Social and economic assessment of climate proofing of road infrastructure in the Western Guadalcanal, Solomon Islands

Padma Narsey Lal and Valentine Thuirarajah

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Acronyms

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1. Introduction

The Solomon Islands are exposed to a wide range of geological, hydrological and climatic hazards, including tropical cyclones, landslides, floods and droughts. Between 1980 and 2009, for example, the country experienced 17 major disaster events costing over USD20 million dollars and affecting almost 300,000 people. Of these there were six major natural disasters – two earthquakes and four tropical cyclones, and associated floods and storms, directly impacting over 100,000 people with over 100 deaths. Climate related events, including floods, landslides and storms, dominate the disaster events, both in terms of the number of incidents as well as the number of people affected and damage and losses experienced.

In response to regular flooding and its impact on vital infrastructure, the Solomon Islands Government, with the assistance of ADB, the Government of Australia (AusAID), the Government of New Zealand (NZAID) and the European Union, undertook a programme of road rehabilitation, Solomon Islands Road Improvement Project (SIRIP). A second Road Improvement Program referred to as SIRIP 2 sub project, was undertaken following the rain event of early 2009 in the western Guadalcanal Province. Heavy rains caused these extreme floods defined as by 1-in-50 years Average Recurrence Interval (ARI).

The primary goal of the SIRIP 2 sub project was to rehabilitate selected parts of the road and bridges to be able to withstand extreme flooding events. The original SIRIP 2 sub project was designed to repair and improve the road between Tamboko and Naro Hill, which was further extended eastwards to Poha River following the January-February 2010 floods. These 2010 floods caused significant damage to existing bridges, wet crossings, engineering fords, causeways, scouring of pile foundations of main bridges, and disrupting a major transport route in West Guadalcanal. The regular flooding adversely impacts on local communities.

Hence, the original SIRIP 2 sub project was revisited and designed in part to 'climate proof' the roads infrastructure reflecting increases in climatic risks under predicted climate change through adaptation of engineering designs to reduce the impacts of high intensity precipitation and flooding on key road infrastructure (Cardno Acil 2010 b).

Climate proofing infrastructure generally refers to investing in measures that reduces risks to an acceptable level through long-lasting and environmentally sound, economical viable and socially acceptable activities (ADB 2005). In practical terms, climate proofing involves (Sveiven 2010):

- identification of risks to a development project as a consequence of climate variability and change; and
- ensuring that those risks are reduced to acceptable levels through environmentally sound, economically viable, and socially acceptable changes.

Such climate proofing of development activities are implemented often at one or more of the following stages in the project cycle: planning, design, construction, operation and decommissioning. To inform specific climate proofing responses, including engineering solutions, understanding the nature of hazards and vulnerability is critical, as this helps to identify targeted adaptation responses, as well help select adaptation responses that maximises returns on limited financial investment.

The objective of this case study, as part of the wider DCCEE-IUCN project, *Social and economic assessments of climate change adaptation in the Pacific: Making informed choice,* include to:

- identify how economic and social assessment informed the nature and design of the ADB supported climate proofing of infrastructure project in the Solomon Islands (Solomon Islands Road Improvement Project, SIRIP 2 sub project), and its relationship to the SI government's policies, plans and decision-making processes regarding climate change adaptation;
- identify key constraints to mainstreaming climate change and how SI governments' governance (policies, plans and decision-making) process (es) could be strengthened to better mainstream risks associated with climate change into identification, selection and design of infrastructure projects.

The findings of the detailed case study analysis was used to inform the overall analytical framework proposed for improving social and economic assessment-based climate change adaptation decisions in the Pacific, recognising the presence of often incomplete information and climatic uncertainties.

The case study on the assessment of climate proofing of infrastructure project in the Solomon Islands adopted a climate risk management framework (UNDP 2002) which includes:

- assessment of current, and expected changes in hazards and vulnerability (risks) under climate change and variability;
- identification of adaptation measures to reduce the risks to an acceptable level, and
- the selection of adaptation measures that reflects consideration of potential impacts on social and economic and environmental systems.

The case study also adopted a systems-based decision-making framework that recognises the importance of enabling policy and institutional processes within which specific project level adaptation decisions are made.

The report is structured as follows: Chapter 2 provides an overview of the nature of weather and climate related hazards in the Solomon Islands, particularly the Guadalcanal Island, and underlying vulnerability of the Solomon Island communities. Chapter 3 reviews hazard and risk assessments undertaken to inform 'climate proofing' options for the improvements in the road between Tamboko and Poha River. Chapter 4 reviews social and economic assessments of adaption measures undertaken to inform preferred choices for the engineering design for 'climate proofing' of the road and river crossing infrastructure. Chapter 5 provides an overview of the policy and institutional environment context of the climate proofing decisions by the Solomon Island Government and the ADB and identify areas that could be strengthened. Lastly, Chapter 6 concludes by highlighting key decision-making processes for strengthening to encourage integrated assessment of risk and risk reduction and climate proofing of infrastructure.

2. Weather and Climate Associated Hazards in the Guadalcanal Island

Guadalcanal is prone to natural disasters and experiencing in the order of 40 different disaster events between 1950 and 2009. The province is classified as ‘high vulnerability’ to cyclones, coastal flooding and ‘medium vulnerability’ to earthquake, and tsunami, drought, and river flooding and ‘low vulnerability’ to landslides. (Cardno/ACIL Initial Poverty and Social Assessment Report No 40).

Guadalcanal and other islands of the Solomon Islands are located along the equatorial belt and enjoy a warm and wet equatorial climate. Guadalcanal is the largest of the six major islands of the Solomon group, with an area of 5,310 km^2 and an island that is 150 km long from northwest to southeast and, at its broadest 45 km wide (Figure 2.1). The Southern coasts of Guadalcanal is considered to be one of the wettest places on earth with a mean annual rainfall of around 8000mm, hence has acquired its name ‘the weather coast’ (Hackman 1979). The Solomon Islands weather is dominated by seasonal movement and development of the Inter-tropical Convergence Zone (ITCZ), where the trade winds meet to cause convection in an unstable atmosphere with high moisture content from the ocean In January, ITCZ is situated in the south of the Solomon Islands. The northwest trade winds dominate in the period from November to April, and bring heavy rainfall during this period. In July, ITCZ moves to the Northern Hemisphere. The southeast winds prevail with rainfall on the windward side of the islands, during the period from May to October (JICA and Ministry of Natural Resources 2000).

The mean annual rainfall is indicated as 3,000 mm in the western part of the Solomon Islands and increases to 5,000 in the eastern part. In January, the monthly rain exceeds 350 mm over the entire country, while it slightly decreases in July. The available annual rainfall data for the period from 1955-1997 for key stations in the major islands are summarised in the Table 2.1. The southern half of the island is a mountainous zone rising to over 2,300m with a northwest-to-southeast trending spine. The mountains are flanked on the northern side by foothills that form an intermediate zone of intensely dissected plateaux hills and rolling ridges.

Numerous rivers transact this zone, draining generally northwards from the mountains. Hence, there are more than 24 streams and rivers that intersect in the project area, between Tamboka and Poha Hill, in the North-western Guadalcanal (Figure 2.2). The project area also includes three rivers with large catchment areas. These are Tamboko River (catchment area of 63.7 km^2), Poha River (catchment area of 48.1km^2) and Sassa River (with a catchment area of 27.3 km^2). These rivers and streams regularly experience flooding during rainy season, and which is expected to be exacerbated under climate change.

Figure 2.1 Map of Solomon Island Road Improvement Project (SIRIP 2): Western Guadalcanal Road Improvement Sub Project

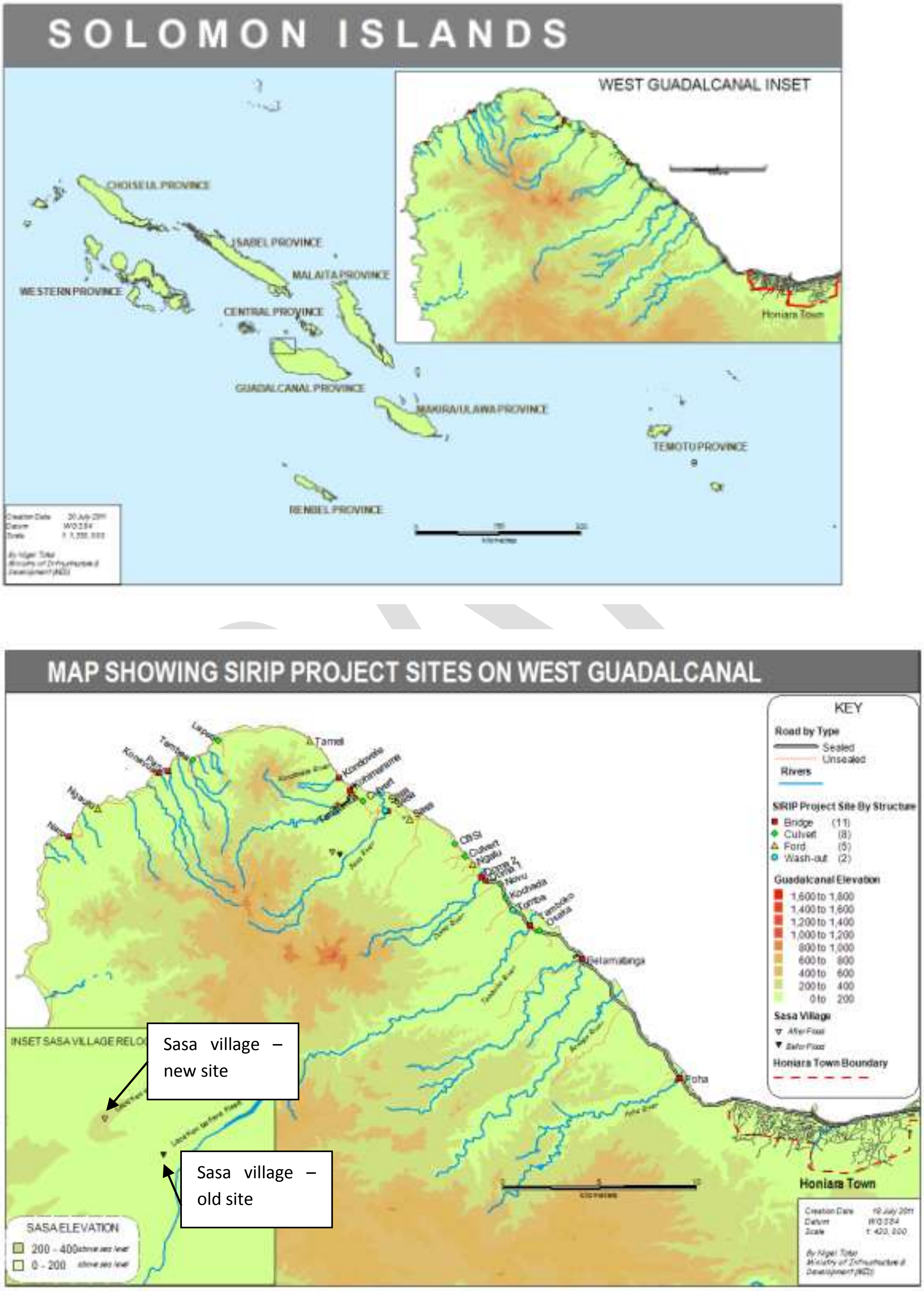
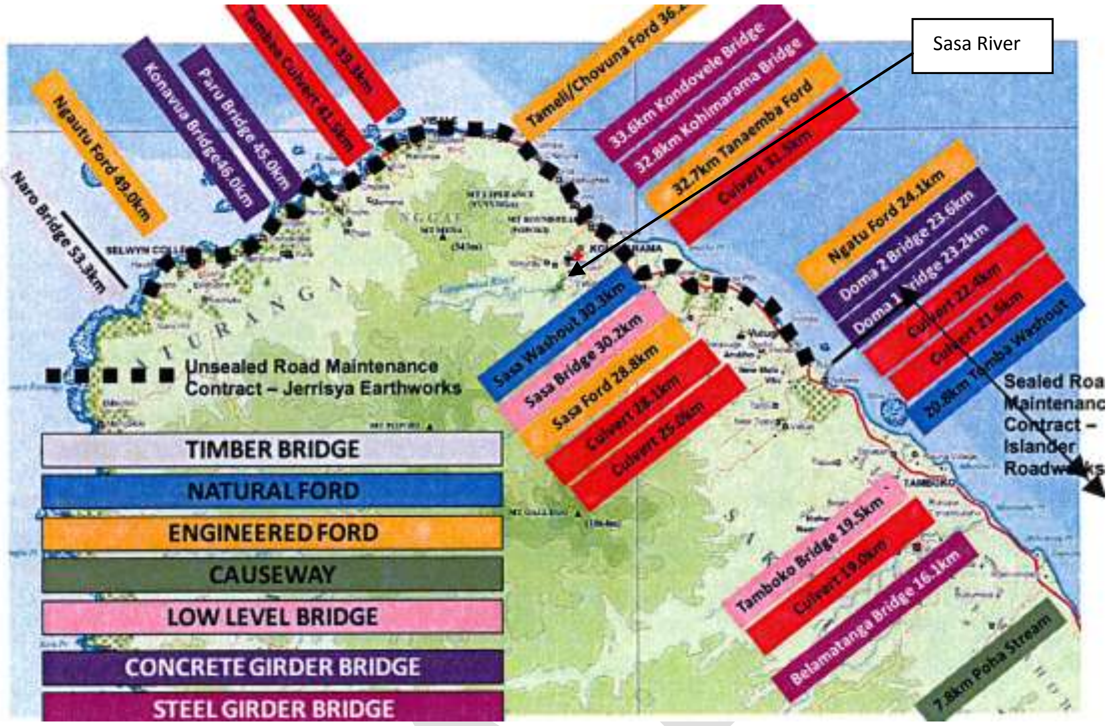


Figure 2.2 Detailed stream and river crossings targeted for improvement under SIRIP 2 subproject



Source: Cardno Acil (2009).

Table 1.1 Average Annual rainfall data for key weather station in the country, 1933-1997

Station (Islands)	Average Annual Rainfall (mm)	Data Period (including breaks)
Taro (Choiseul)	3,375	1975-1997, 20 years
Munda (New Georgia)	3,492	1956-1997, 43 years
Buala (Santa Isabel)	3,860	1982-1997, 10 years
Auki (Malaita)	3,109	1956-1997, 42 years
Honiara (Guadalcanal)	2,004	1954-1973,1979-1997, 37 years
Henderson (Gudalcanal)	1,813	1974-1997, 23 years
Kirakira (San Cristbal)	3,454	1965-1997, 23 years
Lata (Santa Cruz Islands)	4,271	1970-1997, 27 years
Paeu (Santa Cruz Islands)	5,609	1933-1948, 1952-1954 1956-1967, 26 years
Source: JICA (2000).		

Weather related Hazards

Guadalcanal Island is regularly subject to several types of hazards, brought about by natural climate conditions. Common hazards experienced in the Western Guadalcanal (and elsewhere in the Solomon Islands) include

- tropical cyclones and associated heavy rains and high winds
- heavy rain induced flooding, landslide hazards and debris flows
- sea level rise and coastal storm surges

Such hazard events cause considerable damage and loss to societies, including local livelihood and well being, as well as physical and other infrastructure. For example, during the heavy rainfall following cyclone and high tides between 29 January and 2nd February 2009, for example, a 53 kilometre length of the main road west of Honiara on the Guadalcanal Island was overtopped in a number of locations. This had caused major damage to existing bridges, wet crossings, engineering fords, causeways, extended bridge slabs and bridge wing walls. Heavy scouring took place at pile foundations of main bridges as well as physical damage to the road itself impacting adversely on river crossings and affecting vital transport for local communities.

The total economic damage and loss was estimated to be about UD$3 million (World Bank 2008). The local communities also suffered widespread damage to housing and food gardens. An estimated 52,000 were affected, including 2,000 people being displaced and 13 people killed or drowned, particularly in the Sasa Village. At Sasa Bridge and Tamboka Bridges, flood waters had left behind huge logs and debris extending to some 20m on the upstream of the widened river causing river diversion of about 50m of the existing structure. In 2010, the area once again suffered from intense rainfall and flooding along road between the Poha and Naro Bridges on the north-western Guadalcanal.

Flooding hazards

In Solomon Islands, extreme flooding is usually associated with high rainfall caused by tropical cyclones. The following overview draws on a large number of published and grey literature on the Guadalcanal river basins, to draw out the salient flooding and landslide vulnerability issues relevant to infrastructure in the SIRIP 2 sub project area.

Tropical Cyclones on Flooding

It is estimated that annually, on average there are nine tropical cyclones in the South Pacific, which bring intense rainfalls and severe storms, resulting in extreme hydrological responses in Pacific Island streams and rivers (Terry 2007). Cyclone induced peak flows are often in excess of maximum channel capacities, leading to extensive overbank inundation causing devastation to houses, agriculture, infrastructure such as bridges and roads. Such effects have been well documented for the Solomon Islands, including the case of Tropical Cyclone Namu which affected parts of Solomon Islands and Guadalcanal from 17-20 May 1986. Cyclone Namu brought damages to houses, food gardens, roads and bridges in NW-Guadalcanal being disrupted for more than 2 weeks and claimed 10 lives (Bonte-Grapentin 2009).

Accurate and long term rainfall and stream flow data are critical for assessment for hazard assessment for road infrastructure engineering designs (and other uses such as hydropower). Available river discharge data from the nine gauging stations are very limited, largely because of observation breaks and vandalism. Nonetheless some local information and empirical assessments are available in the country and elsewhere. For example, the JICA and Ministry of Natural Resources undertook a Hydropower Master Plan Study, using the Lungga River flow data for other rivers to calculate river flow intake for hydropower development for other rivers in Guadalcanal (JICA 2001). The Lungga water level gauging stations at the Lungga Bridge in Guadalcanal has the longest records of river flow data in Solomon Islands with about 12 years of complete daily data. JICA also used the modelling results of the Lungga River to estimate river-flow estimates for Sasa River for example. They used the standard catchment conversion method from the Lungga Bridge gauging station of 377 km^2 to the intake site catchment of 22 km^2, and estimated the mean annual discharge for Sasa River basin to be 2.2 m^3/s for the Sasa River basin.

For infrastructure design, ideally rainfall data and stream flow data for the past 100 years would be required for each crossing site (Telford pers com). However in the absence of such detailed information available for Solomon islands, as discussed below the consultants on the SIRIP 2 sub project used rainfall data for Honiara that they could access to determine daily rainfall extremes to produce estimates of 1-in-2 year (or a 2 year ARI period), 1-in-10 year (10 year ARI period), 1-in-50 year (50 year ARI period) and 1-in-100 year (100 year ARI period) rainfall events. The 2009 rainfall event was estimated to be 1-in-50 year ARI event (Cardno Acil 2009) (Table 4.9).

River basin Characteristics and Flooding

The geomorphology of the West Guadalcanal is dominated by Volcanic headlands of Mt Galleo (1,064 m) and Mt Popori (969 m) rising in an west-east direction. Orientation of the major river networks is radial in nature from these central highlands. The rivers draining north-easterly on to the Guadalcanal plains are strongly sub-parallel (Trustrum 1990). North-eastern Guadalcanal catchments beginning with the Lungga River give rise to large flood plains, known as the '*Guadalcanal Plains*'.

High intensity rainfall also trigger severe flooding in the small and steep catchments of NW-Guadalcanal, particularly due to the effects of rugged terrain, which increases rainfall-runoff and encourages rapid transfer of water into river channels, leading to a rapid hydrological response. This phenomenon, known as the hydrological short-circuiting displaying flashy behaviour, gives little lag times between the onset of intense rainfall and the rise in the rivers (Terry 2007).

Hazards due to Landslides and Debri Flows

Guadalcanal Island is also susceptible to major landslide damage from cyclones. 'The term 'landslides' is used to refer debris slides, debris flows and rockfalls (Trustrum 1990). Land sliding is primarily related to rainfall relief, slope steepness and previous erosion history. Landslide-hazard risk is moderately high as much of Guadalcanal is rugged and steep, and it is common and widespread in the northern Guadalcanal watersheds of Mbalisuna, Ngalimbu and Mberande (Trustrum 1990).

Most land sliding occurs in the central mountains, where rainfall is highest, relief greatest and sloes steepest. In this zone, the location of landslides is largely independent of rock types but in other areas geology may affect landslide, size and frequency, through its influence of topography. Debris flows and debris slides are very common types of slope failure in the mountains and hilly terrains of volcanic islands in the south Pacific and a generally confined to the top 2-5 m of residual soils and weathered rock (Terry 2007). Although debris flows are initiated by sliding, they quickly transform into viscous and highly mobile slurries. Debris flows are composed of large logs carried by mud and water mixture. Debris flows may travel long distances and be deposited well away from the original site of landslide. They may erode areas on the way exceeding a hectare in size and are sometimes capable of transporting enormous boulders up to 25m in diameter in rivers.

During heavy rains, debris collects quickly and may arrive as log jam with hundreds of tonnes of debris impacting on the piers at the one time (Boyce 1987)). Recent fieldwork by SOPAC (2009) on three river basins in the project area namely Sasa River, Tomba and Tamboko River were investigated after heavy rainfall which caused severe flooding in North-western Guadalcanal on 29-30 January 2009. The SOPAC report indicated that the high intensity of rainfall mobilized bed-material consisted of water, rocks and wooden debris and further eroded beds and banks of the tributary creeks and mobilized boulders of up to 5 metres. They also found that that the debris flows also ripped off most of the trees and shrubs in the valley bottom, and these uprooted trees and massive sediments contained in the flooding were mainly responsible for the damage incurred to houses, infrastructure and food gardens. Trees and sediments carried by the flow jammed bridges and caused the erosion of some approaches in Tamboko and Sasa rivers and caused damage to the Ndoma bridge. Log jams caused the flood waters to divert at several places along the Sasa River and created new or reactivated old river channels (Photo 2.1), which led to the destruction of infrastructure and houses.

Plate 2.1 Sasa Bridge immediately following the 2009 heavy precipitation and flooding

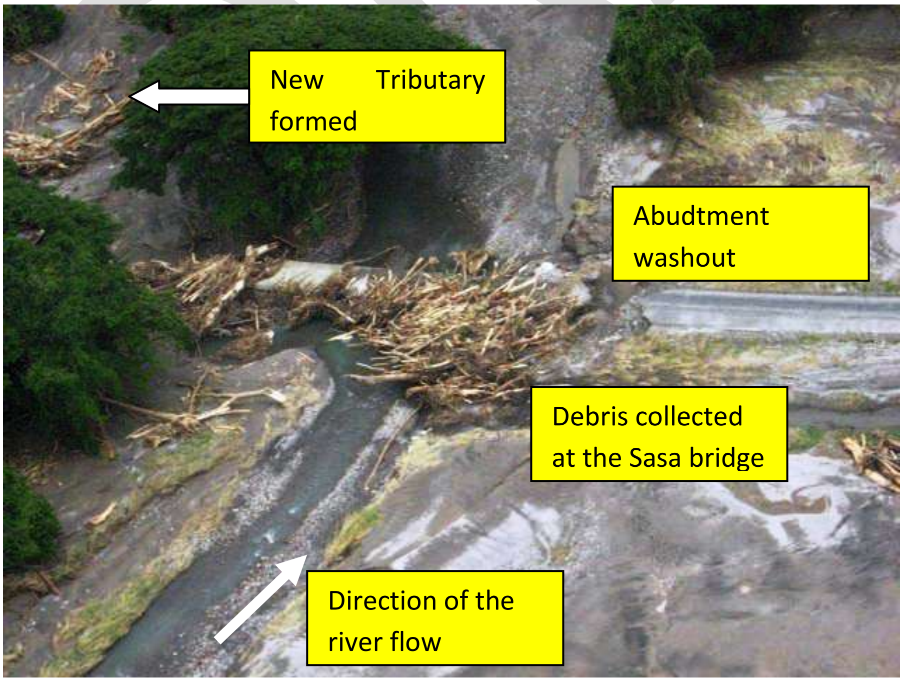
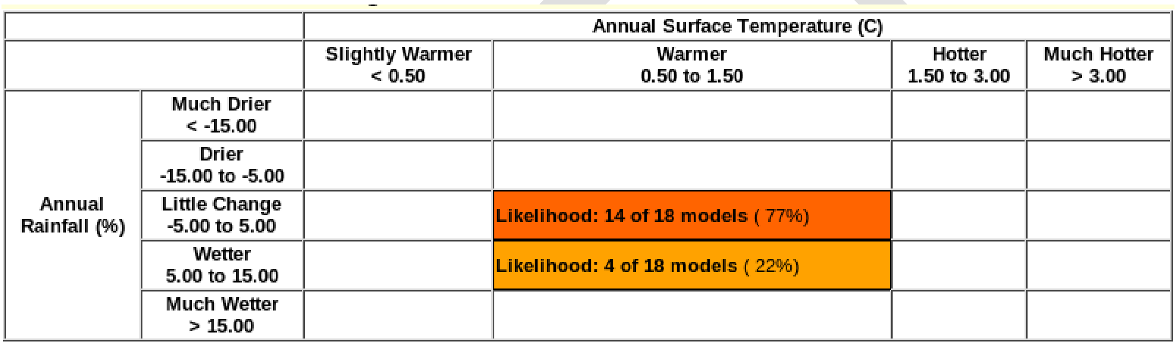


Photo: Tony Telford, Cardno Acil Ltd.

Climate change and extreme events

Weather and climatic conditions experienced in the Pacific region is a product of both human induced climate change and the natural cyclical climate patterns. Collins and others note that there is consensus that 'due to the influence of global warming, the mean climate of the Pacific region will probably undergo significant changes. The tropical easterly trade winds are expected to weaken; surface ocean temperatures are expected to warm fastest near the equator and more slowly farther away; the equatorial thermocline that marks the transition between the wind-mixed upper ocean and deeper layers is expected to shoal; and the temperature gradients across the thermocline are expected to become steeper' (Colins et.al. 2010 p, 1). Although the subregional and country level changes in climatic conditions is unclear. The recent BOM and CSIRO climate change modelling, based on downscaled global climate models for the Pacific, suggests that while there is good chance the Solomon Islands may not see much change in their average rainfall, there is about than 25 % chance of wetter and warmer climate by 2030 (Table 1.2). In addition the islands are expected to experience increased climatic extreme events.

Table 1.2 Climate future for Solomon Islands by 2030 under the A2 emission scenario



		Annual Surface Temperature (C)			
		Slightly Warmer < 0.50	Warmer 0.50 to 1.50	Hotter 1.50 to 3.00	Much Hotter > 3.00
Annual Rainfall (%)	Much Drier < -15.00				
	Drier -15.00 to -5.00				
	Little Change -5.00 to 5.00		**Likelihood: 14 of 18 models** (77%)		
	Wetter 5.00 to 15.00		**Likelihood: 4 of 18 models** (22%)		
	Much Wetter > 15.00				

Source: BOM and CSIRO (2011 (draft))

What is not clear though is the effects of the naturally occurring El Niño–Southern Oscillation (ENSO) cycles on climate variability and climate extremes and the extent that these will be influenced, if at, all by climate change. El Niño events, which occur every 3–8 years or so, are defined by warmer than normal sea surface temperatures in the eastern tropical Pacific, and are associated with anomalous atmospheric circulation patterns known as the Southern Oscillation. ENSO fluctuations in the South Pacific region have a strong influence on cyclone patterns, indicating that uncertainties associated with the changes in ENSO events will also provide uncertainty as to changes in cyclone behaviour. For most of the south west Pacific, an ENSO cycle is accompanied by periods of low rainfall and higher cyclone activity (during the El Niño phase) and periods of high rainfall and lower cyclone activity (during the La Niña phase). ENSO events are likely to continue to be a significant source in climate variability for the region and are not directly related to a longer term climate warming trend. For the purpose of this study the advice of the CSIRO under the Australian Government's Pacific Climate Change Science Program is to assume "no change in climate variability associated with the El Niño Southern Oscillation (ENSO) due to a lack of consensus in ENSO projections" (April 2011).

IPCC in its Fourth Assessment Report notes that although there is no clear indication of changes on frequency of extreme events, there are clear indication of increases in the intensity of tropical cyclones and subsequent storm surge events along the coastal areas. The BOM and CSIRO, recently concluded that the Pacific islands are expected to see more extreme events, with significant impactions for the scale and intensity of hazard conditions (BOM and CSIRO 2011 (draft)). For the Solomon Islands, this could mean that islands such as the Guadalcanal could experience increased intensities of flooding, particularly with catchments where the rainfall-runoff lag is relatively small.

Relationship between rainfall and altitude in Guadalcanal

Modelling exercise by the Institute of Hydrology, UK, indicate that rainfall on Guadalcanal increases with elevation (Institute of Hydrology 1993). This was based on four rainfall monitoring sites established along the northerly section of the transect ranging in elevation between 13m to 1250m and two additional monitoring sites along the south of the island divide at altitudes 45m and 495m. This relationship appears to be of a simple linear form, with no elevation of maximum rainfall (although a maximum rainfall may well occur at an elevation above the range of the transect sites). The relationship between altitude and rainfall though differs to the north and south of the island divide. To the north mean annual rainfall increases by about 320mm for every 100m rise in elevation compared to an increase along the southerly section of the transect of 435mm. At any given altitude mean annual rainfall on the southern side of the island is likely to be 400mm greater than that on the north. The study also revealed that both rainfall intensity and frequency increase with altitude and that it rains more often at higher altitudes rather than it raining harder. Thus with expected increased in extreme events, flooding intensities are expected to increase in areas such as North-western Guadalcanal.

The Guadalcanal terrain is also subject to heavy river flows, changing local of rivers and stream as well as associated serious scouring of land along streams and rivers and physical infrastructures. The damages are often compounded by large volume of debris coming down the main rivers and streams.

Upper Catchment Issues

Poor forest management practices, combined with heavy rain induced landslides and uprooting of trees, is a major contributor of the debris flows often blocking streams and rivers (Bonte-Grapentin 2009). There is evidence that commercial logging operations are taking place in some of the upper catchments of the streams in the project area. There were two logging companies and three contractors operating in the western part of Guadalcanal, with two of these operating in and around in the Naro-Hill-Lambi area (Cardno Acil 2011). The consulting team observed cut logs in the debris trapped at bridge sites that would have contributed to the damages caused. However, no assessment was made by the SIRIP 2 sub project to assess the extent of commercial logging or land management practices contributing to cut logs moving downstream with debris sliding, as this was considered to be beyond the scope of the project (Tony Teleford, pers. comm., October, 2011).

Debris Impact Assessment

The SIRIP 2 sub project paid specific attention to assess impacts of debris flow on main bridges as part of engineering adaptation to climate proof infrastructure; no doubt recognising the potential high costs of not çlimate proofing' such investments. For example, the Tambok0 Bridge originally was designed as low-level bridge at Q_{10} level, with upstream river training and debris catcher. Following the 2010 flooding events (and the initial contract award), the bridge design was changed to a high-level bridge, (1.5 m above Q_{100} level) to allow for debris to pass under the bridge deck. The high level bridge also has 30 spans so that there are significantly less obstructions to the flow. The debris catcher was also designed specifically for the Tamboko site due to the high load of debris that occurred during the 2009 and 2010 flood events (Tony Telford, Cardno Acil, pers com, October 2011).

Sea-level rise and Storm surges

In Solomon Islands, sea level rise (SLR) is predicted to exacerbate coastal erosion and storm surges increasing the risk of inundation of infrastructure, settlements and livelihoods. At locations where the road passes close to the coast, climate proofing measures would require coastal protection works, such as gabion baskets, rip-rap or other bio-engineering alternatives, to protect the road and help stabilize the shoreline(Cardno/ACIL Initial Environmental Examination 2009).

Vulnerability

Solomon Islands is one of the most disadvantaged developing countries in the world, despite its significant natural resource endowments. Its vulnerability to natural and social shocks is derived from the country's relatively low human development conditions, such as economic well being, access to water and sanitation, education, and health services, as well as regular exposure to natural hazards.

Economic and social wellbeing in the country

Its estimated population of 507,000 is scattered across a vast area of 28,450 km^2, with majority living on the six main islands - Guadalcanal, Malaita, Makira, Isabel, Choisel, and New Georgia – most of which have poor infrastructure. The country's population was estimated at just over half a million in 2009 with a high annual population growth rate of 2.8%. About 85% of the population live in rural villages relying mainly on subsistence living off the land and marine resources. The formal sector is dominated by large scale commercial and largely resource development based enterprises, with exports of fishery, logs, copra, palm oil, coconut oil, palm kernel and cocoa. Overall with growing population and limited commercial sector, there are limited economic opportunities for the people.

Annual economic growth has averaged 5.9% and macroeconomic stability has been retained. The larger part of the growth from 2004 to 2008 was due to unprecedented high unsustainable logging rates of logging accounting for 60% of exports in 2008. Job creation has not kept pace with the high population growth and labour supply, and its economy has unfortunately been going down with the real Gross Domestic Product per capita falling US$204 in 1997 to US$ 134 in 2000.

In 2008, the country had a Human Development Index (HDI) of 0.602, and is categorised as a Least Developed Country (LDC), together with Samoa, Tuvalu, Vanuatu and Kiribati in the Pacific (Dawson and Spannagle 2009). The country is ranked the third lowest among all Pacific island nations in the United Nations Human Development Index 2009 ranking, with notable variations in the human development levels in the nine provinces and the capital Honiara (ADB Fact Sheet, 2009). Social indicators generally fall short of short of the targets set for the Millennium Development Index (MDGs) and the country is unlikely to meet the majority of the MDG targets by 2015.

According to the analysis of the Household Income & Expenditure Survey 2005/06 (ES) survey, people are considered to be struggling to meet daily or weekly living expenses, particularly those that require cash payments. Based on the estimation of the poverty lines, the study showed that the average national incidence of basic needs poverty was 18.8.% of households and 22.7% of the population, and for rural areas the rate of basic needs poverty was 15.2% of households and 18.8% of the population. Hardship has been further exacerbated by political tension and social conflict, the ensuring law and order problems, financial crisis, a contracting economy and rising employment, and high population rates.

Traditional land and resource management is based on customary ownership and governed by small kinship based social relationships. Some 87% of land is under this form of tenure. The remaining land is registered under the *Land and Titles Act 1988* as state land.

Vulnerability of the road infrastructure

Western Guadalcanal community and infrastructure is highly sensitive to climate extremes, not only due to intense rainfall and associated flooding, as was experienced during the 2009 and 2010 cyclone and flood events, but also due to the underlying landslide risks and debris flow on the Western Guadalcanal landscape. Most of the streams in Guadalcanal have alluvial riverbeds and floodplains, as such the streams and rivers are prone to major shifts in distribution, shifting river directions as well as creating new river channels (Terry 2007). This is often compounded by large volume of debris coming down the main rivers and streams, as mentioned above. Poor forest management practices, combined with heavy rain induced landslides and uprooting of trees, is a major contributor of the debris flows often blocking streams and rivers (Bonte-Grapentin 2009);

For most of its length the SIRIP 2 sub project main road passes over streams on alluvial areas; these streams regularly change course in places in times of heavy rain and flooding. The Tamboko River, for example, changed course and widened its channel upstream of the bridge during the 2009 heavy rains. This resulted in the collapse of the eastern approach due to overtopping of the bridge. which had threshold coping capacity for 1-in-2 year flood event – the 2009 flood event was considered 1-in-50 ARI event (Cardno Acil 2009). Such landlside and flooding hazard create acute challenges in locating and designing crossing infrastructures such as bridges, culverts and fords, etc. In recognition of this potential hazard, the SIRIP2 sub project introduced some river training activity.

Changing river directions, if not explicitly and adequately taken into account, can increase the risks of damage loss in times of heavy rains. Damages to the physical infrastructure, such as culverts and bridges, will then have flow on effects in terms of road access to local communities. Loss in lives and community livelihoods are common when flooding occurs beyond the capacity of the local environments to cope, as was the Sasa village experience where as mentioned earlier, the village lost their crops and homes, 8 persons, had lost their lives. This was the first major flooding experience for the Sasa village and following that event, the village relocated to higher grounds (see Figure 2.1), although some continued to use the original site for their gardens.

Concluding remarks

The above brief overview of the nature of hazards prevalent in the western Guadalcanal suggests that a comprehensive integrated risk (hazard and vulnerability) assessment is required to inform responses to the current disaster risks as well as climate proofing of road infrastructure in the light of projected increases in risks due to climate change. Before conducting social and economic assessment of risk and risk reduction efforts, it is important to understand the context specific hazards and vulnerabilities of the project site, the ecosystem dynamics and how these may change under climate extremes and climate variability, and how they may determine potential adaptation measures required for reducing current and projected risks. Locally available data may well constrain comprehensive hazard and risk analysis. These are discussed in Chapter 3.

3. Hazard, risk and risk reduction assessments North-western Guadalcanal

The SIRIP 2 sub project team followed the standard key steps of a combined project development cycle and risk assessment framework. The team's activities included:

- key context analysis to identify current in relation to hazards and vulnerabilities and possible adaptation solutions;
- assessment of adaptation options based on key selection criteria;
- cost benefit analysis to selected a preferred option; and
- climate change scenario analysis and identification of selected changes to the preferred solution to 'climate proof' to an acceptable risk threshold.

Current risk and risk reduction analysis

Scientific impact assessment formed the basis of the current and projected risks and risk reduction assessments, focussing mainly on the regular high intensity precipitation and associated flooding although somewhat constrained by lack of reliable and long term accurate data.

The Flood Estimation and Analysis

Hydrological and flood hazard assessment was undertaken in the SIRIP 2, noting that absence of long term rainfall intensity and steam flow data for streams.

Hazard analysis was conducted using hydrological modelling-based analysis to produce estimates of river flow velocity, depth, frequency and flooding at each of the stream/ river crossing. A *flood analysis* was undertaken and included in the engineering assessment report. In the absence of detailed stream flow modelling information available for the rivers in the north-western Guadalcanal region, the consultants used the available rainfall data for Honiara to determine daily rainfall extremes expected for 1-in-2 year (or a 2 year return period), 1-in-10 year (10 year return period), 1-in-50 year (50 year return period) and 1-in-100 year (100 year return period) rainfall events; the 2009 rainfall was considered to be 1-in-50 year ARI event (Cardno Acil 2009) (Table 3.1).

Table 3.1 Modelling-based rainfall pattern associated with various extreme rainfall events

Rainfall extreme event (or return periods)	Maximum rainfall (mm/day)	Daily rainfall intensity (mm/hr)
1 in 2 year (2 year)	106.1	4.4
1 in 10 year (10 year)	194.6	8.1
1 in 50 year (50 year)	254.0	10.6
1 in 100 year (100 year)	282.1	11.8
Source: Table II.1 from Cardno Acil (2009)		

The project team used the ‘Rational Method’ for the estimation of flood flows at stream crossing for 2, 10, 50, and 100 year return periods based on the following equation (SMEC 1990):

$$Q_T = C_R I_{T,tc} C_A C_T C_S A/3.6$$

Where:

Q_T – Peak discharge m3/sec for return period T (years)
$I_{T,tc}$ – Point rainfall intensity (mm/hour of duration and t_c for return period T at Honiara
A – Catchment area (km2)
C_A – Altitude compensation factor
C_T – Storm duration adjustment factor
C_S- Areal rainfall reduction factor
C_R – Run off coefficient for the catchment area

Values of run-off coefficients C_R of 0.40, 0.49, .52 and 0.55 are adopted for 2, 10, 50 and 100 year return periods respectively; these were derived from those values recommended in the PNG Manual for Flood Estimation (SMEC 1990 and Australian Rainfall and Runoff Guidelines (Institute of Australian Engineers, 2000) for similar catchment conditions.

This analysis together with a compensatory factor recommended for PNG (SMEC 1990), the team determined the respective flood levels and velocity of river flows at the crossings associated with the respective return periods and for each of the rivers and streams in the project area. The above equation was rewritten for each stream crossing as follows, to determine flooding regimes for each river and stream:

$$Q_T = C_R i A/3.6$$

Where:

i -catchment rainfall intensities 9mm/hour) for the stream crossing for major catchments.

Such an approach was adopted although the team notes *the accuracy of the flood predictions based on the above method [Rational Method] is unknown* (p 10, Cardno Acil 2009). The results of the Rational Method were then used to determine the design of culverts and bridges to cope with 1 in 10 year event. No doubt, greater time series rainfall and runoff data, together with hydrological models for the local rivers, would help improve the reliability of flooding and flood impact assessments, and thus the robustness of the physical infrastructure designs.

Climate proofing infrastructure: Design considerations

The main focus of the hazard assessment was on floods, and associated effects, and their implication on the design of the physical road and crossing infrastructure. In particular the SIRIP 2 sub project included:

- Scour protections at 24 streams/river locations;

- River Training works at five locations;
- Construction of four low level- bridges (three re-construction of a steel girder bridge (Naro) and steel truss bridges (Sasa Washout and replacement of Sasa Bridge); and
- The construction of high level bridge at the Tomboko river.

The project did not consider other risk reduction options, such as major realignment of the roads due to land tenure issues (Cardno Acil 2010 b).

For each of the physical infrastructure, engineers determined the types of actual adjustments that needed to be made to the initial choice of road repairs and improvements, using different levels of acceptable thresholds. Thus for example, in the case of Sasa Ford (#13 (the Option B was designed to withstand 2 – year event (Q_2). Under climate change scenario this was increased in standard to withstand a 1 in 10 year precipitation and flooding event (or Q_{10}), thus 'climate proofing' that ford. In comparison, the Selwyn Ngautu Ford's design quality was increased from Q_2 to Q_{20}. In the case of structures that were already designed to withstand 1-in-10 year event, such as Sasa washout, no changes were required to cater for the projected increase in threshold tolerance.

Other hazard considerations- landslide and debris

The hazard risk assessment undertaken to inform the engineering solution does not seem to have explicitly taken into account other geophysical characteristics of the Guadalcanal catchments, rivers and stream flows, and flood plains. For example, as discussed in Chapter 2, significant shifts in soft alluvial plains are commonly experienced in the Guadalcanal flood plains, resulting in regular redirection of rivers and streams, abatement washouts, and scouring of soils around infrastructures, compounded particularly when large amounts of debris come down the catchment. Western Guadalcanal is also prone to serious landslides, which is related to rainfall, slope, and soil characteristics. Landslides, too, add to the siltation of rivers and streams and changes in river dynamics. Debris combined with high velocity river flows generally cause scouring of foundations (abutment) around bridges and other crossing structures.

For example, Boyce (1987) found that inadequate considerations of the debris loading in the design of bridges could have been a major cause of the collapse of the Ngalimbu bridge (beyond SIRIP Project site) after cyclone Namu. He found that bridge was destroyed by an enormous load of debris brought down as a result of extensive landslides in the upper catchment following intense rainfall produced by cyclone Namu. He noted that even though the flow was well in excess of that for which the bridge was designed, the bridge had coped adequately until the debris arrived (Boyce 1987).

In the SIRIP 2 sub project, a debris impact assessment was taken into account in various engineering designs of bridges, such as Tamboko Bridge, where it was designed for the depth of debris mat and scour below the stream bed level.

Parts of the road, but not the bridges, in the project area were very close to the coast, potential impact of sea-level rise, of storm surges were not factored in the risk reduction consideration, even though Solomon Island regularly experiences high winds and variabilities in the sea level due to ENSO events. These observations thus raise the question about what effect a comprehensive integrated risk assessment would have had on the risk thresholds and the engineering standards adopted for the structures at each of the rivers and streams along the main road, and the effects these would have subsequently had on the costs and benefits and the choice of repair and road improvement options discussed below.

Choice of Risk Reduction Option

Engineering approach and solutions was the primary focus of risk reduction measures considered by the team, targeting different types of river crossing structures, such as causeways, fords and different types of bridges. The team had also decided not to undertake any significant realignment of the existing road inland (as commended in the Cardno Acil report (2010 b), although the instability of the soft alluvial soils, which may necessitate realignment inland by about 1.5 km, was acknowledged. This adaptation measure was not explored because of concerns about land tenure issues and the impact of realignment on local communities (Tony Teleford, Cardno Acil, pers comm. June 2011). Risk reduction measures did though include some minor road realignments on land belonging to the same customary land owners, as well as drainage improvements, scour protection and river training. The team had, however, noted , but not pursued, the need to also pursue non-engineering climate adaptation strategies, such as better land management, including minimisation of the impacts of commercial logging practices, deforestation, and reforestation (Cardno Acil 2010 b).

Choice criteria

The choice of the risk reduction and climate change adaptation measure was based on predetermined minimum risk tolerance threshold assessed ' by serviceability [of the roads] in floods arising from high intensity storms' and 'as far as economically feasible' (p 11 Cardno Acil 2010). For each of the physical structures a decision was made about the level of risk threshold that could be tolerated, taking into account the magnitude of rainfall events assessed using hydrological modelling discussed above (Q_2; Q_{10}; Q_{50}; Q_{100}); and modelled flow velocities, as well as expected flood levels for particular streams and rivers (see Table II.5, Cardno Acil 2009). Taking into account, the design of structures required to withstand different magnitudes of rainfall events, and acceptable threshold levels, three engineering project designs were considered, in addition to the 'do nothing option' as discussed below. It seems that the cost of particular acceptable risk tolerance threshold was implicitly considered when deciding on which level of acceptable threshold would be used for the different structures along the Poha-Naro road.

Climate projections

The SIRIP2 sub project undertook a '*Preliminary Climate Change Assessment for the North West Guadalcanal Road – Poha to Naro Hill*' in May 2010. The following climate change scenarios were assumed, based on IPCC AR 4 report, in the projected increases in climatic risks for the SIRIP 2 sub project:

- increase in mean precipitation and intensity, possibly including more intense rainfall in wet season (January to March) and leading to more intense surface flooding of road sections.
- Increases in maximum and mean tropical cyclone intensities
- Sea-level rise of + 0.77 mm/year
- Significant increases in the annual number of hot days and warm nights
- Increases in the frequency of hot extremes

No specific climate change projections for Solomon Islands were carried out in this SIRIP 2 Guadalcanal sub project, using neither global climate change models (GCMs) to inform the climate proofing exercise, or downscaled regional and local models. This is in marked contrast with the modelling work commissioned by ADB to inform the SIRIP 2 sub project in Malaita.

It is though generally accepted that projected climate change on its own is not sufficient to inform climate change adaptation measures, including specific project designs, particularly when these are based on limited time series weather and climate data and there are uncertainties about climatic futures. Instead a hybrid a hybrid ‘impacts first’ and ‘vulnerability first’ approaches is more suitable (Willows and Connell 2003; Ranger, Milner et al. 2010). Some elements of this approach are observed in the north-western Guadalcanal SIRIP 2 sub project.

4. Social and economic assessment of SIRIP 2 sub project – North-western Guadalcanal

The goal of the adaptation assessment is to identify and prioritise the most appropriate adaptation measures in response to the current and projected disaster risks. This includes the identification of strategies to minimise damages caused by the changing climate, as well as to take advantage of the opportunities that a changing climate may present (ADB 2011). The goal of the economic analysis of adaptation options is to provide decision makers with information pertaining to the expected costs and benefits of each technically viable option and to rank these options according to the net benefits they each deliver.

Economic analysis of projects is an important component of ADB's internal operations when selecting projects, using the criteria of economic efficiency, reflected in measures such as net economic benefits (NB), net present values NPV), benefit cost ratios (BCR), and economic internal rates of returns (EIRR), estimated using cost-benefit analysis. Each adaptation option would then be compared using such economic efficiency measures estimated using cost benefit analysis. ADB's preferred measure is usually EIRR, which represents the discount rate which point the benefits and costs are equal. ADB's 'basic criteria for a project's acceptability' is an economic internal rate of return of 12 percent (Dole and Abeygunawardena 2002). A return of as low as 8-10 per cent is though acceptable for projects where 'additional unvalued benefits can be demonstrated, and where they are expected to exceed unvalued costs', with the lower limit of 8 % accepted for weakly performing countries (Rishi Adhar, ADB, pers. Comm., October 2011).

The key aspect of the economic CBA is the need to estimate benefits and costs with and without the adaptation measure. Given the uncertainty associated with predicted climate change impacts, the conduct of CBA of adaptation options requires particular attention to the treatment of risk and uncertainty in the assessment of the costs and benefits of adaptation options under two scenarios. A probabilistic CBA is used when a probability distribution of disaster events are known together with their associated costs and benefits. Such probability distributions may be constructed using historical data, and probabilistic CBA will provide probability distribution of net present values, or loss distribution function (Mechler and The Risk to Resilince Study Team 2008).

In the absence of such detailed understanding of the probability distribution of hazard events as well as the associated costs of disasters and benefits of adaptation measures, sensitivity analysis is common (eg. ADB 2001), and this approach was used in the SIRIP 2 sub project. In the context of CBA, sensitivity analysis essentially involves changing the value of one or more variables which may affect the bet benefits of the adaptation option (for example assuming that the cost of the adaptation option could be 20% higher than estimated, or assuming that the flooding return period could be 1-in-30 years instead of say 1-in-50 years). For each of the changes therefore as it is necessary to re-compute the net present value of the options, varying key parameter values. This exercise may be repeated as may be deemed necessary. In the context of sensitivity testing switching values are often computed; a switching value is the value of a specific variable which makes the net present value to switch from positive to negative, or conversely. The purpose of the sensitivity testing is to raise the level of confidence in recommending a preferred option.

SIRIP 2 Sub Project Cost Benefit Analysis

ADB undertook economic cost benefit analysis of the original SIRIP 2 subproject, focussing mainly on the repairs of existing culverts, fords and bridges long the Poha-Naro road. CBA requires firstly the identification of the desirable adaptation responses, followed by the estimation of costs and benefits associated with each adaption option.

Different Engineering adaptation options

The project ream considered three engineering project designs in addition to the status quo. The options included:

- ‘Do-nothing’ Option
- Option A
- Option B and
- Option C

These options reflected alternative design structures that could withstand different magnitudes of rainfall events, and acceptable threshold levels; acceptable risk tolerance threshold identified, it seems also reflected some considerations of the costs implications of different design standards.

Do-Nothing Option

This option refers to the situation without reducing the current disaster risks. It involves the maintenance of the roadway in its current state i.e. the works that were conducted as ‘emergency works’ in response to February 2009 rainfall events will be left as is and become the permanent standard of the road. In the event of future storm events leading to a degradation and deterioration, maintenance works would have been conducted to restore the road to current condition. The do-nothing option would have involved expensive routine maintenance. The cost of maintenance is estimated to increase 5% per year as the maintenance works are not designed to restore or improve the river and road conditions. Subsequently the road would become increasingly difficult to maintain with higher maintenance costs as emergency works were not designed to be permanent.

Option A

Option A is similar to the pre-2009 road condition with additional washout and scour protection and reinforcement. It has a similar overtopping regime to the baseline option. The road would be overtopped during events greater than a 1 in 3 month ARI. Significant damage to the road would not occur until larger events occur due to the additional scour and reinforcement of the road. Option A includes the restoration and upgrade of key connection points (e.g Tamboko Bridge) and key infrastructure irreparably damaged following the 2009 wet weather events to accommodate 2 year ARI flows. The works do not significantly improve on current disaster risks. On the other hand, Options B and C are designed to reduce the vulnerability of structures and road network to a slightly higher level of threshold than under the ‘do nothing’ option of current risk tolerance.

Option B

Option B is designed to convey at least the 2 year ARI flow through the culverts and bridges under the road. During the 10 years ARI event, overtopping would be expected to occur but at depths less than 300 mm maintaining connectivity for higher clearance vehicles.

Option C

Option C is similar to Option B and is designed to convey at least the 2 year ARI flow through the culverts and bridges under the road. However Option C offers a greater proportion of infrastructure designed to convey 100 year ARI flows.

Costs

The primary costs associated with each of the upgrade option are as follows:

- The initial capital outlay
- The recurrent maintenance cots based upon general expected maintenance and
- Restoration costs following predicted storm events.

The current financial capital cost of structures was assumed to have been undertaken within the first year. Maintenance costs of the *Do-nothing Option* was based on the existing maintenance contracts for the road, and assumed to increase each year by 5%. The estimated annual maintenance costs were based on estimated capital costs of the options as well as the capital value of existing structures that are proposed to be retained under each option. The three options show that that option A is low capital cost but high maintenance cost and option c is high capital but low maintenance costs and option B is relatively a medium capital cost and medium maintenance cost. In addition, under each option, it is assumed that there will be additional flood repair costs, albeit to different degrees, depending on the assumed threshold design level under each option, and the magnitude of the storm events. The SIRIP 2 sub project analysis assumes that a simple linear relationship exists between cost of damage and flood magnitude, the following expected annual flood damage as a proportion of structures capital value of the physical structures:

Less than Q2 Structures - 26%

Q2 Structures - 3.5%

Q10 Structures - 0.05%

Q100 Structures - 0%

By applying these ratios to the known existing and proposed capital value of structures, an estimated expected annual flood repair costs for each structure under each of the option was estimated.

Estimation of Benefits

The first step in assessing the benefits of a project is to identify the sphere of project's influence and identify peoples whose livelihoods would be directly and indirectly affected. The primary beneficiaries of this SIRIP project are the people living in the wider catchment areas around the Poha to Naro road. Based on the 1999 Census population and adjusted for annual growth, the population directly affected by the SIRIP project is expected to be 7, 782. It should be noted that an additional 21,160 people who live between Lambi and Wanderer Bay and along the Weathercoast (Southern

Coast) also rely on access from the subproject road. The population considered to be served by this road improvement project is 28,942 (Cardno Acil 2010). More specifically, the beneficiaries included:

- Existing road users, be they vehicle drivers or passengers and or non-motorised transport users.
- Households living in villages along and in the catchment area of the Main Road who grow or sell a range of cash crops including copra and cocoa
- Passenger and goods transport service providers and commercial truck drivers
- School children and teachers and schools and major facility at Selwyn College
- Small businesses and traders including vendors at the local and or informal markets, trade store owners and produce buyers
- Provincial authorities and key social service providers such as the education and health sector

The key benefit of the proposed adaptation response is increased access for the local population for both travel and transport of goods and services, resulting from the improvements in the infrastructure resulting in reduction in the periods of overtopping of the roads and bridges and providing. To inform this assessment, the project team used different sources of information:

- Field Traffic Surveys (SIRIP Annual Road User Survey April 2008 and March 2008)
- Field Social Survey for the project in 2009
- Previous economic studies in the region

The 2008 traffic survey and the social survey have been used for the calculation of the following benefits:

- Reduction in Travel times
- Reduced road disruption and
- Repair cost savings

Reduction in Travel Times

The challenge with any economic analysis is identifying those benefits that can be readily quantified. In the SIRIP project, the loss in travel time and wages due to flood related road closure is used to determine the costs associated with the current disaster risks. Conversely, a reduction in travel time, or time spent on the road, and wages not lost, as a result of road improvements is considered as economic benefit to the community. A reduction in travel times will also result in lower overall transportation costs as well. In economic analysis the reduction of costs due to the project options A, B and C are all counted as benefits as opposed to the Do-Nothing Option. This reduction in travel time benefits both individuals seeking employment and commercial trucks transporting agricultural goods especially cocoa and copra to the Honiara market.

In addition to cargo costs, there are substantial employment wage costs associated with the lack of access to places of employment. The project assumes that 75% of workers would be unable to work following road closure. With an estimated working population of 4125, this equates to approximately 2870 people unable to work during road closures. Hence under the Do-Nothing option approximately 27.22 days are lost per year per individual estimated at 218 hrs. Applying an average wage rate of SBD 14.15, value hours lost per year per individual is SBD 3081 (US$ 400). Hence, the total loss of value per year is SBD 9.8 million or US 1.1. million.

In the Do-Nothing Option, the number of days lost due to flooding is determined to be 27.22 days. The road upgrades under different engineering Options provides reductions in the number of days closed, and the associated opportunity costs are summarised in Table 4.1.

Table 4.1 Costs of 'no action' and shadow value of benefits generated from different climate adaption options

Option	No of days lost per person	Value of loss in travel time, wages, goods	Savings (Benefits) due to improvement over *Do nothing option*
Do-Nothing Option	27.22	SID8.8 million	
Option A	15.35	SID 4.96 million	SID 3.9 m (USD 0.5 million)
Option B	3.06	SID 0.989 million	SID 7.83 m (USD 1.02 million)
Option C	2.23	SID 0.712 million	SID 8.09 m (USD 1.05 million)

Source: Derived from Cardno Acil (2010)

The SIRIP 2 sub project in accordance with the National Transport Plan made use of Labour Based Equipment Supported (LBES) policy for construction and maintenance to create local employment and to encourage community participation and support for the works. LBES involves the engagement of community groups and small labour contractors in the maintenance and minor works. The expenditure on LBES creates direct employment and may have local and regional economic benefits through the multiplier effects. In addition there are other flow-on social benefits, such as from getting access in times of need to health services. Such indirect benefits are difficult to quantify, and such they were not explicitly considered in the BCA of the SIRIP 2 sub project.

Cost Benefit Analysis

Based on ADB's internal economic criteria for accepting a project, a project may be considered economically viable if the EIRR exceeds the relevant opportunity costs of capital; ADB's guidelines suggest an opportunity costs of capital of 12% is applied in accordance with ADB guidelines. Based on the economic assessment, and using economic efficiency as criteria the SIRIP 2 sub project team chose the option B, where at least 1-in-2 year flow can be tolerated, and during 1-in-10 year events, some flooding of the structures may occur but vehicles with higher clearance could still pass through. Option B gave the highest EIRR (Table 4.2).

Table 4.2 Economic evaluation of the increased level of threshold tolerance under Options, A, B & C compared with the 'Do-Nothing option'

Option	Do-nothing	A	B	C
PV Cost	$6.84 million	$12.52 million	$15.93 million	$20.88 million
Net PC Cost (compared with Do-Nothing)		$5,62 million	$9.10 million	$14.05 million
PV Benefits (compared with Do-Nothing Option)		$11.96 million	$23.18 million	$23.93 million
NPV		$6,28 million	$14.09 million	$9.88 million
EIRR (%)		28.1%	30.8%	20.5%
BCR		2.1	2.5	1.7
Source: Cardno Acil (2010)				

Sensitivity Analysis of the Preferred Option

A series of sensitivity analysis suggests *Option B* is still the preferred choice. A decrease in the benefits by five-fold is required for the NPV to become zero, when the proposed adaptation option would not be acceptable. Similarly costs, including capital and maintenance costs, would need to increase by 167% before the NPV becomes zero. Further sensitivity analysis assuming a higher design standard, but assuming no change in climate risk, did not change the choice of Option B.

Cost Benefit analysis of climate proofed measures

Climate change consideration was included only following the 2010 floods, when a preliminary climate change assessment was commissioned. The preliminary assessment, as mentioned above, relied on the Fourth Assessment Report scenarios for the South Pacific Region (discussed in Chapter2), and projected changes in precipitation, temperatures, cyclones and sea-level rise to draw general about climate change scenarios..

In the absence of detailed climate change predictions, the SIRIP 2 sub project team assumed that climate change will result in increases in rainfall intensities of 20% in large storm events in 20 years time. For frequent storm events, such a 1 in 3 month rainfall event, it is assumed that the frequency will remain unchanged. Using such assumed climatic parameters, the team then estimated the expected frequency of a given design flood in 20 years time. For example, under the assumed increase in the rainfall intensity of a current 10 year ARI design flood would be equivalent to a 5 year ARI design flood in 20 years time. Based in these assumptions, and using 6-hour rainfall intensities from the Engineering report, the existing rainfall intensities were converted to a 2-year, 10-year, 50-year and 100-year ARI design events.

Using these general projections, engineers identified possible consequences for the road infrastructure and the nature of adaptation measures required (See Cardno Acil 2009b).

For each of the physical infrastructure, engineers then determined the types of actual adjustments that needed to be made to the initial choice of road repairs and improvements, using different levels of acceptable thresholds (Table 4.3). Thus for example, in the case of Sasa Ford (#13 (the Option B was designed to withstand 2 – year event (Q_2). Under climate change scenario this was increased in standard to withstand a 1 in 10 year precipitation and flooding event (or Q_{10}), thus 'climate proofing' that ford. In comparison, the Selwyn Ngautu Ford's design quality was increased from Q_2 to Q_{20}. In the case of structures that were already designed to withstand 1-in-10 year event, such as Sasa washout, no changes were required to cater for the projected increase in threshold tolerance.

Table 4.3. Types of engineering design changes made in the light of projected climate change conclusion

No	Structure	Chg (kms)	Option B Proposed Restoration	Option B+CCA Proposed Restoration
1	Poha Bridge	7.8	New bridge 7 x 7m x 4.2m and raised approaches, scour protection, river training	New truss bridge 2x30m spans, 5.25m wide, demolish existing bridge, scour protection
3	Culvert	19.0	New Q2 causeway using 2m wide box cells	New Q10 causeway using 2m wide box cells
4	Tamboko Bridge	19.5	New bridge 10 x 7m x 4.2m and raised vented approaches, scour protection, river training	New bridge 10 x 7m x 4.2m perpendicular to flow and raised vented approaches, scour protection, river training extending upstream to village, debris catcher
9	Doma 2 Bridge	23.6	Replace eastern and western approach slabs with RC span and piled abutments, scour protection	New Q100 steel girder bridge using 21m span
13	Sasa Ford	28.8	New Q2 causeway using 2m wide box cells	New Q10 causeway using 2m wide box cells
14	Sasa Bridge	30.2	New truss bridge 2x30m spans, 5.25m wide, demolish existing bridge, scour protection	New truss bridge 2x30m spans, 5.25m wide, demolish existing bridge, scour protection
15	Sasa Washout	30.3	New truss bridge 2x30m spans, 5.25m wide, scour protection, approach embankments, land bridge embankment, river training	New truss bridge 2x30m spans, 5.25m wide, scour protection, approach embankments, land bridge embankment, river training
20	Tameli / Chovuna Ford	36.2	New Q2 causeway using 2m wide box cells	New Q10 causeway using 2m wide box cells
24	Konavua Bridge	46.0	Reinstate approach slabs, scour protection	Reinstate approach slabs, scour protection
25	Selwyn Ngautu Ford	49.0	New Q2 causeway using 2m wide box cells, sealed approaches	New Q20 causeway using 2m wide box cells, sealed approaches

Source: Cardno Acil (2009).

Based on the proposed engineering solutions under assumed climate change scenarios and qualitative assessment of projected impacts, further economic cost benefit analysis was undertaken for the indicative climate change adaptation.

Costs

The upfront capital costs are much higher in climate preferred infrastructure as compared to Do-Nothing option. Similarly, the annual repair costs are reduced due to better resilience of the climate proofed infrastructure against flooding. It is assumed that the maintenance costs remain the same under both climate change and non-climate change conditions. However, in reality longer wet periods and higher temperatures may result in more maintenance being required under climate change.

Benefits

Higher engineering protection measures to reflect increased risks under climate change by 2020 means that the benefits would be higher in terms of less road closures and reduction in travel times, loss in cargo down time and less loss in wages.

Cost benefit analysis

The economic net benefit of the CCA changes to the *Option B* was then compared with the net benefit of the chosen risk reduction measure for addressing current disaster risk engineering solution. As the benefit cost ratio was greater than 1 and the economic internal rate of return was estimated to be 12.8 (that is greater than 12% considered being an acceptable threshold); the decision to proceed with the changes in the engineering solutions was made (Table 4.3).

Table 4.3 Economic cost benefit analysis of Option B with higher design standard, and no increase in climate risk

	Option B	**B with higher standard but no increase in climate risks**
PV Cost	**$16.10 million***	**$19.23 million**
Net PV Costs (compared with Option B)		**$3.13 million**
PV Benefit of CCA		**$3.90 million**
NPV		**$0.774 million**
EIRR%		**14.4%**
BCR		**1.2**
Source: Table 5.9 Cardno Acil (2010b)*This value differs slightly from the figures quoted in Table 5.1 in the same report		

Sensitivity analysis did not change the conclusion of *Option B-CCA* response as the preferred strategy. A sensitivity analysis was undertaken by testing a 10% and 30% increase in rainfall intensities in 20 years time. This analysis indicated that should the changes in rainfall intensities increased by only 10% in 20 years time, then the EIRR would be 10.8%, which is still considered to be within the acceptable range (Dole and Abeygunawardena 2002).

Sea Level Rise Risk

The road under investigation runs parallel to the west coast of Guadalcanal. Field work by the IUCN team indicated that in some instances the road was perilously close to the sea often less than only 1 metre in height. Since no predicted sea level rise or a digital elevation model was available the height of the road and the risk of any predicted sea level rise could not be assessed. Hence, the climate proofed infrastructure only captures flooding impacts on the road infrastructure and does not incorporate the potential impacts of a rise in sea level rise.

Concluding remarks

Although the extended ADB-SIG SIRP 2 sub project was aimed at ‘climate proofing’ the repair and improvement of the roads in the North-Western Guadalcanal, the focus was on rain-induced flooding risks and its effects on crossing structures designed for various rivers and streams. Other sources of hazards were partially considered, while other types of climate change adaption measures were considered to be beyond the scope of the project TOR.

Robustness of risk assessment

The robustness of science or ‘impact first’ based risk assessment implicitly adopted in the sub project to address current weather related risks depends on the underlying data sourced and used. It is though acknowledged that national climate information service needs considerable strengthening with rainfall and stream velocity measuring stations established for key rivers.

In the presence of limited empirical data and good scientific understanding, translating the effects of the climate change on hazards and vulnerability conditions can be difficult. In addition, it can be equally challenging to identify relevant solutions to address the respective vulnerability conditions. All that may be possible is some qualitative assessment, and making some decisions based on expert knowledge and experiences, using tools such as multi criteria analysis.

For the Solomon Islands, and Pacific island countries in general, a systematic application of the hybrid ’impacts first and vulnerability first’ assessment approach based risk assessment, can help identify what could be empirically assessed and what could only be qualitatively described. Using cost benefit analytical framework, qualitative and quantitative measures of costs and benefits of alternative adaptation measures could then be compared using multiple criteria to inform preferred adaptation choice.

For mainstreaming climate change, care is needed when defining the terms of reference of a project so that climate proofing activities closely reflect context specific scale, scope and nature of weather and climate related risks. To encourage the adoption of a systematic approach to making informed choices on climate change adaption in the Solomon Islands, some institutional strengthening is relevant, as discussed in the next section.

5. Institutional and policy context for CCA in the Solomon Islands

Solomon Islands Government has made some progress towards taking a more systematic approach to climate change related decisions. It also recognises that a lot more needs to be done to strengthen their capacity (Solomon Islands Government 2008).

The Solomon Islands Government ratified the United Nations Framework Convention on Climate Change (UNFCC) on 28 December 1994, and submitted its Initial National communication (INC) to the UNFCC on 30 September 2004. The country also ratified the Kyoto Protocol on 13 March 2003 (Solomon Islands Government 2008). With the ratification, the SIG was able to take advantage of international resources available, particularly under the Least Developed Countries (LDCs) Fund to support the preparation and implementation of the National Adaptation Plan (NAPA). The Marrakech Accords where a programme of work for the implementation of Articles 4.9 was adopted by the conference of the Parties (COP) to the UNFCC (decision 5/CP.7). The programme of work for LDCs included the establishment of the LCDCs Fund to support the preparation and implementation of the NAPA.

The overall framework for adaptation to climate change and for development in Solomon Islands is embedded in the Medium Terms Development strategy 2008-2010 (MTDS). One of its key national objectives is to ensure sustainable utilization and conservation of the natural resources and environment and successful adaptation to climate change. One of the major policy objectives is to ensure the sustainable utilization and conservation of the natural resources and environment and successful adaptation to climate change. The Solomon Islands has yet to develop a national environmental policy document to guide environment policy activities in the country. The primary document for environment is the National Environment Management 1993 (NEMS) which has not been implemented or updated since it production (Solomon Islands Government 2008).

The Ministry of Environment, Conservation and Meteorology (MCEM), with the assistance of SPREP, prepared its national adaptation plan of action (NAPA) using the guidelines provided by the UNFCCC. It helped to consider climate change issues in their national and sectoral development plans and strategies. The SI NAPA report was released in November 2008. In 1997 the Solomon Islands Government had released its National Disaster Management plan, prepared by the National Disaster Management Office (Solomon Islands Government 1997). Efforts have also been made to enhance the disaster risk management in line with the Regional framework of Action on Disaster risk reduction and disaster management. These two national action plans are implemented by two different arms of the Government, with until recently limited coordination.

Two important policy instruments came in to affect recently, that is expected to improve institutional coordination. Firstly, climate change concerns have now been brought in line with disaster risk management by the creation of a new Ministry of Environment, Climate Change, Disaster and Meteorology (MECDM) in 2011. MECDM is an independent Ministry with specific mandate of co-ordinating and guiding the sustainable use and conservation of the Solomon Islands natural resources and ecosystems. For the first time the government elevated the climate change unit to a the status of a Division, when it established a Climate Change Division to coordinate all climate change issue related activities in the country. Secondly the MECDM will also be expected to provide key data services such as metrological information and disaster risk reduction and management strategies across all sectors (MECDM 2011-2014). These no doubt will help strengthen institutional capacity to manage climate and other disaster risks in a more cost effective manner, since climate risk management and other disaster risk management principles under the UNFCCC and the Hyogo Framework of Action (HFA) respectively are very similar.

Infrastructure Sector: adaptation to climate change

The NAPA adopts a sectoral approach to adaptation and outlines key threats of climate change and relevant response strategies required in each of the key national sectors, including agriculture, fisheries, infrastructure and mining.

Under the infrastructure sector, NAPA outlines adverse impacts of climate change in respect of infrastructure development. Floods, storm surges, tropical cyclones and sea level rise have particularly been identified as damaging to roads and bridges. NAPA states that bridges and wharves are designed to withstand extreme events similar to past hazards, and do not reflect projected increased risks under climate change. Currently SIG does not though have a national policy on the climate change and infrastructure development.

Transport Sector

The SIG released its National Transport Plan 2011-2030 (NTP) Final Draft in October 2010, which identifies a set of strategies, policies and immediate priorities for the development of the transport system. It notes that expenditure on transport infrastructure will be concentrated on the rehabilitation and maintenance of the existing infrastructure, with prioritisation occurring at two stages: at the project and programs level at modal or sub-sector level.

The NTP provides a strong commitment to comply with the Environment Act, by stating that all infrastructure development projects require EIA while some risk factors not necessarily on climate change related issues are included in the design and construction of bridges, roads and wharves. It also makes strong commitments support climate change adaptation and NAPA to '*improve the resilience of key infrastructure to climate change and sea level rise*'. The NTP (Annex C) highlights the following impacts resulting from climate change in respect of infrastructure development that would need particular attention:

> *Flood will have great effect on this sector especially regarding roads and bridges. In some [past incidents roads and bridges were washed away or damaged. The most affected areas are on Guadalcanal, Makira and Malaita. Tropical cyclones will adversely affect road transport and that sea level rise poses great risks coastal roads if no adaptation measures are considered. NTP also states that currently engineers are designing ridges and wharves to*

> *withstand extreme events caused by climate after past experiences and goes on to say that there is no clear direction of taking future climate change impacts into account.*

The Government is currently revising their guidelines for social assessment of transport sector projects, including climate proofing related projects, consistent with the regulations passed in 2008 under their Environment Act (discussed below) (Government of Solomon Islands 2010).

Environmental Legislative Framework

Social and economic assessment of climate change risks could be considered in the context of environmental impact assessment requirements under the Environmental Act. *The Environment Act of 1998 (No. 8 of 1998)* is the single most important environment legislation. It is essential an environmental impact assessment legislation. The Environment Act has considerable powers by virtue of article 4 (i) which states that in the event of conflict between the Environment Act and other legislation, the provisions of the environment act has prevail.

The Act provides guidance on development control, environmental impact assessment and pollution control. All prescribed projects require a simple assessment through a 'screening' or scoping to see what level of assessment is required. Most prescribed projects require a *Public Environmental Report* (PER). On the other hand, many major projects such as logging, large agricultural developments, mining, tourism development and infrastructure projects will also need second stage of EIA, which includes detailed technical, economic, environmental and social investigations, and presented in the *Environmental Impact statement.*

In the Second Schedule, the Act lists prescribed developments for which consent accompanied by an EIA are required. In respect of road construction or rehabilitation, prescribed activities to be subjected to EIA include:

- (2) Non-metallic industries: (d) extraction of aggregates, stones or shingles; and
- (9)Public works sector (b) infrastructure development and (b) soil erosion and silt control.

However, the EIA Guidelines for Planners and Developers produced in 1996 pre-dates the Environment Act and are not legally binding. In 2008, the SIG released a system of environmental impact assessment regulations passed under the Environment Act and details guidance on the social assessments to be included in an EIA.

Currently there are no guidelines for environmental impact assessment at the sector or project level. Nor are there any sector guidelines for infrastructure development and guidance on climate resilience adaption of infrastructure. It is noted that although the Environment Act does not make reference to climate change in its scope, climate risk could easily be considered in the context of social and environment impact assessment. Similarly, considerations of community based effects of climate change could be addressed at the Provincial level. The Provincial Government Act 1997 that provides for provinces to create their own legislation in respect of environment and conservation. Provincial regulations are particularly effective where they provide for community based resource management and or/address any gaps or weaknesses in national regulation such as protected areas.

Furthermore, where external funded projects are involved, climate risk considerations could be made explicit during the project cycle process, by adopting a project-cycle-based climate risk management cycle. Many development partners, including ADB, usually have clear policies when it comes to project development and evaluation process, including economic, environmental and social impact assessments, and more recently risk assessments. However, as the ADB had categorised the SIRIP 2 sub project as not a new infrastructure but rather as a rehabilitation of existing structures, the SIRP 2 project was not subjected to the SIG's detailed EIA. Instead the ADB presented its own internal environmental examination report (as required under the ADB policy), to MECM, as a fulfilment of the Government EIA requirements. The MCEM accepted the statement from ADB with it seems limited scrutiny (Mr. Moses Virivolomo, then Under Secretary, MID, and Mr Joe Horouku, Director Environment Division, MCEM, pers comm. June 2011). Nor it seems did the MECEM had capacity to provide significant inputs into the project design. As noted by the World Bank, there are major gaps and barriers that needs to be overcome for effective climate change adaptation, including the absence of effective mechanisms for cross-sector collaboration and cooperation (World Bank 2010); the advisory Climate Change Country Team originally established under during the preparation of the Initial National Communication had became largely defunct after the First Communication report was submitted to the UNFCCC. Efforts are currently being made to resurrect this advisory committee and establish a more permanent technical committee (Rence Sore, Permanent Secretary, MCEDM, pers comm, June 2011).

ADB Environment and Climate Change Assessment and SIRIP 2 Sub Project

Since the early 1990s, the ADB has been at the forefront in assisting countries in the Asia and Pacific region to address climate change through various technical assistance programs and lending operations (ADB 2005). ADB recognises that climate change adaptation is ultimately an issue of sustainable development. The cornerstone of ADB's assistance in the Pacific to climate change is Climate Change Adaptation Program for the Pacific (CLIMAP) to assist Pacific member countries to enhance adaptive capacities and resilience to climate change and climate variability including extreme events.

ADB commissioned *Climate Proofing – A Risk Based approach to Adaptation* as a result of a regional technical assistance (RETA) funded by donors (ADB 2005). This ADB report (2005) included a series of case studies, in places like Kosrae and Cook Islands, to demonstrate the importance of adaptation to current and future climate risks through use of Integrated Risk Reduction Framework and Methodology. It also went on to state that for infrastructure projects, it is possible to avoid most of the damage to costs in a cost-effective manner, if climate proofing is undertaken at the design stage of the project.

While ADB did not appear to use its own Integrated Risk Reduction Framework and Methodology in the case of the Western Guadalcanal SIRIP project, it did attempt to do so in the case of coastal roads rehabilitation project in North Malaita in 2011 (Cardno Acil 2011; Thompson, Knee et al. 2011). Here, ADB commissioned the Hadley Centre in United Kingdom to undertake Sea-level Rise Projections (Hadley Centre 2010), which was used to design the engineering adaption options under the SIRIP 2 North Malaita sub project.

It seems that although significant policy commitments and project funding are evident in the ADB, there remain some gaps in their implementation in the Pacific. The ADB also recognises that there is a need to produce specific guidelines for mainstreaming climate proofing in environmental impact assessment procedures (www.adb.org/doucments/Guidelines/Environment.Assessments). The Rapid Environmental Assessment Checklists now include climate change related questions but these are optional only at this stage. Draft Practical Guides for Adaptation are currently being prepared by ADB (Roop, Senior Environmental Specialist, ADB pers comm, 2011).

ADB could though use its environmental policy to explicitly consider climate change related risks in this project. The ADB's Environmental Policy approved in 2002 and supported by a set of procedural guidelines and various sections of the Operations manual (OM), prescribed that all ADB investments are subject to categorization to determine the level of environmental assessment required. According to OM 20, Environmental categorization of ADB projects are classified as one of three key categories as follows:

Category A – projects with likely significant adverse impacts. These projects require an EIA and a summary EIA (SEIA) addressing the significant environmental impacts.

Category B- projects that will have impacts on environmentally important areas or people that are less adverse than Category A. Category B projects require an IEE and summary SIEE to determine whether or not significant environmental impacts warranting an EIA are likely.

Category C – projects that are likely to have minimal or no adverse environmental impacts. Category C projects do not require an EIA or IEE but need to be reviewed for identification of mitigation measures that can be incorporated directly into project design or could be subject to an environmental management plan.

Consistent with its project cycle policy, ADB commissioned a series of reports in addition to the engineering report, including:

- Initial Environmental Examination Report, Repair and Rehabilitation of Main Road: Guadalcanal Province (July 2009), Report No:40 Cardno/ACIL
- Initial Poverty and Social Assessment, North West Guadalcanal Roads, Poha to Naro Hill, Guadalcanal Province, Feasibility Study (June 2009) Cardno/ACIL
- Economic Assessment, Guadalcanal Flood Damage Restoration Subproject (July 2010), Report No: 40A

Rationale for ADB's Environmental Assessment of SIRIP

ADB categorised the SIRIP 2 sub project project as falling into **Category C** that does not require a full EIA as the main road already existed and did not traverse any primary forests, protected or ecologically sensitive areas, heavily populated settlements and does not cause resource use conflicts. The project is focused on maintenance and rehabilitation works of an existing main road infrastructure in west Guadalcanal such as widening the road by 1-2 m, shaping and improving road drainage, repairing failed roads and bridges and compacting. The subproject – Main Road- will include repairs and rehabilitation works of bridges, culverts, some rivertraining works but acknowledged that this can lead to potentially adverse but not significant environmental impacts if implemented without mitigation.

It listed that the SIRIP 2 sub project would in fact be providing environmental improvements from improved drainage, reduced habitat destruction and less mobilization of sediments during rain.

The ADB Initial Environment Examination states that consultations with the MECM had confirmed that this initial environmental examination will be acceptable as the level of assessment for the subproject in respect of the Environment Act. Hence, no further environmental assessment such as EIS or PER was produced. Following this assessment ADB submitted the IEE and SIEE to MID and MECM for approval prior to submission to the ADB Board. Since the Solomon Islands Environment Act did not cover climate change issues, ADB did not address this issue in any great detail. In accordance with ADB guidelines, SIRIP 2 sub project prepared a Environmental Management Plan and an Environmental Monitoring Plan. The MECM assessed this and approved the IEE and SIEE but did not require further assessment or incorporation of climate change modelling or specific adaptation measures; this suggests some capacity constraints within MECM to deal with cross cutting issues such as climate proofing of infrastructure projects.

In conclusion, this institutional and policy assessment highlights that even where current legislative framework and decision-making process within the Solomon Islands may not explicitly include strategies to address climate change adaptation needs, they could still have been used in the interim by the government to evaluate investment projects through the climate risk lens, together with the standard technical feasibility and economic viability criteria. This could have also been possible if the Government and the development partners adopted a broader view of climate proofing when environment assessment reports were commissioned, and or there was capacity in the Government to consider climate risk issues before approving such an investment project. As a minimum greater consideration of climate change issues could have been facilitated had greater cross sectoral inputs been included in the SIRIP 2 sub project development process.

6. Concluding remarks

The assessment of the climate proofing of the SIRIP 2 sub project in the north-western Guadalcanal highlights key challenges faced by the Solomon Islands government when addressing particularly a cross cutting issue such as climate change. Such an endeavour requires, amongst other things:

- clear establishment of the relationship between national development policies, sectoral goals and programs, and outcome focussed projects, operationalising government development policies;
- cross sectoral collaboration and coordination of efforts across different government agencies;
- government policies and decision-making processes that reflects an understanding of the dynamics of not only weather and climate systems but also about the dynamics of social and economic systems affected by weather and climate hazards;
- community needs and aspiration, their vulnerability and perception of current and projected risks, and their risk tolerance threshold;
- integrated climate risk assessment and risk management that requires a number of different sets of data collected and maintained by different agencies, as well as experiential knowledge of the local communities in disaster risk management;
- institutional and human capacity and tools to undertake hazard mapping, and vulnerability, risk assessments and risk management decisions.

The SIRIP 2 assessment also emphasises climate change adaption decision-making processes could be strengthened by making robust knowledge based climate risk and risk reduction assessment an explicit requirement of all externally funded projects, and strengthening the interface between the Government agencies and development partner processes. As a first step towards this, climate risk considerations in the project development and evaluation process, including environmental and social impact assessments, could be made an explicit requirements for all major projects, taking advantage of existing development and environmental legislative requirements and decision-making processes, and strengthening intersectoral interactions and engagement. In October 2011, the Solomon Islands Government established a Climate Change Working Group (CCWG) which consists of departments, development partners and NGOs to strengthen their knowledge based decision-making. The CCWG will be supported by a number technical working groups, which no doubt when fully functioning would help address some of the current challenges .

In conclusion there is considerable scope to improve knowledge based climate proofing of infrastructure projects, including by developing not only suitable climate prediction models for the Solomon Islands, but also suitable rainfall-runoff and hydrology models for local rivers and streams, and better risk and risk reduction assessments. . As a first step, a system of decision-making would help embrace ‘vulnerability first’ risk management approach supported by climate information services that integrated available scientific, social and economic information and traditional experiential knowledge targeting current disaster risks, while taking into account projected increases in risk due to climate change. Furthermore, a strengthened enabling environment, decision-making processes and institutional and technical capacity within the Government would help in ensuring robust climate change adaption decisions that meets national development goals.

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