shown in Figure 4-8.

Figure 4-8 Mean daily evaporation

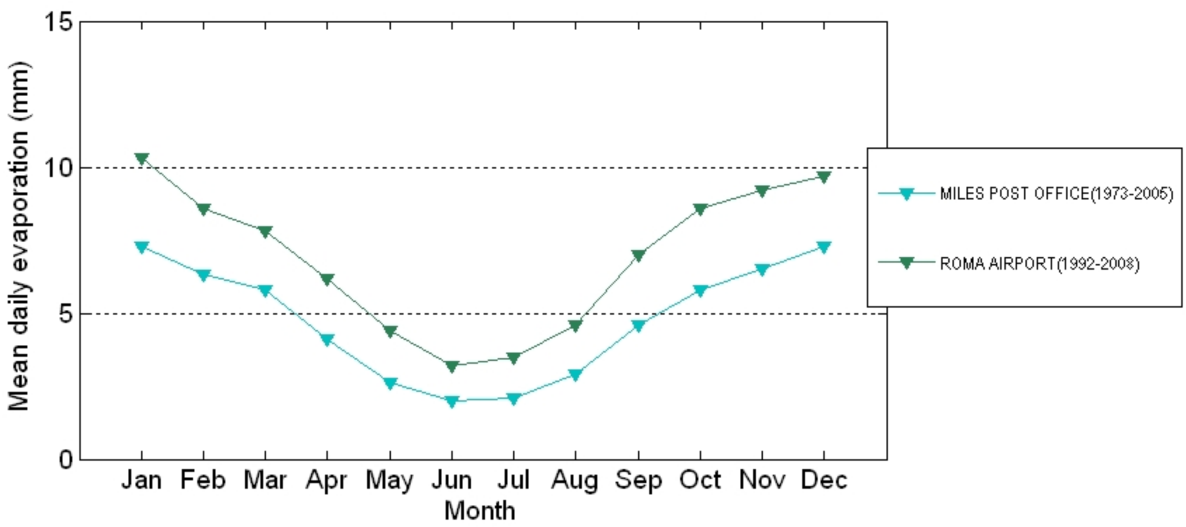


Figure 4-8 shows that mean daily evaporation is highest between the summer months of November and February inclusive. In this period, the mean daily evaporation rate was 8.3 mm (approximately 248 mm of evaporation per month). The winter months of June and July have a mean daily evaporation of approximately 3 mm (approximately 90 mm per month).

Figure 4-5 shows that the mean monthly summer and winter evaporation rates for Roma Airport are greater than the corresponding median rainfall in summer (58 mm to 70 mm) and winter (16 mm to 24 mm). Similarly, at Miles Post Office, evaporation rates are greater than the corresponding summer (54 mm to 82 mm) and winter (25 mm to 26 mm) median rainfall is lower. Therefore, for the whole year evaporation exceeds rainfall, which creates a surface water deficit.

4.4.4 Solar exposure

Figure 4-9 shows mean daily solar exposure.

Figure 4-9 Mean daily solar exposure

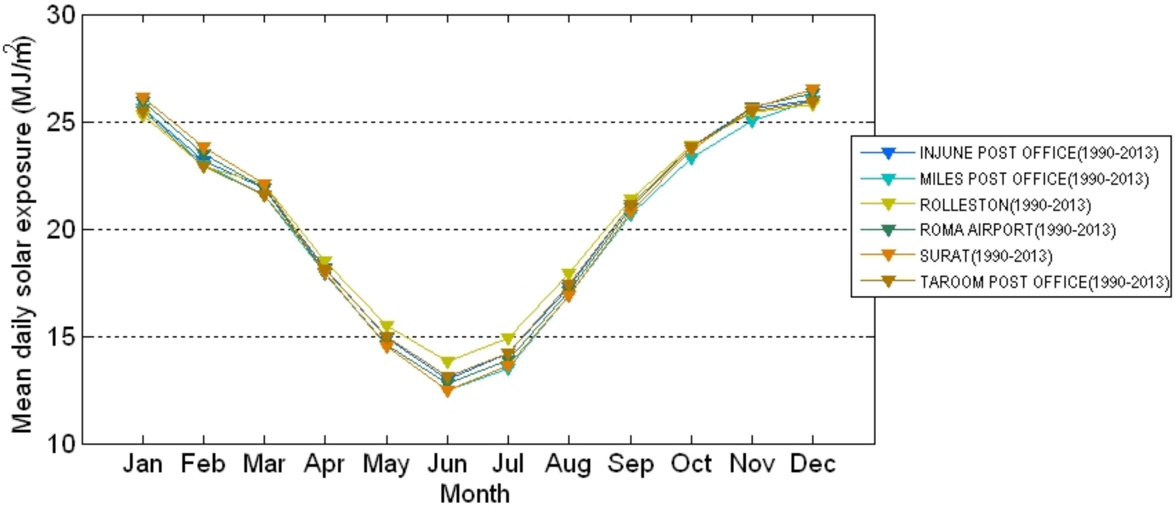


Figure 4-9 shows that solar exposure is highest in the summer months at Surat. In November to January, the mean daily solar exposure was in excess of 25 megajoules per square metre (MJ/m^2) at all stations, which is approximately 750 MJ/m^2 per month. The lowest mean daily solar exposure of 12 MJ/m^2 was observed at Surat in June, which is approximately 360 MJ/m^2 per month and half the summer peak. The Rolleston and Surat records indicate that the solar exposure variation between winter and summer is greatest in the south and lowest in the north of the GFD Project area.

4.4.5 Relative humidity

Observed monthly average 9:00 am and 3:00 pm relative humidity is shown in Figure 4-10.

Figure 4-10 Mean relative humidity

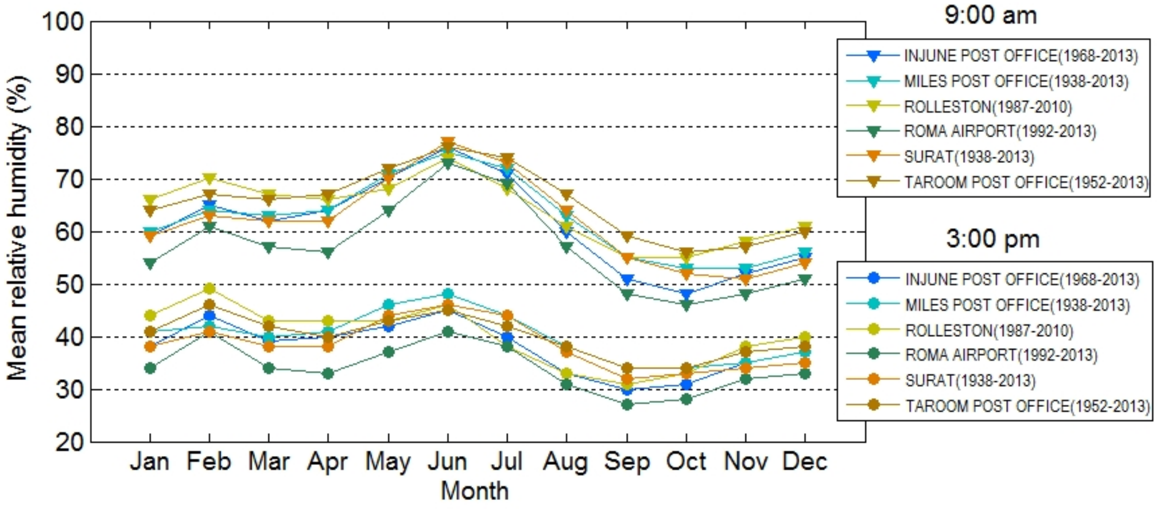


Figure 4-10 shows that mean monthly 9:00 am relative humidity varies throughout the year with two peaks occurring in February and June. The highest 9:00 am relative humidity was observed in June for the stations. The highest 9:00 am mean monthly relative humidity observation of 77% was made at Surat.

Relative humidity observations are lower at 3:00 pm than 9:00 am. Mean monthly 3:00 pm relative humidity peaks in February and June. Mean monthly relative humidity ranges from 27% to 49% while at 9:00 am the relative humidity readings range between 66% and 76%. The Rolleston records indicate that relative humidity at 9:00 am varies less in the north of the region. Roma Airport has the lowest relative humidity throughout the year at 9:00 am and 3:00 pm.

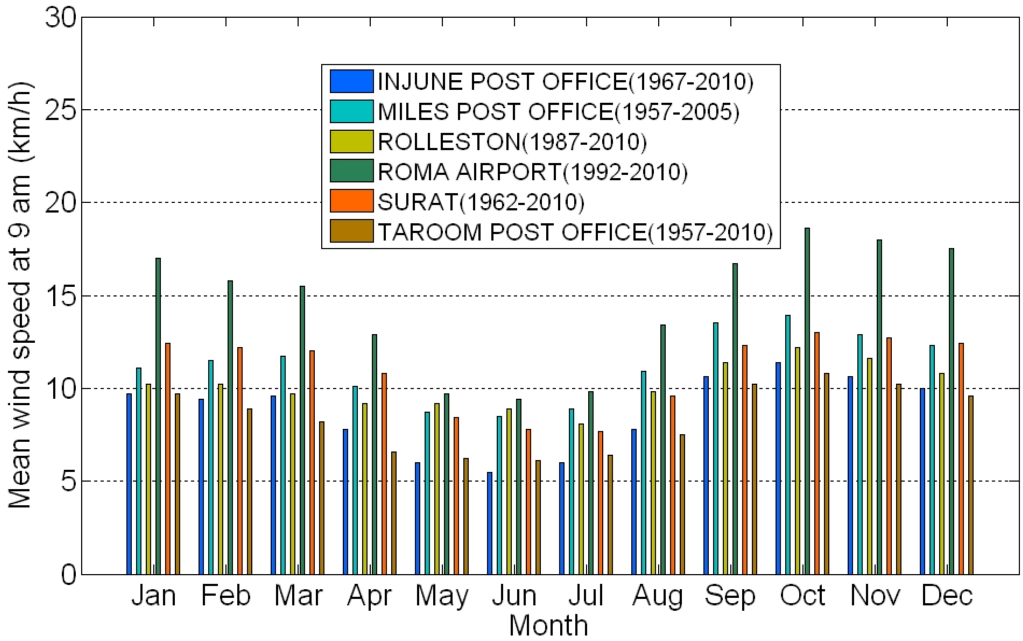
4.4.6 Wind speed and direction

Wind is characterised by its strength, frequency and direction. Wind speed is usually observed in the morning and afternoon. Wind speed, direction and frequency are reported through annual and seasonal wind rose plots.

Wind speed

Figure 4-11 and Figure 4-12 show the mean morning wind speed (9:00 am) and afternoon wind speed (3:00 pm) in kilometres per hour (km/hour).

Figure 4-11 Mean morning wind speed (9:00 am)



4 Existing climate

Figure 4-12 Mean afternoon wind speed (3:00 pm)

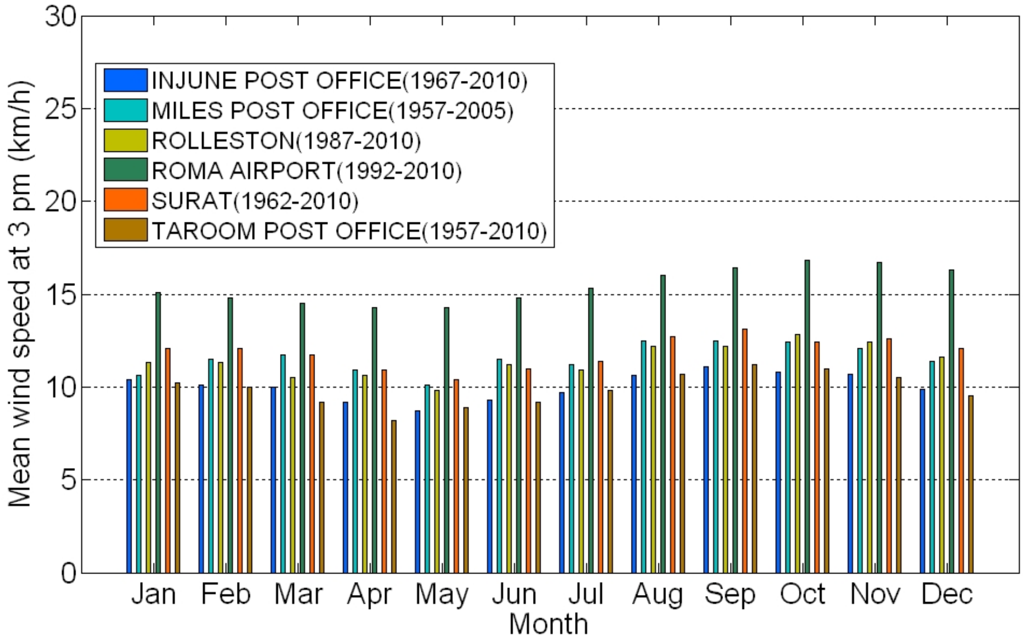


Figure 4-11 and Figure 4-12 show that the highest wind speeds are observed at Roma Airport at 9:00 am and 3:00 pm in the south of the GFD Project area. Wind speeds vary, with the highest 9:00 am mean wind speeds observed at Roma Airport (18.6 km/h) in October and the lowest at Injune Post Office (6 km/h) in July. At 3:00 pm, the highest mean wind speed was observed at Roma Airport (16.8 km/h) in October) and the lowest at Taroom Post Office (8.2 km/h) in July).

For observations taken at 9:00 am and 3:00 pm, the lowest wind speeds were observed in the winter months of May to July. The variation in wind speed at 9:00 am during the year is greater than at 3:00 pm for the different stations. Wind speeds are lower at 9:00 am in the winter months May, June and July.

Wind roses

Long-term wind speed, direction and frequency records are displayed as wind rose plots in Figure 4-13. The wind rose for Rolleston Airport represents the north of the GFD Project area, Miles - Constance Street the southeast, and Roma Airport the south.

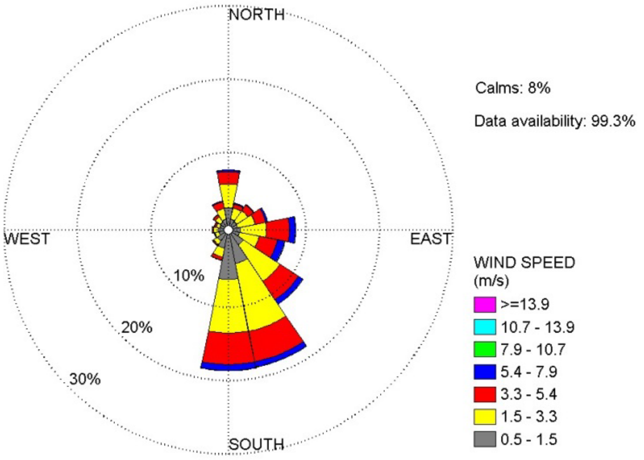
Figure 4-13 shows that wind speed and direction at the three monitoring stations varies across the region. In the north (Rolleston Airport), the wind blew from the south or south-southeast for 38% of hours between 2010 and 2012. The strongest winds were between 5.4 metres per second (m/s) and 7.0 m/s. In the south of the GFD Project area (Miles - Constance Street and Roma Airport), winds blow predominantly from the north. At Miles - Constance Street the wind blew from the north for 20% of hours between 2004 and 2012 and at Roma Airport for 16% of hours between 1997 and 2012. The strongest winds blew at Roma Airport from the north and were between 7.9 m/s and 10.7 m/s.

4 Existing climate

Figure 4-13 Wind roses

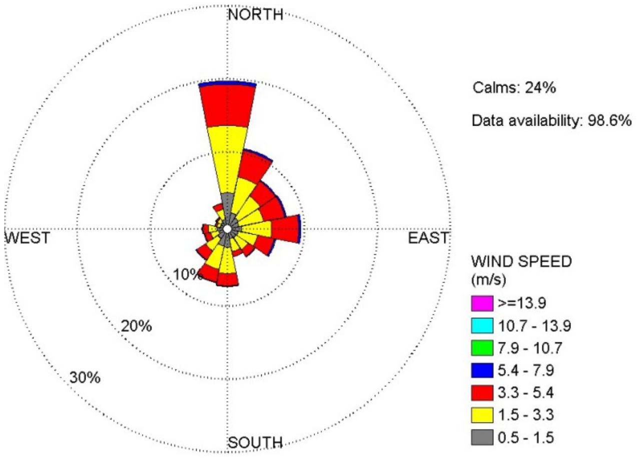
Rolleston Airport (35129)

2010 to 2012



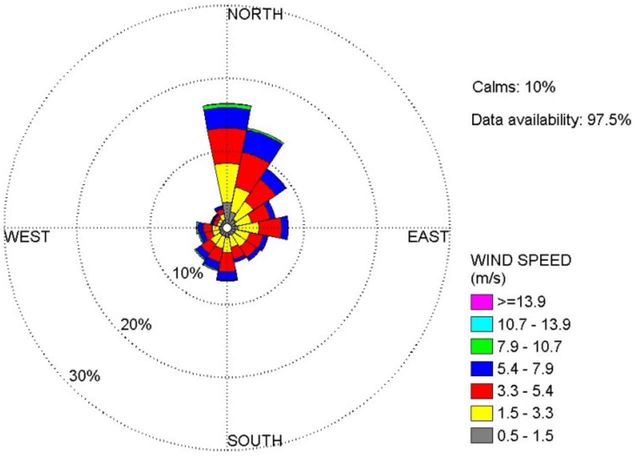
Miles – Constance Street (42112)

2004 to 2012



Roma Airport (43091)

1997 to 2012



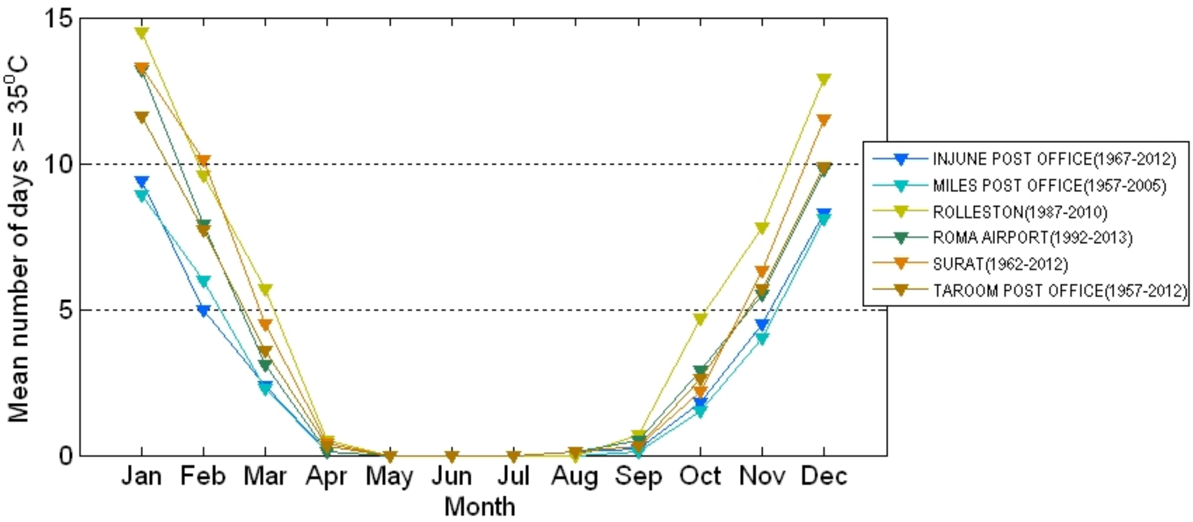
4.5 Natural hazards

Natural hazards include extreme temperatures, droughts, bushfires, floods, severe storms and cyclones. Extreme climate events can cause sedimentation, erosion, stormwater damage, contamination and health and safety risks to the GFD Project workforce and the general population. This section describes the potential for these extreme climate events to occur in the GFD Project area and the projected changes to these hazards as a result of climate change.

4.5.1 Extreme temperatures and heatwaves

The subtropical climatic zone of the region is characterised by very hot summers and is prone to extreme temperature events, which can be characterised by the number of hot days exceeding 35˚C. Figure 4-14 shows the average number of days that exceed 35˚C at the observation stations. It also shows that the number of hot days is likely to be highest in the north of the GFD Project area (Rolleston) for most of the year. However, in February the number of hot days is highest at Surat in the south.

Figure 4-14 Average number of days exceeding 35º C



4.5.2 Extreme rainfall and flooding

The GFD Project area is located within the Condamine-Balonne and Fitzroy River basins. These two basins experience seasonal flow, as the subtropical climate brings significant rainfall in the summer months of November to April and minimal rainfall in the cooler months of May to October. Major rain intensity is strongly associated with La Niña and has the ability to cause extensive flooding in Queensland, like that experienced in 2011.

Portions of the GFD Project area and the Condamine-Balonne Basin were affected by flooding from December 2010 to February 2011. The floods were attributed to a severe La Niña event in the Pacific Ocean. Enhanced rainfall conditions overwhelmed the ephemeral networks and caused one of the most devastating weather events in Queensland's recorded history. The Fitzroy River Basin has a long and well-documented history of floods, dating back to 1859, and like the Condamine-Balonne Basin, was also affected by extensive and widespread flooding in 2011, recording a flood level of 9.2 m on the Rockhampton gauge. The highest recorded flood occurred in January 1918, which reached 10.1 m on the Rockhampton gauge (BoM, 2013).

Santos GLNG has previously undertaken flood risk modelling for the GLNG Project. Flood levels for both the 50 and 100 year ARI (average recurrence interval) event were investigated along waterways within a 5 km radius of proposed hub and campsite areas. This will be the same procedure that will be applied to the GFD Project prior to final siting of camps or permanent infrastructure. This information allows Santos GLNG to determine appropriate locations for hub and camp developments for the GFD Project so they are not impacted by 50/ 100 year ARI flood events as appropriate.

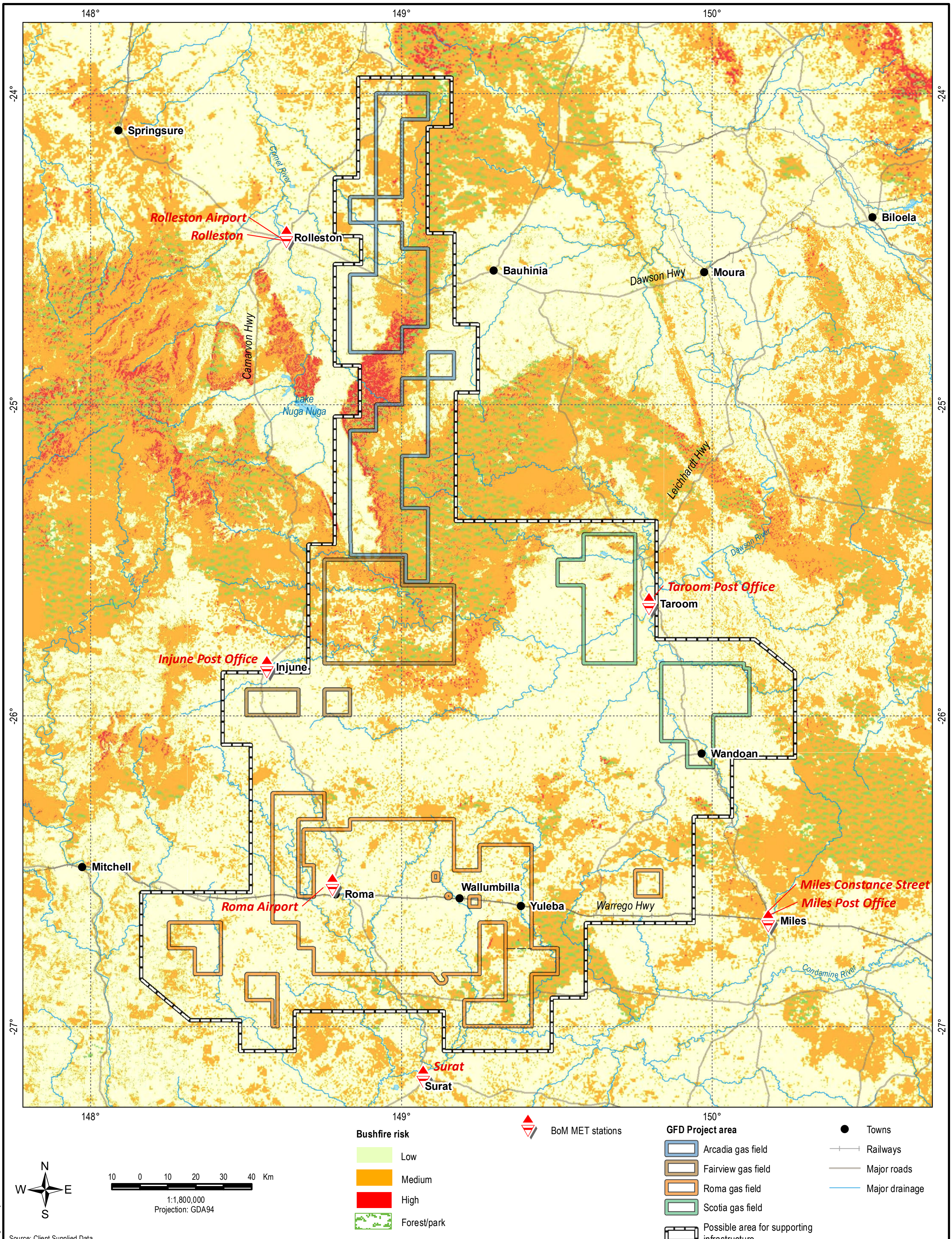
4.5.3 Bushfires

A combination of high vegetation density, high temperatures, strong winds, and low humidity increases fire risk. The fire season for most of southern Queensland extends from spring to mid-summer. The greatest danger occurs after the dry winter/spring period, before the onset of wet weather in summer.

The GFD Project area is located within the Banana Shire and Maranoa, Central Highlands, and Western Downs Regional Council areas, which are predominantly in southern Queensland. The Queensland Rural Fire Service has mapped the bushfire risk in each of these local government areas (Queensland Rural Fire Service, 2013). This is shown in Figure 4-15.

The southern region of the GFD Project area is characterised by predominantly low to medium fire risk. Further north, the GFD Project area is assessed to have a generally low to medium fire risk, with small areas of high fire risk.

The cleared pastureland around Roma has the lowest fire hazard despite relatively low rainfall and high winds. This is a function of the limited vegetation available to act as fuel in these cleared areas.



Source: Client Supplied Data

Santos GLNG Project

GFD PROJECT EIS

BUSHFIRE RISK ASSESSMENT

URS

CLIMATE

Figure: **4-15**

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4.5.4 Drought

Drought is an extended period of months or years when a region experiences a rainfall deficiency below 10% of records for the period in question. The most recent drought experienced in Queensland was from 2001 to 2008 and this was the most severe on record. The previous worst recorded drought was the Federation Drought from 1898 to 1903.

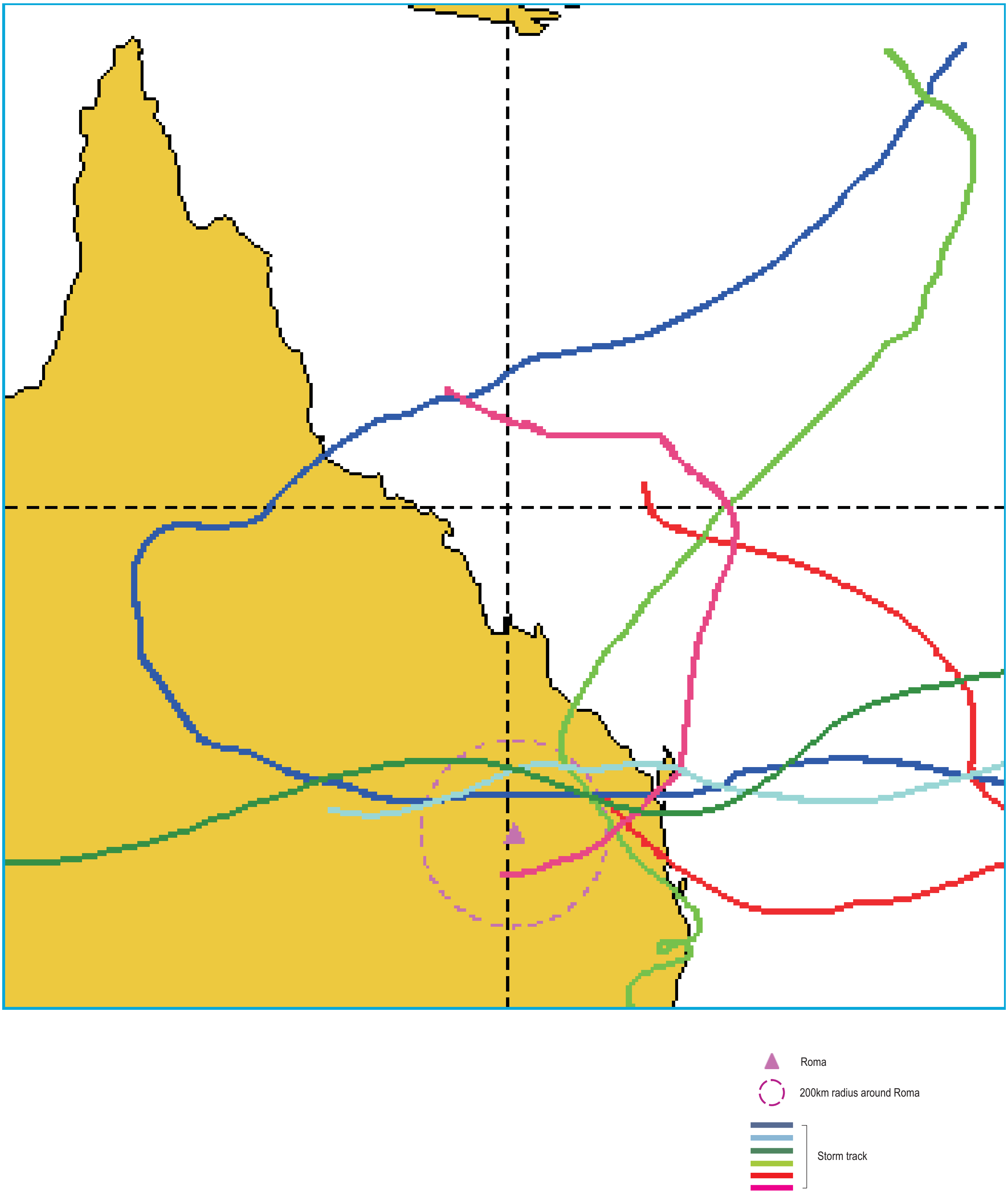
4.5.5 Severe storms and lightning strikes

Severe storms are the most frequently occurring natural hazard in Queensland. They can result in severe events such as heavy rains, damaging strong winds, hail, flash floods, and lightning that can lead to bushfires. Most severe storms in Queensland occur between the months of September and March (Department of Emergency Services, 2007).

Thunderstorms generate lightning, which has the potential to impact on GFD Project infrastructure. BoM has mapped the mean annual number of thunder-days between 1990 and 1999, and the lightning total flash density and lightning ground flash density across Australia between 1995 and 2006. The GFD Project area experiences an average of 20 to 35 thunder days/year, 5 to 10 lightning flashes/km^2/year and 1 to 3 lightning ground flashes/km^2/year (Kuleshov *et al*., 2006).

4.5.6 Cyclones

Queensland experiences frequent storm events, such as tropical cyclones and thunderstorms. On average 4.7 tropical cyclones per year affect Queensland (Queensland Government, 2010).Figure 4-16 shows the tropical cyclone activity within a distance of 200 km of Roma between 1970 and 2006.



Source:

Santos GLNG Project

GFD PROJECT EIS

TROPICAL CYCLONE TRACKS (1970 TO 2006) WITHIN 200KM OF ROMA

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CLIMATE

Figure: **4-16**

File No: **42627064-g-2040.cdr** Drawn: **XL** Approved: **RS** Date: **22-08-2014** Rev. **A** A4

As shown in Figure 4-16 the GFD project area is located approximately 400 km inland where cyclones rarely have a direct effect on the region. However, weakened tropical cyclone systems are associated with flooding in inland regions and can result in significant periods of rain (Queensland Government, 2012). BoM records indicate that there have been 10 cyclones in the past 100 years that have crossed the GFD Project area (based on data within 200 km of Roma).

4.6 Climate change predictions

4.6.1 Data and information sources

The following sources were used to review future climate change projections for Australia in a national and regional context, which enabled a climate change impact risk assessment to be undertaken for the GFD Project:

- *Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios* (IPCC, 2000)
- *(IPCC Fourth Assessment Report* (IPPC, 2007)
- *Climate Change in Australia: technical report 2007* (CSIRO, 2007)
- *State of the Climate 2012* (CSIRO and BoM, 2012)
- *Climate change in the Maranoa and Districts Region* (Queensland Government ClimateQ: toward a greener Queensland, 2009a)
- *Climate change in the Central Queensland Region* (Queensland Government ClimateQ: toward a greener Queensland, 2009b).

4.6.2 Climate change scenarios

Six emissions scenarios for greenhouse gases (GHG) from year 2000 to 2100 were described within the IPCC's *Special Report on Emissions Scenarios* (2000). The scenarios combine a number of assumptions with respect to economic, demographic, and technological variables likely to affect future GHG emissions. The six emission scenarios are summarised below:

- *Scenario A1*—a world of very rapid economic growth with global population peaking mid-century and the rapid development of new and more efficient technologies. Scenario A1 is divided into three groups, which differ based on the direction of technological change:
  - *Scenario A1FI*—continued dependence on fossil fuels
  - *Scenario A1T*—alternative fuel sources used in preference to fossil fuels
  - *Scenario A1B*—a balanced use of different energy sources.
- *Scenario A2*—a heterogeneous world with high growth in population, but slow economic and technological development.
- *Scenario B1*—a convergent world with a population identical to Scenario A1, but with more rapid economic changes to focus on a service and information economy.
- *Scenario B2*—a world with intermediate population and economic growth, with a local emphasis on providing solutions to economic, social, and environmental sustainability.

The impacts of each emissions scenario on climate change were presented for the near and long-term in the IPCC *Fourth Assessment Report* (2007). The projected GHG emissions for each scenario were processed by carbon models to derive atmospheric concentrations. The concentrations were subsequently converted to an equivalent radiative forcing of the climate system, either as positive forcing (warming), or negative forcing (cooling) of the climate. The changes in radiative forcing were provided to global climate models (GCMs), which were used to model future projections of Earth's climate.

Research groups from around the world contributed to 23 GCMs used for projecting future climate based on the aforementioned emissions scenarios. These models have been used to generate climate projections for Australia, as reported within the CSIRO technical report (2007).

Climate change projections for Queensland were based on three of the IPCC GHG emissions scenarios (Queensland Government, 2009) for years 2030, 2050, and 2070. Given the expected GFD Project duration, climate change projections for years 2030 and 2050 were assessed using the following emissions scenarios:

- Medium emissions growth (IPCC Scenario A1B) to year 2030 (2030 Medium)
- Low emissions growth (IPCC Scenario B1) to year 2050 (2050 Low)
- High emissions growth (IPCC Scenario A1FI) to year 2050 (2050 High).

The GCMs demonstrated little variation in climate projections under the low, medium, and high emissions scenarios up to year 2030. As such, the 2030 climate change projections for Queensland were based on the medium emissions growth scenario. Conversely, the climate projections modelled by the GCMs predict greater disparity at year 2050 and beyond, under the various emissions scenarios. Consequently, the 2050 projections are based on the low and high emissions scenarios.

The regions encompassing the GFD Project area are 'Central Queensland' and 'Maranoa and Districts'. Projected climate changes for the GFD Project area under the three emission scenarios are based on the published climate change projection summaries for these GCM regions (Queensland Government, 2009a and 2009b) and the technical report on climate change in Australia (CSIRO and BoM, 2007).

4.6.3 Predicted climate changes for GFD Project area

4.6.3.1 Climate change projections

The Australian climate has been warming each decade since the 1950s, with the average daily maximum temperature in Australia increasing by a total of 0.75 ˚C since 1910 (CSIRO and BoM, 2012). Despite the occurrence of natural climate variability, such as El Niño and La Niña events leading to hot droughts (e.g. 2002–03) and cooler wet periods (e.g. 2010–11), the long-term warming trend has prevailed. This is consistent with the global trend with the increase in anthropogenic GHG emissions understood to be the main contributor.

Australian average temperatures are projected to increase by 0.6 ˚C to 1.5 ˚C by 2030, compared with the climate of 1980–1999 (CSIRO and BoM 2012). By 2070, using the IPCC GHG emission scenarios the projected warming is between 1.0 ˚C and 5.0 ˚C. An increase in the frequency of dry years is expected, but it is likely that rainfall events will be more intense during wet periods.

4 Existing climate

The projected changes in climate for Central Queensland are presented in Table 4-2 and for Maranoa and Districts in Table 4-3. Given the range of uncertainty within the GCMs, the median or best estimate projected change is reported. The projections are provided for each of the three emissions scenarios (Section 4.6.2), relating to the following climate variables:

- Mean temperature
- Rainfall
- Rainfall intensity
- Potential evaporation
- Extremes of temperature
- Wind speed
- Cyclones.

Table 4-2 Summary of climate change projections for Central Queensland

Climate variable	Period	Historical mean 1971-2000	Emissions scenarios: projected changes		
			2030 'Medium'	2050 'Low'	2050 'High'
Temperature (˚C)[1]	Annual	21.6 ˚C	+1.0 ˚C	+1.2 ˚C	+2.0 ˚C
	Summer	26.9 ˚C	+1.0 ˚C	+1.2 ˚C	+2.0 ˚C
	Autumn	22.0 ˚C	+1.0 ˚C	+1.2 ˚C	+1.9 ˚C
	Winter	15.2 ˚C	+1.0 ˚C	+1.2 ˚C	+2.0 ˚C
	Spring	22.5 ˚C	+1.0 ˚C	+1.3 ˚C	+2.1 ˚C
Rainfall (%)[1]	Annual	692 mm	-3%	-4%	-7%
	Summer	295 mm	-2%	-2%	-3%
	Autumn	162 mm	-4%	-5%	-8%
	Winter	80 mm	-5%	-5%	-9%
	Spring	145 mm	-6%	-7%	-12%
Rainfall intensity for Queensland east coast (%)[2]	24 hours based on a 20 year statistical analysis	N/A	N/A	+3.9% (median) -24.1% to 34.3% (range of model values)	
Potential evaporation (%)[1]	Annual	1,997 mm	+3%	+4%	+7%
	Summer	661 mm	+3%	+3%	+6%
	Autumn	449 mm	+4%	+4%	+7%
	Winter	300 mm	+4%	+4%	+8%
	Spring	588 mm	+3%	+4%	+6%
Extreme temperatures at Barcaldine[3], approximately 305 km west of the project area	Annual average number of hot days above 35˚C	87 days	+23 days	+28 days	+47 days
	Annual average number of very hot days above 40˚C	8.9 days	+7.4 days	+9.9 days	+19.8 days
	Annual average number of very hot runs (3 to 5 consecutive days) above 40˚C	1.2	+1.7	+2.3	+5.0

Climate variable	Period	Historical mean 1971-2000	Emissions scenarios: projected changes		
			2030 'Medium'	2050 'Low'	2050 'High'
Wind speed (%)[4]	Annual average	N/A	+2% to 5%	+2% to 5%	+5% to 10%
Cyclones[5]	A slight decrease in tropical cyclone frequency off the east coast of Australia is projected. However, studies indicate a likely increase in the proportion of long-lived tropical cyclones in the intense categories, with a 130 km southward shift in cyclone tracks. This could result in a greater cyclone impact in the Central Queensland region.				

Observational mean provided using a 30-year base period (1971 – 2000) to allow projections to be referenced against historical climate
[1] Projections for temperature, rainfall and potential evaporation are relative to the model base period of 1980 – 1999. The median ('best estimate') value is provided (Queensland Government, 2009a).
[2] Source: Rafter and Abbs, 2009. Refer Table 2, p. 46 for mean, maximum, minimum and median percentage change (relative to a 40-year period centred on 1980) for one-day rainfall totals from the 11 models, for a time slice centred on 2055, for Queensland east coast). The 3.9% quoted is the median of the median projections of the 11 models. The Queensland east coast region is considered representative of the northern extent of the GFD Project area.
[3] Source: CSIRO, 2010; using a base period of 1971-2000
[4] Source: CSIRO, 2013.
[5] Source: CSIRO and BoM, 2007 and Queensland Government, 2009a.

Table 4-3 Summary of climate change projections for Maranoa and Districts

Climate variable	Period	Current historical mean (1971-2000)	Emissions scenarios: projected changes		
			2030 'Medium'	2050 'Low'	2050 'High'
Temperature (˚C)[1]	Annual	20.2 ˚C	+1.1 ˚C	+1.3 ˚C	+2.2 ˚C
	Summer	26.9 ˚C	+1.1 ˚C	+1.3 ˚C	+2.2 ˚C
	Autumn	20.5 ˚C	+1.0 ˚C	+1.3 ˚C	+2.1 ˚C
	Winter	12.7 ˚C	+1.0 ˚C	+1.2 ˚C	+2.0 ˚C
	Spring	20.9 ˚C	+1.2 ˚C	+1.4 ˚C	+2.3 ˚C
Rainfall (%)[1]	Annual	582 mm	-3%	-4%	-6%
	Summer	220 mm	-1%	-1%	-2%
	Autumn	134 mm	-4%	-4%	-7%
	Winter	87 mm	-6%	-7%	-11%
	Spring	137 mm	-6%	-7%	-12%
Rainfall intensity for Queensland east coast (%)[2]	24 hours based on a 20 year statistical analysis	N/A	N/A	+4.2% (median) -16% to 35.7% (range of model values)	
Potential evaporation (%)[1]	Annual	1,985 mm	+3%	+3%	+6%
	Summer	735 mm	+3%	+2%	+6%
	Autumn	443 mm	+3%	+4%	+7%
	Winter	242 mm	+4%	+4%	+8%
	Spring	569 mm	+3%	+3%	+5%
Extreme temperatures at Miles[3], located within the project area	Annual average number of hot days above 35˚C	31 days	+15 days	+19 days	+34 days
	Annual average number of very hot days above 40˚C	1.3 days	+1.2 days	+1.8 days	+4.5 days
	Annual average number of very hot runs (3 to 5 consecutive days) above 40˚C	<0.1	+0.1	+0.2	+0.8

Climate variable	Period	Current historical mean (1971-2000)	Emissions scenarios: projected changes		
			2030 'Medium'	2050 'Low'	2050 'High'
Wind speed (%)[4]	Annual average	N/A	+2% to 5%	+2% to 5%	+5% to 10%
Cyclones[5]	Less frequent, but more intense and long-lived cyclones have a greater chance of impacting on inland areas such as in Maranoa and Districts. The impacts could be caused from the decay of cyclones into rain bearing depressions or from the cyclones tracking further inland.				

Observational mean provided using a 30-year base period (1971 – 2000) to allow projections to be referenced against historical climate
1 Projections for temperature, rainfall and potential evaporation are relative to the model base period of 1980 – 1999. The median ('best estimate') value is provided (Queensland Government, 2009b).
2 Source: Rafter and Abbs, 2009. Refer Table 2, p. 46 for mean, maximum, minimum and median percentage change (relative to a 40-year period centred on 1980) for one-day rainfall totals from the 11 models, for a time slice centred on 2055, for Queensland east coast). The 4.2% quoted is the median of the median projections of the 11 models. The southeast Queensland region is considered representative of the southern and eastern extents of the GFD Project area.
3 Source: CSIRO, 2013.
4 Source: CSIRO and BoM, 2007 and Queensland Government, 2009a.
5 Source: Queensland Government (2009b).

4.6.3.2 Projected changes to natural hazards

Extreme temperatures and heatwaves

A near doubling of very hot days (>40 ˚C) within the Central Queensland region by 2030 is projected. There will be three times as many hot days by 2050 with runs of 3 to 5 consecutive very hot days occurring up to six times per year by 2050.

In the Maranoa and Districts region a near doubling of very hot days (>40 ˚C) by 2030 is projected and up to four times as many very hot days by 2050. Runs of consecutive very hot days are projected to occur once every 10 years by 2030 and once every 2 years by 2050.

Extreme rainfall and flooding

A decline in annual and seasonal average rainfall and associated increase in the frequency of dry years is expected, but it is likely that rainfall events will be more intense during wet periods. An increase in 24-hour rainfall intensities of 3.9% (Queensland east coast median) and 4.2% (southeast Queensland median) by 2055, relative to that of the base period 1980-1999 (Queensland Government, 2012) is predicted.

Bushfires

A decline in annual and seasonal average rainfall, particularly in winter and spring, will lead to more severe droughts and provide more favourable conditions for bushfires where vegetation is available as fuel.

Drought

Due to projected changes in rainfall and increases in evaporation, 20% more drought months are anticipated across Australia by 2030 and 40% more across Eastern Australia relative to the period 1980-1999 (Bureau of Meteorology and CSIRO, 2007). Projections have shown that by 2030 exceptionally low soil moisture years are likely to affect approximately 7% of Queensland and occur once every 13 years on average (Bureau of Meteorology and CSIRO, 2008). Based on these projections, it is expected that droughts will occur in the project area during the life of the GFD Project.

Storms and cyclones

Severe storms and lightning strikes

Severe storms and lightning strikes are predicted by determining the likelihood of the large-scale environmental conditions favourable to these events and inferring the risk of occurrence.

In Australia, favourable conditions for the formation of cool season tornadoes are likely to be reduced under global warming (Kounkou et al., 2007) but there is no information specific to the GFD Project area. No change is predicted for the frequency of hail (Niall and Walsh, 2005) and no information relating to the change in frequency of lightning strikes is available for the GFD Project area.

Cyclones

Global and regional climate models have been used to predict changes in the frequency and intensity of cyclones in Australia (Bureau of Meteorology and CSIRO, 2007). Studies by Walsh et al. (2004) and

Leslie et al. (2007) indicate that there will be little or no significant change in tropical cyclone frequency off the east coast of Australia. A third study based on CSIRO simulations shows a decrease of 9% in cyclone frequency off eastern Australia.

However, the three studies report a significant increase in the intensity of severe Category 3–5 storms. Walsh et al. (2004) predicted an increase of intensity of these storms of 56% by 2050 using a 30 km global model and Leslie et al. (2007) of 22% by 2050 using a 50 km global model. The variation in these projections is due to the lack of good observational data and the limited ability of global climate models to represent cyclone behaviour.

4.6.3.3 Summary

The key projected climate changes by 2030 and 2050, which have the potential to impact on the GFD Project, are shown in Table 4-4.

Table 4-4 Projected climate change impact

Climate change variable	Projection
Increase in rainfall intensity	An increase in 24-hour rainfall intensities of 3.9% (Queensland east coast median) and 4.2% (southeast Queensland median) by 2055, relative to that of 1980.
More extreme temperatures and heatwaves	A near doubling of very hot days (>40 ˚C) within the Central Queensland region by 2030 and more than three times as many hot days by 2050 (‘2050 High’ scenario), with runs of 3 to 5 consecutive very hot days occurring up to six times per year by 2050. A doubling of very hot days within the Maranoa and Districts region by 2030 and up to four times as many very hot days by 2050, with runs of consecutive very hot days occurring once every 10 years by 2030 and once every 2 years by 2050. Increased risk and intensity of bushfires from drier, hotter conditions resulting from decreases annual rainfall, higher potential evaporation and increased temperatures.
More frequent droughts due to reduced annual rainfall and higher evaporation rates	A decline in annual and seasonal average rainfall, particularly in winter and spring, leading to more severe droughts and providing favourable conditions for bushfires.
Increase in intensity and frequency of extreme storm events and cyclones	The potential for less frequent, but more intense and long-lived cyclones with studies suggesting cyclone tracks may shift southward along the east coast of Australia (Queensland Government, 2009a). A greater impact on inland areas could occur resulting from the decay of cyclones into rain bearing depressions or from cyclones tracking further inland. However, no significant trends in the total numbers of tropical cyclones or in occurrence of the most intense tropical cyclones have been identified at present in Australia (CSIRO and BoM, 2012).

Potential impacts and management

5.1 Potential impacts

GFD Project infrastructure and workforce could potentially be subject to heat stress, flood, drought, bushfire and storm events. The key potential impacts associated with these climate hazards are described below.

5.1.1 Extreme temperatures and heatwaves

During summer months or extreme temperatures or heatwaves, the GFD Project workforce will be subject to high temperatures during work hours with the potential to cause heat stress and other health issues.

Extreme temperatures are associated with increased energy demand for cooling buildings, plant and equipment and can result in heat-induced damage to building materials (e.g. pipelines) and inefficiencies in gas compression, power generation and transmission.

Bushfires are likely to occur when periods of low rainfall and high temperatures coincide at the end of winter months (Section 4.4.2). Bushfires could damage GFD Project infrastructure such as accommodation camps, gas and water treatment and processing facilities, and access roads or tracks. Well operations may be impaired if bushfires block transportation routes and access to in-field infrastructure. Bushfires may also impact upon the workforce travelling to and from the GFD Project area or residing in accommodation camps.

5.1.2 Increase in rainfall intensity and flooding

Flooding is likely to occur during periods of extreme rainfall. Periods of increased rainfall intensity and flooding are most likely in late spring through to summer when cyclonic activity is more common (Section 4.4.1). Floods could damage GFD Project infrastructure such as accommodation camps, gas and water treatment and processing facilities, and access roads or tracks. Well operations may be impaired if flooding blocks transportation routes and access to in-field infrastructure. Flash flooding may also impact upon the workforce travelling to and from the GFD Project area or residing in accommodation camps.

During extreme climatic events involving heavy rainfall or flooding there is potential for design criteria for drainage and erosion and sediment control systems to be exceeded. This could result in an unplanned overflow of coal seam water storage facilities or failure of bunding at chemical, fuel or waste storage areas. Where loss of containment occurs, contaminants may flow into adjacent water bodies, potentially resulting in reduced water quality.

Extensive flooding is a high risk natural hazard and can cause sheet, rill and gully erosion. This can be exacerbated by GFD Project infrastructure, which can include modifications such as widening, deepening or realigning waterways or floodplains. The extent of watercourse and bank erosion is dependent on soil profile and topography.

5.1.3 More frequent droughts

Droughts can impact on the GFD Project by reducing available water supply and groundwater levels. Extended drought period can cause soil shrinkage and movement, which may impact on structural integrity and longevity of GFD Project infrastructure. Excessive dust levels and progressive rehabilitation will demand increased attention to be effectively managed.

5.1.4 Increased storm events and intensity of cyclones

Of the natural hazards and climate change extremes identified, thunderstorms and associated lightning strikes pose the smallest risk to the GFD Project. These are unlikely to cause significant impacts to the GFD Project expect possibly in the most extreme cases. However, impacts from thunderstorms and lightning strikes could be expected to pose short-term disruption to telecommunication or other utilities.

Increased evaporation associated with drought conditions may adversely affect the supply of water to the GFD Project's rehabilitation activities. However, the planning and design of GFD Project infrastructure will accommodate these risks. As such, the impacts would generally be short-term but could require restorative actions.

5.2 Management framework

State and local governments in the region have emergency response and management plans in place to address significant weather hazards. For example, the Queensland Fire and Rescue Service actively manage severe and widespread bushfires in the region. Santos GLNG will consult with the Queensland Fire and Rescue Service and other relevant authorities regarding emergency response plans and procedures for the GFD Project.

Santos GLNG has developed and implemented a range of strategies to manage risks to the GLNG Project, which is located in the same region as the GFD Project.

Table 5-1 lists the relevant management plans and their key control strategies.

Table 5-1 Climate impact management strategies and documents

Document	Key management strategies
Bushfire management plan	The plan provides clear direction for Santos GLNG gas fields operations on how to prepare for and respond to the risk of bushfire. The four main objectives include: • Reduce the likelihood of ignition • Reduce the likelihood of personnel being exposed to bushfires • Increase the level of bushfire protection • Increase the level of emergency response preparedness.
Emergency response plan (ERP)	The ERP forms part of Santos GLNG's overall emergency response. It is supplementary to the Queensland Incident management plan and provides the necessary information to deal with emergencies at the asset level.

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Document	Key management strategies
GFD Project Environmental protocol for constraints planning and field development (the Constraints Protocol)	The Constraints protocol applies to all gas field related activities. The scope of the Constraints protocol is to: • Enable Santos GLNG to comply with all relevant State and Federal statutory approvals and legislation • Support Santos GLNG's environmental policies and the General Environmental Duty (GED) as outlined in the EP Act • Promote the avoidance, minimisation, mitigation and management of direct and indirect adverse environmental impacts associated with land disturbances • Minimise cumulative impacts on environmental values. The Constraints protocol provides a framework to guide placement of infrastructure and adopts the following management principles: • Avoidance — avoiding direct and indirect impacts • Minimisation — minimise potential impacts • Mitigation — implement mitigation and management measures • Remediation and rehabilitation — actively remediate and rehabilitate impacted areas • Offset — offset residual adverse impacts in accordance with regulatory requirements. The Constraints protocol enables the systematic identification and assessment of environmental values and the application of development constraints to effectively avoid and / or manage environmental impacts.
Journey management plan	Journey management plans are developed on an as needs basis (normally by contractors) to specify travel issues, including which roads are to be used. These plans are operational and journey specific. Journey management plans include information relating to: communication requirements, call-in procedures, approved roads, weather conditions and potential hazards.
Land release management plan (LRMP)	The LRMP addresses the management of releases of water to land in Santos GLNG's gas fields, including: • Coal seam water use for irrigation, construction and operations purposes • Treated sewage effluent releases to land • Use of treated sewage effluent for construction and operational purposes • Low point drain water releases to land • Hydrostatic test water releases to land. The document includes the principles, methods and controls to effectively manage and minimise the risk environmental harm being caused by release of water to land.
Pest and weed management plan (PWMP)	The management of pest and weed species will be undertaken in accordance with the PWMP. The plan includes measures such as: • Identification of pest and weed species and areas of infestation • Avoidance of traversing and placing infrastructure in areas of known infestation • Prevention of the spread of pest and weed species by implementing appropriate work practices and promotion of risk awareness • Control of identified pest and weeds through containment, reduction or eradication as required by legislation.
Queensland incident management plan (QIMP)	The QIMP describes the use of the Santos GLNG incident management framework, including the procedures and systems that apply to the Santos GLNG operations and activities.
Rehabilitation management plan	The Rehabilitation management plan outlines the rehabilitation objectives for Project-related disturbances within the GFD Project area. This includes the

5 Potential impacts and management

Document	Key management strategies
	phasing of rehabilitation to first achieve stabilisation and subsequently final rehabilitation for disturbances to land (i.e. ground surface). The Rehabilitation management plan: • Describes Santos GLNG's approach to rehabilitation • Identifies key rehabilitation objectives and criteria to deem rehabilitation success • Outlines general rehabilitation actions to be undertaken by Santos GLNG when rehabilitation a disturbance • Provides an overview of monitoring and maintenance actions to be conducted on rehabilitated areas.

Risk assessment

6.1 Overview

There are no relevant quantified guidelines to measure impacts for climate; therefore the level of impact has been determined by how each particular climatic hazard is to be managed. A risk assessment approach was used based on *AS/NZS 31000:2009 Risk Management – Principles and Guidelines* and the Santos GLNG standard for hazard identification, risk assessment and control.

6.2 Assessment methodology

A semi-quantitative risk assessment process was applied to evaluate the risk of impacts on the construction and operations of the GFD Project for the climate change scenarios identified by the IPCC. Criteria used to rank the likelihood and consequences of potential impacts are set out in Table 6-1 and Table 6-2 respectively.

Table 6-1 Likelihood criteria

Likelihood category	Description
Almost certain Common	Will occur, or is of a continuous nature, or the likelihood is unknown. There is likely to be an event at least once a year or greater (up to 10 times per year). It often occurs in similar environments. The event is expected to occur in most circumstances.
Likely Has occurred in recent history	There is likely to be an event on average every one to five years. Likely to have been a similar incident occurring in similar environments. The event will probably occur in most circumstances.
Possible Could happen, has occurred in the past, but not common	The event could occur. There is likely to be an event on average every 5 to 20 years.
Unlikely Not likely or uncommon	The event could occur but is not expected. May have heard it discussed as a possibility but an extremely unusual one. A rare occurrence (once per 100 years).
Remote Rare or practically impossible	The event may occur only in exceptional circumstances. Very rare occurrence (once per 1,000 years). Unlikely that it has occurred elsewhere; and, if it has occurred, it is regarded as extremely unique.

Table 6-2 Consequence criteria

Consequence category	Description
Critical Severe, widespread long-term effect	Destruction of sensitive environmental features. Severe impact on ecosystem. Impacts are irreversible and/or widespread. Regulatory and high level government intervention/action. Community outrage expected. Prosecution likely. Financial loss in excess of $100 million.
Major Wider spread, moderate to long-term effect	Long-term impact of regional significance on sensitive environmental features (e.g. wetlands). Likely to result in regulatory intervention/action. Environmental harm either temporary or permanent, requiring immediate attention. Community outrage possible. Prosecution possible. Financial loss from $50 million to $100 million.

Consequence category	Description
Moderate Localised, short-term to moderate effect	Short term impact on sensitive environmental features (e.g. gibber plain). Triggers regulatory investigation. Significant changes that may be rehabilitated with difficulty. Repeated public concern. Financial loss from $5 million to $50 million.
Minor Localised short-term effect	Impact on fauna, flora and/or habitat but no negative effects on ecosystem. Easily rehabilitated. Requires immediate regulator notification. Financial loss from $500,000 million to $ 5 million.
Negligible Minimal impact or no lasting effect	Negligible impact on fauna/flora, habitat, aquatic ecosystem or water resources. Impacts are local, temporary and reversible. Incident reporting according to routine protocols. Financial losses up to $500,000.

The level of risk of each environmental impact was determined by combining the likelihood and consequence criteria to assign a risk rating as shown in Table 6-3.

Table 6-3 Risk matrix

	Likelihood				
Consequence	**Almost certain**	**Likely**	**Possible**	**Unlikely**	**Remote**
Critical	Very high	Very high	High	High	Medium
Major	Very high	High	High	Medium	Medium
Moderate	High	Medium	Medium	Medium	Low
Minor	Medium	Medium	Low	Low	Very low
Negligible	Medium	Low	Low	Very low	Very low

6.3 Results

A summary of the risk assessment for the GFD Project based on the climate change variables described in Table 4-4 is shown in Table 6-4. The risk controls described can be found in the documents shown Section 5.2.

6 Risk assessment

Table 6-4 Climate change risk assessment outcomes and adaptation measures

Potential impact	Phase	Pre mitigated risk			Mitigation / Adaptation	Residual risk		
		Likelihood	Consequence	Risk		Likelihood	Consequence	Risk
Extreme temperatures and heatwaves								
Heatwave health risks and reduced productivity for the GFD Project workforce.	Construction	Possible	Minor	Low	HSHS05 sets out control strategies and mandatory heat stress and awareness training for workforce and sub-contractors. HSHS05 also requires suitable control strategies to be implemented, such as air conditioned refuge and/or shade. Santos GLNG will implement an ERP in accordance with EHSMS13 Emergency preparedness. This will include the relevant Significant Hazard Risk Register developed in accordance with EHSMS09 Managing EHS risks. This will be required during extreme heatwave events which require increased medical supervision, integration of more shade structures, water coolers and scheduled rest breaks, and an increase in the rotation of shifts.	Unlikely	Minor	Low
	Operations	Likely	Minor	Medium		Unlikely	Minor	Low
	Decommissioning	Likely	Minor	Medium		Unlikely	Minor	Low
Increased energy demand for cooling, and inefficiencies in gas compression, power generation and transmission.	Construction	Unlikely	Minor	Low	Engineering design specifications will consider the expected atmospheric and climatic conditions and the potential for a decrease in the efficiency of plant such as gas compression and power generation during high temperatures. Inspection and maintenance programs will consider the potential risk of an increase in the extent and duration of heatwaves. Engineering design specifications will also consider the expected atmospheric and climatic conditions and the potential	Remote	Minor	Very Low
	Operations	Likely	Minor	Medium		Possible	Minor	Low
	Decommissioning	Likely	Minor	Medium		Possible	Minor	Low

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Potential impact	Phase	Pre mitigated risk			Mitigation / Adaptation	Residual risk		
		Likelihood	Consequence	Risk		Likelihood	Consequence	Risk
					for an increase in the demand for cooling during high temperatures. This may include an increase in the use of passive engineering designs such as building orientation, material selection, sunshades, treated windows and insulation.			
Heat-induced damage to gas and water gathering and transmission pipelines.	Construction	Remote	Minor	Very low	Engineering design specifications will consider the expected atmospheric and climatic conditions and the potential increase in the extent and duration of heatwaves. Inspection and maintenance programs will consider the potential risk of an increase in the extent and duration of heatwaves.	Remote	Minor	Very low
	Operations	Remote	Minor	Very low		Remote	Minor	Very low
	Decommissioning	Remote	Minor	Very low		Remote	Minor	Very low
Increased risk of bushfire in gas fields potentially affecting the GFD Project workforce safety, infrastructure and the surrounding environment.	Construction	Unlikely	Minor	Low	The Bushfire Management Plan will consider the range of expected atmospheric and climatic conditions and the potential for an increase in the extent and duration of heatwaves. The Bushfire Management Plan aims to: • Reduce the likelihood of ignition • Reduce the likelihood of personnel being exposed to bushfires • Increase the level of bushfire protection • Increase the level of emergency response preparedness. The ERP forms part of Santos GLNG's overall emergency response and provides the necessary information to deal with emergencies. Journey Management Plan includes information relating to: communication requirements, call-in procedures,	Remote	Minor	Very Low
	Operations	Possible	Minor	Low		Unlikely	Minor	Low
	Decommissioning	Possible	Minor	Low		Unlikely	Minor	Low

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Potential impact	Phase	Pre mitigated risk			Mitigation / Adaptation	Residual risk		
		Likelihood	Consequence	Risk		Likelihood	Consequence	Risk
					approved roads, weather conditions and potential hazards.			
Changes in range of invasive weed and pest species.	Construction	Remote	Moderate	Low	In accordance with EHS09 Pest Plants and Animals, Santos GLNG will implement the Rehabilitation Management Plan and the PWMP to control risks posed by certain plant species for invasiveness.	Remote	Moderate	Low
	Operations	Remote	Moderate	Low		Remote	Moderate	Low
	Decommissioning	Remote	Moderate	Low		Remote	Moderate	Low
Increase in rainfall intensity								
Capacity of water management systems (e.g. coal seam water storage, brine storage, exceeded resulting in: • More frequent overflows and localised flooding with potential for erosion • Larger stormwater flows may cause greater water damage to various facilities and infrastructure • Greater risk of contaminated stormwater discharged into receiving environments.	Construction	Unlikely	Minor	Low	In accordance with the Constraints protocol, Santos GLNG will consider the risk associated with flood events in the selection of infrastructure locations. Engineering design specifications will consider the range of expected atmospheric and climatic conditions and the potential for an increase in rainfall intensity and duration, including the risk of isolation by flood water. Dams will be designed in accordance with the Manual for Assessing Consequence Categories and Hydraulic Performance of Structures (EHP, 2013).	Remote	Minor	Very Low
	Operations	Possible	Minor	Low		Unlikely	Minor	Low
	Decommissioning	Possible	Minor	Low		Unlikely	Minor	Low

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Potential impact	Phase	Pre mitigated risk			Mitigation / Adaptation	Residual risk		
		Likelihood	Consequence	Risk		Likelihood	Consequence	Risk
Degradation and failure of materials and structural integrity of essential infrastructure including roads, transmission line, telecommunications, pipelines, foundations of buildings and facilities, etc.	Construction	Remote	Minor	Very Low	Engineering design specifications will consider the range of expected atmospheric and climatic conditions and the potential increase in the extent and duration rainfall events. Inspection and maintenance programs will consider the potential risk of an increase in the extent and duration of rainfall events.	Remote	Minor	Very Low
	Operations	Unlikely	Minor	Low		Unlikely	Minor	Low
	Decommissioning	Unlikely	Minor	Low		Unlikely	Minor	Low
More frequent droughts due to reduced annual average rainfall and higher evaporation rates								
Water shortage causing GFD Project operations to be restricted, or higher costs for water usage.	Construction	Remote	Minor	Very Low	In accordance with the Draft Environmental Management Plan (Draft EM Plan), Santos GLNG will ensure that: • GFD Project will use coal seam water for operational purposes where practicable. • Potable water is trucked in from appropriate water suppliers or extracted from groundwater bores.	Remote	Minor	Very Low
	Operations	Remote	Minor	Very Low		Remote	Minor	Very Low
	Decommissioning	Remote	Minor	Very Low		Remote	Minor	Very Low
More dusty conditions increasing the cost to maintain equipment and water demand for dust suppression.	Construction	Remote	Negligible	Very low	In accordance with Santos GLNG's EHS05 Air emissions, Santos GLNG will implement specific procedure and suite of controls based on the GLNG Project construction management plans to address dust and air quality impacts. Control measures may include: • Temporary use of cover crops to stabilise bare soil stockpiles or other bare soil areas • Where practicable, organic mulching and/or planting of bare soil surfaces will be undertaken to reduce the	Remote	Negligible	Very low
	Operations	Possible	Negligible	Low		Unlikely	Negligible	Very low
	Decommissioning	Possible	Negligible	Low		Unlikely	Negligible	Very low

6 Risk assessment

Potential impact	Phase	Pre mitigated risk			Mitigation / Adaptation	Residual risk		
		Likelihood	Consequence	Risk		Likelihood	Consequence	Risk
					effects of dust generation and wind and water erosion • Long-term access roads with the potential for dust development will be upgraded with gravel or bitumen where practicable • Watering of the right of way, access tracks and soil and demolition spoil stockpiles will be undertaken on an as-required basis to minimise the potential for dust generation • Use of coal seam water where practicable for dust suppression with approval and in accordance with the LRMP.			
Damage to buildings and infrastructure due to movement of footings and foundations caused by soil shrinkage in long dry periods.	Construction	Remote	Minor	Very Low	Engineering design specifications will consider the range of expected atmospheric and climatic conditions and the potential increase in the extent and dry periods or rainfall events. Inspection and maintenance programs will consider the potential risk of an increase in the extent and duration of dry periods or rainfall events.	Remote	Minor	Very Low
	Operations	Unlikely	Minor	Low		Unlikely	Minor	Low
	Decommissioning	Unlikely	Minor	Low		Unlikely	Minor	Low
More difficult to revegetate disturbed or rehabilitation areas.	Construction	Unlikely	Minor	Low	In accordance with the Rehabilitation Management Plan, areas of disturbance will be progressively rehabilitated to a pre-clearance state or another stable landform consistent with the surrounding undisturbed areas or to final acceptance criteria.	Unlikely	Minor	Low
	Operations	Likely	Minor	Medium		Possible	Minor	Low
	Decommissioning	Likely	Minor	Medium		Possible	Minor	Low

6 Risk assessment

Potential impact	Phase	Pre mitigated risk			Mitigation / Adaptation	Residual risk		
		Likelihood	Consequence	Risk		Likelihood	Consequence	Risk
Increase in intensity and frequency of extreme storms events and cyclones								
Increased damage to essential in-field infrastructure causing temporary cessation of operations or reduction of production output.	Construction	Remote	Moderate	Low	Engineering design specifications will consider the range of expected atmospheric and climatic conditions and the potential increase in the extent and duration of extreme storms and cyclone events including the risk of isolation by flood water. Inspection and maintenance programs will consider the potential risk of an increase in the extent and duration of extreme storms and cyclone events.	Remote	Moderate	Low
	Operations	Possible	Moderate	Medium		Unlikely	Moderate	Medium
	Decommissioning	Possible	Moderate	Medium		Unlikely	Moderate	Medium
Loss of life or injuries to workforce on-tenure or travelling to the GFD Project area due to sudden or unpredictable climatic hazards such as extreme storm events, cyclones, flash floods or bushfires.	Construction	Remote	Critical	Medium	Journey Management Plan includes information relating to: communication requirements, call-in procedures, approved roads, weather conditions and potential hazards. Santos GLNG will implement an ERP in accordance with EHSMS13. This will include the relevant Significant Hazard Risk Register developed in accordance with EHSMS09 Managing EHS Risks. This will include the risk of extreme weather events including storms and cyclones.	Remote	Critical	Medium
	Operations	Remote	Critical	Medium		Remote	Critical	Medium
	Decommissioning	Remote	Critical	Medium		Remote	Critical	Medium
Increased damage or maintenance costs to	Construction	Remote	Minor	Very Low	Engineering design specifications will consider the range of expected	Remote	Minor	Very Low
	Operations	Possible	Minor	Low		Unlikely	Minor	Low

6 Risk assessment

Potential impact	Phase	Pre mitigated risk			Mitigation / Adaptation	Residual risk		
		Likelihood	Consequence	Risk		Likelihood	Consequence	Risk
telecommunications, power supply / reticulation, plant infrastructure and equipment due to increased frequency and length of power outages, and disruption of other services such as telecommunications.	Decommissioning	Possible	Minor	Low	atmospheric and climatic conditions and the potential increase in the extent and duration of extreme storms and cyclone events including the risk of isolation by flood water. Inspection and maintenance programs will consider the potential risk of an increase in the extent and duration of extreme storms and cyclone events.	Unlikely	Minor	Low

7 Adaptation commitments

The key climate change effects for the GFD Project are primarily associated with increased extreme storm events, extreme heat related risks, and drier conditions. In summary, Santos GLNG is committed to the following actions to mitigate the effects of climate change on the GFD Project:

- Avoidance – the siting of infrastructure will consider the potential risks of atmospheric and climate factors (storms events / cyclones, duration and ranges of temperature and rainfall).
- Mitigation – the following mitigation measures will consider the range of atmospheric and climatic factors:
  - Engineering design specifications
  - Inspection and maintenance programs
  - Procedures, control strategies and awareness training on the management of potential risks associated atmospheric and climate factors.
- Management Plans- the following management plans will also consider the risk of atmospheric and climatic factors:
  - Bushfire management plan
  - Emergency response plan
  - Journey management plan
  - Rehabilitation management plan.

Conclusion

The risk assessment shows that the residual natural hazards and climate change impacts are considered to range from very low to medium, and that the GFD Project's design and operational systems would accommodate the majority of possible climate change impacts. With the application of appropriate risk controls, most residual risks remain very low and low.

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Any estimates of potential costs which have been provided are presented as estimates only as at the date of the report. Any cost estimates that have been provided may therefore vary from actual costs at the time of expenditure.

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