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Naro Hill to Lambi Road Rehabilitation

Climate Risk and Adaptation Assessment

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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 Naro Hill to Lambi road rehabilitation (the project) is one of the priority projects for the TSDP.

The objectives of this report are to:

- 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.

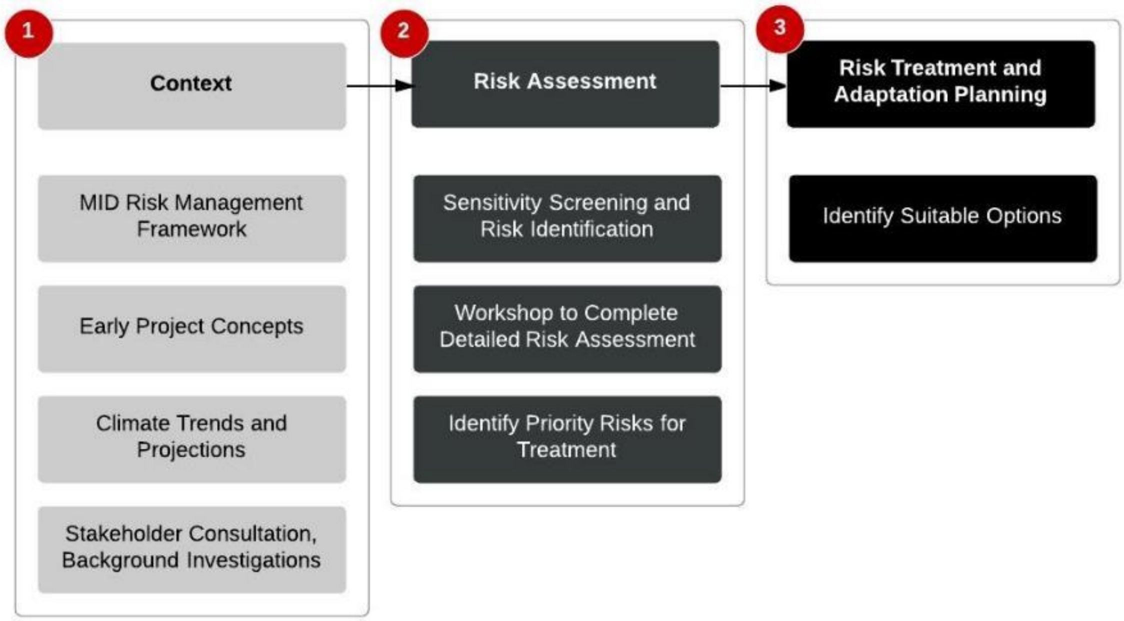

Figure 1: Overview of approach to complete the climate risk and adaptation assessment

2 Description of the project

The project is located in Guadalcanal Province, along the western coast of the island. The project is generally aligned north-south, and is approximately 16 km in length. The majority of the project is within close proximity to the coast and varies in elevation from near sea level to approximately 25 m above sea level. Figure 2 provides an indication of the project location.

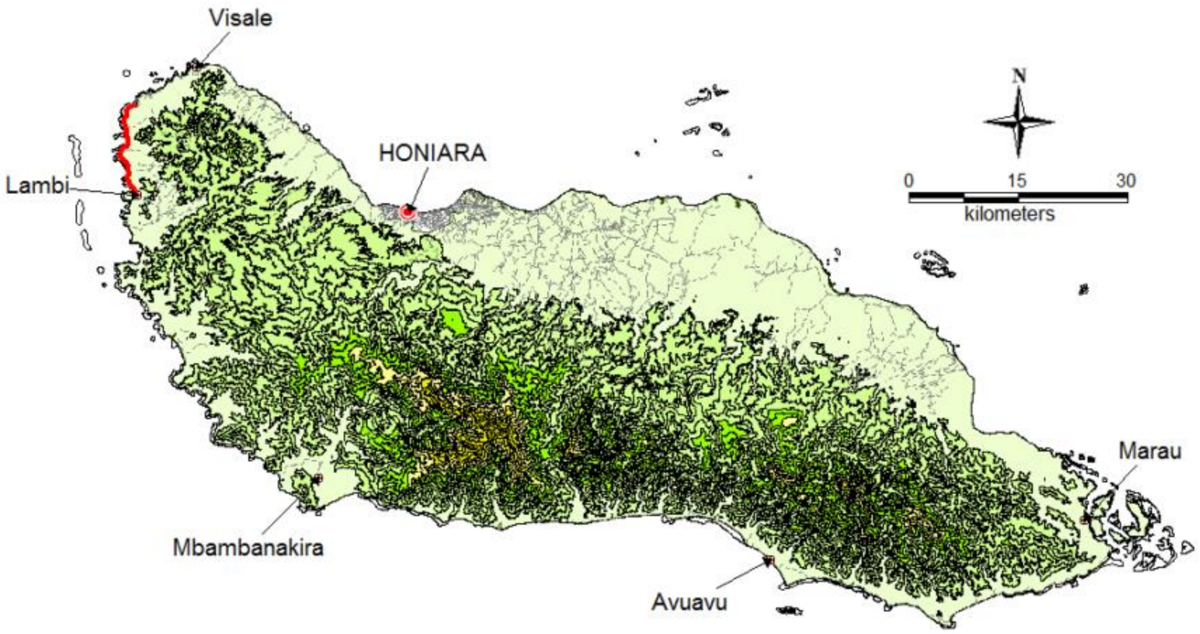

Figure 2: Approximate location of the Naro Hill to Lambi road rehabilitation project

Construction would require the formation of the road, excavation and possible removal of incompetent materials, provision of cross drainage, and supply of base and surface materials. For the entire length of the road, an application of 150mm thick gravel pavement is proposed. During construction, the contractor will determine the source of materials; however, it is possible that road base materials may be supplied from a quarry alongside the road while aggregate may be sourced from deposits within the bed of the Charupehe River.

The upgrading works are proposed to involve construction of crossings across main rivers (Charupehe, Malgili and Bora Rivers) and other smaller and unnamed watercourses. The Bora River crossing, and crossings at Bahi and Lambi are all located within close proximity to the coastline, and may be subject to coastal erosion during times of extreme sea levels.

Local environment

The Naro Hill-Lambi Road intersects approximately 19 river and stream systems, the majority which flow west. The mouths of the streams are often characterized by the presence of beach bars which pond up the rivers and may limit the flow or divert exiting water to one side. During peak flow periods, they may break through and be subsequently built up by long-shore and beach building processes during the intervening periods.

Around Lambi Bay near the southern end of the project, much of the coastline is in an erosional or neutral state. There are clear signs of tree loss from the shorelines, particularly in the area near Tapou School where the road runs very close to the shoreline (see Figure 3). On the southern part of Lambi Bay there were some areas of apparent accretion.

Figure 3: Example of existing coastal erosion on the northern side of Lambi Bay looking north at low tide

Around the project area, the dominant marine ecosystems are narrow fringing coral reefs, landward of which are developed back-reef and sea-grass areas. Small patches of sandy lagoon habitats occur where the reef interacts with outflow from streams and small coastal lagoons have formed at the mouth of many of the rivers.

The Naro Hill to Lambi road runs along the coast and traverses areas of what would have been lowland coastal forest, small pockets of freshwater swamp and even smaller pockets of mangroves near the mouth of rivers. The road is located in a continuous and narrow coastal alluvial area defined at its landward end by higher volcanic outcrops that has been heavily affected by village development, subsistence activities, as well as commercial activities such as coconut and cocoa plantations, and more recently commercial logging. The vegetation is now largely degraded coastal lowland forest vegetated with coconut and cocoa plantations, and interspersed with subsistence gardens and regenerating scrubland. Where there are no gardens or plantations, the coastal forest usually comprises *Callophyllum sp*, *Barringtonia asiatica*, *Macaranga sp*, *Morinda citrifolia*, *Pometia, Ficus* and Terminalia species.

Cocoa and coconut plantations that are scattered round the island are the main commercial land use, and prior to the ethnic tensions there was a copra buying points at Lambi.

There is more economic activity on the north coast and in other locations with access to Honiara than on the Weather Coast. Subsistence food production is important, with the main crops being sweet potato, cassava and banana. The main sources of cash income for villagers and settlers are sales of fresh food and animals at Honiara market and other locations, as well as copra and cocoa production. There has previously been significant agricultural development in North Guadalcanal with both small-holder agriculture and large-scale estate development. The latter includes production of copra, cocoa, rice, cattle, and oil palm.

The main livelihood activity on the Weather Coast is subsistence food production, with sweet potato as the staple food. Food supply tends to be disrupted in the wettest months (May to September) each year. There is very limited cash income, and few opportunities for earning cash. A little copra is now being produced on the Weather Coast and small quantities of betel nut are sold into Honiara.

At the time of writing, a logging company had recently been operating in the Marumbo area, moving vehicles through the study area. These activities are likely to have resulted in changes to the behaviour of catchments in the study area, contributing to increases in debris loads during extreme rainfall events. The contractor has a log port at Marumbo and has, in the past, built and maintained log bridges and parts of the road. Anecdotally, a proportion wear and tear of the Naro Hill to Lambi road could be attributed to the passage of these large vehicles.

There are only two schools along the Naro Lambi Road, Ngalimuata Primary School and Lambi Community High School.

Limitations

This assessment has been prepared as part of the development of the project, and was based on preliminary design concepts for the road carriageway and watercourse crossing structures. Detailed designs for the project are yet to be developed. This assessment utilised available survey for the project, but was unable to confirm the vertical datum for this survey. For this reason an assumption has been made that the vertical datum for the survey be taken as Mean Sea Level.

Given the coarse nature of available topographic data for the broader project area (circa 10m vertical resolution), detailed mapping has not been undertaken. Climate projections used, while being the best available, are derived from global models typically at coarse resolution, and therefore unable to reliably represent local fluctuations in rainfall as a result of elevation or topographical influences. For these reasons, hydrology calculations made as part of the hydrology investigations do have some inherent limitations.

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 Honiara, some 40 km east. This station located close to sea level, is unlikely to provide representative rainfall information for part of the study area, particularly the upper catchments, however is the best 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

Rainfall at the Honiara station is marked by a distinct wet (November to April) and dry season (May to October). The wet season typically account for almost 70% of the total annual rainfall, with average monthly totals up to 300 mm. During the dry season, monthly rainfall averages are around 100 mm per month. Over the course of records from 1950 to 2009, rainfall observations in Honiara show no significant statistical trends.

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 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).

Temperature

Based on observations in Honiara the temperature is relatively uniform ranging from an average minimum of 23°C to an average maximum of 31°C throughout the and an overall average temperature of 27°C. Relative humidity shows little seasonal variation but has marked diurnal fluctuation. Humidity is highest in the morning and frequently reaches 90%.

Over the course of the observational record from 1951, a warming trend is evident for the Honiara station. Maximum temperatures have increased at a rate of approximately 0.15°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, 41 tropical cyclones passed within 400 km of Honiara (BOM and CSIRO, 2011). Historical tropical cyclone tracks to have passed in the vicinity of the Solomon Islands are shown in Figure 4. 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 one cyclone per season (see Figure 5). Tropical cyclones were most frequent in El Nino years, and least frequent during La Nina years.

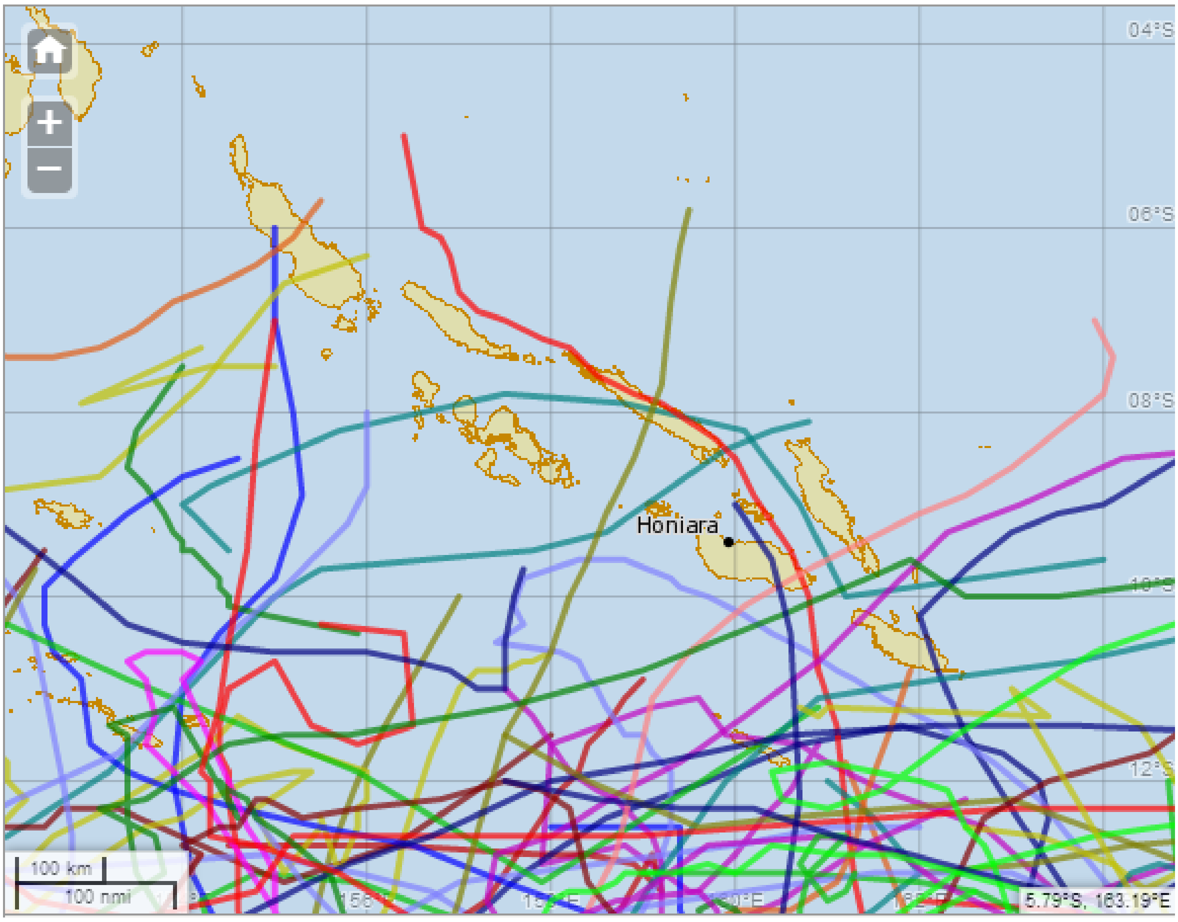

Figure 4: Historical tropical cyclone tracks recorded from 1969/70 - 2010/11 (BOM, 2013)

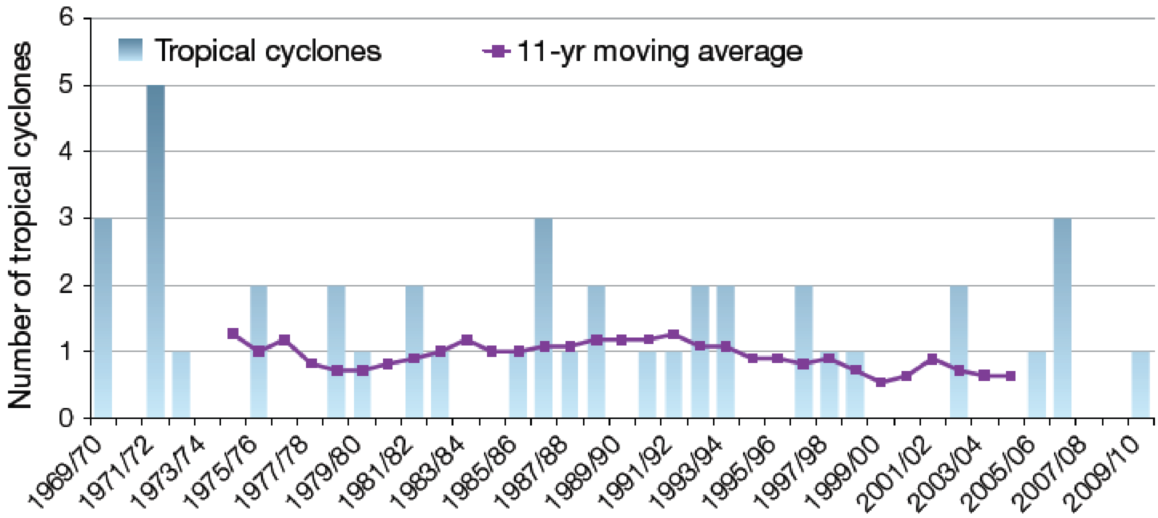

Figure 5: Number of tropical cyclones passing within 400 km of Honiara (BOM and CSIRO, 2011)

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 5.7 m. Figure 6 below presents a summary of the wave information obtained from COSPPac for the study area.

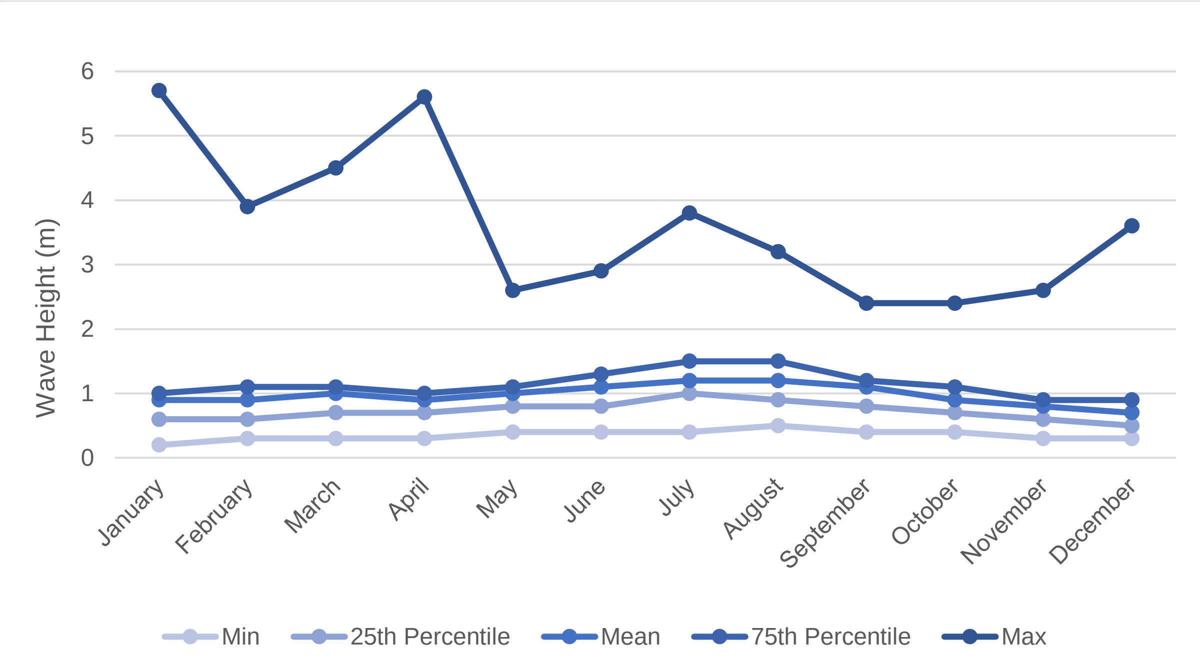

Figure 6: Summary of significant wave height information within the study area obtained from COSPPac

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%)[1] 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 (worst case) 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 are expected to become less frequent, while the frequency of 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 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.

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

On the basis that Mean Sea Level (MSL) is taken as the datum for the survey used in the project (see Section 2), then it is expected that pavement areas below 1.03 m could be inundated within the life of the project (i.e. 2030).

Temperature

Annual average temperatures are projected to continue to increase over the course of the 21st century. By 2030 an 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. Although there is a 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 0.15° C/ten years)	↗ +0.7° C (+/- 0.3° C)	↗ +2.7° C (+/- 0.6° C)
Tropical cyclones		On average, 10 cyclones each decade within 400kms of Honiara	↘ (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 5.7 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:

- Major Watercourse Crossings – Structures built to cross waterways that drain catchments greater than 4 km^2.
- Minor Watercourse Crossings – Watercourse crossings of catchments that are smaller than 4km^2 and minor drainage infrastructure, e.g. pipes and minor culverts.
- Road Corridor (obstructions) – Relates to the road pavement, and the ability of traffic to effectively travel between Lambi and Naro Hill. Any obstructions in the road corridor could limit the ability of traffic to use the road, and thereby reduce the level of service of the project.
- Unsealed pavements – The form of the road pavement proposed for the project.

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

		Component			
		Major Watercourse Crossings	Unsealed pavements	Minor Watercourse Crossings	Road corridor (obstructions)
Sea	Sea level rise	x	x	x	-
	Storm surge	x	x	x	x
	Surface temperature	-	-	-	-
	Ocean Acidity	x	-	-	-
	Currents	-	-	-	-

		Component			
		Major Watercourse Crossings	Unsealed pavements	Minor Watercourse Crossings	Road corridor (obstructions)
Rainfall	Annual average rainfall	✗	-	✗	-
	Extreme rainfall events (flooding)	✘	✘	✘	✗
	Drought	-	-	-	-
Temperature	Annual average temperature	-	-	-	-
	Extreme temperature events	✗	-	-	✗
Atmosphere	CO_2	✗	-	✗	-
Wind	Cyclones	✗	-	✗	✘

Strong relationship (or uncertain)	✘
Potential relationship	✗
No apparent relationship	-

Sensitive Project Elements

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

1. Storm Surge: Watercourse crossings and bridges; low lying unsealed pavements.
2. Sea level rise: Low lying unsealed pavements
3. Extreme Rainfall: Watercourse crossings; unsealed pavements; minor drainage infrastructure
4. Cyclones: Road corridor

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.

Road Pavements

1. Increase in extreme rainfall, causes greater degree of pavement erosion impeding vehicle access
2. High tides inundate low lying pavements causing accelerated degradation

3. Road pavement in low lying areas is subject to temporary inundation following storm events, impeding vehicle access
4. Storm surge and wave action generally on top of a high tide and sea level rise causes substantial damage to road pavement in low lying areas.
5. Increased variation in wet/dry spells and decrease in available moisture may cause degradation of road pavement
6. Increase in mean sea levels cause a reduction in the effectiveness of coastal vegetation buffer, leading to damage of road pavement and structures from coastal erosion

Road Corridor

7. Increased severity of tropical cyclones results in greater road corridor obstructions as a result of storm debris
8. Increase in extreme rainfall events leads to a greater incidence of landslides and mudslides that damage pavements and drainage structures, and impede vehicle access.
9. Increase in extreme rainfall results in more debris impeding road access

Watercourse Crossings

10. Increase in extreme rainfall results in greater loads of flood debris, higher flow velocity and catastrophic failure of minor watercourse crossing structures
11. Increase in extreme rainfall leads to failure of bridge and culvert embankments impeding vehicle access
12. Increase in extreme rainfall results in greater loads of flood debris, higher flow velocity and catastrophic failure of major watercourse crossing structures
13. Minor watercourse crossings within close proximity to the shoreline are subject to increased scour from storm surge, leading to reduced effective design life.
14. Major watercourse crossings within close proximity to the shoreline are subject to increased scour from storm surge, leading to reduced effective design life.
15. Increased levels of atmospheric CO_2 lead to faster deterioration of concrete structures, and a reduced effective design life.
16. Increase in extreme temperature events causes thermal expansion in bridges and a reduction in effective design life
17. Increased severity of tropical cyclones results in greater loading on bridge structures
18. Increased tropical cyclone severity and extreme rainfall results in greater blockages of minor drainage infrastructure, and the need for increased maintenance.
19. Increase in ocean acidity causes accelerated degradation of bridge piers

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 over two thirds of the risks assessed were low or medium. Five risk scenarios were 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.

The key issues to emerge from the risk assessment (high risk issues) are:

1. Damage to low lying pavements from both temporary and permanent inundation, and increased instability of sections of pavement resulting from coastal erosion.
2. Failure (or reduced design life) of major watercourse crossings (namely the Chaurpehe, Bora, and the Malhjili) from extreme rainfall induced flooding and scour, and associated debris impacts, and in the case of the Bora, Bahi and the Lambi Bailey Bridge, also from potential impacts of exacerbated coastal erosion.

These risks are 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 road network and major watercourse crossing structures following storm events, flooding and coastal erosion.
- Provision of flood relief supplies following severance of communities as a result of watercourse crossing failures.
- 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 risks 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. The treatment of the key risks emerging from the risk assessment is discussed below in the following sections dealing with low lying pavements, major watercourse crossings, and coastal bridges.

Low lying pavement areas

Low lying pavement areas could be subject to inundation from rising sea levels, and in locations close to the coast would likely be increasingly exposed to the erosive forces of the coastal zone. For the purposes of this assessment (and noting the limitations identified in Section 2 with respect to the vertical survey datum), areas of natural ground below 1.03 m were identified as being “low lying”. This is the level of the high tide that could be expected to occur by 2030, and within the design life of the pavements for the project. Areas of the road alignment sufficiently setback from the coast, with vegetation and land for buffers are expected to be less susceptible to inundation or impacts from coastal processes within this timeframe.

The design of the road specifies that a minimum of 150 mm of gravel will sit on top of either natural ground level (where suitable), or select fill material to the desired design level. A 150 mm buffer below this gravel layer should be factored into the design to ensure adequate stability. This means that pavement areas below 1.33 m (as at final design), and with no horizontal buffer to the sea, could be subject to accelerated wear and decreased useable life, given the potential for increased inundation. Across the length of the project there are two main areas with sections of low lying pavement. In general terms these are isolated sections between chainage 53+000 - 55+600 (northern section), and 65+500 - 67+750 (southern section). Many of these low lying areas are located in the vicinity of minor drainage lines, with proposed crossings. In these locations, the pavement is expected to be raised in line with developing appropriate approaches compliant with minimum sight distance requirements.

A longer stretch of low lying pavement in the northern section is buffered from the coastline by a dense coastal vegetation strip. Subject to this area being retained, it is unlikely that the road would be adversely affected by any impacts from regular wave action, even under the expected sea level rise scenario within the design life of the project.

In the southern section, the road is already subject to signs of coastal erosion. In some areas buildings are located on both sides of the road. Without mitigation, it is expected that the road will increasingly be subject to erosive processes. For this reason, coastal protection measures have been specified as part of the project to limit the impact of this existing erosion on the stability of the road pavement. Provision for periodic monitoring and where necessary installation of up to an additional 500 m of coastal protection works for pavements, or in the vicinity of coastal bridges has been allowed for over the course of the 20 year life of the project. As far as practicable all coastal protection measures should be designed to be sympathetic to any existing vegetation. Wherever possible coastal protection works should also incorporate complementary revegetation measures.

Substantially raising the pavement in the southern section could result in undesirable impacts to the community, given that the road would be elevated relative to the adjacent buildings. Such an approach could require additional cross drainage measures to avoid flooding of houses, and the landward side of the road after rainfall events.

Longer term it is likely that sea level rise combined with current coastal process, may necessitate the relocation of these buildings away from the hazard zone immediately adjacent to the coastline, and by default away from the road. Consequently, consideration may need to be given to the relocation of the road alignment further inland. Given the long lead time associated with securing land access, it may be prudent to share with local communities the issues discussed here, and the longer term need to consider minor realignments to the road.

Table 4: Proposed measures for low lying pavements

#	Aspect	Discussion	Timeframe
1	Ensure that coastal vegetation between the road alignment and the sea is retained in the northern section	The marine areas adjacent to this location are already identified as conservation areas, and formalising the retention of the coastal vegetation buffer, through agreement or formal understanding with the local community will serve to enhance these marine conservation values, and support a more resilient road formation.	Ongoing from the commencement of construction
2	Low lying areas in the vicinity of water course crossings are raised consistent with required design approaches.	Construction of crossings and associated approaches are expected to raise the pavement in these areas to sufficient levels.	During construction
3	Periodically review and where necessary install coastal protection in additional areas in the southern section subject to coastal erosion.	Coastal protection has already specified for areas of existing coastal erosion. Rising sea levels could be expected to impact additional sections of pavement over time. For this reason, provision for an additional 500 m of coastal protection works have been proposed to be installed, where necessary, periodically over the 20 year life of the project. Total coast over life of project SI$ 2.25 M. These measures could also be used for additional protection in the vicinity of coastal bridges.	Review at five year periodic intervals following construction
4	Consider minor realignments inland in the southern section	Over time buildings may need to move away from the coastal zone. Given some of the potential adverse impacts associated with raising the pavement, consideration could be given in the longer term to relocating the road alignment inland away from immediate zone of coastal erosion.	Long term, at least 20 years after construction

Major watercourse crossings

The major watercourse crossings for the project include the Chaurpehe, Bora, and the Malhjili rivers. These crossings are identified as being “major” on the basis that the catchments draining to the crossing are in excess of 4 km^2. The bridge designs for these crossings have all been specified as having a 1 in 100 AEP flood immunity.

Climate change projections indicate a likely increase in the severity of extreme rainfall events. With moderate confidence, modelling indicates that by 2090 there could be up to 21% increase in wet season rainfall. Inherent uncertainties exist with the catchment response to this rainfall. Notwithstanding, sensitivity testing including an increase in rainfall events, and associated runoff of up to 21% showed that the these bridges will retain their designed 1 in 100 AEP flood immunity, even under the specified climate change scenario.

On the basis that the bridge designs are modelled to be able to accommodate the potential increase in flood levels as a result of climate projections, the primary issues that could affect the integrity of these structures stem from scour around crossing abutments, and the potential impacts of debris load during flood events. For these reasons, measures to address the implications of these potential impacts on the structure are proposed as part of the general suite of measures to manage these major watercourse structures.

Table 5: Proposed measures for major watercourse crossings

#	Aspect	Discussion	Timeframe
1	Design of scour protection for bridge structures and approaches to address modelled flood velocities	During detailed design adequate scour protection around bridge structures and approaches should be designed to respond to modelled flood velocities.	During design and construction
2	Post storm inspection and where necessary removal of any accumulated flood debris	The build-up of flood debris can substantially reduce the ability of the crossing to accommodate subsequent flood events, potentially leading to significant damage to the structure or approaches. Regular inspection and maintenance will enable these potential impacts to be adequately managed.	As necessary following significant storm events, and otherwise at regular maintenance intervals

Coastal bridges

The Bora, Bahi and Lambi Bailey Bridges are all located within close proximity to the sea and could be subject to exacerbated coastal erosion, particularly under a scenario of rising sea levels. Issues related to the impact of riverine flooding for the Bora Bridge have been discussed above, and this section therefore focusses on measures to address potential adverse impacts from coastal erosion.

All three bridges have relatively intact vegetation either side of the channel, and out to the coast. On the assumption that these vegetated channel buffers are maintained, impacts from coastal erosion processes will be substantially mitigated. Coupled with the installation of appropriate scour protection measures in the vicinity of the bridge structure and the approaches, impacts from any exacerbated coastal erosion processes are expected to be managed to an acceptable level.

Regardless, the provision for the periodic inspection and where necessary proactive maintenance in the form of installing additional coastal protection, will address any potential future issues with instability as a result of increased coastal erosion.

Table 6: Proposed measures for coastal bridges

#	Aspect	Discussion	Timeframe
1	Post storm inspection and where necessary installation of any required coastal protection.	On average tropical cyclones historically occur ten times each decade within 400 km of Honiara. Inspections should ideally occur after any such significant event.	As necessary following significant storm events, and otherwise at five year periodic intervals following construction.

#	Aspect	Discussion	Timeframe
2	Installation of bridge structure and approach scour protection measures.	To be specified during detailed design, and in consideration of projected rising sea levels of up to 15 cm by 2030 and up to 60 cm by 2090.	During detailed design and construction.
3	Retention of vegetation located either side of the waterway between the bridge and coast	Formalising the retention of this vegetation, through agreement or formal understanding with the local community will support the stability of these bridges.	Ongoing from the commencement of construction

7 Economic Consideration of Adaptation Options

In August 2013 a draft economic assessment of the Naro Hill to Lambi rehabilitation project was completed within the Transport Sector Development Program. The assessment comprised a quantitative economic cost benefit analysis which followed ADB economic evaluation guidelines.

It contained an estimate of present value of costs totaling SBD$65.1m. The present value of savings/benefits was estimated at SBD$73.2m. This produces a positive Net Present Value (NPV) of SBD$8.0m and a higher than base requirement Economic Internal Rate of Return (EIRR) for the scheme of 13.8%.

Investigation of these results revealed that most of the savings accrue from reduction in fares, which is estimated at SBD$36.2m (49% of total savings). This is followed by savings from improved access to health services, estimated at SBD$27.2m (37% of total savings); and savings in improved access to education estimated at SBD$5.1m (7% of total savings).

However, the analysis did not consider the impact of reductions in service levels associated with climate change. The subsequent risk assessment highlights three broad adaptation options for the Naro Hill to Lambi road rehabilitation project. These options are not mutually exclusive and could influence the overall design of works for this project.

Based on the draft economic assessment, a proportion of the savings might be considered to be at risk concerning impacts of climate change. Given total benefits were estimated at SBD$73.2 million, a reduction of 11% or more in identified benefits would produce a negative economic return. One way to think of this is in terms of days' access to transport services along this road. If benefits are uniformly distributed across a year, this would be equivalent to climate related impacts reducing transport access by 40 days or more per annum.

In the absence of detailed design information, a high level review of economic issues relating to each of these adaption options is discussed 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 project.

Low lying pavement

Risks associated with climate change risk for low lying pavements identified above included two elements: (1) increasing coastal erosion; and (2) expected sea level rise. This has several potential cost implications for low lying pavements:

- Routine maintenance tasks can be expected to increase as a result of climate change as increased rate of erosion of low lying pavement is expected. In addition, opportunities for vegetation management to reduce this rate of erosion may trigger further costs.
- In the longer term, rising sea levels will trigger a need for a more detailed investigation around realigning low lying pavement.
- In mitigating some or all of the flood risk for low lying payment along the existing alignment, there may also be costs to avoid consequential localised flooding of communities along this route if the pavement height is raised.

There are a number of potential benefits that could be realised from these climate change adaptation options. The benefits are largely expressed in terms of costs that would otherwise be imposed by climate change impacts. These benefits are most likely through a revised approach to road maintenance and early stage reconsideration of detailed design.

- Road access in the absence of a response to climate change can be expected to be compromised. This will result in more frequent interruptions to access, reducing service levels. This has a consequent flow on impact to communities along this road as reduced access leads to denial of access to education and health services – with consequent costs to society – as well as reduced access to markets.
- This road access will be affected both by increased frequencies of inundation and longer periods of time where road service quality is affected by erosion.
- In the absence of a longer term strategy for realignment of the road, the service could be expected to be cut completely.

In the absence of data on potential erosion rates, flood level information and detailed, localised climate data, it is difficult to assess the engineering impacts on both the road structure and its achievable service level.

Major water course crossings

The climate change risk assessment identified two issues that could affect the integrity of these structures: (1) scour around crossing abutments, and (2) the potential impacts of debris load during flood events. Cost implications for the major water course crossings could therefore include:

- An increasing tempo in repairing and replacing scour protection and watercourse approaches, involving both an increase in capital expenditures and ongoing maintenance costs.
- Increased costs associated with rising debris loads from increasing rain event frequencies and intensities. In the absence of additional flood and debris load modelling the risk of debris-related damage to major water course crossings potentially increases.

Benefits associated with major water course crossings are potentially compromised by climate change impacts where these are not incorporated in the design of these structures:

- Damage or loss of one or more of these structures reduces access to transport services that in turn provide access to education and health services, along with access to markets.
- Increasing flood levels associated with climate change reduce the availability of these structures during those events.
- In the long term these assets will significantly underperform their design life and designed service level.

A consequence of this is that the full economic benefit of investing in these assets will not be realised in a situation where climate change impacts are not considered.

Coastal bridges

The climate risk assessment highlighted key issues facing coastal bridges. This brings together two aspects of climate change impacts: (1) riverine risks associated with increased levels of flooding; and (2) marine risks associated with rising sea levels. Cost implicaitons for coastal bridges include:

- An increasing tempo in repairing and replacing scour protection and coastal bridge approaches, involving both an increase in capital expenditures and ongoing maintenance costs.
- Increased costs associated with rising debris loads from increasing rain event frequencies and intensities. In the absence of additional flood and debris load modelling the risk of debris-related damage to coastal bridges potentially increases.
- Sea level rise per se may not have an impact on these bridges if they are designed for a higher level flood response. However, the combination of a short term riverine event, intensified by climate change, with a general marine environment trend – rising sea levels – could impose significant costs.

Benefits associated with coastal bridges are potentially at risk in the absence of a response to climate change impacts. These benefits are similar to those for low lying pavements and major water course crossings. This is because these assets all provide a transport function. Transport is a derived demand in that users have a purpose for travel and realise benefits associated with that purpose.

8 References

Alexander, L., X. Zhang, et al. (2006). "*Global observed changes in daily climatic extremes of temperature and precipitation*." Journal of Geophysical Research 111(D05101).

Australian Bureau of Meteorology and CSIRO, 2011. *Climate Change in the Pacific: Scientific Assessment and New Research.* Volume 2: Country Reports, Solomon Islands.

BOM, 2013. Cyclone tracks - Southern Hemisphere [beta], available at http://reg.bom.gov.au/cyclone/history/tracks/index.shtml accessed 15/8/13

Engineers Australia, 2011. *Implications of climate change on flood estimation, discussion paper for the Australian rainfall and runoff climate change*. Engineers Australia Water Engineering, Barton, ACT.

Groisman, P. Y., R. W. Knight, et al. (2005). "*Trends in intense precipitation in the climate record.*" Journal of Climate 18: 1326-1350.

Radford, D.A., and Blong, R.J. 1992. *Natural Disasters in the Solomon Islands*. School of Earth Sciences, Macquarie University, Australia.

Trenberth, K. E., P. D. Jones, et al. (2007). *Observations: Surface and Atmospheric Climate Change. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. S. Solomon, D. Qin, M. Manning *et al*. Cambridge, Cambridge University Press.

Walsh, K.J.E., McInnes, K.L., McBride, J.L., 2012. *Climate change impacts on tropical cyclones and extreme sea levels in the South Pacific – A regional assessment*. Global and Planetary Change, 80-81, pp 149-164.

Appendix A - Risk Assessment

Table 7: 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 8: 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 likely than not 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 9: Descriptions of different consequence levels utilised for the risk assessment

Consequence	Description
Insignificant	Infrastructure: No infrastructure damage. 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.
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	Likelihood	Likelihood Statement	Consequence	Consequence Statement
1	Increased severity of tropical cyclones results in greater road corridor obstructions as a result of storm debris	Medium	8	Likely	Honiara receives an average of 10 cyclones per decade. Although the number of cyclones are projected to decline, there is a projected increase in the proportion of the most intense storms.	Minor	Cyclones result in the deposition of a range of debris from destroyed vegetation and buildings. Such debris could cause temporary closure of roads, and impeded access.
2	Increase in extreme rainfall leads to failure of bridge and culvert embankments impeding vehicle access	Medium	9	Possible	Climate projections indicate extreme rainfall days are likely to occur more often.	Moderate	Increases in extreme rainfall could accelerate erosion of embankments. Such impacts would be expected to be isolated to specific crossings, and able to be managed via maintenance activities.
3	Increase in extreme rainfall, causes greater degree of pavement erosion impeding vehicle access	Medium	6	Possible	Climate projections indicate extreme rainfall days are likely to occur more often.	Minor	Increases in extreme rainfall could accelerate the development of potholes and erosion. Such impacts would be expected to be isolated and minor, and able to be managed via periodic maintenance.
4	Increase in extreme rainfall results in greater loads of flood debris, higher flow velocity and catastrophic failure of minor watercourse crossing structures	Medium	9	Possible	Climate projections indicate extreme rainfall days are likely to occur more often. Minor watercourse crossing are not expected to be subject to the same levels of flood debris found in larger catchments, and therefore the likelihood of these structures failing is limited.	Moderate	Minor watercourse crossing is defined as a crossing of a catchment smaller than $4km^2$. Failure of these crossings may involve some financial cost to remedy but could likely be fixed with basic equipment, and in a short space of time, thereby minimising impacts to vehicle access.
5	Increase in extreme rainfall events leads to a greater incidence of landslides and mudslides that damage pavements and drainage structures, and impede vehicle access.	Medium	6	Possible	Climate projections indicate extreme rainfall days are likely to occur more often.	Minor	Land adjacent to the project with slopes of greater than 15 degrees could be expected to be at greater risk of landslides. Such events could cause substantial localised damage to the road pavement, and impede access for some time.

#	Risk Statement	Risk Level	Score	Likelihood	Likelihood Statement	Consequence	Consequence Statement
6	High tides inundate low lying pavements causing accelerated degradation	High	12	Likely	Sea levels have risen on average around 8mm each year. By 2030 (within the design life of the project) sea levels are expected to be between 4 and 15cm higher than 1990 levels. On this basis, areas of the project less than 1.03m would be expected to be regularly inundated by 2030.	Moderate	Higher sea levels would result in inundation of low lying pavements, but coupled with higher water tables could also affect the integrity of subbase materials. With ongoing vehicle use, particularly heavier vehicles, lower lying pavements will be expected to deteriorate rapidly.
7	Storm surge and wave action generally on top of a high tide and sea level rise causes substantial damage to road pavement in low lying areas.	High	16	Likely	By 2030 it is expected that areas below 1.03m would be regularly inundated. Wave action generally could further damage pavement at levels above this.	Major	Without protection, low lying areas of the project, within close proximity to the coast could be substantially affected by coastal process. Locally this could result in partial closure of the road, and the need for ongoing repairs.
8	Increase in extreme rainfall results in greater loads of flood debris, higher flow velocity and complete failure of major watercourse crossing structures	High	15	Possible	Climate projections indicate extreme rainfall days are likely to occur more often. Coupled with logging in the larger catchments, this could lead to greater incidence of flood debris, and higher flow velocities around the major watercourse crossing structures.	Catastrophic	Major watercourse crossing is defined as a crossing of a catchment greater than $4km^2$. Failure of these crossings crossing would likely be costly from a financial perspective, and take considerable time to rectify, during which time the road would be impassable.
9	Road pavement in low lying areas is subject to temporary inundation following storm events, impeding vehicle access	Medium	9	Possible	By 2030 it is expected that areas below 1.03m would regularly inundated. Such impacts could exacerbate the impacts of localised riverine flooding resulting in areas of the project being temporarily inundated. However most low lying areas close to the coast are not in the vicinity of watercourses, and therefore not typically subject to riverine flooding.	Moderate	Temporary inundation, could result in the road access being impeded for a period up to days, while water subsides. Following the inundation event areas of the pavement may need to be cleared of debris to allow the effective passage of vehicles.

#	Risk Statement	Risk Level	Score	Likelihood	Likelihood Statement	Consequence	Consequence Statement
10	Minor watercourse crossings within close proximity to the shoreline are subject to increased scour from storm surge, leading to reduced effective design life.	Medium	8	Likely	By 2030 it is expected that areas below 1.03m would be regularly inundated. Wave action generally could exacerbate erosive forces for structures located within close proximity to the shoreline.	Minor	Increased scour, leading to reduced effective design life, or structural failure, would be possible to fix without the need for specialised equipment of expertise. Such impacts would likely result in temporary closure of the road to vehicles.
11	Major watercourse crossings within close proximity to the shoreline are subject to increased scour from storm surge, leading to reduced effective design life.	High	16	Likely	By 2030 it is expected that areas below 1.03m would be regularly inundated. Wave action generally could exacerbate erosive forces for structures located within close proximity to the shoreline.	Major	Increased scour, leading to reduced effective design life, or structural failure, would be costly to remedy, and likely involve specialist expertise and machinery. Such impacts would likely result in extended closure of the road to vehicles.
12	Increased levels of atmospheric CO_2 lead to faster deterioration of concrete structures, and a reduced effective design life.	Low	4	Very Unlikely	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. Within the design life of the project the change in CO_2 levels is not expected to be material.	Major	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.
13	Increase in extreme temperature events causes thermal expansion in bridges and a reduction in effective design life	Low	4	Very Unlikely	By 2030 average temperature are expected to have increased by up to 1°C. Increases in average temperatures will also result in a rise in the number of hot days and warm nights and a decline in cooler weather.	Major	Increased extreme heat events may adversely affect operation of bridges fitted with expansion joints.

#	Risk Statement	Risk Level	Score	Likelihood	Likelihood Statement	Consequence	Consequence Statement
14	Increased severity of tropical cyclones results in greater loading on bridge structures	Medium	6	Unlikely	Honiara receives an average of 10 cyclones per decade. Although the number of cyclones are projected to decline, there is a projected increase in the proportion of the most intense storms. Given the likely small nature of the bridge structures, the likelihood of wind loading leading to failure is unlikely.	Moderate	Bridges designed with large expanses of solid material may experience loading that could weaken the structural integrity, and lead to increased maintenance requirements, or reduced effective life.
15	Increase in extreme rainfall results in more debris impeding road access	Low	4	Unlikely	Climate projections indicate extreme rainfall days are likely to occur more often.	Minor	Incidence of debris impeding the passing of vehicles is expected to localised, and minor in nature. Minor remedial works would likely be able to restore vehicle access.
16	Increased tropical cyclone severity and extreme rainfall results in greater blockages of minor drainage infrastructure, and the need for increased maintenance.	Medium	6	Possible	Honiara receives an average of 10 cyclones per decade. Although the number of cyclones are projected to decline, there is a projected increase in the proportion of the most intense storms. Such storms could increase the incidence of blocked culverts from associated storm debris, reducing their effectiveness.	Minor	Culverts may require post storm monitoring and as necessary maintenance to ensure that they are functioning as per design, and flows do not back up causing localised flooding, or erosion of pavement and approaches.
17	Increased variation in wet/dry spells and decrease in available moisture may cause degradation of road pavement	Medium	6	Unlikely	Average annual and seasonal rainfall is projected to increase. Climate projections also indicate extreme rainfall days are likely to occur more often. Drought projections suggest that future drought conditions are likely to be similar to current drought conditions across the Solomon Islands.	Moderate	Differential shrink and swell of sub base materials could influence the profile of the road pavement, leading to greater degree of potholing, surface depressions, and areas more susceptible to erosion.

#	Risk Statement	Risk Level	Score	Likelihood	Likelihood Statement	Consequence	Consequence Statement
18	Increase in ocean acidity causes accelerated degradation of bridge piers	Low	4	Very Unlikely	The acidity level of sea waters in the Solomon Islands region will continue to increase over the 21st century. Such increases are not expected to result in material changes for bridge piers.	Major	Corrosion of materials used in bridge piers could lead to the structural failure of the structures, requiring replacements or substantial maintenance.
19	Increase in mean sea levels cause a reduction in the effectiveness of coastal vegetation buffer, leading to damage of road pavement and structures from coastal erosion	High	16	Likely	By 2030 it is expected that areas below 1.03m would regularly inundated. Increases in salinity could adversely affect coastal vegetation and reducing the effective vegetation cover of low lying coastal areas.	Major	A reduction in the vegetation cover will lead to areas being more susceptible to coastal erosion processes. Such erosive process if subjected directly to unprotected road pavement and structures, will likely cause substantial damage, in need of major repairs.

Appendix B - Plates

Plate 1: Local bus transport east of the Charupehe River

Plate 2: Existing section of the Naro Hill to Lambi Road

Plate 3: The start of the project area, with a sign indicating previous clearing and grubbing works since complete.

Plate 4: Community conservation area at the start of the project, adjacent to northern low lying pavement area

Plate 5: Example of the current Naro Hill to Lambi Road

Plate 6: Indication of the proximity of the current road to the sea, and current elevation. Note the dense coastal vegetation buffer between the road and the ocean

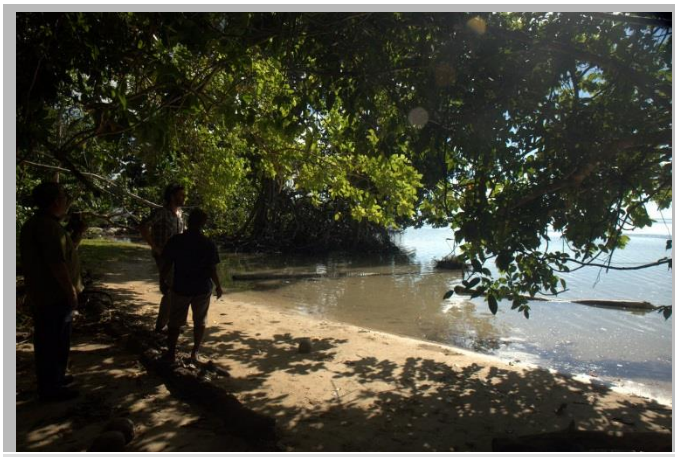

Plate7: Coastal vegetation , including mangroves at the same location as indicated in Plate 6

Plate 8: Bahi River, in the northern section of the project. Note the intermittent open and closed lagoon nature of the waterway.

Plate 9: Unnamed minor watercourse crossing along the Naro Hill to Lambi Road

Plate 10: Location of the Ngalimuta Primary School, where a minor diversion is proposed to avoid direct conflict with school playing areas.

Plate 11: Bora River, with a recently refurbished bridge decking.

Plate 12: Bora River, looking to the sea. Logging equipment can be seen crossing the river at the shallow mouth to the sea.

Plate 13: Bora River looking from the coast back inland.

Plate 14: Detail of the underside of the Bora Bridge. Even though the bridge deck has been refurbished, the foundations have not been upgraded, and show signs of significant

Plate 15: Approaching the Charupehe River looking towards Lambi

Plate 16: From the middle of the Charupehe River looking towards the coast.

Plate 17: Detail of existing coastal erosion in the vicinity of Lambi Village, with the road in close proximity.

Plate 18: Detail of existing coastal erosion in the vicinity of Lambi Village. The existing road can be seen in the background, with some house located beyond.

	Plate 19: Recently refurbished bridge deck at Lambi.
	Plate 20: Recently refurbished bridge deck at Lambi, with the sea in the background. This waterway is also part of an intermittent open and closed lagoon system.