4. Climate, natural hazards and climate change

Table of contents

Table index

Figure index

4.1 Overview

This chapter discusses local climate characteristics, seasonal conditions, climatic extremes, natural hazards and climate change as it relates to the Lower Fitzroy River Infrastructure Project (Project) as per Part B, Section 5.5 - 5.7 of the terms of reference (ToR) for the environmental impact statement (EIS). Flood plain management (Sections 5.8 and 5.9 of the ToR) (including a comprehensive flood study) is addressed separately in Chapter 9 Surface water resources. A table cross-referencing the ToR requirements is provided in Appendix B. A risk assessment has been undertaken and is presented in Chapter 20 Hazard and risk. Management measures relating to climate and natural hazards are used to inform the environmental management plan (Chapter 23 Environmental management plan).

4.2 Local climate and seasonal conditions

The nearest Bureau of Meteorology (BoM) station to the Project is Rockhampton Aero (station ID: 039083). Rockhampton, located approximately 60 km east of the Project area, is dissected by the Tropic of Capricorn and is characterised by a humid coastal and sub-coastal subtropical climate.

Climate statistics compiled from the BoM for Rockhampton Aero are illustrated in Figure 4-1. Analysis of the climate statistics indicates that the region experiences hot summer months from November to April. A cooler, usually dry winter period then follows from May to October. Monthly mean maximum and minimum and highest and lowest recorded temperatures are shown in Table 4-1.

The annual mean maximum temperature for Rockhampton is 28.3°C (Table 4-1). The warmest months are November to March, with mean maximum temperatures during these months ranging from 30.5°C to 32.1°C. The coolest month is July, with a mean minimum and maximum temperature of 9.5°C and 23.1°C, respectively.

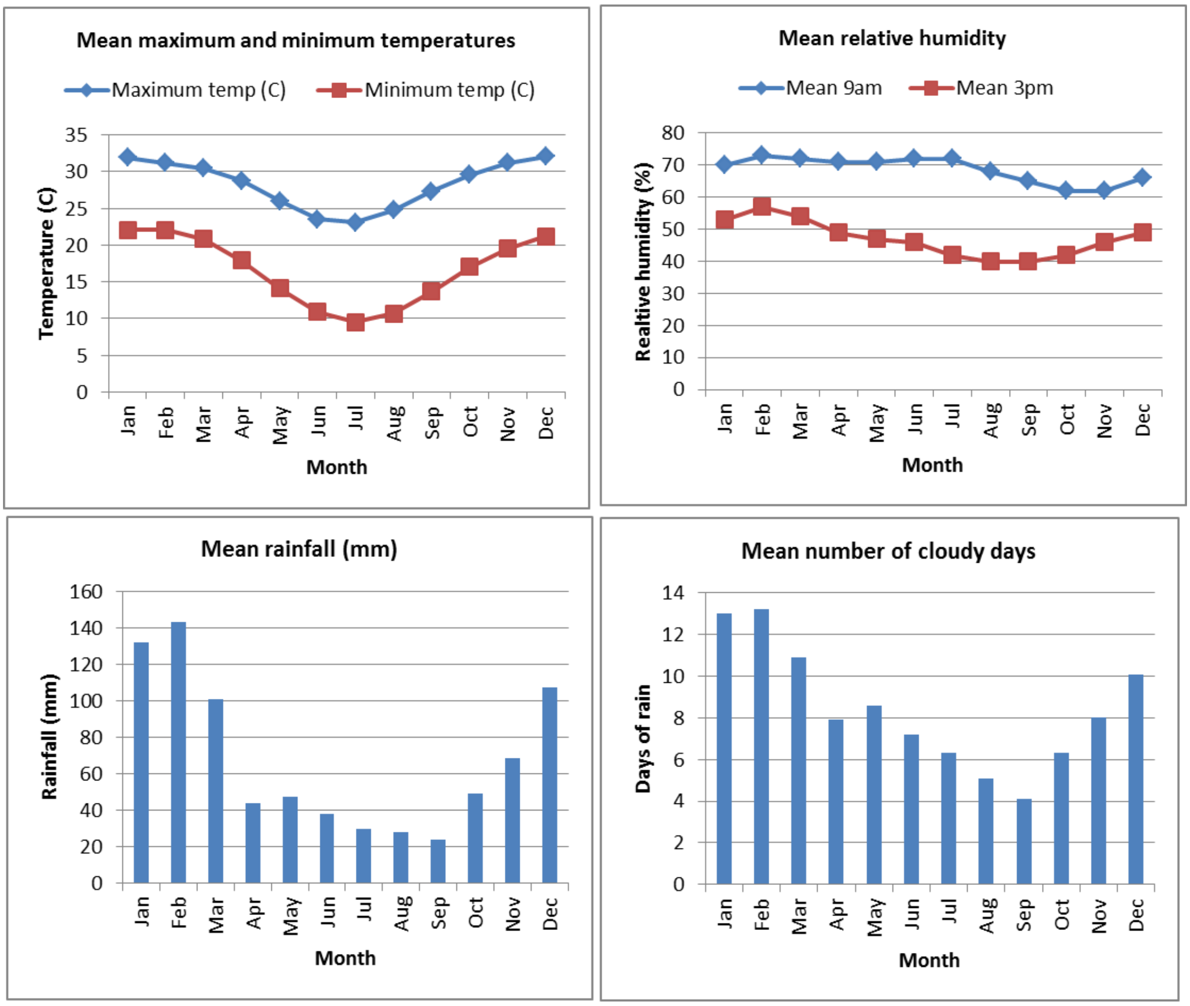
Summer rainfall months typically have a high relative humidity. Winter months have a lower relative humidity and are typically warm, mild days with cool to cold nights. Morning frosts throughout the months of May to August are common in the Project area.

Seasonal irregularity is a defining feature of the study area, with long dry spells often followed by intense wet season rainfalls. Mean annual rainfall for Rockhampton is 811.9 mm, with recorded annual totals ranging between 360 mm in 2002 to 1,631 mm in 1973 as shown in Figure 4-2. The highest daily rainfall recorded was 348 mm on 25 January 2013 and the highest monthly rainfall recorded was 660.2 mm in January 1974. Both of these events were associated with a strong, positive Southern oscillation Index (La Niña event) for Australia.

Mean daily evaporation for Rockhampton is shown in Table 4-2 and ranges from an average of 3.5 mm per day in June to 7.6 mm per day in December.

The Rockhampton area experiences winds predominantly from the south-east and east (with a frequency of around 35 to 40 per cent of the time). Average wind speeds are typically in the 10 to 20 km/h range as shown in Figure 4-3.

Figure 4-1 Climate statistics



Source: BoM 2009, Rockhampton Aero

Table 4-1 Temperature summary

Month	Mean maximum temp (°C)	Mean minimum temp (°C)	Highest recorded temp (°C)	Lowest recorded temp (°C)
January	31.9	22.1	42.5	16.3
February	31.2	22.1	43.3	16.2
March	30.5	20.8	42.1	11.0
April	28.8	17.9	35.4	4.7
May	26.0	14.1	32.6	2.9
June	23.5	10.9	32.3	-1.0
July	23.1	9.5	30.6	-0.9
August	24.8	10.7	35.1	-0.3
September	27.3	13.7	37.1	3.4
October	29.6	17.0	41.1	7.0
November	31.2	19.5	45.3	9.4
December	32.1	21.2	41.3	10.2
Annual	28.3	16.6	45.3	-1.0

Note: highest and lowest monthly mean temperatures are shown in red and blue text, respectively.

Source: BoM 2009, Rockhampton Aero

Figure 4-2 Average annual rainfall (Rockhampton)

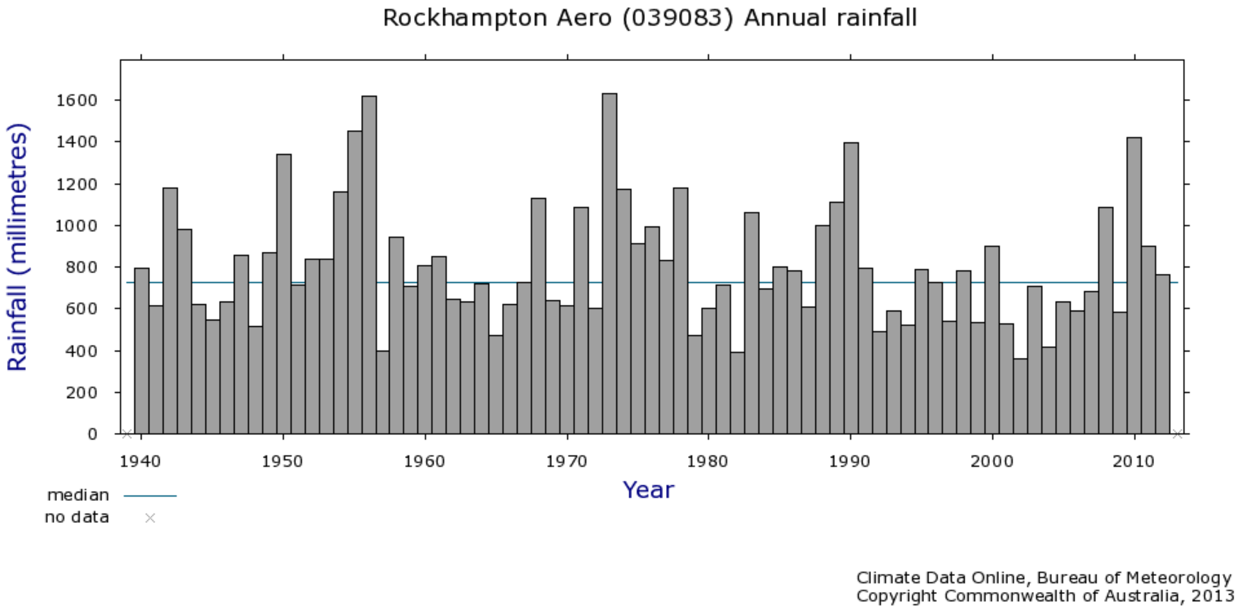
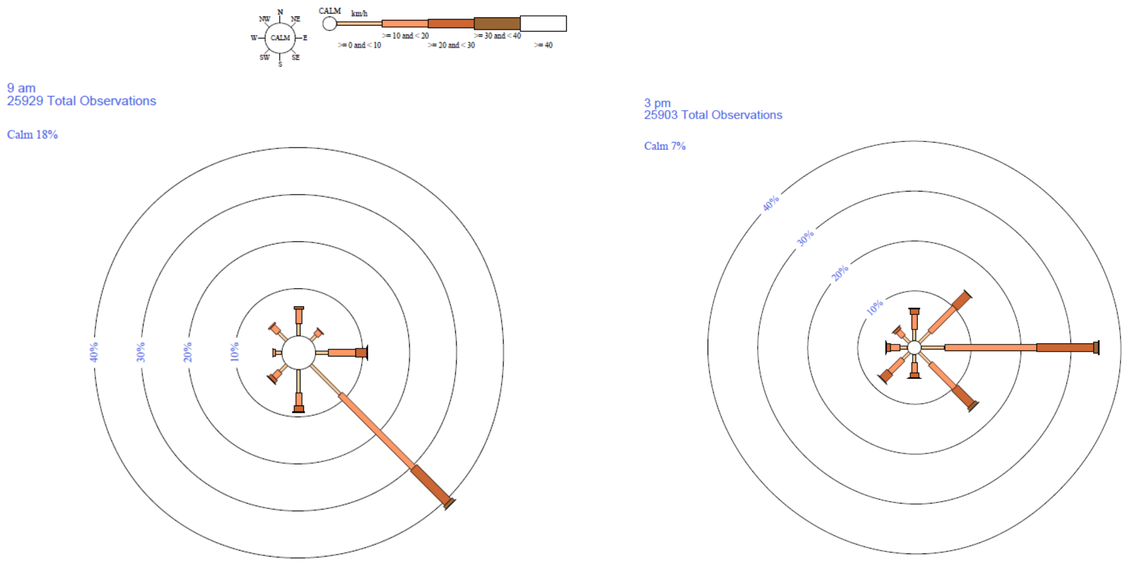


Figure 4-3 Annual wind rose 09:00 am (left) and 03:00 pm (right)



Source: Beaureau of Meterology 2009, Rockhampton Aero

Table 4-2 Evaporation summary

Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean daily evaporation (mm)	7.3	6.5	6.2	5.3	4.1	3.5	3.6	4.4	5.7	6.8	7.5	7.6	5.7

Source: BoM 2009, Rockhampton Aero

4.3 Extremes of climate and natural or induced hazards

4.3.1 Overview

This section describes the vulnerability of the Project to extremes of climate and natural or induced hazards. The potential risks these hazards pose to the Project have been addressed through design, construction scheduling and measures within the Project environmental management plan (EMP) (Chapter 23 Environmental management plan) including site layout, location and sizing of sediment basins, sediment and erosion control measures and dust suppression measures. A risk assessment detailing the potential threats to the construction and operation of the Project as a result of climatic extremes and natural or induced hazards is provided in Chapter 20 Hazard and risk.

4.3.2 Floods

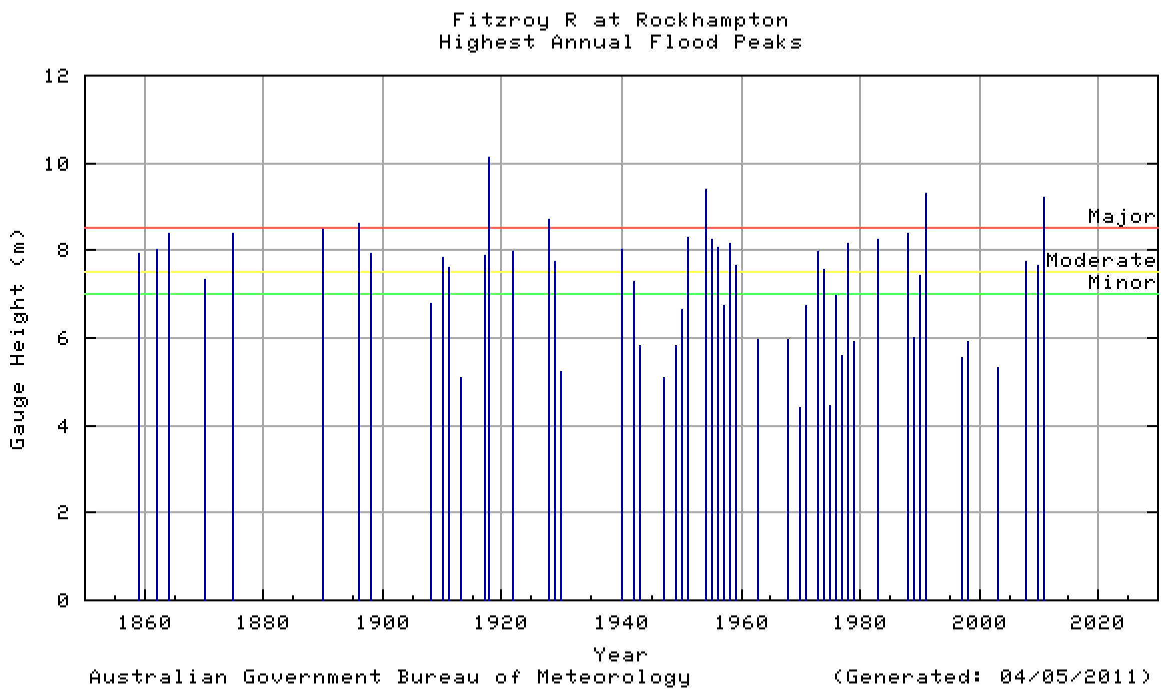
The Fitzroy Basin is described as having an immense size and fan-like shape which is capable of producing severe flooding following heavy rainfall events (BoM 2011). Its major tributaries, the Dawson, and Mackenzie rivers (including the Nogoa-Comet and Isaac-Connors systems), rise in the ranges of the Great Dividing Range and join together about 100 km west of Rockhampton. Major floods can result from either the Dawson or the Mackenzie Rivers. Significant flooding in the Rockhampton area can also occur from heavy rain in the local area below Riverslea, which is near the proposed Rookwood Weir site.

The Fitzroy River at Rockhampton has a long and well-documented history of flooding with flood records dating back to 1859. The highest flood occurred in January 1918 and reached 10.11 m on the Rockhampton gauge[1] (8.65 m AHD). In 2010/2011 the Fitzroy River reached 9.20 m on the Rockhampton gauge (7.75 m AHD) (BoM 2011) (approximately 4 m higher that the full supply level of the Fitzroy Barrage impoundment at 3.78 m AHD). More recently in late January/early February 2013, ex-Tropical Cyclone Oswald produced heavy to intense rainfall over the eastern Australian coast and resulted in major flooding of the Connors, Isaac, Mackenzie and Fitzroy rivers (amongst others). At the Rockhampton gauge, the Fitzroy River peaked at 8.60 m (BoM 2013a).

Figure 4-4 shows significant flood peaks in the Fitzroy River at Rockhampton and indicates major, moderate and minor flood peaks defined by BoM (2013a) as follows:

- **Minor flooding:** Low-lying areas next to watercourses are inundated which may require the removal of stock and equipment. Minor roads may be closed and low-level bridges submerged
- **Moderate flooding:** The area of inundation is substantial in rural areas requiring the removal of stock. Main traffic routes may be submerged and the evacuation of some houses may be required
- **Major flooding:** Extensive rural areas and/or urban areas are inundated. Properties and towns are likely to be isolated and major traffic routes likely to be closed. Evacuation of people from flood affected areas may be required.

Figure 4-4 Significant flood peaks – Fitzroy River, Rockhampton



[1] The Rockhampton gauge (Bureau station number 039264) is on the Fitzroy River at 56.6 km AMTD and the reduced level of the gauge zero is -1.450 m AHD.

In general in the region, the flood extents for the current 1 in 2 annual exceedance probability (AEP) event are typically contained within the river banks. Anabranch flows develop during the 1 in 5 AEP event. Flooding starts becoming quite extensive across the river floodplains and anabranches start to run full during a 1 in 20 AEP event. Further detail on flood hydrology and hydraulics is provided in Chapter 9 Surface water resources.

Flooding during the construction stage of the Project has the potential to:

- Damage property and partially completed structures
- Place construction personnel staff at risk
- Increase erosion resulting in unstable banks and a reduction in water quality
- Hinder access to sites.

Construction is scheduled to be undertaken around the wet seasons (Chapter 2 Project description). In dry years when construction can continue through spring and summer, activities will be primarily focussed on low risk works, such as works not in the river bed. Weather forecasts will be used to determine the risk. BoM issues regular weather forecasts as well as flood and severe weather warnings. The construction contractor will be responsible for monitoring warnings and taking actions to minimise damage during construction and, if required, evacuate site workers, plant and equipment. The construction contractor will also be responsible for ensuring that the site layout locates any immoveable and high risk items, such as fuel storage tanks and waste storage areas, outside any high flood risk areas.

The strategy for flood management during construction would be to isolate the works area via construction of coffer dams at appropriate upstream and downstream locations and installation of an in-stream diversion channel around the works. Coffer dams do not store large volumes of water and diversion strategies allow river flows to pass the construction areas.

Construction access to sites is proposed to be augmented. It is acknowledged that there may be periods that access by road is restricted as a result of flooding and the construction schedule and evacuation procedures will consider such events.

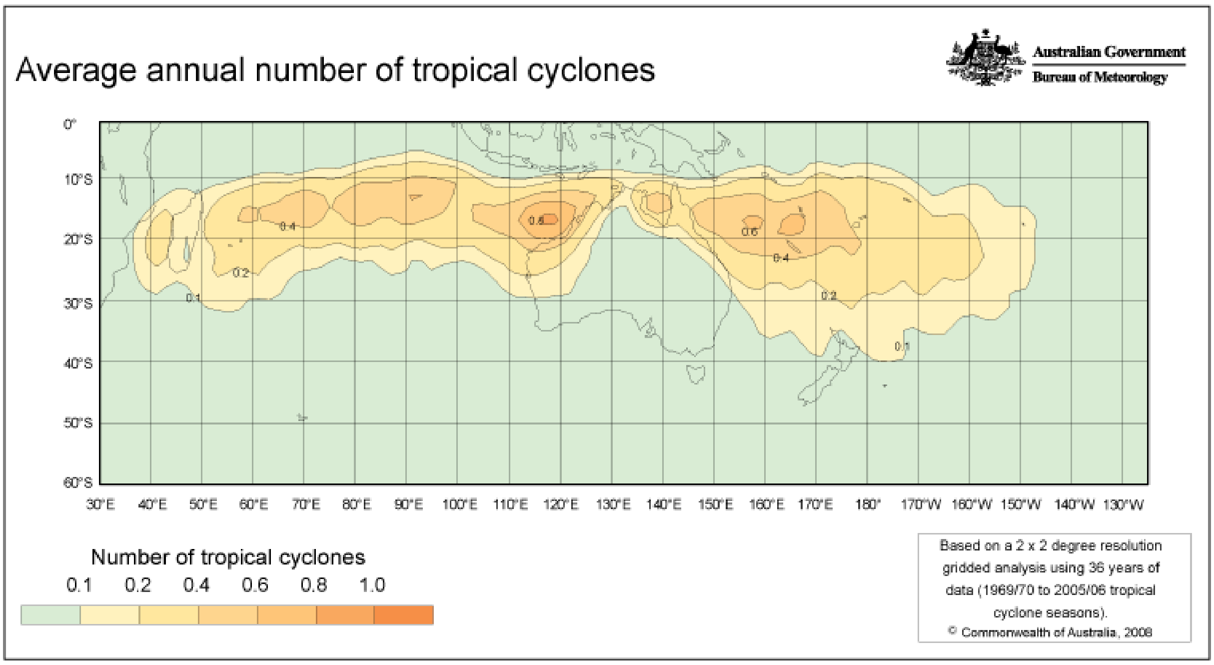
During operations, the weir operator will be responsible for monitoring floods likely to impact on the weirs and on the surrounding land use. A flood warning system is in place for the Project area and is operated by BoM. Emergency Management Plans will be developed to facilitate emergency response actions (Chapter 20 Hazard and risk). During detailed design appropriate locations and levels for permanent site facilities (such as control rooms) will be determined. Flooding is discussed further in detail in Chapter 9 Surface water resources.

4.3.3 Tropical cyclones

Tropical cyclones are defined as low pressure systems that form over warm tropical waters and have well defined wind circulations of at least gale force strength (sustained winds of 63 km/h or greater with gusts in excess of 90 km/h). The Project area is located within the Australia Eastern Region for cyclone activity. The cyclone season occurs each year from November through to April although cyclones are known to occur outside of this period. Strong winds, heavy rains, flooding and storm surges can be associated with cyclone activity.

Figure 4-5 shows the average number of tropical cyclones through the Australian region and surrounding waters based on a 36 year period from the 1969/70 to 2005/06 tropical cyclone season (BoM 2013b).

Figure 4-5 Average annual number of tropical cyclones (1969/70 – 2005/06)



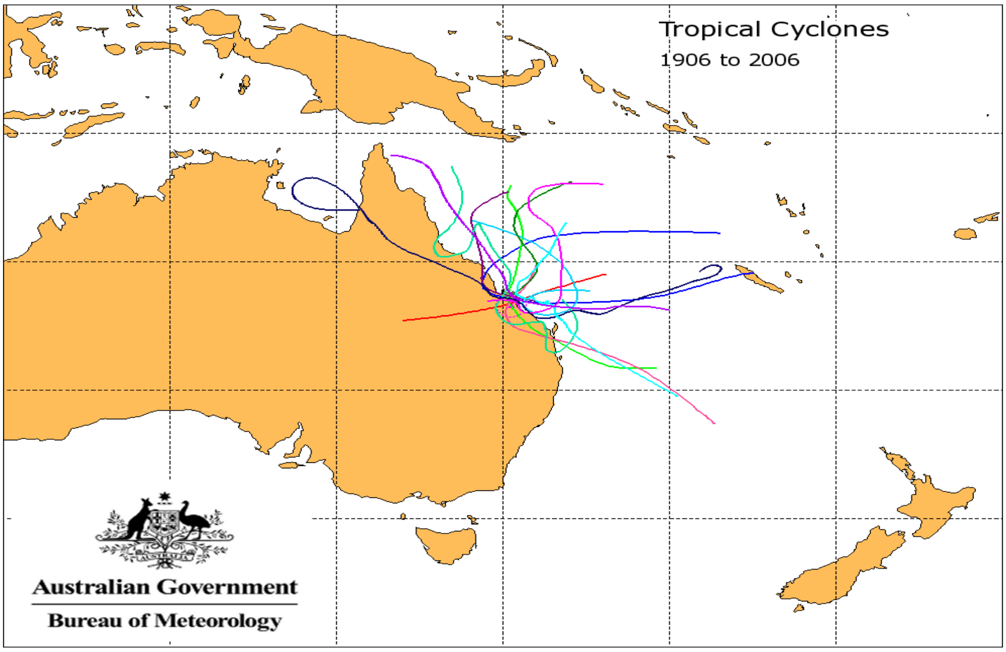
For the period 1906 to 2006, 42 cyclones have been recorded crossing within 200 km of Rockhampton. Of these, 12 cyclones were recorded crossing within 100 km of Rockhampton as shown in Figure 4-6. Five of these occurred in February, two in January and one in December, March, April, May and June. One unnamed cyclone passed within 50 km of Rockhampton in February 1949. In more recent times (early 2013), ex-tropical Cyclone Oswald produced heavy rainfall and flooding in the Project areas.

Tropical cyclones influencing the Project area have the potential to result in strong winds, heavy rain and flooding. Similar to flooding above, strong winds during construction and operation have the potential to:

- Damage property and temporary and permanent structures
- Place construction personnel at risk
- Increase dust generating activities during dry ambient conditions.

Strong wind conditions during construction will be further considered and managed through the implementation of a construction environmental management plan. The operations control building has been defined as an Importance Level 4 structure that is ‘buildings or structures that are essential to post-disaster recovery or associated with hazardous facilities’ (Australian Standard 1170.0 - 2002 Structural design actions – Part 0: General principles). The control building has a design wind speed for a 1:2,000 AEP event. Further detail is provided in Chapter 20 Hazard and risk.

Figure 4-6 Recorded tropical cyclones within 100 km of Rockhampton (1906-2006)



4.3.4 Severe storms

Severe storms are localised events usually affecting smaller areas than tropical cyclones. A severe thunderstorm is defined by the BoM (BoM ND) as one which produces: hail with a diameter of 2 cm or more; wind gusts of 90 km/h or more; flash floods; tornadoes or any combination of these.

Severe storms in the region are generally confined to the spring and summer months (FSC and RCC 2007) and occur on average at least twice per year (Aurecon 2012). The effects of storms are usually localised and may include damage from torrential rain and flash flooding, high wind, hail and lightning which pose a risk due to economic loss and fatalities. Flash flooding from these events can be quite damaging, for example rainfall intensities of 600 mm in 56 hours were recorded in Yaamba in 1994 and 200 mm in 3 hours in Rockhampton in 2008 (Aurecon 2012). These rainfall events were equivalent to 100 year to 150 year average recurrence interval (ARI) events.

The average thunderstorm in the Rockhampton area has an 8 km wide front and a path up to 64 km long. The highest recorded wind speed in Rockhampton is 159 km/h for a severe storm in November 1971 and this compares to recorded wind speeds of 161 km/h during the tropical cyclone from the 7 to 16 February 1949 (Aurecon 2012).

As for tropical cyclones (Section 4.3.3), severe storms have the potential to result in flooding and strong winds. Power and communications to the weir sites may be disrupted during severe storms. Back-up power is proposed to be installed sufficient to operate the weir and provide capacity for communications and telemetric operations. Consistent with the management of impacts from flooding and strong cyclonic winds, severe storm conditions will be considered further and addressed in planning and design and will be managed through the implementation of EMPs during construction and operation.

4.3.5 Drought

Like much of Central Queensland, the Project area frequently experiences drought conditions, the most recent being between 2000 and 2007. Hydrographs presented in Chapter 9 Surface water resources show that during drought conditions, wet season flows were sustained at a similar magnitude to those occurring historically but over a shorter period of the season, whilst dry season flows generally decreased throughout the season.

Project demand triggers may arise as result of drought conditions in the region (Chapter 1 Introduction). Yield estimates for the Project and the influence that drought may have on yield are discussed in Chapter 9 Surface water resources.

4.3.6 Extreme temperatures

Maximum temperatures in Queensland typically occur between November and February but days of excessive heat have been known to occur anytime between October and March (Aurecon 2012). Using the threshold for temperature within the top five per cent of daily maximum temperatures for a continuous three-day period, Queensland has experienced at least 18 heatwave events since 1899 giving an ARI of five to six years (Aurecon 2012). Of these, ten occurred in January, three in December, two in March, two in November and one in February. The highest temperature recorded was 45.3 ºC in November 1990. Monthly mean maximum and minimum and highest and lowest recorded temperatures are shown in Table 4-1.

The preparation and implementation of workplace health and safety procedures would reduce the risk to site staff of dehydration, heat stroke and sunburn. Appropriate design standards will facilitate functionality of operational components, for example the operational control building is fitted with appropriate air-conditioning to protect electrical equipment.

Extreme cold temperatures are not considered a hazard in the region with the lowest average minimum temperature being 9.5 °C (Table 4-1).

4.4 Climate change

4.4.1 Overview

The Queensland Climate Change Centre of Excellence (QCCCE) predicts that Queensland’s climate will experience greater variability with more extreme events in the future (QCCCE 2009). Climate change has the potential to impact on water infrastructure projects through changes in mean and peak stream and river flows and uncertain water availability (QCCCE 2009).

The climate change projection data in this report have been extracted from the Climate Change in Australia Technical Report (CSIRO and BoM 2007) with the regional summaries for Central Queensland prepared by the QCCCE using the same data source (QCCCE 2009).

Projections are given relative to the period 1980-1999 (referred to as the 1990 baseline for convenience). The projections give an estimate of the average climate around 2070, taking into account consistency among climate models. Individual years will show variation from this average. The 50th percentile (the mid-point of the spread of model results) provides a best estimate result. The 10th and 90th percentiles are given as a guide to the uncertainty range. Emissions scenarios are from the Intergovernmental Panel on Climate Change (IPCC 2000) Special Report on Emission Scenarios with low emissions being the B1 scenario, medium emissions the A1B scenario and high emissions the A1FI scenario.

Projected changes for 2050 and 2070 are increasingly dependent on the emissions scenario chosen (CSIRO and BoM 2007). The common timeframes used for climate change projections are 2030, 2070 and 2100. Based on a 100 year design life of the Project, the projections for the climate change assessment presented below are based on the year 2070.

4.4.2 Approach and methodology

The methodology used to assess the potential vulnerability of the Project to the impacts of climate change involved:

- A literature review of publicly available climate change projections for Central Queensland
- A review of literature regarding the vulnerability of water infrastructure and catchment scale processes to the impacts of climate change
- A review of government policies and standards relating to climate change adaptation
- An internal Project team workshop to assess potential impacts on the Project from climate change and to identify where adaptation methods may need to be implemented or investigated in the design of the weir infrastructure, or associated Project studies, to minimise any identified climate change impacts. The workshop specifically considered rainfall, evaporation, temperature, extreme weather and sea level rise in accordance with the Queensland Government Climate Change Impact Statement guidelines (QOCC 2008a) for projects expected to exist beyond 2070.

Details relating to the timeframe, scenario and source of the information regarding climate change projections for the Rockhampton region are included in this report. Climate change projections are based upon assumptions about events and circumstances that have not yet transpired and accordingly, there is no assurance that projections are representative of the situation that will actually occur.

4.4.3 Projections

4.4.3.1 Rainfall, temperature and evaporation

Rainfall is dependent on what happens to the general atmospheric circulation, and thus not all climate models agree on whether rainfall is likely to decrease or increase (QOCC 2008b). The estimates show a general reduction in rainfall in Central Queensland of ten per cent, but there is a range in projected change as shown in Table 4-3.

There is more variability in rainfall projections than temperature projections as there is more of a direct link between greenhouse gas concentrations and temperature (CSIRO and BoM 2007). Across Queensland, annual average temperatures are projected to increase, with inland areas expected to warm more rapidly than the coastal areas (QOCC 2008b). The average number of hot days (over 35°C) is expected to increase as is annual, summer and winter potential evaporation.

The rainfall, temperature and evaporation projections for the Central Queensland region for 2070 using the high emissions (A1FI) scenario are summarised in Table 4-3. The current/historical conditions for Rockhampton and resulting conditions at that site taking the best estimate (50th percentile) climate change projections for the region into account are also presented.

Table 4-3 Climate change projections summary for Central Queensland

Climate variable		Current / historical conditions (Rockhampton Aero*)	Climate change projection 50th (10th and 90th) percentile^	Projected 2070 conditions (50th percentile)
Rainfall	Mean annual rainfall	811.9 mm	-10% (-35 and +17%)	730 mm
	Mean summer rainfall	381.8 mm	-5% (-34 and +26%)	363 mm
	Mean winter rainfall	95.8 mm	-14% (-45 and +25%)	82 mm
Temperature	Annual mean maximum temperature	28.3°C	+3.2 °C (+2.2 and +4.5 °C)	31.5°C
	Summer mean maximum temperature	31.9°C	+3.2 °C (+2.0 and +4.7 °C)	35.1°C
	Winter mean maximum temperature	24.8°C	+3.1 °C (+2.1 and +4.5 °C)	27.9°C
	Mean annual number of hot days (over 35°C)	17.6 days	+46 days (+24 and +82 days)	63.6 days
Evaporation	Mean annual daily evaporation	5.7 mm	+10% (+7 and +15%)	6.3 mm
	Average summer daily evaporation	7.1 mm	+10% (+5 and +15%)	7.8 mm
	Average winter daily evaporation	3.8 mm	+12% (+7 and +19%)	6.3 mm

* All years of data (1939 – 2013) (BoM 2013)

^ Source QCCCE 2009

4.4.3.2 Extreme climatic events

The Fitzroy Basin is located in an area prone to flooding, cyclones, severe storms, drought and extreme temperatures (heatwaves) (Section 4.3). Studies have shown that future precipitation regimes may have longer dry spells interrupted by heavier precipitation events (CSIRO and BoM 2007). The peak intensity of tropical cyclones may increase by five to ten per cent and precipitation rates may increase by 20 to 30 per cent (CSIRO and BoM 2007). It is expected that as global climate models develop, the simulation of tropical cyclones will improve. These improvements will lead to a greater certainty in projections of tropical cyclone changes in the future (CSIRO and BoM 2007).

4.4.4 Potential impacts and adaptation strategies

A literature review was conducted to identify potential climate change impacts relevant to water infrastructure projects across Australia including both direct impacts on water infrastructure, as well as potential cumulative impacts on ecosystems (Table 4-4).

Table 4-4 Potential impacts associated with climate change for water infrastructure projects across Australia

Climate variable	Potential impacts
Rainfall changes and increases in potential evaporation	• Reduced (and/or inconsistent) yield as a result of: – A decrease in overall rainfall and higher evaporation rates[1, 2, 3, 4] – Increased variations in wet and dry spells and an increase in the proportion of total rainfall from heavy falls[2] • Reduced river flows exacerbated by competition with the needs of agriculture and settlements leading to alteration in quality and quantity of detritus flowing downstream leading to disruptions in detritus based food webs[5] • Changes in total suspended solids[6] • Beneficial use of water storages as an option for managing future water needs (water supply and environmental flows) and mitigating against drought[7]
Temperature and solar radiation increases	• Impacts of bushfires on water quality and increased silt levels[1, 4] • Higher average and maximum temperatures leading to increased evaporation [1] • Lower flows and higher temperatures may also reduce water quality within the catchment. For example resulting in elevated nutrients and creating an environment for potentially harmful algal blooms[3, 4] • Increase in water temperature leading to impacts on temperature sensitive species such as algae[6] • Reduction in depth of lowest oxygenated zones in some cases, leading to local extinction of some fish and other vertebrates[5] • Longer lived plants such as trees may be vulnerable if climate change ‘moves’ suitable establishment sites for seedlings beyond seed dispersal distance at a rate exceeding generation time[5].
Extreme events (increases in extreme daily rainfall, winds and hot days)	• Effects of flooding on storage and spillway capacity[1] • Increase in frequency and intensity of storms[2] • Increased flooding will affect the movement of nutrients, pollutants and sediments, riparian vegetation and erosion[5].

Sources: [1]Australian Academy of Technological Sciences and Engineering 2008, [2]CSIRO 2007a, [3]CSIRO 2007b, [4]Cobon and Toombs 2007, [5]Steffen et al. 2009, [6]Cobon et al. (2007), [7]Water Services Association of Australia 2013.

Table 4-5 summaries the assessment of climate change risks and benefits relating to the Project. Options for adaptation are identified for different phases of the Project so that the Project can withstand impacts associated with future climate change predictions.

Table 4-5 Climate change impact and adaption summary

Potential impacts	Adaptation or benefit	Area for consideration
Increased temperatures, increased evaporation and reduced rainfall		
Cost recovery of the infrastructure may be altered if yield decreases.	Relevant Integrated Quantity and Quality Model developed by the Queensland Department of Science, Information Technology, Innovation and the Arts has been used for yield assessment. Development to be staged in response to actual demand triggers. Staging will allow for economic assessment based on available yield and demand. Undertake sensitivity analysis for various climate change scenarios.	Planning and design phase - yield assessment and economic assessment Detailed design phase
Increased demand for water resources.	Water storages can be used to manage future water supplies and will mitigate against drought. Development to be staged in response to actual demand triggers. Staging will allow for economic assessment based on available yield and demand.	Planning and design phase - Project strategy
Increase in intensity of rainfall events		
Increased extent and duration of flooding.	Modelling undertaken with different rainfall and peak flow scenarios to test the sensitivity to changes in rainfall intensity (Chapter 9 Surface water resources). Modelling has been used to inform design parameters used for the Project infrastructure. Failure impact assessments undertaken for weir infrastructure and reviewed at five yearly intervals in accordance with the *Water Supply (Safety and Reliability) Act 2008*.	Planning and design phase - hydraulic and hydrological modelling. Operational phase

4.5 Summary

The Rockhampton region experiences hot summer months from November to April followed by a cooler, usually dry winter period from May to October. Seasonal irregularity is a defining feature of the study area, with long dry spells often followed by intense wet season rainfalls. The Fitzroy River has a long and well-documented history of flooding. Major floods can result from either the Dawson or the Mackenzie Rivers although significant flooding in the Rockhampton area can also occur from heavy rain in the local area below Riverslea.

The Project area is located within Australia Eastern Region for cyclone activity and the cyclone season occurs each year from November through to April. The region also experiences severe storms which occur on average at least twice per year during spring and summer months. Like much of Queensland, the Project area frequently experiences drought conditions, the most recent being between 2000 and 2007.

Predicted increased temperatures, increased evaporation and reduced rainfall as a result of climate change may impact catchment yields. Staging the development will allow the Project to respond to actual demand over time taking into account climate variation, economic considerations and Government policy, planning instruments and guidelines based on circumstances at the time. Water storages are likely to become more important for the purpose of water supply, mitigating drought and for maintaining environment flows as climate change impacts are realised.