Infrastructure and Climate Change in the Pacific

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Abbreviations

ACCPIR	SPC/GTZ Regional Programme on Adaptation to Climate Change in the Pacific Island Region
ATWG	Adaptation Technical Working Group
AusAID	Australian Agency for International Development
CCA	Climate Change Adaptation
CROP	Council for Regional Organisations of the Pacific
DCCEE	Department of Climate Change and Energy Efficiency
EBAS	Evidence Based Adaptation Strategies
GIS	Geographic Information System
ICCAI	International Climate Change Adaptation Initiative
ISO	International Standards Organisation
ICT	Information and Communication Technology
JNAP	Joint National Action Plan for Climate Change Adaptation and Disaster Risk Reduction
MOU	Memorandums of Understanding
O&M	Operation and Maintenance
PASAP	Pacific Adaptation Strategy Assistance Program
PIC	Pacific Island Countries
PICT	Pacific Island Countries and Territories
SLR	Sea Level Rise
SIDS	Small Island Developing States
SOPAC	SPC Applied Geoscience and Technology Division
SPC	Secretariat of the Pacific Community
UN	United Nations
UNDP	United Nations Development Programme
UNFPA	United Nations Population Fund
USP	University of South Pacific

Preface

The Australian Government's Pacific Adaptation Strategy Assistance Program (PASAP) is part of the Australian Government's International Climate Change Adaptation Initiative (ICCAI).

PASAP aims to:

- Help develop evidence based adaptation strategies (EBAS).
- Inform long-term national planning in partner countries.
- Enhance the capacity of partner countries to manage adaptation strategies.
- Mainstream adaptation into decision making.

Under PASAP a regional overview paper is being prepared on climate change adaptation around the Pacific. Areas of focus within the paper are:

- Food security
- Water security
- Coastal inundation
- Human health
- Infrastructure

The first four are priority areas for PASAP. However, to effectively address these four areas PASAP saw it as important to understand their relationship with infrastructure and how infrastructure can impact solutions. Infrastructure also plays an important role in social and economic development.

The focus of this paper is to

- Identify the impacts of climate change on infrastructure in the Pacific, and
- Identify what we need to understand, in order to develop and implement effective adaptation strategies.

Executive Summary

The Pacific Island Countries and Territories (PICTs) are a collection of Small Island Developing States (SIDS) in the Pacific, consisting of some 2.5 million people (excluding PNG) scattered over some 11,000 islands, themselves scattered over an area of 165.2 million square kilometres. The PICTs are dependent on infrastructure to deliver basic living services, government services, and to support their economy. The PICT islands are of three different types, due to three different formation processes: volcanic, atoll, and raised atoll. On each type, infrastructure is distributed in a particular way, often focused around the edge. Other principal characteristics of Pacific infrastructure include a division between centralised urban and decentralised rural infrastructure, and between infrastructure built for the local population and infrastructure built for tourists.

The small size, exposure, geographical isolation, small population and small economies of the PICTs give rise to a particular set of infrastructure challenges, even prior to the impact of climate change. Some of these are physical, for instance the marine environment, the dispersed population, and the fact that most infrastructure is located on the foreshore. Other challenges are institutional, including the smallness of government, fragile economies, and a shortage of infrastructure professionals compared to requirements.

Climate change adaptation strategies cannot address all of the existing conditions and constraints in the Pacific, but by recognising they exist, it may be possible to develop an approach to managing climate change impacts that addresses other limitations in the system. The focus of this paper, however, is to identify what information is required by political decision-makers and infrastructure managers to better manage the impacts of climate change on their infrastructure.

Climate change in the Pacific presents a variety of possible impacts on infrastructure. The most important fall into three categories: coastal inundation, more extreme weather, and changes in precipitation. These impact the following important sectors of Pacific infrastructure: energy, water, ICT, transport and buildings. The interactions between impact and infrastructure are complex and multiple, but can be summarised in simple matrices, included in this paper.

In addition to the direct impact of climate change on infrastructure, there are interdependencies between infrastructure sectors that need to be analysed in order to fully understand infrastructure vulnerability. A coastal airport is impacted not only directly by climate change increasing the risk of coastal inundation, but also by climate change impact on the road that connects to the town, on the power supply for which it depends, and the homes of the employees that operate it. In turn, the closure of the airport has downstream impacts on disaster response, on aid programs, on tourism, and on trade.

Again, these interdependencies can be mapped by way of matrices. Thus, understanding impact of climate change in the Pacific is not a simple matter of assessing the vulnerability of individual pieces of infrastructure, but also of mapping that impact onto other infrastructure, onto the economic/community services it supports, and finally onto the population.

Ultimately, it is the population, not the infrastructure that needs to be protected. Focussing solely on protecting existing infrastructure assets may be unaffordable, and prioritisation needs to frame the infrastructure policy in terms of social policy. Response needs to take into account three levels of analysis, each critical to the effectiveness of the response. The first is to identify the populations most vulnerable to climate change, and the infrastructure vulnerabilities that impact them. This may involve complex interrelationship mapping of the kind described above. Then, for each piece of infrastructure in the causal impact chain, a variety of responses must be examined. These are: hardening the infrastructure itself, moving it, finding alternatives, focussing on resilience rather than protection, and using natural rather than built protection. Finally, implementation of these strategies requires certain capacities among the 'actors' involved in each country: government, funders, implementing agencies, and the research communities. It also requires that they act together in a coordinated way, in order to build systemic capacity in the face of uncertainties about the extent and impact of climate change, and improve the effectiveness and cost-benefit of various adaptation strategies.

There are knowledge gaps in each of the three steps mentioned above: understanding impact, deciding adaptation strategies, and strengthening adaptation capacity. For the Pacific Islands, each of these steps involves entering into new territory, and the particular circumstances of the Pacific Islands means that strategies and knowledge developed elsewhere, will often not readily apply. In the realm of population impact and prioritisation, the key areas for investigation are: impact of infrastructure on populations; infrastructure impacts on other infrastructure; planning for climate change time frames (short, medium and long term) and uncertainty; developing specific local adaptation plans; integrating climate change into existing systems; and rethinking business as usual. In the domain of strategy options, the main areas to research include investigating approaches to hardening, relocation, alternatives, resilience and natural systems. In the domain of implementation capacity, the main areas for research are the capacity gaps in each of the main actors: governments, funders, implementing agencies, and the research community itself.

This paper highlights three major areas of research that are critical for PICTs impacted by climate change, and identifies a series of sub-questions that can be explored as part of this research. This research will provide a foundation for PICTs to make decisions regarding investment in infrastructure and its management. The three areas are:

- How to protect infrastructure for remote and poor communities?
- The need for new technical standards and innovations for design and implementation of infrastructure projects and cycles
- Planning and management of infrastructure operations and maintenance in the PICT context.

1. Introduction

1.1 The challenge of climate change for Pacific infrastructure

Climate change threatens to have serious impacts on infrastructure in the Pacific, and to thus hinder development. This threat has been recognised in a range of documents developed or adopted by Pacific governments. [1] These documents emphasise that adaptation to climate change is integral to sustainable development throughout the Pacific. Climate change adaptation and sustainable development need to be addressed with a single coordinated response.

Infrastructure plays a vital role in development, so understanding the relationship between climate change and infrastructure is critical. This paper recommends research that will contribute to the ability of PICT governments and communities to respond effectively.

In many cases throughout the Pacific, the stress on infrastructure (and human development in general) posed by climate change is an increase in stresses already present. Infrastructure in the Pacific already operates in an environment in which:

- design and construction are rendered difficult and expensive by problems of remoteness, a harsh marine operating environment, and poor access to materials and transport[2]
- there is a scarcity of personnel who are both professionally skilled and knowledgeable about local conditions
- there are insufficient managerial and budgetary resources to ensure effective operating and maintenance
- government systems—including planning and monitoring—are weak[3], leading to poor infrastructure planning and management and deficiencies in donor coordination.[4]

These last weaknesses in coordination lead to infrastructure investments that:

- lean towards short-term hardware interventions[5]
- are partitioned into sectoral silos.

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[1] Mauritius Strategy for Further Implementation of the Programme of Action for the Sustainable Development of Small Island Developing Nations, 2005; A Framework for Action 2005-2015: Building Resilience of Nations and Communities to Disasters – An Investment for Sustainable Development in the Pacific Island Countries, Disaster Risk Reduction and Disaster Management, July 2008; Bangkok Call to Action, Realising Development Effectiveness: Making the most of Climate Change Finance, 28 October, 2010.

[2] Building Resilience of Nations and Communities to Disasters – An Investment for Sustainable Development in the Pacific Island Countries, Disaster Risk Reduction and Disaster Management, July 2008.

[3] The Pacific Infrastructure Challenge: A review of obstacles and opportunities for improving performance in the Pacific Islands, World Bank, 2006.

[4] http://www.forumsec.org.fj/resources/uploads/attachments/documents/DevelopmentPartner Reporting_AnalyticalReport.FINAL.pdf

[5] See Footnote 3

The PICTs have ongoing problems with the quality, quantity, operation and maintenance of their infrastructure[6]. These problems manifest at the day-to-day level in power shortages, troublesome telecommunications, water shortages, and expensive and difficult transport.

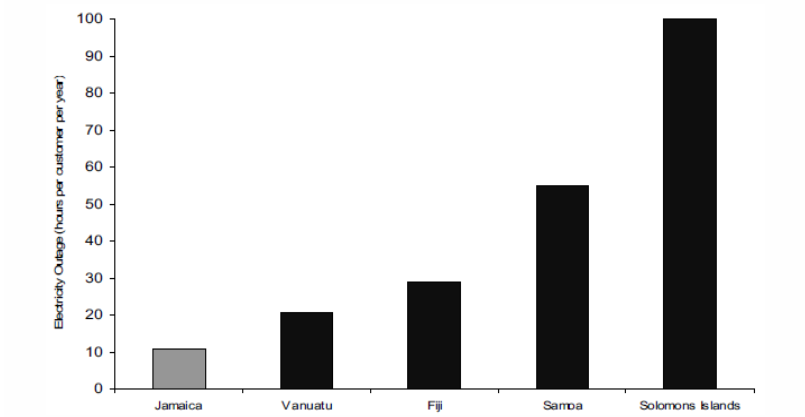

Figure 1: Service Outage – Electricity Outage Time[7]

These day-to-day difficulties then weaken the ability of PICT societies to respond resiliently to natural disasters, which can cause damage amounting to 10% of GDP. In other countries disasters rarely cost more than 1-2% of GDP.[8] On top of this, climate change impacts in the Pacific are likely to be high, because of the preponderance of coastline, and of fragile island ecosystems. It is the piling up of climate change stress on top of an already stressed infrastructure system that characterises the Pacific.

In the case of small island states, a single disaster event can cause a debilitating shock to a national economy. The World Bank estimates the economic cost of disasters in Pacific Island Countries at between 2-7 per cent of GDP per annum. This rises to an average of 46 per cent of GDP during disaster years. It is predicted that the cost of a 1-in-100-year cyclone in any of the capital cities of Fiji, Solomon Islands, Vanuatu, Samoa or Tonga would result in potential economic losses of up to 60 per cent of GDP. In the 1990s the cost of extreme events in the Pacific Island region is estimated to have exceeded US$1 billion. This includes the cost of Cyclones Ofa and Val, which hit Samoa in 1990/91, causing losses of US$440 million (greater than the country's average annual GDP). In Niue, Cyclone Heta is estimated to have caused an impact of about NZ$37.7 million, which is approximately 25% of its GDP.

http://www.sprep.org/att/irc/ecopies/pacific_region/507.pdf

6 The Pacific Infrastructure Challenge: A review of obstacles and opportunities for improving performance in the Pacific Islands, World Bank, 2006.

7 Source Data: Country Data and Castalia Research
Note 1: Vanuatu has been excluded as the very high tariffs and system losses distort the trend data
Note 2: FSM: Federated States of Micronesia

8 Guide to Developing National Action Plans – A Tool for Mainstreaming Disaster Risk Management Based on experiences from selected Pacific Island Countries, Pacific Disaster Risk Management Partnership Network, October 2009

Responding to climate change has initiated a new regional dialogue that cuts across disciplinary and sectoral boundaries. This new dialogue creates the opportunity to question 'business as usual' in a systemic way.

In many cases, the impact of climate change necessitates this questioning, because it is not possible to respond effectively to the additional stress of climate change, without addressing weaknesses in the existing systems.

1.2 Approach and methodology

This paper contributes to the PASAP regional overview by:

- describing the Pacific islands infrastructure context
- describing the impacts of climate change on Pacific infrastructure
- analysing the steps required to take action to adapt
- identifying gaps in our understanding that need to be filled in order to better adapt infrastructure to changing climate.

The paper was prepared based on input from a broad range of sources:

- conducting literature reviews,
- consulting with representatives in organisations working in the Pacific,
- consulting with a range of infrastructure specialists across various sectors.

Based on these reviews and consultations, an overview of activities that are occurring across the Pacific could be developed. By comparing current activities and research with the needs, it was possible to identify research themes that required further investigation.

The stakeholders we have considered in preparing this paper are:

- The PICTs and their populations
- Regional Agencies, including SPC (including SOPAC Division), SPREP and other members of CROP
- Donors, including the World Bank (WB), the Asian Development Bank (ADB), and the Australian Government Department of Climate Change and Energy Efficiency (DCCEE) and the Australian Agency for International Development (AusAID).

1.3 Structure

The following describes the contents of the report:

Section 1: Introduction—this section—sets out the background and framework for the paper.

Section 2: Infrastructure in the Pacific will provide an overview of the infrastructure in the Pacific.

Section 3: Impacts of climate change on infrastructure examines how climate change will impact that infrastructure

Section 4: The adaptation response sets out options for responding to the impact of climate change on infrastructure, and the constraints on exercising those options.

Section 5: Key areas for further research derives the main gaps in knowledge about options and constraints for adapting to climate change. Addressing these gaps is needed to respond to the challenge.

2. Infrastructure in the Pacific

This section provides an overview of the infrastructure in the Pacific, what outcomes it supports, what processes depend upon it, and therefore why it is important. It also drills down into the various types of infrastructure, how they vary by island type, and their particular characteristics. Finally, it looks at cross-cutting issues that need to be considered when formulating responses.

2.1 The purpose of Pacific infrastructure

The principal outcomes which infrastructure supports in the Pacific are, for the purpose of this paper:

1. Basic well-being of the population
2. Delivery of government services
3. Enabling economic activity

Each of these outcomes requires certain processes. Each of those processes is reliant on certain types of infrastructure. When the infrastructure asset becomes inoperative, the process is interrupted, and the outcome put at risk.

For the Pacific, infrastructure typically consists of the following types of assets:

Table 1: Role of Infrastructure in the Pacific

	Outcome	Principal infrastructure
1	Basic well-being of the population	Housing Water Waste (sanitation, solid waste)
2	Delivery of government services	Health Education Justice Government Administration
3	Enabling economic activity	Transport (roads, bridges, airports, ports/jetties) ICT Energy Agriculture/Fisheries/Forestry Tourism

All populations need to have basic needs such as housing, water supply and waste management (sanitation and solid waste) in order to be safe and healthy. What distinguishes

Pacific populations is that there are still many remote islands with no or limited economic infrastructure, minimal or intermittent government social services, and surviving with a mixture of traditional and imported infrastructure for primary wellbeing. These populations need to be considered in climate change scenarios, as well as the urban centres which will tend to have more centralised infrastructure to provide water, sanitation, drainage and waste treatment systems, and more ready access to building materials for housing and other social infrastructure.

Government services such as health, education, and justice as well as other administrative functions are important for the operation of a country. Most of these services occur from a variety of buildings that may be damaged during storms and floods, or be impacted by coastal inundation as sea level rises. One of the most important aspects of this infrastructure is the need to maintain health services to support communities, especially during disaster events. The approach to adapting health service buildings, therefore, may differ to those used for schools, training centres, courts and prisons. The unique purpose of the various buildings needs to be considered when developing adaptation strategies.

Transport infrastructure is especially critical in the Pacific, because of the highly dispersed population and the need to move goods and services across large areas. It becomes even more critical in times of disaster when emergency services are essential. ICT costs tend to be high per capita, for the same reason.

Energy assets are another important piece of infrastructure for ongoing development. To date, energy has largely been supplied through fossil fuels, which are imported, and increasingly expensive. As fossil fuel prices are tied to world markets and events it also results in PICTs being highly vulnerable to events well beyond their borders.[9] This has a follow on effect on energy reliability and costs, and therefore economic development.

Case study: *Tonga is highly dependent on imported fuels to meet its overall energy requirements. The Tongan economy and electricity consumers have been exposed to high and volatile electricity prices linked to oil prices over the last 10 years. The Tongan government, in 2009, responded to the twin challenges of reducing the Tongan contribution to global greenhouse gas emissions and improving national energy security by approving a policy to supply 50% of electricity generation by renewable resources by 2012.*

Finally, economic activities such as agriculture, fisheries, forestry, and tourism play key roles throughout the PICTs so any infrastructure associated with these activities is important to sustaining livelihood. This economic infrastructure is expensive to build and maintain and can account for a significant amount of a nation's budget. In many PICTs, the funding to build the major infrastructure often comes from the donor community, with the exception of tourism assets which are largely supported by the private sector. However, external support for ongoing maintenance and repair is very limited.

To a certain degree, all of the above categories of infrastructure overlap in their roles and outcomes. The following matrix in Table 2 shows cross dependencies between categories.

[9] Tonga Energy Road Map 2010-2020, A Ten Year Road Map to Reduce Tonga's Vulnerability to Oil Price Shocks and Achieve an Increase in Quality Access to Modern Energy Services in an Environmentally Sustainable Manner, April 2010.

Table 2: Contribution of Infrastructure in the Pacific to Social and Economic Outcomes

	INFRASTRUCTURE																
	Basic Well-Being						Government				Economic						
OUTCOME	Housing	Water	• Supply	• Waste Water	• Drainage	Solid Waste	Health	Education	Justice	Administration	Transport	• Roads	• Ports	• Airports	ICT	Energy	Tourism
Primary Well-Being	Strong	Strong	Strong	Strong	Strong	Strong	Strong	Moderate	Moderate	Weak	Moderate	Moderate	Moderate	Moderate	Moderate	Strong	Moderate
Government Services	Weak	Moderate	Moderate	Moderate	Moderate	Moderate	Strong	Strong	Strong	Strong	Strong	Strong	Strong	Strong	Strong	Strong	Moderate
Economic	Moderate	Strong	Strong	Strong	Strong	Strong	Moderate	Moderate	Moderate	Strong	Strong	Strong	Strong	Strong	Strong	Strong	Strong

Key Strong Moderate Weak

2.2 Exposure of Pacific infrastructure

Infrastructure in the Pacific has characteristics that affect its vulnerability to climate change. These vary primarily according to island type. The three islands types in the Pacific depend on the process of formation:

- **Volcanic:** in which the formative volcanic cone is above sea level; the island has high slopes inland, and a fringe reef. Such islands for example have greater risks of landslides from heavy rainfall which can damage infrastructure.
- **Atoll:** in which the formative volcanic cone has sunk or eroded, and only a low-lying built up reef remains above sea level. Such islands are particularly exposed to risks from sea level rise and changed intensity of cyclones.
- **Raised Atoll:** an atoll which has risen, providing an atoll like structure substantially above sea level, with steep cliffs at the edge descending to the sea. Infrastructure on such islands can be highly exposed to coastal erosion.

These geographies affect the way of life and economies on the island. Each island type has its own form of economy, and related infrastructure, and its own characteristic exposure to climate change.

On atolls such as Kiribati, for instance, there is no high land on which to build to escape rising king tides, or sea level rises. On raised atolls such as Niue, however, it was possible to rebuild the health facility inland, in order to minimise future storm damage. In Nauru, on the other hand, the interior has been cratered by phosphate mining forcing settlement onto the fringe beach and exposing them to the sea. In volcanic Samoa, a significant amount of infrastructure is raised reasonably well above sea level, and only the foreshore is exposed. Across the Pacific, however, tourism resorts and fishery infrastructure are largely located on the foreshore and therefore, are very vulnerable to changes in tides, sea level as well as major storm impacts.

Varying soil types will also influence infrastructure with volcanic based soils more reactive than those found on atolls and in sandy areas, and as a result require different infrastructure design and in some cases may contribute to increased damage to infrastructure as it does in other countries[10].

Figure 2 provides some examples of the type and location of infrastructure assets in different PICTs.

Kiribati: No high land[11]

Niue: Buildings on shoreline cliffs[12]

Apia: Town on volcanic slopes[13]

Nauru: Town on fringe beach[14]

Figure 2: Examples of Infrastructure in Different Locations around the Pacific Region

However, there is no generic PICT. Each PICT is different. Some of the difference is driven by island typologies, but others include the specific characteristics of the island; the geographical spread of islands; and the strength and level of urbanisation of the local economy. Every PICT needs its own infrastructure strategy to adapt to climate change.

[10] Ibrahimi, F, Seasonal variations in Water Main Break due to Climate Variability and Ground Movement, Australian Water Association, May 2005

[11] http://listverse.com/2007/08/30/top-10-densely-populated-nations/(wikepedia)

[12] http://www.apiarotary.ws/

[13] http://www.traveltroll.info/2011/05/sailing-season-commences-on-niue.html

[14] http://www.britannica.com/EBchecked/media/101125/Islet-of-Bairiki-South-Tarawa-Kiribati

2.3 Other dimensions of infrastructure

Infrastructure can be defined in many different ways and its management involves so many different factors. To prioritise infrastructure investments for adapting to climate change in the Pacific, it is important to understand the various dimensions of assets, and not just assess it in terms of the outcomes identified in Table 2. Table 3 highlights characteristics of infrastructure in the Pacific that need to be recognised and the implications of these characteristics incorporated into adaptation strategy development.

Table 3: Characteristics of different forms of infrastructure and their implications for adaptation strategies

Categorisation	Issues	Strategy Implication
Centralised / Decentralised		
• **Centralised** infrastructure constitutes what most would normally connote: large installations with an extensive catch basin of users, such as main wharves, airports, trunk roads, power plants and urban water supplies. • **Decentralised** infrastructure includes houses, shops, schools, small jetties, paths, and stand-alone water supplies and energy installations.	Donor funding tends towards centralised infrastructure, because it is more easily programmed and managed, and more clearly needs external inputs. However, this can lead to decentralised infrastructure being underfunded, in comparison to the size of population that depends upon it. As donors recognise this, it is changing. Energy projects currently underway in the Solomon Islands, Vanuatu and Tonga illustrate this change15.	In developed economies, government tends to invest in heavy infrastructure, leaving light infrastructure to individuals. In the PICTs, individuals, and local communities, tend to lack the resources and knowledge to mitigate and adapt to the extremes expected due to climate change. Light infrastructure has to be on the development menu.

[15] Promoting Access to Renewable Energy in the Pacific (Solomon Islands), Interim Report, Asian Development Bank, 2011; Vanuatu Electrification (Microhydropower) Feasibility Study at Talise, SPREP, Final Report, 2009; Tonga Energy Road Map 2010-2020, Government of Tonga, April 2010.

Categorisation	Issues	Strategy Implication
Tourism / Local		
• **Tourism** is a major form of income for many PICT countries, and large sections of urban and rural infrastructure are built to accommodate this industry. This includes: some parts of heavy infrastructure, plus marina facilities, hotels, many restaurants, and tourism attractions.	Much tourism infrastructure is capitalised privately, and benefits flow to private enterprise, some of it offshore. In considering public sector spending, there is an argument that protection of tourism assets should be primarily a private sector cost.	Given the scarcity of resources, the fragility of local economies and ecologies, PICTs need to undertake careful analysis before investing in tourism assets. Cost benefit studies need to help delineate what tourism assets are of overwhelming public benefit, and priority given to local assets with a direct impact on population's well-being. Tourism operators, as well as PICT governments, will need to analyse the impact of climate change on the tourism industry and therefore, the overall economy of the country.
• **Local** infrastructure is that component of the infrastructure that largely services the local population and is relied upon by local populations for their survival.	Local infrastructure is essential for providing basic services for local populations and is therefore, important to their well-being.	

Categorisation	Issues	Strategy Implication
Urban / Rural		
The distribution of populations across many small islands can make the urban/rural divide extreme, with some rural populations separate from any urban centre by hundreds of kilometres of open sea. • **Urban** infrastructure supports a town/commercial centre and tends to be characterised by centralised infrastructure, such as a coordinated road network, central water supply, and central power. Buildings tend to be larger than those in rural areas as they often include government and commercial buildings. • **Rural** area infrastructure is more likely to be the responsibility and at the cost of the householder.	Because a breakdown in urban infrastructure directly impacts on government, industry, and public health, it usually attracts investment. But PICT populations are primarily rural, and adaptation should be applied to the whole population. Many PICT poor live in urban settlements. In terms of infrastructure, these can be considered rural in their conditions, but without the access to land and resources enjoyed by rural settlements.	Most of the population in the PICTs is rural. They are also among the most vulnerable, dependent on transportation infrastructure for goods, services, and often their livelihoods. Infrastructure planning for climate change needs to include priorities for rural and poor populations.

2.4 Weaknesses of Pacific infrastructure

Infrastructure in the Pacific is widely considered to be of relatively low quality[16], with the exception of large, donor-funded centralised infrastructure projects. Even these tend to suffer in the operations and maintenance phase of their lifecycle. The source of problems varies, but in general, can be attributed to:

- Geographically dispersed populations separated by ocean, making infrastructure construction, operations and maintenance difficult;
- Small economies and small governments with small budgets, limiting what governments can do, and the capacity of its internal skill base;
- Weak education systems, and limited professional opportunities within small island economies, leading to an outflow of skilled infrastructure professionals, and limited attractiveness for external professionals to enter the market.

[16] The Pacific Infrastructure Challenge, World Bank, 2006; Discussions with SPC.

The predominant weaknesses are:

- **Accessibility to remote islands:** The remoteness of many islands makes it prohibitively expensive to build quality buildings, because of the cost of taking materials, skilled labour, and supervisors to those islands. In remote locations there are numerous building practices that are applied using more locally available materials that can be replaced more easily after damage. These local practices may provide some insight into options for adapting to climate change.
- **Access to raw materials:** Most PICTs have few, if any, quality local materials. Even sand can be difficult to access without damaging the local eco-system. Imported materials are expensive, often nil-stock, and not well supported in terms of local advice, trade skills, and ongoing spare parts or repair systems.
- **Poor design:** PICTs find it difficult to maintain a local base of skilled professionals. Pay is low and many migrate to the US, Australia or New Zealand. The small island economies make it difficult to maintain workflow. There are few opportunities for continuing professional development. Project experience is limited to the few types of infrastructure built on the islands. Where design expertise is imported by external donors or investors, foreign designers do not always have a deep understanding of the stresses and limitations imposed by the local environment, and many foreign-built buildings are difficult to maintain within the shallow local construction economy.
- **Poor construction quality:** This comes from a lack of a deep resource pool of professional construction personnel, along with poor infrastructure quality governance, and low levels of demand for quality from the client base. For example, poor concrete mixes result in infrastructure which deteriorates much more quickly[17].
- **Limited resources:** Other than donor-funded or large scale tourism projects, there is little money for infrastructure. Government, local business, and private individuals tend to opt for low cost solutions, rather than identifying solutions that provide the best lifecycle value for money that are more characteristic of developed economies.
- **High dependency on donor funds:** Small local budgets compared to the enormity of need generated by a small population widely dispersed across many islands means that most PICTs are dependent on donors for infrastructure. Although these flows are of value, this partitioning of the infrastructure economy can lead governments to leave infrastructure to the donors, and to fail to invest in proper infrastructure planning and asset management. This in turn can result in inappropriate infrastructure investments or rapid decline of the asset after construction.
- **Sectoral fragmentation of responsibilities:** Although it's a truism that sectors affect each other, and need to be run in an integrated way, this tight integration is especially necessary in small island ecologies, and for governments with stressed and under-resourced departments. However, integration is not commonplace in the Pacific. As in many countries, infrastructure ministries and departments tend to operate in isolation with minimal interaction with others. Solutions tend to focus only on that sector rather than exploring options for integrated approaches. In discussions with donors such as the ADB, it was also

[17] Discussion with Asset Management Adviser, Preparing the Transport Sector Development Project, ADB, 2010

noted that in some cases the support of donors does not help to alleviate this sectoral approach and is an area that could be better managed.

Figure 3: Jetty in the Solomon Islands in need of repair

- **Poor infrastructure management:** The ongoing development and application of appropriate and up to date building standards and regulations requires an investment in skilled government or professional human resources. Both are in short supply among the PICTs. Good infrastructure governance also requires investments in planning, public education, inspection and enforcement, and ongoing operation and maintenance (O&M). The ability to rationalise the operations, maintenance, renewal and replacement cycle of infrastructure is a critical aspect of asset management and is not well done in the Pacific. These activities must all be carried out by the necessary number of trained, qualified and supported government staff. Again, these are difficult to sustain in the PICTs and have been identified as key barriers to growth and development[18]. This issue in particular will be an important component of developing effective climate change adaptation strategies for all infrastructure assets in the Pacific. It will be explored later in this report.
- **Land tenure:** Land is the most basic infrastructure, and land tenure is basic to almost every infrastructure project. Where land tenure is insecure, or shoreline changes upset the tenure

[18] The Pacific Infrastructure Challenge, World Bank, 2006

system, problems follow with other forms of infrastructure. For example, if a roadway needs to be moved to a safer location due to climate change issues, land tenure and land use issues are likely to arise. Communities seeking compensation for loss of land in situations such as this will be a political challenge for governments and donors.

- **Poorly informed clients:** Most onshore investors in infrastructure have expectations formed by their experience with the existing infrastructure stock. Since the quality of stock is low, expectations are low. The limited building pool means that investors in infrastructure also have little exposure to new or innovative infrastructure solutions.
- **Few exemplary prototypes:** As noted above, because overall quality is low, and expectations are low, there are very few examples of how to build quality, energy-efficient buildings. This absence of examples feeds into a cycle of low quality.

While climate change adaptation strategies cannot address all of the issues highlighted above, it is important to recognise the operating environment in which climate change adaptation of infrastructure must be developed and implemented.

Example: *Remote schools could be exemplars of good water management, good hygiene, good construction, disaster resilience, multi-function asset planning, use of local materials, maintenance and maintainability, community governance, and good sanitation. However, most departments are fully occupied with their normal duties; rarely have time to visit remote schools; don't have time nor direction to coordinate across departments; and struggle to maintain existing schools. They are not resourced or led to develop the necessary exemplars.*

* * * * *

The PICTs are dependent on infrastructure to deliver basic living services, government services, and to support their economy, but the characteristics of the region create a unique environment in which infrastructure must be constructed and maintained. The PICT islands are of three different types, due to three different formation processes: volcanic, atoll, and raised atoll. On each type, infrastructure is distributed in a particular way, often focused around the edge. Other principal characteristics of Pacific infrastructure include a division between centralised urban and decentralised rural infrastructure, and between infrastructure built for the local population and infrastructure built for tourists. The small size, exposure, geographical isolation, small population and small economies of the PICTs give rise to a particular set of infrastructure challenges, even prior to the impact of climate change. Some of these are physical, for instance the marine environment, the dispersed population, and the foreshore location of most infrastructure. Other challenges are institutional, including the smallness of government, fragile economies, and a shortage of infrastructure professionals compared to requirements.

In developing strategies for adapting to climate change, the existing conditions and constraints need to be recognised. Climate change adaptation cannot address all of these issues, but in some instances it may be possible to develop an approach to managing climate change impacts that addresses other limitations in the system. The focus of this paper, however, it to identify what information is required by political decision-makers and infrastructure managers to better manage the impacts of climate change on their infrastructure.

3. Impacts of climate change on infrastructure

The focus of **Section 2: Infrastructure in the Pacific** was to establish the characteristics of the current state of infrastructure as a system of investment, operation and maintenance, and outcomes. Section 3 analyses the additional challenges presented by climate change.

3.1 Overview of climate change impacts

The projected impacts of climate change in the Pacific are documented in various reports[19] and with varying detail. It is recognised that climate change will influence each PICT uniquely, and therefore the responses will also be different in each country. While it is not the purpose of this paper to describe all the impacts of climate change on each PICT, the *UNFCC Climate Change: Impacts, Vulnerabilities and Adaptation in Developing Countries Report (2007)* provides a useful summary of the impacts of climate change in all small island developing states (SIDS) based on work completed by Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. The details of these impacts are continually being refined for each PICT as more information becomes available. An extract of relevant impacts and vulnerabilities in the Pacific is outlined in Table 4. The vulnerabilities identified below relate directly to the areas of priority identified in the PASAP program.

Table 4: Regional Impacts and Vulnerabilities to Climate Change in Small Island Developing States (SIDS)

Impacts of Climate Change
Temperature • SIDS will experience warming. Warming in the Pacific will be lower than the global average *Precipitation* • Increase in annual rainfall in the equatorial Pacific • Decrease in rainfall east of French Polynesia in the Pacific *Extreme Events* • Increasing intensity of tropical cyclones, storm surge, coral bleaching and land inundation

[19] For example, Mainstreaming Climate Change in ADB Operations, Climate Change Implementation Plan for the Pacific (2009-2015), Asian Development Bank, 2009; National Adaptation Program of Actions, SPREP

Sectoral Vulnerabilities
Water Security • Water resources seriously compromised due to rising sea level, changes in rainfall and increased evapotranspiration eg. In the Pacific a 10% reduction in average rainfall by 2050 would lead to a 20% reduction in the size of the freshwater lens on the Tarawa Atoll (Kiribati)
Agriculture and Food Security • Agricultural land and thus food security will be affected by sea-level rise, inundation, soil salinization, seawater intrusion into freshwater lens, and decline in freshwater supply • Agricultural production affected by extreme events • Fisheries affected by increasing sea surface temperature, rising sea level and damage from tropical cyclones *Health* • Increases in the intensity of tropical cyclones increase risks to life • Heat stress and changing patterns in the occurrence of disease vectors and climate sensitive diseases affect health *Coastal Zones* • Most infrastructure, settlements and facilities are located on or near shore and will be affected by sea-level rise, coastal erosion, and other coastal hazards, compromising social well-being of island communities and states • Accelerated beach erosion, degradation of coral reefs and bleaching will all have impacts on incomes from fishing and tourism • Habitability and thus sovereignty of some states threatened due to reduction in island size or complete inundation *Terrestrial Ecosystems* • Replacement of local species and colonisation by non-indigenous species • Forests affected by extreme events are slow to regenerate. Forest cover may increase on some high latitude islands.
Adaptive Capacity
Small islands are especially vulnerable to the effects of climate change, sea level rise, and extreme events. Characteristics such as limited size, proneness to natural hazards and external shocks enhance the vulnerability of islands to climate change. In most cases, they have low adaptive capacity, and adaptation costs are high relative to GDP.

As highlighted in Table 4, changes in climatic conditions lead to changes in the local natural environment. It is these changes that impact on infrastructure in many different ways. The changes that most impact the capacity of infrastructure to deliver social and economic outcomes are:

1. Coastal inundation;
2. Extreme weather events which bring high winds, storm surge, increased wave action and flooding;
3. Changes in precipitation that impact water security.

Table 5 illustrates how climate change impacts tend to impact on different types of infrastructure.

Table 5: Major climate change impacts on infrastructure assets

INFRASTRUCTURE	CLIMATE IMPACT									
	Coastal	• Storm Surge	• Sea level rise	• King tide	• Wave action	**Rainfall**	• Drought	• Prolonged Rain	• Flood	**Cyclonic Wind**
Energy		Moderate	Moderate	Moderate	Moderate		Moderate	Moderate	Moderate	Strong
Water										
• Supply		Strong	Strong	Strong	Strong		Strong	Strong	Strong	Strong
• Waste Water		Strong	Strong	Strong	Strong		Strong	Strong	Strong	Strong
• Drainage		Strong	Strong	Strong	Strong		Strong	Strong	Strong	Strong
Solid Waste		Moderate	Moderate	Moderate	Moderate		Weak/None	Strong	Strong	Strong
Transport										
• Roads		Strong	Strong	Strong	Strong		Moderate	Moderate	Strong	Strong
• Ports		Strong	Strong	Strong	Strong		Moderate	Moderate	Strong	Strong
• Airports		Strong	Strong	Strong	Strong		Moderate	Moderate	Strong	Strong
ICT		Moderate	Moderate	Weak/None	Weak/None		Weak/None	Weak/None	Moderate	Strong
Buildings										
Settlements		Strong	Strong	Strong	Strong		Strong	Strong	Strong	Strong
Health		Strong	Strong	Strong	Strong		Strong	Strong	Strong	Strong
Education		Strong	Strong	Strong	Strong		Strong	Strong	Strong	Strong
Tourism		Strong	Strong	Strong	Strong		Strong	Strong	Strong	Strong

Key: Strong | Moderate | Weak/None

3.2 Impacts of climate change on infrastructure

In the Pacific, the risks to infrastructure as a result of climate change are varied and specific to the assets being considered. In Section 2, principle types of infrastructure were categorised with respect to the key outcomes they fulfilled. In order to discuss the impacts of climate change, this section classifies those assets into five main categories:

- Energy
- Water and Waste
- Transport
- Information and Communication Technology (ICT), and
- Buildings.

The Buildings category includes all sizes and types of building stock such as housing, community buildings, health, education, justice, administration, and businesses.

The following sections highlight how the five different categories of infrastructure are expected to respond to climate changes based on current experience and an understanding of how and why infrastructure is damaged or deteriorates. Some of these impacts—such as increased storms and variable rainfall—are being felt already, others—such as sea level rise—are expected to have a greater influence in years to come. As mentioned above the specific nature of each of these impacts is continually being refined and in some instances changed as more specific data becomes available.

The impacts fall into two categories. Major impacts that produce significant damage to the functioning of the asset and are largely due to the three key impacts identified above: coastal inundation, extreme weather, and changes in precipitation. The second category consists of less severe impacts. These secondary impacts do not have the same priority as the major impacts, but will contribute to the overall impact of a changing climate on infrastructure. Proper management of these impacts will maximise the lifespan of the infrastructure.

3.2.1 Energy

Energy systems in the Pacific are a vital part of development. They are required to cool homes, offices, and institutions, operate water supply and waste management systems, light buildings and streets, as well as support a wide variety of businesses, such as tourism, which contribute to the overall economic development of the countries. Urban centres tend to have on-grid systems, so anything that damages the powerhouse or grid transmission lines will have wide ranging consequences. Alternatively, rural areas tend to operate small off-grid systems that supply energy to a household or small number of households. However, both are important for the service they provide and the support they provide to other infrastructure assets.

The infrastructure is vulnerable to a number of climate change impacts. Major impacts are:

- Storms and their associated strong winds and heavy rains can damage various elements of the energy system infrastructure including water intakes of hydropower systems, wind turbines, fuel storage, power houses, and the distribution network[20].
- Heavy rains and flooding destabilises soil foundations and can cause transmission lines to lean or fall over. There have been cases where the electricity lines remained live despite the transmission towers leaning over[21].
- Heavy rains and storms that cause washout or damage to road surfaces can cut off access to the power station. Therefore, workers and supplies (i.e. fuel, spare parts) cannot get to the power house to run the system.
- The majority of energy generated in the Pacific is from diesel systems so any damage to ports and roadways from storms can prevent diesel fuel getting to the powerhouse which may cause interruptions in power supply.

Figure 4 :Transmission poles in East Timor following major rainfall and storm events.

[20] Photos from Cyclone Heta in Nuie I 2004 illustrate the damage to all sectors of infrastructure http://www.nunames.nu/nuimages/cycloneheta.htm

[21] Photograph from the East Timor Rural Power Delivery Project, ADB, 2011

- Increased sea spray from storms and heavy winds can increase the corrosion rates of metal structures in the energy system including the distribution systems[22.]
- If any larger energy systems use water for cooling any shortage of water will have a negative impact on the operation of the energy system.

Other less severe impacts of climate change on energy systems include:

- Concrete is susceptible to corrosion[23,] especially if it is locally made or of poor standard. Corrosion rates of concrete are influenced by evapotranspiration, humidity levels, temperature and the acidity/alkalinity of soils and water in the environment. All of these are impacted by climate change which would increase the deterioration rate of concrete. Increased deterioration increases the maintenance regimes of any concrete based infrastructure in an energy system.
- Climate variability can stress the system by changing demands on the system. For example, prolonged heat periods can increase the demand for cooling systems in some locations and strain the capacity of the system. This leads to increased operation and maintenance (O&M).
- Changes in weather patterns (increased cloud cover) can influence solar energy generation by changing the amount of available solar energy (light hours). This can create instability in solar energy systems[24].
- Changing wind regimes can influence the generation of wind energy and create instability in the system[25.]
- Unpredictable rainfall patterns which impact water flow rates in rivers and streams create uncertainty when running hydropower systems and can lead to inefficiencies in equipment operation and therefore, more wear and tear on equipment[26.]
- Higher peak temperatures can create increased sag in power lines. This may have occupational, health and safety implications.

From the list of impacts above, it is clear that climate change will have varying impacts on energy infrastructure and influence not only the asset, but also the ability to effectively operate and maintain the energy systems which support the community and economy.

3.2.2 Water and waste

Water is vital to sustaining life so any event which limits the ability to withdraw, treat or distribute water supply to households will have detrimental effects on community health. Certain businesses and utilities are also highly dependent on water for their operations. Similarly, effective sanitation and solid waste management/wastewater treatment is also

[22] Tonga Energy Roadmap, On Grid Distribution; TA 7113 – PNG: Preparing the Power Sector Development Project, ADB, 2010; East Timor Rural Power Delivery Project, ADB, 2011.

[23] Ravindrarajah, R.S., Kizana, D., Deterioration and Restoration of Concrete Jetties, Centre for Built Infrastructure Research, University of Technology, Sydney, Presented at the 11th Asia-Pacific Corrosion Control Conference, Vietnam, November 1999.

[24] On- Grid Energy Report, Renewable Energy Supply to the Four Islands Grid in Tonga, Report prepared by GHD for World Bank

[25] See Footnote 24.

[26] Solomon Islands Mini Hydro Project, Promoting Access to Renewable Energy in the Pacific, ADB, 2010

essential for maintaining healthy populations so impacts that hinder the ability of systems to effectively treat waste/wastewater will have health implications.

Effective drainage has two functions: it minimises contact with any contaminated water which is important for human health, and it controls flooding. Figure 5 from Samoa indicates what happens when drainage infrastructure is not sufficient to handle increased water flows.

Water related infrastructure has a range of vulnerabilities to the impacts of climate change. The major impacts are:

- The winds and heavy rains associated with storms/cyclones can damage water infrastructure that subsequently needs to be repaired. Furthermore, undersized drainage systems can also result in heavily damaged road infrastructure.
- Flooding due to storms or heavy rains impacts the efficient operation of the water and wastewater treatment systems. This tends to increase operation and maintenance requirements of these systems. Wastewater treatment systems are generally based at the bottom of a catchment, therefore, making them more susceptible to flooding or sea level rise[27].

Figure 5: Poor drainage in Samoa contributes to flooding and the potential contamination

[27] Samoa Sanitation and Drainage Project, ADB

- Flooding can also contaminate water supply systems impacting the health of users[28].
- Increased rainfall requires increased pipe size/channels and when bigger pipes/channels also have to contend with very variable flows there tends to be more deterioration in the pipes. Again this results in increased maintenance of the pipework.
- Changing rainfall patterns can alter soil characteristics causing pipework and buildings associated with water supply to shift/crack[29].
- Channels and pipes fill with sediment during heavy rains and will require more maintenance to keep them operating effectively. Increased sedimentation also influences the amount of the waste stream that needs to be discarded in any waste treatment system.

Other impacts of climate change that will also need to be considered over time include the following examples:

- Corrosion rates of concrete are influenced by evapotranspiration, humidity levels, temperature and the acidity/alkalinity of soils and water in the environment. All of these are impacted by climate change which will likely increase the deterioration rate of concrete. Increased deterioration of concrete increases the maintenance regimes of any concrete based infrastructure.
- Corrosion rates of any metal structures are also increased with changing climate conditions – higher temperature, humidity, higher CO2 levels in the atmosphere.
- Increased temperatures/flow-rates impact the effectiveness of biological treatment processes potentially leading to partially treated effluent being discharged from wastewater treatment plants and contaminating receiving waters[30].

Flooding, temperature and the corrosive sea environment all impact water and waste infrastructure and all of these are likely to increase as a result of climate change. With water being such a vital contributor to human health, strategies to protect and manage this infrastructure are very important for Pacific communities.

3.2.3 Transport

The remoteness of islands throughout the Pacific means that transport to, from and within each country is important for the survival of communities. The following summarises expected impacts of climate change on three transport sectors: Roads/bridges, airports, and sea transport (ports, wharves, jetties).

- Roadways and bridges, especially coastal roads, damaged by severe storms through flooding, scouring, land shifting and cutting off access to other key infrastructure[31].
- Sea level rise can inundate coastal roads.

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[28] Photos from the Samoa Sanitation and Drainage Project, ADB

[29] Dili Water Supply Performance Improvement Project, ADB

[30] Metcalfe and Eddy

[31] Photo from Samoa Sanitation and Drainage Project, Asian Development Bank– road cut off due to flooding.

- Bridges washed out by increased flooding and landslides.
- Coastal erosion changes flows around rivers/streams causing undercutting of bridge structures.
- Culverts damaged by floods and heavy rains reduce their ability to handle increased drainage. This can cause damage to the road foundations and require more repair.
- Airport terminal destroyed by strong winds/heavy rains.
- Airstrips/runways damaged by flooding, extreme storms.
- Ports, wharves, and jetties damaged by strong winds and heavy storms. Increased wave heights and splash zones impact the integrity of the concrete/steel structures due to corrosion[32].
- Sea level rise means port heights need to be increased[33].
- Concrete structures need to be able to withstand stronger winds, heavy rains and waves.
- Severe storms damage port buildings.

Figure 6: Roadways flooded during major storms in Samoa.

[32] See Footnote 23

[33] Vanuatu Maritime Transport Project, ADB; Federated States of Micronesia (FSM) Pohnpei Port Scoping Study, Pacific Region Infrastructure Facility, October 2010.

Examples of secondary impacts of climate change on transport infrastructure include the following:

- Corrosion rates of concrete are influenced by evapotranspiration, humidity levels, temperature and the acidity/alkalinity of soils and water in the environment. All of these are impacted by climate change. It is expected that deterioration rates of concrete will increase under these changing conditions requiring increased maintenance regimes of any concrete based infrastructure related to transport.
- Increases in temperature can result in longer runways required for take-offs/landings.

Transport to, from and within the PICTs has become essential to their continued development and their ability to access goods and services in both disaster situations, as well as for ongoing daily activities. With a reliance on external sources of fuel, food and medical supplies, the impacts of climate which limit the movement of supplies needs to be managed to ensure long term sustainability of the communities.

3.2.4 Information and communication technology (ICT)

The remoteness of the Pacific communities means that they are very reliant on effective communication systems. While most communities can manage for a period with no external communication, to continue economic activities and to receive external supplies/support, proper ICT is essential.

Climate change impacts on ICT include:

- Communication towers destroyed by extreme storms[34].
- System stops operating if power supply cut off or damaged.
- Any sensitive equipment used in the ICT system will be susceptible to the corrosive environment already existing in the Pacific and which will likely increase due to the impacts of climate change.

These impacts have not been categorised as they are all important for the ICT systems. One of the most important aspects of damage to ICT systems is to have back up plans in place so that some form of communication can commence in an emergency situation. This is probably more important than the actual infrastructure itself and needs to be considered in climate change adaptation strategies.

3.2.5 Buildings

There are a wide range of buildings in the Pacific from homes and businesses, meeting places/markets, government buildings, schools, health facilities, churches and tourist facilities. These different buildings can be made from a wide range of materials. While management of the buildings with respect to climate change may be different depending on how critical the building is to community well-being, the impacts are very similar. As a result, buildings are initially being considered as one category of infrastructure.

[34] See Footnote 20, Cyclone Heta in Nuie

The following are impacts of climate change on buildings.

- Heavy winds and rain blow off roofs and destroy buildings[35].
- Flooding damages buildings.
- Hospitals and other medical facilities damaged by flooding, heavy rain and strong winds and can't provide medical support.
- Education facilities damaged by flooding, heavy rain and strong winds.
- Road access cut off following extreme weather events.
- Towns and villages inundated with flooding due to storm surge and sea level rise[36].
- Towns and villages inundated due to increased precipitation.
- Damage to water supply system cuts off drinking water access.
- Damage to electricity supply system cuts off access to electricity.

Again, all of these issues are important in the Pacific context. There are numerous examples around the Pacific of damage to buildings from severe storms, storm surges, and flooding. Damage to buildings is going to be a costly[37] ongoing challenge to PICTs so strategies to manage this situation need to be developed. Some initial work has been undertaken to estimate the costs associated with these disasters and how they will increase due to climate change[38].

The Pacific Catastrophe Risk Assessment and Financing Initiative[39] is developing an exposure database and disaster risk modelling and assessment tools to assist with identifying the probabilities of buildings and other infrastructure assets from being damaged in disaster events. This is going a long way to assisting PICTs understand where disaster is likely to hit, and therefore how they can manage their response. A range of strategies can be used to manage the impacts identified above in order for PICTs to respond effectively to current and future climate scenarios. All of these options need to be explored and decisions made will be unique in each case.

3.3 Interdependencies between infrastructure assets

The discussion above highlights the impacts of climate change based on current predictions on the five categories of infrastructure. It also started to point out a number of the key interdependencies between the different infrastructure assets. Understanding these interdependencies is important for developing holistic and coordinated adaptation responses. This is particularly important in a resource poor environment.

[35] See Footnote 20, Cyclone Heta in Nuie

[36] Photos from storm/flooding events in Samoa.

[37] Economic Costs of January 2009 Nadi Floods, SOPAC Technical Report 426, September 2009.

[38] Economics of Adaptation to Climate Change, Samoa, World Bank, 2010.

[39] Pacific Catastrophe Risk Assessment and Financing Initiative – Progress Brief, A joint initiative by the World Bank, Asian Development Bank, SOPAC Division of SPC with co-funding by the Japan Policy and Human Resources Development Fund and the Global Facility for Disaster Reduction and Recovery, February 2011

Figure 7 illustrates pictorially many of the interdependencies between different infrastructure assets. If climate change impacts one asset it is important to understand the ramifications for other assets.

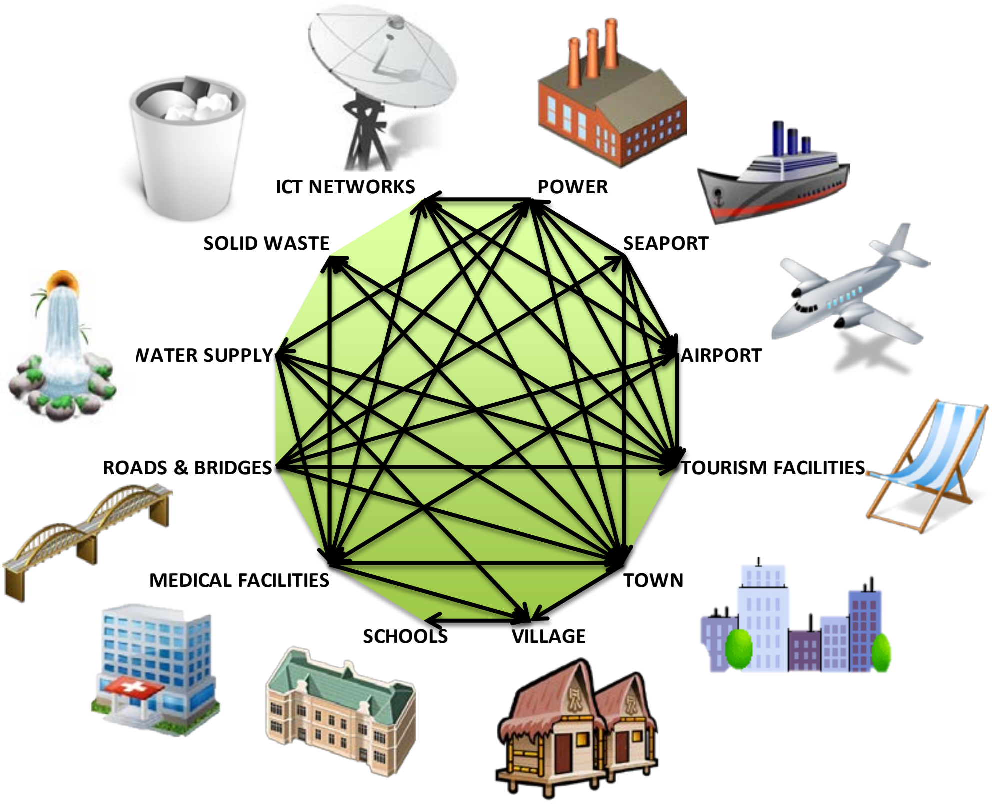

Figure 7: Indicative interdependencies between different infrastructure assets in the Pacific

Energy systems are important in the day-to-day operations of life in the Pacific. Problems with the energy production and distribution can impact the effective operation of other assets such as water supply and wastewater systems that rely on on-grid/centralised supply. They are also an important element in effective operation of ICT systems, although some of these systems in the Pacific have localised energy sources. Alternatively, energy systems require a continual fuel source and to date have relied heavily on the importation of diesel fuel. Therefore, any damage to ports and roads that hinder fuel transport to the powerhouse site has the potential to interrupt energy production. The energy/road example highlights just some of the critical interdependencies between different infrastructure assets.

As discussed in Section 3.2.3, transportation in the Pacific is vital. The ability to get food, medical supplies, diesel fuel, materials for reconstruction/rebuilding are all reliant on air, road and coastal infrastructure (ports, wharves, jetties). Therefore, the transport system is inextricably linked to economic development, as well as community health, education, medical facilities, water supply and sanitation, and energy systems. Vanuatu and PNG consider their roadways as one of their most vital pieces of infrastructure[40], and this would be true of many PICTs. As tourism is one of the largest contributors to economies in many of the PICTs, anything which limits the ability of tourists to get in and out also has a detrimental impact on the economy, which then leads onto other challenges for local communities. Therefore, damage to airports and their associated infrastructure will also influence other infrastructure and their related activities such as hospitals, hotels, restaurant, and businesses.

To build on the transport example, the vulnerability of a typical airport to heavy winds, rain and storm surge illustrates how one asset is impacted by climate change impacts and how that interacts with many other assets. The following scenario further highlights many of these interactions:

- A typical airport is built on the coast, because of the availability of flat land along the coast, and because the coastal location provides safe flight paths over water. A typical airport will therefore have high exposure.
- The airport itself depends for its operation on the town power supply, and the power reticulation system. A full understanding of the vulnerability of the airport, and an appropriate response, requires inputs from the analysis of the power system.
- The road to the airport may be affected by rising sea levels, or erosion. An operational airport without road connection to the rest of the island is useless.
- The power supply will typically depend on fuel imports, and so even if there is access to the power supply, if the wharf goes down, fuel supplies may be interrupted, again causing the loss of the airport function.
- The airport operations depend on skilled personnel. If these are not available at critical times because their homes and families are being affected, and they don't come to work, the airport may still be non-operational.
- Keeping clearing equipment functional, available and safe requires well-functioning government asset systems, which if not in place may cause that safeguard to fail.

[40] Vanuatu National Adaptation Plan of Action; Pilot Program for Climate Resilience, Proposal for Papua New Guinea Phase 1 Activities, Climate Investment Fund/Asian Development Bank, 2010.

Figure 8: A coastal airstrip in Samoa

- An understanding of downstream affects is also important. What impact will prolonged airport closure have? One primary impact will be on tourism, since most come by air. However, the tourism industry is largely owned by overseas interests, and is itself highly dependent on imports to operate. It will take a detailed economic analysis to understand what the economic impact of airport operations are, including income flows from employees, and secondary tourism operators. These are human systems that also need to be considered to fully understand the impact of climate change impacts on infrastructure.

Considering all of the incoming and outgoing linkages, we can describe the airport as a node in a network of infrastructure systems. Impact, vulnerability, prioritisation and response have to be understood in terms of this network; not a simple linear path. Table 6 illustrates the many interdependencies between different assets in the Pacific and whether the linkages are strong or weak. It is clear that there are many connections, and if one fails to understand these links then adaptation strategies will be weakened.

Table 6: Interdependencies of the operation/damage of one type of infrastructure on other assets

INFRASTRUCTURE IMPACTED	INFRASTRUCTURE IMPACTING: Energy	Water	• Supply	• Waste Water	• Drainage	Solid Waste	Transport	• Roads	• Ports	• Airports	ICT	Buildings	• Settlements/Homes	• Health	• Tourism	• Education
Energy			Moderate	Moderate	Moderate	Weak/None		Strong	Strong	Strong	Moderate		Strong	Strong	Strong	Moderate
Water																
• Supply	Strong			Strong	Strong	Strong		Strong	Moderate	Moderate	Weak/None		Strong	Strong	Strong	Moderate
• Waste Water	Strong		Strong		Strong	Strong		Strong	Moderate	Moderate	Weak/None		Strong	Strong	Strong	Moderate
• Drainage	Moderate		Moderate	Moderate		Weak/None		Strong	Weak/None	Weak/None	Weak/None		Strong	Strong	Strong	Moderate
Solid Waste	Strong		Moderate	Weak/None	Strong			Moderate	Moderate	Weak/None	Weak/None		Moderate	Moderate	Moderate	Weak/None
Transport																
• Roads	Strong		Weak/None	Weak/None	Strong	Moderate			Weak/None	Weak/None	Weak/None		Moderate	Weak/None	Weak/None	Weak/None
• Ports	Strong		Moderate	Moderate	Moderate	Moderate		Strong		Weak/None	Weak/None		Moderate	Weak/None	Weak/None	Weak/None
• Airports	Strong		Weak/None	Weak/None	Strong	Moderate		Strong	Strong		Weak/None		Moderate	Weak/None	Weak/None	Weak/None
ITC	Strong		Weak/None	Weak/None	Weak/None	Weak/None		Moderate	Moderate	Moderate			Weak/None	Weak/None	Weak/None	Weak/None
Buildings																
• Settlements/Homes	Strong		Strong	Strong	Strong	Strong		Strong	Strong	Strong	Weak/None			Strong	Strong	Weak/None
• Health	Strong		Strong	Strong	Strong	Strong		Strong	Strong	Strong	Strong		Strong		Weak/None	Weak/None
• Tourism	Strong		Strong	Strong	Strong	Strong		Strong	Strong	Strong	Strong		Strong	Weak/None		Weak/None
• Education	Moderate		Moderate	Moderate	Moderate	Moderate		Moderate	Moderate	Moderate	Moderate		Moderate	Moderate	Moderate	

Key Strong Moderate Weak/None

Understanding the specific impacts of all of these interactions in a particular location in the Pacific is not well developed. The Joint National Action Plans on Disaster Risk Management and Climate Change are starting to introduce this kind of thinking. Similarly, the CHARM[41] approach to managing risks associated with development planning incorporates a more integrated approach. However, as highlighted in a number of ADB reports the integration of climate change initiatives within different sectoral ministries remains weak[42]. To develop more holistic adaptation strategies that address the interdependencies between infrastructure, it will be important for sectoral ministries and utilities—such as Public Works, Transport, Water, Energy and Resources —to understand how the impacts on one asset influences other assets.

[41] Comprehensive Hazard and Risk Management (CHARM) - Guidelines for Pacific Island Countries, SOPAC, 2001

[42] Strengthening Climate Risk and Resiliency in PDMCs, Asian Development Bank, July 2011.

The Climate Pilot Program for Climate Resiliency being funded by the Climate Investment Fund has commenced in Tonga and PNG through an ADB project and this will provide some useful lessons on how to mainstream climate change adaptation into infrastructure ministries. As an issue, however, this needs to be an area of focus for all PICTs ministries going forward.

* * * * *

Climate change in the Pacific presents a variety of possible impacts on infrastructure, but the most important ones fall into three categories: coastal inundation, more extreme weather, and changes in precipitation. These impact the following most important sectors of Pacific infrastructure: energy, water, ICT, transport, and buildings. The interactions between impact and infrastructure are complex and multiple, but can be captured by simple matrices, included in this paper. In addition to the direct impact of climate change on infrastructure, there are interdependencies between infrastructure sectors that need to be analysed in order to fully understand infrastructure vulnerability. A coastal airport is impacted not only directly by climate change increasing the risk of coastal inundation, but also by climate change impact on the road that connects to the town, on the power supply for which it depends and on the homes of the employees that operate it. In turn, the closure of the airport has downstream impacts on disaster response, on aid programs, on tourism, and on trade. Again, these interdependencies can be mapped by way of matrices. Thus, understanding impact of climate change in the Pacific is not a simple matter of assessing the vulnerability of individual pieces of infrastructure, but also of mapping that impact onto other infrastructure, onto the economic and social services the infrastructure provides, and finally onto the population.

4. The adaptation response

This section examines scenarios and issues that PICT nations must consider to identify options available to them for responding to the impacts of climate change on infrastructure. Following on from Section 3 that discussed the numerous impacts of climate change on infrastructure, this analysis provides the context for identifying research areas for PICTs based on their unique characteristics. Any constraints that need to be integrated into the response strategies are also identified.

During the preparation of this report, numerous professionals who have worked for many years in the Pacific, many in infrastructure related fields, highlighted technical and management information that is required for developing improved management of infrastructure. Much of this information would contribute to the development of effective adaptation strategies. A number of these are highlighted below.

The following information is important for infrastructure management in the Pacific:

- Adjustments required in design criteria to reflect the changing climate ie. design heights for ports, strength of materials in buildings or concrete structures, storm surge implications, water flow rates[43.]
- Adjustments in planning criteria to avoid infrastructure being built in flood zone/coastal inundation areas.
- Identification of alternative solutions if an asset cannot be climate proofed ie. use locally available materials, use a ferry instead of building a bridge, relocation of an asset.
- Identification of the additional cost of operation and maintenance for infrastructure under different climatic conditions. Some very preliminary work that has been conducted by some of the development banks indicating that costs are in the order of two times current costs.
- Identification of approaches that governments can use to finance the additional costs of climate change impacts.
- Materials that can be used in different scenarios depending on whether an asset is to be rebuilt quickly or is to withstand strong winds, storms or withstand the harsh climate in the PICTs. This is particularly required for remote populations.

Information on these subjects, including clarity on methods, is important for decision-makers and policy makers to better plan and manage their infrastructure assets in the context of a changing climate. There remains a lot of uncertainty as to exactly what this impact will be, but regardless the Pacific is highly vulnerable to existing climate variability and all of the above information will all assist PICTs being better able to manage their infrastructure regardless of the extent of climate change. These start to form the basis of identifying information requirements to assist PICTs in making effective decisions to adapt their infrastructure to climate change impacts. With limited resources available in the Pacific, however, the key to collecting the most useful information is to identify the priority infrastructure and populations for which such information needs to be collected. This is the focus of the following section.

[43] Coastal Protection Feasibility Study, Cook Islands, Final Report, Report prepared by GHD for SOPAC, August 2005

Options are considered at three levels:

- *Prioritisation*: Assessment of a range of factors is necessary to develop a prioritised list of adaptation responses and determine where resources are allocated;
- *The strategic response* which looks at the physical characteristics of the infrastructure and the range of options that are available to adapt infrastructure. These will determine where resources are spent; and,
- *The management response* which ensures the infrastructure is properly managed and provides value for money over the whole of the project lifecycle.

At this stage of the paper, the investigations shift from the "what is known" of the previous two sections, to "what is not known, and needs to be known." Therefore, this section is dominated by open questions. These questions set the scene for **Section 5: Key areas for further research**, in which they are synthesised and sorted into three principal categories.

4.1 Prioritisation

Much work is required throughout the Pacific to effectively adapt its infrastructure to climate change. To prepare appropriate infrastructure adaptation strategies it will be necessary for each PICT to prioritise initiatives as it will not be possible to do everything at once. There are a range of factors to consider when developing these priorities and these will be discussed in this section, including:

- Impact of infrastructure on populations
- Infrastructure impacts on other infrastructure
- Planning for climate change time frames and uncertainty
- Developing specific local adaptation plans
- Integrating climate change into existing systems
- Rethinking business as usual.

Where further information is required to improve understanding, this will be highlighted. In particular, we will look not just at the prioritisation of action, but also prioritisation of research to fill the major knowledge gaps.

Impacts of infrastructure on population

To date, impact on infrastructure has largely been analysed on the basis of how climate change is impacting infrastructure, and what is seen as "key infrastructure" such as ports or roads. This is one way of identifying priority infrastructure but is not the only one.

Little work has been done on how the relative impact of climate change impacts on key infrastructure subsequently impacts other sectors and communities. For instance, what sectors of the population are most impacted by a closure of the airport? A preliminary assessment is that the sectors affected would be (a) food/medical supplies, (b) the aid sector, and (c) the tourism sector. Impacts on each of these sectors would then flow into other parts of the economy, impacting various sectors. In order to prioritise investment in infrastructure, it is necessary to understand how these impacts flow, in order to understand the degree to which the impacted population will be affected, and where along that chain of impacts it is most cost-efficient to intervene.

Example: *There might be a small rural road used to bring crops to market. It is not as vulnerable as coastal roads, but increased rainfall from climate change will lead to its deterioration. If the rural populations are more impacted by the loss of this road, than other populations are from the loss of a coastal road (for which there might be alternatives), then we might choose to prioritise this road, over the more vulnerable coastal road. This is a specific decision that can be made when the entire context is understood.*

One strategy for identifying priority adaptation activities for infrastructure might be to look at vulnerable populations. Under this strategy, we might look at which populations are most vulnerable overall to climate change, and invest in the infrastructure needed to protect them, ahead of less vulnerable populations.

Example: *there is an argument that, of these three groups:*

- *urban;*
- *peri-urban;*
- *rural;*

it is the peri-urban who are most are risk, because they build on marginal land, are more subject to flooding, have neither good formal construction methods nor good traditional methods, and therefore are highly vulnerable. However, it may be that the rural populations who are most at risk, because they do not have access to urban jobs, medical care, and schools. From another perspective, these rural populations may in fact be quite adaptable to environmental impacts, because of their access to materials and their continued use of traditional construction techniques, which allows for ready rebuilding.

However, this **population approach** looks only at the vulnerability of the population groups, and not their poverty.

Alternatively, a **pro-poor approach** could be considered. But even a pro-poor approach is not the end of the analytic chain, because there are questions of:

- efficiency (to protect the infrastructure of the poor on remote islands might be more expensive per capita, than to protect the infrastructure of the urban population), and
- inter-relatedness (the rural villages depend on the urban dwellers for jobs, remittances and for professional services, such as health; the urban dwellers depend on their rural villages for food).

This discussion highlights that it is difficult to have an infrastructure response policy, without at the same time having a social policy[44]. Every infrastructure response will affect different sectors of the population in different ways. Every response will draw upon different sources of funds: public and private. Every response will be more or less efficient.

How policies ultimately protect infrastructure, and who is served by that infrastructure, is a social question for Government. It is also a complex question that requires a deep

[44] National Adaptation Program of Action (NAPA), Republic of Kiribati, Environment and Conservation Division, Ministry of Environment, Land and Agricultural Development, Government of Kiribati, January 2007.

understanding of the human-built-natural environment system to answer. These considerations are all part of prioritising investment in infrastructure adaptation.

Remoteness of communities is a core characteristic of many PICTs and initiatives to assist these communities is an essential part of the adaptation strategies to be developed. An improved understanding of innovative approaches to adapting infrastructure in remote locations to climate change will be essential for the Pacific. It is one of the factors that makes climate change adaptation in the Pacific unique.

Infrastructure impacts on other infrastructure

There is little mapping, to date, of the inter-relationship between infrastructure components. For instance, protecting an airfield may require moving it, or raising it, or building a sea wall. But protecting the airport function may also require protecting the road that links the airport to the population; protecting the seaport that brings fuel for refuelling; protecting tourism facilities that generate demand for air travel, and the ongoing interest in air travel to the country. Without the base tourism load, a smaller airport elsewhere may be a better investment.

A full understanding of the vulnerability and importance of the airport requires an understanding of how it is impacted by natural changes such as climate change, but also other infrastructure, and by human systems such as institutions, management, expert cohorts, and the labour supply, which may themselves be impacted by climate change directly, or by failures in other infrastructure components.

Thus, we need to define the network view of infrastructure, summarised in Figure 9. The key elements of the diagram are:

- a complex network of interactions between different components, in three categories: human, built and natural environment
- an understanding of how climate change is impacting the natural environment
- a mapping of the flows of impact through the human and built nodes.

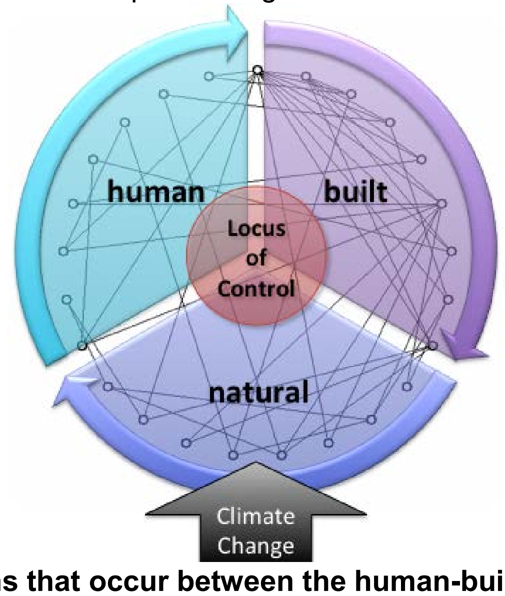

Figure 9: Interactions that occur between the human-built and natural environments.

The JNAPs, NAPAs and CHARM approaches are starting to look at these issues, but more detailed work is required to develop effective infrastructure adaptation plans.

Planning for climate change time frames and uncertainty

Planning for climate change impact is unusual in that it adopts, ultimately, 100-year time frames. Whereas most infrastructure planning is based on the continuity of historical patterns revealed by data, climate change requires infrastructure planning based on changing patterns moving forward. Planning in this context of uncertainty raises questions not dealt with by traditional infrastructure plans. For instance:

- What actions should we take now, in order to prepare for the future?
- How should we take those actions in such a way as to avoid the high cost of planning for "worst case" scenarios?
- What should we be planning for seriously?
- How can we do any of this with the broad range of unknowns?

Forms of planning and management that attempt to deal with such questions include:

- Adaptive management
- Scenario planning

However, no work has been done to understand how these or other planning tools can be adapted to the Pacific infrastructure context to develop priority adaptation plans.

Developing specific local adaptation plans

The National Adaptation Plans of Action (NAPAs) have provided an initial basis for understanding the impacts of climate change, but one criticism made to date is that they remain generic, and are thus of limited usefulness when determining specific actions[45]. Every PICT needs a locally-specific Adaptation Plan. Samoa's plan is widely cited in interviews as a model that works, however, no formal analysis has been identified of their work or other tools that would assist in developing these specific plans.

For example, the CHARM model for risk management is one tool that is focussed on helping the PICTs to integrate disaster management into development planning. It is unclear the success of these approaches and how widely used they are used. Lessons learned from these processes would provide valuable insight into how to develop Local Adaptation Plans. Analysis on how governments have used or are using these tools to develop local plans would be invaluable.

Integrating climate change into existing systems

As described in Section 2: Infrastructure in the Pacific, the impacts of climate change come on top of existing weaknesses in the infrastructure system:

- Difficult day-to-day operations, in which the infrastructure for day to day living is already complicated by remoteness of small, scattered populations; a corrosive marine environment; few of the natural resources required for infrastructure construction.

[45] Discussions with SPC

- High exposure to natural disaster capable of causing damage equal to 10% of GDP, whereas most countries natural disaster impact is limited to 1-2% of GDP.

This vulnerability has a number of strategic implications for response to climate change. Adding to the complexity of this issue is that fact that climate already has considerable variability over the short term, despite any longer term climate change impacts. Therefore, approaches to managing infrastructure need to take account of current climate variability, as well as consider long-term climate change. The Water Division of SPC SOPAC has developed a useful diagram[46] which illustrates how day to day challenges that PICTs face are exacerbated further by climate variability and then again by longer term climate change.

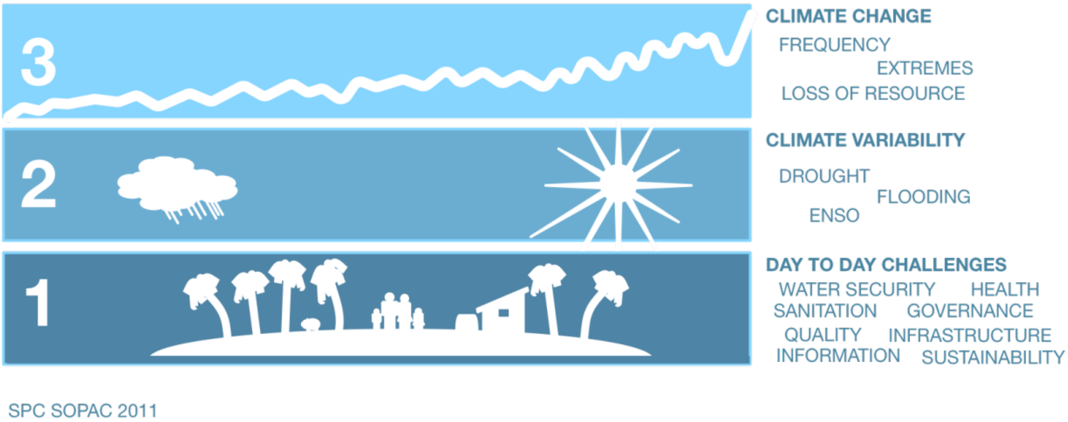

Figure 10: The mounting pressures of climate change and climate variability

This is another set of linkages and interdependencies that are little understood. For instance, where climate change adaptation requires changes to road design, how do the impacts of this new design call upon the existing capacities of PICT governments and institutions, and how do these calls in turn call upon changes in investment strategies from donors?

Re-thinking business as usual

In addition to this high vulnerability, management of infrastructure is complicated by:

- Weak institutional capacities for the planning, operations and maintenance of infrastructure.
- Difficult design and construction conditions, which makes it difficult to build sustainable, affordable infrastructure.

The additional stress of climate changes may reach a point at which it uneconomic or unfeasible to pursue “business as usual”: i.e. present strategies. This raises two questions:

- When and where are those points likely to arise?
- What are alternative, proven business strategies?

[46] SOPAC Division of SPC, Water Division, 2011

4.2 Strategic options

With limited funds to design, construct and maintain infrastructure assets, PICTs cannot afford to respond to climate change impacts with only engineering solutions. More innovative and holistic approaches are required. This was emphasised through consultations with numerous agencies working in the Pacific such as SPC, ADB, USP, and IUCN. As these agencies work closely to develop and implement different aspects of climate change adaptation, it is becoming clear that engineering solutions are only one small part of effectively adapting infrastructure to climate change.

Therefore, within a strategic response, there needs to be a variety of designs options available for implementation. The availability of options may also—explicitly or tacitly—influence strategy. In early thinking on specific projects, engineering teams have begun to frame novel questions about technical solutions. Each of these requires further investigation and research, and defines aspects of an entire research area.

Using the airport example as an illustration, the adaptive capacity, or ability of assets to "bounce back" from damage can be approached in different ways.

Example:

The practical solutions to addressing damage to an airport would include some short term responses such as:

- *The runway might require only clearing or smoothing in order to regain operation. The resilience of the buildings depends on whether there is structural damage. However, operations might be resumed using temporary facilities, while repair is undertaken.*
- *Another short-term response for the airport might be to ensure that the appropriate equipment for clearing the runway of debris is available, accessible and safe. Buildings might go through a structural check, and reinforcing, and have special shutters provided for openings to limit storm damage.*

However, more long term non-engineering solutions may consider:

- *Identifying if a protective screen of native vegetation could protect the assets;*
- *Could the airport be located in a less vulnerable location? In many cases, the location of an airport is limited, but there are other assets where more effective planning would provide effective solutions i.e. re-locating a road, water supply operation away from vulnerable locations. This needs to be coordinated with the replacement lifetime of the asset.*

These two simple approaches introduce the need to think beyond the asset itself to management and planning aspects of infrastructure. They are more holistic than simply trying to fix the problem, and will usually involve multiple agencies/ministries.

The strategic response to climate change involves both engineering and non-engineering approaches.

Hardening

The simplest response is a linear one: to "harden" or otherwise strengthen existing infrastructure models. These are the traditional engineering solutions. There is significant work that is being conducted worldwide on how to improve designs for a wide range of infrastructure.

This information can be drawn upon for the Pacific but does need to be adapted to Pacific conditions. While analysis of international design standards is useful, the constraints of operating in the Pacific make many of them untenable. Approaches that will be appropriate to the Pacific would be extremely valuable.

As an example of hardening approaches, a building could be reinforced by the Public Works Department to protect it against strong winds, the transportation ministry may design/upgrade ports to accommodate sea level rise or reinforce the concrete to make it stronger. However, as many countries around the world assess the costs of engineering a response to climate change, the costs are prohibitive. Even in a developed country in the region like New Zealand, this is the case.

***Case study:** Consider the application of earthquake codes to buildings in New Zealand is a useful analogy. Consider the City of Christchurch, which was seriously damaged by the 6.3-magnitude earthquake on 22 Feb 2011. New Zealand has a very well developed understanding of earthquakes, and one of the most advanced earthquake building codes in the world. The reason that the damage was so severe was that New Zealand cannot afford to retrofit all of its building stock, to the level mandated by current knowledge. One estimate of the cost of doing so that for the city of Christchurch was on the order of 1,000 billion dollars. If an OECD country cannot afford to "harden" its second largest city against a single kind of natural disaster, then the smaller Pacific Island countries are unlikely to be able to harden their own entire infrastructure.*

In the Pacific there are limited funds to provide most of the basic infrastructure, let alone infrastructure that is fully engineered to respond to climate impacts. While development funds provided for major infrastructure will likely include budget for hardening, government budgets usually can't extend to this level. To exacerbate this problem the planning, funds and capacity to undertake operation and maintenance is also limited and as highlighted in the previous discussion in Sections 3.2.1 to 3.2.5 climate change is likely going to increase these demands. What often occurs in the Pacific is money that has been allocated to operation and maintenance gets redirected to disaster management from the intense storms[47].

While there are limitations to hardening infrastructure, there are also a number of strengths of this hardening approach:

- Existing models are well known and understood
- Builds on existing land and infrastructure

The weaknesses of this strategy are that:

- hardened infrastructure may not represent the best overall systemic value for money

[47] Preparing the Transport Sector Development Project, Asian Development Bank, October 2010.

Use of sea walls: *Sea walls are often used to protect other infrastructure such as ports, roads and buildings. However, these can have unintended consequences. During the tsunami in Samoa, these sea walls generated projectiles that caused significant damage to coastal infrastructure. Whilst tsunamis are not related to climate change, intensive storms could potentially cause similar damage.*

Improved drainage: *In Apia, Samoa, there was some available funding on a water and sanitation project to be directed to climate change initiatives. After a range of consultations amongst the Samoa Water Authority it was determined that the funds should be directed towards drainage. There was no formalised process for this to occur within the SWA.*

Wharfs: *Increasing sea levels are causing engineers to rethink the design parameters required to design wharf and port structures. However, to design a port that will work in 20-30 years time means that it will not work now. In Vanuatu, on an ADB ports project, the solution was to reinforce the pilings which supported the wharf so that as the sea level rose the height of the platform could be raised using additional concrete. The added weight of the concrete could be supported by the existing pilings.*

Federated States of Micronesia – Pohnpei Port Scoping Study, Pacific Region Infrastructure Facility, October 2010: A scoping study was undertaken in Pohnpei to upgrade the existing port facilities to accommodate current and future trading volumes. In designing the upgrade the expected sea level rise was estimated at 0.5 m over the next 90 years. Combining sea level rise with high tides this resulted in a still water level of +1.72 m to Mean Lower Low Water which provided a freeboard for the quay of 1.33 m. This is a relatively small freeboard but acceptable. It was also determined that the quay wall structure was nearly 40 years old and would probably reach its useful life in the next 20 years. At this time, when a new quay structure is built, there will be the opportunity to raise the deck level of the quay to an appropriate level above tide and any increased sea level. This is an excellent example of a pragmatic approach to engineering a port upgrade.

Relocation

Since much infrastructure, because of the shape and development of island societies, is located on the coast, and many of the threats posed by climate change are coastal impacts, a long-term solution is to simply relocate infrastructure to safer locations.

Strengths:

- Does not require changes in technology, or radically more expensive installations
- Can be phased as existing infrastructure comes to the end of its design life.

Weaknesses

- May require relocation as well of networks: roads, ITC, power
- Requires interaction with the problematic land tenure system

__Vanuatu roads__: On an aid project in Vanuatu, the idea of a road being relocated away from the coastal area to a less vulnerable location was suggested. Difficulties arose quickly with land owners who wanted compensation for the land that the new road would be constructed on. These are challenges that will need to be overcome.

Alternatives

Both hardening and relocation assume the same infrastructure support to a social delivery process. However, there may be cases where the same process might be better addressed by adopting a different infrastructure path altogether.

__Remote roads__: For instance, roads on remote islands may only be lightly used, and a better long term strategy might be to strength boat transport around the island, rather than invest in keeping the road. Another road example is the building of a bridge. In the Solomon Islands, bridges are traditionally built over the streams, normally 30-40 m wide. However, with increased flows and changing land patterns, the stream could potentially be 200m wide in years to come. Designing bridges for this uncertainty is not cost-effective. In this situation, perhaps a ferry would be more beneficial.

Strengths:

- May be more efficient and viable in many cases, given the amount of infrastructure exposed to coastal impact, and the remoteness of many islands

Weaknesses:

- Requires accompanying social and economic shifts to the new form of infrastructure.

Resilience

A fourth option is to allow infrastructure to be impacted, but focus instead on the social and economic capacity to restore function despite the impact.

Example: *Schools. For a long time, donors have been investing in stronger and stronger school buildings, to resist existing environmental hazards: the five perils, as well as ongoing problems of the corrosive marine environment, and poor or non-existent maintenance regimes. An alternative lower cost, resilient option might be to harden only core buildings with high value contents, such as library and admin, and provide other buildings to be locally built in traditional ways. Rather than attempt to implement maintenance regimes, allow these traditional structures to fall apart or be blown away, and provide periodic inputs to rebuild them. This is the traditional strategy. Advantages would be lower initial investment, more money flowing into the local community, and more ongoing flow of funds.*

Strengths:

- Will result in more sustainable, locally maintained forms of infrastructure.
- Depending on case-by-case, may have lower lifecycle costs.

Weaknesses:

- Requires innovation, and therefore risk.

Environmental management and use of natural systems

The above strategies all focus on the built environment itself. However, protection can also be afforded by strengthening natural barriers and buffers. This has been termed "investing in natural infrastructure" by some agencies in the Pacific48.

A commonly used example is the use of mangroves to protect coastal infrastructure49.

***Community based adaptation**: USP has been working with local communities in Fiji to identify community based adaptation activities that they can implement themselves. This has involved educating the selected communities as well as taking them through the prioritisation of what infrastructure is important to them. One of the solutions that has been identified through this process is for communities to plant mangroves in specified coastal zones to protect local infrastructure. This approach is actually being applied on a larger scale along stretches of coastline in Kiribati as part of the Kiribati Adaptation Program[50].*

Another is the implementation of better upland forest management in order to control flooding.

***Nadi floods:** The floods in Nadi in 2009 highlighted the damage that can be caused from excess rainfall. The exact cause of the floods is unknown but there are several contributing factors including poor upland forest management. There are similar examples from other AusAID projects in Vanuatu where poor forest management has contributed to the damage of road and bridge structures. Poor land management allows increased water flows to move across land areas at a much greater rate and during high rainfall events this can contribute to increased flooding. Effective adaptation strategies will often require addressing issues that are not directly related to climate change impacts.*

Strengths:

- Same investment provides both ecological and built environmental benefits.
- Can be organised using community-based processes, rather than expensive imported resources.
- Lifecycle costs likely to be lower.
- Socially more likely to be sustainable.

Weaknesses:

- Requires social and governance change.

All of the above strategies are important considerations in selecting, designing and constructing infrastructure, as well as developing alternatives to an engineering solution. As a result, they will play a critical role in assisting decision makers determine optimum design and strategy responses for infrastructure in a changing climate. Improved understanding of all of these design options will be invaluable for the PICTs moving forward.

[48] Discussions with IUCN; IUCN materials and projects

[49] Kiribati and Samoa examples

[50] Kiribati Adaptation Project Reports

4.3 Managing adaptation

Once infrastructure is designed and built there is a physical asset which needs to be managed. The visible hardware of infrastructure is part of a larger cyclical system that makes investment decisions, funds them, designs, builds them, operates and maintains them, and then monitors, evaluates and researches them in order to inform further decisions. This cycle of decisions, resourcing, execution and learning constitutes a capacity building cycle. This learning cycle is critical to an infrastructure response, because:

- Climate science is changing.
- There are no "ready-made" solutions for the Pacific, and many of the strategy options listed above require innovation, and research.
- There are no cross-sectoral solutions, of the kind required to provide.

This active learning approach will be important to the Pacific going forward, and is prevalent in a number of initiatives underway, including the JNAPs, NAPAs, and donor funded activities such as the Pacific Regional Infrastructure Facility, and ongoing SPC and SPREP programs. While many of these activities touch on infrastructure, the direct involvement of infrastructure ministries is really just commencing.

As highlighted numerous times throughout this report, planning, effective operation and maintenance of infrastructure in the Pacific is weak. This is an area that infrastructure ministries are going to have to improve in the long run. Effectively, undertaking these tasks is vital for PICTs to adapt their infrastructure to the impacts of climate change.

Approaches to ensuring this can occur are required, as well as more specific information regarding the benefits of planning, operation and maintenance. The cost benefits of such asset management programs are especially important as it is much cheaper to fix a small problem rather than wait until a major replacement project is necessary .

Asset management: *NZAID[51] recently supported some asset management training in the Solomon Islands. As part of that training, the asset management cycle was discussed with the Solomon Island Government. It included: planning, inspection, cleaning/minor repairs, renewal (major repairs), replacement of the asset. For the case of road management, if roads are inspected regularly, small potholes can be fixed for minimal cost. However, if they are not fixed early, a pothole can turn into a costly major repair or in the worst case a major replacement. Understanding this balance will become even more critical in a change climate context. Effective asset management is an important part of strategic planning for infrastructure management. What is not well understood in the Pacific is the rate of deterioration of the assets as well as the cost benefits of undertaking such work.*

Management roles

To improve planning, operation and maintenance, it is important to understand the different actors involved in Pacific infrastructure that have a role in infrastructure management, and some of the constraints in which they work. This will enable strategies to overcome these

[51] Solomon Islands Government Transport Sectors Asset Management Training, ADB and GHD, March 2011

issues to be developed. Historically, each actor in the Pacific has had a primary locus of responsibility. Each of these actors faces internal challenges to fulfil their functions in this cycle.

Table 7: Different roles within the Pacific context related to Infrastructure Management.

Function	Actor	Challenges
Decision-making	Governments	• they are small • they face difficult operational contexts day to day • they cannot compete with private sector for skilled infrastructure professionals, even where such professionals are locally available.
Funding	Development partners	• a general aversion to risk • a preference for large infrastructure rather than small, dispersed, risky and difficult to manage small interventions
Execution	Implementing agencies and private sector contractors	• professional skills drain from the PICTs • the demands inherent in the PICT context: dispersed small communities separated by sea
Research and M&E	Regional organisations and development partners	• focus on scientific research, whereas this role requires an extension into strategy and evaluation. • finance model which depends on ad hoc demand from client governments. • only project-level M&E

In reviewing many of the challenges identified above, it is possible to start developing strategies to overcome these issues. Climate change will contribute to driving these strategies as effective adaptation requires new approaches.

Table 8 below highlights approaches that can be considered in adaptation strategies for effective infrastructure management. It is organised to address each of the constraints identified in Table 7 above.

Table 8: Strategies for Improving Capacity to Adapt to Climate Change

Responsibility Locus of Responsibility	Constraints	Strategy
DECISION-MAKING PICT Governments	Small size, overloaded	**Decentralise and deconcentrate**: This involves pro-actively pushing as much responsibility down to the local communities and local governments. Projects must therefore be tailored to utilise the capacity of those communities. Central governments must focus on providing the information, policy and resources to allow provinces, local communities to succeed.
		Implementation frameworks: Central governments cannot attempt to implement climate change initiatives. They have to focus on setting up frameworks within which other actors can implement.
		Integrated approach: Insist on an integrated approach to climate change; will pull together into unified strategies: • day to day challenges • climate variance and the five perils • climate change So that climate change is not just mainstreamed, but used as a driver to fix the problems that overload PICT Governments currently.
		Mobilise private sector and NGOs: Specific attention has to be paid to ways to mobilise private sectors and NGOs other than in the traditional way of “response to government”. The private sector and NGOs need to be given active decision-making roles, within the broader policy framework. The NGO label must be applied broadly, to include churches and unincorporated community groups.

	Lack of skilled infrastructure professionals	**HR policy**: This problem cuts across sectors and needs to be addressed at national and regional levels. It is a problem faced worldwide in rural and regional areas, in all sectors. Climate change adaption strategies cannot be implemented without a human resource policy that addresses this problem.
		Regional support system: It's difficult and very expensive to attract professionals to PICTs. It may be easier to set up regional networks based in the most urbanised PICTs (e.g. Fiji, New Caledonia) to work at a regional level.
FINANCE Donors	Risk aversion, preference for centralised projects	**Adopt appropriate models**: Throughout the developing worlds, a number of models have been adopted for small-scale dispersed infrastructure projects. Some of these have been developed for school construction, in response to the MDG goal of EFA. These can be researched, evaluated and adopted to the more general task of infrastructure.
		Generic risk management: For many donors, formal risk management is done at only two levels: • agency • project However, infrastructure response to climate change in the Pacific carries with it a very specific set of risks, which have to be treated as a whole: so that the donor can package finance for projects; and so the specifics can be adequately dealt with. This involves developing a suite of financing models that address these risks, but account for: need to mainstream and disperse responsibility; logistic and supervision difficulties; small skilled infrastructure resource pool.

EXECUTION Implementing Agencies and Contractors	Professional skills drain from the PICTs	**Broad-based consultation**: This is an entrenched problem which has as yet no known solution. Solutions have to be sought from other than traditional sources. Development actors that might be approached include: • developed country professional associations • volunteer agencies • churches • local NGOs • educators
	Logistics and costs of PICT context	**Rethink risk models**: Often, government and donors attempt to offload all risk to the executing agency or contractor. This then biases designs against remote areas, against small dispersed and difficult to QA interventions. Alternatively, the cost of this risk skyrockets. Risk strategies have to be developed that operate differently, for instance either by working statistically (many small contracts or grants, with an allowance that some will fail completely), or more towards the alliance model, where implementer and financier work together to manage risk.
		Rethink technologies: Rather than design the best, or most effective, technological response for PICTs, design processes might have to start instead with questions of sustainability. What technologies are sustainable in the long term? How can these technologies be used, and made adequate, even if they do not at the outset seem adequate? This is a resource-based, rather than needs-based, approach.

		Rethink response: In many remote island communities, local materials have been replaced by concrete blocks and iron sheeting. For example: in school systems. This is the result of a strategy of "hardening" against the five perils. However, the result of this is that: Local communities have increasingly smaller roles in building their own environments Costs skyrocket. This strategy needs rethinking. One alternative might be to revert more to the traditional strategy seen in some PICT house forms: roof and walls may be swept away, but can be rapidly rebuilt using local materials. This in turn might require a rethink of financing methods: Rather than focus on donor funds for capital costs, and expect recurrent costs to be met locally (which create a bias towards a "hardened" approach to infrastructure), allow modest capital costs, and provide the difference in ongoing maintenance and reconstruction.
LEARNING Regional research agencies	Ad hoc finance model	**Long-term programming**: Climate change is a long-term problem, and requires long-term solutions. Infrastructure is expensive, and designed to last 5-30 years. It is a major line item in national and donor budgets. Therefore, the research programming should match the long-term nature of the subjects being learned about
	Focus on scientific research	**Shift strategic focus**: Make a structural shift away from a focus on pure research, towards a greater focus on learning about implementation, including: • more staff with experience in implementation • more funding for monitoring and evaluation • more funding for translating scientific findings into strategies, and testing them

		Mainstreaming and extension: “Research” and “learning” should not be considered the province of research agencies. In the distributed, mainstreamed response, research and learning will be occurring in remote villages as well as in urban centres. A remote island will have on it—needs to have on it—all four types of capacity, and sustain its own learning cycle. This implies that another new function of the research agencies will be to develop and disseminate models for PICT, provincial and village level governance to do their own monitoring, their own evaluation, and to be coming to their own conclusions to guide local action.

* * * * *

Ultimately, it is the population, not the infrastructure that needs to be protected. Focussing solely on protecting existing infrastructure assets may be unaffordable, and prioritisation within the infrastructure policy needs to be framed in terms of social policy. Response needs to take into account three levels of analysis, each critical to the effectiveness of response. The first is to identify the populations most vulnerable to climate change, and the infrastructure vulnerabilities that impact them. This may involve complex interrelationship mapping of the kind described above. Then, for each piece of infrastructure in the causal impact chain, a variety of responses must be examined. These are: hardening the infrastructure itself, moving it, finding alternatives, focussing on resilience rather than protection, and using natural rather than built protection. Finally, implementation of these strategies requires certain capacities among the actors involved: government, funders, implementing agencies, and the research communities. It also requires that they act together in a coordinated way, in order to build systemic capacity in the face of uncertainties about the extent and impact of climate change, and about the effectiveness and cost-benefit of various adaptation strategies.

5. Key areas for further research

Drawing from the discussions in Sections 2, 3 and 4, this section will confirm basic gaps in three areas of research related to climate change and infrastructure in the Pacific. It will also propose a series of questions that will contribute to the knowledge base of that research area.

5.1 Three key areas

From our previous discussions, we know that:

- Infrastructure exists to provide basic well-being, to support the delivery of social infrastructure services, and to support the economy.
- Infrastructure climate adaptation cannot be divorced from social policy, in that climate impact on infrastructure will affect different sectors of the population differently.
- In the Pacific, the sectors of the population least well served by basic infrastructure, by social infrastructure services, and by economic development are those away from the major cities, in remote and rural areas. It is this disparity that drives urban drift. And in the Pacific, 70% of the population still lives in a non-urban areas subsisting still on a non-cash economy. These are most likely to depend on decentralised infrastructure.
- Modern infrastructure knowledge is biased towards the professionally-built and managed centralised facilities. This is the type infrastructure that predominates in non-island nations.

As highlighted in Section 4, climate adaptation policy also needs to integrate social policy. Special consideration needs to be given to the most vulnerable populations. Throughout the Pacific, the most vulnerable populations are those in remote areas, with poor access to the economy and to government services. However, little is known on how to protect these remote and poor populations from the impacts of coastal inundation, extreme storms and water security. Therefore, **one key area of research proposed is how to protect infrastructure for remote and poor populations**. A population's reactions to a loss of service arising from for example damage to infrastructure can indicate a cost-effective adaptation strategy.

Urban centres are addressed in our next area of research.

From our discussions, we also know that:

- There are five key modes of adaptation strategy for the Pacific are: hardening, relocation, alternatives, resilience, and environmental management.
- Of these, only hardening is a purely technological strategy. The others all require—because of the limited reach of central government, and the distributed nature of the population—some level of community change and community management.
- The financial, technical and social processes required to effectively and reliably execute such processes are not well developed, and not well understood.

New technical standards and innovations for design and implementing infrastructure projects and cycles is therefore the second key area for research proposed. All the different options above need to be explored and documented so that lessons can be shared around the region. Specific adaptation strategies are unique to each situation, but the successful approaches can be altered to suit the local scenario.

Finally, we know that even for centralised infrastructure in towns, there are ongoing problems in the Pacific with appropriate design, maintenance and operations. These problems do not exist to the same extent in larger or more developed countries, with compact populations, and bigger government budgets.

As climate change impacts this infrastructure system, these weaknesses in planning and management will be further stressed, and will need to be strengthened in order to effectively deal with the new stresses from climate change.

The third proposed area for research is therefore planning and management of operations and maintenance in the PICT context.

The research program that addresses these will be different in focus from most climate science:

- It will require a broader range of disciplines from the natural sciences, including social science, and professional disciplines such as engineering, government and management.
- It will require programs that cut across disciplines, combining natural systems with social, economic, financial and governmental systems.
- Some of the research, to be complete, will require a complete cycle of innovation: invention, deployment, monitoring and evaluation.

The following sections build on each of these three research areas and identify the types of questions that can be explored.

5.2 Infrastructure for vulnerable populations

In section 4, we identified six areas that were critical to properly understand the impact of climate change on the most vulnerable communities. These were:

- Impact of infrastructure on populations
- Infrastructure impacts on other infrastructure
- Planning for climate change time frames and uncertainty
- Developing specific local adaptation plans
- Integrating climate change into existing systems
- Rethinking business as usual.

Each of the last five points is a component of understanding and adapting the first: vulnerable populations. Simply put: adaptation response action needs to be prioritised for populations at risk from climate change impacts.

Each of these areas has research gaps, and raises questions. Questions for each area are suggested below:

Impact of infrastructure failure on populations

There are basic gaps in knowledge here on the quantum of impact on population groups. Some of the more severe forms of impact, such as coastal inundation, or the impact of climate change on water supplies, are better understood than others. There is a common view that more remote communities, which have less infrastructure, are less vulnerable to the loss of the infrastructure they have. However, this hypothesis has not been tested; nor has their vulnerability to the failure of centralised infrastructure that serves them remotely, in particular transport infrastructure and central health infrastructure. An analysis of the different populations in each country would enable these assessments to be undertaken.

Infrastructure impacts on other infrastructure

There is as yet no complete mapping of the interdependency of infrastructure components: the way in which airports depend on power, roads and ITC; the way in which tourism depends on airport and ports; the way in which ports depend on worker populations resident in vulnerable settlements, and so forth. Such a map of interdependencies needs to be developed. The matrices in this paper are conceptual. They do not reflect the particular infrastructure systems of typical PICTS. Therefore such maps need to be done at the level of the PICT, and within the PICT at the level of the island community.

From population impact maps, and interdependency maps, the next question that should be ascertained is: What is the most critical infrastructure for vulnerable communities and how is that impacted by the failure of other infrastructure? For example, if the wharf is damaged by storms, how does the community get fuel to run a small water supply? What back up system can be put in place, e.g. a hand pump?

Planning for climate change time frames and uncertainty

Once the totality of impact on communities is mapped, communities can be informed. Actual response decisions will most likely have to be made by different levels of government: village, provincial and national governments. In order to make adaptation plans, each level of government will need to be provided with a set of validated response strategies or tools. Identifying, documenting and validating these tools forms another important avenue of research.

What are key activities that remote communities need to undertake now in order to plan for future climate impacts? What activities can they delay until later? For example, planting mangroves now will provide sufficient time for them to settle and grow so that they can provide a strong defence mechanism in years to come. A jetty that is located in a particularly vulnerable site may be better placed at another location, but this could be done once the existing jetty is past is useful life. These type of solutions need to be explored and shared around the region.

Developing specific local adaptation plans

Different levels of government will have different capacities to plan and implement adaptation. Social and management research is required to understand: What is the existing capacity? How can planning and adaptation be built around that capacity? What additional capacity is required, and how can that be efficiently delivered?

Integrating climate change into existing systems

Throughout the above, there is a risk that answers will be developed which are simply separate and additional to the existing infrastructure financial and managerial load. Such unintegrated answers, representing an additive design approach, will be inherently at risk of being inefficient.

They are also inherently at risk of being difficult to implement. Therefore, a key line of inquiry will be how to redesign existing systems so as to integrate climate change adaptation into the whole-of-life and whole-of-purpose approach.

Rethinking business as usual

Throughout this series of questions, there is a risk that answers that are developed will not be implementable within the framework of historic "business as usual" in the Pacific. Parallel to the above strands of research, an ongoing and separate line of inquiry must be asking: what are the major risks to change within existing governance, socio-technical, and cultural systems? How can these risks best be ameliorated, through change in systems, or changes in approach?

5.3 Technical standards and innovations

In Section 4, we defined five strategic options for adaption response. Each of these calls for new technical standards, and innovations in the design and execution of infrastructure. The five strategic options were hardening, relocation, alternatives, resilience, and environmental management. Each of these categories requires significant information that can be supported by further research and is a package of work in itself. A series of questions have been identified that explore different facets of that climate change adaptation approach, Research that answers these sets of questions would assist decision-makers and engineers in determining the optimum adaptation strategy for adaptation assets using one or all of the above options.

Hardening

Early attempts at simple hardening as an adaptation response suggest that alone, this response will be expensive, and in some cases create additional problems, such as wharves that are too high for existing water levels, drains that don't flush naturally. Research on existing infrastructure and infrastructure types needs to ask for each type: what kind of hardening is cost-effective? And where it is cost-effective, what form should that hardening take. That research will result in a set of technical design solutions for climate change adaptation.

However, much of the infrastructure in PICTS—in particular many small buildings—are not professionally designed. Here, a different set of solutions will need to be developed. Out of the solutions, two questions can be asked:

- What kinds of planning and building regulations are appropriate for remote communities and can feasibly be implemented?
- How can such plans and regulations be administered given the current constraints of geography, capacity, education and finance?

Regulations without realistic enforcement processes and resources do not, in themselves, constitute adaptation.

Relocation (and location)

Relocation is potentially the most sustainable of solutions, because it involves moving the infrastructure away from the threat.

The key questions of relocation (or the location of new facilities) are:

- For what kinds of infrastructure is this kind of expense likely to be economical?
- How much infrastructure funding can be saved using simple relocation?

Relocation can be expensive because it involves abandoning one site in favour of another. This raises a further question:

- What are the strategies available for ameliorating the expense - for example postponing the relocation until the current asset is well into its lifespan?
- Relocation requires a transition between old infrastructure being allowed to run down, and investment in new infrastructure instead of maintenance and replacement of the old. What is the most economical way of managing such a transition?

The question of location can be determined at a facility-specific level. Better, though, is to determine safe locations for a whole island, at the level of policy and planning. This larger scale approach requires investigation of the following questions.

- What planning rules need to be instituted to guide the future location of infrastructure?
- What does the relocation option demand of planning, land management, land tenure, and government negotiations?

In the Pacific, relocation will quickly run into the issues associated with the indigenous traditional land. Despite the perception of indigenous land systems as being intractable, this is not always the case. It is generally the case where an outside actor is perceived as being the owner and beneficiary of what will be done with the land. In such cases, traditional landowners take very rational asset management tactics of extracting as much rent as possible. The key is to consider this question of ownership and benefit:

- When location of non-government assets (such as churches) is done in rural areas using rural land tenure systems, how does the existing land tenure system allow for this?
- Can these local systems be adapted to climate change strategies?

Alternatives

Government, planners and designers have a standard set of infrastructure solutions in mind when doing their work. As climate change impacts, on top of other difficulties in day to day operation, any disaster impacts may push some of these models to the “tipping point” where alternatives are more economical.

Research is required to identify:

- Given remote rural economics, basic life activities, and government services, what alternative infrastructure forms are likely to be sustainable under a climate change scenario?
- What is the relative cost of moving to alternatives, versus hardening or relocation?

Resilience

It is difficult, if not impossible, to build community resilience based on the weaknesses of a community. A strengths based approach is required. If a village is skilled in boat building and handling, but not in road building or maintenance, it is better to depend on the former, than the latter.

Basic research is required into the understanding the strengths of rural communities upon which resilience strategies can be based. Once these are identified, research into successful programs in the PICTs and beyond is required to understand how Government can best support and develop these strengths. What agencies in government are capable of reaching down into communities? What is the scope, role and capacity of civil society in developing and implementing resilience? How can resilience be coordinated and maintained over long time scales, while most actors are distracted by the urgency of daily problems and challenges?

Building community resilience is half the equation. The other half is designing infrastructure that taps that resilience. Given the resilience capacities of local communities, what forms of infrastructure are most amenable to the use of local resilience for a lower overall lifecycle cost/benefit? What are smaller, lighter, cheaper forms of infrastructure than can be more effectively part of a resilience strategy?

Environmental management

There are strong calls for good environmental management of the fragile ecologies of the PICTs. However, these have not in general looked at human-built infrastructure as part of the total ecology, and asked: What forms of environmental management can be instituted in order to protect infrastructure?

Further research can extend the domain of environmental management to include the built as well as the natural environment, as a stable, protected system. There are obvious questions of management structure; costs, benefits and relative efficiency compared to other approaches; and the many technical issues that will arise in an integration of the two systems. These are all manageable by scientific, technical and professional approaches.

More difficult will be the fact that such integrated environmental management will require a cross-sectoral, cross-departmental approach. Attention will have to be paid to the existing silos on both the donor and PICT government sides, and where these silos and traditional programmatic boundaries need to be changed in order to enable effective total environmental management.

5.4 Development and management of infrastructure

In Section 4, we identified four lead actors involved in any adaption of infrastructure to climate change. These were:

- Government
- Funder
- Implementing agency
- Research community

The climate change challenge creates new demands for the way in which each of these actors approaches its role in the infrastructure development and management cycle. These new demands in turn raise questions about the role and operation of each actor. Section 4 also identified that planning, operation and maintenance was a key activity going forward in being able to adapt to climate change. Therefore, the following questions relate to the role of the different actors with respect to improving these processes. These questions form the basis of research to incorporate improved planning, operation and maintenance into the PICT situation.

Government

What policies do governments need to put in place to encourage infrastructure departments to develop asset management plans and understand how to optimise cost effectively the operation/maintenance/renewal/replacement balance? This requires strategic plans to be developed for all infrastructure assets.

Funder

How can funders alter their processes to encourage PICTs to improve their planning, operation and maintenance practices rather than waiting for existing infrastructure to deteriorate and seek funding to replace or upgrade this existing assets.

Implementing agency

The main challenges facing implementing agencies are: lack of overall government integration of adaptation response; lack of skills and resources to call upon for design and implementation; lack of clear overall planning and design. Key questions for research are: where in the government should infrastructure adaptation be coordinated? What legal instrumentality is required to make coordination effective in the PICT context? What strategies will most cost-effectively ameliorate the systemic shortage of highly skilled professional staff also familiar with the PICT social and environmental context?

Research community

The main challenges facing the research community are: an uncertain funding stream, often tied to the immediate requirements of PICTS, and not to the long-term requirements of climate change adaptation; an historical context that has focused on the natural phenomenon of climate change, and has not yet built capacity in the cross-disciplinary natural-social-technical research required to inform adaptation. The key questions here are in the area of research programming and institutional planning, and of defining effective linkages between researchers, government, professionals, and communities. This requires research in the area of governance.

There are knowledge gaps in each of the three steps mentioned above: understanding impact, deciding adaptation strategies, and strengthening adaptation capacity. For the Pacific Islands, each of these steps involves entering into new territory and the particular circumstances of the Pacific Islands means that mainland strategies and knowledge will often not apply. In the realm of population impact and prioritisation, the key areas for investigation are: impact of infrastructure on populations; infrastructure impacts on other infrastructure; planning for domain change time frames and uncertainty; developing specific local adaptation plans; integrating climate change into existing systems; and rethinking business as usual. In the domain of strategy options, the main areas are hardening, relocation, alternatives, resilience and natural systems. In the domain of implementation capacity, the main areas for research are the capacity gaps in each of the main actors: governments, funders, implementing agencies, and the research community itself.

6. Conclusion

This paper has highlighted three major areas of research that are critical for PICTs going forward in an environment that will be impacted by climate change, and highlighted a series of sub-questions that can be explored as part of this research. There are many facets of the climate change-infrastructure relationship that can be explored, but these are deemed to be priority areas. This research will provide a foundation for PICTs to make decisions regarding investment in infrastructure and its management. Increased knowledge in these areas and even more importantly, effective implementation of the results will put PICTs in a much better position to respond to climate change. Infrastructure is a vital component of development and needs to be prioritised, managed and financed in the most effective way for PICTs to develop a resiliency to the impacts of climate change.

Appendix A

Consultations

A list of agencies, organisations and individuals consulted during this assignment, as well as the purpose for the engagement is provided in the following Table A-1.

Table A-1 Consultations

Ministry / Agency	Purpose for Engagement
South Pacific Commission (SPC) Brian Dawson, Climate Change Advisor Russell Howorth, Director of the SOPAC Division	◗ Understand some of the key messages that SPC would like explored through this study ◗ Explore Brian and Russell's views of climate change adaptation nees in the Pacific with regards to infrastructure
GHD – Bruce Harper	◗ Utilise experience in cyclone modelling and climate change impacts
GHD – Bob McKelvey	◗ Utilise experience in range of infrastructure throughout the Pacific (Energy systems, roads, water supplies, ports, geotechnical assessments and the impacts of climate change.
GHD – Pedro Vong	◗ Utilise experience in energy transmission systems throughout the Pacific and the impacts of climate change on these systems.
GHD – Sundar Suntharesan	◗ Utilise experience in airports and risk assessment and the impacts of climate change
GHD – Brian Heggie	◗ Utilise experience in coastal infrastructure management in the Pacific, particularly PNG
GHD – Vikas Ahuja	◗ Utilise experience in sustainability and climate change adaptation approaches used in Australia for infrastructure
SOPAC Division of SPC – Dr Russell Howorth, Director Dave Hebblethwaite , IWRM Adviser Arthur Webb, Ocean and Islands Program Litea Biukoto, Advisor Hazards Assessment, Disaster Reduction Programme Peter Sinclair, Water Resources T. Hassan, Water Services	◗ Explore the work of SOPAC in the development activities, disaster risk management, and climate change adaptation throughout the Pacific ◗ Obtain their understanding of the gaps for better understanding the impacts of climate change on infrastructure ◗ Understand the work they are doing in their 3 divisions: Oceans and Islands, Water, and Disaster Risk Reduction ◗ Based on their existing and projected work obtain their views on additional work that needs to be completed to better adapt infrastructure to climate change impacts
World Bank – Michael Bonte, Disaster Risk Reduction Specialist, Timor Leste, Papua New Guinea & Pacific Islands	◗ Exploring the Disaster Risk Reduction work being undertaken by the WB and identifying some of the programs they are planning in the next couple of years ◗ Based on existing work identify gaps that could require further exploration and support
SPC – Economic Development Division (EDD) Captain John P.B. Hogan, Director Captain John E. Rounds, Shipping Adviser, Transport Programme Siaosi Sovaleni, Manager, Pacific ICT Outreach Programme Rupeni Mario, Energy Adviser, Energy Programme Uzumma Erume, Energy/Transport Economist	◗ Understand the role and work of the SPC Economic Development Division and how they are addressing climate change in the infrastructure sectors they are working in: Energy, Transport, ITC ◗ Explore how they will explore future work in climate change adaptation ◗ Obtain their views on what is needed to make progress in climate change adaptation of infrastructure going forward, especially for the large assets

Ministry / Agency	Purpose for Engagement
SPC,Land Resources Division (LRD) Inoke Ratukalou, Director	◗ Understand the infrastructure needs of the agriculture, forestry and other land management practices ◗ Explore the approach of LRD to climate change and its influence on infrastructure which is important to their role
Pacific Power Authority (PPA) Andrew Daka, Executive Director	◗ Explore how PPA works with its association members to assist them in adapting to climate change ◗ Understand the role of climate change in managing the energy sector.
University of South Pacific (USP) – Professor G.L. (Bill) Aalbersberg, Director, Institute of Applied Science	◗ Explore how USP trains people in climate change science and climate change adaptation ◗ Understand practical field work they understand in the climate change adaptation sector
University of South Pacific (USP) – Professor Murari Lal, Professor of Climate Change, Pacific Centre for Environment and Sustainable Development (PACE) Dr Helene Jacot Des Combes, Research Fellow, PACE	◗ Explore how USP trains people in climate change science and climate change adaptation ◗ Understand practical field work they understand in the climate change adaptation sector
South Pacific Tourism Organisation Illisoni Vuidreketi, Chief Executive Officer	◗ Explore the views of the tourist industry on the impacts of climate change to their business ◗ Understand what the needs of the tourism industry to better adapt to climate change.
International Union for Conservation of Nature (IUCN) Taholo Kami, Regional Director Oceania Bernard O'Callaghan, Oceania Programme Coordinator	◗ Understand IUCN's view of the adaptation of infrastructure to the impacts of climate change and the interaction between natural systems and infrastructure ◗ Obtain their views on how to approach the adaptation of infrastructure ◗ Understand the activities they currently undertake in the climate change sector
SPC-GIZ, Coping with Climate Change in the Pacific Island Region	◗ Understanding how the SPC-GIZ project is contributing to the overall climate change adaptation agenda in the Pacific Region ◗ Understand the approaches they are using to develop adaptation strategies for the resources sectors (fisheries, agriculture, forestry) in the Pacific ◗ Understand the interaction of these resource sectors with infrastructure
Graham Sem, Independent Consultant	◗ Explore Graham's views of the impacts of climate change on infrastructure and the country needs to better adapt ◗ Explore Graham's current work with DCCEE on developing the Overview of climate change adaptation in the Pacific.
Asian Development Bank (ADB) Marc Overmar	◗ Understand the work that the ADB is undertaking in the Pacific in climate proofing major infrastructure, especially road and port infrastructure. ◗ Understand the approaches the ADB is applying to identify and adapt to climate change impacts in its country and project planning
AusAID Fiji Ryan Medrana	◗ Understanding AusAID's approach to climate change and the nature of the activities they are undertaking in the Pacific related to infrastructure and climate change

Ministry / Agency	Purpose for Engagement
AusAID Infrastructure Adviser Peter Kelly	◗ Gain insight into experience gained with infrastructure projects in the Pacific and understand how they were mainstreaming climate change risk into current activities.
Pacific Infrastructure Advisory Centre (PIAC) Willem Overbeek John Austin	◗ Explore how PIAC/PRIF is addressing the issue of climate change in all the activities it is undertaking as part of PRIF ◗ Identify areas of work that PRIF is not exploring where further research is required.
Australian National University (ANU) Padama Lal, Researcher, Advisor for IUCN	◗ Understand the work she is undertaking in the economics of climate change
Pacific Water and Wastewater Association (PWWA) Latu Kupa, Executive Director	◗ Explore how the PWWA is supporting its association members to identify and develop strategies for adapting water and wastewater infrastructure to the impacts of climate change ◗ Identify needs of the association to support the work it does with its members
Tony Falkland, ACTEW	◗ Explore the work he has been undertaking in water security as part of the DCCEE PASAP activities
GHD Paul O'Keefe, Coastal Modelling and Marine Engineering	◗ Explore Paul's experience in coastal modelling and the impacts of coastal environments on infrastructure and how these will change with changing climate

Appendix B

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