FEBRUARY 2014

Lambulambu Wharf Rehabilitation

Climate Risk and Adaptation Assessment

Document Tracking

Document title: Lambulambu Wharf Climate Risk and Adaptation Assessment

Document filepath: Lambulambu CCRA v2-0.docx

Date: February 2014

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Approved by:

Document History and Status

Revision	Date issued	Reviewed by	Approved by	Date approved	Revision Type
1	10/13				Draft
2	2/14				Final

Distribution of Copies

Revision	Copy No	Quantity	Issued to
1	1	1	

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1 Introduction

The Government of Solomon Islands, with support from ADB, AusAID and NZAID seeks to improve the transport network in the Solomon Islands under Transport Sector Development Project (TSDP). TSDP seeks to upgrade or rehabilitate rural roads, bridges, airstrips and wharves that are high development priorities

(i) based on their contribution to the objectives of the National Economic Reform, Recovery and Development Plan (NERRDP),
(ii) as projects identified in the National Transport Plan (NTP), and to
(iii) ensure connections between rural production and markets and improve access to health, education and other services.

The Lambulambu Wharf rehabilitation (the project) is a priority project for the TSDP, having been previously identified for rehabilitation following comprehensively damaged after the 2007 earthquake and tsunami.

As a sub-discipline within the suite of feasibility investigations, this climate risk and adaptation assessment has the following objectives:

- Identify and consider the significance of potential climate change risks to the project.
- Where necessary, identify potential adaptation options to manage risks deemed unacceptable for the project.
- Consider potential adaptation options from a range of social, environmental, economic and technical feasibility perspectives.
- Recommend any preferred options for further attention as part of the economic assessment for the project.

Overview of Approach

This report builds on previous work completed as part of investigating the feasibility for the project, comprising social and environmental safeguards work (including local community consultation), and preliminary design and hydrology investigations. The approach undertaken in this assessment is indicated below in Figure 1.

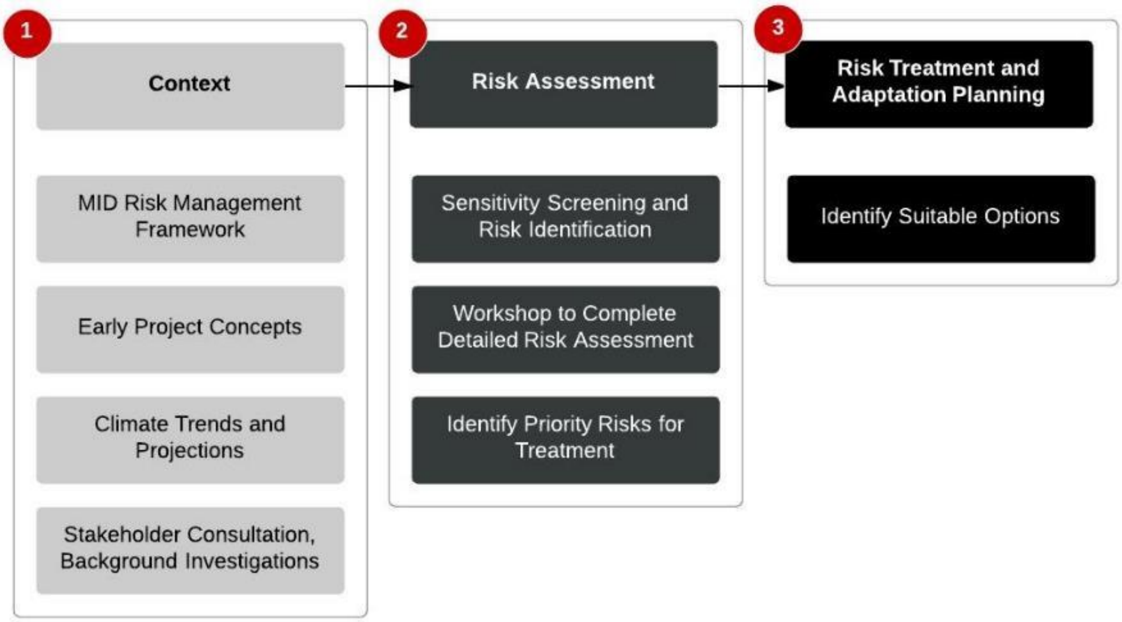

Figure 1: Overview of approach to complete the climate risk and adaptation assessment

2 Description of the project

The project is located in Western Province, on the eastern side of Vella La Vella Islands, as indicated in Figure 2: Approximate location of the Lambulambu Wharf projectFigure 2 below. The Lambulambu Sub-project comprises a single new wharf to be built to replace the existing wharf which has been submerged by the earthquake and subsequent tsunami in 2007.

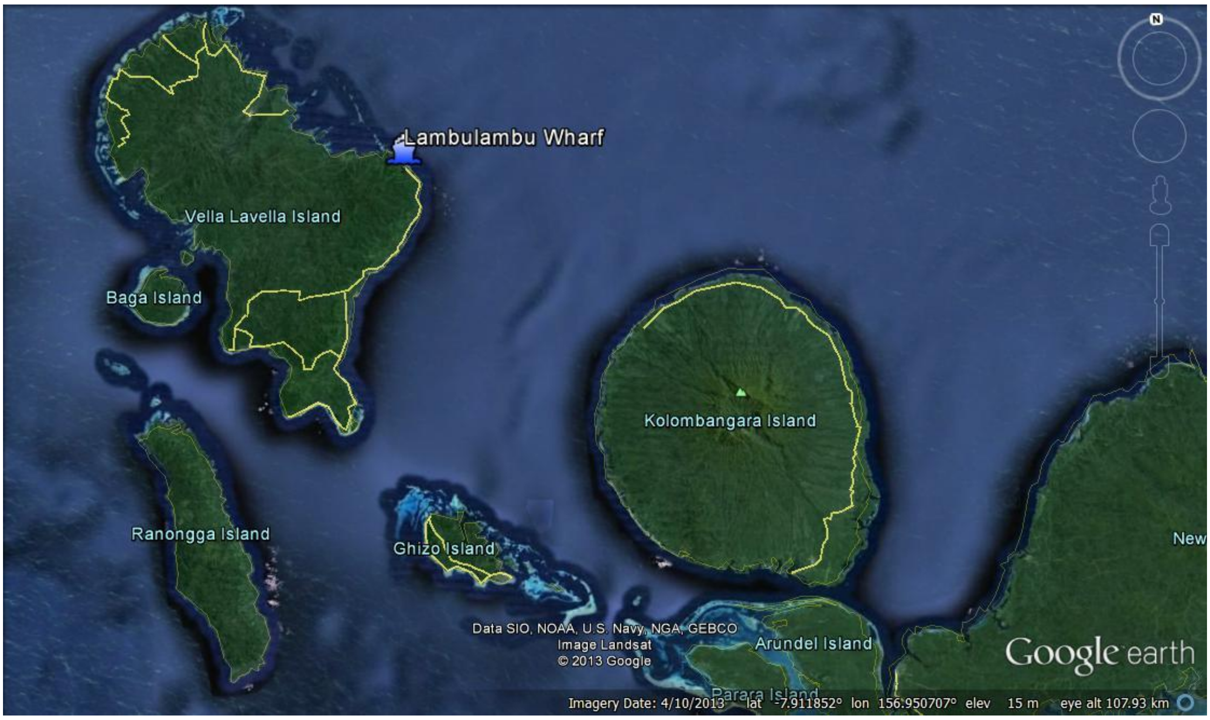

Figure 2: Approximate location of the Lambulambu Wharf project

The scope of works includes the proposed reconstruction of the Lambulambu wharf which will involve construction of a new piled reinforced concrete wharf head and approach jetty and upgrade of an existing coronous embanked causeway. The wharf design will be based on the design and layout developed under the recent ADB funded Domestic Maritime Support Program (DMSP) with modifications where required to suit the particular site.

A piled structure is recommended in this location as the preferred solution for a number of reasons. These include:

- sufficient provision for access of expected boats;
- earthquake resistance;
- long design life (50 years);
- minimal maintenance;
- fast to construct; and
- minimal impact on the environment as limited site excavations and fill are required.

The Solomon Islands Government (SIG) previously constructed large numbers of gravity type wharves based on the use of gabions however these have not been durable and long lasting as they are prone to earthquake damage and corrosion and require on-going maintenance.

Limitations

This assessment has been prepared as part of the development of the project, and was based on preliminary design concepts for the wharf. Detailed designs for the project are yet to be developed. No detailed terrestrial or marine survey is available, and as such recommendations are general in nature, and would need to be considered during the detailed design for the project.

3 Relevant climate considerations and natural hazards

Introduction

The words hazards and risks tend to be used interchangeably but refer to distinct (though closely related) aspects. Hazard can be defined as: “A potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation. Hazards can include latent conditions that may represent future threats and can have different origins: natural (geological, hydro-meteorological and biological) or induced by human processes (environmental degradation and technological hazards)” (UN/ISDR 2004).

The occurrence of a given hazard results in a risk situation when assets, human life, socio-economic or environmental values are potentially exposed. The vulnerability of a given population can also influence the level of risk. In some circumstances, multiple hazards can occur simultaneously or as a chain of events (for example storm surge and flooding from extreme rainfall) and can lead to multi-risk situation; this tends to result in the highest damage but is also harder to identify, analyse and prepare for.

The following sections present information on observed and projected climate variables and natural hazards. The majority of weather observations are drawn from the closest weather station to the project area, located in Munda, some 90 km south east. This station, located close to sea level, is the best weather observation information available. The majority of climate projections and analysis has been drawn from the 2011 *Climate Change in the Pacific: Scientific Assessment and New Research* published by the Australian BOM and CSIRO.

Observations

Rainfall

The heaviest rainfall period of the year at the Munda station occurs during the months of December, January and February, with an average total of 1075 mm, which compares with the average total for the lowest three month period (September to November) being 729 mm. The total annual average rainfall for Munda is 3555 mm. Over the course of records from 1962 to 2012 rainfall observations in Munda show a reduction in annual average rainfall of 4.28 mm per decade – although the statistical significance is not known.

Inter annual variability of rainfall is substantial due in large part to the influence of the El Nino-Southern Oscillation (ENSO), a natural climate pattern that occurs across the Pacific. ENSO is characterised by two extreme phases, La Nina and El Nino, as well as a neutral phase. In general terms El Nino events bring warmer, drier wet seasons, whereas La Nina is commonly associated with cooler wetter wet seasons.

Sea Level

In 1994 a SEAFRAME gauge was installed at Honiara[1] as part of the South Pacific Sea Level and Climate Monitoring Project. It records sea level, and other meteorological data at hourly intervals. The datum of the gauge is 0.204 m above the Tide Gauge Zero (TGZ). With a highest recorded sea level of 1.37 m, this translates to a highest sea level (relative to TGZ) of 1.57 m (or 0.88 m relative to Mean Sea Level (MSL)). The sea-level rise near Solomon Islands measured by satellite altimeters since 1993 is mostly over 8 mm per year (BOM and CSIRO, 2011).

[1] In the absence of specific measurement at Lambulambu, or Munda, these observation values represent the best available for sea level.

Temperature

Over the course of the observational record from 1962, a warming trend is evident for the Munda station. Average maximum temperatures have increased at a rate of approximately 0.10°C per decade (BOM and CSIRO, 2011). Average minimum temperatures have also increased at a rate of 0.17°C per decade (BOM and CSIRO, 2011).

Tropical Cyclones

The window for tropical cyclones in the Solomon Islands is typically between November and April. In the period from 1969 to 2010, 28 tropical cyclones passed within 400 km of Gizo (located approximately 40 km south east of the study area) (BOM and CSIRO, 2011). Historical tropical cyclone tracks to have passed in the vicinity of the Solomon Islands are shown in Figure 3. Over the period of records, the number of events in any given year can has varied from none to five, with a long term average of less than one cyclone per season (see Figure 4).

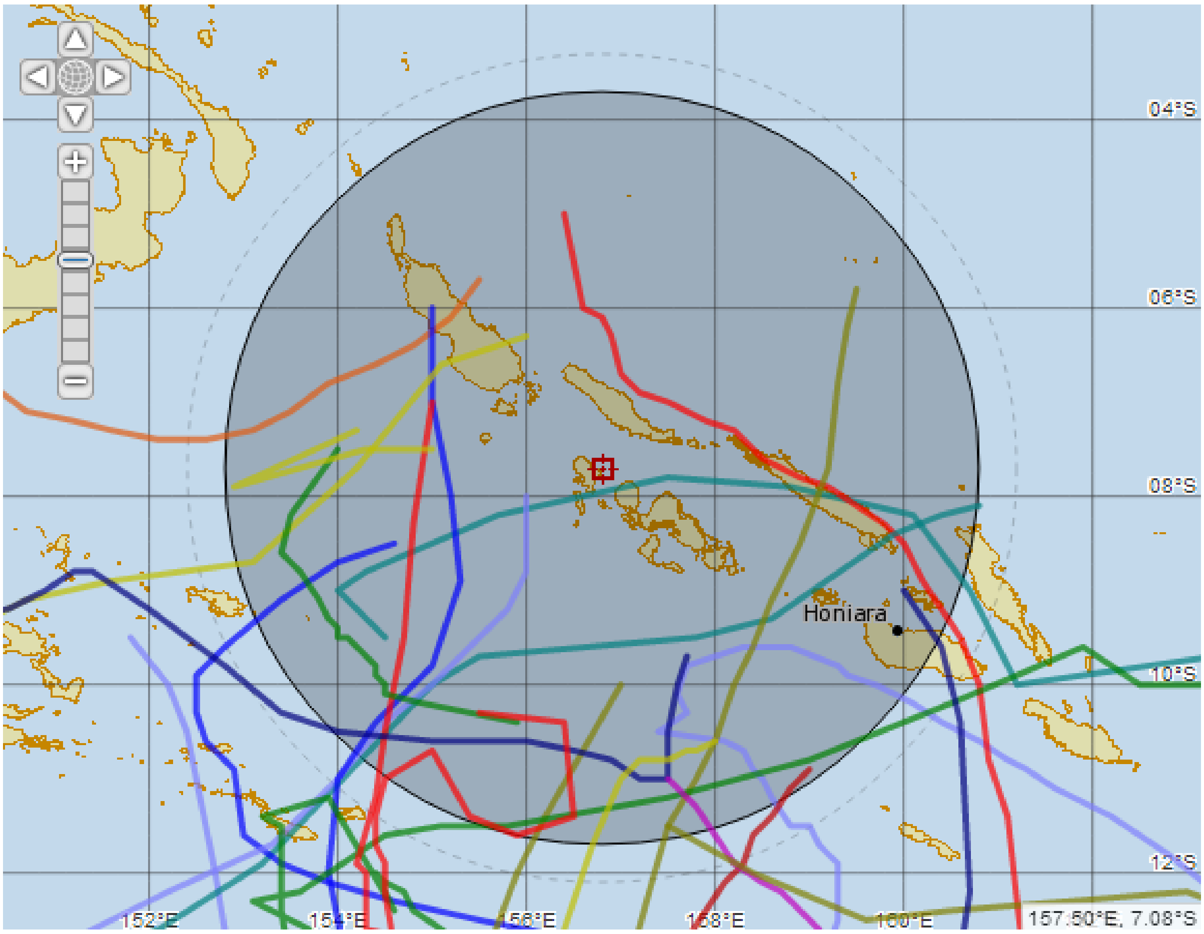

Figure 3: Historical tropical cyclone tracks recorded from 1969/70 - 2010/11 (BOM, 2013)

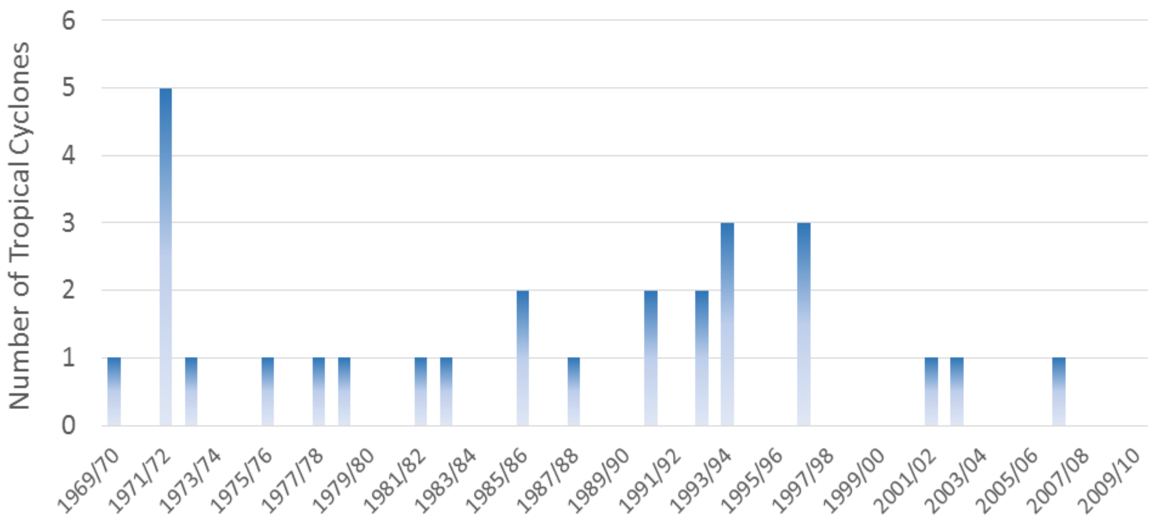

Figure 4: Number of tropical cyclones passing within 400 km of Gizo (BOM and CSIRO, 2011)

Significant wave heights

Information on the wave dynamics of the study area was obtained from the Climate and Oceans Support Program in the Pacific (COSPPac) Oceans Portal. The wave information is derived from the WAVEWATCH III® wind-wave model. The Centre for Australian Weather and Climate Research ran the model over the period 1979 – 2009. Of relevance to this investigation is the magnitude of significant waves. Significant wave height is the average height (peak to trough) of the upper one third of all waves. For the study area, the mean significant wave height is measured as 1.0 m, with a maximum recorded wave height of 4.9 m. Figure 5 below presents a summary of the wave information obtained from COSPPac for the study area.

Between March and November the mean wave direction (the direction towards which the waves are travelling) is known to be between 300 and 330 degrees (approximately NW). During December, January and February, the mean wave direction is around 240 degrees, or approximately SW. Given the alignment of the bay within which the Lambulambu wharf is located (running approximately NW/SE), it is during this time that waves could most likely influence the operation of the wharf. The location of the wharf though is generally speaking well protected from prevailing ocean conditions.

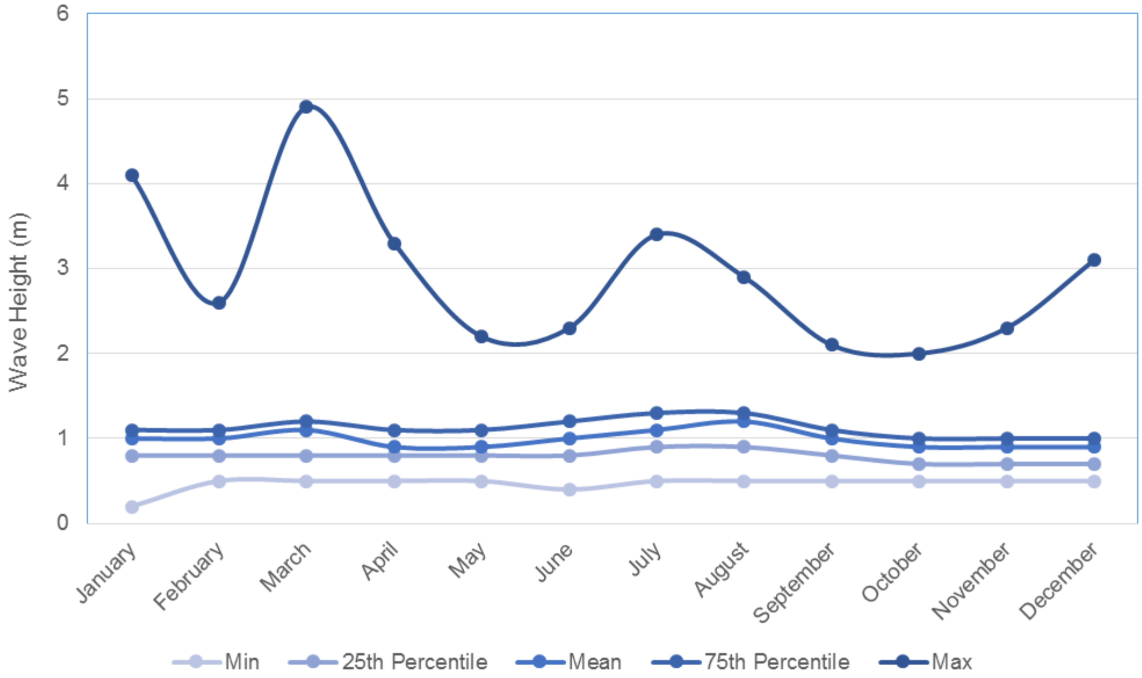

Figure 5: Summary of significant wave height information within the study area obtained from COSPPac

The term "storm tide" refers to coastal water levels resulting from the combined effects of astronomical tide and meteorological water level forcing. The meteorological component of the storm tide is commonly referred to as "storm surge" and collectively describes the variation in coastal water levels in response to atmospheric pressure fluctuations and wind setup.

Storm surge is a phenomenon which occurs only during severe weather events and results in a temporary raising of sea level caused by a combination of low atmospheric pressure and onshore wind. Reliable indications of storm surge are not available for the project area. It is known however that shelf conditions that favour high storm surges (wide gently sloping continental shelves) tend to attenuate the influence of waves, whereas the shelf conditions that attenuate storm surge (steep shelf margins) allow a larger contribution of waves (Walsh *et al*, 2012). Anecdotally, the bathymetry of this location would not facilitate large storm surge events, given the steep subsea topography, however surges of up to 1.5 m could reasonably be expected based on second hand observations (Radford and Blong, 1992).

Climate Projections

Rainfall

Based on information from the 2011 BOM and CSIRO report, annual rainfall projections indicate an increase of 2% (+/- 6%)[2] by 2030, and 9% (+/- 12%) by 2090 under a high emissions scenario. Values for the wet season are also projected to increase by 2% (+/- 7%) for 2030 and 9% (+/- 11%) by 2090 under a high emissions scenario. Similar increases are also projected for dry season rainfall. There is moderate confidence around these values.

These projected changes in rainfall also correspond to a projected decrease in drought conditions over the course of the 21st century. Modelling projects that mild drought conditions

[2] The error margin away from the indicated multi-model mean represents approximately 95% of the range of model projections.

are expected to reduce somewhat, while moderate and severe droughts are expected to remain relatively consistent with current conditions occurring on average twice and once every 20 years respectively (BOM and CSIRO, 2011).

The majority of models project that the current 1-in-20-year extreme rainfall event will occur, on average, three to four times per 20-year period by 2055 scenario and five times per 20-year period by 2090. This means that the 1 in 20 year event is going to increase in incidence to on average 1 in every 4 years by 2090.

In its 2011 discussion paper for the Australian rainfall and runoff climate change workshop, Engineers Australia noted that a number of global-scale observational studies support this projection, showing that even in areas where mean precipitation is not changing, heavy precipitation events are becoming more common (Groisman, Knight *et al*. 2005; Alexander, Zhang *et al*. 2006; Trenberth, Jones *et al*. 2007). The discussion paper notes that much of the increase in extreme rainfall is likely to occur at much finer sub-daily timescales.

Sea Level

Sea levels are expected to continue to rise in the future. By 2030 sea levels are expected to rise by up to 15 cm. By 2090 under a high emissions scenario sea levels are expected to have risen by up to 60 cm (BOM and CSIRO, 2011). There is moderate confidence around these projections.

Temperature

Annual average temperatures are projected to continue to increase over the course of the 21st century. By 2030 a minor increase in the annual average temperature of 0.7°C (+/- 0.3°C) is projected. By 2090 the increase is projected to be 2.7°C (+/- 0.6°C) under a high emissions scenario. There is high confidence around these projected values.

Projections of extreme temperatures are not available for 2030, however by 2090 under a high emissions scenario, the 1 in 20 year event is projected to increase by 2.5°C (+/- 1.8°C). There is low confidence around these projections.

Tropical Cyclones

Extreme events like tropical cyclones are rare which means there is limited data available to make assessments regarding changes in their frequency or intensity. The more rare the event the more difficult it is to establish any long-term trends or changes. Notwithstanding, drawing on information from a range of sources, the 2011 assessment by BOM and CSIRO indicated with moderate confidence that tropical cyclone numbers are projected to decline in the south-west Pacific Ocean basin during the 21st century. Despite this projected reduction in total cyclone numbers, the majority of the climate simulations used show an increase in the proportion of the most severe cyclones over this period.

Summary

Based on the information presented in the previous sections, Table 1 below provides a summary of the key climate variables considered from the observational record, and projected for the future.

Table 1: Summary of observed and projected climate variables

		Historic trend	Projected (2030)	Projected (2090)
Total annual rainfall		Variable (no statistical trend)	↗ +2% (+/- 6%)	↗ +9% (+/- 12%)
Extreme rainfall (daily)		Variable (no statistical trend)	↗ (+15 mm for 1:20 year event)	↗ (+30 mm for 1:20 year event)
Sea level rise		↗ (about 0.8 cm/year)	↗ (up to 15 cm)	↗ (up to 60 cm)
Temperature		↗ (max temperatures up 0.10°C/ten years)	↗ +0.7° C (+/- 0.3° C)	↗ +2.7° C (+/- 0.6° C)
Tropical cyclones		On average, 7 cyclones each decade within 400kms of Gizo	↘ (number of cyclones) ↗ (cyclone intensity	↘ (number of cyclones) ↗ (cyclone intensity)
Wave patterns		Historically, mean significant wave heights for the study area are 1.0 m, with a maximum recorded wave height of 4.9 m. There are no future projections of wave heights.		

4 Sensitivity screening

In the context of climate change, risk sources are the potential impacts resulting from direct changes in the climate and natural hazards patterns (mean and extreme). These changes can be both direct and indirect. Direct changes may include more frequent floods or more intense cyclones. Indirect changes can include, for example, changes to biophysical or socio-economic systems such as environmental degradation leading to increased consequences of natural hazards (e.g. degradation in mangroves and coral reefs leading to more damaging storm surge for coastal settlement). Prior to completing the risk assessment for the project, the climate variables and climate driven natural hazards (risk sources) that could impact the project were identified.

Methodology and results

An initial screening exercise was completed, to investigate the potential sensitivities of the project to climate related hazards. This process looked at the different physical components of the project, and the services they provide. In this way distinct project elements are established. For the project the following elements are relevant:

- The wharf deck – including the piles and supporting structure.
- The causeway and approach jetty – this component of the project is the key element facilitating land access to the wharf itself.
- Sea access – includes the ability of maritime traffic to approach and use the wharf.
- Coastal protection – the combination of natural features and engineered structures that contribute to the protection of the approach jetty and causeway from coastal erosion.

The results of the risk screening exercise are presented in Table 2, whereby climate driven risk sources are placed in the left hand column, and project elements are located along the top row. Relationships between these two elements were identified, and these relationships form the basis for the risk statements that are considered in the detailed risk assessment. Comprehensive identification is critical, because a risk that is not identified at this stage will not be included in further analysis. Identification should include all risks, whether or not MID can exercise any direct control over them.

Table 2: Risk screening matrix used for the project

		Project Components			
		Wharf Structure	Land Access	Sea Access	Coastal Protection
Sea	Sea level rise	×	✖	✖	✖
	Storm surge	✖	✖	✖	✖
	Surface temperature	-	-	-	-
	Ocean Acidity	×	-	-	-
	Currents	×	-	×	✖
Rainfall	Annual average rainfall	-	-	-	-
	Extreme rainfall events	-	×	-	-

		Project Components			
		Wharf Structure	Land Access	Sea Access	Coastal Protection
	Drought	-	-	-	-
Temperature	Annual average temperature	-	-	-	-
	Extreme temperature events	-	-	-	-
Atmosphere	CO_2	×	-	-	-
Wind	Cyclones	-	×	✖	-

Strong relationship (or uncertain)	✖
Potential relationship	×
No apparent relationship	-

Sensitive Project Components

An initial screening exercise was completed, indicating that the following project elements may be sensitive to climate impacts and climate change:

1. Storm Surge: Wharf Deck, Causeway and Approach Jetty, Sea Access and Coastal Protection.
2. Sea level rise: Causeway and Approach Jetty, Sea Access and Coastal Protection.
3. Currents: Coastal Protection.
4. Cyclones: Sea Access.

Risk statements

Following the completion of the screening process a number of risk statements were developed to respond to the identified sensitivities associated with the project. These risk statements represent potential scenarios that could impact on key project activities, or ultimately the ability of the project to deliver its stated objectives. These risk statements form the basis of the detailed risk assessment for the project.

1. Wharf deck design, as a result of sea level rise restricts the ability of some maritime traffic to effectively utilise the wharf
2. Existing coastal process combined with higher sea levels reduce the effectiveness of coastal protection, leading to instability of the approach jetty and causeway
3. Extreme sea levels reduce the stability of the approach jetty and causeway
4. Extreme sea levels adversely impact on the stability of the wharf
5. Tropical cyclones affect the ability of maritime traffic to utilise the wharf
6. Debris from tropical cyclones causes debris to block land access to the wharf
7. Increased levels of atmospheric CO2 lead to a faster deterioration of concrete structures
8. Extreme rainfall events causes degradation of causeway
9. Construction of the wharf structure results in changes to local currents, which in turn affect stability of approach jetty and causeway
10. Sea level rise affects the stability of the wharf structure

5 Risk assessment

Overview

In its simplest form, probabilistic risk assessment defines risk as the product of the adverse consequences of an event and the probability or likelihood that the event will occur.

Risk = Consequence x Likelihood

For instance, the risk to a bridge from flooding might be calculated based on:

- The value placed on the economic disruption and access to services, and the cost to repair or replace the structure.

Multiplied by:

- The likelihood that the river floods above a certain design level, inflicting damage to the structure and disrupting the local community's economic livelihood, and access to key services.

Hazard, exposure, and vulnerability contribute to 'consequences.' Hazard and vulnerability also both contribute to the 'likelihood': Hazard to the likelihood of the physical event (e.g., the river flooding) and vulnerability to the likelihood of the consequence resulting from the event (e.g., economic disruption).

Results

For each risk assessed a level of likelihood and consequence is estimated, and the resultant risk level is established. It is important to note that the risk assessment for the project is based on a pre-adaptation, in other words base case, or business as usual specification. It is expected that the key risks identified can either be managed through climate informed design, or the development of specific adaptation measures to be incorporated into the project. The complete risk assessment for the project, including the descriptors for determining the likelihood and consequences of the identified risk statements is presented in Appendix A. The analysis indicated that the majority of the risks were low or medium. One risk scenario was identified as being high risk. No extreme risks were identified.

Risk Evaluation

The *MID Transport Sector Climate Adaptation Guidelines* (in preparation) stipulate different management actions depending on the level of risk identified. The level of risk and corresponding response are represented below:

Table 3: Levels of risk, and required responses

Level of Risk	Required Response
Low	- Low risks should be maintained under review but it is expected that existing controls should generally be sufficient and no further action should be required to treat them unless they become more severe. - These risks can be acceptable without treatment.
Medium	- Medium risks could be expected to form part of routine operations but they should be assigned to relevant managers for action, maintained under review and reported upon at middle management level. - These risks are possibly acceptable without treatment.

Level of Risk	Required Response
High	- High risks are the most severe that can be accepted as a part of routine operations without MID sanction but they should be the responsibility of the senior operational management and reported upon to the Director. - These risks are not acceptable without treatment.
Extreme	- Extreme risks demand urgent attention at the most senior level and cannot be simply accepted as a part of routine operations without MID sanction. - These risks are not acceptable without treatment.

On this basis, the only high risk issue to emerge from the risk assessment involves a reduction in the ability of some maritime traffic to effectively use the wharf as a result of sea level rise and the design of the wharf deck. This risk is identified as being unacceptable without some form of treatment.

6 Adaptation options

Introduction

Failure to manage the key risks identified in Section 5 above could result in a number of significant consequences, as outlined in the risk assessment for the project in Appendix A. These consequences could present substantial costs to the community, MID and the broader Solomon Islands government in the form of:

- The cost of repairs and increased maintenance costs to the wharf, throughout the design life.
- The need to utilise other more costly forms of transport, especially during periods of emergency response.
- Reduced community access to essential health and educational services, and economic markets.

These damages and costs would result if insufficient action is taken to address the identified risks. If action is taken to address the identified risks, then some proportion of the damages and costs outlined above would be reduced. These avoided costs would be expected to form part of the benefits of treating the key risks to emerge from the risk assessment.

Process for considering options

To formulate appropriate treatment recommendations for the key risk emerging from the risk assessment a number of potential options were considered. The options were considered against a range of criteria to establish a shortlist of potentially feasible options. The criteria considered aspects of:

- Local Support.
- Feasibility, Practicality.
- Effectiveness.
- Environment, Sustainability.
- Indicative Cost.
- Durability, Longevity.
- Maintenance Requirements.
- Timeframe until Effective.

Options that were deemed appropriate as a result of this screening analysis were then put forward as recommendations for the project.

Level of service under a sea level rise scenario

Based on ADB requirements the wharf should be constructed 1500 mm above the Mean High Water Mark (MHWM), plus 200 mm for projected sea level rise. Early in the project this design could limit small vessel access at low tide, while at the end of the design life (50 years) larger vessels could be impacted at high tide as a result of sea level rise.

Sea levels have risen on average around 8 mm each year. By 2055 (within the design life of the project) sea levels are expected to be 300mm higher than 1990 levels. On current trends, at the end of the design life of the project, sea levels could be up to 400 mm higher than 1990 levels.

The treatment of this key risk considered a number of potential options to ensure that a range of maritime traffic is able to effectively use the wharf at all times throughout the life of the project. The options considered are presented in Table 4.

Table 4: Options to maintain level of service under a sea level rise scenario.

Options:	**Name:**	**Brief Description/Comments:**
Option 1	Higher Wharf Deck	Lifting the wharf deck to be consistent with the design objectives at the end of the 50 year design life, i.e. 1500mm above the mean high water mark. This would mean adding up to an approximate 400mm to the design height to account for projected sea level rise.
Option 2	Higher Wharf Deck with Floating Jetty	Lifting the wharf deck to be consistent with the design objectives at the end of the 50 year design life, i.e. 1500mm above the mean high water mark, with an additional component of a floating jetty attached to the wharf deck to allow for smaller vessels to effectively use the wharf in the short term.
Option 3	Do Nothing	Maintain the status quo, i.e. no new wharf construction.
Option 4	Wharf Deck for current conditions (basecase)	Build the wharf to be 1500mm above the current mean high water mark plus an additional 200mm to account for sea level rise (as per ADB requirements, *ADB Environmental Assessment and Review Framework, 2012*)
Option 5	Build two wharves	Stage the building of two wharfs, each with a shorter design life, the first wharf built to current conditions, and the second wharf built in some 25 years to future conditions.
Option 6	Wharf that can be retrofitted	Build a wharf to current conditions, but with the ability to have an additional deck added in the future to respond to sea level rise. This would require stronger piles to be able to support the increased weight of an additional deck.

The results of the analysis (see Appendix B) against the criteria showed that only three of the options were worth considering further for the project, namely:

- Higher wharf deck.
- Higher wharf deck with floating jetty.
- Wharf deck for current conditions (base case).

7 Economic Considerations

The risk assessment highlighted a number of potential adaptation options for the Lambulambu wharf rehabilitation project. As a result of the shortlisting process (see Appendix B) three were considered significant enough to warrant further analysis.

A cost benefit analysis was finalised in 2013 prior to the preparation of the climate change risk assessment (Economic Appraisal Lambulambu Wharf Rehabilitation, October 2013). The analysis was conducted in accord with ADB economic appraisal guidelines. It identified a set of benefits providing a justification for rehabilitating the wharf, which included:

- Savings in ship operating costs while in port
- Induced local agricultural and marine production
- Value of time saved by persons in loading and unloading export and import cargoes
- Reduction in cost of fares incurred by the community
- Income generated as a result of additional agricultural and marine production
- Income generated through increased local market activity; and
- Income generated local participation in the annual maintenance activities.

Construction and maintenance costs were estimated based using recent contract costs reported from other tender responses. The estimated present value of construction and maintenance costs for the project was estimated at $9.52 million (12% discount rate over 40 years) with over 90% occurring in year 1. Design standards adopted for the analysis recognized the following needs:

- Location, dimensions and water depth to enable accessibility by regular interisland trading ships operating locally and connecting to Gizo, Noro and Honiara;
- Durable standards to withstand climatic, environmental and seismic activity;
- Safe conditions and facilities for loading and unloading cargo and passengers; and
- Connectivity between wharf, local export storage sheds and commercial premises.

Based on the above streams of benefits and costs, the base case project economic internal rate of return (EIRR) and economic net present value (ENPV) results of the project are as follows:

- ENPV over 20 years - $2.3 million
- EIRR over 20 years 8.5%
- ENPV over 40 years $0.1 million
- Adjusted EIRR over 40 years 12.1%.

The project is estimated to have an overall EIRR of 12.1%, which is marginally above the usual threshold of 12%.

While the analysis considered climatic (weather) elements, an assessment of climate change risks were not modelled in the economic streams of benefits and costs.

There are two factors to consider. First, as the asset is intended to be a long lived piece of infrastructure, an extended appraisal period is warranted. This does expose realisation of later-year benefits to significant climate change impacts. Second, the ADB has recognized an 8% real discount rate is appropriate for countries like the Solomon Islands that are part of a fragile or conflict group of countries identified by the ADB. On that basis the ENPV is likely to be some $2.7 million higher over the first 20 year period, assuming costs and benefits remain unchanged. Realising an 8% EIIR target over this period means the project could potentially sustain additional climate change related capital expenditures of this amount up front to minimize the risk of securing later-year benefits.

In the absence of detailed design information, a high level review of economic issues relating to each of these adaption options in presented in the table below. The purpose of this is to show how further net economic benefits may be gained by incorporating climate change into the engineering considerations of this wharf rehabilitation project.

Table 5: Qualitative assessment of climate change adaptation option costs and benefits.

Options:	Name:	Qualitative comments on costs and benefits:
Option 1	Higher Wharf Deck	**Costs**: Minimal additional construction costs could be expected. Altering the height of the wharf deck by up to 400mm is not expected to add any measurable cost to the project, as it will only require an increase in the length of the piles, with no changes expected to the wharf deck or the approach or causeway. **Benefits**: Design life would be realised, so a major benefit could be measured in terms of additional years of use of the asset. However this may be partially offset by reduced short term access to the higher wharf by smaller marine craft. The decision on the ultimate height of the wharf deck therefore needs to be the subject of consultation with the local community and relevant users of the wharf. This consultation should establish the optimum height, taking into consideration sea level rise and utility in the short and long term.
Option 2	Higher Wharf Deck with Floating Jetty	**Costs**: Construction costs could be expected to be higher than for Option 1. Ongoing maintenance costs are likely to be marginally higher than for Option 1. Adding a floating jetty to the wharf would however add an additional cost to the project. It is expected to be minor in the context of the project, adding in the order of 2-3% of the total project cost estimate – approximately $2M - $3M. **Benefits**: Full design life would be realised, so a major benefit could be measured in terms of additional years of use of the asset. Final determination of the need or otherwise for this measure should be made on both the basis of the economic analysis, and consultation with the local community.
Option 4	Wharf Deck for current conditions (basecase)	**Costs**: Construction costs could be expected to be similar to Option 1 with some minor savings on materials. Operating costs would not be dissimilar to Option 1. **Benefits**: Full 50 year design life will not be realised but service life would be improved on a ‘do nothing’ option. Small marine craft access to the wharf would need to be assessed together with potential use by the local community.

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Appendix A – Risk Assessment

Table 6: Risk matrix used as part of the MID climate risk assessment process

		Consequences				
		Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Catastrophic (5)
Likelihood	Almost certain (5)	Medium (5)	Medium (10)	High (15)	Extreme (20)	Extreme (25)
	Likely (4)	Low (4)	Medium (8)	High (12)	High (16)	Extreme (20)
	Possible (3)	Low (3)	Medium (6)	Medium (9)	High (12)	High (15)
	Unlikely (2)	Low (2)	Low (4)	Medium (6)	Medium (8)	Medium (10)
	Very Unlikely (1)	Low (1)	Low (2)	Low (3)	Low (4)	Medium (5)

Table 7: Details for different likelihoods used in the risk assessment

Descriptor	Recurrent risks / Single events
Very Unlikely	Recurrent Events: Unlikely during the next 25 years. Single Events: Negligible / Probability very low Probability: < 15%
Unlikely	Recurrent Events: May arise once in 10 years to 25 years. Single Events: Unlikely but not negligible / Probability low but noticeably greater than zero. Probability: 16%−35 %
Possible	Recurrent Events: May arise once in 10 years. Single Events: Less than likely but still appreciable Probability: 36%−59%
Likely	Recurrent events: May arise about once per year. Single events: More likely than not Probability: 60%−84%
Almost Certain	Recurrent events: Could occur several times per year. Single events: Noticeably more likely than not Probability: > 85%

Table 8: Descriptions of different consequence levels utilised for the risk assessment

Consequence	Description
Insignificant	Infrastructure: No immediate loss of service Financial Loss: Asset damage < $ 100K. Reputation: Some public awareness. Livelihoods: Negligible or no impact on the livelihood system. Health/Safety: Negligible or no changes to the public health profile or fatalities as a result of extreme events. Industry: Any impacts can be absorbed within existing systems.
Minor	Infrastructure: Localised infrastructure service disruption / No permanent damage / Some minor restoration work required. Financial Loss: Asset damage between $100K and $500K. Reputation: Some adverse news in the local media / Some adverse reactions in the community. Livelihoods: Isolated and temporary disruption to an element of the livelihood system. Health/Safety: Slight changes to the public health profile or isolated increases in fatalities as a result of extreme events. Industry: Isolated and temporary disruption to a key economic element.
Moderate	Infrastructure: Widespread infrastructure damage and loss of service / Damage recoverable by maintenance and minor repair / Partial loss of local infrastructure. Financial Loss: Asset damage between $500K and $2 million. Reputation: Adverse news in media / Significant community reaction. Livelihoods: Localised and temporary disruption to an element of the livelihood system, leading to the requirement of supplemental inputs. Health/Safety: Noticeable changes to the public health profile or localised increases in fatalities as a result of extreme events. Industry: Short-term and localised disruption to a key economic element.
Major	Infrastructure: Extensive infrastructure damage requiring extensive repair / Permanent loss of local infrastructure services. Financial Loss: Asset damage between $2 million and $5 million. Reputation: Damage to reputation at national level; adverse national media coverage; Government agency questions or enquiry; significant decrease in community support. Livelihoods: Widespread and reversible or localised and permanent impacts to core elements of the livelihood system. Health/Safety: Marked changes in the public health profile or widespread increases in fatalities as a result of extreme events. Industry: Widespread and reversible or localised and permanent disruption to a key economic element.

Consequence	Description
Catastrophic	Infrastructure: Permanent damage and/or loss of infrastructure service / Retreat of infrastructure. Financial Loss: Asset damage > $5 million. Reputation: Irreversible damages to reputation at the national and even international level / Public outrage. Livelihoods: Core elements of the livelihood system are permanently impacted. Health/Safety: Substantial changes to the public health profile or substantial increases in fatalities as a result of extreme events. Industry: Widespread and permanent disruption to a key economic element.

#	Risk Statement	Risk Level	Score	Consequence	Consequence Statement	Likelihood	Likelihood Statement
1	Wharf deck design, as a result of sea level rise restricts the ability of some maritime traffic to effectively utilise the wharf	High	12	Moderate	Based on ADB requirements the wharf should be constructed 1500mm above the MHWM, plus 200mm for projected sea level rise. Early in the project this design could limit small vessel access at low tide, while at the end of the design life (50 years) larger vessels could be impacted at high tide as a result of up to 400mm sea level rise.	Likely	Sea levels have risen on average around 8mm each year. By 2055 (within the design life of the project) sea levels are expected to be 300mm higher than 1990 levels. At the end of the design life of the project, sea levels could be up to 400mm higher than 1990 levels.
2	Existing coastal process combined with higher sea levels reduce the effectiveness of coastal protection, leading to instability of the approach jetty and causeway	Medium	6	Moderate	Unmanaged coastal erosion could impact on the stability of approach jetty and the causeway reducing ease of land access, and requiring remedial maintenance. Impacts could affect the movement of good to and from the wharf.	Unlikely	Sea level rise over the course of the project will shift the wave impact zone higher, potentially causing additional impacts to the causeway and approach jetty. However, given the location of the wharf within a well protected inlet, these impacts are not considered likely.
3	Extreme sea levels reduce the stability of the approach jetty and causeway	Medium	6	Moderate	Storm surge could impact on the stability of approach jetty and the causeway reducing ease of land access, and requiring remedial maintenance. Impacts could affect the movement of good to and from the wharf.	Unlikely	Storm surge as a result of tropical cyclones is considered unlikely as Gizo receives a long term average of less than one cyclone per season.
4	Extreme sea levels adversely impact on the stability of the wharf	Medium	8	Major	A significant storm surge event could adversely impact the stability of the wharf, or even result in extensive damage.	Unlikely	Details of historical storm surge in the area are not known. Anecdotally, the bathymetry of this location would not facilitate large storm surge events, given the steep subsea topography. Although waves on top of storm surge could compound this risk, given the sheltered location of the wharf, substantial wave influence is not expected.

#	Risk Statement	Risk Level	Score	Consequence	Consequence Statement	Likelihood	Likelihood Statement
5	Tropical cyclones affect the ability of maritime traffic to utilise the wharf	Medium	8	Minor	During cyclones, access to the wharf by maritime traffic is expected to be restricted, resulting in localised and temporary disruption	Likely	Gizo receives a long term average of seven cyclones per decade. Notwithstanding this during cyclones, maritime traffic will be temporarily disrupted.
6	Debris from tropical cyclones causes debris to block land access to the wharf	Low	4	Insignificant	Cyclones result in the deposition of a range of debris from destroyed vegetation and buildings. Such debris could cause temporarily impede access to the wharf.	Likely	Gizo receives a long term average of less than one cyclone per season. Although the number of cyclones are projected to decline, there is a projected increase in the proportion of the most intense storms. Such events are expected to cause localised debris issues.
7	Increased levels of atmospheric CO_2 lead to a faster deterioration of concrete structures	Medium	9	Moderate	Deterioration of structures can place greater tensile stresses on the concrete causing cover cracking and eventually spalling and loss of structural capacity. This could eventually result in expensive maintenance or failure of the structure, during which time disruptions could be experienced by industry and community.	Possible	CO_2 levels are expected to rise in line with economic growth. The deterioration of concrete structures can be affected directly or indirectly by climate change that is linked to the change in CO_2 concentration, temperature and relative humidity.
8	Extreme rainfall events causes degradation of causeway	Low	4	Minor	Extreme rainfall could influence the stability of the short causeway, although being coronus, and fail short (approx. 75m) any impacts (if occurring) would likely be very localised, and relatively straightforward to amend.	Unlikely	Climate projections indicate extreme rainfall days are likely to occur more often. Notwithstanding this, the causeway is short, and unlikely to suffer substantial damage given its construction type.

#	Risk Statement	Risk Level	Score	Consequence	Consequence Statement	Likelihood	Likelihood Statement
9	Construction of the wharf structure results in changes to local currents, which in turn affect stability of approach jetty and causeway	Low	2	Minor	Placement of the piles for the wharf could influence local currents, altering the dynamics of local erosion and deposition patterns. Theses changes could affect the stability of the causeway, and approach jetty.	Very Unlikely	The wharf piles are not expected to substantially alter local currents such that local erosion could occur. The proposed piles are relatively slender, and allows water to pass through the structure.
10	Sea level rise affects the stability of the wharf structure	Low	1	Insignificant	The wharf is designed as a piled structure. Sea level rise itself is not expected to result in any direct impacts to the structure.	Very Unlikely	Although sea level rise is almost certain, it is very unlikely that this alone will adversely impact the wharf structure.

Appendix B – Review of Adaptation Options

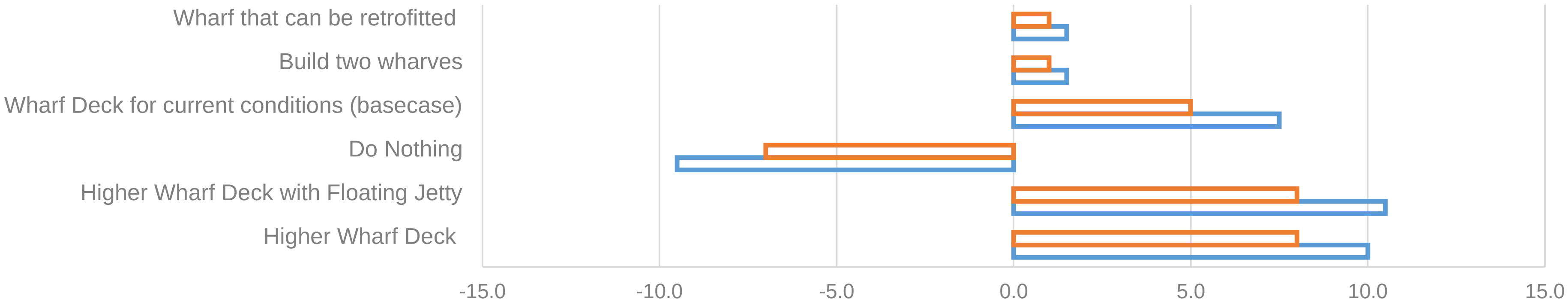
Project Name:	Lambulambu Wharf Rehabilitation

Risk to be treated:	Wharf deck design, as a result of sea level rise restricts the ability of some maritime traffic to effectively utilise the wharf

Options:	Name:	Brief Description/Comments:
Option 1	Higher Wharf Deck	Lifting the wharf deck to be consistent with the design objectives at the end of the 50 year design life, i.e. 1500mm above the mean high water mark. This would mean adding up to an approximate 400mm to the design height to account for projected sea level rise.
Option 2	Higher Wharf Deck with Floating Jetty	Lifting the wharf deck to be consistent with the design objectives at the end of the 50 year design life, i.e. 1500mm above the mean high water mark, with an additional component of a floating jetty attached to the wharf deck to allow for smaller vessels to effectively use the wharf in the short term.
Option 3	Do Nothing	Maintain the status quo, i.e. no new wharf construction.
Option 4	Wharf Deck for current conditions (basecase)	Build the wharf to be 1500mm above the current mean high water mark plus an additional 200mm to account for sea level rise (as per ADB requirements, *ADB Environmental Assessment and Review Framework, 2012*)
Option 5	Build two wharves	Stage the building of two wharfs, each with a shorter design life, the first wharf built to current conditions, and the second wharf built in some 25 years to future conditions.
Option 6	Wharf that can be retrofitted	Build a wharf to current conditions, but with the ability to have an additional deck added in the future to respond to sea level rise. This would require stronger piles to be able to support the increased weight of an additional deck.

Assessment Criteria		Importance
1	**Local Support**	**Very Important**
2	**Feasibility, Practicality**	**Important**
3	**Effectiveness**	**Very Important**
4	**Environment, Sustainability**	**Less important**
5	**Indicative Cost**	**Very Important**
6	**Durability, Longevity**	**Important**
7	**Maintenance Requirements**	**Important**
8	**Timeframe until Effective**	**Less important**

	Local Support	Feasibility, Practicality	Effectiveness	Environment, Sustainability	Indicative Cost	Durability, Longevity	Maintenance Requirements
Higher Wharf Deck	Good	Very Good	Good	Neutral	Neutral	Very Good	Very Good
Higher Wharf Deck with Floating Jetty	Very Good	Very Good	Very Good	Neutral	Poor	Good	Good
Do Nothing	Very poor	Very poor	Very poor	Good	Good	Very poor	Good
Wharf Deck for current conditions (basecase)	Very Good	Very Good	Neutral	Neutral	Neutral	Neutral	Very Good
Build two wharves	Good	Good	Good	Poor	Very poor	Neutral	Good
Wharf that can be retrofitted	Good	Neutral	Neutral	Poor	Poor	Good	Good



	Higher Wharf Deck	Higher Wharf Deck with Floating Jetty	Do Nothing	Wharf Deck for current conditions (basecase)	Build two wharves	Wharf that can be retrofitted
Unweighted	8.0	8.0	-7.0	5.0	1.0	1.0
Weighted Score	10.0	10.5	-9.5	7.5	1.5	1.5

Appendix C – Plates

Plate 1: Location of proposed wharf structure at the end of existing informal coral causeway

Plate 2: Looking from the existing informal coral causeway inland from the location of the proposed wharf

Plate 3: Fragmented mangrove vegetation adjacent to the location of the proposed wharf

Plate 4: Condition of the existing Lambulambu Wharf in 2012

Plate 5: Approximate extent of proposed causeway to the new wharf, taken from draft *Public Environment Report*, 2013