APPENDIX 1

ARROW LNG PLANT

Climate and Climate Change Adaptation

REPORT

ARROW LNG PLANT– CLIMATE AND CLIMATE CHANGE ADAPTATION

Coffey Environments Australia Pty Ltd

On behalf of

Arrow CSG (Australia) Pty Ltd

Job No: 3678B

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A PEL Company

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ES1 EXECUTIVE SUMMARY

Arrow CSG (Australia) Pty Ltd (Arrow Energy) proposes to develop a liquefied natural gas (LNG) facility on Curtis Island, off the central Queensland coast near Gladstone. The project, known as the Arrow LNG Plant, is a component of the larger Arrow LNG Project. The Arrow LNG Plant will be supplied with coal seam gas from gas fields in the Surat and Bowen basins.

The LNG plant will have a base-case capacity of 16 Mtpa, with a total plant capacity of up to 18 Mtpa, and will consist of four LNG trains, each with a nominal capacity of 4 Mtpa. Construction of Phase 1 is scheduled to commence in 2014 with train 1 producing the first LNG cargo in 2017. Construction of Phase 2 is anticipated to commence approximately five years after the completion of Phase 1 but will be guided by market conditions.

Power for the LNG plant and associated site utilities is to be supplied from the electricity grid (mains power), gas turbine generators, or a combination of both. As a result four configuration options (mechanical, mechanical/electrical, mechanical/electrical - construction and site utilities only, and all electrical) were proposed.

The following relevant national frameworks, state policies and action plans for climate change adaptation were considered:

- National Climate Change Adaptation Framework.
- Climate Change Risks to Australia's Coast report.
- Adapting to Climate Change in Australia position paper.
- Climate Change Adaptation Actions for Local Government report.
- ClimateSmart Adaptation 2007-2012 action plan.
- State Planning Policy (SPP) 1/03.
- Queensland Coastal Plan.
- Gladstone Region Community Plan.
- Planning Scheme of the City of Gladstone.

Risks associated with changing climate patterns, in accordance with Shell Australia LNG[a] *Terms of Reference* (ToR) dated January 2010, were also assessed. The assessment was based on the existing climate averages and extremes in the vicinity of the project, and review of predictions for various climate parameters as a result of expected anthropogenic effects on climate.

Observed climate trends show that the average annual rainfall in the Central Queensland region (which includes Gladstone) over the 1998-2007 period has fallen by approximately 14% in comparison with the previous 30 years. The average annual temperatures in Central Queensland have increased by 0.5 °C over the last decade (i.e., 2000-2009) and in most years since the late 1970's, an increase in the number of days over 35 °C was identified. Trends in tropical cyclone activity in the Australian region have shown that the number of cyclones has decreased in recent decades, although the number of stronger cyclones (with minimum central pressure <970 hPa) has not declined. Although there are variations from decade to decade, longer-term data indicate a warming, drying trend in the region.

[a] Shell Australia was the original project proponent.

IPCC's projections for 2030, 2050 show that temperature is expected to continue to increase in the study area. For other climate variables, there is large uncertainty surrounding projections. However, 'best estimate' forecasts indicate a decrease in rainfall accompanied by an increase in evaporation, and in intensity of storms and cyclones. The trend in moisture balance would see increased propensity for drought conditions and increased frequency and intensity of bushfires. More intense storms arising from the higher moisture and energy content of the atmosphere would likely bring higher storm surge levels on top of an increasing general sea level.

The most likely climate change impacts are predicted to be increased risk to the health of workers due to heat-stress, insect borne diseases and bushfires; potential infrastructure damage due to heat-stress, increased winds, extreme water levels, and bushfires; and decreased power output of gas turbines, due to higher ambient temperatures affecting the turbine inlet temperatures.

Climate change adaptation strategies were considered for the design of buildings and equipment, storage/transmission/use of gas and LNG, health and safety plans, and emergency response plans. The adaptation strategies recommended for each area of climate change risk are therefore presented in Table 4.1. It is also recommended that Arrow stays abreast of ongoing refinement of climate change projections within Government and scientific communities, and considers future adaptation requirements should additional or revised risks be identified.

ES2 GLOSSARY

Abbreviation	Meaning
AHD	Australian Height Datum
ARI	Average Recurrence Interval
BOM	Australian Government Bureau of Meteorology
COAG	Climate Change Adaptation Framework
CSG	Coal Seam Gas
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCCEE	Department of Climate Change and Energy Efficiency
DERM	Queensland Department of Environment and Resource Management
EEO	Energy Efficiency Opportunities
EITE	Emission Intensive Trade Exposed
ENSO	El Niño-Southern Oscillation
EPA	Environmental Protection Agency
EPC	Engineering, Procurement and Construction
GAMS	Gladstone Airshed Modelling System
GCM	General Circulation Model
GEC	Gas Electricity Certificate
GHG	Greenhouse Gas
HAT	Highest Astronomical Tide
IPCC	Intergovernmental Panel on Climate Change
LAT	Lowest Astronomical Tide
LNG	Liquefied Natural Gas
MHWN	Mean High Water Neaps
MLWN	Mean Low Water Neaps
MHWS	Mean High Water Springs
MLWS	Mean Low Water Springs
MOF	Materials Offloading Facility
MPI	Maximum Potential Intensity
MSL	Mean Sea Level
NCCAF	National Climate Change Adaptation Framework
NGERS	National Greenhouse and Energy Reporting System
OCC	Office of Climate Change
QCCCE	Queensland Government's Climate Change Centre of Excellence
QGS	Queensland Gas Scheme
SESP	Smart Energy Savings Program
RH	Relative Humidity
RO	Reverse Osmosis
SOI	Southern Oscillation Index
TWAF	Temporary Worker Accommodation Facility

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1 INTRODUCTION

1.1 Project Description

1.1.1 Proponent

Arrow CSG (Australia) Pty Ltd (Arrow Energy) proposes to develop a liquefied natural gas (LNG) facility on Curtis Island off the central Queensland coast near Gladstone. The project, known as the Arrow LNG Plant, is a component of the larger Arrow LNG Project.

The proponent is a subsidiary of Arrow Energy Holdings Pty Ltd which is wholly owned by a joint venture between subsidiaries of Royal Dutch Shell plc and PetroChina Company Limited

1.1.2 Arrow LNG Plant

Arrow Energy proposes to construct the Arrow LNG Plant in the Curtis Island Industry Precinct at the southwestern end of Curtis Island, approximately 6 km north of Gladstone and 85 km southeast of Rockhampton, off Queensland's central coast. In 2008, approximately 10% of the southern part of the island was added to the Gladstone State Development Area to be administered by the Queensland Department of Local Government and Planning. Of that area, approximately 1,500 ha (25%) has been designated as the Curtis Island Industry Precinct and is set aside for LNG development. The balance of the Gladstone State Development Area on Curtis Island has been allocated to the Curtis Island Environmental Management Precinct, a flora and fauna conservation area.

The Arrow LNG Plant will be supplied with coal seam gas from gas fields in the Surat and Bowen basins via high-pressure gas pipelines to Gladstone, from which a feed gas pipeline will provide gas to the LNG plant on Curtis Island. A tunnel is proposed for the feed gas pipeline crossing of Port Curtis.

The project is described below in terms of key infrastructure components: LNG plant, feed gas pipeline and dredging.

1.1.3 LNG Plant

Overview. The LNG plant will have a base-case capacity of 16 Mtpa, with a total plant capacity of up to 18 Mtpa. The plant will consist of four LNG trains, each with a nominal capacity of 4 Mtpa. The project will be undertaken in two phases of two trains (nominally 8 Mtpa), with a financial investment decision taken for each phase.

Operations infrastructure associated with the LNG plant includes the LNG trains (where liquefaction occurs; see 'Liquefaction Process' below), LNG storage tanks, cryogenic pipelines, seawater inlet for desalination and stormwater outlet pipelines, water and wastewater treatment, a 110 m high flare stack, power generators (see 'LNG Plant Power' below), administrative buildings and workshops.

Construction infrastructure associated with the LNG plant includes construction camps (see 'Workforce Accommodation' below), a concrete batching plant and laydown areas.

The plant will also require marine infrastructure for the transport of materials, personnel and product (LNG) during construction and operations (see 'Marine Infrastructure' below).

Construction Schedule. The plant will be constructed in two phases. Phase 1 will involve the construction of LNG trains 1 and 2, two LNG storage tanks (each with a capacity of between

120,000 m^3 and 180,000 m^3), Curtis Island construction camp and, if additional capacity is required, a mainland workforce accommodation camp. Associated marine infrastructure will also be required as part of Phase 1. Phase 2 will involve the construction of LNG trains 3 and 4 and potentially a third LNG storage tank. Construction of Phase 1 is scheduled to commence in 2014 with train 1 producing the first LNG cargo in 2017. Construction of Phase 2 is anticipated to commence approximately five years after the completion of Phase 1 but will be guided by market conditions and a financial investment decision at that time.

Construction Method. The LNG plant will generally be constructed using a modular construction method, with preassembled modules being transported to Curtis Island from an offshore fabrication facility. There will also be a substantial stick-built component of construction for associated infrastructure such as LNG storage tanks, buildings, underground cabling, piping and foundations. Where possible, aggregate for civil works will be sourced from suitable material excavated and crushed on site as part of the bulk earthworks. Aggregate will also be sourced from mainland quarries and transported from the mainland launch site to the plant site by roll-on, roll-off vessels. A concrete batching plant will be established on the plant site. Bulk cement requirements will be sourced outside of the batching plant and will be delivered to the site by roll-on roll-off ferries or barges from the mainland launch site.

1.1.3.1 LNG Plant Power

Power for the LNG plant and associated site utilities may be supplied from the electricity grid (mains power), gas turbine generators, or a combination of both, leading to four configuration options that will be assessed:

- Base case (mechanical drive): The mechanical drive configuration uses gas turbines to drive the LNG train refrigerant compressors, which is the traditional powering option for LNG facilities. This configuration would use coal seam gas and end flash gas (produced in the liquefaction process) to fuel the gas turbines that drive the LNG refrigerant compressors and the gas turbine generators that supply electricity to power the site utilities. Construction power for this option would be provided by diesel generators.
- Option 1 (mechanical/electrical – construction and site utilities only): This configuration uses gas turbines to drive the refrigerant compressors in the LNG trains. During construction, mains power would provide power to the site via a cable (30-MW capacity) from the mainland. The proposed capacity of the cable is equivalent to the output of one gas turbine generator. The mains power cable would be retained to power the site utilities during operations, resulting in one less gas turbine generator being required than the proposed base case.
- Option 2 (mechanical/electrical): This configuration uses gas turbines to drive the refrigerant compressors in the LNG trains and mains power to power site utilities. Under this option, construction power would be supplied by mains power or diesel generators.
- Option 3 (all electrical): Under this configuration mains power would be used to supply electricity for operation of the LNG train refrigerant compressors and the site utilities. A switchyard would be required. High-speed electric motors would be used to drive the LNG train refrigerant compressors. Construction power would be supplied by mains power or diesel generators.

1.1.3.2 Liquefaction Process

The coal seam gas enters the LNG plant where it is metered and split into two pipe headers which feed the two LNG trains. With the expansion to four trains the gas will be split into four LNG trains.

For each LNG train, the coal seam gas is first treated in the acid gas removal unit where the carbon dioxide and any other acid gases are removed. The gas is then routed to the dehydration unit where any water is removed and then passed through a mercury guard bed to remove trace concentrations of mercury contained in the gas. The coal seam gas is then ready for further cooling and liquefaction.

A propane, precooled, mixed refrigerant process will be used by each LNG train to liquefy the predominantly methane coal seam gas. The liquefaction process begins with the propane cycle. The propane cycle involves three pressure stages of chilling to pre-cool the coal seam gas to -33°C and to compress and condense the mixed refrigerant, which is a mixture of nitrogen, methane, ethylene and propane. The condensed mixed refrigerant and precooled coal seam gas are then separately routed to the main cryogenic heat exchanger, where the coal seam gas is further cooled and liquefied by the mixed refrigerant. Expansion of the mixed refrigerant gases within the heat exchanger removes heat from the coal seam gas. This process cools the coal seam gas from -33°C to approximately -157°C. At this temperature the coal seam gas is liquefied (LNG) and becomes 1/600th of its original volume. The expanded mixed refrigerant is continually cycled to the propane precooler and reused.

LNG is then routed from the end flash gas system to a nitrogen stripper column which is used to separate nitrogen from the methane, reducing the nitrogen content of the LNG to less than 1 mole per cent (mol%). LNG separated in the nitrogen stripper column is pumped for storage on site in full containment storage tanks where it is maintained at a temperature of -163°C.

A small amount of off-gas is generated from the LNG during the process. This regasified coal seam gas is routed to an end flash gas compressor where it is prepared for use as fuel gas.

Finally, the LNG is transferred from the storage tanks onto LNG carriers via cryogenic pipelines and loading arms for transportation to export markets. The LNG will be regasified back into sales specification gas on shore at its destination location.

1.1.3.3 Workforce Accommodation

The LNG plant (Phase 1), tunnel, feed gas pipeline, and dredging components of the project each have their own workforces with peaks occurring at different stages during construction. The following peak workforces are estimated for the project:

- LNG plant Phase 1 peak workforce of 3,500, comprising 3,000 construction workers: 350 engineering, procurement and construction (EPC) management workers and 150 Arrow Energy employees.
- Tunnel peak workforce of up to 100.
- Feed gas pipeline (from the mainland to Curtis Island) peak workforce of up to 75.
- A dredging peak workforce of between 20 and 40.

Two workforce construction camp locations are proposed: the main construction camp at Boatshed Point on Curtis Island, and a possible mainland overflow construction camp, referred to as a temporary workers accommodation facility (TWAF). Two potential locations are currently being considered for the mainland TWAF; in the vicinity of Gladstone city on the former Gladstone Power Station ash pond No.7 (TWAF7) or in the vicinity of Targinnie on a primarily cleared pastoral grazing lot (TWAF8). Both potential TWAF sites include sufficient space to accommodate camp infrastructure and construction laydown areas. The TWAF and its associated construction laydown areas will be decommissioned on completion of the Phase 1 works.

Of the 3,000 construction workers for the LNG plant, it is estimated that between 5% and 20% will be from the local community (and thus will not require accommodation) and that the remaining fly-in, fly-out workers will be accommodated in construction camps. The 350 EPC management and 150 Arrow Energy employees are expected to relocate to Gladstone with the majority housed in company facilitated accommodation.

The tunnel workforce of 100 people and gas pipeline workforce of 75 people are anticipated to be accommodated in the mainland in company facilitated accommodation. The dredging workforce of 20 to 40 workers will be housed onboard the dredge vessel.

Up to 2,500 people will be housed at Boatshed Point construction camp. Its establishment will be preceded by a pioneer camp at the same locality which will evolve into the completed construction camp.

1.1.3.4 Marine Infrastructure

Marine facilities include the LNG jetty, materials offloading facility (MOF), personnel jetty and mainland launch site.

LNG Jetty. LNG will be transferred from the storage tanks on the site to the LNG jetty via above ground cryogenic pipelines. Loading arms on the LNG jetty will deliver the product to an LNG carrier. The LNG jetty will be located in North China Bay, adjacent to the northwest corner of Hamilton Point.

MOF. Delivery of materials to the site on Curtis Island during the construction and operations phases will be facilitated by a MOF where roll-on, roll-off or lift-on, lift-off vessels will dock to unload preassembled modules, equipment, supplies and construction aggregate. The MOF will be connected to the LNG plant site via a heavy-haul road.

Boatshed Point (MOF 1) is the base-case MOF option and would be located at the southern tip of Boatshed Point. The haul road would be routed along the western coastline of Boatshed Point (abutting the construction camp to the east) and enters the LNG Plant site at the southern boundary. A quarantine area will be located south of the LNG plant and will be accessed via the northern end of the haul road.

Two alternative options are being assessed, should the Boatshed Point option be determined to be not technically feasible:

- South Hamilton Point (MOF 2): This MOF option would be located at the southern tip of Hamilton Point. The haul road from this site would traverse the saddle between the hills of Hamilton Point to the southwest boundary of the LNG plant site. The quarantine area for this option will be located southwest of the LNG plant near the LNG storage tanks.
- North Hamilton Point (MOF 3): This option involves shared use of the MOF being constructed for the Santos Gladstone LNG Project (GLNG Project) on the northwest side of Hamilton Point (south of Arrow Energy's proposed LNG jetty). The GLNG Project is also constructing a passenger terminal at this site, but it will not be available to Arrow Energy contractors and staff. The quarantine area for this option would be located to the north of the MOF. The impacts of construction and operation of this MOF option and its associated haul road were assessed as part of the GLNG Project and will not be assessed in this EIS.

Personnel Jetty. During the peak of construction, base case of up to 1,100 people may require transport to Curtis Island from the mainland on a daily basis. A personnel jetty will be constructed at the southern tip of Boatshed Point to enable the transfer of workers from the mainland launch site to Curtis Island by high-speed vehicle catamarans (Fastcats) and vehicle or passenger ferries (ROPAX). This facility will be adjacent to the MOF constructed at Boatshed Point. The haul road will be used to transport workers to and from the personnel jetty to the construction camp and LNG plant site. A secondary access for pedestrians will be provided between the personnel jetty and the construction camp.

Mainland Launch Site. Materials and workers will be transported to Curtis Island via the mainland launch site. The mainland launch site will contain both a passenger terminal and a roll-on, roll-off facility. The passenger terminal will include a jetty and transit infrastructure, such as amenities, waiting areas and car parking. The barge or roll-on ,roll-off facility will have a jetty, associated laydown areas, workshops and storage sheds.

The two location options for the mainland launch site are:

- Launch site 1: This site is located north of Gladstone city near the mouth of the Calliope River, adjacent to the existing RG Tanna coal export terminal.
- Launch site 4N: This site is located at the northern end of the proposed reclamation area for the Fishermans Landing Northern Expansion Project, which is part of the Port of Gladstone Western Basin Master Plan. The availability of this site will depend on how far progressed the Western Basin Dredging and Disposal Project is at the time of construction.

1.1.4 Feed Gas Pipeline

An approximately 8-km long feed gas pipeline will supply gas to the LNG plant from its connection to the Arrow Surat Pipeline (formerly the Surat Gladstone Pipeline) on the mainland adjacent to Rio Tinto's Yarwun alumina refinery. The feed gas pipeline will be constructed in three sections:

- A short length of feed gas pipeline will run from the proposed Arrow Surat Pipeline to the tunnel launch shaft, which will be located on a mudflat south of Fishermans Landing, just south of Boat Creek. This section of pipeline will be constructed using conventional open-cut trenching methods within a 40-m wide construction right of way.
- The next section of the feed gas pipeline will traverse Port Curtis harbour in a tunnel to be bored under the harbour from the mainland tunnel the launch shaft to a receival shaft on Hamilton Point. The tunnel under Port Curtis will have an excavated diameter of up to approximately 6 m and will be constructed by a tunnel boring machine that will begin work at the mainland launch shaft. Tunnel spoil material will be processed through a de-sanding plant to remove the bentonite and water and will comprise mainly a finely graded fill material, which will be deposited in a spoil placement area established within bund walls constructed adjacent to the launch shaft. Based on the excavated diameter, approximately 223,000 m^3 of spoil will be treated as required for acid sulfate soil and disposed of at this location.
- From the tunnel receival shaft on Hamilton Point, the remaining section of the feed gas pipeline will run underground to the LNG plant, parallel to the above ground cryogenic pipelines. This section will be constructed using conventional open-cut trenching methods within a 30-m wide construction right of way. A permanent easement up to 30-m wide will be negotiated with the relevant land manager or owner.

Should one of the electrical plant power options be chosen, it is intended that a power connection will be provided by a third party to the tunnel launch shaft, whereby Arrow Energy would install a power cable within the tunnel to the LNG plant.

Other infrastructure, such as communication cables, water and wastewater pipelines, may also be accommodated within the tunnel.

1.1.5 Dredging

Dredging required for LNG shipping access and swing basins has been assessed under the Gladstone Ports Corporation's Port of Gladstone Western Basin Dredging and Disposal Project. Additional dredging within the marine environment of Port Curtis may be required to accommodate the construction and operation of the marine facilities. Up to five sites may require dredging:

- Dredge site 1 (dredge footprint for launch site 1): The dredging of this site would facilitate the construction and operation of launch site 1. This dredge site is located in the Calliope River and extends from the intertidal area abutting launch site 1, past Mud Island to the main shipping channel. The worst-case dredge volume estimated at this site is approximately 900,000 m^3.
- Dredge site 2 (dredge footprint for launch site 4N): The dredging of this site would facilitate the construction and operation of launch site 4N. This dredge site would abut launch site 4N and extend east from the launch site to the shipping channel. The worst-case dredge volume identified at this site is approximately 2,500 m^3.
- Dredge site 3 (dredge footprint for Boatshed Point MOF 1): The dredging of this site would facilitate the construction and operation of the personnel jetty and MOF at Boatshed Point. This dredge site would encompass the area around the marine facilities, providing adequate depth for docking and navigation. The worst-case dredge volume identified at this site is approximately 50,000 m^3.
- Dredge site 4 (dredge footprint for Hamilton Point South MOF 2): The dredging of this site would facilitate the construction and operation of the MOF at Hamilton Point South. This dredge site would encompass the area around the marine facilities, providing adequate depth for docking and navigation. The worst-case dredge volume identified at this site is approximately 50,000 m^3.
- Dredge site 5 (dredge footprint for LNG jetty): The dredging of this site will facilitate the construction of the LNG jetty at Hamilton Point. This dredge site extends from the berth pocket to be dredged as part of the Western Basin Strategic Dredging and Disposal Project to the shoreline and is required to enable a work barge to assist with construction of the jetty. The worst-case dredge volume identified is approximately 120,000 m^3.

The spoil generated by dredging activities will be placed and treated for acid sulfate soils (as required) in the Port of Gladstone Western Basin Dredging and Disposal Project reclamation area.

1.2 Legislative Context and Standards

The following sections describe the national framework and state policy and actions specific to climate change adaptation, as well as Australian standards that require consideration of climatic factors in design.

1.2.1 National Framework for Climate Change Adaptation

Climate change adaptation is one pillar of the Australian Government's three pillar strategy to address climate change; with the other pillars being emissions reduction (e.g., through the introduction of the *Clean Energy Plan* and carbon pricing (Australian Government, 2011)) , and Australia's participation in developing a global response. Please note that climate change adaptation strategies are not part of the *Clean Energy Plan* put forward on 10 July 2011. As such, the government is preparing a number of actions specifically focused on climate change adaptation separate to the emissions reductions initiatives described in the *Greenhouse Gas Impact Assessment* (PAEHolmes, 2011). Key progress on climate change adaptation to date includes:

- In 2007, the Council for Australian Governments (COAG) endorsed the *National Climate Change Adaptation Framework* (COAG, 2007). Recognising climate change adaptation is a long-term agenda, the Framework established targeted, medium-term strategies to guide actions by governments for the period 2007 to 2014. Strategies, including climate change projections and regional scenarios, aim to support informed decisions on adaptation, and to identify sectors and regions especially vulnerable to climate change impacts, with Australia's coast being a particular focus.
- In response to the national framework, the Department of Climate Change[b] released the report, *Climate Change Risks to Australia's Coast: a first pass national assessment* in 2009 (DCC, 2009). The scope of the report included but was not limited to identifying via spatial analysis areas at high risk to climate change impacts, and helping to identify national adaptation priorities for the coastal zone. In the same year, the House of Representatives Standing Committee on Climate Change, Water, Environment and the Arts released its Inquiry report, *Managing our coastal zones in a changing climate: the time to act is now* (Australian Government, 2009). The Inquiry report made 47 recommendations with regard to managing the coastal zone in the context of climate change, including 14 recommendations specifically relating to adaptation.
- In early 2010, the Department of Climate Change released its position paper, *Adapting to Climate Change in Australia* (DCC, 2010). The position paper sets out the Australian Government's vision for adapting to the impacts of climate change, and expresses the Australian Government's desire to work through COAG to develop a national adaptation agenda. With the coastal adaption identified as one of the six priority areas for national adaptation, the *National Climate Change Forum: Adaptation Priorities for Australia's Coast*, was held in Adelaide, South Australia in February 2010. The forum initiated dialogue on the national coastal adaptation agenda and a report detailing the outcomes of the forum was subsequently published (DCCEE, 2010).
- Building the capacity of local governments to identify and implement climate change adaptation actions has also been an area of Australian Government focus. In 2010, the Department of Climate Change and Energy Efficiency (DCCEE) re-issued the report, first published in 2007, *Climate Change Adaptation Actions for Local Government* (DCCEE, 2009), which considers, along with other matters, climate change adaption in the context of local government planning and development approval functions.

1.2.2 State Policies and Action Plans

The Queensland Government's focus on climate change adaptation is governed through state planning policies as well as climate, community and coastal action plans and planning schemes. Those relevant to the Arrow LNG include:

- *ClimateSmart Adaptation 2007-2012: An action plan for managing the impacts of climate change*, originally prepared by the Queensland Government Department of Natural Resources and Water (DNRW, 2007). Containing 62 actions across sectors including

[b] The Department of Climate Change (DCC), established on 3 December 2007, is currently known as the Department of Climate Change and Energy Efficiency (DCCEE).

business and industry, the five-year plan was developed as part of Queensland's broader ClimateSmart 2050 strategy. The Office of Climate Change (OCC), within the Environmental Protection Agency (EPA), now has responsibility for implementing the plan. The latest progress report prepared in April 2010 stated that 52 priority actions have been completed out of the 62 included in the adaptation plan (OCC, 2010).

- *State Planning Policy (SPP) 1/03: Mitigating the Adverse Impacts of Flood, Bushfire and Landslide* (DES & DLGP, 2003). The SPP requires likely impacts of climate change on natural hazards to be incorporated into hazard assessment studies. Suitable data sources for climate change predictions must be used.
- Queensland Coastal Plan, expected to come into effect in mid-2011: The coastal zone is also a priority area of focus for the Queensland Government (DERM, 2011). The Queensland Coastal Plan comprises two policies; the *State Policy for Coastal Management*, and the *State Planning Policy for Coastal Protection*. The former policy applies to development not assessable under the *Sustainable Planning Act 2009* (Qld), while the latter relates to assessable developments. Both policies seek to ensure that the projected effects of climate change are taken into account in infrastructure design, and that development is undertaken in a manner which maintains or enhances coastal values. Under the plan, coastal hazard risk assessments are to be based on:
  - Planning period of 90+ years.
  - Projected mean sea level rise of 0.8 m by 2100.
  - 100 year Average Recurrence Interval (ARI) for extreme storm events or water levels.
  - Increased cyclone intensity of 10% (compared to maximum potential intensity).
- *Gladstone Region Community Plan*, adopted by the Gladstone Regional Council on 17 May 2011 (Gladstone Region Community, 2011). The community plan includes the goal of being responsive to emerging climate change and sustainability requirements. This includes 'ensuring, through conducting detailed "sustainability checks", that world's best-practice is proven before new industries and companies come to the region.'
- *Planning Scheme of the City of Gladstone, The Gladstone Plan,* (Gladstone City Council, 2006) requires premises situated below 4 m Australian Height Datum (AHD) to improve flood and storm surge immunity.

1.2.3 Australian Standards

The Australian Standard *AS 4997-2005 Guidelines for the design of maritime structures* includes the requirement to incorporate a sea level rise factor in design as appropriate to the structure's design life. Sea level rise factors are 0.1, 0.2 and 0.4 m for 25, 50 and 100 year design life respectively. Design measures which enable future modification of structures are also encouraged.

Other Australian standards that address climatic factors in design (but not specifically climate change) include:

- AS/NZS 1170.2:2011 Structural Design Actions – Part 2: Wind Actions.
- AS 3959-2009 Construction of buildings in bushfire-prone areas.

1.3 Objectives of Study

The objective of this study is to assess the risks to the Arrow LNG Plant associated with changing climate patterns, in accordance with Section 3.1.2 of the Shell Australia LNG[c] Project *Terms of Reference* (ToR) dated January 2010. To this end, the following items have been included in the study:

- Review recommended frameworks for climate change adaptation strategies based on the general framework for climate change adaption presented in the Queensland Government's *ClimateSmart Adaptation 2007-2012*, as well as frameworks prepared by the Commonwealth Government and other states.
- A summary of the existing climate and climate extremes in the vicinity of the project based on data collected by adjacent existing Australian Bureau of Meteorology (BOM) stations, over a significant period (seventeen to over fifty years).
- Review of climate change predictions for various climate parameters drawn from existing projections by the Intergovernmental Panel on Climate Change (IPCC), the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Queensland government. Assessment of the risks associated with the project.
- Recommendations on strategies to mitigate climate change risks.

[c] Shell Australia was the original project proponent.

2 EXISTING CLIMATE

The Arrow LNG Plant project is located in the Gladstone region, which has a subtropical climate, with wet, hot and humid summers, and dry, mild winters. The weather in the summer is mainly influenced by its position within the southeast trade wind belt, as it is too far south to experience a regular North West monsoonal influence. The frequency of storm activity is high in summer relative to other seasons due to unstable atmospheric conditions. Tropical systems (such as cyclones and tropical lows) occur infrequently in the region during the late summer months. The weather in winter tends to be influenced by the northward migration of the sub-tropical anticyclonic belt with its associated stable atmospheric conditions.

Information on the long-term climate for the project site at Curtis Island has been sourced from two Australian Bureau of Meteorology (BOM) weather stations: Gladstone Radar and Gladstone Airport. Gladstone Radar started weather monitoring in 1957, and has more than 50 years' data available; Gladstone Airport was established in 1993, and has about 17 years' data available. The latter site is not optimal as the period used to define long-term climate is greater than 30 years, as defined by the World Meteorological Organization (WMO). Please note that the cut off date for climate data at both locations is 2010 unless noted otherwise.

A summary of the location, elevation and available time series data for each BOM station is provided in Table 2.1.

Table 2.1: Available Meteorological Data

Station Name	Latitude	Longitude	Station Height (m above MSL)	Start Date	End Date
Gladstone Radar	23.8553°S	151.2628°E	74.5	01/1957	2010
Gladstone Airport	23.8690°S	151.2214°E	16.6	10/1993	2010

For most parameters the climate statistics from the two BOM weather stations are very similar, and can be assumed to be broadly representative of Curtis Island. However, wind data differs between the two weather stations, a result of spatial variations influenced by proximity to the sea and local topography (it can be seen in Table 2.1 that the elevations at the weather stations differ significantly). In coastal regions there is often a significant variation in wind regimes within several kilometres of the coastline. Therefore, wind data has been extracted specifically for Curtis Island based on one year's data from the Gladstone Airshed Modelling System for 2001 (DERM, 2008).

Sufficient observational data was not available for temperature inversions, hence modelling data has been used to characterise temperature inversions at the project site within the study area. Note that the modelling data is based on observational data from 2001.

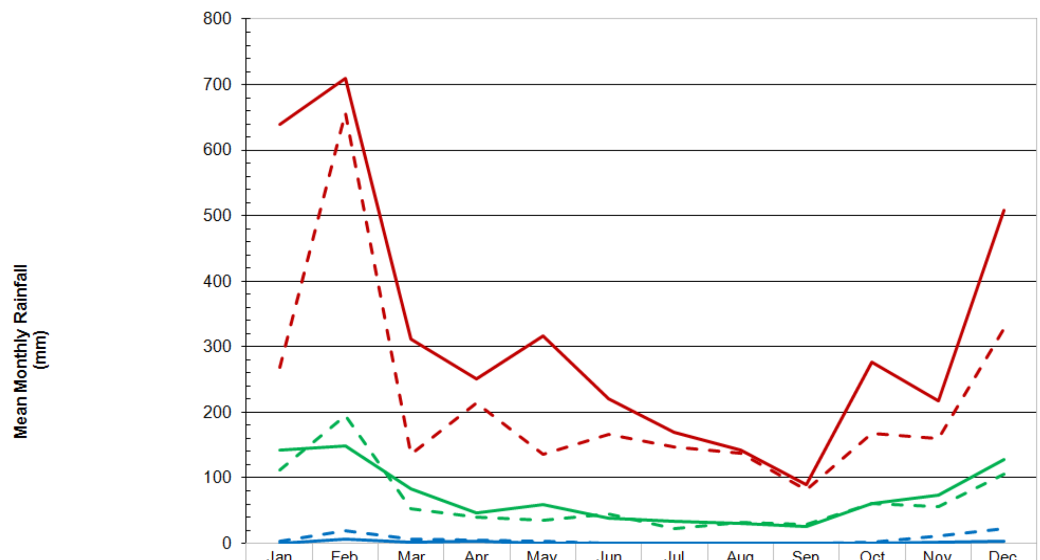
Climate variability is an important aspect of existing climate. As such, seasonal variability, based on monthly averaged data, has been included in this assessment. Long-term climate variability has been presented in this assessment as ranges and as climate extremes. Causes of long-term climate variability include the El Niño-Southern Oscillation (ENSO) cycle, which repeats every 2-8 years (a natural climate system of oscillating behaviour in the tropical Pacific); and Pacific Decadal Oscillation, which influences decadal and inter-decadal climate variability.

2.1 Rainfall

The average annual rainfall is 878 mm for Gladstone Radar, and 793 mm for Gladstone Airport. A summary of the long-term monthly average rainfall at the monitoring locations is presented in Figure 2.1. The figure shows that the seasonal rainfall patterns are similar between the two BOM stations. The bulk of the rainfall occurs during the summer months, with averages of approximately 100-190 mm/month. During winter, average monthly rainfall varies between 20 and 45 mm/month. The wettest months are January and February, when storm activity is most intense and most widespread.

The difference between maximum and minimum rainfall is significant, indicating great variation of monthly rainfall among different years. ENSO accounts for some of the variation: during El Niño years, the rainfall tends to be less than average; and during La Niña years, above average rainfall or floods are often observed. Interannual rainfall variations are also influenced by short-duration, intense weather systems such as tropical or extra-tropical cyclones.

Extreme rainfall statistics recorded at Gladstone Radar station are presented in Table 2.2. It can be seen that no highest monthly rainfall events were recorded in the last decade (2001-2010), conversely, for four months the lowest recorded monthly rainfall occurred in the last decade. It can also be seen that the highest ever recorded daily rainfall of nearly 248 mm occurred in February 2003.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Gladstone Radar - Max Rainfall	640.1	709.8	311.6	250.4	316.4	220.3	170.2	141.6	89.6	276.8	218.1	508.9
Gladstone Airport - Max Rainfall	269.2	657.4	135.4	214.2	135.2	166.6	147	136.8	81.2	167.6	160.2	327.2
Gladstone Radar - Mean Rainfall	142	148.3	83.3	46.4	59.6	38.9	34.4	31.2	26.2	61.5	73.2	128.7
Gladstone Airport - Mean Rainfall	111.9	195.6	52.9	39.7	36	45.3	22.4	32.5	28.2	61.2	56.8	105.4
Gladstone Radar - Min Rainfall	0.4	7.2	2.4	3.8	0.2	0	0	0	0	0.4	1.4	2.8
Gladstone Airport - Min Rainfall	3.6	19.8	6.8	5.6	3.8	0.4	0	0	0	2.4	11.4	22.4

Figure 2.1: Monthly Average Rainfall at Gladstone Airport and Gladstone Radar Stations

Table 2.2: Rainfall Statistics (mm) at Gladstone Radar Station (1957-2010)

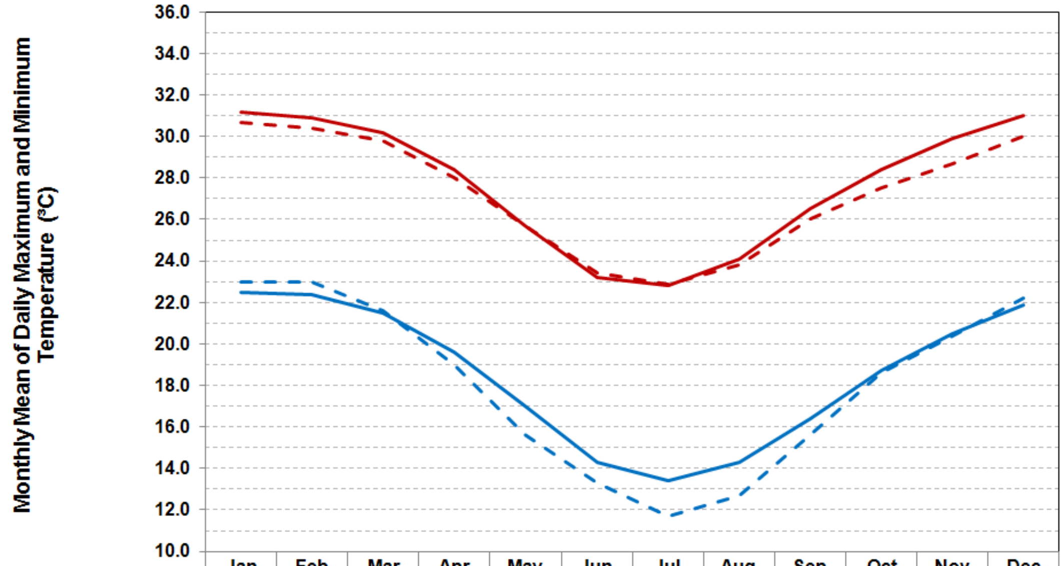
Month	Highest monthly rainfall		Lowest monthly rainfall		Highest daily rainfall	
	Rainfall	Year	Rainfall	Year	Rainfall	Year
January	640.1	1974	0.4	2003	196.8	1983
February	709.8	1971	7.2	1983	248	2003
March	311.6	1990	2.4	1995	112.3	1962
April	250.4	1990	3.8	1978	93.4	1989
May	316.4	1983	0.2	1984	178	1977
June	220.3	1967	0	1968	94.8	2006
July	170.2	1973	0	2002	92.7	1964
August	141.6	1998	0	2004	78.2	1988
September	89.6	1998	0	1980	75	1986
October	276.8	1975	0.4	2006	149.4	1961
November	218.1	1961	1.4	1982	88	1999
December	508.9	1962	2.8	1972	196	1988

2.2 Temperature

The long-term monthly average temperatures at Gladstone display typical ranges for subtropical regions, as shown in Figure 2.2. The monthly mean temperature patterns are similar between the two BOM stations. Mean monthly minimum temperatures range between 21 and 23°C in the summer and between 12 and 14°C in the winter at Gladstone Airport. The mean maximum temperatures vary between 30 and 32°C in the hottest months and between 22 and 23°C during the coolest part of the year.

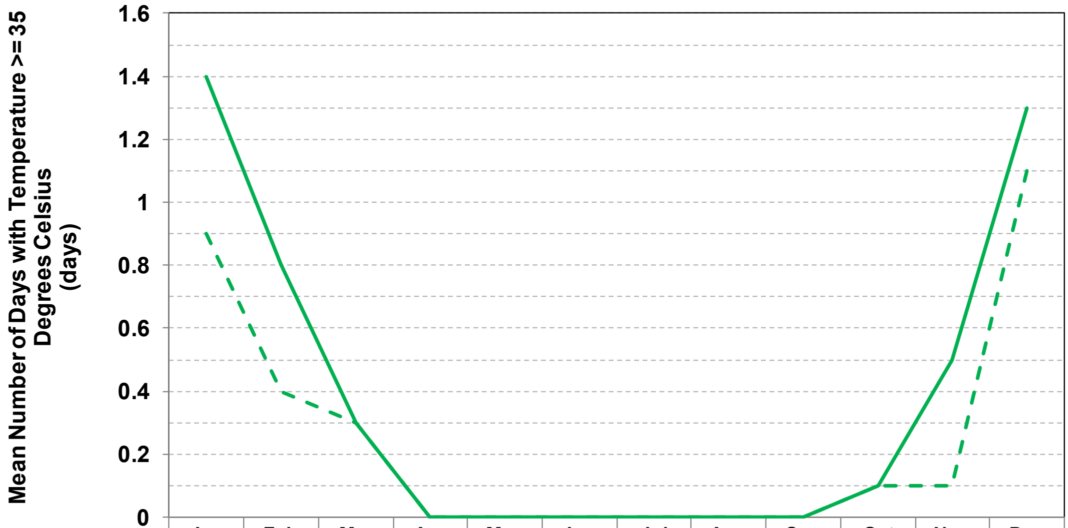
The annual mean number of days with recorded temperatures greater than or equal to 35°C is 2.9 for the Gladstone Airport site and 4.4 for the Gladstone Radar site, as shown in Figure 2.3. These extreme high temperatures mainly occur between December and February.

Extreme temperature statistics by month are presented in Table 2.3, based on data from the Gladstone Radar station. As can be seen, for five months of the year, the highest recorded temperature occurred in the last decade, and for four months of the year, the highest minimum temperature occurred in the last decade. Lowest recorded temperatures are spread through the decades 1960-2000.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Gladstone Airport Max	30.7	30.4	29.8	28.0	25.7	23.4	22.9	23.8	26.0	27.5	28.7	30.0
Gladstone Airport Min	23.0	23.0	21.6	19.0	15.6	13.3	11.7	12.7	15.6	18.6	20.4	22.2
Gladstone Radar Max	31.2	30.9	30.2	28.4	25.7	23.2	22.8	24.1	26.5	28.4	29.9	31.0
Gladstone Radar Min	22.5	22.4	21.5	19.6	17.0	14.3	13.4	14.3	16.4	18.7	20.5	21.9

Figure 2.2: Monthly Mean of Daily Maximum and Minimum Temperature at Gladstone Airport and Gladstone Radar Stations



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Gladstone Airport	0.9	0.4	0.3	0	0	0	0	0	0	0.1	0.1	1.1
Gladstone Radar	1.4	0.8	0.3	0	0	0	0	0	0	0.1	0.5	1.3

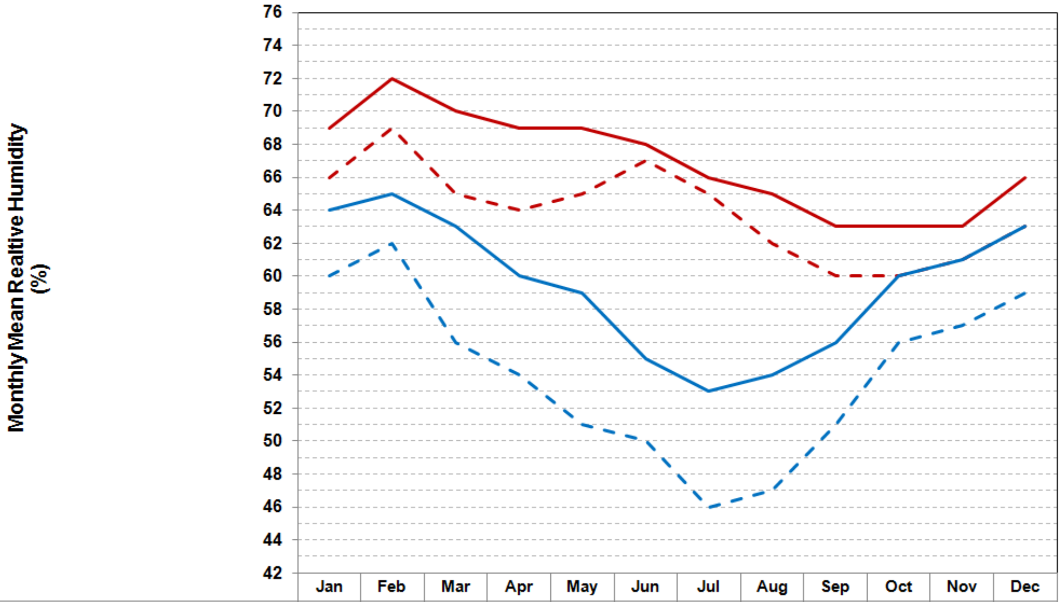
Figure 2.3: Mean Number of Days When Temperature Exceeds 35°C at Gladstone Airport and Gladstone Radar Stations

Table 2.3: Extreme Temperature Statistics at Gladstone Radar Station (1957-2010)

Month	Highest Temperature		Lowest Temperature		Highest Minimum Temperature	
	Temp (°C)	Year	Temp (°C)	Year	Temp (°C)	Year
January	38.3	1967	12.8	1997	27.1	1983
February	40.1	1990	17.2	1996	26.7	1997
March	42	2007	16.2	1970	28.1	1995
April	34.4	2009	11	1999	25.7	2006
May	31.3	1973	8.5	1987	22.6	1968
June	29.7	2002	6.1	1960	21.2	2002
July	29.4	2009	4.4	1960	19.4	1986
August	31.6	2009	4.7	1995	20.2	2009
September	33.8	1989	9.6	1978	22.1	1997
October	40	1958	10.9	1981	23.7	2007
November	40.1	1990	14.7	2006	26.3	1987
December	39.8	1981	12.4	1995	27.8	1958

2.3 Humidity

Figure 2.4 displays the mean monthly relative humidity (RH) at 9am and 3pm for both the Gladstone Airport and Gladstone Radar weather stations. The Gladstone Airport station records lower mean relative humidity than the Gladstone Radar station at both 9am and 3pm. This is most likely due to the Gladstone Radar station's location in closer proximity to the coast than the Gladstone Airport station, leading to a greater moisture content in the air. In all cases, the highest RH is observed in February. The lowest 3pm RH is recorded in July and the lowest 9am RH occurs during September and October.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Gladstone Airport 9am Relative Humidity	66	69	65	64	65	67	65	62	60	60	61	63
Gladstone Airport 3pm Relative Humidity	60	62	56	54	51	50	46	47	51	56	57	59
Gladstone Radar 9am Relative Humidity	69	72	70	69	69	68	66	65	63	63	63	66
Gladstone Radar 3pm Relative Humidty	64	65	63	60	59	55	53	54	56	60	61	63

Figure 2.4: Monthly Relative Humidity at Gladstone Airport and Gladstone Radar Stations

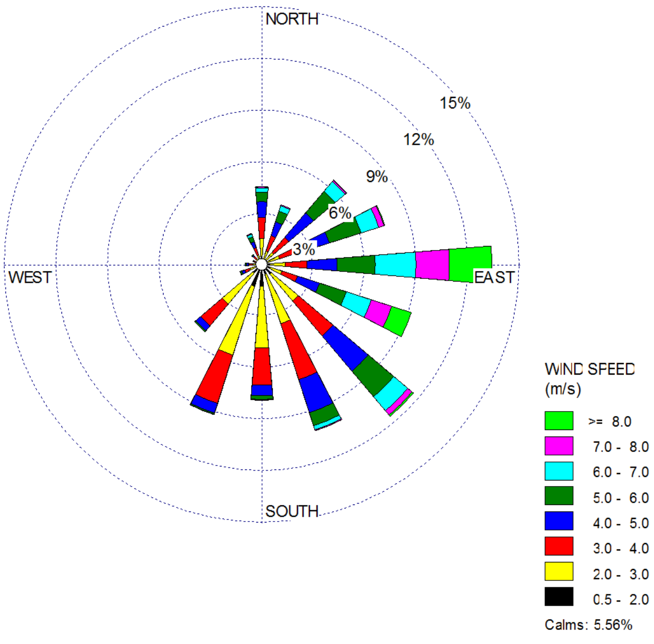
2.4 Wind

Wind roses show the frequency of occurrence of winds by direction and strength. The bars correspond to the 16 compass points (N, NNE, NE, etc.). The bar at each wind direction in the wind rose diagram represents winds blowing from that direction, e.g., north. The length of the bar represents the frequency of occurrence of winds from that direction, and the colours of the bar sections correspond to wind speed categories shown in the associated legend.

Wind roses generated for the two BOM monitoring stations in Gladstone are presented in Figure 2.5. Hourly data from 1996 to 2009 is used for these wind roses. They show that wind at both sites is generally from the south and the east. In comparison, Gladstone Airport has a higher frequency of wind from the south to south-southwest and has a higher number of calms, a wind with a speed under 1.6 km/hr which is classified as the lowest force on the Beaufort scale, than Gladstone Radar.

Wind roses were generated for the Santos GLNG project site, which is adjacent to the Arrow LNG Plant site on Curtis Island, and were thus used in this assessment (please refer to Figure 2.6). Unlike the long-term data from the BOM sites, URS derived wind roses for the Santos GLNG Project wind roses are based on one year's meteorological modelling output from the Gladstone Airshed Modelling System (GAMS) for 2001 (DERM, 2008). However, the wind rose for the project site on Curtis Island is similar to the wind rose at the Gladstone Airport site, with wind predominantly blowing from the east, and a high frequency of wind from the south.

Based on hourly BOM meteorological data for Gladstone Radar for 1994-2010, the maximum recorded wind gust was 36.6 m/s, and the maximum hourly average wind speed was 18.5 m/s. Wind roses generated using BOM data were for 1996-2009, as these years all featured good data coverage (i.e. frequency of wind directions and speeds is not biased towards periods with most data).



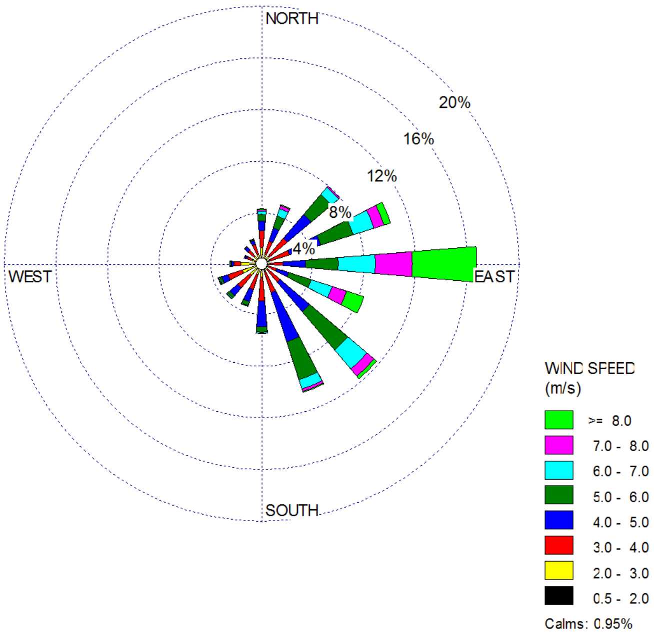


Figure 2.5: Wind Roses at Gladstone Airport and Gladstone Radar Stations (1996 – 2009)

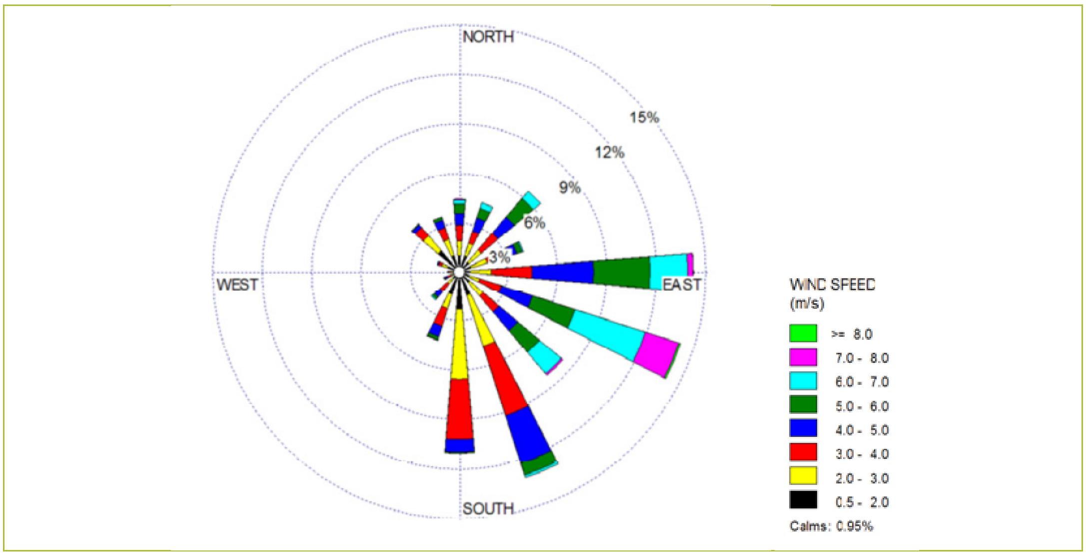


Figure 2.6: Wind Roses at Curtis Island at Santos GLNG Project Site for 2001 (Santos, 2009)

2.5 Temperature Inversions

A temperature inversion refers to a layer of air in the atmosphere in which the temperature increases with height (instead of a general profile of temperature decreasing with height). Overnight, the ground cools as heat is radiated to space. Air in contact with the ground then cools through conduction, and forms a typical night-time near ground inversion layer with the warmer overlying air. Elevated inversions can also form from other mechanisms such as when warm air moves over a cool surface or when adiabatic heating occurs through large-scale descent of an air mass under an anticyclone. The lack of convective mixing within the lower-level inversion layer traps lower-level pollution within the inversion layer, sometimes resulting in elevated levels of air pollutants. However, the presence of an inversion is only one of several possible causes of elevated pollution levels.

The lower-level temperature inversion strength and frequency have been estimated for the June to August period (the most frequent period for inversions), based on GAMS meteorological modelling output obtained by URS for the nearby Santos GLNG Project on Curtis Island for the year 2001 (Santos, 2009), as presented in Table 2.4.

Table 2.4: Frequency of Inversions for Winter Months at Curtis Island for 2001

Time Inversion Strength	Percentage of occurrence (%)	Number of hours
>3ºC per 100 m	0.3%	6
>2ºC per 100 m	4%	87
>1ºC per 100 m	28%	621
>0ºC per 100 m	54%	1,188

Source: Santos (2009)

2.6 Evaporation

Figure 2.7 presents monthly potential evaporation monitored at the Gladstone Radar station. No data was available for the Gladstone Airport station. The values were calculated based on daily pan evaporation records aggregated over a month. It shows strong seasonal variations, reaching the highest in the summer and the lowest in the winter. Evaporation peaks in January at approximately 190 mm a month and is the lowest in June at approximately 90 mm a month. Mean evaporation is greater than mean rainfall on a monthly basis. For comparison, average rainfall is 142 mm/month in January and 39 mm/month in June (refer to section 2.1). The average moisture deficit (excess of evaporation over rainfall) totals 884 mm and ranges from a peak of over 100 mm/month between September and November and a minimum of below 50 mm/month in January, February and May. In individual months and years, values can vary greatly and reach a surplus in wet periods.

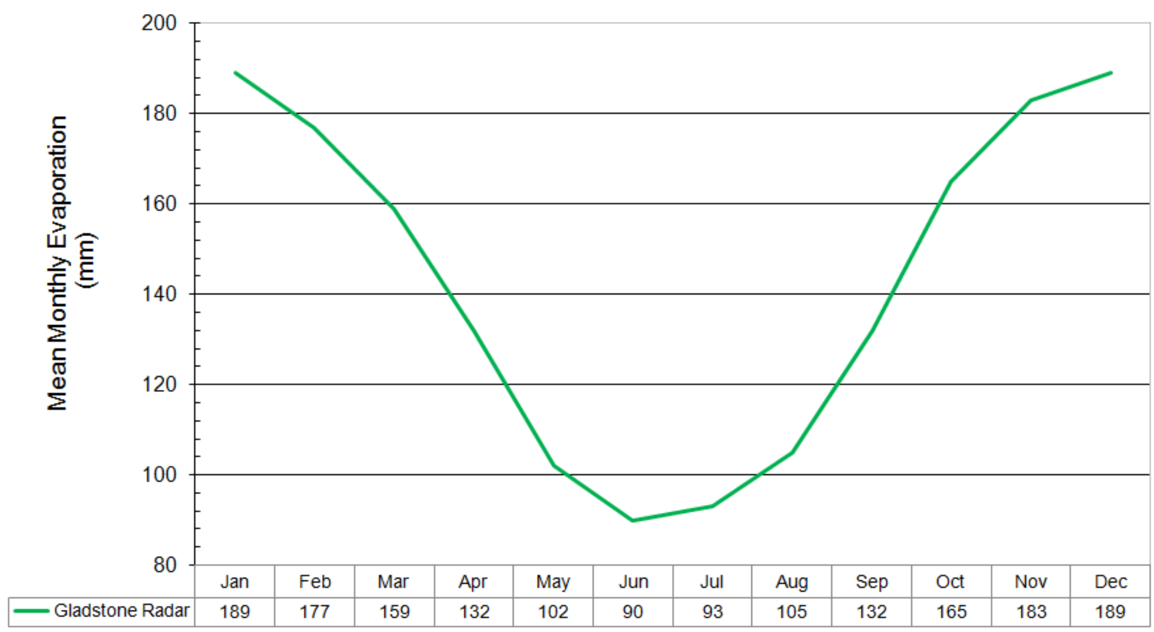


Figure 2.7: Monthly Evaporation at Gladstone Radar Station

2.7 Sea Level

Table 2.5 presents the tidal conditions for 2011 for the Gladstone region and more specifically Fisherman's Landing (DTMR, 2010). The mean sea level for the current year (i.e., 2011) is estimated to be about 2.34 m above Lowest Astronomical Tide (LAT) at the Gladstone station and 2.41 m above LAT at the Fisherman's Landing station.

Table 2.5: Semidiurnal Tidal Planes for Gladstone (Standard Port) and Fisherman's Landing for Year 2011

Tidal Condition	Gladstone (Standard Port)		Fisherman's Landing	
	Height above Lowest Astronomical Tide	Level AHD (-2.268m)	Height above Lowest Astronomical Tide	Level AHD (-2.43 m)
Highest Astronomical Tide (HAT)	4.83	2.562	5.12	2.69
Mean High Water Springs (MHWS)	3.96	1.692	4.20	1.77
Mean High Water Neaps (MHWN)	3.11	0.842	3.30	0.87
Mean Sea Level (MSL)	2.34	0.072	2.41	-0.02
Mean Low Water Neaps (MLWN)	1.57	-0.698	1.66	-0.77
Mean Low Water Springs (MLWS)	0.72	-1.548	0.76	-1.67
Lowest Astronomical Tide (LAT)	0	-2.268	0	-2.43

2.8 Climate Extremes

2.8.1 Cyclones

Figure 2.8 shows that between 1906 and 2006 34 tropical cyclones passed within 200 km of Gladstone, which is an average of 0.34 per year. Within the same time period, 6 tropical cyclones have passed within 50 km of the study area, which is an average of 0.06 per year (refer to Figure 2.9).

Tropical cyclones in the Queensland region most commonly form from lows within the monsoon trough between November and April. The majority of cyclones impact upon coastal north Queensland; however occasionally a cyclone tracks inland and to southern parts of the state, where they generally reduce in intensity.

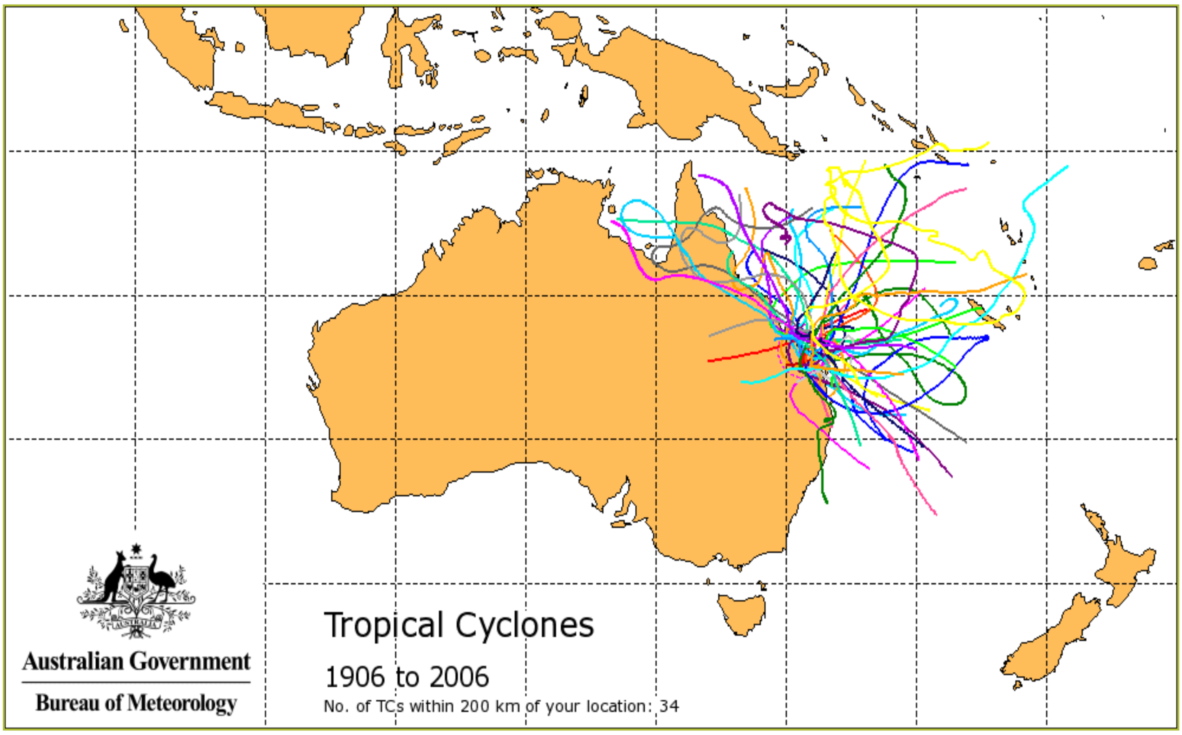


Figure 2.8: Number of Tropical Cyclones within 200 km of Gladstone between 1906 and 2006 (BOM, 2010 accessed 26 May 2010)

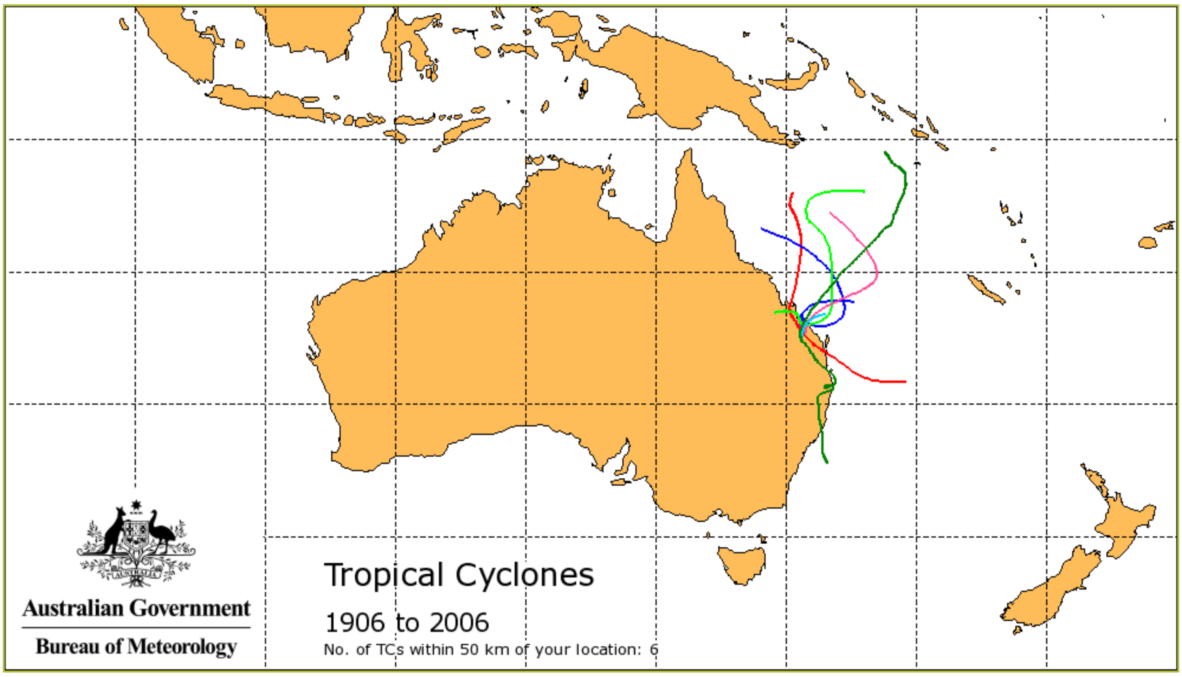


Figure 2.9: Number of Tropical Cyclones within 50 km of Gladstone between 1906 and 2006 (BOM, 2010 accessed 26 May 2010)

2.8.2 Thunderstorm and Lightning

Thunder and lightning frequency maps are available from BOM and provide an indication of the frequency of thunderstorms across Australia.

Figure 2.10 illustrates the average annual thunder days across Australia from 1990-1999 based on activity observed at around 300 weather stations. On average, Gladstone experiences 20 to 25 thunder days per year, some of which can result in localised destructive winds, intense rainfall and flash flooding (BOM, 2011c).

BOM also monitors lightning flashes using satellite data, recorded as both total lightning flash density (including intra-cloud flashes) and cloud to ground flash density per square kilometre per year. Figure 2.11 and Figure 2.12 present averages of expected annual lightning counts across Australia. These show that on average the Gladstone area receives approximately 5 total flashes/km²/year and 2 ground flashes/km²/year

These maps show that the thunderstorm activities at Gladstone region are lower in frequency than the areas of Brisbane, Gold Coast, and Northern NSW and they are also lower than mountain ranges west of Gladstone.

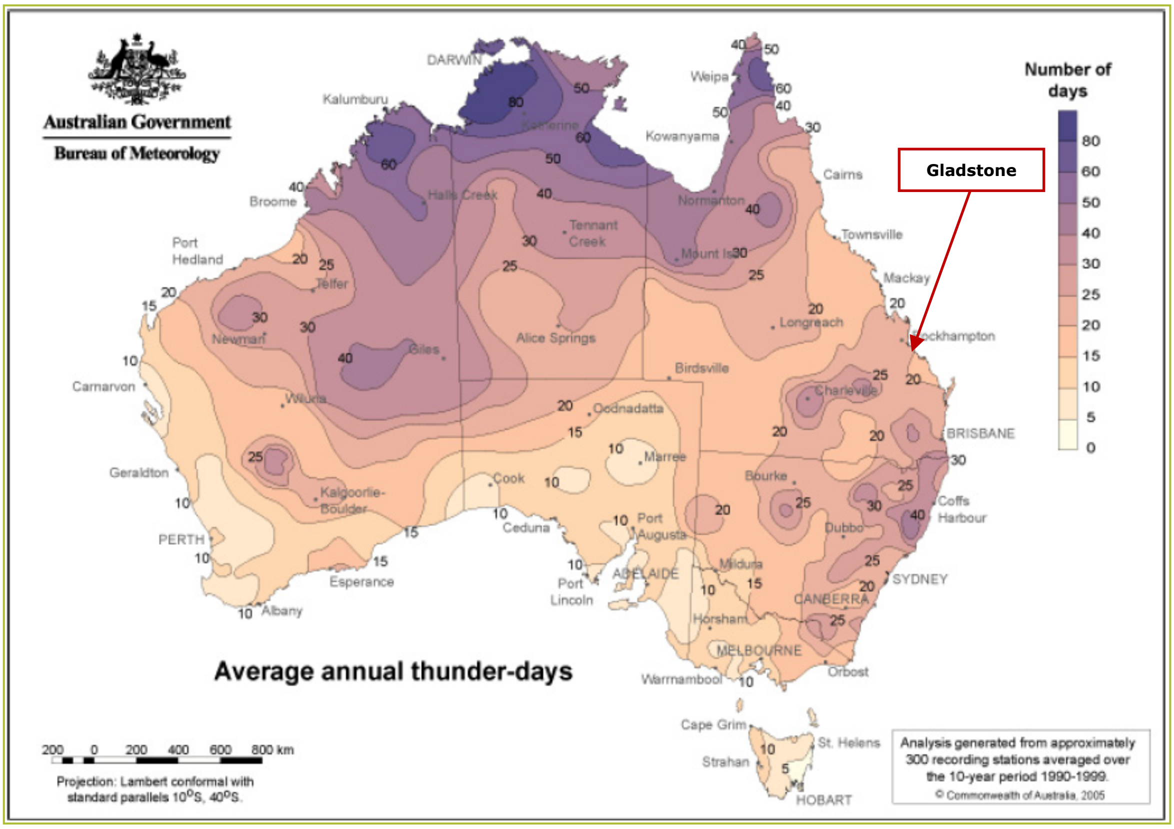


Figure 2.10: Average Annual Thunder Days for Period 1990 – 1999 (BOM, 2011c Accessed 24 May 2011)

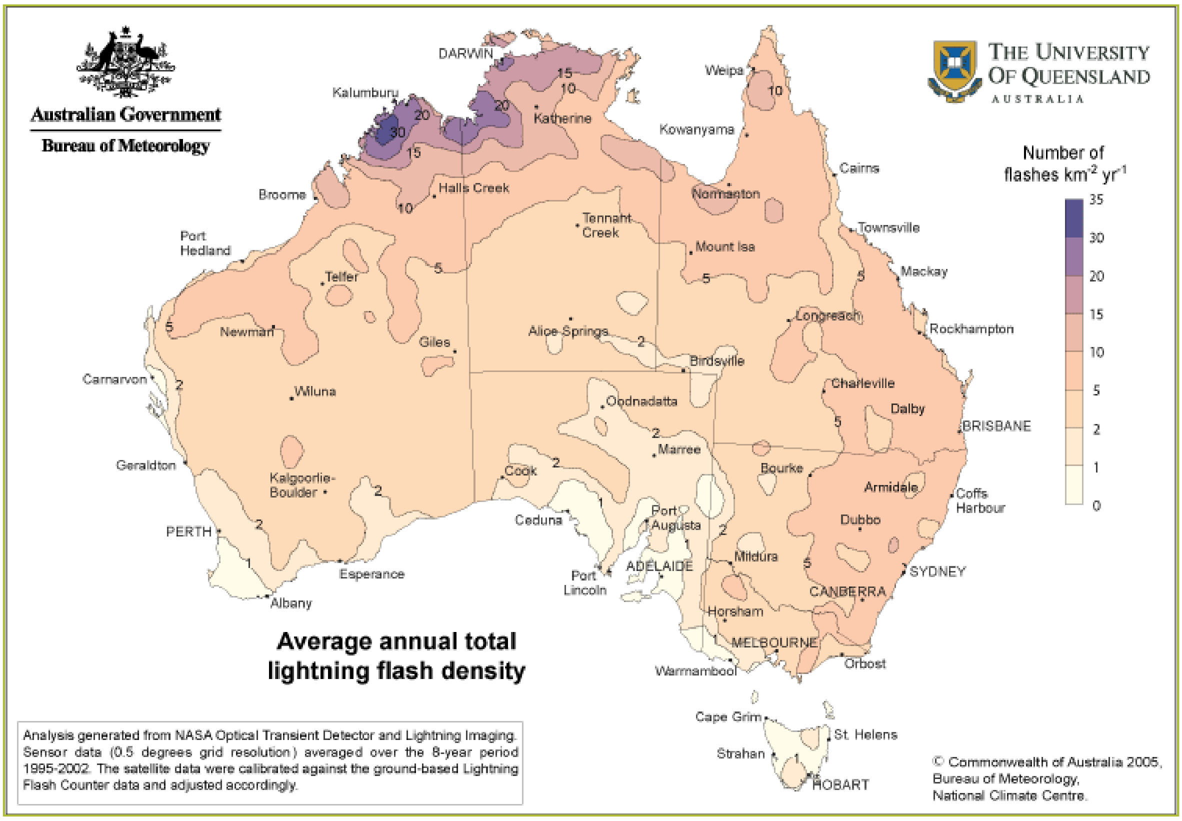


Figure 2.11: Average Annual Total Lightning Flash Density for Period 1906 – 2006 (BOM, 2011c Accessed 24 May 2011)

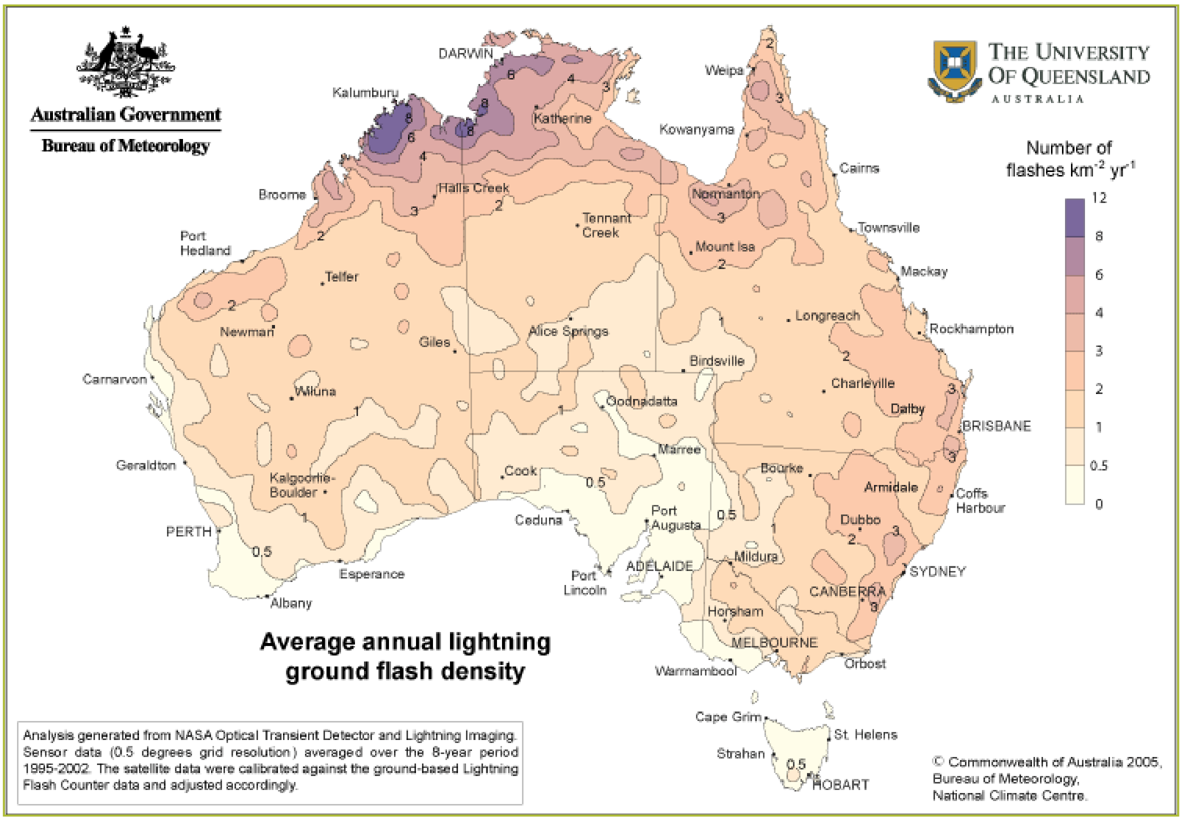


Figure 2.12 Average Annual Lightning Ground Flash Density for Period 1995 – 2002 (BOM, 2011c Accessed 24 May 2011)

2.8.3 Floods

The Calliope River empties into Port Curtis to the west of the city of Gladstone. The proposed mainland launch site 1 is located at the mouth of the Calliope River. The surface water impact assessment for the Arrow LNG Plant EIS notes that *"Numerous floods on the Calliope River have been recorded since the records began in 1938 with the largest being in 1947 and, more recently, the fifth largest in 2003. Regional flooding throughout Queensland in 2010/11 saw the Calliope River subject to flooding in December 2010"* (Alluvium, 2011).."

Auckland Creek is located within the Calliope catchment, albeit not a tributary of the Calliope River. Portions of the TWAF 7 site, which lie within a meander of the creek, are subject to flooding. Flood modelling of 20, 50, 100 and 500 year ARI events is provided in the Arrow LNG Plant EIS surface water impact assessment (Alluvium, 2011).

The project area at Curtis Island is not impacted by river floods. The flood risks on the project site may be associated with drainage issues of the site during heavy rainfall. On the other hand, floods due to storm surges may occur near water facilities such as jetties and roads. A storm surge is a rise above the normal water level along a shore that is the result of strong onshore winds and /or reduced atmospheric pressure. Storm surges accompany a tropical cyclone as it comes ashore. They may also be formed by intense low-pressure systems that are not tropical cyclones (BOM, 2011d). The combination of a storm surge and a normal high tide results in what is called a storm tide. While storm surges can cause a significant number of deaths during tropical cyclones, the combined effects of storm tide and waves can cause the destruction of buildings, wash away roads and run ships aground (BOM, 2011d).

The effects of these flood risks associated with heavy rainfall are further discussed in the surface water assessment (Alluvium, 2011).

2.8.4 Droughts

A drought is an extended period, usually extending for months or years when a region experiences a deficiency in its water supply. Generally, this occurs when a region receives consistently below average precipitation. It can have a substantial impact on local residents, ecosystems, agriculture and other water-intensive industries.

The Gladstone region suffered a significant drought between 1996 and 2003 when inflows to the major water supply for Gladstone city, Awoonga Dam on the Boyne River, were less than water requirements. During this period, inflows to the Dam were less than the driest 25% of years since rainfall records began in 1891. The water level in the Awoonga Dam fell to around 7.6% (i.e., 59,000 ML) of the capacity of the current 40 m dam in January 2003. This event resulted in the implementation of water restrictions for the first time in the region's history, and these water restrictions were applied to both residential and commercial activities (Gladstone Regional Council, 2009). In 2007/08 a Low Supply Alert was issued as Awoonga Dam fell to 29.75 m AHD, which corresponds to approximately 35% of the 40 m Dam capacity (i.e., approximately 280,000 ML storage trigger) (Gladstone Area Water Board, 2009). At May 3 2011, Awoonga Dam was at approximately 101.49% capacity (i.e., 788,447 ML) (Gladstone Area Water Board, 2010a) following an exceptional wet season across the region associated with a La Niña event.

Over long historical time-scales, Australia has been prone to drought events for several periods of a decade or longer, such as during the mid to late 1920s and the 1930s periods when low rainfall was experienced over most of the country, persisting through most of the 1940s over the eastern states. Major droughts in eastern Australia were experienced during the periods 1937-38, 1940-41 and 1943-45. Drought conditions (i.e., rainfall in most years below the long-term average) were also experienced in the 1960s over eastern Australia (BOM, 2011f). Many droughts in northern and eastern Australia are associated with the El Niño phase of the El Niño-Southern Oscillation (ENSO). More recently, the long El Niño event in the early 1990s led to an extreme, lengthy drought over central and southern Queensland. The affected areas in Queensland only experienced relief from the drought at the end of 1995. Drought also affected many Queensland regions between 2001 and 2009 (Long Paddock, 2011).

The Gladstone region has experienced a number of 'short-term' droughts, with limited rainfall over periods of up to 12 months, including months during which the Boyne River experienced zero or very low flows. The most significant short-term droughts occurred in 1941 and 1969 (Gladstone Area Water Board, 2009).'Long-term' droughts were also experienced, coinciding with short-term droughts. Long-term droughts occurred during 1965-67, 1969-70, 1984-84, 1993-95, 1997-2003 and 2004-2008 (Gladstone Area Water Board, 2009).

Historic data suggests that there will be years with minimal inflow, and rare major inflow events. However, the frequency of a drought period is difficult to predict based on past events. The Gladstone Area Water Board's strategy is hence to prepare for such events in order to respond and adapt effectively to these exceptional circumstances (Gladstone Area Water Board, 2009).

Current knowledge of climate variability and climate change suggests that more severe droughts than have been experienced in historical times can occur, without any influence of anthropogenic climate change. Anthropogenic climate change is expected to increase average moisture deficits, thus increasing the propensity for drought to develop. An increase in El Niño event frequency or intensity due to global climate change has been postulated but remains uncertain.

2.8.5 Bushfires

Moisture deficits and drought lead to drier conditions and a change in vegetation, and hence increased chances and severity of bushfires. Figure 2.13 shows that the Gladstone region, including Curtis Island, was predominantly classified as a 'medium bushfire risk level' region in June 2008 (BOM), and as a result bushfires pose a significant risk to the study area. However, according to the Queensland Government, the risk of severe bushfires is low in the Queensland region due to summers being typically wet. Despite the high frequency (i.e., hundreds) of bushfires occurring in Queensland, only a few are significant enough to pose a threat to life and property (DCS, 2010).

Additional information regarding bushfires can be found in *Bushfire Hazard & Risk Assessment, Arrow LNG Plant, 2011* (Eco Logical, 2011).

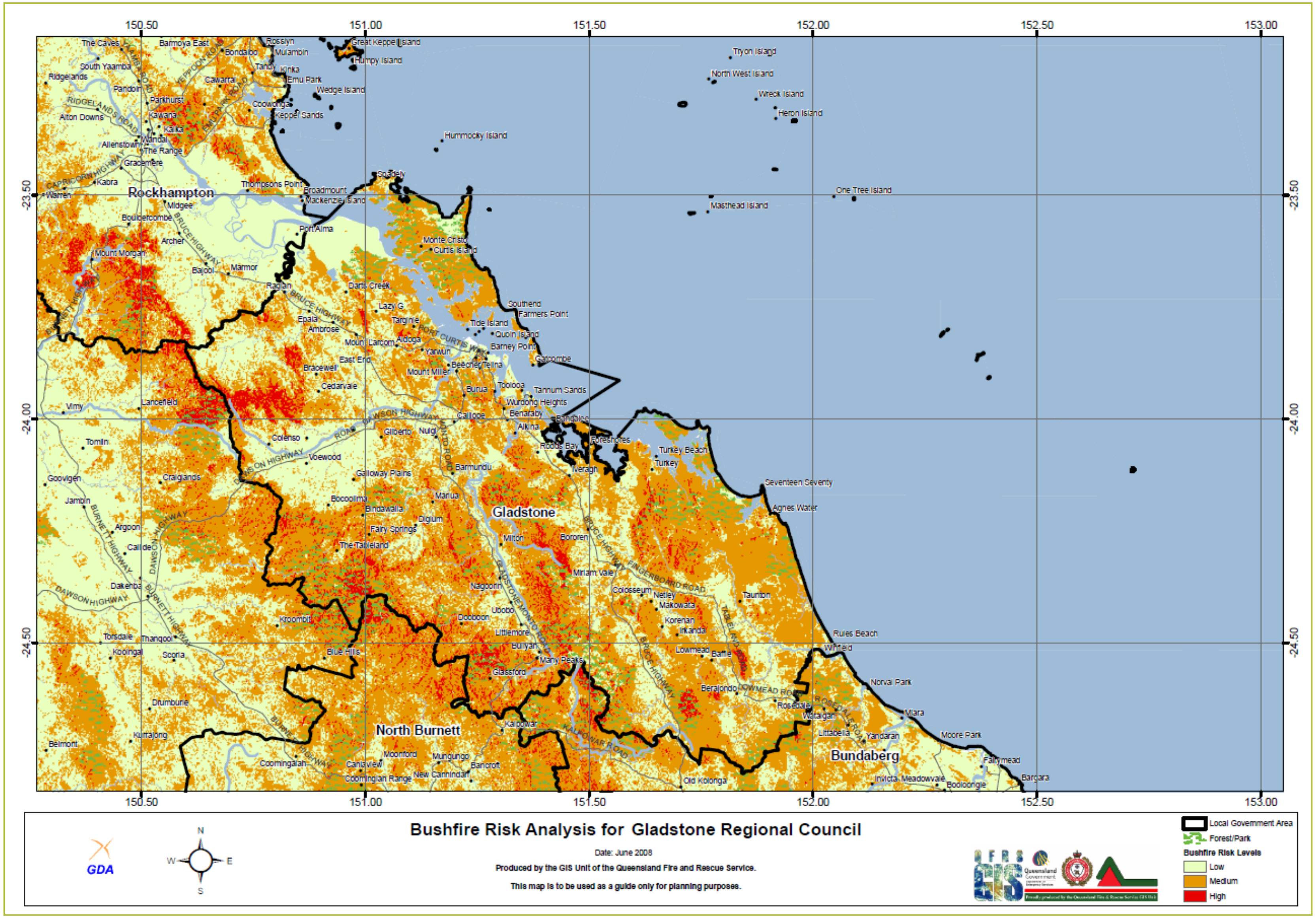


Figure 2.13 Bushfire Risk Map – June 2008 (DCS, 2008 Accessed 04 May 2011)

2.9 Observed Climate Change Trends

Due to the large natural variation of the climate system, good quality long-term data is required to identify trends and cycles. Often individual meteorological station data shows significant year to year fluctuations. Such variations may not accurately reflect regional or global trend and cycles. Apart from local weather variations in the short term, climate changes and shifts in one region can differ markedly in other regions. Hence, climate change must be viewed as a long-term process that is easily masked by natural variability. It must be evaluated on time scales of at least decades.

Regional and global statistical analysis using selected high quality data from many stations yields more reliable results. This approach has been employed by CSIRO and BOM to detect trends for different regions of Australia. Some of the trends identified that are relevant to the Gladstone region are listed below:

- Average annual rainfall in the Central Queensland region (which includes Gladstone) over the 1998-2007 period has fallen by approximately 13.4% in comparison with the previous 30 years (i.e., 1961 – 1990); however this is generally consistent with natural variability (DERM, 2009).
- Over the last decade (i.e., 2000-2009) the average annual temperatures in Central Queensland have increased by 0.5 °C (from 21.6 to 22.1) (DERM, 2009).
- Since the late 1970's, historical temperature records for Rockhampton indicate a general increase in the annual number of days over 35°C (DERM, 2009).
- Trends in tropical cyclone activity in the Australian region have shown that the number of cyclones has decreased in recent decades, although the number of stronger cyclones (with minimum central pressure <970 hPa) has not declined. Historic weather patterns have shown that cyclone activity in Australia decreases during an El Niño pattern and increases during La Niña. Cyclones also show greater tendency to track south during La Niña decades (DERM, 2009).
- Over the 100 years from 1906 to 2005, global sea levels rose by approximately 17 cm (DERM, 2009).

3 CLIMATE CHANGE PROJECTIONS

This chapter outlines climate change projections relevant to the Gladstone area, which draw upon international, Commonwealth and Queensland government climate change projections. It should be noted that there are inherent uncertainties associated with the climate change projections produced by climate models. Further detail of these uncertainties is provided in Appendix A.

The climate change projections presented in this assessment draw upon the following:

- Intergovernmental Panel on Climate Change (IPCC) projections set out in the IPCC's *Third Assessment Report* (IPCC, 2001) *Fourth Assessment Report (AR4)* (IPCC, 2007) and IPCC's *Special Report on Emissions Scenarios* (IPCC, 2000).
- CSIRO's projections for Australia in *Climate Change in Australia* (CSIRO & BOM, 2007).
- Queensland government's projections set out in the DERM report, *Climate Q: toward a greener Queensland,* which references the projections of the *Climate Change in Australia* report (CSIRO & BOM, 2007), which in turn are based on the results of climate modelling undertaken as part of the *IPCC AR4* (IPCC, 2007). Gladstone falls within the Central Queensland region projections.

The IPCC's *Special Report on Emissions Scenarios* (IPCC, 2000) developed the following emissions scenarios:

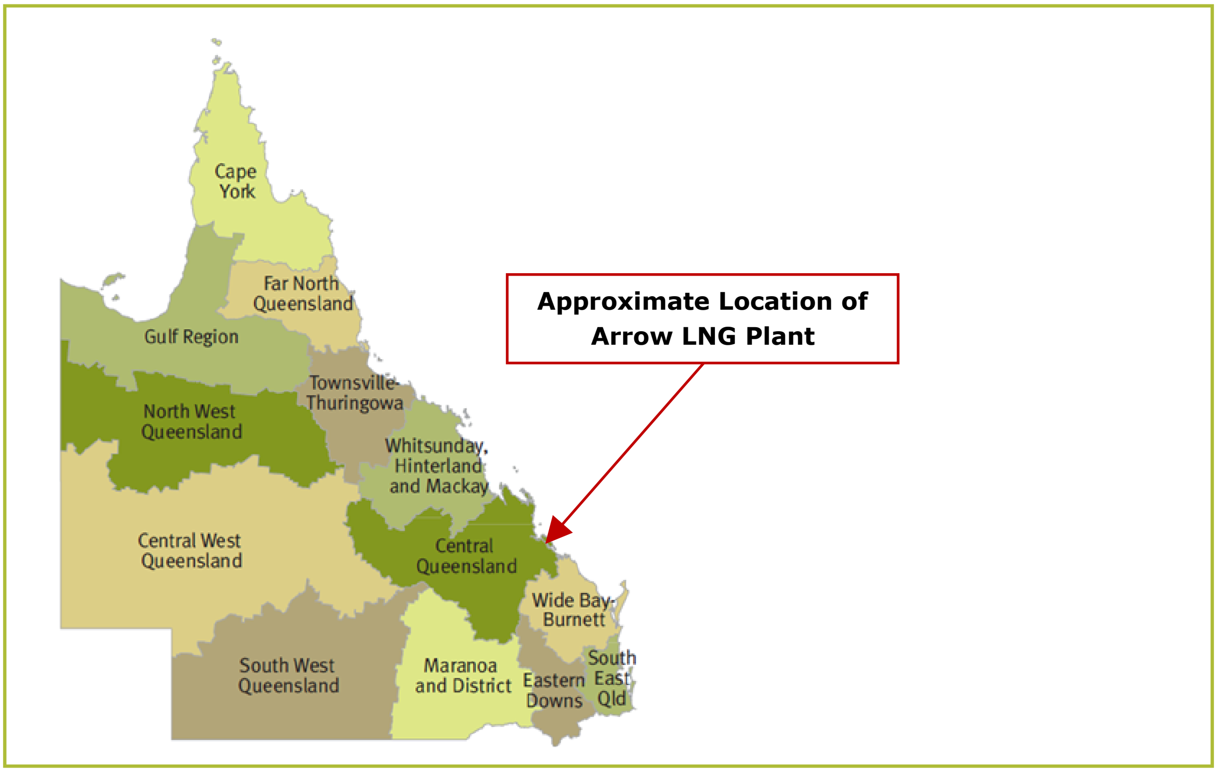
- B1 – low emissions scenario that assumes a rapid shift to less fossil fuel intensive industries.
- A1B – medium emissions scenario that assumes a balance of energy sources.
- A1FI – high emissions scenario that assumes strong economic growth based on continued fossil fuel dependence.

These emissions scenarios were used as the basis of climate change projections presented in *Climate Change in Australia.* The Queensland Government's Climate Change Centre of Excellence (QCCCE) has taken the results from *Climate Change in Australia* and performed numerical downscaling to produce climate change predictions on a finer spatial resolution. This means that the models account for local topography and small-scale weather phenomena, resulting in more accurate climate change predictions for Queensland regions.

Figure 3.1 shows the regions that climate change projections were made for by QCCCE. Climate change projections have been taken for the Central Queensland region, as they provide the estimates most specific to the study area. If data was not available for Central Queensland projections were taken for the Queensland region.

The projected changes have only been presented for scenario A1B (medium) up to 2030, as changes are reported to vary little with respect to emissions scenarios. After 2030, climate change projections are increasingly dependent on the level of emissions, so both low (B1) and high (A1FI) emissions scenarios are used for 2050 and 2070, to illustrate the range of projections (projections for the medium emissions scenario are not presented beyond 2030 as they lie between the projections for the low and high emission scenarios).

The design life of the LNG plant and its associated infrastructure is 25 years, with the concrete jetty and materials offloading facility (MOF) having a design life of 40 years. Therefore emission projections for 2030 and 2050 are the most relevant to the project. Projections up to 2070 have been presented for analytical purposes.



Source: Figure taken from DERM (2009), *ClimateQ: Towards a Greener Queensland* (Chapter 5: *Climate Change Impacts on Queensland's Regions)*

Figure 3.1: Regions used for Queensland Climate Change Projections

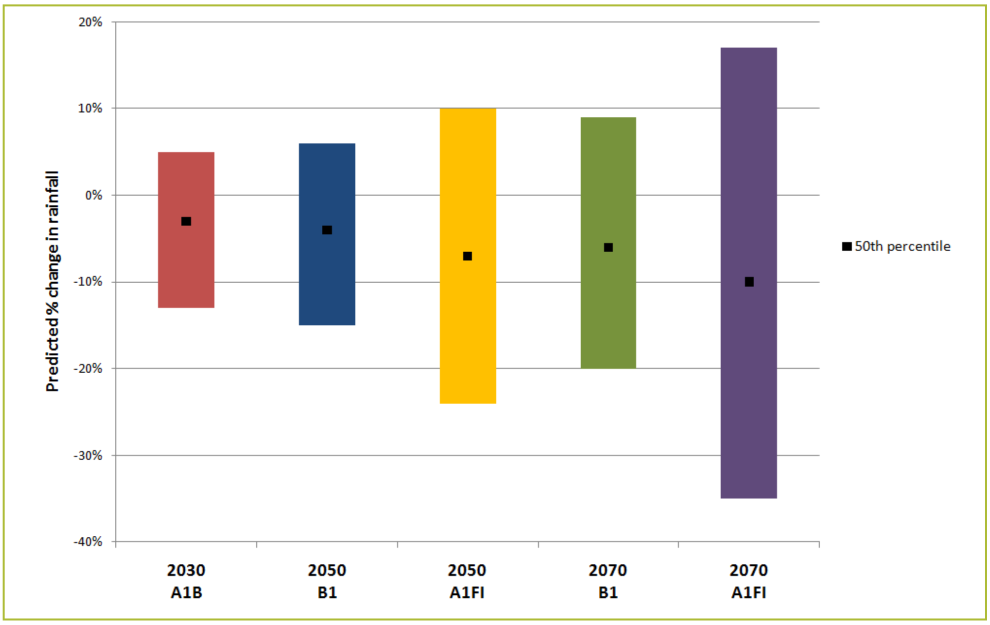
3.1 Rainfall

There is great uncertainty associated with predictions of rainfall change. Rainfall is one of the most difficult variables for climate models to predict. This is because rainfall is influenced by many different scales of weather systems, from the small-scale systems such as localised thunderstorms and tropical cyclones, to large-scale frontal systems. Global climate change models (general circulation models – GCM) are mostly run at a coarse resolution, for example 250 km, which is not fine enough to resolve small-scale rainfall systems such as thunderstorms and tropical cyclones. Rainfall tends to vary locally and is impacted by local terrain, distance to the coastline, etc. Current global climate change models cannot resolve such fine geographic features. Many other climate variables suffer similar constraints. For example, solar radiation is dependent on cloud cover, which is related to predicted rainfall and other climate variables, such as relative humidity.

Figure 3.2 shows that rainfall is expected to either decrease or increase for all modelled emissions scenarios and years. However best estimates (50th percentile) for all years show rainfall is predicted to decrease, with:

- a 3% decrease by 2030;
- a 4% decrease for a low emissions scenario, and 7% decrease for a high emissions scenario by 2050; and
- a 6% decrease for a low emissions scenario, and 10% decrease for a high emissions scenario by 2070.

Rainfall in Central Queensland has consistently decreased since the 1970s (until 2009) with a decrease in summer and autumn average rainfall of 14% and 38% respectively compared to the 1961-1990 average, over the past decade (i.e., 2000-2009). However, these rainfall conditions are similar to those in the early 1920s and late 1960s for autumn rainfall for instance, which implies a naturally occurring succession of wet and dry episodes (DERM, 2009).



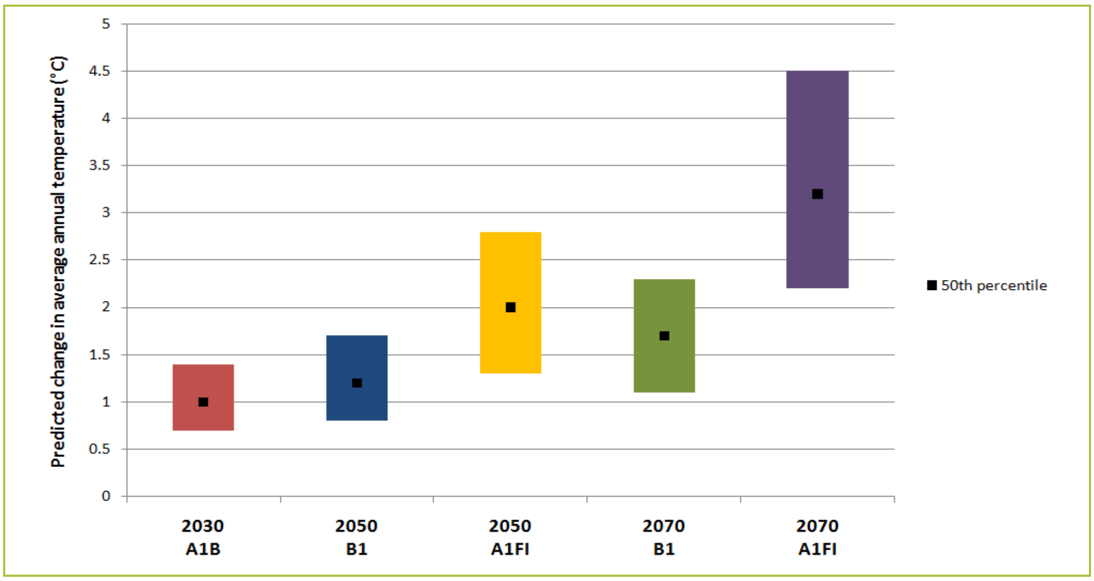
Note: Bars represent range from 10th percentile (minimum) to 90th percentile predictions, sourced from *Appendix 3: Regional climate change summaries*, ClimateQ: toward a greener Queensland, Qld Government, 2009

Figure 3.2: Predicted Change in Rainfall for Central Queensland

3.2 Temperature

Temperature for the Central Queensland region is expected to increase 0.7-1.4 °C by 2030 and 0.8-2.8 °C by 2050, with the level of increase dependent on the emissions scenario. Predictions for 2070 are an increase of 1.1-2.3 °C for a low emissions (B1) scenario and an increase of 2.2-4.5 °C for a high (A1FI) emissions scenario. These results are presented in Figure 3.3. In the decade (1997-2007) prior to the baseline, the annual average temperature of the region increased by 0.5 °C (DERM, 2009).

Based on BOM data from 1957-2010, the historical maximum and minimum average annual temperatures for Gladstone are 27.7°C and 18.5°C respectively. Based on the QCCCE predictions, it is expected that average annual maximum and minimum temperature at Gladstone will increase. However, any increase in average maximum and minimum temperature will not necessarily be the same as the predicted values presented in Figure 3.3, as these values refer to an increase in the overall average temperature, not specifically to maximum and minimum temperatures.

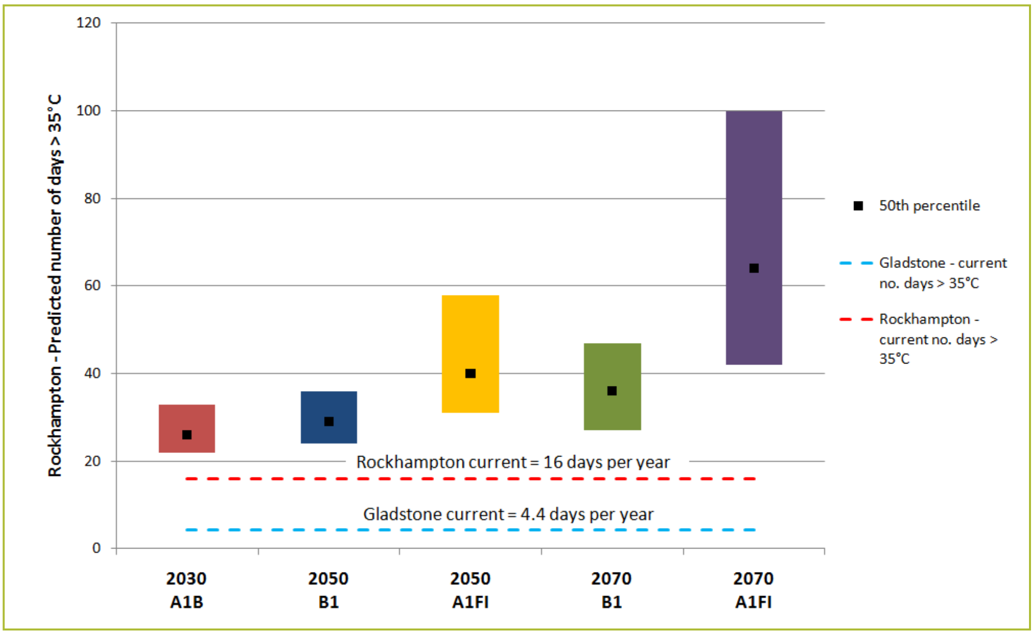


Note: Bars represent range from 10th percentile (minimum) to 90th percentile predictions, sourced from *Appendix 3: Regional climate change summaries*, ClimateQ: toward a greener Queensland, Queensland Government, 2009

Figure 3.3: Predicted Range of Average Annual Temperature Change for Central Queensland

A prediction of the number of days when temperature exceeds 35°C gives an indication of future climate extremes. Data for the Central Queensland region was only available for Barcaldine, which is located approximately 600 km west of Gladstone, and Rockhampton, which is situated at approximately 90 km north-west of Gladstone. As a result, the data from Rockhampton was used in the predictions in Figure 3.4, as it was the most representative data for expected trends in the Gladstone region.

As can be seen in Figure 3.4, best estimates (50th percentile) for Rockhampton are that the number of days with temperature >35 °C is expected to increase for all modelled emissions scenarios and years, with the greatest increase predicted for 2070 under a high emissions scenario. Historically, the number of days >35°C at Rockhampton is 16 per year, while at Gladstone the historical average is 4.4 days per year. Therefore, while it is reasonable to assume that the number of days >35 °C will increase at Gladstone, the actual number of predicted days should not be inferred directly from Figure 3.4.



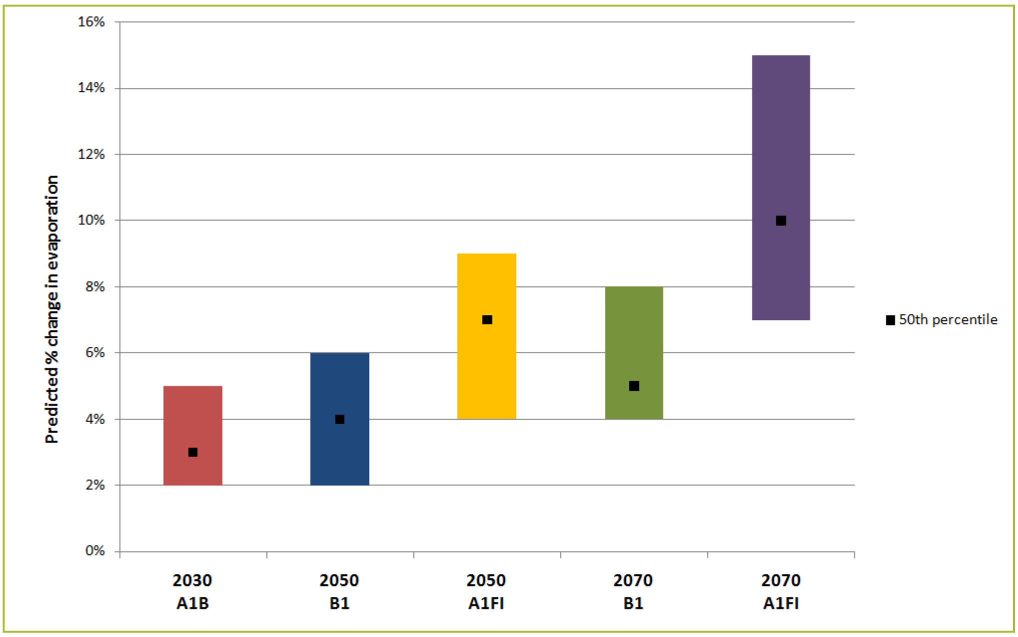
Note: Bars represent range from 10th percentile (minimum) to 90th percentile predictions, sourced from *Appendix 3: Regional climate change summaries*, ClimateQ: toward a greener Queensland, Queensland Government (DERM, 2009)

Figure 3.4: Predicted Average Annual Number of Days >35 °C for Rockhampton

3.3 Evaporation

Potential evaporation in the Central Queensland region is predicted to increase for all emissions scenarios for 2030, 2050 and 2070, as presented in Figure 3.5. Best estimates (50th percentile) are increases of 3% by 2030, 4-7% by 2050 and 5-10% by 2070, with values for 2050 and 2070 dependent on the emissions scenario. Averaged over the Central Queensland region, the annual mean potential evaporation from 1971–2000 is 1997 mm (DERM, 2009). It should be noted that as potential evaporation is dependent on a number of climatic variables, including temperature, relative humidity and cloud cover, there is significant uncertainty in future projections.

The rate of potential evaporation is more than twice the mean annual rainfall recorded for Gladstone from 1957-2010, and three times the average rainfall for Central Queensland. This is a contributing factor to soil moisture depletion (DERM, 2009). Using best estimates, future rainfall is predicted to decrease while potential evaporation is expected to increase, which will result in further depletion of soil moisture.



Note: Bars represent range from 10th percentile (minimum) to 90th percentile predictions, sourced from *Appendix 3: Regional climate change summaries*, ClimateQ: toward a greener Queensland, Qld Government, 2009

Figure 3.5: Predicted Change in Evaporation for Central Queensland

3.4 Sea Level Rise

The IPPC predicts that the global sea level will rise by 18-59 cm by 2100, with a possible additional contribution from melting ice sheets of 10–20 cm (DERM, 2009). The Australian Standard *AS 4997-2005* (refer to section 1.2.3) also contains sea level rise factors which are within the range of the IPCC sea level predictions (i.e., 10, 20 and 40 cm for 25, 50 and 100 year design life respectively). In contrast, the *Queensland Coastal Plan* (refer to section 1.2.2), expected to come into effect in mid-2011, projects a higher mean sea level rise of 80 cm by 2100. It should be noted that there is substantial uncertainty associated with sea level rise projections (CSIRO & BOM 2007).

3.5 Tropical Cyclones

The proportion of tropical cyclones in the more intense categories is expected to increase in Australia; however the total number of cyclones is expected to decrease. It is also projected that, with warmer climate, cyclone activity could have a greater tendency to track southward; presently the project area is to the south of the main area of tropical cyclone occurrence; if cyclones track further south, Gladstone will experience greater impacts from cyclones (CSIRO & BOM 2007).

Historically, tropical cyclone activity in the Australian region has decreased in recent decades; however the number of stronger cyclones (with minimum central pressure <970 hPa) has not declined (BOM, 2009).

3.6 Storm Surges

Changes in climate may extensively affect the magnitude and frequency of storm surges and accordingly, Hardy et al (2004) assessed the storm surge hazards in 50 eastern Queensland coastal locations, including Gladstone, based on three selected greenhouse-induced climate change scenarios. It should be noted that the following scenarios were selected from the Hardy et al study and are not the IPCC's scenarios (refer to section 3):

- scenario A: increase in Maximum Potential Intensity (MPI) of tropical cyclones and poleward shift of tracks (1.3 degrees);
- scenario B: increase in frequency of tropical cyclones (10%); and
- scenario C: mean sea level rise (300 mm).

It was found that the mean sea level rise had the highest impact on storm surge hazard with a significant increase in storm surge and tide level at all locations (Hardy et al, 2004).

The predicted 100-year return period (based on 2003 storm surge and tide levels) for the combined greenhouse scenarios aforementioned will result in a 3.3 m AHD storm surge at Gladstone (Auckland Point). This is an increase of approximately 50 cm due to climate change, based on a baseline year of 2003, where the 100-year return period of storm surge events was 2.82 m AHD (Hardy et al, 2004). For the predicted 500-year return and 1000-year return periods, storm surges are expected to reach 4.18 m AHD and 4.51 m AHD levels, which correspond to a respective increase of 67 cm and 0.71 cm, compared to a baseline year of 2003.

Table 3.1 presents storm tide levels for 2003 and the projected levels for 100, 500 and 1000 years return period which are based on the three greenhouse-induced climate change scenarios mentioned above.

Table 3.1: 2003 Storm Tide Levels and Projected Levels for 100, 500 and 1000 years Return Periods

Location	Storm Tide Level (m AHD)					
	100 year		500 year		1000 year	
	2003	Greenhouse	2003	Greenhouse	2003	Greenhouse
Emu Park (Rosslyn Bay)	2.87	3.28	3.30	3.95	3.54	4.30
Gladstone (Auckland Point)	2.82	3.33	3.51	4.18	3.80	4.51
Tannum Sands (Gatcombe Head)	2.50	2.95	3.05	3.64	3.31	3.94

Source: Table 2, Hardy et al (2004)

3.7 Summary

Due to the increased intensity of cyclones predicted in the climate change scenarios and the sea level rises, the frequency and level of flooding is likely to be higher in the future for the Gladstone region.

As a result of climate change, droughts in Australia are likely to be more severe not only due to rising temperature, but also due to increased evaporation (CSIRO & BOM, 2007).

Fresh water may be scarcer in the future for the Gladstone region due to projected decreased rainfall, an increase in the severity of drought, and an increased population (CSIRO & BOM, 2007).

4 CLIMATE CHANGE IMPACTS AND ADAPTATION STRATEGIES

Potential climate change impacts specific to the operation and viability of the project have been assessed for the climate variables identified in Section 3. Strategies were outlined to adapt to changes in climate, and minimise any associated impacts. These strategies have been developed based on the general framework for climate change adaption presented in the Queensland Government's *ClimateSmart Adaptation 2007-2012*, as well as frameworks prepared by the Commonwealth Government and other states, such as:

- The *Planning Scheme* for the City of Gladstone (2006).
- The Queensland's revised climate change strategy *Climate Q: toward a greener Queensland* (OCC 2009).
- *The National Climate Change Adaptation Framework* (Department of Climate Change and Energy Efficiency, first adopted in 2007).
- *A Draft Climate Change Adaptation Framework for South Australia* (Government of South Australia, 2010).

4.1 General Framework for Climate Change Adaptation

Based on the general frameworks prepared by the Commonwealth, Queensland and other state governments, the following adaptation strategies have been identified as being applicable to the project:

- Access the best available climate change science, projections and data for the project area.
- Include climate change factors in the basis of design to ensure buildings and infrastructure are located and built to withstand:
  - sea-level rise, and
  - more severe extreme weather including storm surges, intense cyclones, flooding, drought, and bushfire.
- Prepare to incorporate climate change induced health risks into future workplace health, safety and environmental management plans, which may include:
  - increased heat stress risk, and
  - geographical shift of insect-borne diseases.
- Include more extreme weather scenarios in the disaster management plan.
- Use water more wisely by lowering water consumption through water efficient technologies and practices and/or by installation of water-efficient devices.
- Estimate and include the climate change costs in the business cost projection, and at the same time take advantage of emerging business opportunities that climate change may create.

4.2 Climate Change Impacts Specific to the Project

4.2.1 Increased Temperature

An increase in ambient temperature has the potential to impact the LNG plant by increasing the operational temperature range of equipment and construction materials, decreasing the efficiency of power generation and increasing risks to human health.

Given that the gas liquefaction process at LNG plant handles a large temperature difference, the potential impacts associated with ambient temperature increase to equipment and construction material are expected to be minor. However, it is recommended that it should be ensured that maximum design temperatures are sufficient to account for future increases in ambient temperature.

An ambient inlet temperature rise of 3.5°C is expected to decrease the power output of the gas turbines by 0.6-1 MW (Arrow Energy, 2010). This will increase the amount of gas required for power generation, reducing the output of product LNG. In addition the increase in temperature may affect the storage and transmission of gas and LNG.

Increased temperatures have the potential to impact human health. In particular, it is likely to have increased occurrences of heat-stress for workers and increased incidents of insect-borne diseases (such as Dengue Fever), for which temperature is a key determinant, during the warmer and wetter seasons. Increased awareness of these impacts is the key adaptation strategy, which is outlined in the Arrow LNG Plant *Health, Safety, Environment and Emergency Response Plan*. In addition, Health, Safety, Environment and Emergency Response Plan employed on site will be subject to regular review of hazards, controls and potential consequences.

4.2.2 Extreme Water Levels and Flooding

An increase in water levels due to global sea level rise and increased intensity of storms and cyclones can be caused by the following events:

- flooding of low lying areas of the coastline, damaging infrastructure and causing embankment instability; and
- higher levels of coastal erosion due to increase wave size and activity.

During the project life, IPCC projects that the global sea level will rise by 18-59 cm by 2100, with a possible additional contribution from melting ice sheets of 10–20 cm (DERM, 2009). Alternatively, the *Queensland Coastal Plan* (DERM, 2011) projects a mean sea level rise of 80 cm by 2100. Mean sea level in conjunction with more intense weather system can cause potential for significant increases in inundation events (DERM, 2009). Based on a study conducted by James Cook University (Hardy et al., 2004), the storm tide is expected to rise from 2.8 m AHD by up to 50 cm to 3.3 m AHD for a 100-year return period (based on year 2003) (refer to Table 3.1). A more significant storm tide level rise is predicted for a 500-year return and a 1000-year-return periods; i.e. a maximum level rise of 67 cm to 4.2 m AHD and of 71 cm to 4.5 m AHD, respectively.

The *Planning Scheme* for the City of Gladstone (2006) indicates that the facility is to be located in an area that is susceptible to a 4m AHD or 100 Year ARI (Average Recurrence Interval) Storm Tide Surge. For the mainland launch site and temporary workers accommodation site options, the *Planning Scheme* also requires that any premises situated below 4 m AHD consider the best strategy for flood and storm surge immunity. In addition to this, the *Surface Water Impact Assessment* (Alluvium, 2011) states that the project will adopt a "*design storm tide maximum level of 4.06 AHD for detailed design and future planning*". It should be considered that this design storm tide level is below the predicted levels for a 500 year return and a 1000 year return periods and therefore further investigation is required.

The impacts of localised flooding can increase if parts of the storm water drainage systems are blocked or if capacity of the systems is exceeded. Due to the project site's proximity to the ocean, it is typically expected that in the event of flooding stormwater will quickly drain to the ocean. However, mitigation measures relating to this issue are provided in the *Surface Water Impact Assessment* (Alluvium, 2011).

In addition, ensuring native vegetation and wetland buffer zones are maintained during the project life and continual monitoring and application of mitigation measures at high risk erosion areas will reduce potential erosion issues across the site.

4.2.3 Stronger Winds

The predicted increase in the intensity of storms and cyclones may lead to stronger winds for the study area at times of extreme weather, increasing strain on LNG plant infrastructure.

The LNG plant will be designed in accordance with Australian Standard AS 1170.2 *Structural Design Actions – Part 2: Wind Actions*. AS 1170.2, which is one of the Australian standards that address climatic factors in design (refer to section 1.2.3). This latter does not specifically address climate change; however it has indicated that the values of the factors used to calculate the design wind speeds may be revised in the future to include the effects of long term climate change. Therefore, the most up to date aforementioned Australian standard will be used in the detailed design phase with regular review of climatic design factors.

4.2.4 Decreased Water Availability

'Best estimate' projects that by 2050 rainfall in the Central Queensland region may decrease by up to 7% (i.e., -48 mm) under a high emissions scenario (i.e., A1FI; refer to Section 3) (DERM, 2009). As described in Section 2.8.4, the Gladstone region is susceptible to drought, as demonstrated in 2002 when the region's only major water supply, Awoonga Dam, supply level fell to 7% capacity.

The LNG plant base case is for its fresh water requirements to be met through reverse osmosis (RO) treatment of sea water on site. However, during the construction phase of the project, water supply to TWAF 8 and the launch site, both located on the mainland, will be required. In addition, water will need to be supplied to the LNG plant until full commissioning of the RO Plant. Any water requirements that will not be met through reverse osmosis on-site will potentially be supplied by the Gladstone Area Water Board (GAWB). It should be noted that the water requirements for the duration of construction are minor in comparison with the water requirements associated with the operation of the plant and the accommodation facilities. Arrow Energy is also committed to minimise fresh water use associated with Arrow LNG's activities as part of its environmental constraints. Decreased fresh water availability in the Gladstone region, due to projected decreased rainfall and increased temperature resulting in increased evaporation (refer to Section 3), is not expected to impact the project's operation. However, Arrow should monitor its fresh water requirements throughout construction and operation and have operational procedures in place to ensure that potable supply is adequate.

4.2.5 Bushfires

The location of LNG plant, on Curtis Island, is in an area currently associated with "medium" risk of bushfires (DCS, 2008). With the predictions of increased temperature, increased evaporation and decreased rainfall, the frequency and severity of bushfires is expected to increase on Curtis Island. The associated mitigation measures are presented in the *Bushfire Hazard & Risk Assessment* (Eco Logical, 2011). This assessment should consider the preventative and responsive measures for the potential for increased frequency and severity of bushfires.

4.3 Arrow LNG Plant Climate Change Adaptation Strategy

A summary of climate change variables, project risks and recommended adaption strategies are presented in Table 4.1.

Climate change risks were evaluated based on the generally accepted framework for risk assessment, which includes:

- risk identification;
- risk analysis;
- risk evaluation; and
- risk treatment.
- Project risks were identified based on the potential impacts associated with climate change variables. However, significant uncertainty is associated with the analysis and evaluation of these risks, as significant uncertainty is associated with the climate change predictions and their likelihood. Due to this uncertainty, risk evaluation and treatment for climate change is primarily consequence driven. In other words, although the potential consequences of climate change with respect to this project cannot be predicted with certainty, the trends in impacts can be used to inform management strategies for project design and operation. The management strategies (treatment) recommended for each area of climate change risk are therefore presented in Table 4.1.

Table 4.1: Summary of Climate Change Variables, Project Risks and Recommended Adaptation Strategies

Climate Change Risk	Consequence to the Project	Adaptation (Treatment) Strategy
Increased temperature	Higher ambient operating temperatures impacting infrastructure and operational efficiency. Storage and transmission of gas and LNG.	Consider maximum increased temperatures in design phase [a]
	Heat stress and incidence of insect-borne disease amongst workers	Increased safety awareness – heat stress [a]
		Include in health and safety documents (existing strategy) [a]
Increased sea levels and flooding	Damage to infrastructure	Consider maximum storm surge levels during project design [b]
		Maintain vegetation buffer to coastline to reduce erosion [b]
		Design appropriate drainage systems and if required flood warning systems [b]
Increased wind speed	Increased strain on infrastructure	Buildings designed in accordance with relevant Australian guidelines [c]
		Design basis should consider the predicted increase in wind speed [c]
Decreased water availability	Decreased potable water supply	Implementation of water management during construction and operational activities which require Gladstone water supply [d].
Increased bushfire frequency and intensity	Human health and infrastructure damage	Refer to the *Bushfire Hazard & Risk Assessment* (Eco Logical, 2011)

a. Refer to Section 4.2.1
b. Refer to Section 4.2.2
c. Refer to Section 4.2.3
d. Refer to Section 4.2.4

As previously stated, there is significant uncertainty associated with climate change projections. Assessment of residual risks should the climate adaptation strategy fail is therefore considered premature.

Ensuring the design of the Arrow LNG Plant takes into consideration high emissions (A1FI) projections for the Central Queensland region, and where possible projections for the Port of Gladstone specifically, is a fundamental first step to reducing the project's vulnerability to potential climate change impacts. It will be necessary for Arrow to stay abreast of ongoing refinement of climate change projections within Government and scientific communities, and consider future adaptation requirements should additional or revised risks be identified.

5 CONCLUSION

This assessment has considered the impacts of climate change on the operation and viability of the project, and recommended adaptation strategies.

Climate parameters are subject to a large degree of natural variability. As such, historical climate statistics for the study area have been presented to show seasonal and long-term natural variability.

Climate change projections for the study area have been presented in this assessment, based on the latest projections for Queensland's regions, prepared by QCCCE. These projections are based on Australian climate change modelling conducted by the CSIRO and BOM, and global greenhouse gas emissions scenarios developed by the IPCC. In addition we have taken projections of storm surge from Ocean Hazards Assessment (Hardy et al, 2004).

Projections for 2030, 2050 and 2070 show that temperature is expected to increase in the study area, under climate change scenarios (see Section 3.2). For other climate variables, there is large uncertainty surrounding projections. However, 'best estimate' forecasts a decrease in rainfall and, conversely, an increase in evaporation, sea-level and storm and cyclone intensities. As a result, increased drought conditions, higher storm surge and sea levels and increased frequency and intensity of bushfires can also be expected.

As the potential consequences of climate change with respect to this project cannot be predicted with certainty, the trends in impacts can be used to inform management strategies for project design and operation. The adaptation strategies recommended for each area of climate change risk are therefore presented in Table 4.1. These adaptation strategies include the design of buildings and equipment, storage/transmission/use of gas and LNG, health and safety plans, and emergency response plans. Assessment of residual risks should the climate adaptation strategy fail is considered premature. It is advised that Arrow stay abreast of ongoing refinement of climate change projections within Government and scientific communities, and consider future adaptation requirements should additional or revised risks be identified. Potential increases in costs associated with climate change should also be considered.

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Appendix A

Uncertainties in Climate Change Projections

Climate change projections presented in *Climate Change in Australia* (CSIRO & BOM, 2007) show annual average and seasonal average changes in climatic conditions. The results are presented in a probabilistic form, with 10th, 50th, and 90th percentiles provided. It is important to note that the site-specific probability distribution represents the range of model results, which were produced by climate models with inherent uncertainty for projected emission scenarios. Actual climate changes may not be within the bounds of these models' predictions.

Uncertainties in model predictions lie in how the models simulate the complicated physical and chemical processes of earth systems. Some of the processes are straightforward, but others may be too complex to simulate. Some systems may involve feedback mechanisms, and a chain of events is far more difficult to model. Climate changes may be gradual or very abrupt (such as the change in route of ocean currents). Processes may be known to scientists and hence incorporated into the existing climate models, while others may remain unidentified by scientific communities. Therefore, it is important to treat the predictions with caution.

Climate change models generally predict mean temperature changes in the most consistent way - in other words, the range of model predictions are narrow. For most other climate variables (such as rainfall, relative humidity, solar radiation, etc.), the predicted changes vary wildly among models. For example, in *Climate Change in Australia*, predicted mean temperature changes for 2030 A1B are all positive, with less than 1 °C uncertainty. In comparison, the predicted changes for rainfall, relative humidity, and solar radiation range from positive to negative, with mean model predictions near zero for the 2030 A1B scenario. Due to the large variations in the model predictions in these climate variables, the best estimate of the change is the ensemble average or multi-model mean.

Rainfall is one of the most difficult variables for climate models to predict. This is because rainfall is influenced by many different scales of weather systems, from the small-scale systems such as localised thunderstorms and tropical cyclones, to large-scale frontal systems. Global climate change models (general circulation models – GCM) are mostly run at a coarse resolution, for example 250 km, and this resolution is not fine enough to resolve small scale rainfall systems such as thunderstorms and tropical cyclones. Rainfall tends to vary locally and is impacted by local terrains, distance to the coastline, etc. Current global climate change models cannot resolve such fine geographic features. Many other climate variables suffer similar constraints. For example, solar radiation is dependent on cloud cover, which is related to predicted rainfall and other climate variables, such as relative humidity.

Appendix B

ToR Cross-Reference Table

Table B.1: Terms of Reference Cross Reference Table for the Arrow LNG Plant Climate and Climate Change Adaption

Terms of reference		PAEHolmes	
Section	EIS requirement	Technical Study Name	Technical specialist report section
3.1.1 Climate	This section should describe: ▪ Rainfall patterns (including magnitude and seasonal variability of rainfall)	Arrow LNG Plant Climate and Climate Change Adaption	Section 2.1 Rainfall
	▪ Air temperatures	Arrow LNG Plant Climate and Climate Change Adaption	Section 2.2 Temperature
	▪ Humidity	Arrow LNG Plant Climate and Climate Change Adaption	Section 2.3 Humidity
	▪ Wind (direction and speed) and	Arrow LNG Plant Climate and Climate Change Adaption	Section 2.4 Wind
	▪ Any other special factors (e.g. temperature inversions) that may affect management of the project	Arrow LNG Plant Climate and Climate Change Adaption	Section 2.5 Temperature Inversions and section 2.6 Evaporation
	▪ Historic weather patterns in the project area and seasonal conditions (e.g. cyclones, thunderstorms, floods and storms) that may influence timing and/or construction methods should be discussed, including how this would be managed.	Arrow LNG Plant Climate and Climate Change Adaption	Section 2.8 Climate Extremes
	▪ Extremes of climate (e.g. droughts, floods, etc) should be discussed with particular reference to water management at the project site.	Arrow LNG Plant Climate and Climate Change Adaption	Section 2.8 Climate Extremes
3.1.2 Climate Change Adaptation	A risk assessment of how changing patterns of rainfall and hydrology, temperature, extreme weather and sea level (where appropriate) may affect the viability and environmental management of the project	Arrow LNG Plant Climate and Climate Change Adaption	Section 4 Climate Change Impacts and Adaptation Strategies
	Preferred and alternative adaption strategies to be implemented	Arrow LNG Plant Climate and Climate Change Adaption	Section 4 Climate Change Impacts and Adaptation Strategies