Making informed adaptation choices: A case study of climate proofing road infrastructure in the Solomon Islands

Padma Narsey Lal and Valentine Thurairajah

November 2011

Australian Government

Department of Climate Change and Energy Efficiency

AusAid

Australian AID

ISBN 978-1-922003-92-8

This report was supported by funding from the Australian Government under the Pacific Australia Climate Change Science and Adaptation Planning (PACCSAP) program.

Copyedited by Econnect Communication

Citation: Lal, P.N. and Thurairajah, V. 2011. 'Making informed adaptation choices: A case study of climate proofing road infrastructure in the Solomon Islands'. A background case study for IUCN's report, Lal, P.N. (2011), Climate Change Adaptation in the Pacific: Making Informed Choices, prepared for the Australian Department of Climate Change and Energy Efficiency (DCCEE), IUCN, Suva, Fiji.

Available from:
IUCN Regional Office for Oceania
Private Mail Bag
5 Ma'afu Street, Suva
Republic of Fiji Islands
Ph: +679 3319084
Fax: +679 3100128
www.iucn.org/oceania

Acronyms

ADB	Asian Development Bank
ARI	average recurrence interval
AusAID	Australian Agency for International Development
BCR	benefit–cost ratio
BOM	Australian Bureau of Meteorology
CBA	cost–benefit analysis
CCA	climate change adaptation
CCWG	Climate Change Working Group
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCCEE	Department of Climate Change and Energy Efficiency
DRR	disaster risk reduction
EIA	environmental impact assessment
EIRR	economic internal rate of return
ENSO	El Niño-Southern Oscillation
GCM	global climate change models
GIS	geographic information system
HDI	Human Development Index
HFA	Hyogo Framework for Action
IEE	initial environmental examination
INC	initial national communication
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Intertropical Convergence Zone
IUCN	International Union for the Conservation of Nature
JICA	Japanese International Cooperation Agency
LBES	Labour Based/Equipment Supported
LDC	least developed country
MDG	Millennium Development Goals
MTDS	Medium-term Development Strategy
MECDM	Ministry of Environment, Climate Change, Disaster Management and Meteorology
MECM	Ministry of Environment, Conservation and Meteorology
MID	Ministry of Infrastructure and Development

NAPA	national adaptation programme of action
NB	net economic benefit
NDS	National Development Strategy
NEMS	National Environment Management 1993
NGO	non-government organisations
NPV	net present value
NTP	National Transport Plan 2011–2030
NZAid	New Zealand Agency for International Development
PER	Public Environmental Report
RFA	Regional Framework of Action on Disaster Risk Reduction and Disaster Management
RTA	regional technical assistance
SBD	Solomon Islands Dollar
SIG	Solomon Islands Government
SIRIP	Solomon Islands Road Improvement Project
SOPAC	Secretariat of the Pacific Community
SPREP	Secretariat of the Pacific Regional Environment Programme
UNFCCC	United Nations Framework of Climate Change Convention

Acknowledgements

A number of people in the government of Solomon Islands and the Asian Development Bank (ADB) kindly assisted the International Union for the Conservation of Nature (IUCN) research team by sharing their project documents and other grey and published literature, as well as their experiences in addressing climate change issues in the Solomon Islands, particularly the Solomon Islands Second Road Improvement Project (SIRIP 2) of the ADB-Solomon Islands Government partnership. In the Solomon Islands Government, we wish to express our gratitude to: Mr Moses Virivolomo, then Undersecretary, Ministry of Infrastructure and Development (MID); Mr Ambrose Kirie, Director of Civil Engineering, Mr Ishmail Alulu, Chief Civil Engineer and Mr Tony Telford, SIRIP 1 & 2 Project Manager from Cardno Emerging Market of MID; Mr Rence Sore, Permanent Ministry of Environment, Climate Change, Disaster Management and Meteorology (MECDM); Mr Douglas Yee and Mr Hudson Kauhiona of the Climate Change Division, MECDM; Mr Joe Horoukou, Director, Environment Division and Mr Frank Wickham, Climate Change Adviser. Mr Nigel Tutuo, Geographic Information System Officer with the MID kindly prepared the map of the SIRIP 2 sub-project site.

We are also grateful to several of the ADB staff from the Sydney and Manila offices who shared various SIRIP 2 sub-project documents, including key reports that summarised engineering, economic, and environmental and climate change assessments of the SIRIP 2 north-western Guadalcanal road improvement project. These included Mr Marfuzuddin Ahmed, Principal Natural Resource Economist, ADB Pacific Operations Division; Mr Jay Roop, Senior Environment Specialist in the Manila office; and Mr Rishi Adhar, Senior Project Officer, Pacific Liaison and Coordination Office, Sydney Office. The comments provided by the ADB staff during the debriefing in Honiara and the subsequent written draft report are also very much appreciated.

Table of contents

List of tables

List of figures

Executive summary

The Solomon Islands regularly experiences climate-related extreme events, including tropical cyclone-related heavy rains, storms and coastal storm surges, causing significant economic losses as well as loss of lives. In response to regular flooding and other such damages, the Solomon Islands Government with the assistance of Asian Development Bank (ADB), the governments of Australia and New Zealand, undertook a program of road rehabilitation, Solomon Islands Road Improvement Project (SIRIP). SIRIP's goal was to rehabilitate the roads to be able to withstand a higher category of weather event. As part of this larger SIRIP project, the original SIRIP 2 sub-project focused on repair and improvements to the road between White River and Naro Hill, north-western Guadalcanal. The sub-project was extended to Selwyn College following the January to February 2009 floods. The designs of bridge and river crossings in particular were subsequently revisited following the 2010 floods to include considerations of projected increases in climate risks. Revisions to the design were made before actual construction work had begun.

This case study, which is part of a wider Department of Climate Change and Energy Efficiency–International Union for the Conservation of Nature project, *Social and economic assessments of climate change adaptation in the Pacific: Making informed choice,* examined the extended SIRIP 2 sub-project plus additional climate-proofing activity to assess the following key issues:

- approaches used to analyse current climatic risks, risk thresholds and projected climate change-related risks
- approach used to identify, analyse and select the appropriate current risk- reduction option
- approach used to identify and select a risk reduction option for climate proofing of the road infrastructure improvements
- key challenges faced in undertaking climate proofing of the road improvement under the SIRIP 2.

Climate risk management process

The SIRIP 2 sub-project followed key steps of the standard risk assessment, drawing on multiple sources of data and multiple technical disciples, including hydrology, engineering and economics. The SIRIP 2 sub-project undertook the following:

- context analysis in relation to hazards and identification of problems and possible solutions
- assessment of risk-reduction measures and selection of preferred choice based on key threshold criteria
- project design
- cost–benefit analysis (CBA)
- analysis of alternative climate change scenario on engineering design and climate proofing of preferred option.

Current risk and risk-reduction analysis

Detailed scientific impact assessment formed the basis of the current and projected hazard and risk assessment, as well as risk-reduction assessment, although it was constrained by baseline data limitations and suitable models. Hazard analysis was conducted, using hydrology and hydraulic modelling-based analysis based on 'Rational Method' to produce estimates of river flow velocity, depth, frequency and flooding at each of the stream/river crossing. In the absence of stream-flow modelling information for the Solomon Islands, a simplified modelling of the available rainfall data for Honiara rainfall was used to determine run-off patterns, together with estimates of flood flows, and the average recurrence period for different flood intensities. This information was used to determine the design of culverts and bridges to cope with a 1-in-10-year flooding event; the associated effects of increased debris flow—resulting from the interaction between heavy precipitation and catchment landscape—on crossing structural designs were considered mainly for the larger bridge structure at one of the rivers.

In the design of the roads and crossing structures, engineers faced many challenges, including considerations of the effects of high intensity precipitation, flash flooding, landslide and debris flow and moving river channels due to soft alluvial soils. Western Guadalcanal is prone to serious landslides, which is related to rainfall, slope, and soil characteristics. These are mentioned in the assessment reports, including the need for strengthening scour protection, widening the bridge span on large bridges and river training. However, landslide risk assessment and terrain analysis were not undertaken, and there was no analysis of the effects of upper catchment land-use changes (particularly due to commercial forestry). These were considered beyond the project scope. The SIRIP 2 sub-project did though consider debris impact assessment in the engineering designs of selected 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, though not the bridges, in the project area are also within metres of the coast. However, potential impacts of sea-level rise, including storm surges, were not factored in the risk-reduction consideration. These observations raise the question about what effect an 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 White River–Naro road, as well as costs and benefits and the choice of repair and road improvement options examined in the SIRIP 2 sub-project.

Choice of risk-reduction option

The focus of the SIRIP 2 sub-project was on 'hard' engineering solutions within the infrastructure sector, targeting reduction in the impacts of regular high intensity precipitation and associated flooding on key road infrastructure in the Western Guadalcanal, including culverts, bridges, causeways and roads. Non-engineering solutions, although noted in the assessments, were not pursued due to land tenure issues or considered to be outside the scope of the project's terms of reference.

Choice criteria: acceptable threshold

The choice of the risk-reduction and climate change adaptation measures was based on predetermined minimum risk tolerance threshold assessed 'by serviceability (of the roads and bridges) in floods arising from high intensity storms' and 'as far as economically feasible'. The project team considered three engineering project designs in addition to the status quo, reflecting alternative design structures that could withstand different magnitudes of rainfall and flooding events, and acceptable threshold levels; acceptable risk tolerance thresholds identified, it seems also reflected some considerations of the costs implications of different design standards.

The four SIRIP 2 design options were then subjected to CBA. Financial costs, including the capital costs of the structures, operation costs and respective regular maintenance costs were assessed. Benefits of the road infrastructure repairs and improvement were assessed in terms of maintaining/ensuring access and/or avoided loss in earnings when structures are under flood water, and/or when breaks in the river crossings prevent movement of vehicles and people. Such benefits were assessed using field traffic surveys; social survey of communities serviced by the road and the savings in repair of flood-damaged structures. Other social benefits of risk reduction, such as improved access to health services, were considered qualitatively.

Cost–benefit analysis ‘without’ climate proofing

Based on the economic assessment, and using economic efficiency as criteria, the SIRIP 2 sub-project team selected option B, the economically feasible road improvement option, where at least 1-in-2 year flow could 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 economic internal rate of return (EIRR). Option B was also the preferred choice when qualitative assessment of social benefits was also being considered by the project team, together with economic efficiency.

Cost–benefit analysis of climate-proofed measures

In the absence of detailed climate change predictions, the SIRIP 2 sub-project team used Intergovernmental Panel on Climate Change AR4 projections to identify changes in the design of the key infrastructure under Option B. For some infrastructures, acceptable threshold values were also revised. As the benefit–cost ratio (BCR) was greater than one and the EIRR was estimated to be 12.8, Option B + climate proofing changes were then accepted and implemented. Sensitivity analysis, varying rainfall intensity projections under AR 4, did not change the conclusion of *Option B-CCA* response as the preferred strategy.

Institutional decision-making process

The assessment of the climate proofing of the SIRIP 2 sub-project highlights key challenges faced by the Solomon Islands Government when addressing a particularly 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 programmes, and outcome-focused projects, operationalising government development policies
- cross-sectoral collaboration and coordination of efforts across different government agencies
- government policies and decision-making processes that reflect an understanding of the dynamics of not only weather and climate systems (the usual focus of much debate), but also about the dynamics of social and economic systems affected by weather and climate hazards
- knowledge of community needs and aspirations, their vulnerability and perception of current and projected risks, and their risk tolerance threshold

- integrated climate risk assessment and management that requires a number of data sets 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.

Significant mainstreaming has been included in national economic development policies and sectoral policies. Further institutional strengthening can help effective implementation of these policy commitments.

A system of decision-making that embraces ‘vulnerability first’ risk-management approaches supported by climate information services would help strengthen the informed adaptation decisions. Such an approach would be supported by analysis of integrated available scientific, social and economic information and traditional experiential knowledge, targeting current disaster risks, and 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 to ensure robust climate change adaptation decisions that meet national development goals. Lack of knowledge-based tools and techniques suitable for Solomon Islands, and/or the region as a whole, is a major constraint in implementing informed climate change adaptation. Climate proofing of infrastructure projects could be improved by developing not only suitable climate prediction models for the Solomon Islands, but also developing/strengthening rainfall–run-off and hydrology models for local rivers and streams, and through better risk and risk reduction assessments. Sector guidelines for climate proofing are also required under the environmental impact assessment (EIA) legislation for infrastructure development.

The lack of a national integrated geographical information system (GIS) system for Solomon Islands is also seen as a major constraint although some discrete GIS systems exist in the some departments, such as the Lands, Mining and Forestry departments. These need to be at least harmonised and linked to help improve sharing of data and expertise in the country.

Climate risk considerations in the project development and evaluation process, including environmental and social impact assessments, could be made explicit requirements for all major projects, taking advantage of existing development and environmental legislative requirements, and strengthening the interface between the government agencies and development partner processes. This, together with a fully functioning Climate Change Working Group, consisting of departments, development partners and non-government organisations and supported by key technical working groups, would strengthen knowledge-based climate change adaptation decision-making.

In conclusion, future infrastructure development projects in the Solomon Islands would benefit from the strengthening of institutional and technical capacity in country, together with strengthening the interface between the national development approval process and development partner’s project development processes. This includes the use of integrated climate change risk considerations, and the mandatory use of climate risk criteria in project selection, together with economic, environmental and social selection criteria.

1. Introduction

The Solomon Islands is 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 and affecting almost 300 000 people. Of these events 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, dominated 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 Asian development Bank (ADB), the governments of Australia (through the Australian Agency for International Development – AusAID) and New Zealand (through the New Zealand Agency for International Development – NZAID), and the European Union undertook a program of road rehabilitation, Solomon Islands Road Improvement Project (SIRIP). A second Road Improvement Programme 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 by what was defined as a 1-in-50 years average recurrence interval (ARI)[1] or return period.

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 to 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 disrupted a major transport route in West Guadalcanal. This 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).

According to the UNFCC (2002), climate proofing in practical terms involves:

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

---

[1] Average recurrence interval (ARI) is equivalent to the term average ‘return period’, and is defined as the long-term average interval in years between the occurrence of a hazard floods or rainfalls, equalling or exceeding the stated value. For example, a flood with a return period of 50 years means that one could expect two floods of this magnitude or larger to occur in any period of 100 years. However, it also means that there is a 2 per cent chance that such a flood could be equalled or exceeded in any single year (SMEC 1990).

Such climate proofing of development activities are implemented often at one or more of the stages in the project cycle: planning, design, construction, operation and monitoring. 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 as help select adaptation responses that maximise returns on limited financial investment.

This case study, which is part of a wider Department of Climate Change and Energy Efficiency–International Union for the Conservation of Nature (DCCEE–IUCN) project, *Social and economic assessments of climate change adaptation in the Pacific: Making informed choices,* examined the extended SIRIP 2 sub-project plus additional climate-proofing activity to assess the following key issues:

- approaches used to analyse current climatic risks, risk thresholds and projected climate change-related risks
- approach used to identify, analyse and select appropriate current risk- reduction option
- approach used to identify and select risk reduction option for climate proofing of the road infrastructure improvements
- key challenges faced in undertaking climate proofing of the road improvement under SIRIP 2.

The findings of the detailed case study analysis were 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 projects 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
- selection of adaptation measures that reflects consideration of potential impacts on social, 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 adaptation 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 identifies areas that could be strengthened. Lastly, Chapter 6 concludes by highlighting key decision-making processes to encourage integrated assessment of risk and risk reduction and climate-proofing of infrastructure.

2. Weather and climate-associated hazards in the Guadalcanal Island

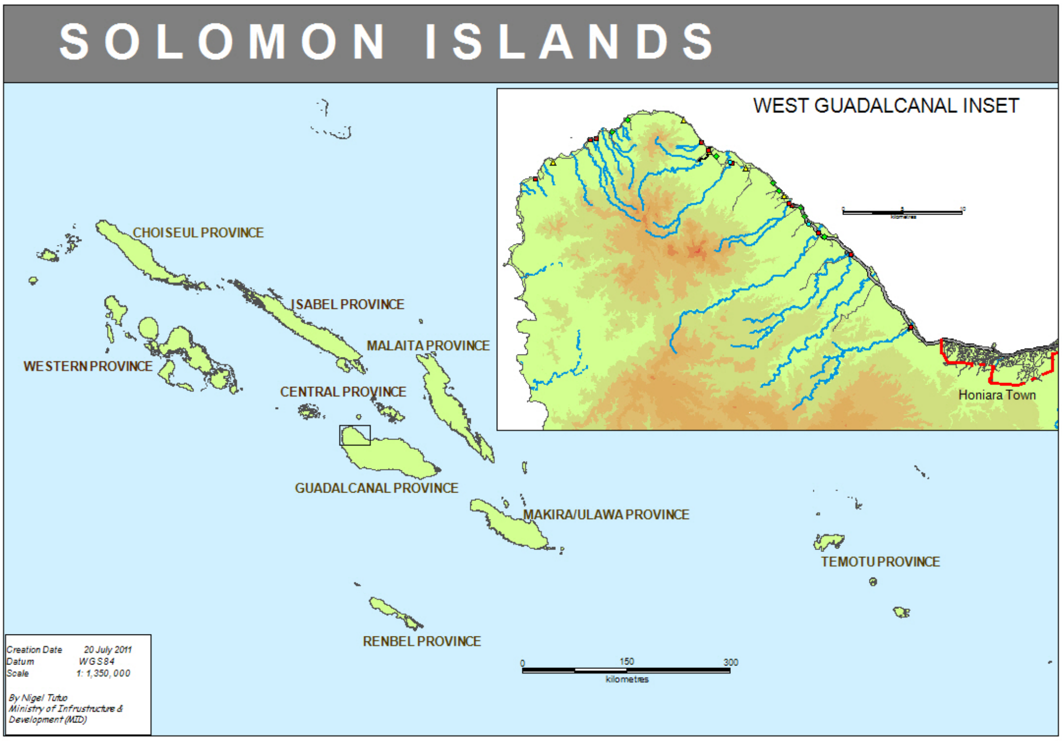
Guadalcanal is prone to natural disasters and experienced about 40 different disaster events between 1950 and 2009. The province is classified as ‘high vulnerability’ to cyclones, and coastal flooding and has ‘medium vulnerability’ to earthquake, tsunami, drought and river flooding, and ‘low vulnerability’ 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 six major islands of the Solomon group, with an area of 5310 km^2 ,it extends 150 km from northwest to southeast and is 45 km at its broadest (Figure 1). The southern coasts of Guadalcanal are considered to be some of the wettest places on earth with a mean annual rainfall of around 8000 mm and hence has acquired the name ‘the weather coast’ (Hackman 1979). The weather of the Solomon Islands is dominated by seasonal movement and development of the Intertropical 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 to the south of the Solomon Islands. The north-west 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 May to October (JICA and Ministry of Natural Resources 2000).

The mean annual rainfall is indicated as 3000 mm in the western part of the Solomon Islands and increases to 5000 mm in the eastern part. In January, the monthly average rain exceeds 350 mm over the entire country, while it slightly decreases in July. The available annual rainfall data for the period from 1955 to 1997 for key stations in the major islands are summarised in the Table 1.The southern half of the island is a mountainous zone, rising to over 2300 m with a north-west to south-east trending spine. The mountains are flanked on the northern side by foothills that form an intermediate zone of intensely dissected plateau hills and rolling ridges.

Numerous rivers transect 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). 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 48.1 km^2) and Sasa River (with a catchment area of 27.3 km^2). These rivers and streams regularly experience flooding during the rainy season and this is expected to be exacerbated under climate change.

Figure 1 Map of Solomon Island road improvement project (SIRIP 2): Western Guadalcanal road improvement sub-project



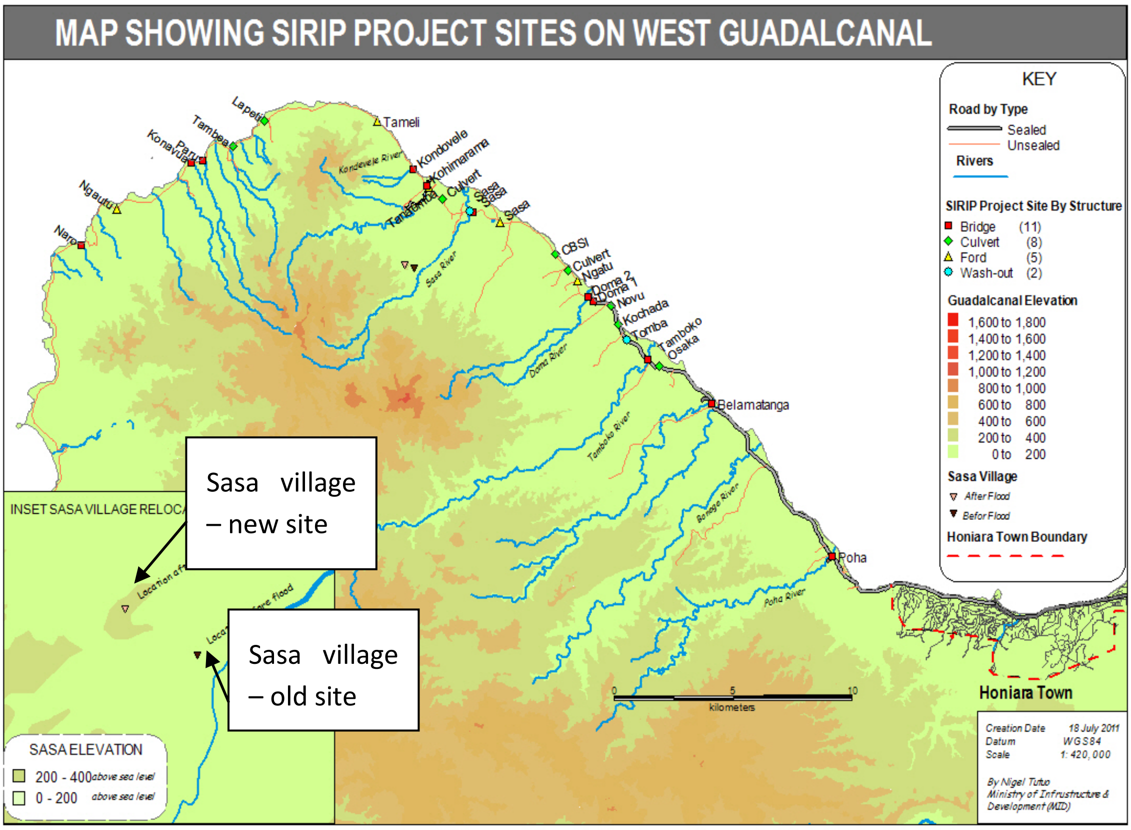
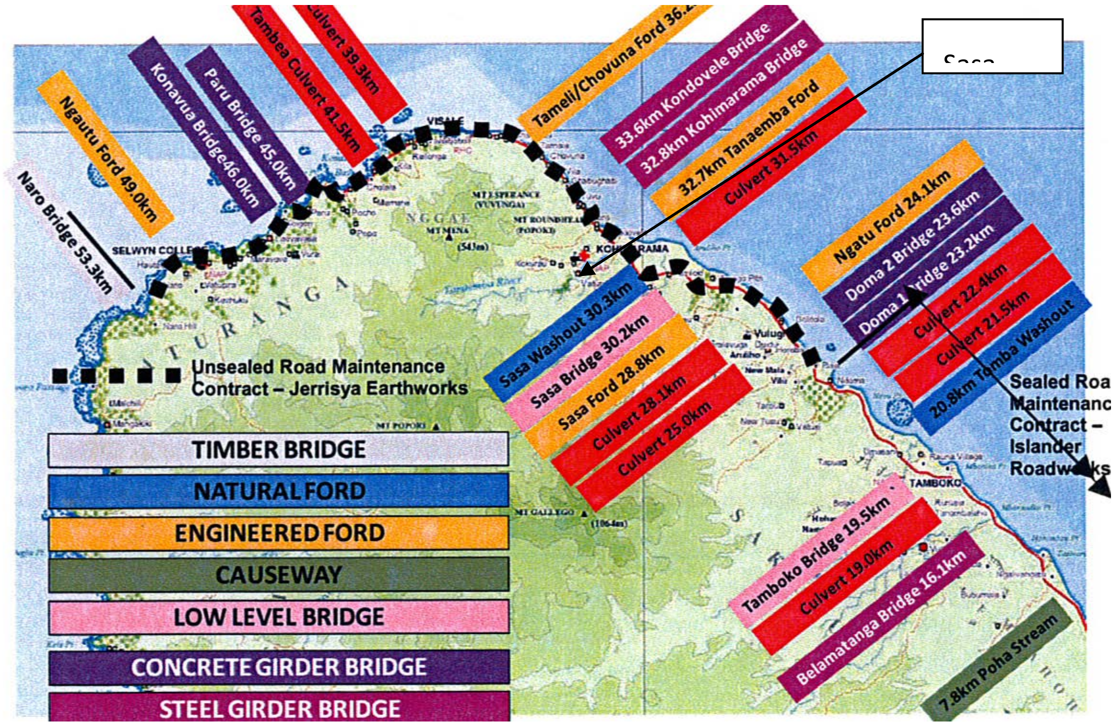


Figure 2 Detailed stream and river crossings targeted for improvement under SIRIP 2 sub-project



Source: Cardno Acil (2009)

Table 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)	3375	1975–1997, 20 years
Munda (New Georgia)	3492	1956–1997, 43 years
Buala (Santa Isabel)	3860	1982–1997, 10 years
Auki (Malaita)	3109	1956–1997, 42 years
Honiara (Guadalcanal)	2004	1954–1973,1979–1997, 37 years
Henderson (Guadalcanal)	1813	1974–1997, 23 years
Kirakira (Makira)	3454	1965–1997, 23 years
Lata (Santa Cruz Islands)	4271	1970–1997, 27 years
Paeu (Santa Cruz Islands)	5609	1933–1948,1952–1954 1956–1967, 26 years
Source: JICA (2001)		

Weather-related hazards

Guadalcanal Island is regularly subject to several types of hazards, brought about by natural climatic 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 to their local livelihood and wellbeing, as well as to physical and other infrastructure. For example, during the heavy rainfall following a cyclone and high tides between 29 January and 2 February 2009, 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. The local communities also suffered widespread damage to housing and food gardens. An estimated 52 000 were affected, including 2000 people being displaced and 13 people killed or drowned, particularly in Sasa village. At Sasa and Tamboka bridges, floodwaters had left behind huge logs and debris, extending some 20 m upstream of the widened river, causing river diversion of about 50 m of the existing structure. In 2010, the area once again suffered from intense rainfall and flooding along the road between the Poha and Naro bridges on the north-western Guadalcanal.

Flooding hazards

In the 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 that 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, and 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 between 17 and 20 May 1986. Cyclone Namu brought damage to houses, food gardens, roads and bridges in North-west Guadalcanal, causing disruption for more than two weeks and claiming10 lives (Bonte-Grapentin 2009).

Accurate and long-term rainfall and stream-flow data are critical 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 have the longest records of river flow data in the Solomon Islands with about 12 years of complete daily data. Japanese International Cooperation Agency (JICA) also used the modelling results of the Lungga River to estimate river-flow estimates for the 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 of 2.2 m^3/s for the Sasa River.

Ideally for infrastructure design, rainfall data and stream-flow data for the past 100 years would be required for each crossing site. However, in the absence of such detailed information for the Solomon Islands, as discussed below, the consultants for the SIRIP 2 sub-project used rainfall data for Honiara that they could access to determine daily rainfall extremes and threshold events considered to be a 1-in-2 year event (or a 2-year ARI period), 1-in-10 year event (10-year ARI period), 1-in-50 year event (50-year ARI period) and 1-in-100 year event (100-year ARI period); the 2009 rainfall event was estimated to be 1-in-50 year ARI event (see Table 4.9 in Cardno Acil 2009).

River basin characteristics and flooding

The geomorphology of the West Guadalcanal is dominated by volcanic headlands of Mt Galleo (1064 m) and Mt Popori (969 m), rising in an west-east direction. Orientation of the major river networks is radial from these central highlands. The rivers draining north-easterly onto the Guadalcanal plains are strongly sub-parallel (Solomon Islands Red Cross 2008). North-eastern Guadalcanal catchments, beginning with the Lungga River give rise to large flood plains known as the '*Guadalcanal Plains*'.

High intensity rainfall also triggers severe flooding in the small and steep catchments of NW-Guadalcanal, particularly due to the effects of rugged terrain which increases rainfall–run-off 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 debris flows

Guadalcanal Island is also susceptible to major landslide damage from cyclones. The term 'landslides' is used to refer to debris slides, debris flows and rock falls (Solomon Islands Red Cross 2008). 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 (Solomon Islands Red Cross 2008).

Most landslides occur in the central mountains, where rainfall is highest, relief greatest and slopes steepest. In this zone, the location of landslides is largely independent of rock types; in other areas, geology may affect landslide, size and frequency, through its influence on 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 are generally confined to the top two to five metres 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 25 m 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 (IFRC 2008). In 2009, SOPAC (2009) investigated three river basins in the project area, namely the Sasa, Tomba and Tamboko rivers, after heavy rainfall severely flooded North-western Guadalcanal on 29 to 30 January 2009. The Secretariat of the Pacific Community (SOPAC) report indicated that the high intensity of rainfall mobilised bed-material consisting of water, rocks and wooden debris and further eroded beds and banks of the tributary creeks and mobilised boulders of up to five metres. They also found that the debris flows uprooted most of the trees and shrubs in the valley bottom, and these trees and massive amounts of sediment 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 floodwaters to divert at several places along the Sasa River and created new or reactivated old river channels (Photo. 1), which led to the destruction of infrastructure and houses.

Figure 3 Sasa Bridge immediately following the 2009 heavy precipitation and flooding

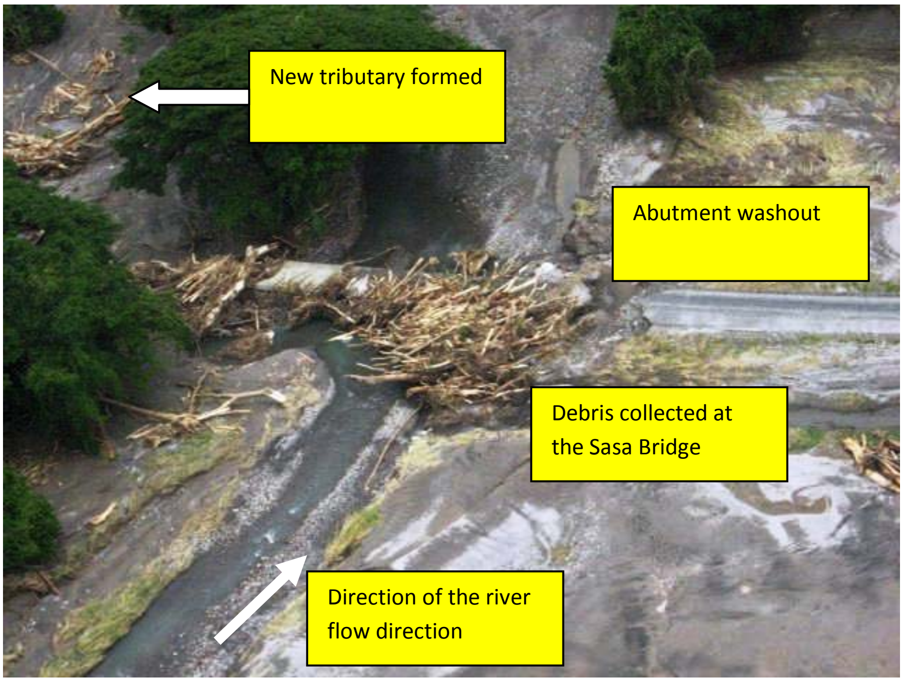


Photo: Tony Telford, Cardno Acil Ltd

Climate change and extreme events

Weather and climatic conditions experienced in the Pacific region are a product of both human-induced climate change and the natural cyclical climate patterns. There is consensus that, due to the influence of global warming, the average climate of the Pacific region is changing, and will undergo significant changes as global warming continues, even if key mitigation efforts were taken today to reduce the emission of greenhouse gases (IPCC 2007; BOM and CSIRO 2011- draft).

What is not clear though, are 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 occur every three to eight years or so and are defined by warmer-than-normal sea surface temperatures in the eastern tropical Pacific. They 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.

The Intergovernmental Panel on Climate Change (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 Australian Bureau of Meteorology (BOM) and Commonwealth Scientific and Industrial Research Organisation (CSIRO) recently concluded that the Pacific islands are expected to see more extreme events with significant impacts on the scale and intensity of hazard conditions (BOM and CSIRO 2011- draft).

For the Solomon Islands, annual surface temperatures are projected to be higher and the number of hot days and warm nights and annual and seasonal rainfall are projected to increase over the course of the 21st century, together with an increased number of extreme rainfall days. Tropical cyclones are projected to be less frequent but each cyclone is likely to be more intense (Table 2).

Table 2 Changing and future climate projections for the Solomon Islands

Observed changes in current climate	**Future climate**
Temperatures have increased	Temperatures will continue to increase and more hot days and warm nights
No clear trend in rainfall	Annual and seasonal rainfall projected to increase and increased number of extreme rainfall days
41 cyclones passed within 400 km of Honiara between 1969 and 2010	Less frequent but more intense tropical cyclones
Sea level has risen – 8 mm per year since 1993 (larger than global average of 2.8 to 3.6 mm/yr)	Sea-level rise expected to continue – sea-level rise projected to be 400–1500 mm by 2030 under high emission scenario
Source: (BOM and CSIRO 2011a)	

In the short-to-medium term, by 2030, 12 of the 18 global climate models for the Pacific suggest that the Solomon Islands may not see much change in its average rainfall under the high global emission scenario (A2). Over the course of 21st century, the intensity and frequency of days of extreme rainfall are projected to increase (BOM and CSIRO 2011). Under the worst case scenario, this means that islands such as the Guadalcanal could experience increased flooding intensity, particularly with catchments where the rainfall–runoff lag is, as discussed below, relatively small.

Relationship between rainfall and altitude in Guadalcanal

Modelling exercises done by the Institute of Hydrology, UK, indicate that rainfall on Guadalcanal increases with elevation (ADB 2011). This was based on four rainfall monitoring sites established along the northerly section of the transect, ranging in elevation between 13 m and 1250 m and two additional monitoring sites along the south of the island divide at altitudes 45 m and 495 m. 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 differs though, to the north and south of the island divide. In the north, mean annual rainfall increases by about 320 mm for every 100 m rise in elevation, compared to a 435 mm increase along the southerly section of the transect. At any given altitude, mean annual rainfall on the southern side of the island is likely to be 400 mm greater than that in 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 increases in extreme events, flooding intensities are expected to increase in areas such as the North-western Guadalcanal.

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

Upper catchment issues

Logging activities have also led to major landslides that deposited large quantities of silted materials around the Sasa Bridge (Cardno Acil Engineering Report No 40 2009). Poor forest management practices, combined with heavy rain-induced landslides and uprooting of trees, are major contributors of 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 the Naro-Hill-Lambi area (BOM and CSIRO 2011a). The SIRIP 2 sub-project consulting team observed cut logs in the debris trapped at bridge sites that would have contributed to the damages caused.

A river basin management, including an investigation of upper catchment land management and land-use changes, with a corresponding terrain analysis would have significantly enhanced the understanding of flooding regimes.

However, the SIRIP 2 sub-project did not 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 Telford, Cardno Acil, 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 climate proofing such investments. For example, the Tamboko Bridge was originally designed as a 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 the Q_{100} level) to allow for debris to pass under the bridge deck. The high level bridge also has 30-metre spans so that there are significantly fewer 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. comm., October 2011). Such an adaptive approach to increase the threshold capacity of these key structures following the 2010 flooding experience was possible, even after the initial contract had been awarded because the actual work on the SIRIP 2 sub-project had not yet commenced.

Sea-level rise and storm surges

In Solomon Islands, sea-level rise 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 normally require coastal protection works such as gabion baskets, rip-rap or other bio-engineering alternatives, to protect the road and help stabilise the shoreline (Cardno Acil Initial Environmental Examination 2009).

Vulnerability

The 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, reflected in their Millennium Development Goal (MDG) indicators on economic wellbeing, access to water and sanitation, education, and health services, as well as regular exposure to natural hazards.

Economic and social wellbeing in the country

Solomon Island's 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 had a population of just over half a million in 2009 with a high annual population growth rate of 2.8 per cent. About 85 per cent of the nation's 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 per cent and macroeconomic stability has been retained. The larger part of the growth from 2004 to 2008 was due to unprecedented high, unsustainable logging rates, accounting for 60 per cent 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 2011, the country had a Human Development Index (HDI) of 0.510, and is categorised as a least developed country (LDC), together with Samoa, Tuvalu, Vanuatu and Kiribati in the Pacific. The country is ranked the second lowest among all Pacific island nations in the United Nations Human Development Index 2011 ranking (UNDP 2011). There is a notable variation in the human development levels in the nine provinces and the capital Honiara (ADB Fact Sheet 2009). Social indicators generally fall short of the targets set for the MDGs and the country is unlikely to meet the majority of the MDG targets by 2015.

Analysis of the Household Income & Expenditure Survey 2005/06 survey, show that 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 per cent of households and 22.7 per cent of the population, and for rural areas, the rate of basic needs poverty was 15.2 per cent of households and 18.8 per cent of the population. Hardship has been further exacerbated by political tension and social conflict, the ensuing law-and-order problems, financial crisis, a contracting economy and rising employment, and high rates of population increase (Solomon Islands Government 2006). Traditional land and resource management is based on customary ownership and governed by small kinship-based social relationships. Some 87 per cent of land is under this form of tenure. The remaining land is registered under the *Land and Titles, 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 flood plains, 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 a threshold coping capacity for 1-in-2 year flood events—the 2009 flood event was considered a 1-in-50 ARI event (Cardno Acil 2009). Such landslide and flooding hazards create acute challenges in locating and designing crossing infrastructures such as bridges, culverts and fords, etc. In recognition of this potential hazard, the SIRIP 2 sub-project introduced some river training activity. Changing river directions, if not explicitly and adequately taken into account, can increase the risk of damage and loss in times of heavy rains. Damage to the physical infrastructure, such as culverts and bridges, will then have flow-on effects in terms of road access to local communities. Loss of life and community livelihoods are common when flooding occurs beyond the capacity of the local environments to cope. This was the Sasa village experience where, as mentioned earlier, the village lost their crops and homes, and eight persons lost their lives. This was the first major flooding experience for the Sasa village and following that event, the village relocated to higher grounds (Figure 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. This will inform responses to the current disaster risks, as well as climate proof 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 followed key steps of the standard risk assessment, drawing on multiple sources of data and multiple technical disciplines, including hydrology, engineering and economics. The SIRIP 2 sub-project undertook the following:

4. context analysis, in relation to hazards and identification of problems and possible solutions
5. assessment of risk reduction measures and selecting preferred choice based on key threshold criteria
6. cost–benefit analysis
7. project design
8. analysis of alternative climate change scenarios on engineering design and climate proofing of preferred option

Current risk and risk reduction analysis

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

Flood estimation and analysis

Hydrological and flood hazard assessment was undertaken in the SIRIP 2, noting the absence of long-term rainfall intensity and stream-flow data.

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 crossings. 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, as mentioned above, was considered to be 1-in-50 year ARI event (Cardno Acil 2009) (Table 3).

Table 3 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 crossings 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 m^3/sec for return period T (years)

C_R Run-off coefficient for the catchment area

$I_{T,tc}$ Point rainfall intensity (mm/hour of duration and t_c for return period T at Honiara)

C_A Altitude compensation factor

C_T Storm duration adjustment factor

C_S Areal rainfall reduction factor

A Catchment area (km^2)

Values for run-off coefficient C_R of 0.40, 0.49, 0.52 and 0.55 are adopted for 2-, 10-, 50- and 100-year return periods respectively; these were derived from those values recommended in the Papua New Guinea Manual for Flood Estimation (SMEC 1990 and Australian Rainfall and Runoff Guidelines, Institute of Australian Engineers, 2000) for similar catchment conditions.

Using this analysis, together with a compensatory factor recommended for Papua New Guinea (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 that 'the accuracy of the flood predictions based on the above method' (i.e. rational method together with various assumptions) *is unknown* (p. 10, Cardno Acil 2009). The results were then used to determine the design of culverts and bridges to cope with the desired flooding thresholds.

The Papua New Guinea Flood Estimation Manual notes caution in using the standard guidelines for the estimation of floods in Papua New Guinea. It recommends that using local knowledge of the specific catchments will sometimes result in the adoption of a design flood discharge which differs from the flood estimates derived by using the generalised 'cookbook' procedures presented in the manual (SMEC 1990). No doubt, greater time series rainfall and run-off 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 reconstructions of a steel girder bridge (Naro) and steel truss bridges (Sasa washout and replacement of Sasa Bridge)
- the construction of a high-level bridge at the Tamboko River.

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

For each of the physical infrastructures, 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 1-in-2 year event (Q_2). Taking climate change into account, 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 a 1-in-10 year event, such as the 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 (2008) 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 the SIRIP project site) after cyclone Namu. Boyce (2008) found that the 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. Boyce 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 (IFRC 2008).

In the SIRIP 2 sub-project, a debris impact assessment was taken into account in the engineering designs of selected bridges, such as Tamboko Bridge, which 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. The potential impact of sea-level rise, including storm surges, was not factored into the risk-reduction consideration, as this was considered to be outside the scope of the project's terms of reference. (The Solomon Islands has experienced about 8 mm of sea-level rise since 1993 and is projected to experience between 400 and1500 mm by 2030 under the high emission scenario for sea-level rise (BOM and CSIRO 2011a). This could affect the longevity of the parts of the SIRIP 2 sub-project road.

Choice of risk-reduction option

Engineering approaches and solutions were 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 recommended in the Cardno Acil report 2010b) 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 particular concerns about land tenure issues (Tony Telford, Cardno Acil, pers. comm., June 2011). Risk reduction measures did though include some minor road realignments on land belonging to the same customary landowners, as well as drainage improvements, scour protection and some 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 2010b).

Non-engineering risk-reduction options, such as upper catchment land management, were also not considered in the SIRIP 2 sub-project.

Choice criteria

The choice of the risk-reduction and climate change adaptation (CCA) measures was based on predetermined minimum risk-tolerance thresholds 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 flooding 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 (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, engineers then identified three engineering project designs, in addition to the 'do nothing option' as discussed below. Given the dynamics of the rivers and streams and associated low-lying landscapes, 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 rivers and streams crossing structures along the Poha–Naro road.

Climate projections

The SIRIP 2 sub-project undertook a 'Preliminary Climate Change Assessment for the North West Guadalcanal Road – Poha to Naro Hill' in May 2010. Based on IPCC Fourth Assessment Report, the following climate change scenarios were assumed, 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. While it is acknowledged that a country-specific model for the Solomon Islands does not exist, more relevant climate projections would have been possible, using available global climate change models (GCMs) to generate Pacific-relevant projections to inform the climate-proofing exercise. This is in marked contrast to the SIRIP 2 sub-project in Malaita, where climate change modelling work was commissioned by ADB in 2010 to inform the SIRIP 2 sub-project design there.

While detailed climate scenario information is critical for climate proofing of long-life infrastructure projects, this may not always be possible, particularly when there is limited time-series weather and climate data and there are uncertainties about climatic futures. In such a situation, available climate change scenario information, together with sensitivity analysis is recommended. This was the approach used in the SIRIP 2 sub-project, using global AR4 climate scenario projections, together with a hybrid 'impacts first' and 'vulnerability first' approaches.

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

Socioeconomic assessment aims to identify and prioritise the most appropriate adaptation measures in response to the current and projected climate risks. This includes the identification of strategies to minimise damage 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 evaluating and selecting projects, using the criteria of economic efficiency, reflected in measures such as net economic benefit (NB), net present value (NPV), benefit–cost ratio

(BCR) and economic internal rates of return (EIRR) estimated using CBA. Each adaptation option would then be compared, using such economic efficiency measures, again estimated using CBA. ADB's preferred measure is usually EIRR, which represents the discount rate showing that the NPV of benefits and costs are equal. ADB's 'basic criteria for a project's acceptability' is an economic internal rate of return of 12 per cent (ADB 2000). A return of as low as 8 to 10 per cent is acceptable though, for projects where 'additional unvalued benefits can be demonstrated, and where they are expected to exceed unvalued costs', with the lower limit of 8 per cent 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 NPVs, 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 (e.g. 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 net benefits of the adaptation option (e.g. assuming that the cost of the adaptation option could be 20 per cent 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 parameters it is therefore, 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 analysis, switching values are also often computed (a switching value is the value of a specific variable which makes the NPV 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 an CBA of the original SIRIP 2 sub-project, focusing mainly on the repairs of existing culverts, fords and bridges along the Poha-to-Naro road. CBA initially requires the identification of the desirable adaptation responses, then the estimation of costs and benefits associated with each adaptation option.

Different engineering adaptation options

The project team considered three engineering project designs, in addition to the status quo. These options reflected alternative design structures that could withstand different magnitudes of rainfall and flooding events, and acceptable threshold levels. The acceptable risk tolerance threshold also identified some considerations of the cost implications of different design standards. Each of these options is discussed below.

'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, that is, 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 storms leading to a degradation and deterioration, maintenance works would have been conducted to restore the road to current condition. This ‘do-nothing’ option would have involved expensive routine maintenance. The cost of maintenance is estimated to increase by 5 per cent per year as the maintenance works only without considering improvements in 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 due to the additional scour and reinforcement of the road is not expected unless larger events occur. Option A includes the restoration and upgrade of key crossings (e.g. Tamboko Bridge) and key infrastructures 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 allow at least the 2-year ARI flow through the culverts and bridges. During the 1-in-10 year ARI event, overtopping would be expected to occur, but at depths less than 300 mm, thus maintaining connectivity for higher clearance vehicles.

Option C

Similar to Option B, Option C is designed to allow at least the 2-year ARI flow through the culverts and bridges. 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 options are as follows:

- initial capital outlay
- recurrent maintenance cost, based upon general expected maintenance
- 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 five per cent. 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.

Analysis shows that option A is a low-capital, but high-maintenance cost option, Option C is a high-capital, low-maintenance cost option. Option B has a relatively medium capital cost and medium maintenance cost. 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 had assumed a simple linear relationship existed between cost of damage and flood magnitude and produced the following expected annual flood damage as a proportion of structures capital value of the physical structures:

< Q_2 structures	26 per cent
Q_2 structures	3.5 per cent
Q_{10} structures	0.05 per cent
Q_{100} structures	0 per cent

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

Estimation of benefits

The first step in assessing the benefits of a project is to identify the sphere of the project's influence and identify people whose livelihoods would be directly and indirectly affected. The primary beneficiaries of this SIRIP 2 sub-project were 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 sub-project was estimated to be 7782. It should be noted that an additional 21 160 people who live between Lambi and Wanderer Bay and along 'the weather coast' (southern coast) also relied on access from the sub-project road. The population considered to be served by this road improvement project was 28 942 (Cardno Acil 2010). More specifically, the existing road users were considered to be the beneficiaries including:

- 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, teachers and schools and the 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 was ensured 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. 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 (see various studies noted in Cardno Acil 2010)

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

- reduction in travel times
- reduced road disruption
- repair cost savings.

The challenge with any economic analysis is identifying those benefits that can be readily quantified. In the SIRIP sub-project, the loss in travel time and wages due to flood-related road closure was 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 was considered as economic benefit to the community. A reduction in travel times also resulted in lower overall transportation costs. In economic analysis, the reduction of costs due to the project options A, B and C were all counted as benefits as opposed to the 'do-nothing' option. This reduction in travel time benefited both individuals seeking employment and commercial trucks transporting agricultural goods, especially cocoa and copra to the Honiara market.

In addition to increased cargo costs, there were substantial losses in employment wages associated with the lack of access to places of employment. The SIRIP 2 sub-project assumed that 75 per cent of workers would be unable to work following road closure. With an estimated working population of 4125, this equated to approximately 2870 persons unable to work during road closures. Hence, under the 'do-nothing' option approximately 27.22 days were lost per year per individual, or 218 hours. Applying an average wage rate of SBD 14.15 (SBD: Solomon Islands Dollar), value of the hours lost per year per individual was SBD 3081 (US$400). Hence, the total loss of value per year was SBD 8.8 million or US$1.1 million.

The road upgrades under different engineering options provided reductions in the number of days closed, and the associated opportunity costs are summarised in Table 4.

Table 4 Costs of 'no action' and shadow value of benefits generated from different climate adaptation 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	SBD 8.8 million	
Option A	15.35	SBD 4.96 million	SBD 3.9 m (US$0.5 million)
Option B	3.06	SBD 0.989 million	SBD 7.83 m (US$1.02 million)
Option C	2.23	SBD 0.712 million	SBD 8.09 m (US$1.05 million)

Source: Derived from Cardno Acil (2010)

The SIRIP 2 sub-project, in accordance with the National Transport Plan made use of the 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 having better access to health services in times of need. Such indirect benefits are difficult to quantify and thus, not included in the economic efficiency measures used to select Option B. The qualitative information was partially considered in the BCA process by scoring expert judgements of the project team members and using multi-criteria analysis to compare the three options A, B and C. Option B was still found to be that preferred.

Cost–benefit analysis

Based on ADB's internal economic criteria, a project may be considered economically viable if the EIRR exceeds the relevant opportunity costs of capital. ADB's guidelines suggest an opportunity cost of capital of 12 per cent. Based on the economic assessment, and using economic efficiency as criteria, the SIRIP 2 sub-project team selected Option B as the economically feasible road improvement option, which can tolerate at least a 1-in-2 year flow, and where during 1-in-10 year events, some flooding of the structures could occur but vehicles with higher clearance could still pass through. Option B gave the highest EIRR and BCA (Table 5).

Table 5 Economic evaluation of the increased level of threshold tolerance under options A, B and C compared with the 'do-nothing' option (SBD)

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' option)		$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: Table 5.1 in Cardno Acil (2010)				

Sensitivity analysis of the preferred option

A series of sensitivity analyses suggest that Option B remains the preferred choice. A decrease in the benefits by five-fold is required for the PV of costs to just outweigh the PV of the benefits and the preferred improvements would not be acceptable. Similarly, costs, including capital and maintenance costs, would need to increase by 167 per cent before the NPV would just equal 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 risks were only considered following the 2010 floods when a preliminary climate change assessment was commissioned. The preliminary assessment, as mentioned above, relied on the IPCC Fourth Assessment Report scenarios for the South Pacific region (discussed in Chapter 2), and projected changes in precipitation, temperatures, cyclones and sea-level rise to draw general conclusions about climate change scenarios.

In the absence of detailed climate change predictions, the SIRIP 2 sub-project team assumed that climate change would result in increases in rainfall intensities of 20 per cent in large storms over the 20-year planning horizon. For frequent storm events, such as a 1-in-3 month rainfall event, it was assumed that the frequency would remain unchanged. Using such assumed climatic parameters, the team then estimated the expected frequency of a given design flood over the 20 years planning horizon. For example, under the assumed 20 per cent increase in the rainfall intensity under projected climate change, the current 10-year ARI flood would be equivalent to a 5-year ARI flood. Based in these assumptions, and using six-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 (Cardno Acil 2009b). Specifically, for each physical infrastructure, engineers determined the types of actual adjustments needed to the initial choice (under Option B) of road repairs and improvements, using different levels of acceptable thresholds (Table 6). Thus, for example, in the case of Sasa Ford (#13), Option B was designed to withstand a 2-year event (Q_2). Under the climate change scenario, the design standard was increased 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 a 1-in-10 year event, such as Sasa washout, no changes were required to cater for the projected increase in threshold tolerance.

Table 6 Types of engineering design changes made in the light of projected climate change conclusion

No	Structure	Option B proposed restoration	Option B+CCA proposed restoration
1	Poha Bridge	New bridge 7x 7 m x 4.2 m and raised approaches, scour protection, river training	New truss bridge 2x 30 m spans, 5.25 m wide, demolish existing bridge, scour protection
3	Culvert	New Q2 causeway using 2m wide box cells	New Q_{10} causeway using 2-metre wide box cells
4	Tamboko Bridge	New bridge 10x 7 m x 4.2 m and raised vented approaches, scour protection, river training	New bridge 10x 7 m x 4.2 m perpendicular to flow and raised vented approaches, scour protection, river training extending upstream to village, debris catcher
9	Doma 2 Bridge	Replace eastern and western approach slabs with RC span and piled abutments, scour protection	New Q_{100} steel girder bridge using 21-metre span
13	Sasa Ford	New Q_2 causeway using 2-metre wide box cells	New Q_{10} causeway using 2-metre wide box cells
14	Sasa Bridge	New truss bridge 2x 30 m spans, 5.25 m wide, demolish existing bridge, scour protection	New truss bridge 2x 30 m spans, 5.25 m wide, demolish existing bridge, scour protection
15	Sasa Washout	New truss bridge 2x 30m spans, 5.25 m wide, scour protection, approach embankments, land bridge embankment, river training	New truss bridge 2x 30 m spans, 5.25 m wide, scour protection, approach embankments, land bridge embankment, river training

No	Structure	Option B proposed restoration	Option B+CCA proposed restoration
20	Tameli/ Chovuna Ford	New Q_2 causeway using 2-metre wide box cells	New Q_{10} causeway using 2-metre wide box cells
24	Konavua Bridge	Reinstate approach slabs, scour protection	Reinstate approach slabs, scour protection
25	Selwyn Ngautu Ford	New Q_2 causeway using 2-metre wide box cells, sealed approaches	New Q_{20} causeway using 2-metre 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 CBA was undertaken.

Costs

The upfront capital costs were much higher in climate-proofed infrastructure as compared to 'do-nothing' option. Similarly, the annual repair costs were reduced due to better resilience of the climate-proofed infrastructure against flooding. It is assumed that the maintenance costs remained the same under both climate change and non-climate change conditions. However in reality, longer wet periods and higher temperatures may result in increased maintenance costs under climate-change conditions.

Benefits

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

Cost–benefit analysis

The economic net benefit of the CCA changes to Option B was then compared with the NB of the original risk reduction measure selected for addressing the current disaster risk engineering solution. As the BCR was greater than one and the economic internal rate of return was estimated to be 14.4 (that is, greater than 12 per cent considered being an acceptable threshold), the decision to proceed with the changes in the engineering solutions was made (Table 7).

Table 7 Economic CBA 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, as some adjustments were made to the maintenance costs under the Option B when the climate proofing goal was considered (Rhys Thomson, Engineer/Economist, ADB, pers. comm., October 2011)		

Sensitivity analysis did not change the conclusion of the Option B-CCA response as the preferred strategy. A sensitivity analysis was undertaken by testing a 10 per cent and 30 per cent increase in rainfall intensities in 20 years time (i.e. by 2030). This analysis indicated that, should changes in the rainfall intensities increase by only 10 per cent in 20 years time, then the EIRR would be 10.8 per cent, which is still considered to be within the acceptable range.

Sea-level rise risk

As mentioned above, the Western Guadalcanal road under the SIRIP 2 sub-project runs parallel to the coasts, and in places, the road is perilously close to the sea, in places being less than only one metre higher than sea level. As noted above, the Solomon Islands experienced about an 8 mm rise in sea level since 1993 and is projected to experience 400 to 1500 mm by 2030 under high emission scenario to sea-level rise (BOM and CSIRO 2011a).The sea-level rise combined with natural year-to-year changes will increase the impact of storm surges and coastal flooding (BOM and CSIRO 2011a). Potential impacts of sea-level rise, including storm surges, were not factored into the risk-reduction consideration. These observations 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. Also of interest are the effects these would subsequently have had on the costs and benefits and the choice of repair and road improvement options discussed below.

It is noted that, although it adopted a partial climate proofing of the SIRIP 2 Western Guadalcanal sub-project, focusing on flood-related risks, ADB considered the effects of climate change in the subsequent SIRIP 2 sub-project in the North Malaita in 2011 when it commissioned the Hadley Centre in United Kingdom to undertake sea-level rise projections (UNDP Pacific Centre and SOPAC Disaster Risk Programme 2011, March draft). The results of the sea-level rise projections were then explicitly used to inform the engineering design for the road and crossing infrastructure.

Concluding remarks

Although the extended 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; other types of climate change adaptation measures were considered to be beyond the scope of the project terms of reference.

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 used. In the presence of limited empirical data and good scientific understanding, translating the effects of 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. Ideally, one would use data and information from many different sources, employing a vast range of technical expertise and drawing on best judgements (Table 8). However, in some cases good data exists but these are scattered across different government agencies, and need to be accessed in a timely manner. Integrated, interdisciplinary analysis drawing on information from across sectors and disciplines is not an easy task, even in the most developed countries, let alone in a developing country such as the Solomon Islands, where capacity is low and institutions are fragmented and weak (Wickham et al. 2009). With the help of external consultants, governments can obtain more advanced analysis to inform their climate-proofing efforts, provided clear terms of reference are articulated.

It is widely acknowledged that the national climate information service needs considerable strengthening on all fronts, including developing and maintaining national systems of rainfall, stream flow and stream velocity measuring stations established for key rivers, modelling and data analysis, and environmental, social and economic impact assessments. In the absence of robust time-series data, 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, which allows quantitative and qualitative assessments to be combined to make a selection.

For the Solomon Islands and Pacific island countries in general, a systematic application of the hybrid ‘impacts first and vulnerability first’ approach-based risk assessment can help identify what could be empirically assessed and what could only be qualitatively described. Even a partial analysis, such as that undertaken in the SIRIP 2 sub-project, although not ideal is still useful for making more informed decisions. Using a cost–benefit analytical framework, qualitative and quantitative measures of costs and benefits of alternative adaptation measures can be identified and compared, using multiple criteria to inform preferred adaptation choice.

This project also highlights that, 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, and relevant ecosystem boundaries as well as the scale and scope of their impacts on the natural and economic systems and local communities. To encourage the adoption of a systematic approach to making informed choices on CCA in the Solomon Islands, some institutional strengthening is relevant, as discussed in the next section.

Table 8 Examples of relevant information needs, disciplinary skills and potential sources of data required for climate proofing road infrastructure, SIRIP 2 sub-project, Western Guadalcanal, Solomon Islands

Examples of information needs	Examples of relevant disciplinary skills	Typical source of data/ information
Climate forecasts • Averages and trends in: o precipitation forecasts (rain, drought, and humidity patterns) o temperature o weather extremes o frequency of extreme events • Uncertainties	Meteorologists and climate modelling	Published and grey literature – global and sub-regional modelling results Time-series historic weather and climate data from meteorological services Climate-modelling institutes Empirical probabilities Professional/expert judgement about confidence statement
Relationship between rainfall, run-off, stream flow and flooding	Hydrologist and rainfall–run-off modeller	Climate services (meteorological services; climate modelling institutes) Modelling results
Landslides, debris mat	Land-use specialist, Geologist Environmental impact analyst	Geo-referenced past hazard records Soil type and sensitivity to extreme rainfalls Grey and published literature
Flood plain dynamics	Geologist Geographer Ecologist	Geo-referenced past hazard records Modelling results Grey and published literature
Effects of rainfall, flooding, debris mat and landslides on roads, bridges, culverts and other physical infrastructures across rivers and streams	Hydrologist Civil engineer	Modelling results

Impact of flooding and sea-level rise on road infrastructure	MID National disaster management officer Damage and loss assessment specialist (disaster economists)	Time-series historic record of road infrastructure impact of different categories of weather and climate events Published and grey literature
Flood inundations and impacts on communities (social impacts): • impacts and exposure to disasters • loss of life, assets, crops, and household wellbeing • incidence of water and insect borne diseases • social (poverty) and human health impacts • economic and employment impacts	National disaster management officer Damage and loss assessment specialist (disaster economists) Medical researchers District/hospital nurse and other health department officials	Time-series historic record of the impact of different categories of weather and climate events Published and grey literature (for Solomon Islands of comparable situations elsewhere Government records of disasters, post disaster economic wellbeing Government health records and/or hospital/district nurse records Post-disaster surveys by the National Disaster Management Office, MID Specialised context specific surveys: • field traffic surveys • social surveys – community and household survey • household income and expenditure surveys • employment data
Costs of treating insect and waterborne diseases	Researchers/economist	Government/local (private) pharmacies/health clinics/district nurses
Engineering standards and flood impact thresholds	Civil engineer	Modelling relationship between flood category and design standard for flooding tolerance (including impact of debris mats, etc.)
Economic engineering costs of road infrastructure (capital, maintenance)	Infrastructure economist	Domestic and international prices, adjusted for tax and subsidy Provincial and local government data on road infrastructure
NB of road improvement sub-project with and without climate proofing, considering uncertainties and under different climate scenarios	Transport economist/Climate change adaptation economist, working closely with engineers and climate scientists	Costs and benefits measures determined using above information, sensitivity analysis

5. Institutional and policy context for climate change adaptation in the Solomon Islands

Countries have been supported in their climate change adaptation efforts through the United Nations Framework of Climate Change Convention (UNFCCC). In parallel, the disaster risk reduction (DRR) agenda is guided by the Hyogo Framework for Action (HFA). These two global instruments share common objectives: to address vulnerability in communities, and to strengthen organisational, institutional, policy and decision-making. The key difference is that disaster risk management traditionally focuses on current risks—risks that communities know and are familiar with—whereas CCA focuses on addressing future risks of changes in average climatic conditions, as well as climate variability and extreme events. Such responses to future climate risks are made in an environment of uncertainties associated with climatic futures (IFRC 2008).

The Solomon Islands Government (SIG) has made some progress towards taking a more systematic approach to climate change-related decisions, including dealing with current disaster risks. It also recognises that a lot more needs to be done to strengthen their capacity (Thompson, Mackey et al. 2009).

The SIG ratified the UNFCCC 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 (Thompson, Mackey et al. 2009). With the ratification, the SIG was able to take advantage of international resources available, particularly under the LDCs Fund to support the preparation and implementation of the national adaptation programme of action (NAPA).

At the national level, significant progress has been made to integrate environment and climate change into development plan and policies. The Solomon Islands Medium-term Development Strategy (MTDS) 2008–2010, includes a national development objective/policy to ensure sustainable use and conservation of the natural resources and environment and successful adaptation to climate change (Solomon Islands Government 2011). In September 2011, the SIG released its National Development Strategy (NDS) 2011–2020, replacing its MTDS 2008–2010. This 10-year development strategy includes Objective 7 that specifically addresses the environment and climate change. It emphasises mainstreaming of climate change by establishing a framework for integrating climate change considerations into national development planning and relevant sectoral policies. It seeks to undertake vulnerability and adaptation assessments, strengthening the meteorological services and increased preparedness for natural disasters (Solomon Islands National Development Strategy 2011–2020), Ministry of Development Planning and Aid Coordination, Honiara, September 2011).

The Ministry of Environment, Conservation and Meteorology (MECM), with the assistance of Secretariat of the Pacific Regional Environment Programme (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 Solomon Islands NAPA report was released in November 2008 (Solomon Islands Government 2008). In 1997, the SIG released its National Disaster Management Plan, prepared by the National Disaster Management Office (Thompson and Gaviria 2004). 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 (RFA), which is based on the global HFA. These two national action plans are implemented by two different arms of the government with, until recently, limited coordination, supported by two separate regional organisations (SPREP for climate change and SOPAC for disaster risk management), as well by two separate global UN agencies (UNFCCC secretariat for climate change, and United Nations International Strategy for Disaster Reduction for disaster risk management) although, it is generally accepted that there is a strong interrelationship between CCA and DRR.

Steps taken by the SIG that came into effect recently are expected to improve institutional coordination. Climate change concerns have now been brought in line with disaster risk management by the creation of a new MECDM in 2011. The MECDM has a specific mandate for coordinating and guiding the sustainable use and conservation of Solomon Islands natural resources and ecosystems. For the first time, the SIG elevated the climate change unit to the status of a 'Division', when it established a Climate Change Division to coordinate all climate change issue-related activities in the country.

The MECDM is also expected to provide key weather and climate data services, such as meteorological information, and DRR 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. Project proponents, including other government agencies and development partners, can also have easier access to relevant data required for designing appropriate CCA measures.

As noted by the World Bank, globally, and the Pacific is no different, there are major gaps and barriers that need to be overcome for effective CCA, including the absence of effective mechanisms for cross-sector collaboration and cooperation (ISDR 2008c). The original advisory Climate Change Country Team established in the Solomon Islands during the preparation of the Initial National Communication had become largely defunct after the first communication report was submitted to the UNFCCC. In October 2011, the SIG established, through a Cabinet Submission and Concept Note, a Climate Change Working Group (CCWG) which consists of departments, development partners, non-government organisations (NGO), regional organisations (SPREP, SOPAC), and the private sector, It's function is to strengthen knowledge-based decision-making. This is a technical level committee which, when fully functioning, would help address some of the current challenges. The Secretariat of the CCWG will be the MECDM. The CCWG is expected to play an oversight role, with views of improving coordination, planning, implementation, monitoring and evaluation programs.

This Cabinet Submission and Concept Note also called for an Annual Environment Donors Roundtable and an Environment Summit every three years. The Environment Summit is a reference to a provision in the *Environment Act 1998*, which calls for a report on the state of the environment to the minister who forwards the report to the National Parliament. The Solomon Islands has, however, yet to develop a national environmental policy document to guide environment-related activities in the country. The primary document for the environment is National Environment Management 1993 (NEMS) which has not been implemented or updated since its production.

Infrastructure sector: adaptation to climate change

Currently, the SIG does not have a national policy on climate change although climate change has been integrated in infrastructure development. The NAPA adopted 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. Floods, storm surges, tropical cyclones and sea-level rise have particularly been identified as damaging to roads and bridges. NAPA notes that bridges and wharves are designed to withstand extreme events similar to past hazards and that they need to also reflect projected increased risks under climate change.

Transport sector

In October 2010, the SIG released its National Transport Plan 2011–2030 (NTP) Final Draft, 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.

The NTP makes strong commitments 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 to infrastructure development that would need particular attention:

> Flood[s] 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 sea level rise poses great risks to 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.

Climate change risks and environmental legislative framework

The NTP makes a strong commitment to comply with the *Environment Act 1988 (No. 8 of 1998)*, by stating that all infrastructure development projects require an EIA. The Environment Act is the single-most important EIA 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 prevails.

Social and economic aspects of climate change risks could be considered in the context of EIA requirements under the Environmental Act. The Act provides guidance on development control, EIA and pollution control. All proposed 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 a more detailed second stage assessment, 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 is required. With respect to road construction or rehabilitation, prescribed activities to be subjected to EIA include:

- (2) Non-metallic industries: (d) extraction of aggregates, stones or shingles
- (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 EIA 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 EIA at the sector or project level. Nor are there any sector guidelines for infrastructure development and guidance on climate resilience adaptation 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.

Since Environment Act identifies the need to explicitly consider key risk factors in the design and construction of bridges, roads and wharves, this could be easily extended to include consideration of climate change-related risks for such infrastructure projects. The MID is currently revising its 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).

Similarly, considerations of community-level impacts of climate change could be addressed at the provincial level. The *Provincial Government Act 1997* provides for provinces to create their own legislation with respect to 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.

Climate-risk considerations could be made explicit during the project development process, by adopting a project-based climate risk management cycle. Many development partners, including ADB, have clear policies when it comes to project development and evaluation processes, including economic, environmental and social impact assessments, and more recently risk assessments. It is acknowledged though that under ADB's operations, the borrower is responsible for assessing projects and their environmental and social impacts, preparing safeguard plans and engaging with affected communities (Cardno/ACIL 2009, IEE 2009). However, the MECM has limited manpower to provide significant inputs into the project design across different sectors.

Asian Development Bank environment and climate change assessment and SIRIP 2 sub-project

ADB formally introduced environmental assessment into its lending operations in 1979 and their current Environmental Policy approved in 2002 is supported by a set of procedural guidelines articulated in their Operations Manual (ADB Safeguard Policy Statement 2009). ADB classifies projects under one-of-four categories, based on generic locational characteristics and magnitude of impacts of projects.

Category A – includes projects with likely significant adverse impacts. These projects require an EIA and a summary EIA, 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 initial environmental examination (IEE) and summary IEE 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.

ADB categorised the SIRIP as Category B, as the overall risks associated and the main road rehabilitation sub-project are considered low because the project is confined to road rehabilitation within the existing road network with surrounding areas already impacted by peri-urban uses, farming and logging.

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

These reports were assessed by the then MCEM under its Environment Act and the SIRIP 2 sub-project developed an environmental management and monitoring plan.

Asian Development Bank and climate change in the Pacific

CCA is a rapidly evolving field. Since the early 1990s, the ADB has been assisting countries in the Asia–Pacific Region to address climate change through various technical assistance programs and lending operations. In 2005, it implemented a regional technical assistance (RTA) project that included climate proofing several infrastructure activities in Kosrae and the Cook Islands. These case studies demonstrated the value of adopting proactive steps against climate change in the design of infrastructure, as compared with retrofitting infrastructure investments against climate change and climate variability, including extreme events.

Since then, significant policy developments are evident in ADB operations. For example, the ADB's Pacific Approach 2010–2014 acknowledges that natural, hazards, climate change and deterioration of the environment pose further development challenges. It listed hazards of concern such as sea-level rise, more frequent and intense tropical storms and flooding, prolonged droughts, bleaching of coral reefs, increasing scarcity of water and higher incidence of vector-borne diseases, as of concern.

ADB's original operational policies, which included three safeguard policies, the Involuntary Resettlement Policy (1995). Indigenous Peoples (1998) and Environmental Policy (2002) are noted for revisions. The Rapid Environmental Assessment Checklists (originally published in 2003) now include climate change-related optional questions (e.g. http://www.adb.org/documents/guidelines/environmental_assessment/REA_Ports_Harbors.pdf).

In 2011, ADB produced Guidelines for climate proofing investment in the transport sector: Road infrastructure projects, providing a step-by-step methodological approach to assist project teams to incorporate adaptation to climate change into transport sector investment projects (ADB 2011). This document also calls for the use of improved understanding of climate change impacts in the design of infrastructure development policies and strategies to ensure appropriate upstream planning and resource allocation.

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 SIG when addressing a particularly cross-cutting issue such as climate change. Such an endeavour requires, among other things:

- clear establishment of the relationship between national development policies, sectoral goals and programs, and outcome-focused projects, operationalising government development policies
- cross-sectoral collaboration and coordination of efforts across different government agencies
- government policies and decision-making processes that reflect 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 aspirations, 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 that CCA decision-making processes could be strengthened by making robust knowledge-based climate risk and risk-reduction assessment an explicit requirement of projects. In the case of externally funded projects, the SIRIP 2 sub-project experience also highlights the need for strengthening the interface between the government agencies and development partner processes.

In the short term, and 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 explicit requirements for all major projects, taking advantage of existing development and environmental legislative requirements and decision-making processes, and strengthening inter-sectoral interactions and engagement. In October 2011, the SIG established a CCWG which consists of departments, development partners and NGOs to strengthen their knowledge-based decision-making. The CCWG, when supported by the proposed technical working groups and when fully functioning will help address some of the current challenges.

While it is acknowledged that significant mainstreaming has been included in national economic development policies and sectoral policies, there remains an institutional weakness in implementing these policy commitments. The CCWG is a key step in co-ordinating at the national level but there is no coordination with the provincial level governments. Significant community-based activities are also coordinated and implemented by a range of NGOs in conservation, CCA and disaster risk reduction.

Lack of knowledge-based tools and techniques suitable for Solomon Islands, and/or the region as a whole, is a major constraint in implementing informed CCA. Climate proofing of infrastructure projects could be improved by developing not only suitable climate prediction models for the Solomon Islands, but also developing/strengthening rainfall–run-off and hydrology models for local rivers and streams, and through better risk and risk-reduction assessments. As a start, a Solomon Islands Flood Estimation Manual similar to the PNG Estimation Manual, with locally relevant parameters, could help improve flood predictions for improved infrastructure designs and for disaster risk preparedness. Further, sector guidelines are also required under the EIA legislation for infrastructure development.

A system of decision-making would help embrace a ‘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 increase in risk due to climate change. Furthermore, a strengthened enabling environment, decision-making processes and institutional and technical capacity within the government would help ensure robust CCA decisions that meet national development goals. A lack of a national integrated GIS system for the Solomon Islands is also seen as major constraint although some discrete GIS systems exist in some departments, such as the Lands, Mining and Forestry departments. These need to be at least harmonised and linked to help improve sharing of data and expertise in the country.

In conclusion, future infrastructure development projects in the Solomon Islands would, no doubt, benefit from the strengthening of institutional and technical capacity in-country, together with ADB’s strengthened infrastructure project development processes, involving integrated climate change risk considerations and mandatory climate risk criteria in project selection, together with economic, environmental and social selection criteria.

References

ADB (2000). Guidelines for the Preparation of Project Performance Audit Reports. Manila, Asian Development Bank.

ADB (2008). Strategy 2020: The long-term strategic framework of Asian Development Bank 2008-2020. Manila, Asian Development Bank.

ADB (2011). Guidelines for climate proofing investment in the transport sector: Road infrastructure projects. Manila, Asian Development Bank.

BOM and CSIRO (2011). Climate change in the Pacific: Scientific assessment and new research: Volume 2: Solomon Islands. Climate change in the Pacific: Scientific assessment and new research Melbourne, Australian Bureau of Meteorology and Commonwealth Scientific and Industry and Research Organisation.

BOM and CSIRO (2011, draft). Climate change in the Pacific: Cook Islands, East Timor, Federated States of Micronesia, Fiji, Kiribati, Marshall Islands, Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu. Melbourne, Australian Bureau of Meteorology and Commonwealth Scientific and Industry and Research Organisation.

BOM and CSIRO (2011a). Current and future climate of the Solomon Islands. Solomon Islands Meteorological Service, Australian Bureau of Meteorology and Commonwealth Scientific and Industry and Research Organisation. Melbourne, Pacific Climate Change Science Program Partners.

Bonte-Grapentin, M. (2009). Technical assessment of the flooding in western Guadalcanal, 30 January 2009: What did cause the floods and how can we mitigate for the future. Suva, Fiji, SOPAC.

Cardno Acil (2009). Solomon Islands Road (Sector) Improvement Project: Guadalcanal Flood Damage Restoration Subproject, Guadalcanal Province- Engineering Assessment. Honiara, Solomon Islands Government, Ministry of Infrastructure Development.

Cardno Acil (2010). Solomon Islands Road (Sector) Improvement Project: Guadalcanal Flood Damage Restoration Subproject, Guadalcanal Province- Economic Assessment. Honiara, Solomon Islands Government, Ministry of Infrastructure Development.

Cardno Acil (2010b). Solomon Islands Road (Sector) Improvement Project: North-West Guadalcanal Road, Poha to Naro Hill, Guadalcanal Province- Preliminary Climate Change Assessment Honiara, Solomon Islands Government, Ministry of Infrastructure Development.

Government of Solomon Islands (2010). National Transport Plan, Ministry of Infrastructure and Development.

IFRC (2008). Bridging the gap: Integrating climate change and disaster risk reduction. Geneva, Switzerland, International Federation of red Cross and Red Crescent Societies.

ISDR (2008c). Towards National Resilience: Good practices of National Platforms for Disaster Risk Reduction. Geneva, Switzerland, United Nations International Strategy for Disaster Reduction.

JICA (2001). Master Plan Study of Power Development in Solomon Islands - Final Report Japan International Cooperation Agency, Ministry of Natural Resources, Solomon Islands Electricity Authority.

Mechler, R. and The Risk to Resilince Study Team (2008). From risk to resilience: The cost-benefit analysis methodology. Katmandu, Nepal, ISET-Nepal and Provention. **Working Paper 1**.

SMEC (1990). Papua New Guinea Flood Estimation Manual. Port Moresby, Papua New Guinea, Snowy Mountains Engineering Corporation Ltd and Department of Environment and Conservation, Bureau of Water Resources.

Solomon Islands Government (2006). Household Income and Expenditure Survey- 2005.6. Honiara, Solomon Islands Statistics Office, Department of Finance and Treasury.

Solomon Islands Government (2008). Solomon Island National Adaptation Programme of Action NAPA New York, UNFCCC.

Solomon Islands Government (2011). Solomon Islands National Development Strategy, 2011-2020. Honiara, Ministry of Development Planning and Aid Coordination, Solomon Islands Government.

Solomon Islands Red Cross (2008). Preparedness for climate change background document: Consequences of climate change for humanitarian work through the eyes of Solomon Islands Red Cross. Honiara, Solomon Islands Red Cross.

Terry, J. P. (2007). Tropical Cyclones: Climatology and Impacts in the South Pacific, Springer.

Thompson, I., B. Mackey, S. McNulty and A. Mosseler (2009). Forest Resilience, Biodiversity, and Climate Change. A synthesis of the biodiversity/resilience/stability relationship in forest ecosystems. Montreal, Canada, Secretariat of the Convention on Biological Diversity. **Technical Series no. 43**.

Thompson, M. and I. Gaviria (2004). Weathering the storm: Lessons in risk reduction from Cuba. Boston, MA, Oxfam, Boston.

UNDP (2002). A climate risk management approach to disaster reduction and adaptation to climate change. UNDP Expert Group Meeting Integrating Disaster Reduction with Adaptation to Climate Change, Havana, June 19-21, 2002, UNDP.

UNDP (2011). The Human Development Report 2011 - Sustainability and Equity: A better Future for All New York, UNDP.

UNDP Pacific Centre and SOPAC Disaster Risk Programme (2011, March draft). A review of the regional disaster risk management mainstreaming programme in the pacific. Suva, Fiji, UNDP Pacific Centre and SOPAC.

UNFCC (2002). Annex : Guidelines for the preparation of national adaptation programmes of action. . Decision 28/CP.7 of the Conference of the Parties on its seventh session, Marrakesh, 29 October -10 November. New York, UNFCCC.

Yodmani, S. (2001). Disaster risk management and vulnerability reduction: Protecting the poor. Proceedings of Asia and Pacific Forum on Poverty: Reforming policies and institutions for poverty reduction. Manila, Philippines, 5–9 February 2001.