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Gladstone Ports Corporation

Report for Western Basin Dredging & Disposal Project

Climate & Climate Change Assessment

September 2009

INFRASTRUCTURE | MINING & INDUSTRY | DEFENCE | PROPERTY & BUILDINGS | ENVIRONMENT

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Executive Summary

The impacts of climate change are likely to affect many infrastructure projects with a projected lifespan greater than 30 years. This report provides an assessment of the Western Basin Dredging and Disposal Project's (the Project) vulnerabilities to climate change.

This assessment of climate change vulnerability was focused on the construction of the Western Basin Reclamation Area, adjacent to the proposed Fisherman's Landing Northern Expansion and the existing port facility at Fisherman's Landing in Gladstone, Queensland. The reclamation works will involve the construction of bund walls to define the boundary of the new development and infilling using material dredged for navigation purposes. The potential vulnerability of any specific facilities to be built on the reclaimed area of land is not assessed in this report. It is expected that climate change risks associated with the construction and operation of these facilities will be considered by the future proponents through separate assessment requirements.

Current plans and guidelines for incorporating the impacts of climate change into project planning were identified, including the State Coastal Management Plan (currently under review), the Queensland Office of Climate Change - EPA Guidelines for Preparing a Climate Change Impact Statement (CCIS), ECOaccess Guidelines Operational Policy Coastal Development - Building and engineering standards for tidal works, and the Australian Standard 4997-2005 Guidelines for the design of maritime structures.

The current climate, and future projected climate change variables for the Gladstone region were summarised, taking into account that research presented by Rahmstorf *et al*. (2007) shows that observed carbon dioxide concentration, global mean temperatures and sea level rise have been tracking at the upper end of the Intergovernmental Panel on Climate Change (IPCC 2000) scenario range from 1990 to 2006. Therefore, projections based on the mid and low IPCC scenarios for later in the 21st century may be less likely than those based on the high emissions scenarios (CSIRO 2007).

Using the figures from a study of storm surge plus tide levels during tropical cyclones along the Queensland coast (Hardy *et al.* 2004), future 2%, 1%, 0.2% and 0.1% annual exceedance probability (AEP) storm surge plus tide levels for the Western Basin site were developed. These levels were developed for the years 2030, 2050, 2070 and 2100, using the high range IPCC AR4 sea level rise projections for each year derived by Hunter (2008). From these calculations, it was demonstrated that, by 2100, a level that currently has a 0.1% annual probability of being exceeded, could have a future 1% AEP. This is equivalent to a '1 in 1000' year event becoming a '1 in 100' year event in this region.

The following table summarises selected available information relating to climate change variables for the Gladstone region. Projections based on high emissions scenarios have been included in this table where available as detailed in the' Scenario/Info' column.

Table 1 Summary of Climate Change Projections for the Gladstone Region

Climate Variable	Current/ Historical Conditions	Source	Climate Change Projection	Scenario / Info	Source
Rainfall/ Runoff	Annual average rainfall: 880 mm	(BoM)	-70%	2070 A1FI emission scenario GFDL-CM2.1 Global Climate Model with high climate sensitivity (IPCC 2007 global warming values)	(CSIRO - OzClim 2009 *Build Number 3.1.05, 26 Jun 2009*)
Air Temp	Annual mean max temp: 27.7°C Annual mean min temp: 21.9°C	(BoM)	Average temp increase: 3.0°C	2070 High emissions (A1FI) scenario Mid range model result (Data for Rockhampton)	(QOCC 2008b)
	Annual average number of hot days (over 35°C): 4.5	(BoM)	Increase in number of days over 35°C : +65 days	2070 High emissions (A1FI) scenario Mid range model result (Data for Rockhampton)	(CSIRO cited in QOCC 2008b
Wind (daily wind climate)	Average 9 am wind speed: 14.2km/h Average 3 pm wind speed: 20.7km/h	(BoM)	Annual 10m wind speed variations: (-2 to +15%)	2070 High emissions (A1FI) scenario (model output range)	(CSIRO 2007)
Sea Level	HAT for Western Basin: 2.54 m, AHD	GHD Design Criteria	Global mean sea level rise: +0.278 m	2050 Estimate of maximum global sea level rise relative to 1980 – 1999 using high emissions (A1FI) emissions scenario	(Hunter 2008, after IPCC 2007)
			Global mean sea level rise: +0.471 m	2070 Estimate of maximum global sea level rise relative to 1980 – 1999 using high emissions (A1FI) emissions scenario	
			Local projected departure from global mean sea level rise: +0.02m	2070 Mid emissions scenario (A1B)	(CMAR 2008)
Tropical Cyclones	Tropical cyclones in the Gladstone region have caused local wind extremes up to 156 km/h (19 Jan 1976)	(BoM)	- likely *increase* in the proportion of cyclones in the more intense categories -possible *decrease* in the total number	Based on projections produced by 3 studies in the Australian region.	(CSIRO 2007)

Climate Variable	Current/ Historical Conditions	Source	Climate Change Projection	Scenario / Info	Source
Storm Surge + Tide	2% AEP : approx 2.91 m, AHD	(Hardy et al. 2004, p.44 – adjusted for Western Basin site and additional non-cyclonic events)	3.40 m AHD 3.52 m AHD	2% AEP storm surge plus tide 2070 SLR only 2070 SLR + 10% increase in cyclone MPI	(Calculated from Hardy et al. (2004, p.54), and Hunter (2008), after IPCC (2007))
	1% AEP: approx 3.04 m, AHD		3.53 m AHD 3.78 m AHD	1% AEP storm surge plus tide 2070 SLR only 2070 SLR + 10% increase in cyclone MPI	
	0.2% AEP: approx 3.72 m, AHD		4.21 m AHD 4.62 m AHD	0.2% AEP storm surge plus tide 2070 SLR only 2070 SLR + 10% increase in cyclone MPI	
	0.1% AEP: approx 4.03 m, AHD		4.52 m AHD 4.97 m AHD	0.1% AEP storm surge plus tide 2070 SLR only 2070 SLR + 10% increase in cyclone MPI	

Using information provided in *Guidelines for Responding to the Effects of Climate Change in Coastal and Ocean Engineering* (Engineers Australia 2004), potential impacts associated with effects of climate change on the Western Basin Project were assessed. The main climate variables that were flagged as having the most significant potential impact were sea level rise and associated increase in storm surge.

Adaptation measures were highlighted for the design of the revetment rock armour, including incorporating an allowance for sea level rise corresponding to the approximate 'high level' mean sea level rise projections for 2050. It was also noted that the rock armour protection that is likely to be adopted at the reclamation is based on a dynamic design. The rock armour, therefore, will move to create a stable profile over its lifetime and may require some maintenance and possibly replenishment of the rock armour in places. Due to the dynamic design of the rock armour that is proposed, the maintenance regime would potentially be able to adapt the volume of the rock armour to maintain design specifications if required.

The individual acceptable level of risk will vary depending on the type of facilities that are constructed on the Reclamation Area, and these will need to be assessed on a case-by-case basis by the future proponents.

1. Introduction

In 2007 the Intergovernmental Panel on Climate Change (IPCC) released its fourth assessment report (AR4) which stated that "warming of the climate system is now unequivocal". Changes in the global climate system as a result of this warming are likely to result in:

- Fewer cold days and nights and an increased frequency of heat waves over most land areas;
- An increase in the proportion of total rainfall from heavy falls;
- An increase in area effected by drought;
- Increased intensity of tropical cyclones; and
- Increased average sea levels leading to increased incidences of extreme high sea level.

Increases in global average air and ocean temperatures and rising global average sea level are already evident from observations during the late twentieth century. For example, over the period from 1961 to 2003, global average sea level rose at a rate of 1.8 (1.3 to 2.3) mm per year and during the period from 1993 to 2003, the rate was faster at approximately 3.1 (2.3 to 3.8) mm per year (IPCC 2007).

The impacts of climate change are likely to affect many infrastructure projects with a projected lifespan greater than 30 years and therefore an assessment of this Project's vulnerabilities to climate change is included in this report.

1.1 Scope of Assessment

This assessment of climate change vulnerability was focused on the construction of the Western Basin Reclamation Area (known hereafter as the study area), adjacent to the proposed Fishermans Landing Northern Expansion and the existing port facility at Fisherman's Landing in Gladstone, Queensland. The reclamation works will involve the construction of rock armour revetment walls to define the boundary of the new development and infilling using material dredged for navigation purposes. The potential vulnerability of any specific facilities to be built on the reclaimed area of land, or berths to be built adjacent are not assessed in this report. It is expected that climate change risks associated with the construction and operation of these facilities will be considered by the future proponents through separate assessments.

1.1.1 Disclaimer

Climate change is an emerging issue and the effects are, at this stage, difficult to quantify but reasonable assumptions have been made as set out in this report. The details relating to the timeframe, scenario and source of the information are included in Section 3 of this report, Climate Change Projections for the Gladstone Region. GHD has prepared this report on the basis of information available as at the date of this report. Where this report refers to information from third party sources, GHD has not verified that information. Climate change projections are based upon assumptions about events and circumstances that have not yet transpired. Accordingly, GHD cannot provide any assurance that the projection is representative of the situation that will actually occur. This report is not for use by any related or third party or for any other project. The information and recommendations are to be read and considered as a whole and the content is not to be used selectively as this may misrepresent the content of the report and provide erroneous project or decision outcomes.

1.2 Methodology

In order to perform an assessment of the potential vulnerability of the study area to the impacts of climate change, the following methodology was used:

- Review policies and guidelines relating to the impacts of climate change on projects;
- Conduct a literature review of the latest climate change projections for the Gladstone region and compare these with existing climatic conditions;
- Identify aspects of the study area that may be affected by climate change; and
- Identify adaptation methods that may be implemented in the design of the revetment to minimise the identified climate change impacts or risks.

2. Background on Climate Change Adaptation

The Intergovernmental Panel on Climate Change (IPCC 2000) defined a number of different emissions scenarios which are used to estimate inputs for global climate models to produce climate change scenarios. These emissions scenarios were defined in the Special Report on Emissions Scenarios and are referred to as the SRES scenarios. The SRES scenarios are based on a range of driving forces of future emissions such as changes in demographics, technology and economics. The main scenarios referred to in this report are the high impact A1FI, medium impact A1B and the low impact B1 scenarios. The A1FI scenario is based on a future world with rapid economic growth and a population that peaks in the mid-century and then declines thereafter with a rapid introduction of new technologies, that are fossil fuel intensive. The A1B scenario is similar to A1FI, except that the new technologies are balanced across fossil fuel and non-fossil fuel energy sources. The B1 SRES scenario differs in that there is a strong focus on clean technologies that are resource efficient.

Research presented by Rahmstorf *et al.* (2007) shows that observed carbon dioxide concentration, global mean temperatures and sea level rise have been tracking at the upper end of SRES scenario range from 1990 to 2006. Therefore, projections based on the mid and low SRES scenarios for later in the 21st century may be less likely than those based on the high emissions scenarios such as A1FI (CSIRO 2007).

2.1 Planning Instruments and Guidelines

Requirements to assess potential risks associated with climate change on development projects, and to implement adaptation strategies, are included in many planning instruments and guidelines as summarised below.

State Planning Policy 1/03 Mitigating the Adverse Impacts of Flood, Bushfire and Landslide

This policy states that, in accordance with the precautionary principle, the projected impacts of climate change such as changes in rainfall, sea level rise, coastal erosion and increased flood risk should be taken into account when undertaking natural hazard assessments. The United Nations Environment Programme Rio Declaration defines the precautionary principal as '*Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.'* (UNEP 1992).

State Coastal Management Plan and the Curtis Coast Regional Coastal Management Plan

Specific approaches to climate change adaptation are set out in the *State Coastal Management Plan* and the *Curtis Coast Regional Coastal Management Plan.* The approaches covered by the existing plans are:

- Avoid – focus on locating new developments in areas not vulnerable to the impacts of climate change;
- Planned retreat – focus on systematic abandonment of land, ecosystems and structures in vulnerable areas;
- Accommodate – focus on continued occupation of near-coastal areas but with adjustments such as altered building design; and
- Protect – focus on the defence of vulnerable areas, population centres, economic activities and coastal resources.

It should be noted that these plans are currently being reviewed by the Queensland Government and are expected to be replaced by the Queensland Coastal Plan. Although the Queensland Coastal Plan is still under development, the sea level rise figures referenced by the plan are noted in the recently released South East Queensland Regional Plan (QDIP 2009). These figures are:

- For land not already subject to a development commitment, a sea level rise of 0.8m by 2100 is to be taken into account.
- For land already subject to a development commitment, the following projected sea level rises are to be taken into account:
  - 2050 0.3m
  - 2060 0.4m
  - 2070 0.5m
  - 2080 0.6m
  - 2090 0.7m
  - 2100 0.8m

QLD EPA - ECOaccess Guidelines Operational Policy – Coastal Development - Building and engineering standards for tidal works

This policy provides the minimum building and engineering criteria for tidal works approved under the *Integrated Planning Act 1997* and states that design water levels must include an allowance for greenhouse sea level rise of 0.3m. This level is also expected to be updated following the review of the State Coastal Management Plan.

Australian Standard 4997-2005 Guidelines for the design of maritime structures

The Australian Standard 4997-2005 guidelines for the design of maritime structures currently includes a requirement for the design of maritime structures to incorporate sea level rise factors for different structure design lives (shown in Table 2 below). The AS 4997-2005 guideline states that the allowance for sea level rise does not necessarily include the construction facilities at a higher level, although in some cases this may be prudent. Allowance for sea level rise may include options to make future adaptations such as raising the heights of restraining piles on floating structures at a later time, or installing substructure of adequate strength to permit future topping of slabs etc.

Table 2 AS 4997-2005 Sea Level Rise Factors

Design Life	Sea Level Rise
25 years	0.1m
50 years	0.2m
100 years	0.4m

The sea level rise values for the AS 4997-2005 standard were based on *mid-range* scenarios from the 2001 IPCC Third Assessment Report (TAR)*Climate Change 2001 - the Scientific Basis.*

QLD Office of Climate Change - EPA Guidelines for Preparing a Climate Change Impact Statement (CCIS)

From 1 July 2008, a CCIS became a required inclusion in all submissions to Cabinet. The CCIS is intended to provide cabinet with specific information in relation to future climate change risks associated with proposals (QOCC 2008a).

The climate change risks that are included in the assessment relate to increased temperatures, increased variability of rainfall, increased extreme weather events and sea level rise. In relation to sea level rise, the guideline for undertaking a climate change adaptation assessment as part of a CCIS includes the following sea level rise figures.

Table 3 CCIS Sea Level Rise Parameters

Expected Life of Proposal	Assess the Impact of the Following Sea Level Rise on the Proposal
2015 and up to 2030	0.17 m
between 2031 and 2070	0.49 m
beyond 2070	0.79 m

These sea level rise figures have been based on the projected global average mean sea level increases for 2100 reported in the IPCC (2007) Fourth Assessment Report (AR4), adjusted, in accordance with advice from CSIRO, to reflect the shorter timescales used in the climate change adaptation assessment. The sea level rise figure for projects expected to exist beyond 2070 is based on the IPCC (2007) *upper estimate* of the high emissions (A1FI) scenario for 2100 (0.59m) with the additional 0.2 m from additional ice melt included (QOCC 2008a).

2.2 Current and Historical Climate for the Gladstone Region

Gladstone is situated on the Queensland coast approximately 500 km north of Brisbane and 100 km south-east of Rockhampton. The climate figures used below have been sourced from the Bureau of Meteorology 'Gladstone Rader' observation site (BoM 2009a).

2.2.1 Rainfall

Average annual rainfall for Gladstone is 880 mm with the majority of rainfall occurring during the summer months. The highest monthly rainfall recorded was 709.8 mm in 1971 and the highest daily rainfall recorded was 284 mm on 5 February 2005. Mean monthly and annual rainfall as well as highest (denoted by red text) and lowest rainfall (denoted by blue text) are summarised in Table 4.

Table 4 Rainfall Summary – BoM Gladstone Radar (1957 – Jul 2009)

Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean rainfall (mm)	143.4	143.4	82.6	46.2	60.5	39.4	35.2	32.4	26.5	62.3	74.2	128.8	880
Highest rainfall (mm)	640.1	709.8	311.6	250.4	316.4	220.3	170.2	141.6	89.6	276.8	218.1	508.9	1731.6
Lowest rainfall (mm)	0.4	7.2	2.4	3.8	0.2	0	0	0	0	0.4	1.4	2.8	432.5

2.2.2 Temperature

Average minimum and maximum temperatures in Gladstone range from 13.3 - 22.8°C in July to 22.5 - 31.2°C in January. Monthly mean maximum and minimum and highest and lowest recorded temperatures are shown below. The highest figures are denoted by red text and the lowest by blue.

Table 5 Temperature Summary – BoM Gladstone Radar (1957 – Jul 2009)

Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean maximum temp (°C)	31.2	30.9	30.2	28.4	25.7	23.2	22.8	24	26.4	28.4	29.9	31	27.7
Mean Min Temp (°C)	22.5	22.4	21.5	19.6	17	14.3	13.3	14.2	16.4	18.7	20.5	21.9	18.5
Highest temp (°C)	38.3	40.1	42	34.1	31.3	29.7	28.7	30.9	33.8	40	40.1	39.8	42
Lowest temperature (°C)	12.8	17.2	16.2	11	8.5	6.1	4.4	4.7	9.6	10.9	14.7	12.4	4.4

On average, Gladstone experiences 4.5 days per year with a temperature equal or greater than 35°C, and 111.6 days per year with a temperature equal or greater than 30°C (BoM 2009a).

2.2.3 Wind

Average wind speeds experienced at Gladstone range from 11.4 to 16.5 km/h at 9 am and from 15.6 to 23.3 km/h at 3 pm.

2.2.4 Sea Levels for the Gladstone Region

The Lowest Astronomical Tide (LAT) values in the table below are the LAT design criteria that form the basis for the preliminary design of the Western Basin Reclamation. The figures have also been shown in relation to the Australian Height Datum (AHD). Each of the sea level acronyms used in Table 6 are described below in Figure 1 and in the following explanations (Maritime Safety Queensland 2008).

Table 6 Current Tidal Range Figures for the Western Basin Study Area

	(m, LAT)	(m, AHD)
HAT	4.97	2.54
MHWS	4.14	1.71
MHWN	3.24	0.81
MSL	2.44	0.01
AHD	2.43	0
MLWN	1.61	-0.82
MLWS	0.71	-1.72
LAT	0	-2.43

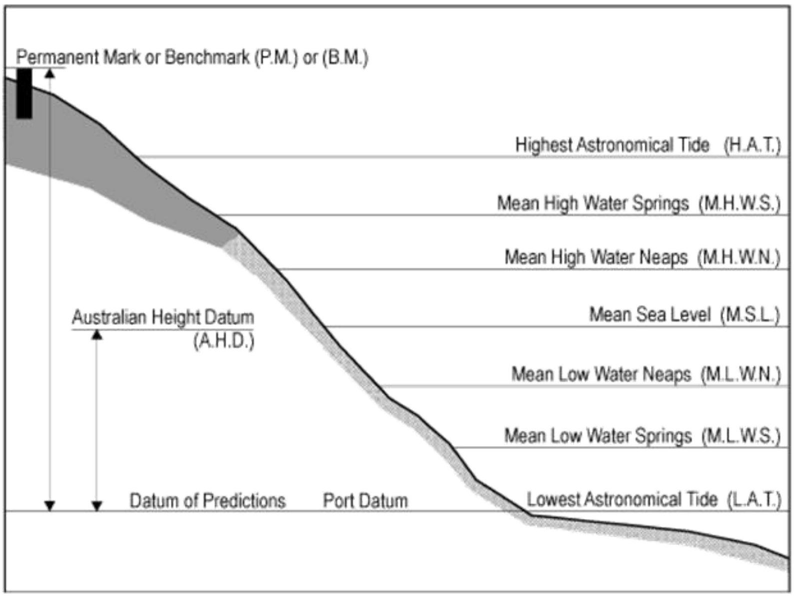


Figure 1 Semidiurnal Tidal Planes (Maritime Safety Queensland 2008)

HAT (Highest Astronomical Tide): These are the highest levels which can be predicted to occur under average meteorological conditions and any combination of astronomical conditions. These levels will not be reached every year. HAT does not represent the extreme levels which can be reached, as storm surges may cause considerably higher levels to occur.

MHWS (Mean High Water Springs): Long term average of the heights of two successive high waters during those periods of 24 hours (approximately once a fortnight) when the range of tide is greatest, at full and new moon.

MHWN (Mean High Water Neaps): The average throughout a year of the heights of two successive high waters when the range of tide is the least, at the time of first and last quarter of the moon.

MSL (Mean Sea Level): The average level of the sea over a long period (preferably 18.6 years) or the average level which would exist in the absence of tides.

AHD (Australian Height Datum): This datum has been adopted by the National Mapping Council as the datum to which all vertical control for mapping is to be referred.

MLWN (Mean Low Water Neaps): The long term average value of two successive low waters over the same periods as defined for MHWN.

MLWS (Mean Low Water Springs): The long term average value of two successive low waters over the same periods as defined for MHWS.

LAT (Lowest Astronomical Tide): These are the lowest levels which can be predicted to occur under average meteorological conditions and any combination of astronomical conditions. These levels will not be reached every year. LAT is not the extreme levels which can be reached, as storm surges may cause considerably lower levels to occur. The LAT value is used as the Port Datum.

2.2.5 Extreme Weather Events

Tropical Cyclone Severe Wind

The coastal strip near Gladstone has been identified as being an area of concern for damaging winds associated with tropical cyclones (GA 2001).

A summary of maximum monthly wind gust speeds recorded in Gladstone, along with the maximum wind gust speeds recorded so far this year is shown in Figure 2. The maximum wind gust speed recorded at Gladstone is 156 km/h on 19 January 1976. These winds were associated with Tropical Cyclone David (BoM 2009b).

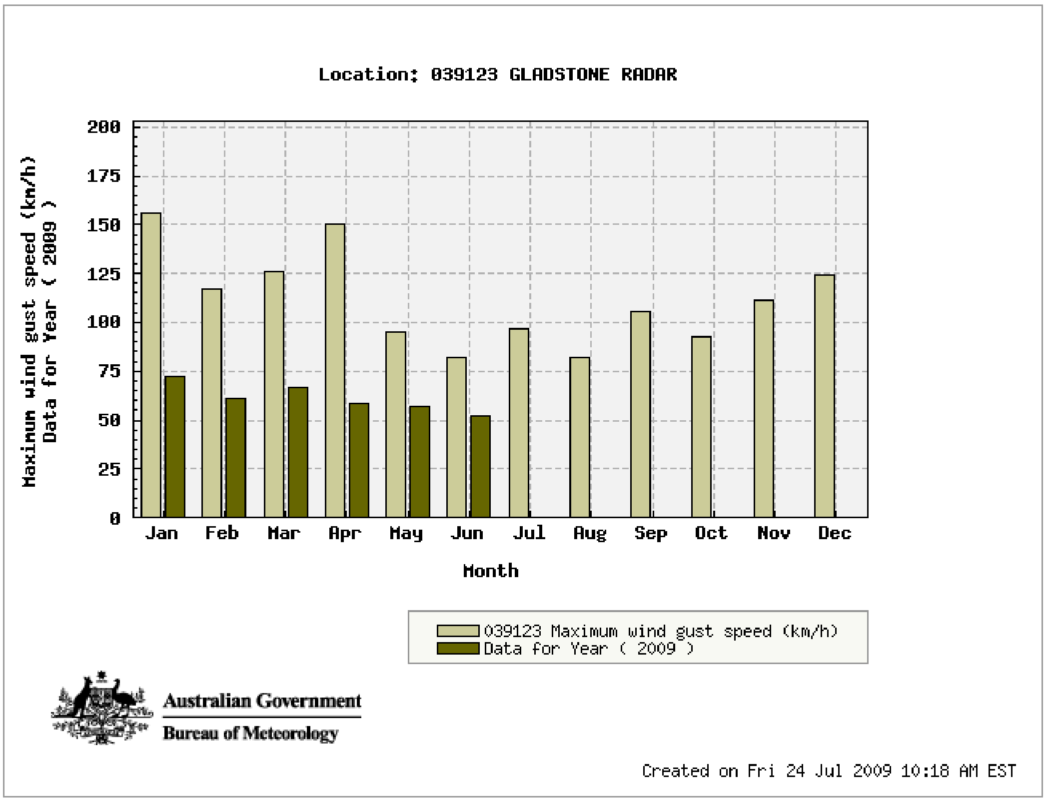


Figure 2 Gladstone Maximum Recorded Wind Gust Speeds (BoM 2009)

The Bureau of Meteorology identified ten tropical cyclones that passed within 100 km of Gladstone between 1940 and 2006 (BoM 2009b) (Figure 3). Additionally, in March 2009, Tropical Cyclone Hamish passed along the coastline near Gladstone. Although the cyclone did not cross the coastline, the event caused the temporary closure of the Gladstone Port (GPC 2009).

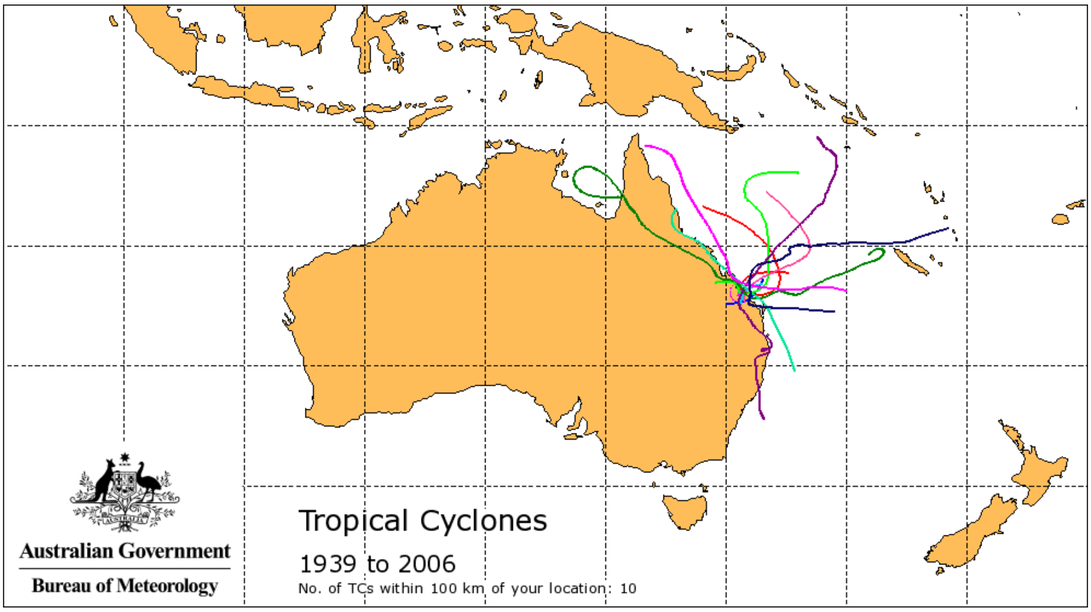


Figure 3 Tropical Cyclones Tracks within 100 km of Gladstone (1940-2006)

Storm Surge

Figure 4 outlines modelled storm surge plus tide levels for various annual exceedance probability (AEP) events for Gladstone at Auckland Point (Hardy *et al*. 2004). It should also be noted that this study did not take wave setup into account.

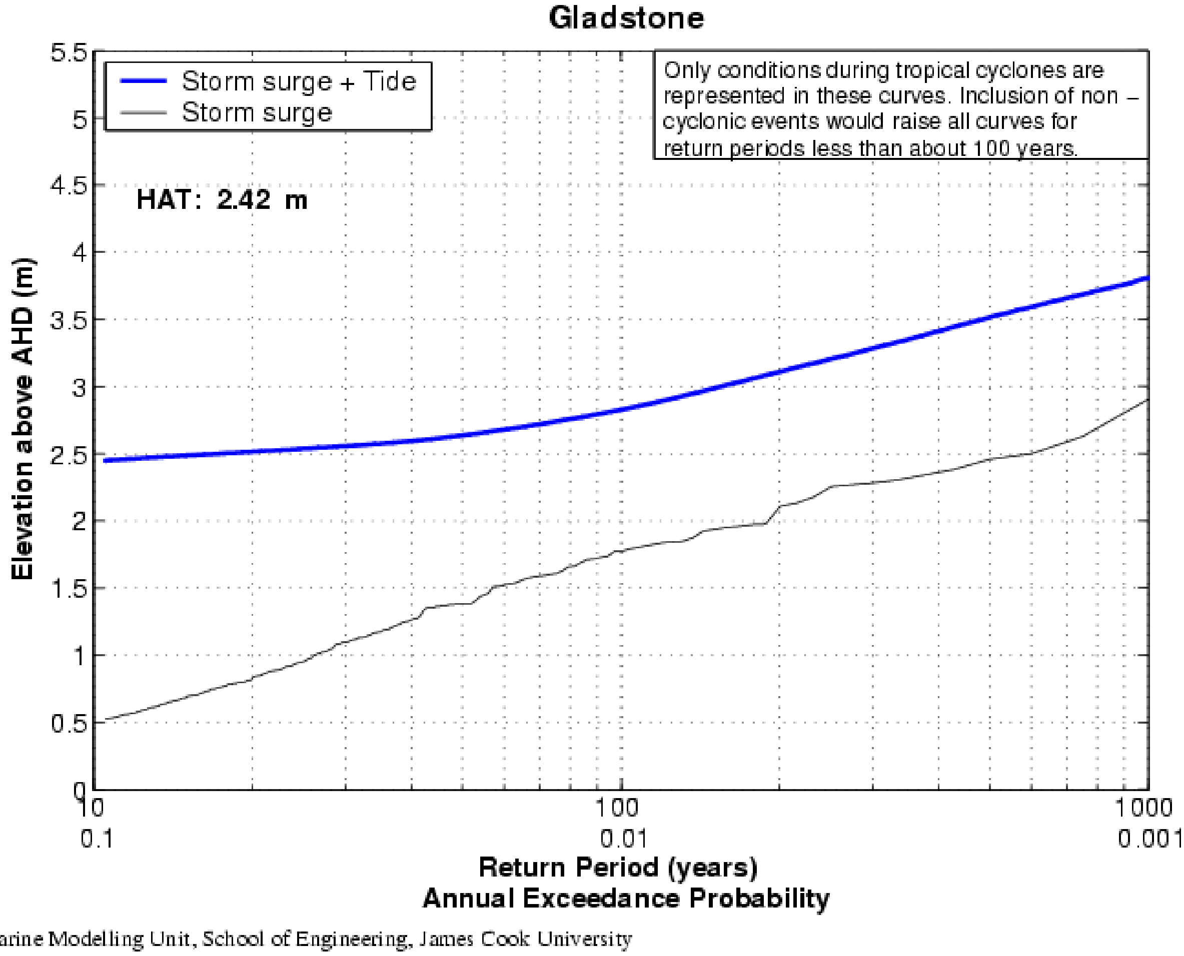


Figure 4 **Gladstone (Auckland Point) Predicted Storm Surge + Tide Levels (Hardy *et.al.* 2004)**

Based on the information in the Hardy *et al*. (2004) report, the elevations above AHD for selected AEPs for the Study Area were calculated as shown in Table 7. Each row of the table is explained below.

Table 7 **Storm Surge plus Tide for Study Area**

	0.02 (2%)	**0.01 (1%)**	**0.002 (0.2%)**	**0.001 (0.1%)**
1: Auckland Point (m, AHD)	2.65 (approx)	2.82	3.51	3.8
2: (Plus 6% increase for Western Basin)	(0.16m)	(0.17m)	(0.21m)	(0.23m)
3: (Plus approximate increase due to non-cyclonic events not included in modelling)	(+0.1m)	(+0.05m)	-	-
4: Western Basin Study Area (m, AHD)	2.91	3.04	3.72	4.03

1: The 1%, 0.2% and 0.1% AEP levels for Auckland Point are reproduced from the Hardy et.al. (2004 p 26) report and the 2% AEP level is estimated from Figure 4.

2: An approximate increase of 6% in tidal range for the study area, compared to Auckland Point was added (see Appendix M of the main EIS - Coastal Processes).

3: The results in the Hardy *et.al*. (2004) study is for tropical cyclone-induced water levels. For smaller storm surge events, non-cyclonic events will be increasingly important. Therefore, the combined curve of tropical and extra-tropical storm tides will be higher than the cyclone-induced curves shown in Figure 4. The increase due to non-cyclonic events is expected to be about 0.2 m for an event with a 10% AEP, reducing to 0 m for an event with about a 0.5% AEP (Hardy *et al*. 2004). Based on these figures, 0.1m and 0.05 m has been added to the values in Table 7 for a 2% and 1% AEP event respectively.

4: The resulting elevations above AHD for selected AEPs for the Study Area.

3. Climate Change Projections for Gladstone Region

The following section outlines climate change projections for the Gladstone region for rainfall, temperature, and average wind, for 2030 and 2070, sea level up to 2100 and extreme weather (general projections for cyclones - storm surge events for AEP events).

Generally, projections for 2030 show little variation between emissions scenarios, as these changes in climate are mostly affected by greenhouse gases that have already been emitted. Due to this, the projections below for 2030 are shown for the mid-range SRES emissions scenario. Projections for later in the 21st century are much more dependent on the scenario used for future emissions and for this reason, projections using both low and high emissions scenarios are shown for 2070. It should be noted however, that research presented by Rahmstorf *et al.* (2007) shows that observed carbon dioxide concentration, global mean temperatures and sea level rise have been tracking at the upper end of IPCC scenario range from 1990 to 2006. Therefore, projections based on the mid and low IPCC scenarios for later in the 21st century may be less likely than those based on the high emissions scenarios (CSIRO 2007).

3.1 Changes in Rainfall

Climate change projections for rainfall are generally much more variable than those for temperature. The projections below have been extracted from CSIRO's web based scenario generator, OzClim (Build Number 3.1.05). The projections have used the CSIRO's recommended inputs for low, medium and high impact model outputs. These are;

- Low impact = MUIB/KMA: ECHO-G Global Climate Model with low climate sensitivity and B1 emission scenario
- Medium Impact = Max Plank ECHAM5/MPI-OM Global Climate Model with medium climate sensitivity and the A1B SRES emission scenario
- High impact = GFDL: GFDL-CM2.1 Global Climate Model with high climate sensitivity and A1FI emission scenario

The annual rainfall projections for the Gladstone region for 2070 vary significantly depending on the emissions scenario and global climate model used however, the high impact scenario shows a definite drying trend.

Table 8 Rainfall Projections

(CSIRO 2009)	2030 * (medium impact)	2070 * (low impact)	2070 * (high impact)
Percentage change in annual rainfall	-4.8%	+1.7%	-70.5%
Percentage change in summer rainfall	-5.0%	+6.6%	-62.2%
Percentage change in winter rainfall	-5.6%	-1.1%	-80.5%

*Values for Gladstone region from CSIRO OzClim scenario generator

3.2 Changes in Temperature

The temperature projections in Table 9 have been sourced from values for Rockhampton, approximately 100 km from Gladstone, summarised by the QOCC (2008). The mean values show a projected increase in average temperature for the region of around 1°C for 2030, and approximately 1.6 to 3 °C for 2070. For the 2070 high emissions scenario, the high range of model outputs projects a possible average temperature increase of up to 4.2 °C. Table 10 identifies the implications of these projected increases in average temperature for the number of days per year with temperatures over 35 °C.

Table 9 Temperature Projections

(QOCC 2008)	2030 Average* (mid emissions)	2070 Average* (low emissions)	2070 Average* (high emissions)
Mean increase in annual temperature (°C)	1.0	1.6	3.0
(Model output range)	(0.6 – 1.3)	(1.1 – 2.2)	(2.1 – 4.2)

*values for Rockhampton – Approx 100 km from Gladstone (QOCC, 2008b)

Table 10 Increase in Number of Days over 35°C

(QOCC 2008)	2030 Average* (mid emissions)	2070 Average* (low emissions)	2070 Average* (high emissions)
Mean increase in number of days above 35°C	26	36	65
(Model output range)	(22 - 33)	(27 – 48)	(42 - 102)

*values for Rockhampton – Approx 100 km from Gladstone (QOCC, 2008b)

3.3 Changes in Wind

Average wind speed change projections are available for the 10 m above ground wind data from 19 climate models for the Australian region (CSIRO 2007). The changes in wind speed below represent the approximate range of percentage change from the models for the annual average 10 m wind speed values for the Gladstone region.

Table 11 Average Wind Projections

(CSIRO 2007)	2030 Average (mid emissions)	2070 Average (low emissions)	2070 Average (high emissions)
Annual average wind speed % change – (Model output range)	(-2 , +5)	(-2, +10)	(-2, +15)

3.4 Changes in Sea Level - Global

Table 12 summarises the latest IPCC (2007) projections for global average sea level rise based on each of the SRES emissions scenarios. The predictions for each scenario in the IPCC Fourth Assessment

Report (AR4) allow for added uncertainty relating to potential accelerations in ice flow of the kind recently observed in Greenland and West Antarctica. An additional 10-20 cm is suggested to be added to the projections to take these changes into account although, it is noted that there is a large degree of uncertainty regarding these processes; and that there is the potential for the upper level of sea level rise to increase substantially (Church *et.al*. 2008).

Table 12 Global Average Sea Level Rise for the SRES Scenarios

(IPCC 2007)	Sea Level Rise (m at 2090 – 2099 relative to 1980 – 1999) Model-Based Range Excluding Future Rapid Dynamical Changes in Ice Flow	Additional Contribution from Ice Sheets (m)
B1 scenario	0.18 – 0.38	0.10 – 0.20
A1T scenario	0.2 – 0.45	
B2 scenario	0.2 – 0.43	
A1B scenario	0.21 – 0.48	
A2 scenario	0.23 – 0.51	
A1FI scenario	0.26 – 0.59	

The IPCC AR4 did not provide a time series of sea-level rise projections, but only a series of maximum and minimum projections for the decade 2090-2099, and for the potential additional contributions from the Greenland and Antarctic Ice Sheets. The table below shows an estimated time series of the maximum sea level rise projections based on the A1FI values from the IPCC AR4, scaled using the time series of sea level rise estimates produced in the IPCC Third Assessment Report (Hunter 2008).

Table 13 IPCC AR4 Max Sea Level Rise Projections (Hunter 2008)

Year	1990	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
A1FI – Max (m)	0	0.028	0.06	0.099	0.146	0.204	0.278	0.368	0.471	0.584	0.701	0.819

3.5 Changes in Sea Level - Local

Local sea level rise is also an important factor to consider when assessing potential future sea level rise. Regional sea level rise projections for Australia are currently unavailable for the high level emissions scenario. However, regional departures from the global mean sea level rise predictions using a mid range emissions scenario have been assessed for the Australian coastline (CSIRO Marine and Atmospheric Research (CMAR) 2008). The results of the CMAR report show the projected mean departure from the global mean for the area of Australian coastline near Gladstone for 2070 is estimated as approximately +0.02 m.

3.6 Changes in Extreme Weather Events

3.6.1 Extreme Wind and Tropical Cyclones

Projections for changes in extreme wind speed have only been examined using a small number of climate models. From these models, winter extreme daily wind changes were shown to be similar to the changes in average seasonal winds. However, there was little relationship shown between summer average and extreme wind changes. This is believed to be due to the fact that extreme winds during the summer are generally due to smaller scale weather systems that are not accurately captured by the resolution of the climate models (CSIRO 2007).

Australasian region studies indicate a likely *increase* in the proportion of the tropical cyclones in the more intense categories, but a possible *decrease* in the total number of cyclones (CSIRO 2007). Depending on the magnitude of the projected changes, it is possible that the increase in the proportion of tropical cyclones in more intense categories may be off-set by a decrease in the total number of cyclones.

It is expected that as global climate models develop, their simulation of tropical cyclones will improve. These improvements will lead to a greater certainty in projections of tropical cyclone changes in the future (CSIRO 2007).

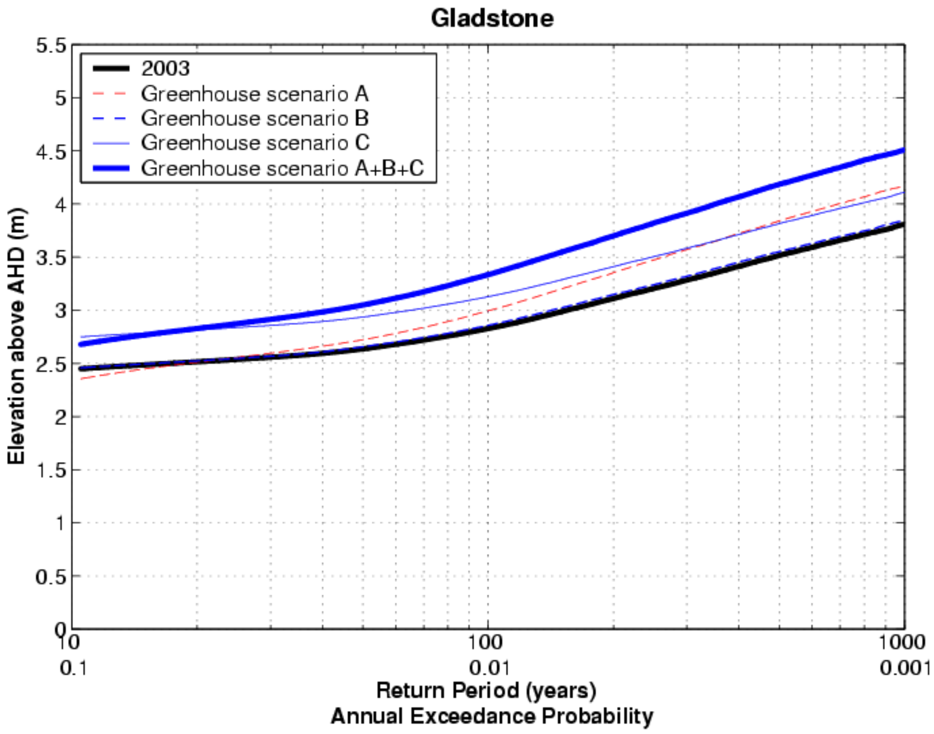
3.6.2 Storm Surge

Figure 5 below summarises the findings for Gladstone (Auckland Point), of a study that estimated sea levels above AHD for 50 open coast locations along the east coast of Queensland for storm surge plus tide levels, taking into account climate change scenarios (Hardy *et al.* 2004).

Climate Change Scenarios included in the modelling to produce the greenhouse figures included:

- Greenhouse scenario A: The combined effect of an increase in Maximum Potential Intensity (MPI) of 10% and a poleward shift in tracks of 1.3^{o};
- Greenhouse scenario B: An increase in frequency of tropical cyclones of 10%; and
- Greenhouse scenario C: Mean Sea Level rise of 0.3m (based on the upper level IPCC (2001, 2007) prediction of MSL rise for 2050).

The study noted that in choosing these figures to represent the effects of climate change on the storm surge and tide modelling, the authors were not endorsing the values. Rather, the intention of the study was to demonstrate the sensitivity of the modelled outputs to these changes in climate scenarios. The study concluded that, the mean sea level rise change was the most important variable and that the effect on the magnitudes of storm tide at the coast for higher AEP (more common) events could be approximated as a linear addition to the AEP curve that was developed for the present conditions. For lower AEP (less common) events, the contribution of scenario A (increase in MPI of 10% and a poleward shift in tracks of 1.3^{o}) also has an effect on the magnitude of the storm tide. This is demonstrated in Figure 5 below.



Marine Modelling Unit, School of Engineering, James Cook University

Figure 5 Gladstone Sea Level Elevations with Greenhouse Scenarios

The elevations above AHD for selected AEP levels are shown in Table 14. The 1%, 0.2% and 0.1% AEP levels are reproduced from a table in the Hardy *et.al.* (2004) report and the 2% AEP level is estimated from Figure 5 above.

Table 14 Storm Surge Plus Tide Taking Climate Change into Account

	0.02 (2%)	**0.01 (1%)**	**0.002 (0.2%)**	**0.001 (0.1%)**
Gladstone (m, AHD)	3.05(approx)	3.33	4.18	4.51
Approximate contribution of modelled sea level rise	0.3m	0.3m	0.3m	0.3m
Approximate contribution of increase in MPI of 10% and a poleward shift in tracks of 1.3^{o}	0.1m	0.21m	0.37m	0.41m

Using the figures above in Table 14 and in Table 7, future 2%, 1%, 0.2% and 0.1% AEP storm surge plus tide levels for the Western Basin site were developed. These levels for the years 2030, 2050, 2070 and 2100 use the high level IPCC AR4 sea level rise projections derived by Hunter (2008) in the first row, for each AEP. The second row for each AEP also factors in an increase in tropical cyclone maximum potential intensity of 10% and a poleward shift in tracks of 1.3 degrees.

Table 15 Future Projected Storm Surge plus Tide Levels for Western Basin Site – (2030 – 2100)

2% AEP (current: 2.91 m, AHD)	2030	2050	2070	2100
Storm surge plus tide including SLR (m, AHD)	3.07	3.20	3.40	3.75
Storm surge plus tide including SLR and increase in TC MPI of 10% and poleward shift in tracks of 1.3 degrees (m, AHD)	3.20	3.33	3.52	3.87
1% AEP (current: 3.04 m AHD)	**2030**	**2050**	**2070**	**2100**
Storm surge plus tide including SLR (m, AHD)	3.20	3.34	3.53	3.88
Storm surge plus tide including SLR and increase in MPI of 10% and poleward shift in tracks of 1.3 degrees (m, AHD)	3.44	3.58	3.77	4.12
0.2% AEP (current: 3.72 m, AHD)	**2030**	**2050**	**2070**	**2100**
Storm surge plus tide including SLR (m, AHD)	3.89	4.02	4.21	4.56
Storm surge plus tide including SLR and increase in MPI of 10% and poleward shift in tracks of 1.3 degrees (m, AHD)	4.30	4.43	4.62	4.97
0.1% AEP (current: 4.03 m, AHD)	**2030**	**2050**	**2070**	**2100**
Storm surge plus tide including SLR (m, AHD)	4.19	4.32	4.52	4.87
Storm surge plus tide including SLR and increase in MPI of 10% and poleward shift in tracks of 1.3 degrees (m, AHD)	4.65	4.78	4.97	5.32

From these calculations, it is demonstrated that, by 2100, a level that currently has a 0.1% annual probability of being exceeded (4.03 m) could have a future 1% annual exceedance probability. This is equivalent to a ‘1 in 1000’ year event becoming a ‘1 in 100’ year event in this region.

It should also be noted that the highest storm surges modelled in the Hardy *et al.* (2004) study, are not the highest possible. The probable maximum water level at a given location would be caused by a tropical cyclone and tide with characteristics including a very severe central pressure, and an astronomical tide level at the time of maximum surge that is close to HAT. The combination of these characteristics would be very rare, but not impossible (Hardy *et.al.* 2004).

3.7 Summary of Climate Change Projections for the Gladstone Region

The table below summarises the climate change projections identified in this section of the report, compared with the historical/current averages for the region. Projections based on the ‘upper level’ scenarios have been included in this table where available due to evidence that suggests that current sea level rise and temperature increases are already tracking above rates noted in the ‘high emissions’ scenarios used by the IPCC (Rahmstorf *et al*. 2007). Information relating to each projection is included in the 'Scenario / Info' column.

Table 16 Summary of Climate Change Projections for Gladstone Region

Climate Variable	Current/ Historical Conditions	Source	Climate Change Projection	Scenario / Info	Source
Rainfall/ Runoff	Annual average rainfall: 880 mm	(BoM)	-70%	2070 A1FI emission scenario GFDL-CM2.1 Global Climate Model with high climate sensitivity (IPCC 2007 global warming values)	(CSIRO -OzClim 2009 *Build Number 3.1.05, 26 Jun 2009*)
Air Temp	Annual mean max temp: 27.7°C Annual mean min temp: 21.9°C	(BoM)	Average temp increase: 3.0°C	2070 High emissions (A1FI) scenario Mid range model result (with high and low range) (Data for Rockhampton)	(QOCC 2008b)
	Annual average number of hot days (over 35°C): 4.5	(BoM)	Increase in number of days over 35°C : +65 days	2070 High emissions (A1FI) scenario Mid range model result (with high and low range) (Data for Rockhampton)	(CSIRO cited in QOCC 2008b
Wind (daily wind climate)	Average 9 am wind speed: 14.2km/h Average 3 pm wind speed: 20.7km/h	(BoM)	Annual 10m wind speed variations: (-2 to +15%)	2070 High emissions (A1FI) scenario (model output range)	(CSIRO 2007)
Sea Level	HAT for Western Basin: 2.54 m, AHD	GHD Design Criteria	Global mean sea level rise: +0.278 m	2050 Estimate of maximum global sea level rise relative to 1980 – 1999 using high emissions (A1FI) emissions scenario	(Hunter 2008, after IPCC 2007)
			Global mean sea level rise: +0.471 m	2070 Estimate of maximum global sea level rise relative to 1980 – 1999 using high emissions (A1FI) emissions scenario	(Hunter 2008, after IPCC 2007)
			Local projected departure from global mean sea level rise: +0.02m	2070 Mid emissions scenario (A1B)	(CMAR 2008)

Climate Variable	Current/ Historical Conditions	Source	Climate Change Projection	Scenario / Info	Source
Tropical Cyclones	Tropical cyclones in the Gladstone region have caused local wind extremes up to 156 km/h (19 Jan 1976)	(BoM)	- likely *increase* in the proportion of cyclones in the more intense categories -possible *decrease* in the total number	Based on projections produced by 3 studies in the Australian region.	(CSIRO 2007)
Storm Surge + Tide	2% AEP : approx 2.91 m, AHD	(Hardy et al. 2004, p.44 – adjusted for Western Basin site and additional non-cyclonic events)	 3.40 m AHD 3.52 m AHD	2% AEP storm surge plus tide 2070 SLR only 2070 SLR + 10%increase in cyclone MPI	(Calculated from Hardy et al. (2004, p.54), and Hunter (2008), after IPCC (2007))
	1% AEP: approx 3.04 m, AHD		 3.53 m AHD 3.78 m AHD	1% AEP storm surge plus tide 2070 SLR only 2070 SLR + 10%increase in cyclone MPI	
	0.2% AEP: approx 3.72 m, AHD		 4.21 m AHD 4.62 m AHD	0.2% AEP storm surge plus tide 2070 SLR only 2070 SLR + 10%increase in cyclone MPI	
	0.1% AEP: approx 4.03 m, AHD		 4.52 m AHD 4.97 m AHD	0.1% AEP storm surge plus tide 2070 SLR only 2070 SLR + 10%increase in cyclone MPI	

4. Climate Change Impacts on the Project

4.1 Potential Impacts

Based on the *Guidelines for Responding to the Effects of Climate Change in Coastal and Ocean Engineering* (Engineers Australia 2004), impacts associated with effects on the Project are summarised in Table 17. The potential impacts suggested in the Engineers Australia Guideline were assessed and modified in relation to this Project, based on discussion with the Project team. This summary outlines potential areas where adaptation may be required in relation to the investigation, design, construction, operation and maintenance of the Western Basin Dredging and Disposal Project. Potential impact for structures and facilities that may be located on or adjacent to the Western Basin Reclamation in the future should be taken into account by future proponents.

Table 17 Potential Impacts on Project

Climate Variable	Effects on Project	Potential Impacts
Rainfall/ Runoff	Investigation	Minor/No effect
	Design	Minor/No effect
	Construction	Minor/No effect
	Operation	Minor/No effect
	Maintenance	Minor/No effect
Air Temp	Investigation	No effect
	Design	Minor/No effect
	Construction	Minor/No effect
	Operation	Minor/No effect
	Maintenance	Minor/Possible increased corrosion rates of construction materials
Wind (daily wind climate)	Investigation	Minor/No effect
	Design	Minor/No effect
	Construction	Minor/No effect
	Operation	Minor/No effect
	Maintenance	Minor/No effect
Sea Level	Investigation	Changing statistics will affect determination of design criteria
	Design	Possible effect
	Construction	Minor/No effect

Climate Variable	Effects on Project	Potential Impacts
	Operation	Structures that don't take into account the potential effects of climate change may be less efficient during operation phase
	Maintenance	Minor effect
Tropical Cyclone/ Storm Surge (Wind and Wave Climate)	Investigation	Changing statistics will affect determination of design criteria
	Design	Possible changes to marginal probability of failure for structures
	Construction	May effect down time during future construction periods
	Operation	May impact depending on function
	Maintenance	Structures that don't take into account the potential effects of climate change may need retrofitting or upgrade

4.2 Assessing the Level of Risk from Potential Impacts

The main impacts for the Western Basin Dredging and Disposal Project have been identified as those associated with potential sea level rise and associated increase in storm surge.

If the Reclamation Area was to be overtopped by storm surge, the consequence level would largely depend on the type of activity, if any that was taking place on the Reclamation , but could potentially be a major consequence based on the Gladstone Port Corporation consequence rating criteria.

In terms of assessing the likelihood of this event actually occurring, the Gladstone Port Corporation likelihood criteria defines an event that may occur only in exceptional circumstances, or not in the next 25 years as rare, and in the next 20 to 25 years as unlikely.

The design height of the bund wall for the Western Basin Reclamation Area has been set at 7 m LAT (see Chapter 2 Project Description). This is equivalent to 4.57 m AHD. Taking storm surge and tide into account, with increasing sea levels and even a 10% increase in tropical cyclone maximum potential intensity (MPI), this level is exceeded only by the 0.1% AEP event in 2050 and by the 0.2% AEP event in 2070.

These levels of consequence and likelihood would equate to a low risk level using the Gladstone Port Corporation risk matrix, but would need to be re-evaluated in the future as more detailed information becomes available.

4.3 Adaptation Measures

For each of the potential impacts of climate change that may affect the Western Basin Dredging and Disposal Project that have been identified, appropriate adaptation measures are highlighted in Table 18 below. This table summarises the adaptation measures that are being implemented in the design of the rock armour for the revetments for the Western Basin Reclamation Area, as well as suggesting some measures that may need to be taken into account for future structures that may be built on the reclaimed area. The individual acceptable level of risk will vary depending on the type of facilities that are to be constructed on the Reclamation Area and these will need to be assessed on a case by case basis by the future proponents.

Table 18 Potential Adaptation Measures for the Western Basin Dredging & Disposal Project

Climate Variable	Potential Adaptation Measures
Rainfall/ Runoff	Only minor effects expected. Therefore, no adaptation measures have been proposed.
Air Temp	Any road surfacing used on the bunds may need to take into account higher future temperatures to reduce any ongoing maintenance costs associated with increases in ambient temperatures on the concrete and/or bitumen. Concrete - Adequate allowance for predicted thermal movements during the design stage. This could be the inclusion of more joints in the pavement to relieve stresses and reduce the risk of damage Bitumen - Evaluate different bitumen formulation to suit projected climate conditions. This might include higher penetration grade bitumen, alternate mix designs or the use of polymer modified bitumen.
Wind (daily wind climate)	Only minor effects expected. Therefore, no adaptation measures have been proposed.
Sea Level	Sea level rise has been included to determine the design wave heights in the design of the rock armour. The sea level rise adopted for the design of the rock armour is as recommended by the EPA Building and Engineering Standards for Tidal Works and corresponds with the approximate 'high level' mean sea level rise projections for 2050.
Tropical Cyclone/ Storm Surge (Wind and Wave Climate)	The rock armour protection that is likely to be adopted at the Reclamation Area is based on a dynamic design. The rock armour, therefore, will move to create a stable profile over its lifetime. It is recognised that during the lifetime of the structure a design event or even bigger may occur. These events will not lead to catastrophic failure, but may require some maintenance and possibly replenishment of the rock armour in places. GPC recognise this and is committed to carrying out this maintenance to allow the structure to be operationally stable for the design life of the reclamation. The rock armour has been designed for cyclonic winds associated with an average return interval (ARI) of 50 years. This is equivalent to a 2% annual exceedance probability (AEP). This AEP is based on historic data for the Gladstone region. Due to the dynamic design of the rock armour that is proposed, the maintenance regime in place would potentially be able to adapt the overall volume of the rock armour to maintain a 2% AEP design specifications if required.

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