Assessing Vulnerability and
Adaptation to Sea-Level Rise
Lifuka Island, Ha'apai, Tonga

# Rising Oceans, Changing Lives

# Final Report

SPC Secretariat of the Pacific Community

Australian AID

Assessing vulnerability and adaptation to sea-level rise on Lifuka Island, Ha'apai, Tonga

# A. Rising Oceans, Changing Lives

## Overview Report

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## Acronyms

| | |
|---|---|
| AusAID | Australian Agency for International Development |
| ADB | Asian Development Bank |
| CIF | Climate Investment Fund |
| DIICCSRTE | Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education |
| GEF | Global Environment Facility |
| GNP | Gross national product |
| HDC | Ha'apai Development Committee |
| ICCAI | International Climate Change Adaptation Initiative |
| JICA | Japan International Cooperation Agency |
| JNAPCCADRM | Joint National Action Plan on Climate Change Adaptation and Disaster Risk Management 2010–2015 |
| LiDAR | Light Detection and Ranging |
| MAFFF | Ministry of Agriculture, Food, Forestry and Fisheries |
| MLSNRECC | Ministry for Lands, Survey, Natural Resources, Environment and Climate Change |
| NCSA | National Capability Self-Assessment |
| NCCFP | National Climate Change Framework and Policy |
| NECC | National Environment Coordinating Committee |
| NGO | Non-governmental organisation |
| PASAP | Pacific Adaptation Strategy Assistance Program |
| PCCSP | Pacific Climate Change Science Program |
| PIFACC | Pacific Plan and Pacific Islands Framework for Action on Climate Change 2006–2015 |
| PMU | Project Management Unit |
| SOPAC | South Pacific Applied Geoscience Commission, Applied Geoscience and Technology Division of SPC |
| SNC | Second National Communication |
| SPC | Secretariat of the Pacific Community |
| SPREP | Secretariat of the Pacific Regional Environment Programme |
| SDP8 | Strategic Development Plan 8 |
| TWG | Technical Working Group |
| TCDS | Tonga Community Development Scheme |
| TCDT | Tonga Community Development Trust |
| TNYC | Tonga National Youth Congress |
| UNFCCC | United Nations Framework Convention on Climate Change |
| UNDP | United Nations Development Programme |

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# Executive summary

The confluence of climate change and seismic events has created significant environmental problems in Lifuka, an island of 2,400 people (2011 Census) in Tonga's Ha'apai Group. The subregion experienced an earthquake on 3 May 2006 that measured approximately 7.9 on the Richter scale. It resulted in subsidence of 23 cm of Lifuka Island, effectively creating instant sea-level rise. Erosion had already been already been a problem on Lifuka for some decades; in the past 40 years, Lifuka has experienced significant coastal erosion of between 2 m and 43 m, depending on location, along the western shoreline.

There have been dramatic effects on the community, with a number of homes, a church, a broadcasting tower, and the hospital now at risk from inundation during periods of heightened wave energy. During daily high tides, many homes are within 2 m of the water and face inundation in strong onshore winds. There are numerous infrastructure, health and social implications.

This project was a partnership between the Australian Government's Pacific Adaptation Strategy Assistance Program (PASAP) and the Government of Tonga's Ministry for Lands, Survey, Natural Resources, Environment and Climate Change (MLSNRECC). The Secretariat of the Pacific Community provided technical and administrative expertise.

Its goal was to provide the evidence needed for communities in Lifuka, and the Government of Tonga, to make informed decisions about adapting to coastal erosion and sea-level rise. The project also aimed to be a blueprint for other low-lying nations considering adaptation options.

There were three guiding principles. First, that the strategy for adapting to sea-level rise in Lifuka be informed by robust evidence about coastal and related environmental processes as well as social needs and values; second, that the strategy for adapting to sea-level rise in Lifuka be selected in association with its people; and third, that the project develop the capacity of local people to conduct similar assessments and formulate adaptation plans.

The scientific component of the Lifuka project involved assessments of shoreline change, groundwater resources, oceanography, the shallow-water marine habitat, and beach sediment composition and transport. The social component involved a household survey to document a range of issues; among them domestic water harvesting reliance and use, the impacts of a 2010 cyclone, household sanitation, beach mining, and perceptions of coastal change. A community engagement strategy and an accompanying manual were developed. Focus-group discussions identified community values and the social impact of sea-level rise and coastal erosion since the 2006 earthquake. An engineering report explored three shoreline protection options.

Water-level scenarios to 2100 were developed and presented in map form, showing what existing homes and amenities would be affected. In addition, the possible storm surge associated with a 1:100 year storm event in Lifuka was modelled and hazard zones identified. The model indicated that a 1:100 year event would likely inundate, to varying degrees, the lowest-lying part of the western coast where most homes and amenities are located.

The technical results and social insights were synthesised, cost–benefit analyses completed[1] and adaptation options developed.

1 See Annexure 3, Summary of PASAP project activities, outputs, personnel, and training, for a full list of activities.

## Options for adaptation presented to the community

In April and May 2013, the project's Technical Working Group (TWG) and Project Management Unit (PMU) presented future climate change scenarios and proposed mitigation measures at public meetings in Lifuka. The options presented were:

- a rock revetment to protect the foreshore (similar to an existing rock revetment at Nuku'alofa);
- sand replenishment (also known as beach recharge, using Waikiki Beach in Hawai'i as an example); and
- managed retreat. This could involve several components, such as the delineation of a coastal setback zone of 25 m to 110 m, depending on location, in which building activity would be restricted in order to mitigate risk, and from which families would retreat. Building standards would favour the elevation of coastal buildings to protect people and property, and a 'living shorelines' approach would favour the maintenance of healthy coastal habitats over engineered solutions.

Having assessed a range of scientific data and consulted with the Lifuka community on the social impacts of sea-level rise and erosion, the TWG and PMU recommended managed retreat as the most effective adaptation option, saying it was inevitable that the community of Lifuka would have to stage a managed retreat to protect families and infrastructure from the impact of storm-driven waves. Shoreline protection such as revetment or sand replenishment would not necessarily protect poorly-sited or designed buildings; storm waves can easily spill over the top of a revetment and cause damage. A managed retreat from the shoreline also helps support a healthy coastal ecosystem.

The teams believe that managed retreat needs to incorporate a coastal setback zone in the erosive and highly-exposed coastal fringes. They therefore recommend that planning for coastal retreat and setback zoning start immediately, and that this be supported by other strategies where suitable, such as the elevation of buildings in hazard areas.

Communities discussed the advantages and disadvantages of each option and asked questions of the TWG, then chose a preferred option. Lifuka's people chose a rock revetment as their preferred adaptation option. Some of the reasons informing this preference are discussed in section D, Adaptation and Community Strategies, 2.0 The Community Response.

## Water resource adaptation options

These options are specific to the impacts of climate change and inundation. Lifuka's water supplies are already at risk from human activity, in particular over-abstraction and contamination from poorly constructed wastewater systems. The potential for sea-water inundation poses risks to water quality as well as water infrastructure.

Investigations identified the probable extent and thickness of the freshwater lens, and also identified potential fresh groundwater resources that are outside the inundation area. In some places in Lifuka, as sea levels rise, the freshwater lens will become thicker as it rises into sediments that are more conducive to retaining groundwater.

In years to come, Lifuka is likely to experience reduced rainfall during dry periods and increased temperatures, which is likely to result in people relying more heavily on groundwater and potentially using higher volumes.

Measurements of salinity (saltiness) at the pumping wells and monitoring bores also indicate over-abstraction at some wells and galleries, suggesting that abstraction rates should perhaps be reduced in order to limit salinity to acceptable levels.

The TWG and the PMU recommend that the Tonga Water Board:

1. builds bunds (retaining walls) around water supply infrastructure as protection against flooding and contamination. This would include all TWB pump installations and the treatment plant.
2. introduces groundwater protection setback zones around TWB infrastructure to reduce contamination risks. A setback area of 100m from groundwater capture zones and well heads should be applied. The setback zone should restrict land-use activities, including housing of pigs and storage and use of chemicals and fuels. Households within the setback zone should be considered for support to replace or improve their on-site wastewater disposal to reduce the risk of contaminating groundwater;
3. fences well heads to provide a nominal 10 m setback distance from the well head, and restricts access in order to reduce contamination risks. This includes fencing TWB well 4, adding a bund and improving surface drainage to direct surface water away from the well head;
4. undertakes additional investigations on the construction of a horizontal gallery in the area near the Pangai High School playing fields. As this area is outside the area of modelled inundation, it would provide additional security and a greater quantity of fresh groundwater for Lifuka;
5. adjusts abstraction rates based on production-well salinity, reducing abstraction when salinity is above an agreed level;
6. reduces the high rate of lost and unaccounted-for water;
7. improves water-quality sampling and adopts a pro-active response to treatment, based on the water-sampling results.

*'No-regrets' options*

'No-regrets' options are activities that should be pursued, regardless of the impacts of climate change, as they ensure the safety and quality of water supply. In general, they are straightforward tasks that in some cases can be carried out by householders themselves.

The TWG and PWG recommend that householders are encouraged to consider:

1. boiling or chlorinating drinking water;.
2. improved guttering maintenance to ensure adequate rain is being captured;
3. installation of a first-flush system and screens at tank openings to reduce the risk of contamination. A first-flush device is a system of pipes that diverts the first rain that falls on the roof after a dry period, reducing the amount of dust, bird droppings, leaves and debris that flows into the tanks; and
4. installation of plastic tanks to replace leaking cement tanks.

## A context for change

Adapting to climate-change impacts is not only about building infrastructure; it is also about changing behaviour. For example, revetments along at-risk stretches of coastline cannot be the sole solution to protect people and infrastructure. Adaptation projects need to include measures that help build people's resilience. The government alone cannot change the way people act; initiatives need to be developed that spur people to take action, building their capacity to intervene, to be innovative and to cope in the face of coastal erosion and climate change.

Adaptation may require re-examination of community roles. For example, Lifuka communities have identified that their decision-making committees are generally composed of older men, which limits the input of women and young people when planning for adaptation and natural disasters. A programme that involves younger people and women invariably broadens the range of ideas that emerge, as well as developing within them a sense of responsibility for and ownership of the future of their island. Younger people could also offer valuable physical strength to their wider community in the event of an emergency. Exchange programmes could be organised between young people (both young women and young men) to expose them to other communities' initiatives, develop their sense of initiative and build a pathway to meaningful involvement in decision-making within their communities.

Investments of time, energy and finance will be required from the government, communities and individuals to make Lifuka a place where people are able to adapt to the very real challenges presented by coastal erosion and climate change.

# SECTION A: INTRODUCTION

It was 4:26 a.m. when the earthquake hit Tonga. S, a 46-year-old woman from Hihifo village on the western shore of Lifuka Island, was startled from her sleep as the ground heaved. Terrified, she gathered her children and ran outside.

By then, S had lived on Lifuka's flat western coastline, in sight of the sea, since 1985, and she was used to cyclones — when one's on the way, her family covers their home's windows with tin sheets and makes sure all belongings are in safe places.

Earthquakes aren't uncommon either — Tonga sits on the 'Pacific Ring of Fire', a seismically active area. But this shake, on Thursday, 3 May 2006, was 7.9 on the Richter scale, with an epicentre just 20 km east of Lifuka. It turned out to be the strongest earthquake recorded in Tonga, and the world's biggest shake for more than a year.[2] S's home was one of a number on the coast that were shaken to pieces.

There were no major injuries as a result of the earthquake, but the hospital, on the western waterfront, suffered severe damage. The wharf was damaged and a number of water pipes and telephone lines were broken. No tsunami was generated, although waves that were higher than usual pushed water well inland. But the worst effect was that the earthquake caused Lifuka to subside by 23 cm, causing, in effect, instant sea-level rise.

In the four years after the earthquake, erosion on the west coast accelerated. In that time, S, who had been relocated inland by the government, saw 20 m of the land where she used to live swallowed by the sea.

Ask S and other people on Lifuka's western shore what other changes they have noted since the earthquake and they will give you a list: the loss of shallow, inshore fishing grounds since the subsidence; damage to the pandanus plants used for fine handicrafts, which affects the quality of the products and therefore their value; saltwater intrusion into water supplies; and corrosion of roofs and damage to plantations caused by salt spray. Ask them how they feel, and one word comes up again and again — fear. Says one: 'I am living in fear because of the sea.'

(Based on information from individual interviews.)

2 Matangi Tonga Magazine (http://pidp.org/archive/2006/May/05-08-09.htm)

*Figure 1: Coastal erosion, Pangai, Lifuka*

## Project background and strategic context

***Background***

*Project origin, concept and consultation process*

As part of the Australian Government's International Climate Change Adaptation Initiative (ICCAI), the Pacific Adaptation Strategy Assistance Program (PASAP) aims to assist the development of evidence-based adaptation strategies to inform robust long-term national planning and decision-making in partner countries. The primary objective of PASAP is: 'to enhance the capacity of partner countries to assess key vulnerabilities and risks, formulate adaptation strategies and plans and mainstream adaptation into decision making' (PASAP, 2011). A major output of PASAP is: 'country-led vulnerability assessment and adaptive strategies informed by best practice methods and improved knowledge'.

This project was developed in conjunction with the Government of Tonga Ministry for Lands, Survey, Natural Resources, Environment and Climate Change (MLSNRECC), PASAP and the Secretariat of the Pacific Community (SPC).

Throughout the project design consultations, coastal erosion was highlighted as a priority problem. Similar projects have been undertaken on Tongatapu, but in contrast with these activities, there is a gap in the expertise and resources needed to undertake the impact assessment on Lifuka Island. The existing research base, alignment with Tonga's strategic priorities, positive feedback from officials in Nuku'alofa and Pangai, and awareness-raising on climate change and committee-strengthening already undertaken in communities of Lifuka Island, make the activity a suitable choice for PASAP.

## National context

Tonga is an archipelago of approximately 170 islands, with a population of 102,000 inhabiting 36 of the islands. The total land area is 650 $km^2$. The main island of Tongatapu is home to 71% of the population. The population of the Ha'apai Group — the region of concern for this project — is 7,570 people at a density of 69 people/$km^2$. Between 1996 and 2006 the annual average net population growth rate for the whole of Tonga was 0.4% (all data from the 2006 Census).

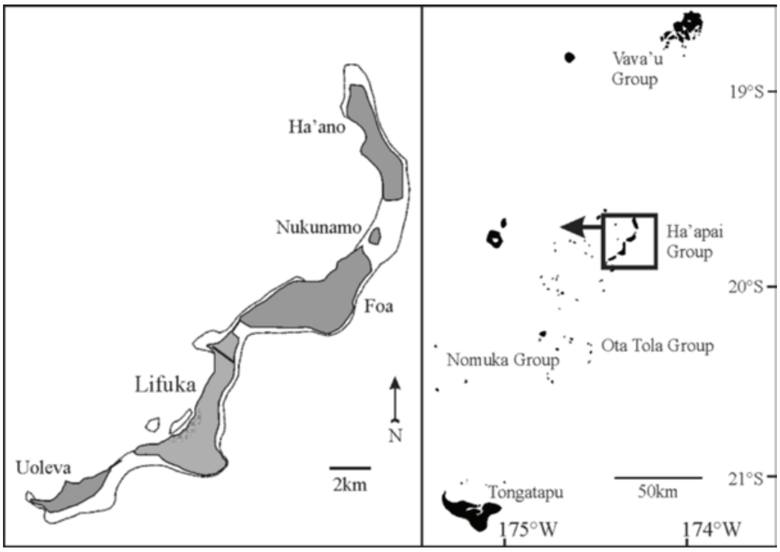



*Figure 2: Lifuka, Ha'apai Group*

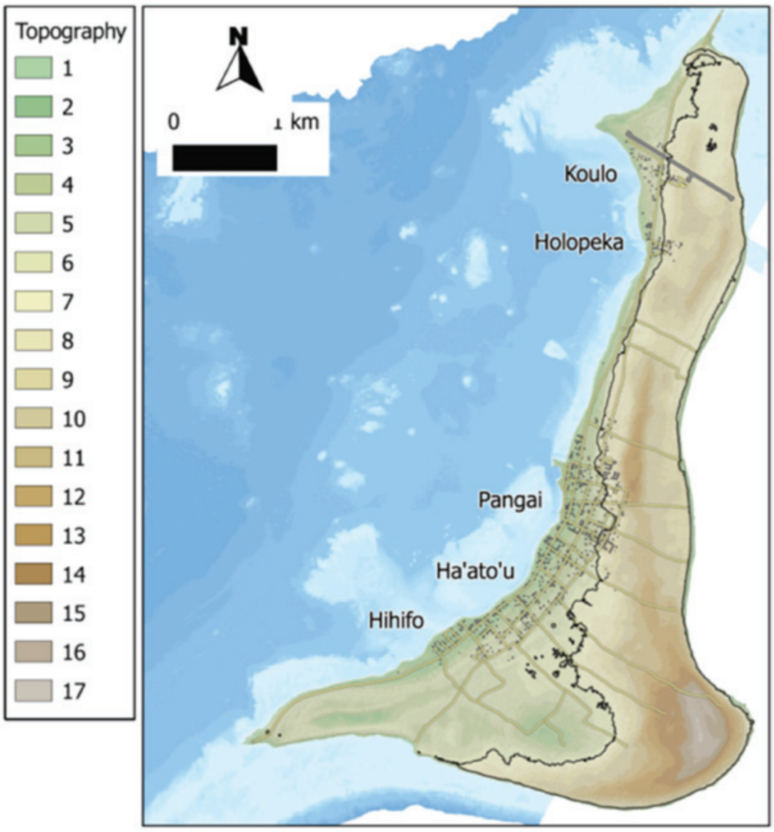



*Figure 3: Topogaphy and infrastructure of Lifuka, relative to mean sea level (2011). Note that the majority of buildings are situated on the low-lying sandy plain of the western shoreline. The black line shows the 6 m contour.*

Tonga is highly dependent on the transfer of remittances from abroad, which account for close to 40% of gross national product (GNP). Tourism and aid both account for approximately 15% of GNP, and agriculture and fisheries are also significant sources of revenue. In recent years annual GNP growth has fluctuated significantly from year to year, ranging from between 3.6% in 1998/1999 and –3.6% in 2004/2005. The linear trend of GNP growth between 1993 and 2008 is 1.8% per annum (data from the 2006 Census).

Crops are grown for subsistence, for sale on the local market and increasingly for export. Successful export crops include squash pumpkin and vanilla. Agricultural exports, including fish, make up 73% of exports, but are vulnerable due to fluctuations in commodity prices, high transportation costs and natural disasters such as cyclones. Traditional root crops and vegetables such as taro, kumara, cassava, watermelon and yams are also exported to the large Tongan communities living in New Zealand, the United States and Australia.

Urban drift to the capital of Nuku'alofa is a feature of the social dynamic in Tonga: over the period 2001 to 2006, Tongatapu's population grew by 1,200 people, whereas it declined in Vava'u, Ha'apai and the Niuas. Youth unemployment on Tongatapu is high, with approximately 40% of 15- to 19-year olds being unemployed according to 2006 Census figures. In 2006, the overall rate of unemployment was 34%, with 1,000 to 1,200 school leavers competing for a limited number of formal employment positions each year.

Tonga ranked 99 out of 182 in the UN Human Development Index for 2007. Town and district officers are elected by villagers, represent government at the local level, and are the face of government with whom communities can engage. Village committees take concerns to town officers and district officers, expecting that these concerns will be raised at government level.

### *The Ha'apai Group*

The Ha'apai Group is composed of 60 small low-lying islands. These are grouped into six administrative districts, with Pangai on Lifuka the administrative centre. As can be seen in Table 1, in 2011, the population of Lifuka was 2,427 in 464 households. High migration rates from Ha'apai in recent years have resulted in negative population growth, with an overall decrease in population of 18.2% in Lifuka between 2006 and 2011. The corresponding figure for the whole of Tonga was +1%.

Lifuka houses the region's airport and main harbour. All islands have primary schools, often with fewer than 20 students, catering for children up to Class 6. Families raise funds to send the children to high school and college in Pangai or Nuku'alofa. The isolation of the Ha'apai islands constrains the delivery of core services and access to markets, and these constraints are exacerbated by the increasing cost of transport, consumable goods and education.

*Table 1: Population distribution, preliminary results, Census 2011*

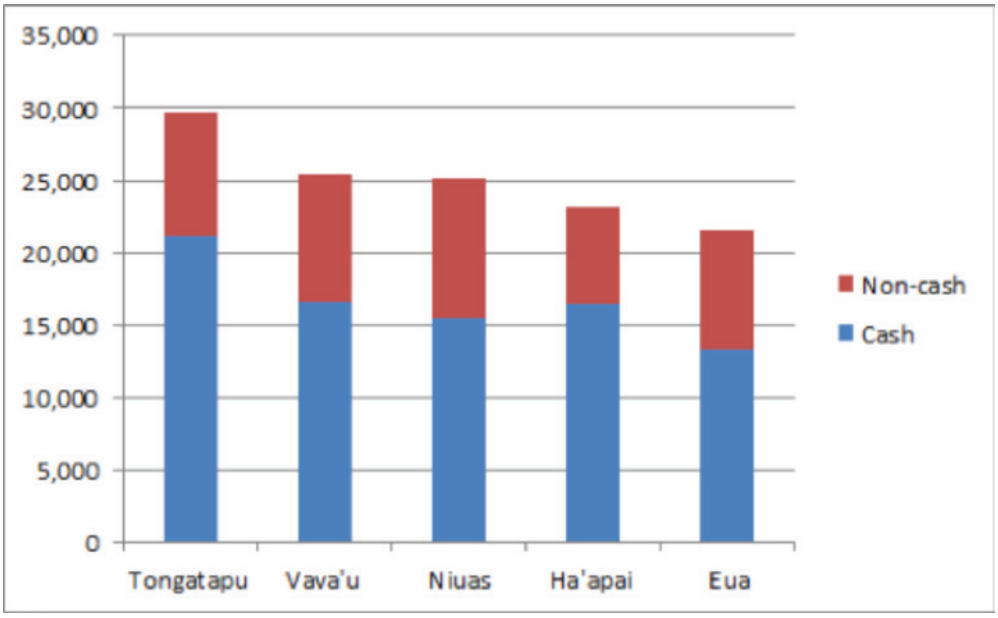
| | Household number | | Population | | Household change | Population change |
|---|---|---|---|---|---|---|
| | 2011 | 2006 | 2011 | 2006 | | |
| Hihifo | 166 | 186 | 833 | 1,078 | -10.8% | -22.7% |
| Koulo | 37 | 46 | 214 | 251 | -9% | -14.7% |
| Pangai | 234 | 264 | 1,239 | 1,445 | -11.4% | -14.3% |
| Holopeka | 27 | 34 | 141 | 193 | -7% | -26.9% |
| **Total** | **464** | **530** | **2,427** | **2,967** | **-12.5%** | **-18.2%** |
| | | | | | | |
| **Tonga** | **18,053** | **103,036** | **17,462** | **101,991** | **3.4%** | **1.0%** |
| | | | | | | |
| Tongatapu | 12,829 | 11,971 | 75,158 | 72,045 | 7.2% | 4.3% |
| Vava'u | 2,817 | 2,871 | 14,936 | 15,505 | -1.9% | -3.7% |
| Ha'apai | 1,260 | 1,372 | 6,936 | 7,570 | -8.2% | -12.2% |
| 'Eua | 865 | 899 | 5 011 | 5,206 | -3.8% | -3.7% |
| Ongo Niua | 282 | 349 | 1,281 | 1,665 | -19.2% | -23.1% |

Most of the houses on each island have individual household rainwater tanks and most islands have groundwater that can be used for both potable and domestic purposes, although some islands are fully reliant on rain for their fresh water. The majority of households also have toilets (flush, composting and pit) and most have access to electricity either through diesel-generated power or solar power (although the cost of diesel energy can limit people's usage).

Families rely on subsistence agriculture (root crops, fruits and greens), fishing, pigs and some goats for food security, although there is limited production of fresh vegetables. Some of the small islands have very little fertile soil for agriculture. A few villages have horses for transportation. Gender roles are quite defined, with men doing fishing, ploughing, planting and harvesting of crops, and preparation of umu (pit cooking). Women do the day-to-day food preparation, treating pandanus and weaving.

Income on the outer islands is derived largely through fishing and weaving (including the sale of pandanus), with the annual sea-cucumber harvest bringing a large income in September. While fishing is a vital income source, most islands do not have refrigeration or ice-block machines for storing fish before selling.

The tourism market in the region is limited. The cost of boat fuel, distance between islands, and rough seas limit the economic viability of selling produce and products and purchasing store goods. Figure 3 shows the average annual household income by island division.




| TOP | Tongatapu | Vava'u | Niuas | Ha'apai | Eua |
|---|---|---|---|---|---|
| Cash | 21,228 | 16,599 | 15,437 | 16,439 | 13,283 |
| Non-cash | 8,529 | 8,817 | 9,750 | 6,760 | 8,326 |

*Figure 4: Average annual household income by island division, 2009*
(Source: Kingdom of Tonga Statistics Department, 2009. Household Income and Expenditure Survey, p 77-79) Coastal erosion on Lifuka

The earthquake on 3 May 2006 resulted in 23 cm of subsidence of Lifuka Island, creating instant sea-level rise. Rising sea levels over the next several decades, and resulting wave impact, particularly at high tide, will further erode the coastline in Pangai, leading to increasing inundation of and damage to infrastructure along the shoreline. There are related impacts on groundwater, health, and food production, and it is notable that some septic systems are below mean high-tide levels. While a groundwater management system is in place, the impact on Lifuka's thin groundwater aquifers has not been assessed since the earthquake.

*Governance for climate change*

In Tonga, responsibility for climate change rests with the Cabinet Committee on Climate Change, established in 2007. This committee includes the Ministers responsible for the environment (Chair), transport, public works, justice, and the Attorney General, and reports to the Prime Minister.

Under this Cabinet Committee sits the National Environment Coordinating Committee (NECC). NECC was originally established in 2004 to coordinate all existing and future donor projects approved by Cabinet to be executed by the former Department of Environment, which became a separate ministry in 2009 and is now part of MLSNRECC. NECC comprises representatives from various government departments, as well as from the Tonga Association of Non-Government Organisations.

Under NECC sits the climate change technical working group (TWG). The TWG coordinates input from other ministries, such as the Ministry of Finance and National Planning (MOFNP) and the Ministry of Agriculture, Food, Fisheries and Forestry (MAFFF). At the working level, MLSNRECC has responsibility for climate change matters and convenes the TWG. In practice, the composition of the TWG is determined on the basis of the issue and project at hand. For example, for the National Communication and National Capacity Self-Assessment projects funded by the Global Environment Facility (GEF), there were two subgroups of the TWG that addressed issues of vulnerability and adaptation respectively.

For this project on vulnerability and adaptation to sea-level rise in Lifuka, the TWG formed by MLSNRECC comprised representatives from MLSNRECC, including its Geology and Geographic Information Systems divisions, the Tongan Meteorological Services, the Tonga Water Board, and the Tonga Community Development Trust (TCDT). Staff drawn from these agencies conducted the work for this project, under the guidance of a Project Management Unit (PMU) housed within MLSNRECC. Project staff worked in two teams — a physical resources (coastal and groundwater) assessment team and a social assessment team — under the guidance of a Project Coordinator.

The Ha'apai Development Committee (HDC) also played an important governance role for this project. HDC meets in Nuku'alofa on a regular basis to address issues and make decisions on matters regarding Ha'apai, including approving projects and proposing new budget measures to government. HDC reports to the Deputy Prime Minister and is required to obtain final approval from Cabinet on funded projects.

The Ha'apai Governor, who is a member of HDC, has an office in Pangai. The main line ministries with officers in Ha'apai include the MLSNRECC; Finance and National Planning; Agriculture and Food, Forests and Fisheries; Commerce, Tourism and Labour; Works and Natural Disaster; Health; Education, Women's Affairs and Culture; Transport, Civil Aviation, Marine and Ports; Tourism; Justice; and the Ministry of Police, Prisons and Fire Services. Three national NGOs have regional offices in Pangai — the Red Cross; TCDT and the Youth Congress.

Town and district officers are elected to office and paid by government to manage local law and order, resolve conflicts, hold information meetings (fono) and supervise village cleanliness. Town/village committees exist, but may not meet frequently. Other committees such as electricity and phone committees operate relatively effectively to collect and manage fees from households.

## Strategic context

*Programmatic context – regional*

This activity is framed within several overlapping and complementary regional strategies and programmes to support climate change adaptation.

In setting the Pacific region's priorities for climate change, the Pacific Islands Framework for Action on Climate Change (PIFACC) 2006–2015 identifies 'Adaptation measures to the adverse effects of climate change developed and implemented at all levels' as a target and calls for, among other things, international assistance to 'assist with the design, financing and development of national adaptation measures, such as those referred to above,' and 'to provide capacity-building and training for the implementation of national adaptation measures'.

Australia's support for climate change adaptation in the Pacific region is consistent with PIFACC and responds to calls from Pacific Island Forum Leaders in August 2008 through the Niue Declaration on Climate Change for development-partner commitment to increase technical and financial support for climate change action on adaptation.

Through ICCAI (2008–2013), Australia works with partner countries to:

- establish a sound policy, scientific and analytical basis for long-term Australian action to help developing partner countries adapt to the impacts of climate change;
- increase understanding in partner countries of the impacts of climate change on their natural and socio-economic systems;
- enhance partner country capacity to assess key climate vulnerabilities and risks, formulate appropriate adaptation strategies and plans, and mainstream adaptation into decision-making; and
- identify and help finance priority adaptation measures to increase the resilience of partner countries to the impacts of climate change.
- ICCAI includes PASAP and the Pacific Climate Change Science Program (PCCSP), as well as bilateral and multilateral measures to support climate change adaptation in partner countries.

*Programmatic context – national*

Tonga's National Strategic Planning Framework (NSPF 2009–2019), approved by Cabinet in February 2009, provides a long-term strategic approach that focuses on the key determinants of economic and social development. The framework highlights a limited number of uniquely national or whole-of-government priorities, with action in other supporting areas being required of ministers through their ministries' corporate plans. The framework identifies the following climate change related priority in a list of seven: 'Integrate environmental sustainability and climate change into all planning and executing of programmes'.

Several climate change strategies have also been established in Tonga. In January 2006 Cabinet approved the National Climate Change Framework and Policy (NCCFP), which was informed by Tonga's Initial National Communication, published in 2006. Updating the NCCFP is the Joint National Action Plan on Climate Change Adaptation and Disaster Risk Management 2010–2015 (JNAPCCADRM — JNAP for short), *which is the key national document dealing with climate change adaptation. JNAP was formulated by government and non-government stakeholders with SPREP and SOPAC assistance, and approved by Cabinet on 28 July 2010.*

The six strategic goals for JNAP are: (1) improved good governance (mainstreaming and strengthening institutional policy frameworks); (2) enhanced technical capacity and awareness; (3) improved analysis/ assessments; (4) enhanced community preparedness and resilience; (5) technically reliable, economically affordable and environmentally sound energy to support the sustainable development of the kingdom; and (6) strong partnerships across government and with NGOs/civil society.

JNAP is also consistent with the Pacific Plan, the Pacific Islands Framework for Action on Climate Change 2006–2015 (PIFACC) and Pacific Disaster Risk Reduction and Disaster Management Framework for Action (2005–2015). Improved information and assessments on coastal erosion, including in Ha'apai, are identified as priorities under the second and third goals in the JNAP.

At the sub regional level, HDC commissioned a Ha'apai Development Master Plan under the Ministry for Finance and Planning that determines development priorities across multiple sectors. Coastal erosion is identified as a significant concern in this plan.

In terms of climate change assessments, Tonga's Initial National Communication and its National Capacity Self-Assessment: Stocktaking and Thematic Report under the United Nations Framework Convention on Climate Change (UNFCCC), produced in 2008, contain a significant amount of background detail on research and consultations already undertaken to identify Tonga's vulnerability to climate change. The Initial National Communication also describes conditions on Lifuka, including groundwater recharge rates and rainfall.

The Initial National Communication identifies several adaptation options open to Tonga in response to coastal erosion. These adaptation options, which are also reflected in Tonga's National Capacity Self-Assessment report, include:

- coastal protection systems (foreshore protection infrastructure);
- coastal replanting;
- eliminating onshore sand mining;
- reviewing and assessing the current coastal protection system;
- promoting public awareness;
- reviewing/amending the existing legislation; and
- law enforcement.

## Project description

***Activity summary***

This project was developed to provide the evidence needed for communities in Lifuka, and the Government of Tonga, to make informed decisions about adaptation to sea-level rise. It also seeks to support the capacity of the Government of Tonga and relevant NGOs to work with communities in conducting this and other assessments of coastal and social vulnerability to sea-level rise.

The confluence of climate change and seismic events has created significant environmental problems in Tonga's Ha'apai Group. In the past 40 years, Lifuka has experienced significant coastal erosion of between 2 m and 43 m, depending on location, along the western shoreline.

This has had a dramatic effect on the community, as a number of homes, a church, a broadcasting tower, and the hospital are now at risk from inundation during periods of heightened wave energy. During daily high tides, many homes are within 2 m of the water and face inundation in strong onshore winds. In some cases, septic systems and water tanks are below mean high-tide levels, and threaten pollution of the nearshore coast and adjacent coral reef. As erosion progresses, many of the less salt-tolerant trees and plants along the coast will begin to die, and without the support of root systems in the soil, the rate of erosion is likely to accelerate.

*Figure 5: A sea wall project in Hihifo before, during and after Tropical Cyclone Rene (2010)*

Responding to the Government of Tonga's priorities, the PASAP project on Lifuka developed an evidence-based strategy for adapting to sea-level rise on the island.

The scientific component of the Lifuka project involved assessments of shoreline change, groundwater resources, oceanography, the shallow-water marine habitat, and beach sediment composition and transport. The social component involved a household survey to document a range of issues, among them domestic water harvesting reliance and use, the impacts of a 2010 cyclone, household sanitation, beach mining, and perceptions of coastal change. A community engagement strategy and an accompanying manual were developed. Focus-group discussions identified community values and the social impact of sea-level rise and coastal erosion since the 2006 earthquake. An engineering report explored three shoreline protection options.

Water-level scenarios to 2100 were developed and presented in map form, showing what existing homes and amenities would be affected. In addition, the possible storm surge associated with a 1:100 year storm event in Lifuka was modelled and hazard zones identified. The model indicated that a 1:100 year event would likely inundate, to varying degrees, the lowest-lying part of the western coast where most homes and amenities are located.

The technical results and social insights were synthesised and cost–benefit analyses completed. Adaptation options were developed and presented to the Lifuka community.

*Activity partners, stakeholders and beneficiaries*

The project was managed and led by the Government of Tonga through MLSNRECC. External technical expertise and management support is provided through SPC. See Section 4 'Implementation Arrangements' for full details.

The project developed a partnership between the Government of Tonga and SPC to deliver an evidence-based adaptation strategy to reduce coastal erosion on the western side of Lifuka Island. The project supported interagency planning in Tonga, led by MLSNRECC, and provided information as a basis for decision-making at the national and sub-regional levels (including the Climate Change Committee of Cabinet and the Ha'apai Development Committee).

The project partnered with Tonga-based organisations, and coordinated with regional agencies and major development partners, drawing on the expertise and information generated from PCCSP.

The project beneficiaries included:

- the people of Lifuka Island, particularly those communities living and using facilities in proximity to the western foreshore;
- technical agencies and NGOs engaged in the project;
- the Government of Tonga, particularly MLSNRECC and other line ministries engaged in delivery of the project, as well as planning committees for the Ha'apai Group;
- the Australian Government, including the Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education (DIICCSRTE), as the project delivered an improved understanding of how its partners in the Pacific can respond to the impacts of climate change; and
- regional organisations that can draw from the project's methods and outcomes to inform similar responses to climate change in the Pacific environment.

***Non-governmental organisations (NGOs)***

The Tonga Community Development Trust (TCDT) has been most an active NGO working with the Lifuka community on development and environmental projects. It has a mandate to alleviate poverty in Tongan families and communities and foster self-reliance and sustainable community development. In Ha'apai, it has strengthened the capacity of the town committee and its sub-committees to run meetings and practise good leadership, allowing them to serve as models for surrounding towns. TCDT is also implementing a climate change project that started in 2009 to empower five communities on Lifuka Island (extended to Foa Island in 2010) to mitigate and adapt to climate-change impacts.

The Hihifo sea-wall project supported by TCDT provided important lessons for climate-change adaptation in Tonga. The limited budget permitted use of only flour/wheat sacks for sandbags and allowed just one trip to Ha'apai for the project team, which had to be combined with other projects. The sandbags were reasonably effective for a short period, but constant wave energy and several severe storms (including Tropical Cyclone Rene in early 2010) have now shattered the wall.

## Goal and objectives

The project's goal was to develop an evidence-based strategy for adapting to sea-level rise on Lifuka Island.

The objectives were:

- To assess the impacts of seismic subsidence on the coastal zone and people of Lifuka
- To assess the vulnerability of the coastal zone and people of Lifuka to future rises in sea level
- To propose and assess a range of adaptation strategies for adapting to sea-level rise in Lifuka
- To enhance government and local community understanding of the opportunities and risks associated with various strategies for adapting to sea-level rise
- To support the capacity of the Government of Tonga and relevant NGOs to conduct assessments of coastal and social vulnerability and the gender perspective of vulnerability and adaptation to sea-level rise
- To design a system for monitoring ongoing changes in natural and social systems on Lifuka.

***Project methodology***

There were 13 steps to meeting this project's aims. Each step is described in detail in the project document and is summarised in Annexure 2.

The study started with a geoscientific assessment of the resources and pressures in the area. This information was supplemented by data on the social context (norms, pressures, processes) in the community that affect or are affected by the coastal hazards identified. Combined, these sets of data were used to identify options to adaptation that could be assessed for feasibility. On the basis of subsequent community consultations, preferred recommendations have been identified (Figure 6).

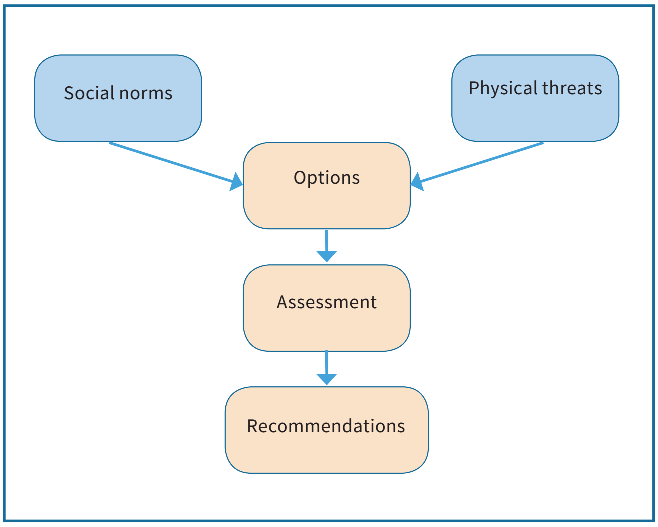



*Figure 6: Schematic view of project methodology*

In order to have a more complete picture of community vulnerability and capacity to adapt to coastal erosion, the project adopted an approach to support women's participation in the community assessment and development of adaptation plan. Separate focus groups for women only were organised, where the same facilitation tools and questions were used to engage discussion. An equal number of women and men were interviewed during individual interviews with people who were most vulnerable to the effects of coastal erosion because of their location.

## Implementation arrangements

In order to maximise the success of this activity, the following governance structure, monitoring and evaluation plan, and measures were implemented.

***Management and governance arrangements and structure***

This is a Government of Tonga project, delivered as a partnership between MLSNRECC and SPC, through the collaboration of its Human Development Programme and its Applied Geoscience and Technology Division. SPC, in collaboration with MLSNRECC, established a Project Management Unit (PMU — see the next section). Administrative and financial support was provided by MLSNRECC for a fee, with additional support provided by SPC as required. A Technical Working Group (TWG) was established to monitor and provide advisory support for the project. The TWG was convened by MLSNRECC and included representatives of other Tonga ministries and agencies, namely MLSNRECC, including its Geology and Geographic Information Systems divisions; the Tonga Meteorological Services; the Tonga Water Board; the Ha'apai Development Committee; and the Tonga Community Development Trust. Terms of reference for the TWG were agreed at the outset to ensure the project received the guidance needed to proceed with and respond to changes during implementation. The strategic activity management was undertaken by DIICCSRTE, via the PASAP Manager (based in Apia), who reported to the PASAP Management Committee on a regular basis. The PASAP Manager participated in meetings of the TWG as appropriate. A memorandum of understanding (MOU) was developed for the project identifying the obligations of project partners.

*Project Management Unit (PMU)*

The PMU was made up of four SPC staff members located in Noumea and Suva, and three Tonga-based positions (one of which was the Director of MLSNRECC at the time, who served as the National Project Director).

The remaining two Tonga-based positions were the National Project Coordinator and the Technical Project Officer. These positions coordinated and supported the activities of the project under the joint management and oversight of the National Project Director based in MLSNRECC and the SPC Project Coordinator based in Noumea. Also, as a result of experience in the inception phase of the project, the Tonga Community Development Trust was assigned the lead role in developing and implementing the social and community assessment component of the project, working closely with the PMU.

An overview of the governance arrangements is shown below.

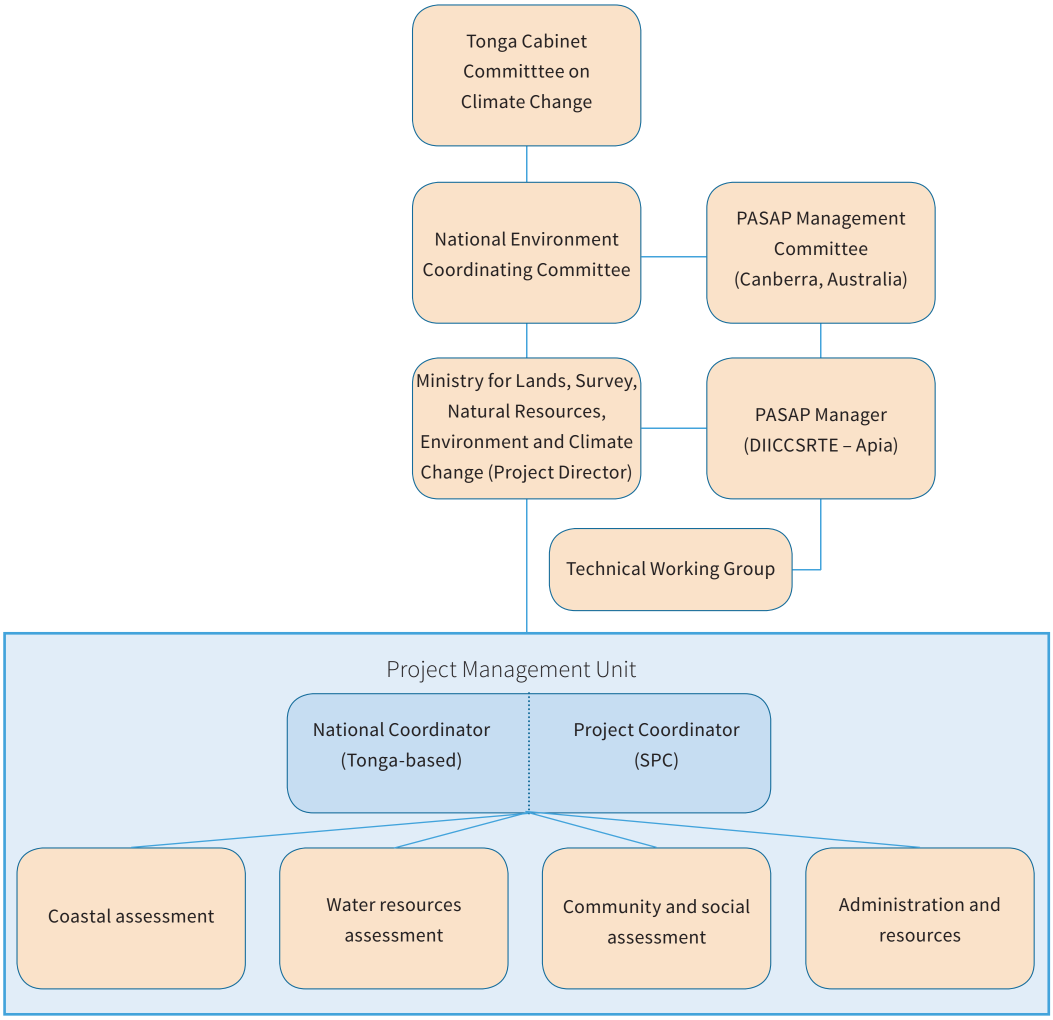



*Figure 7: Project governance arrangements*

*Outcomes*

The outcomes of the project were:

- An informed basis for selecting appropriate adaptation response to future sea-level rise and storm surge in the western coastal zone of Lifuka
- Improved community understanding of climate change impacts in the western coastal zone of Lifuka relating to future sea-level rise and storm surge
- Increased capacity in relevant agencies in the Government of Tonga to conduct assessments of coastal and social vulnerability and adaptation to sea-level rise
- Improved regional awareness and understanding of the potential impacts of climate change on coastal zones.

*Reports*

In addition to workshops and equipment installation, the project outcomes consist of reports from each of the project steps. The project outcomes are as follows:

- Annotated bibliography and accompanying overview of the activity based on the information reviewed
- Agreed project implementation plan developed through an inception meeting
- Project Management Unit (PMU) positions in Tonga advertised/appointed
- Report on initial shoreline mapping and survey of monitoring bores
- Report on results from geophysical investigations and initial monitoring bore rehabilitation work
- Report on quarterly shoreline and groundwater surveys
- Workshop report including methodology and a participatory strategy for community engagement
- Report of shoreline dynamics, including maps of shoreline position over several decades and rates of shoreline movement
- Report on analysis of social impacts including a gender perspective
- Report on the collected household survey data, its analysis and presentation of results including water resources assets and reliance on different water sources
- Report on the island sediment system including maps of benthic habitats and representative sediment composition
- Installation of current meters and wave gauges
- Report on the process dynamics of the reef system from the reef crest to shoreline and inundation modelling
- Report, concept drawings, and preliminary costing on basic shoreline protection options
- Report describing community values
- GIS database on infrastructure
- Report identifying community concerns and exposure to risk
- Report on cost–benefit analysis
- Workshop report describing the project's method, presenting data and findings, and describing a range of adaptation strategies and the communication strategy for community outreach extension
- Report describing the community engagement process including the methodology used, the level of community engagement, the preferred adaptation strategy, and the lessons learned from the process
- Report describing the Lifuka Climate Impacts Monitoring System
- Final project report collating each output report into a synthesis document for the project, including in the Tongan language
- Financial and narrative reports
- Report summarising the capacity building initiatives undertaken during the course of the project
- Report providing an assessment of project management arrangements
- Compilation of communication and advocacy materials including a project video documentary.

## Budget

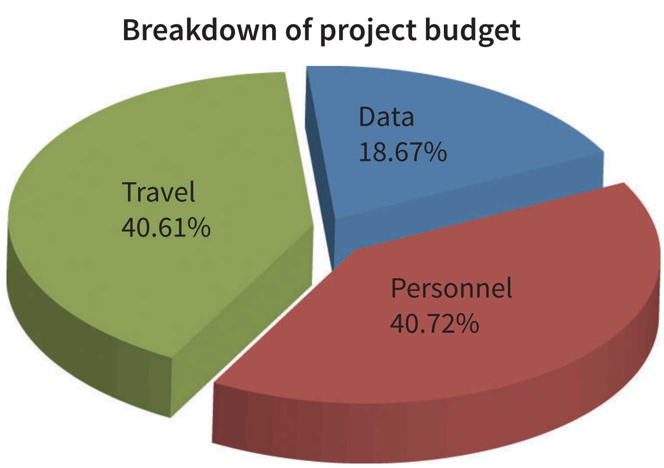
SPC and DIICCSRTE signed an agreement on financial arrangements for the project on 30 June 2011. In accordance with Schedule 1 (Project Details), DIICCSRTE contributed AUD562,000 to SPC for the implementation of this project in collaboration with PASAP and MLSNRECC.

Following receipt of this funding, a Project Inception Mission to Tonga was undertaken by the SPC members of the PMU. This provided the opportunity for the SPC team to meet with key stakeholders in order to: (1) develop a common understanding of the project and its objectives; (2) discuss in detail the activities of the project including implementation arrangements, scheduling and costing; and (3) agree and finalise management arrangements between MLSNRECC and SPC with the involvement and approval of PASAP management.

During and directly as a result of the Project Inception Meeting, the SPC team was able to make a more realistic assessment of the cost of project delivery and reviewed the project budget, factoring in discussions and experience of stakeholders and the situation on the ground in Nuku'alofa, where the majority of the implementing partners were based, in addition to the cost of project delivery from the four project locations: Suva, Noumea, Nuku'alofa and Lifuka Island in the Ha'apai Group — the main project location and focus of project activity.

As a result, the project budget was revised upwards by AUD216,000 to a total of AUD778,000 to accommodate: (1) capacity building for local government institutions and agencies; (2) investment in utilising local skills and expertise; (3) introduction to the project for Lifuka local government officials and community leaders; (4) Tonga Community Development Trust (NGO) taking the lead on the community engagement component of the project; (5) engagement of the SPC Statistics for Development Division in development and analysis of the household survey; (6) engagement and more realistic costing of a resource economist, including contribution to the social and community assessment component of the project; (7) media and communications; (8) revised project management arrangements to include additional site visits for the National Project Director and PMU meetings involving team members from all three locations; (9) MLSNRECC monthly finance and administrative service fee to replace project position; and (10) increases in the cost of travel, freight, local transport and per diems.

*Table 2: Breakdown of project budget by data and equipment, personnel and travel*



## Monitoring and evaluation plan

***Project progress review***

Implementation of the project was monitored according to the PASAP Performance Management Framework, which was tailored for this project based on the proposed outcomes and outputs. There are a number of output reports associated with the 13 steps of the project. Each output report reflects delivery of project documentation associated with a project step.

The PMU provided the PASAP Manager with monthly exception reports raising any urgent changes or issues for the project (which were then discussed), and six-monthly reports on the financial status and work progress, including an assessment of the performance against project steps. These reports were cleared through MLSNRECC.

This is the single final report of the activity prepared by SPC in collaboration with the PMU and MLSNRECC as required by DIICCSRTE and AusAID, and includes an assessment of the performance against outputs and overall activity impact.

The PMU Project Coordinator, the National Coordinator and the PASAP Manager regularly reviewed the progress of the project against its objectives and identified actions required. The PMU Project Coordinator, in consultation with the SPC Programme Manager, kept the PASAP Manager informed of progress, challenges and key issues for this activity.

***Stakeholder feedback***

Feedback by key stakeholders and uptake activity achievement by community organisations and others was monitored. At the end of community workshops, feedback was requested and compiled. Activity outputs are being made accessible by the PMU and disseminated further by PASAP and ICCAI.

***Financial monitoring***

Formal arrangements were put in place between SPC and MLSNRECC to implement the project, and financial arrangements were approved by the PASAP Management Committee through an MOU between DIICCSRTE and SPC. SPC facilitated payment of the PMU positions and managed the project budget. SPC, through the PMU, maintained records and accounts relating to the project, including disbursements. Financial reports were provided to the PASAP Management Committee via the PASAP Manager, and final acquittal was completed within three months of the end of the project. All financial accounts and statements were expressed in Australian dollars as a requirement of the MOU. An audit of the project finances is to be conducted in August/September 2013.

## Setting up the project in Tonga

Setting up the project in Tonga involved establishing partnerships and working relationships with local counterparts in Tonga and in Lifuka; putting in place the Tonga-based PMU, including recruitment of the National Project Coordinator and the Technical Support Officer; identifying a suitable location for and establishing the project office, which was located in MLSNRECC premises; opening a project bank account and putting in place administrative and financial systems and working arrangements to ensure smooth implementation involving the teams in Suva, Noumea and Nuku'alofa; and establishing and obtaining approval of a memorandum of agreement between the project and TCDT for the delivery of services under the social assessment component of the project. This process was completed by the end of first quarter 2012. Coordination with TCDT in Tonga on all aspects of project delivery as they relate to the social and community assessment and engagement component was critical, as TCDT led the planning and facilitation of this work in the community in Lifuka. This coordination was primarily the responsibility of the National Project Coordinator.

# SECTION B: MAPPING THE RESOURCES

## B1: Physical resources

### 1.2 Shoreline assessment (outputs 4, 6)

***Introduction***

A shoreline assessment involves mapping shoreline positions and geomorphology (the scientific study of landforms and the processes that shape them), and undertaking monitoring to quantify rates of change over time. To document the state of Lifuka's shoreline, the following activities were undertaken.

***Method***

**Topographical mapping:** Topographical mapping of survey sites was completed and permanent benchmarks were established in the six communities in Lifuka. The benchmarks served as reference points from which profile lines were run to survey the status of the beach and understand its processes.

**Temporary tide gauge installation:** The objective of the tide-gauge observations was to derive mean sea level in relation to the benchmarks used for beach profile surveys. A tide staff was installed at the wharf in Pangai and observed for 24 hours at 10-minute intervals. These visual observations were related to readings from a nearby depth logger made over a period of 42 days. The mean sea level for the survey period was calculated to be 1.40 m below the LiDAR benchmark.

**Beach profiling:** This is a simple surveying technique used to measure changes in the contour of a beach. Five sets of beach profiles were completed. Profile lines were run from the benchmark to the base of the beach. Elevations were usually recorded at 2 m intervals, as well as at distinct features such as the edge of vegetation lines and at the tops of scarps.

**Shoreline photo mapping:** A total of 2,758 geocoded photos were produced, providing a detailed record of the state of the shoreline and adjacent coastal structures. The photos taken over the survey period were compared, providing information on shoreline changes and, in particular, showing impacts on coastal structures such as sea walls. The photos and accompanying files are available from SPC's SOPAC Geonetwork server (see www.sopac.org).

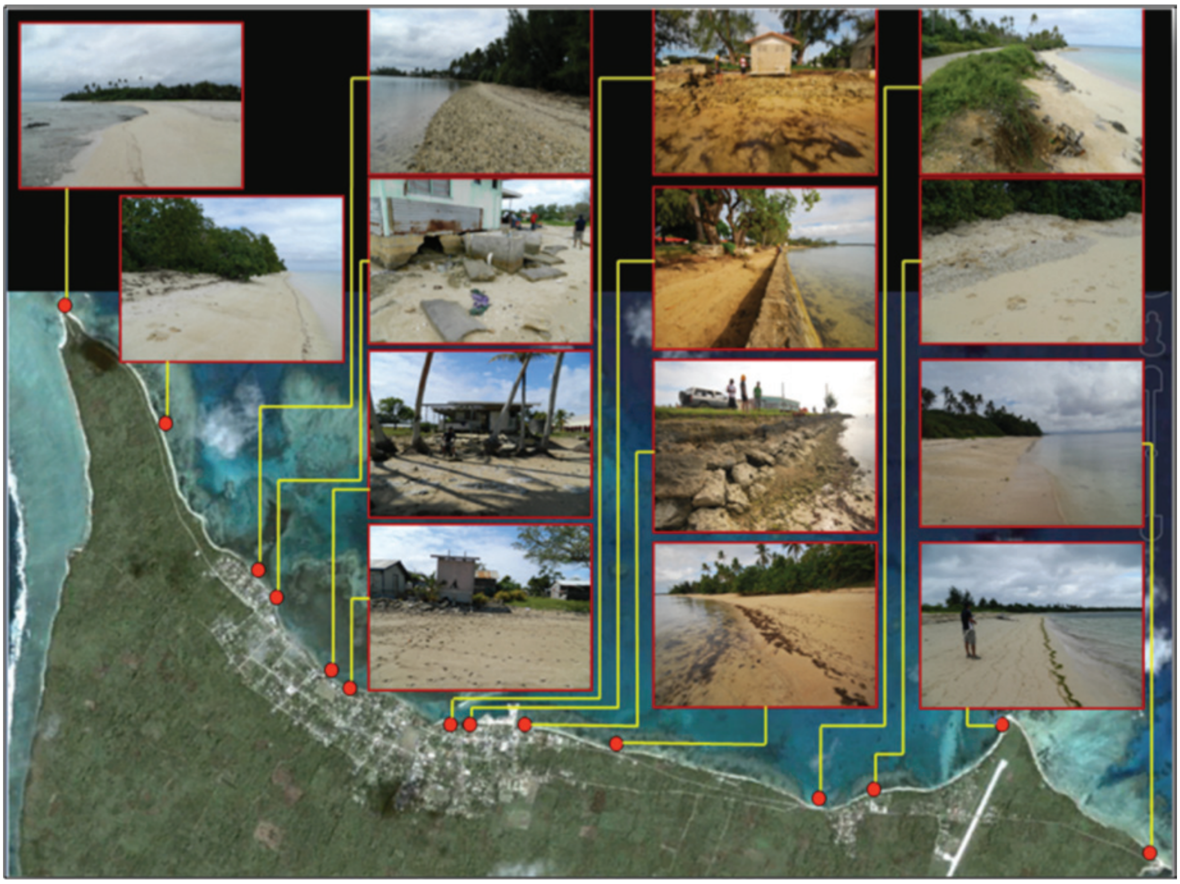


*Figure 8: Examples of photos taken during the shoreline survey plotted on Google Earth*

Cyclone Cyril inundation survey: Category Two Tropical Cyclone (TC) Cyril moved into Tonga waters from the northwest and passed north of the Ha'apai Group during the first week of February 2012, offering an opportunity to measure its impact on the coastline. Inundation and wave runup measurements (wave runup is the maximum vertical extent of wave uprush on a beach or structure above the still-water level) were made on 14 and 15 February 2012 at seven locations along the western shoreline of Lifuka. Standard land-survey techniques were used to map the inundation, the distance from base of beach to debris line, and runup levels. The probability of Lifuka being inundated and its coastal zones affected by high-energy waves was clearly evident.

***Key findings***

Overall, the survey provided the necessary baseline information to provide a clear picture of the current state of Lifuka's coastal zones, including beaches and adjacent coastal structures.

For Benchmark 1, at the hospital, most of the changes observed resulted from land reclamation and construction of a sandbag revetment. During the first phase of the survey, erosion and inundation were evident in the hospital compound, mainly in front of the hospital wards. During high tide, seawater was seen to be reaching the vegetation line, and the two water tanks nearest the lagoon were undercut by erosion. This prompted action from the government and a shoreline protection structure using cement-mix sandbags was initiated. With regard to beach morphology, minimal change was observed. Towards the end of the survey, accumulation of sand was observed on the south corner of the beach; this is presumed to be a result of sand from sandbags being washed away.

Changes in beach morphology (natural characteristics) were observed at benchmark 2, at the old store in Ha'ato'u. Data show that the width of the beach decreased after TC Cyril in February 2012. Waves from the cyclone may have washed the sand away, probably southwards. Now, as a result, waves frequently reach the vegetation line during high tides. This also affects nearby homes.

Benchmark 3, located at the king's palace, showed some changes. An increase in height was noted, resulting probably from soil and aggregates accumulating after TC Cyril. Minor erosion was observed on the scarp. A few palm trees were observed to have fallen in that area as a result of the continuing erosion.

Benchmark 4 was at the police station. There were minimal changes. Boulders and concrete slabs have been placed on the beach face and a seawall shelters the beach and land from high-energy waves.

Benchmark 5, at Holopeka, didn't show much change in morphology. An increase in height at one point was a result of disturbance due to overgrown vegetation. With regard to erosion, beach size did not change but the scarp next to the vegetation seemed to be increasing, and this was evident after TC Cyril.

## 1.3 Groundwater resources assessment (outputs 5, 6)

### *Introduction*

Groundwater is an important water source for Lifuka. Water sourced from private wells and the Tonga Water Board supplies 80% of Lifuka's freshwater needs. Groundwater assessment is a practice in which aquifers are studied, mapped, and assessed for quality. This groundwater resource assessment captured information on the extent and thickness of Lifuka's fresh water lens, the impact on the lens from a sudden increase in sea level related to subsidence from the 2006 earthquake, groundwater contamination threats and impacts, and the potential exposure to inundation of the freshwater lens and abstraction infrastructure.

### *Rainfall in Lifuka*

Rainfall in the islands of the Ha'apai Group averages about 1,706 mm per year. Lifuka has the lowest average rainfall and correspondingly some of the lowest monthly averages in Tonga over a 30-year period, indicating that it lies in a rain shadow relative to other locations.

PCCSP, funded by the Australian Government and AusAID, undertook comprehensive research into the climate and ocean projections for 14 Pacific nations. The projections and predictions are the result of joint research by the Australian Bureau of Meteorology and CSIRO.

The summary of climate predictions for Tonga indicate that sea level will continue to rise, and by 2030 sea-level rise is expected to be 5–15 cm (moderate confidence). A rising sea level will increase the impact of storm surges and coastal flooding.

The most obvious concern in terms of water resources is the projected decrease in rainfall during the dry season. As rainwater supplies become stressed and less reliable, residents are expected to turn increasingly to groundwater. With corresponding increased temperatures there is potential for increased demand on groundwater for irrigation and non-potable domestic needs.

The rainfall prediction indicates little change in rainfall totals, but the intensity and frequency of rainfall events will increase. The impact on households may include shorter periods in which rainwater can be harvested and stored, requiring consideration of infrastructure needs such as increased storage capacity or increased guttering and downpipe sizing to cope with the more intense events and assist in the collection and storage of rainwater.

***Method***

*Groundwater-supply infrastructure*

Tonga Water Board (TWB) has four sites in Pangai and Hihifo constructed and equipped to abstract groundwater. TWB usage data indicates that 269 KL/day is abstracted from the four TWB abstraction wells. Households are metered for the TWB piped water, indicating 131 KL/day of household usage. This suggests that 51% of total water production is unaccounted for. It is calculated that 13% of total production is lost between the production wells and the treatment plant and 20% of total production is lost between the bulk meter and the household, with an additional 18% of total production considered unaccounted-for water lost at the household.

Water from the four pumping sites is piped to the TWB treatment plant in Hihifo and stored in three 45,000 L fibreglass tanks. The standard water treatment involves mixing 500 ml of chlorine granules into each of the three raw-water storage tanks every day. There are times when treatment of the water with this volume of chlorine is inadequate, as indicated by March 2012 water quality sampling.

Salinity levels of the piped TWB water received at the tap varies seasonally in response to rainfall and the volumes of water abstracted from the four TWB pumping sites.

*Groundwater resource mapping*

The 2006 earthquake and Lifuka's subsequent subsidence provide a unique opportunity to assess the impact of a sea-level 'rise' of 23 cm on the groundwater resources in a low-lying atoll-type island setting. It is worth noting that this subsidence caused a relative sea-level rise on the island equivalent to 39% of that predicted to result from climate change by the year 2100 (based on IPCC 2007 estimates).

The fieldwork was designed to investigate:

- how groundwater responded to this 'rise' in sea level;
- the potential impact on existing groundwater abstraction infrastructure from a rise in sea level;
- the potential for additional groundwater resources and future groundwater abstraction; and
- the impact of contamination from current land-use activities.

The investigation drew upon the resources and staff of SPC, MLSNRECC, and TWB from September 2011 to December 2012.

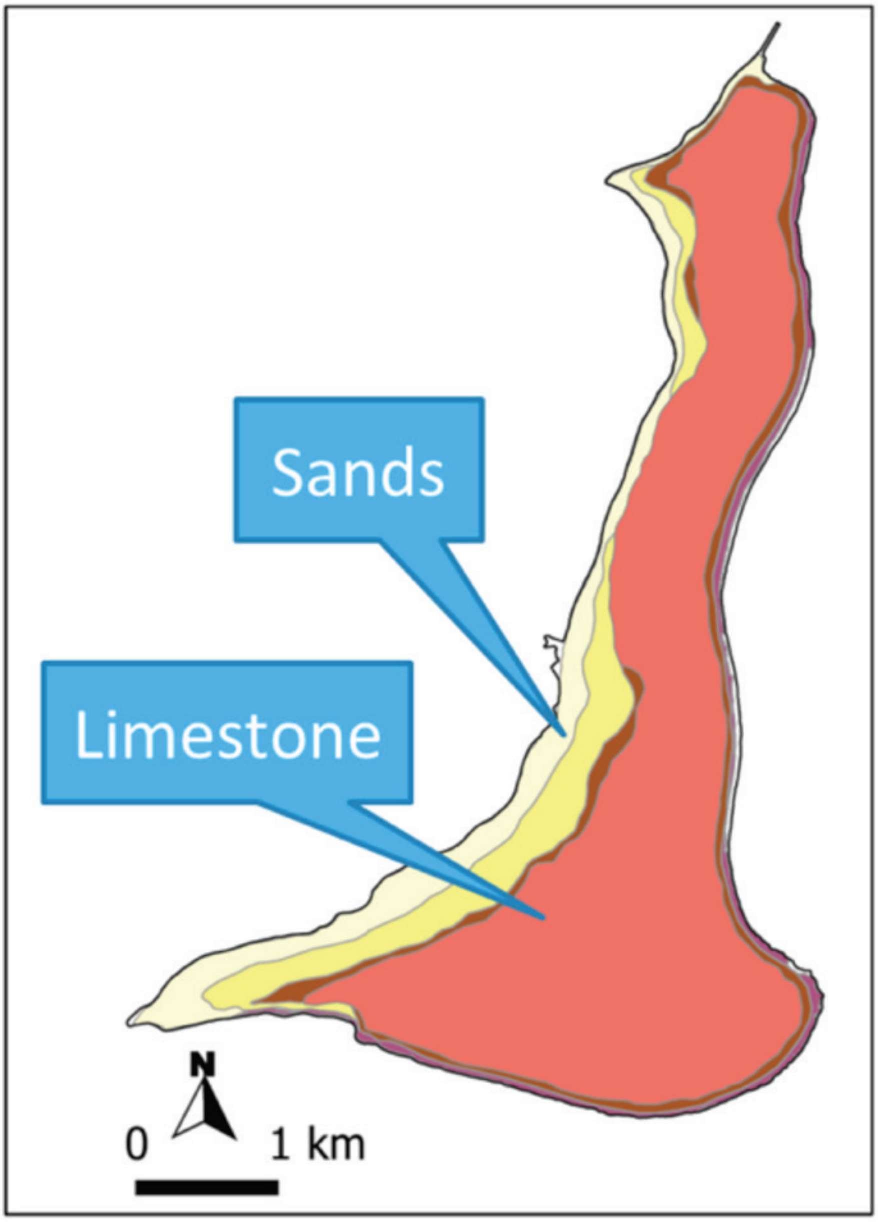



*Figure 9: Simplified soils map of Lifuka. Note that the low-lying coastal plains of the western shoreline comprise unconsolidated sands.*

*Hydrogeology*

The groundwater investigations were restricted to the thicker unconsolidated sediments found on the western side of Lifuka, where geological conditions provide the greatest potential for fresh groundwater resources.

A conceptual diagram of groundwater resources for Lifuka indicates lens thickness and the processes (Figure 10).

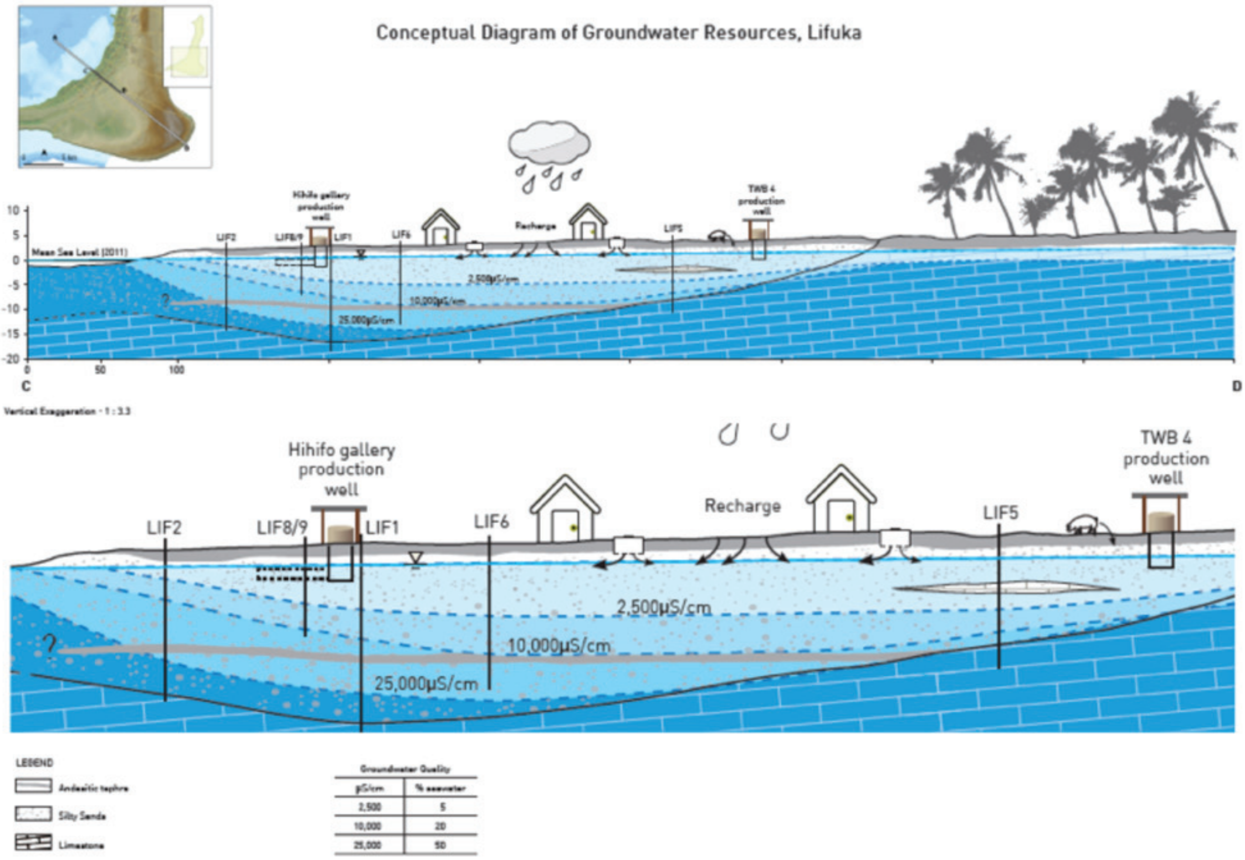



*Figure 10: Conceptual diagram of groundwater resources, Lifuka*

*Geophysical surveys*

These are an efficient way to identify salt and freshwater boundaries and estimated freshwater lens thickness in atolls. Monitoring bores installed in 1999, which had not been sampled since 2001 were used, where available, to guide the calibration of the geophysics and to monitor changes in lens salinity over time.

The information obtained from the electromagnetic and resistivity surveys helped to confirm the thickness and shape of the freshwater lens. It is essentially a thin wedge found within the unconsolidated sand sediments and overlying brackish water.

This information will be useful in guiding future groundwater development and protection. The area to the north of Pangai near the high-school playing fields holds promise for additional groundwater development (Figure 11). The field work was undertaken at the end of a prolonged dry period and showed that at the time of the survey (September 2011), the lens was very thin.

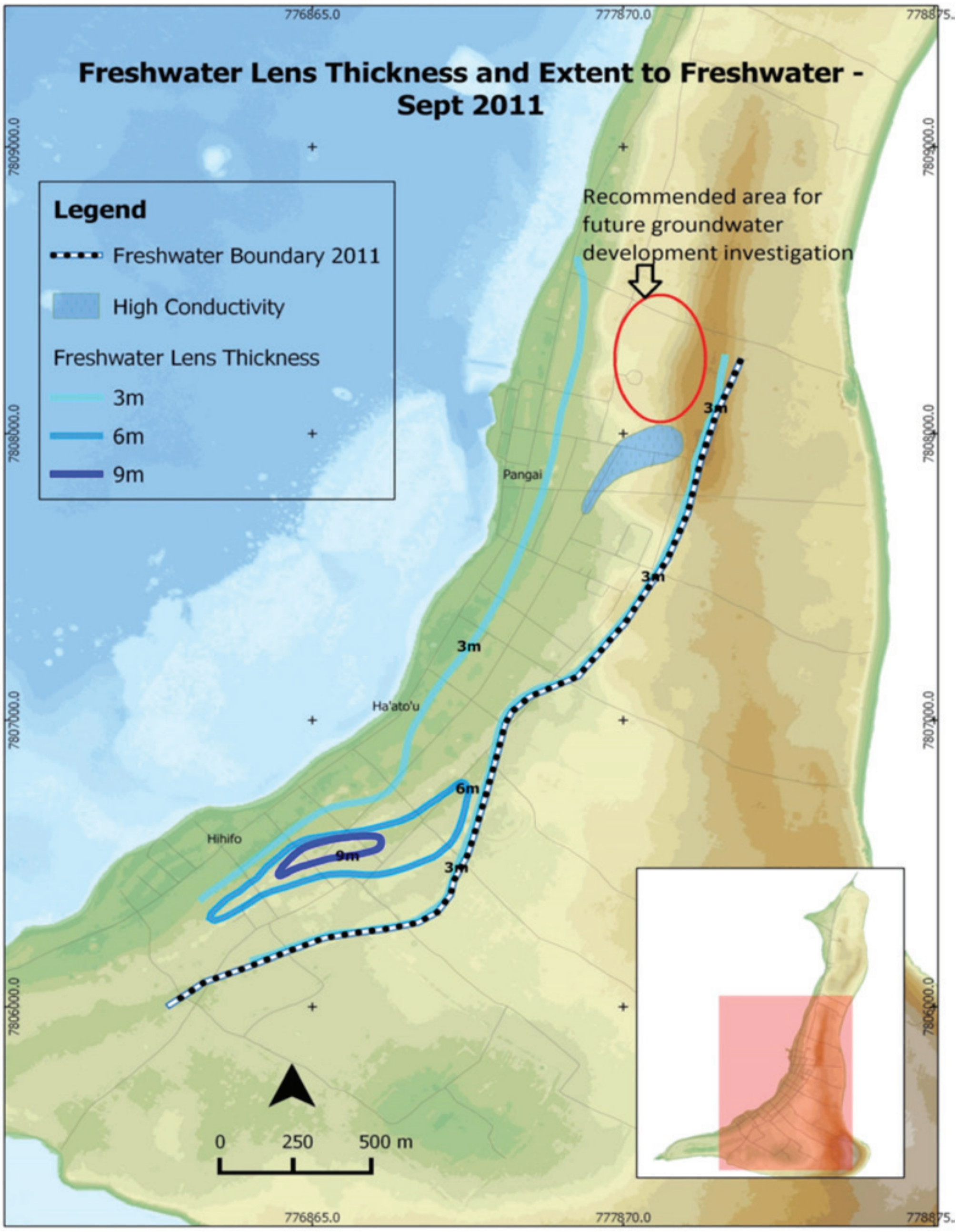



*Figure 11: Extent of fresh groundwater lens, showing area with potential for further groundwater development*

***Sustainable yield***

A preliminary assessment based on experiences in similar Pacific environments suggests a sustainable yield of 30%-40% of recharge would be applicable (Fry and Falkland 2011), indicating a sustainable yield for the fresh groundwater area to be 159,989 $m^3$/year to 213,318 $m^3$/year.

Utilising a sustainable yield range of 30%-40% of recharge for sustainable yield equates to an average sustainable yield value of 4.2kL/day /Ha to 5.6kL/day /Ha. This is equivalent to a sustainable pumping rate per square kilometre of about 0.4ML/day to 0.56ML/day or about 4.8-6.5L/s.

Given the thin nature of the lens at the time of the survey, a more conservative value for sustainable yield of 159,989 $m^3$/year, or 30% of recharge, is applied. Under current estimated abstraction from the lens of 98,185$m^3$/year, current abstraction is equivalent to 61% of the estimated sustainable yield.

It should be noted that current abstraction involves four TWB wells and is not spread across the freshwater lens area. This suggests that abstraction rates for some bores will be too high, leading to increased potential for the abstraction of brackish water during dry periods, as indicated by the measured salinity readings at some TWB wells.

*Salinity and water level measurements*

Six monitoring bores near TWB production wells were monitored on a quarterly basis for the 12 months from September 2011 to October 2012 to provide valuable information on both the variability of the freshwater lens and the potential impact of Lifuka's May 2006 subsidence.

The monitoring demonstrates considerable variability in salinity of the lens in response to rainfall. After a period of increased rainfall there is a corresponding decrease in salinity. Similarly, a period of decreasing rainfall results in an increase in salinity.

It is possible to get an appreciation of the lag time between the rainfall event and impact on salinity. The data suggest that for the deeper part of the lens, the time lag between the event and the response in salinity is up to five months. A quicker response, as to be expected, is indicated for the shallower and fresher parts of the lens, with freshening of the lens at the top of the aquifer occurring more rapidly, often within a month of substantial rainfall.

The effects of the relative sea-level rise of 0.23 m in response to the May 2006 earthquake was observed in two monitoring bores (LIF 7 and LIF9), and corresponds to a rise in water levels of 0.45 m and 0.55 m respectively.  Based on monitoring bores LIF 7 and LIF 9, the freshwater component of the lens is 0.5 m thicker than compared with the 1998–1999 monitoring period and the 2006 earthquake.

Whilst rainfall is expected to be a dominant factor in determining the thickness of the lens, it is noted that the drilling logs indicate the presence of sandy silt sediments in the zone in which the water table now is located, following the lifting of the freshwater lens into more favourable geological conditions allowing it to develop. It is suggested that the improved geological conditions and the probable increased recharge account for the increased storage and thickness of the freshwater lens observed at these sites.

*Water level and salinity loggers*

Instruments called Diver CTD loggers were installed in three of the active pumping galleries from March 2013 to July 2013: Hihifo Gallery East (diesel), Hihifo gallery North, (electric), and Pangai Gallery North (solar) — to establish water-level and salinity trends over time and how the water levels in these bores interact with tidal activity, the impact of pumping on the water levels and responses to rainfall. It was observed from logger data that abstraction from Hihifo Gallery North is stressing the aquifer, and that abstraction during dry periods should be reduced to avoid pumping brackish water.

*Seawater inundation impacts*

A 1:100 year inundation event, as modelled for the project, Assessing Vulnerability and Adaptation to Sea-Level Rise, Lifuka Island, Ha'apai, Tonga, is indicated to result in inundation of up to 5 m above the current mean sea level. The impact of an event this size would affect 79% of existing infrastructure, including the TWB water treatment plant. Whilst this rarer event would clearly be catastrophic for Lifuka's communities, there is potential for inundation events of smaller magnitude to impact on land and infrastructure, including water supply wells, with increased frequency.

The area of modelled inundation with regards to the impact on the extents of the freshwater lens has been calculated. Under a 1:100 year event, 73% of the freshwater lens would be impacted.

*Water quality testing results*

In March 2012, a total of 42 domestic, communal and TWB wells were tested for *E. coli*. Alarmingly, 95% indicated the presence of *E. coli,* which indicates the potential for faecal contamination and associated water-borne disease and illness if ingested. Accordingly, **all groundwater in Lifuka should be considered to be contaminated by faecal matter.** Among the reasons are poorly-constructed septic tanks and soakaway pits; the shallow and sandy nature of local soils, offering few barriers to the transmission of bacteria; the density of housing; and the large number of roaming animals, such as pigs and dogs, near wells and on areas with direct access to groundwater.

According to the results of the household survey, Lifuka's people prefer rainwater for drinking, cooking, and some washing. Groundwater is still important, accounting for more than 80% of all water used by households, but is more likely to be used for bathing, gardening and outdoor needs. Rainwater collected from roofs and directed into tanks is the primary source of drinking water for 92% of households.

Just 7% of households say Tonga Water Board's metered groundwater, piped to houses, is their primary source of drinking water. Taste is likely to partly account for this, as the salinity (saltiness) of Lifuka's groundwater varies depending on rainfall and abstraction rates, with salinity increasing during dry seasons and becoming noticeable to consumers.

## Key findings

The key findings from this investigation:

- The freshwater lens in Lifuka is naturally very dynamic and fragile. It is very responsive to rainfall events and begins to thin within a few months of little or no rainfall.
- Inundation modelling identifies that all existing TWB reticulated infrastructure, including the production bores and galleries and the treatment plant, are at risk of some level of inundation from a 1:100 year inundation event.
- The subsidence and the associated rise in sea level in Lifuka has impacted on the fresh groundwater lens, where the lens has been 'lifted' by an observed 0.5 m in monitoring bores. In some cases, this appears to have increased the thickness of the freshwater lens and the storage.
- The freshwater lens is mapped as being thickest in the area around Hihifo Gallery East. Geophysics indicates a lens thickness of up to 9 m, but of limited extent.
- The sustainable yield for the fresh groundwater area is conservatively estimated to be 159,989 $m^3$/year.

- Abstraction rates for some bores are too high, causing localised increased salinity during dry periods.
- The potential for increased development of the freshwater lens is limited. The area of the existing Pangai High School offers greatest potential for development of a horizontal infiltration gallery. Additional investigations are recommended to confirm the optimal location in this area.
- Rainwater harvesting should be promoted to increase water security. However, the projected climate scenarios of longer dry periods and wetter wet seasons suggest that Lifuka's communities will have a greater reliance on groundwater in future.

## 1.4 Oceanographic assessment (output 13)

### Shoreline change analysis

***Introduction***

A shoreline change analysis uses historical records to document change by erosion and accretion in a coastal zone, and can be used as a foundation for future scenarios. It needs to be pointed out that the scenarios and results do not predict future changes, but describe future potential conditions to support decision-making.

Appropriate archives were searched and five sets of imagery capturing Lifuka were found, spanning four decades: 1968 (aerial photo), 1990 (aerial), 2004 (satellite image), and 2008 (satellite), and 2011 (an orthophoto, derived from digital imagery that was taken as part of a LiDAR survey).

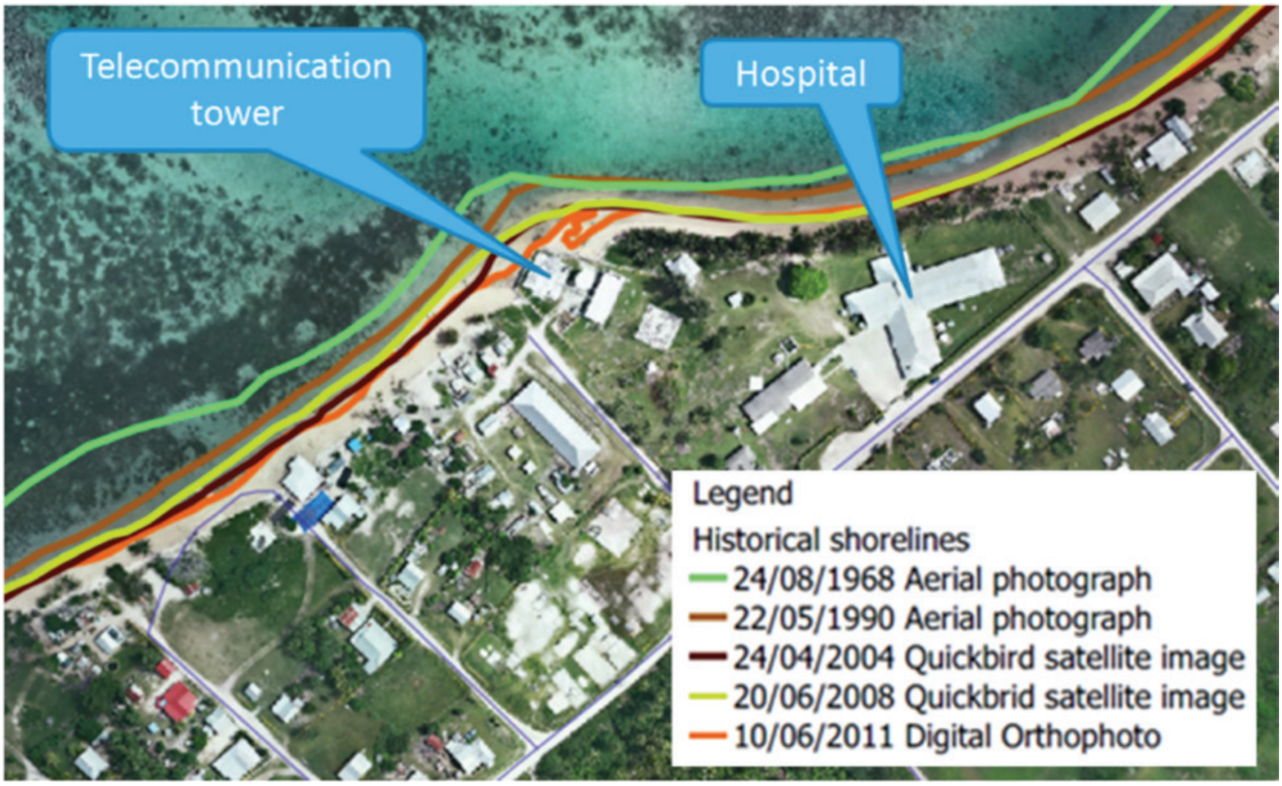



*Figure 12: Detail of the Hihifo area showing how information in the five images was plotted, with the 2011 image as a backdrop*

After digitising the shoreline, the historical shoreline change analysis was carried out using the Digital Shoreline Analysis System, DSAS v4.3, computer software that computes rate-of-change statistics from multiple historic shoreline positions residing in a geographic information system (GIS).

Mean annual erosion rates were calculated for the coastal communities of Koulo, Holopeka, Pangai and Hihifo, and used to establish a distance to define a coastal setback zone using a formula. See Report 1.0 Adaptation Options for details of the extent of these zones and to see aerial representations.

## Coastal inundation

***Introduction***

In order to map the coastal hazards associated with inundation, we considered extreme water levels due to the following:

- Astronomical tides
- Longer-term variations
  - Interannual changes due to the El Niño-Southern Oscillation (ENSO)
  - Sea-level rise
- Storm surge
  - Inverse barometer effect
  - Wind stress
- Wind-wave contributions
  - Wave setup
  - Wave runup.

## Method

Coastal inundation was computed using a combination of various statistical, parametric and dynamic methods that led to:

- a database of position, speed and direction, minimum pressure, maximum wind speed, and radius of maximum wind speeds for several thousand synthetic tropical cyclone positions within a 400 km radius of Lifuka;
- surface wave parameters for these synthetic tropical cyclone conditions;
- annual exceedance probabilities, including 100-year return intervals (100 RI), for metocean conditions (meteorology and oceanography) at Lifuka;
- boundary conditions for the XBeach model (this is a two-dimensional model for wave propagation, long waves and mean flow, sediment transport and morphological changes during storms);
- XBeach output files of water depth, wave height, and velocities; and
- inundation mapping that led to GIS shape files and maps, as well as an A0 poster on hazard zones.

## Key findings

Synthesis of the above is presented in Section C: Vulnerability and Hazard Assessment

# 1.5 Benthic habitat assessment (output 11)

## Introduction

The benthic zone is the ecological region in the shallows of a body of water such as an ocean or a lake, including the sediment on the sea floor and some of the layers underneath.

Marine habitat mapping uses sound data-based approaches to capture biological and physical information about this environment. Then maps are created that help us to:

- understand the distribution and extent of marine organisms and their habitats;
- recognise the importance of marine habitats as sources of beach sediments;
- provide evidence-based information to safeguard habitats; and
- assess any changes in marine habitats as a result of human activities.

## Method

The coastal waters (less than 20 m in depth) on the western coast of Lifuka were mapped. An important first step was analysing satellite imagery of the coast, which included tapping the expert knowledge of local fishermen in order to identify known marine habitats.

SPC and the Tongan Fisheries Department worked together to conduct field data collection in June 2012. This involved taking three sets of photos: the seabed at low tide, taken from the reef; underwater photographs taken by a snorkeller; and from a boat, using an over-the-side drop video camera. Each image was tagged by time and position.

A total of 607 geo-referenced photos were acquired, and examples are below.

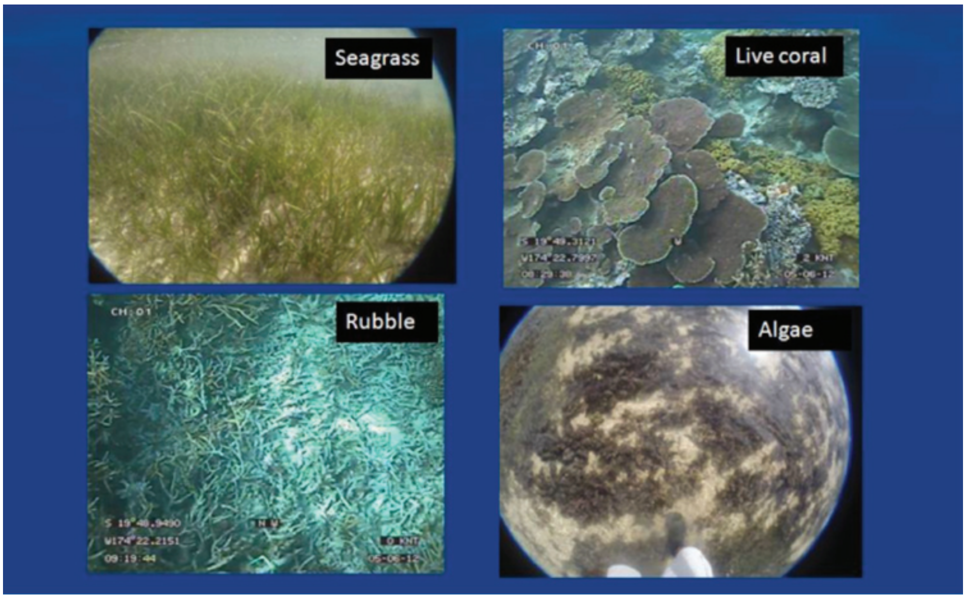



*Figure 13: Examples of geo-referenced photos*

### Key findings

Analysis shows that the major benthic category is substrate (which includes sand, rock, rubble, and dead coral), covering more than half of the area (52%). Seagrass represents 22%, live coral 15% and algae 10%.

Three habitat maps were produced:

**1: Zone type map.** This showed that bank/shelf and land were the largest zones, each comprising around 30% of the total area.

**2: Geomorphological (landform) structure maps.** There are two artificial structures in the reef system — the wharf at Pangai and its protective breakwater. The most abundant landforms were aggregate patch reef (31%), followed by scattered coral/rock in sand (27%), and sand (24%).

**3: Coral reef – biological cover map.** Coral is the predominant biological cover, spreading to almost half of the mapped area at around 43%. Seagrasses and algal beds cover very small areas. However, there are some limitations to the biological cover data that should be noted.

## 1.6 Beach sediment assessment (output 11)

### Introduction

Sediment is loose, erodible material that can contain a range of components, from rocks and minerals to plants and fossils. Sediment can be carried by wind, waves, water and gravity to a new location.

Low-lying islands and their reefs, like Lifuka and its reef, are dependent on carbonate-derived sediments for their stability, as the sediment and rock is mostly made up of material derived from marine organisms. However, relative sea-level rise and coastal development in the recent past has affected the sediment sources, sinks and pathways. Understanding Lifuka's sediment system provides important basic data to assist in effective coastal management and rehabilitation.

This summary was derived from SOPAC Technical Report 165, Understanding the Sediment System. It documents:

- a grain-size analysis (to identify the distribution of grains); and
- a point count analysis (to determine their composition).

This study was based on sediment samples collected from 24 beach and lagoon sites. Sample sites were recorded by GPS coordinates. Analysis was carried out using appropriate technology and approaches.

## Method

***Grain-size analysis***

The majority of the samples collected from the beach were coarse to medium, whereas most lagoon samples were medium- to fine-grained.

The general sediment migration trend was north to south, moving southwards from the causeway north of Lifuka. The southward movement appears to be interrupted by the Pangai wharf.

***Point count analysis***

The composition of sediment provides vital clues to its origin and its movement through coastal zones. Analysis showed sediment samples largely comprised Foraminifera (a single-celled organism that forms shells of calcium carbonate), followed by coral, molluscs (invertebrates) and coralline algae. These marine organisms live in the nearby reef system and the sediment is therefore of a marine origin.

Foraminifera (also known as forams) are rounded particles of 1 mm in size. They are easily picked up and suspended in the water by waves and transported onshore and along the shore by wave- and current-induced water flows. Larger materials, such as coral fragments from reef zones, are disintegrated by waves and biological activities, and generally deposited in the lagoon.

Forams are an important species, since more than half of the sand grains found on Lifuka's west coast beaches are the shells of dead forams. This organism is sensitive to change in its environment (particularly to food availability), as well as to changes to salinity, temperature and nutrients. For this reason, the organism is considered a useful indicator of environmental changes on both a local and global scale.

Forams are a critical source of sand replenishment, and many reef-fringed islands in the South Pacific have a predominance of them in their sand. The majority of the forams found on the beaches of Lifuka were worn by friction, and few consisted of recently live specimens.

## Key findings

Sediment transportation on Lifuka's west coast generally runs north to south, but appears to be halted by the wharf. The presence of reef-derived Foraminifera sediment on the beach is a positive sign, as the coastal plain acts as a reservoir for it. However, sea-level rise and wave events, specifically Lifuka's longshore currents, suggest that in future, the rate of erosion on Lifuka's west coast may risk outstripping the rate of natural sand replenishment.

# 1.7 Household survey (output 10)

## Introduction

The purpose of the household survey was to identify households' reliance and use of different sources of water and how these supplies and households themselves might be vulnerable to the effects of coastal erosion and se-level rise. It also sought householders' perceptions of the rate and causes of coastal erosion and sea-level rise.

## Method

Trained enumerators and technicians visited each Lifuka household to administer the survey. There were 12 topics: Drinking water sources and treatment; domestic water use; well water use; sanitation; rainwater harvesting; water purchase; household tenure; coastal inundation: Tropical Cyclone Rene (2010) damage; other effects from Tropical Cyclone Rene; coastal erosion, and beach mining.

The survey was based on, and links back to, Tonga census data. Of 464 houses on the island, the heads of a total of 392 households were interviewed (some houses were vacant or the residents were absent). This represented 84% of households. A total of 95% of all domestic properties (439) were physically surveyed to document the condition of wells and rainwater tanks.

## Key findings

***Housing and inhabitants***

Of the 392 respondents, 219 were female (56%) and 173 were male (44%). The average age of respondents was 48 years.

A total of 69% of households (269) owned their house. Of those households that didn't own the house in which they lived, just 3.3% (four) paid rent for it. The other households occupied their house rent-free.

The majority of households (59%, or 231) reported that their house was on their own land, and the next largest group reported that it was on land belonging to extended family (20%, or 78). Another 7% (28 households) lived on government-owned land. Notably, 42 households (11%) said the land was owned by another party, which was often a church.

***Water supply***

Lifuka's people preferred rainwater for drinking, cooking, and some washing. Groundwater was still important, but more likely to be used for bathing, gardening and outdoor needs. Rainwater collected from roofs and directed into tanks was the primary source of drinking water for 92% of households. Nearly all households collected their drinking water from an external tap attached to the tank.

Adult men and women (that is, over 15 years of age) were equally responsible for collecting primary drinking water for the household from the external tap. Adults were more than twice as likely to collect household water as young people.

Just 7% of households said Tonga Water Board's metered groundwater, piped to houses, was their primary source of drinking water. Taste is likely to partly account for this, as the salinity (saltiness) of Lifuka's groundwater varies.

Households were asked to identify where they would get drinking water if, for some reason, they were unable to use their usual primary source of drinking water. Interestingly, 83% didn't nominate an alternative drinking water source, suggesting that they either didn't have another source, or that any alternative source was not used or not required.

It's possible that these households have never been in a position where rainwater was unavailable, due to household prioritisation and rationing of available rainwater, or because neighbours and/or family would provide drinking water.

The remainder of the households indicated they would use TWB water (13%) and private wells (4%) when rainwater was not available for drinking.

TWB treated groundwater is piped to 68% of all Lifuka households, and groundwater still provides a

significant proportion of the total volume of water households use, according to TWB figures for July 2011 to August 2012. However, as stated above, people prefer to use this water for personal bathing and gardening, as well as other tasks for which non-potable water is appropriate.

### *Water treatment*

One in five households (79%) said they never or rarely treated their drinking water to ensure it was safe. Of the remaining 21% of households that did treat their drinking water, boiling was the most common treatment.

However, treatment was fairly haphazard, with just 5% of households saying they always, or mostly, treated their drinking water.

Of those households that treated water, 54% said all adults (that is, people over 15 years of age) in the household were responsible for water treatment. Women were solely responsible in 34% of households and men were solely responsible in 12% of households.

### *Security of supply*

More than half of households (60%) said they rarely or never ran out of primary drinking water. For the 32% that did report regular shortages — interpreted as a shortage of rainwater for drinking once every six months — possible explanations included limited collection due to inadequate guttering on roofs, overuse, inadequate storage for family size, and leaking storage.

*Water storage*

Asked where they stored their primary drinking water, 40% of households said it sat in the outside rainwater tank until needed, with other people putting tank water in bottles (23%), pots or bucket with lids (21%), or pots or buckets without lids (14%).

*Water use*

In general, households preferred rainwater for drinking, cooking, and clothes washing, opting for groundwater (mostly from TWB but some from private wells) to use in flush toilets, showers and baths, outside taps, and garden use.

In general, households with access to TWB water were more likely to have access to water-consuming appliances such as flush toilets, washing machines and showering facilities, compared with households without TWB water. This is likely to reflect the availability of a piped water supply, as well as socio-economic factors.

*Views on improving water supply and quality*

Asked how water supply and quality could be improved, people selected, in order of preference, another water tank, a better tank or better maintenance of the current tank, better service from TWB, and cheaper TWB water. However, the community appeared to believe that installation and maintenance of rainwater harvesting equipment for households was the government's responsibility, rather than an individual responsibility.

Lifuka's people get water from more than one source, that is, rainwater harvesting and groundwater, which improves water security. Rainwater harvesting alone is unlikely to meet demand, especially in periods of low rainfall, and it is also important that the community recognises how much it relies on these sources and ensures protection and improvements to maintain quality and quantity.

The survey showed that water quantity was considered more important than water quality. But this may reflect a general lack of awareness about the risks of poorly maintained and stored rainwater and the extent of groundwater contamination.

*Coastal inundation and erosion: Where does flooding happen, and how often?*

Most of Lifuka's infrastructure is inland, and more than 92% of surveyed households reported never having suffered sea-water flooding. Of the 8% (30 households) that reported their properties had been flooded, half said they were flooded annually and the other half said flooding was a rare occurrence.

However, when narrowing the focus to land within 120 m of Lifuka's coast, an estimated 29% of households had been flooded in the past, with 14% reporting annual flooding. The King's Palace, the hospital, and island council offices are among the commercial and residential infrastructure within 120 m of the coast.

In Pangai, a significant 39% of households within 120 m of the coast reported flooding in the past.

Percentages were somewhat lower in Holopeka (29%), Hihifo (25%) and Koulo (20%). In Pangai, 30% of households reported suffering annual flooding, and 10% of Hihifo and Koulo households reported the same. There were no reports of annual flooding at Holopeka.

Amongst the Pangai households that reported their land had been inundated, 29% said the water level reached above the living-room floor on at least one occasion.

The results were mapped for each area as below.

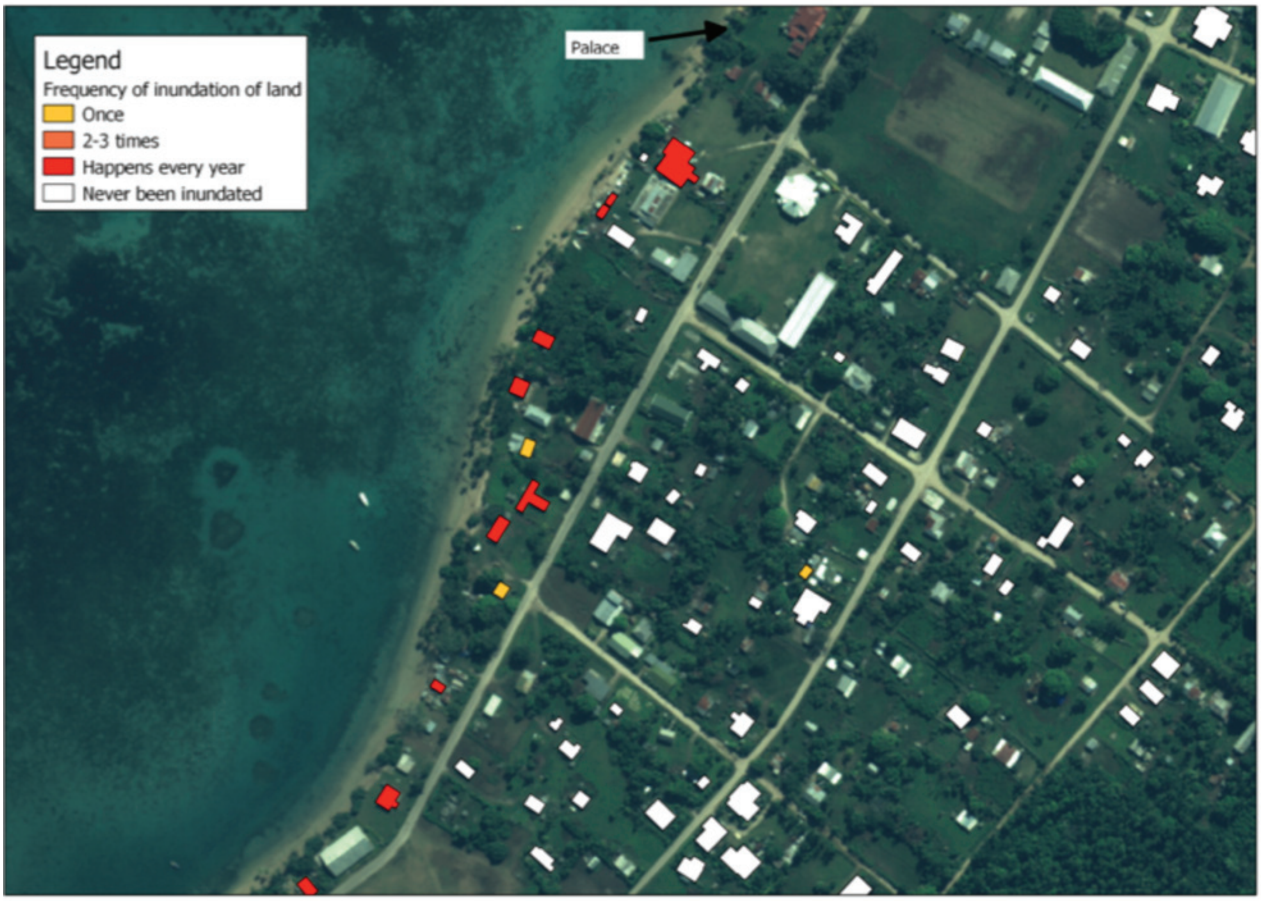



*Figure 14: Map of Pangai, with households that reported sea-water flooding marked*
*The impact of Tropical Cyclone Rene*

Lifuka people agree that Tropical Cyclone Rene (2010) was the most damaging event of recent years. The cyclone, which reached Category 4 strength at its peak, passed through the Ha'apai Group on Monday 14 February 2010, accompanied by heavy rain, strong winds and storm surges.

Of the 392 households interviewed, just 11 (3%) reported that their house had been inundated as a result of Rene. They were in Hihifo (seven houses, giving a 4.8% inundation rate), and Pangai (four houses, for a 2.1% inundation rate). Of these houses, more than half (55%) reported no damage, and 45% reported minor damage requiring minimal repairs.

As a result of Rene-caused flooding, four of these households lost floor coverings (33%), three households (25%) lost refrigerators, three (25%) lost beds, mattresses, chairs, tables, or wardrobes, and two lost washing machines (17%).

After Rene, one in three households (122) reported having problems with their water supply. The main causes were rainwater tank or roof damage, such as cracks and leaks, and a lack of power for water pumps. In the meantime, most households continued using rainwater. Seven households (1.9%) reported someone suffering a cyclone-related illness following Rene, and nine households (2.3%) reported lost days of paid work due to the need to clean up.

### *Community perspectives on coastal erosion*

Coastal erosion is a serious concern, with 98% of households expressing the opinion that the western coastline has receded in recent years. People considered coastal erosion to be a recent phenomenon, with 52% of households stating that the erosion started after the 2006 earthquake. Those who considered that erosion started before 2006 believed it had accelerated in the aftermath of the earthquake.

Pangai people, on average, believed that their beach had shrunk by 18 m (Hihifo 18.3 m, Koulo 16.6 m, Holopeka 10.1 m). Erosion is most notable in Pangai, but it appears to be worse than residents think: satellite imagery analysed by the SPC Oceanography team suggested the beach at Pangai had receded up to 40 m in the past 44 years.

The coastal modelling that is a part of the wider project will quantify the erosion process. However, we need to know the community's perceptions of coastal erosion to design adaptation strategies for Lifuka.

Asked how coastal protection should be improved and given a list of options, people most often chose building a foreshore/seawall (76%, or 298 households), although some expressed concern over the quality of any new foreshore and the need for ongoing maintenance.

Replanting of coastal vegetation was the second most favoured option (35%, or 137 households), though many respondents stressed the necessity for salt-resistant vegetation.

The majority of households didn't link coastal erosion with human activities such as beach mining for domestic purposes, and just 17 households (4%) chose the third most commonly-cited option to protect the coast, halting mining. Beach mining in Lifuka is illegal without a permit, but was commonly practiced — 46% of households (180) reported undertaking beach mining, with the village of Koulo having the highest percentage of households that mined (78%). Both men and women mined, using the materials for general building purposes (69%) as well as domestic tasks, including gardening and landscaping (25%).

Whilst beach mining by householders is reported to be relatively small (on average 2.4 cubic metres a year per household), the largest proportion occurs within Pangai, which can be reasonably expected to contribute to the area's coastal erosion. But without knowing more about the replenishment rate of the Lifuka coastline, it is difficult to determine how much aggregate mining is contributing to coastal erosion.

On the question of coastal protection, a small percentage of respondents (eight households or 2%) believed that the causeway connecting Lifuka and Foa might be a cause of coastal erosion, suggesting redesigning it in case it was preventing sand sedimentation on the shoreline.

### *Community perspectives on sea-level rise*

All 366 households that commented on sea-level rise expressed concern about it, with 20.5% (75 households) believing that it posed a serious threat to their livelihoods and would cause further damage to the coastline.

Many of this group feared that Lifuka would one day be submerged. The most frequently-cited solution (by 18%, or 65 households) was migration elsewhere, facilitated by the government.

As discussed earlier, when asked how coastal erosion could best be managed, respondents generally showed little enthusiasm for relocation. However, when asked about sea-level rise, people commonly suggested relocation as a viable option.

It appears that Lifuka's people perceive coastal erosion as seen as something local and visible that can be dealt with through structural means, but that sea-level rise causes fear. None of the respondents suggested infrastructural solutions to cope with rising sea levels. This suggests a widespread lack of knowledge regarding the effects of sea-level rise, or understanding that while these changes are happening slowly, they are a reality and communities need to adapt.

A total of 5% of respondents (17) connected sea-level rise with human actions, identifying the need to reduce emissions and to protect the beach from sand mining and tree clearing. A total of 5% of people (19 households) believed that nothing could be done to prevent or mitigate sea-level rise. A small number (3%, or 14 households) argued that the phenomenon was 'God's will' and that only prayer would provide a solution.

***Groundwater and rainwater infrastructure***

The majority of households (85%) had adequate roofing — usually made of corrugated iron — for rainwater harvesting, but 15% of roofs required replacement or substantial repair.

The amount of rainwater collected could be improved by adding guttering to cover more roof area and better maintenance of gutters. More than 85% of all households collected 50% or less of the rain falling on the roof. More than 75% of all houses had gutters that were improperly fitted, had sections missing or broken, or for which the survey indicated water losses.

Rainwater in tanks was not tested for contamination, but a risk assessment on the quality of rainwater in tanks suggested that two-thirds of all households had a moderate to high risk of contamination, which increased the potential for water-borne disease.

Improvements could be made to reduce the risk of contamination, such as ensuring tank openings were screened, regular clearing of gutters, removing any vegetation overhanging roofs that might provide ready access for birds and other animals to roofs (which could introduce faecal contamination), keeping buckets clean and out of reach of animals, and protection of taps on tanks from animals. In general, rainwater harvesting systems required low but regular maintenance.

Groundwater is an important water source for Lifuka, supplied by both the Tonga Water Board and private wells. But as cited in 1.2 Groundwater resources assessment, 95% of groundwater samples tested positive for *E. coli*, requiring treatment prior to its use for most domestic purposes.

## Key findings

Without improved on-site wastewater disposal, the risk of water-borne diseases will remain high. Alternative options for sewage disposal should be developed, such as properly installed and maintained composting toilets or improved wastewater treatment systems and better enforcement of building codes for on-site wastewater systems.

Protection of TWB wells and pumping galleries from surface inflow of contaminants and access by animals, and targeting these areas for well-head protection, will assist with improved water quality from the TWB source areas.

TWB's water treatment at the time of sampling was found to ineffective in removing *E. coli*. Better

enforcement of standard operating procedures or improved treatment is required. Groundwater was tested for salinity and this was found to be at acceptable levels.

The management of coastal mining around Lifuka should be revisited. Given that the community requires a regular supply of aggregate, and that it is inappropriate to mine beaches that are identified as vulnerable, consideration of more appropriate locations would be worthwhile.

Consideration should be given to an awareness-raising programme providing incentives to householders to maintain an efficient and safe rainwater harvesting system. An effective way forward would be a community-based approach to water safety planning, with the clear message that householders are responsible for maintaining an efficient and safe drinking water supply.

Encouraging community engagement is suggested as a way to raise awareness about sea-level rise and what it means for lives and livelihoods.

# B2: Community assessment

## 2.1 Community Engagement Strategy and Community Assessment Manual (outputs 9, 20 )

### Introduction

This process aimed at engaging people in order to collect qualitative data. While the Household Survey provided situational data, individual interviews and focus-group discussions provided qualitative data on the impacts of coastal erosion, such as recording people's experiences coping with coastal erosion and what was important to them in devising ways to adapt.

### Method

The objectives of the Community Engagement Strategy and Community Assessment Manual included:

- perception of the impacts of coastal erosion and changes on availability and the quality of fresh water, and the implications for people's activities and wellbeing;
- identification and description of existing coping strategies/adaptation practices to deal with coastal erosion and the scarcity of fresh water; and
- assessment of particular needs to improve the adaptive capacity and the resilience of Lifuka's communities.
- A participatory, focus-group approach was adopted, as it presents several advantages:

- It enabled different members of the communities to express their views and to be involved in identifying what factors make them vulnerable to coastal erosion and sea-level rise.
- Information generated by the communities, combined with technical assessment and scientific knowledge, contributed to developing a holistic view of adaptation issues.
- Such an approach facilitated exchanges of information and partnerships between different stakeholders from communities, civil society organisations and governmental institutions.
- It supported the identification of suitable solutions to enhance communities' capacity to adapt.
- It increased ownership and viability of adaptation strategies by the communities.

The methodology to set up community consultations including concepts, processes, planning, the tools to foster a safe and open environment for discussion, and tips for facilitators, are contained in the manual "Working with Communities"; they were developed from an approach employed by the Tonga Community Development Trust and tools from the Climate Witness manual developed by WWF. Training was provided to representatives of institutions involved in the project and facilitators. These tools can be replicated in a wide range of community settings.

The community assessments were conducted by a team of four facilitators coordinated by TCDT. A series of focus-group discussions were conducted in Lifuka In April and May 2012 in order to identify and analyse people's perception of the causes and impacts of coastal erosion and sea-level rise. In the first round, 60 focus groups were held with the following breakdown: in each of the five communities, 12 meetings were held with men and women in separate groups and two with young people. An average of 16 people from each cluster participated in each focus-group discussion, and more than 100 people participated, which represents more than 120 hours of consultation for the initial phase. The groups provided information on people's perception of changes in their environment and how those changes were impacting on their lives.

During the second round of focus-group discussions, communities were asked to develop their own action plans for adapting to climate change. At this point, 24 people in Koulo, 26 in Holopeka, 35 in Pangai, 35 in Ha'a'tou, and 37 in Hihifo took part in three-hour sessions held in each community.

In March 2013, representatives of the communities were invited to participate in a two-day briefing in Nuku'alofa, during which the technical working group presented the conclusions of its technical assessments and discussed adaptation measures. In April 2013, meetings were organised in each Lifuka community where, once more, the technical assessments and possible adaptation measures were presented.

*Interviews*

In May and June 2012, residents of 63 households, one guest-house and workers in eight offices in Pangai and Hihifo were interviewed individually in order to obtain a greater depth of information than was possible in a focus-group setting. The respondents were those who, because of where they lived and/or worked, were more vulnerable to sea-level rise and environmental change.

The interviews collected information about how people perceived the impacts of coastal erosion and sea-level rise, as well probing as their values, their ideas on possible solutions and the potential obstacles, and what they thought could enhance people's capacity to adapt to environmental change.

## Creating participatory tools in focus groups

There were between six and 12 people in each focus group, led by appropriately trained, local facilitators. Men, women and young people conferred in separate groups, recording their ideas in words and pictures on large sheets of paper. Then, all groups were brought together to share their ideas and the overall results were documented. The amount of time spent on this varied depending on the activity.

The following tools were used:

1: Village map and land-use map

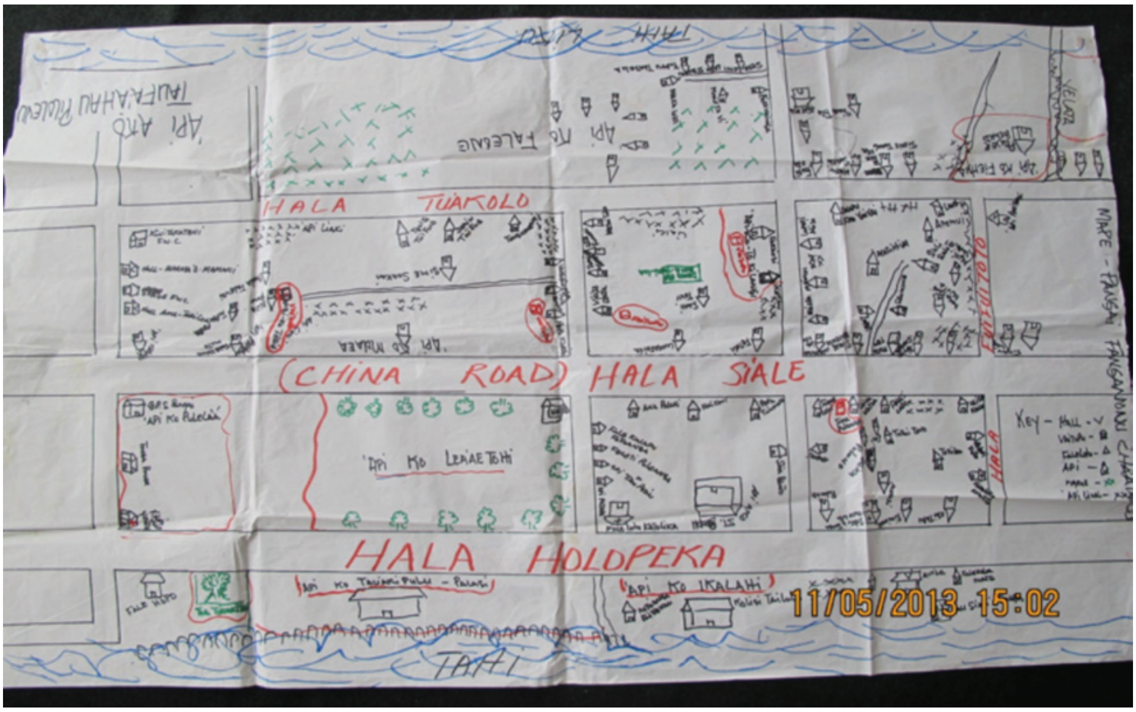



*Figure 15: Example of a community map, Holopeka community*

2: Historical timeline

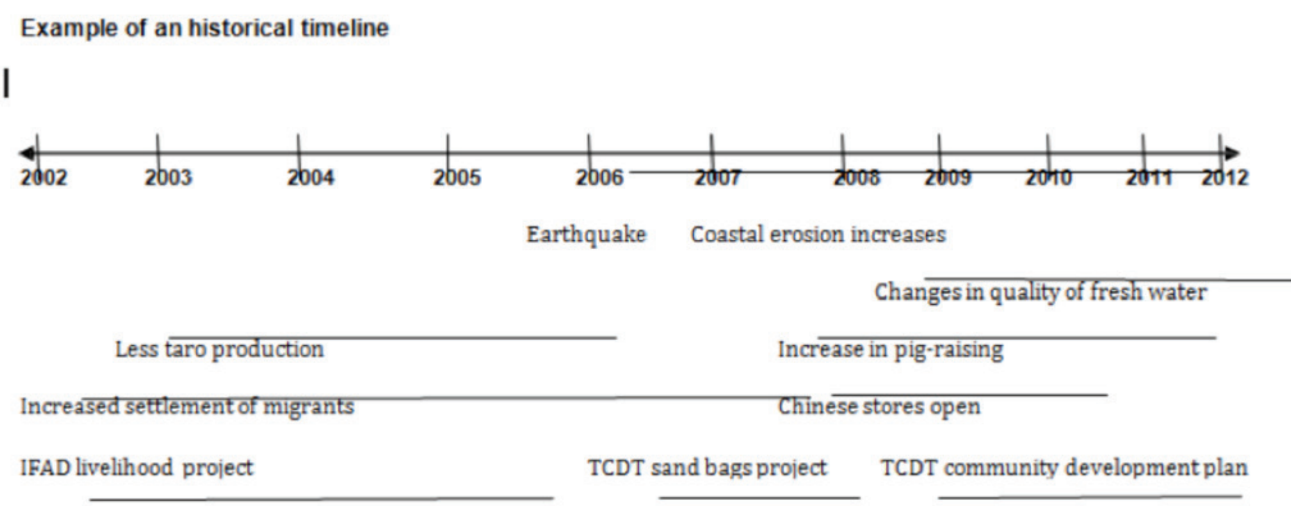



*Figure 16: Example of an historical timeline*

3: Seasonal calendar

4: Seasonal dependency matrix

5: Food security assessment


*Figure 17: Changes in food consumption, Lifuka, 2012*

6: Inventory of natural resources and changes in biodiversity

7: Division of labour and activity matrix

8: Impacts of coastal erosion, water stresses, and climate variability on natural resources and livelihoods. See Table 3 for an example.

*Table 3: Results from a Lifuka meeting, 2012*

| **Changes in the community after the 2006 earthquake** |
|---|
| **Environment**<br>The coastline of Lifuka from Koulo to Hihifo is undergoing coastal erosion and is changing.<br>**Displacement of households further inland in Hihifo**<br>Two houses already relocated and six more still awaiting completion of government procedures.<br>**Household income**<br>Household income is decreasing due to sea level and transformation at sea affecting type of fishing carried out in the coastal area (too deep) and discouraging people from fishing.<br>**Ocean and coastal area**<br>Species usually collected are octopus, sea grapes, seashells, etc.<br>There used to be a mountain of sand in between the southern end tip of Lifuka/Hihifo and Uoleva Island in the late 1970s up to late 1990s. Now it has disappeared.<br>Before 2006, no boat could come near the beach because it was shallow. They all anchored further away in the deep sea.<br>Nowadays boats almost come right over and anchor on the beach because of sea-level rise.<br>Seafloor is no longer covered by stones/sand. It is now covered by seaweed which attracts 'ufu, a type of fish that is a good indicator for seaweed environment.<br>**Type of fishing**<br>Fishing methods of the past are no longer used these days.<br>Fewer people do ama ta (fishing at night at low tide using a cane knife and torch) because the area is still deep at low tide.<br>Fewer people go fishing because fishing gear is more expensive and unaffordable for many.<br>Women are now diving when reef fishing, whereas in the past, it was just men who dived.<br>Decline of certain fish seasons (e.g. taa oo).<br>**Handicrafts**<br>Taking pandanus to the sea: sea is not clean any more, which affects the cleanliness and quality of the pandanus and mats.<br>Cultural sites<br>Before 2006, when grave lids were opened for burial of new bodies, they were dry. Nowadays, when graves are opened for funerals they are already full of water.<br>Some people have already taken action by relocating their dead to cemetery inland. Alternatively, people can raise the grave's floor to a much higher level before burial, but this costs more. |
| **Changes in water resources** |
| **Rainwater**<br>Not enough water harvesting systems — water tanks and gutters.<br>Water treatments change the taste of the water.<br>Some cement tanks were cracked during the earthquake.<br>Cement tanks need to be treated by the Ministry of Health regularly.<br>Water from tanks of homes on the beach is salty because of salt spray.<br>Taste of the water in cement tanks is different from the filters (fibre ones). The water from cement water tanks is cooler.<br>**TWB water**<br>Problems with the water pump causes water shortage sometimes.<br>Before the tap water was salty, now it's sweeter (vaitaki).<br>**Groundwater/well water**<br>Underground water level goes down when the sea is at low tide.<br>There used to be a groundwater well close to the sea, where the Lofanga residence is situated now. People used to fetch water from the well for washing and cooking. The construction of Lofanga residence led to the land filling of the well and people are now relying on piped water. |

| Climate change |
| --- |
| **Weather patterns**<br>Cooler weather from January to December.<br>Cyclone no longer occurs according to its season but any time of the year.<br>In the past, cyclones rarely occurred but the intensity was stronger. But these days they occur frequently with low intensity.<br>**Physical environment**<br>Before there used to be no German grass but these days there is lots of it. This is due to lots of cutting and mowing bringing in new grass.<br>The size of the fruits and taste is not the same. This is caused by soil infertility and climate change.<br>Too much cultivation of the same land leading to infertility of the soil affecting the fruit trees or crops production and infertility of the soil.<br>Fruit trees no longer bear according to seasons.<br>**Health**<br>There are changes in people's features and lots of different type of diseases (e.g. diabetes and high blood pressure).<br>More people got sick in the past. People are more health-conscious at present.<br>**Agriculture**<br>People started using chemicals.<br>Sometimes people used something to soften up the soil before digging (e.g. watering the area they are going to dig).<br>Labourers are no longer used and tractors and ploughs are now replacing them.<br>The size of banana and plantain are smaller compared to the past.<br>**Lifestyle and behaviour**<br>In the past people used to consume traditional food and they were stronger, but these days people are depending on unhealthy food from stores. |

9: Management of fresh water. This tool identifies people's reliance on different sources of fresh water through focused questions about well water and groundwater, rainwater harvesting, and reticulated water.

10: Institutional mapping and Venn diagram

11: Community values

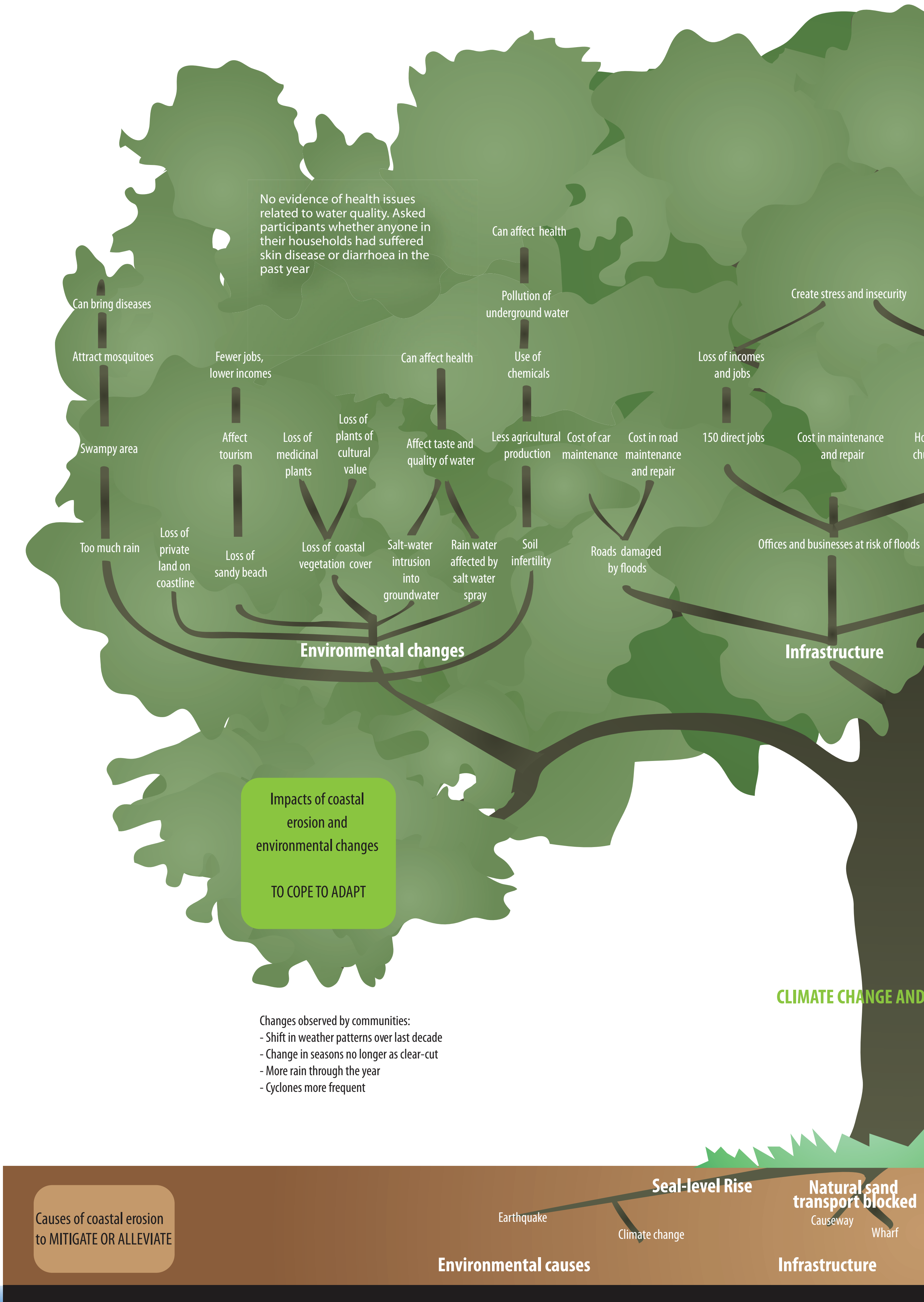
12: Causes and impacts of vulnerability to coastal erosion and water stresses: This tool identifies the causes of vulnerability and impacts of coastal erosion and sea-level rise. Communities drew a 'problem tree' with the trunk of the tree representing the problem, the roots representing the causes of vulnerability and the leaves the impact of this vulnerability.

*Priority ranking*

13: Planning adaptation: The tool supports each community to develop its own adaptation plan to cope with coastal erosion and sea-level rise. The root causes were listed, and identified were possible solutions, the individuals and institutions responsible, resources needed, a time frame for action and responsibility for monitoring and follow-up.

*Table 4: Example of community plan from Ha'ato'u, 2012*

| | ROOT CAUSES | SOLUTIONS | WHO WILL BE RESPOSIIBLE FOR THIS ACTIVITY IN THE COMMUNITY | INSTITUTIONS REQUIRED TO ASSIST | RESOURCES NEED | TIME LINE | MONITORING & FOLLOW UP |
|---|---|---|---|---|---|---|---|
| 1 | Sand transport blocked | Use piling system for the wharf landward<br><br>Open (channel) the causeway to Foa<br><br>Build a bridge instead | District officer, town officer, youth president for Lifuka, division committee within the community, people's representatives to Parliament | Environment & Survey, Mins of Infrastructure, HDC | Heavy machinery and all construction materials needed | Dec 2012 | HDC, district officer, town officer |
| 2 | Sand mining | Enforce existing legislation<br><br>Establish a specific location for sand mining<br><br>Appoint someone to guard/patrol around the coast making sure this activity is not carried out | Village police, village committee, people occupying the coastal areas | Fisheries, Mins of Infrastructure, Environment & Survey, Governor's office in Ha'apai, Fisheries | Warning billboard to be installed in areas where sand mining<br><br>banned. Fence site established for this activity<br><br>Security house at this site, camera | Dec 2012 | Village committee, district officer, Survey and Environment |
| 3 | Burning of solid waste – plastics and tyres | Establish an official dumping site for Lifuka<br><br>Enforce existing legislation<br><br>Require households to have their own private dumping areas on their properties and stop disposing of their rubbish on vacant lands and on public areas | Town officer, village committee, health inspector | Mins of Health, Tourism | Garbage truck. Piece of land as dump site, rubbish cans and plastic bags | Dec 2012 | Village committee, Environment, HDC |
| 4 | Cutting of coastal vegetation | Enforce existing legislation<br><br>Replant more plants<br><br>Re-establish the village police post | Young people, village police post | TCDT, Environment, Agriculture | Plants and seedlings to plant, billboard to warn people off site, wires to protect new plants, bicycle, camera | Jan 2013 | Environment & Survey, police, village committee, people living near the coast |
| 5 | Sea-level rise | Build a foreshore<br><br>Cease building houses and infrastructure near the areas vulnerable to coastal erosion.<br><br>Replant more trees | Town officer, district officer, village committee | Environment & Survey, Fisheries, TCDT, civil society | Heavy machinery for construction of the foreshore | April 2014, foreshore | Environment, HDC, Mins of Infrastructure |



No evidence of health issues related to water quality. Asked participants whether anyone in their households had suffered skin disease or diarrhoea in the past year
Can affect health
Pollution of underground water
Can bring diseases
Attract mosquitoes
Fewer jobs, lower incomes
Can affect health
Use of chemicals
Create stress and insecurity
Loss of incomes and jobs
Swampy area
Affect tourism
Loss of medicinal plants
Loss of plants of cultural value
Affect taste and quality of water
Less agricultural production
Cost of car maintenance
Cost in road maintenance and repair
150 direct jobs
Cost in maintenance and repair
Too much rain
Loss of private land on coastline
Loss of sandy beach
Loss of coastal vegetation cover
Salt-water intrusion into groundwater
Rain water affected by salt water spray
Soil infertility
Roads damaged by floods
Offices and businesses at risk of floods
Environmental changes
Infrastructure
Impacts of coastal erosion and environmental changes
TO COPE TO ADAPT
Changes observed by communities:
- Shift in weather patterns over last decade
- Change in seasons no longer as clear-cut
- More rain through the year
- Cyclones more frequent
Seal-level Rise
Natural sand transport blocked
Earthquake
Climate change
Causeway
Wharf
Causes of coastal erosion to MITIGATE OR ALLEVIATE
Environmental causes
Infrastructure


*Figure 18: Problem tree from a Lifuka group, 2012*

## 2.2 Community Values and Social Impact Analysis (outputs 9, 15, 17)

### Introduction

We can judge the success of adaptation planning only by knowing what outcomes people seek, either in terms of impacts avoided or gains achieved. This means understanding what values people accord to elements that are put at risk by climate change, such as access to services, health, housing, income, land, lifestyles, and community stability. The objective here was to understand the values affecting the capacity of the community and different groups of people to adapt, and the values that will likely guide the community's choice of adaptation strategy.

Drawing on the information collected through the participatory approach as described in 2.1, Community Engagement Strategy and Community Assessment Manual, the project team had information to assist in answering the following questions:

1. How do communities perceive changes in their livelihood and wellbeing in relation to coastal erosion and sea-level rise?
2. How have communities adapted/changed/responded to coastal erosion and water stresses in terms of livelihood, disaster preparedness, housing, and natural resources management, etc.?
3. What values guided their choices?
4. What is their pattern of natural-resource use (land-based, ocean-based, fresh water, etc.), and how has this has changed in the face of coastal erosion and sea-level rise?
5. How do they see the future of their community?
6. How they could be involved in addressing some of the issues related to coastal erosion?

### Key findings

In summary, alongside the erosion of their western coastline, Lifuka's people have witnessed a steady erosion of the traditional habits and values that have sustained life for centuries. While change is not in itself a bad thing — and change and diversification are adaptation strategies — some of the patterns of change Lifuka's people report may undermine their ability to be self-reliant and self-sufficient.

Their changing environment was affecting their livelihoods. Based on the consultations conducted, seafloor vegetation was perceived to have changed in several areas, with seagrass beds and hard corals negatively affecting many species, and sea urchins, shellfish and octopus are now found in places they never used to inhabit. Women were generally responsible for inshore fishing, but most were now doing far less of this activity. As a result, households were perceived to be losing a source of protein as well as a source of household income.

In addition, according to those who took part in focus groups and interviews, as the coast has receded, plantations of cassava, taro and yam have been increasingly affected by salt spray, as have pandanus, medicinal plants and the soil itself. Root crops now required chemical treatment to replace nutrients lost from the soil, but yields were lower than in the past. Overall, Lifuka's communities reported that agriculture was declining.

People said that they were increasingly dependent on imported food and this increased their need for cash and affected their health. However, more people now had access to alternative sources of incomes such as paid employment, production of sea cucumber for exportation, and seasonal migration. Production of fine mats remained a major source of income for most families.

It was difficult to assess to what extent increased consumption of imported food was due to the decrease in agricultural production and coastal fishing, or if it was driven by social factors such as availability and preference. It was possible that people were investing less time and effort in traditional and strenuous livelihoods as food was available to buy.

Family and individual safety was a major preoccupation for those living on the coast. Approximately 89 occupied houses were within 50 m of the shoreline, and at severe risk of flooding during storm events. Some houses had already been abandoned and others had suffered foundation damage. Many people were living in fear and wanted to move but could not afford to, or had no land to move to, or were civil servants tied to government-owned accommodation.

Respondents were asked if they thought their dependent children would stay in Lifuka once they reached adulthood. Half said it would be better for their children to leave Lifuka because they would be safer and/or they would have better job opportunities. This showed that at least half the population did not believe the situation would improve in a way that would sustain their current lifestyles. Respondents were asked if they thought their dependent children would stay in Lifuka once they reached adulthood. Half said it would be better for their children to leave Lifuka because they would be safer and/or they would have better job opportunities. This showed that at least half the population did not believe the situation would improve in a way that would sustain their current lifestyles. As Table 1 showed, Lifuka's population decreased 18% between the 2006 and 2011 censuses; increased migration could disrupt the normal pathways and networks by which traditional knowledge is transmitted.

In general, the values that underpinned life in Lifuka were common across Tonga, such as land on which to live, family cohesion, a strong religious faith, the means to sustain life and fulfil community obligations, a good education for children to give them options in the future, and income-generating skills. On Lifuka, there was anxiety that the importance of these values could be disrupted by the changes being wrought through climate change and sea-level rise. People had seen their precious coastal land erode, and with that erosion came anxiety about individual and family safety and security as well as concerns about the preservation of important historical sites and cemeteries.

# SECTION C: VULNERABILITY AND HAZARD ASSESSMENT

## 1.1 Coastal hazards (outputs 8, 13)

***Introduction***

This section summarises the synthesis of information collected in Section B: Mapping the resources.

***Findings***

***Erosion and sea-level rise in Lifuka: 1968 to 2011***

Using satellite images, we are able to see how much the Lifuka coastline has changed in the last 45 years.


*Figure 19: On the left, Pangai in 1968 with the 2011 shoreline superimposed. On the right, Pangai in 2011 with the 1968 shoreline superimposed. Note that the old piled jetty visible in the top third of the 1968 image was replaced by a stone causeway in 1982, and that the present Pangai Harbour, opened in 1996, is visible near the top of the 2011 image.*

Over the past four decades, the shoreline has receded at an average rate of 0.7 m/year, with localised rates as high as 1.4 m/year. Erosion intensified after 1982, when a jetty consisting of concrete piles and timber decking was replaced by a stone causeway and ramp. Coral heads in the area were also blasted to provide a swing basin. The present Pangai Harbour and breakwater were completed in 1996. This construction interrupted the natural longshore sediment drift and appears to have contributed to the erosion south of the harbour along Pangai.


*Figure 20: Left, Hihifo in 1968 with the 2011 shoreline superimposed. Right, Hihifo in 2011 with the 1968 coastline superimposed. Note the intense coastal development over the last four decades along this eroding shoreline.*

## Basic effects of sea-level rise

The Pangai wharf currently sits at 2.5 m above mean sea level (MSL 2011); mean sea level is the average height of the ocean's surface, or half-way point between the mean high tide and the mean low tide. In this case, MSL 2011 was determined by observing the sea level for 39 hours in August 2011.

*Figure 21: Pangai wharf*

The graphic below shows the current-day, calm-weather situation at the wharf.

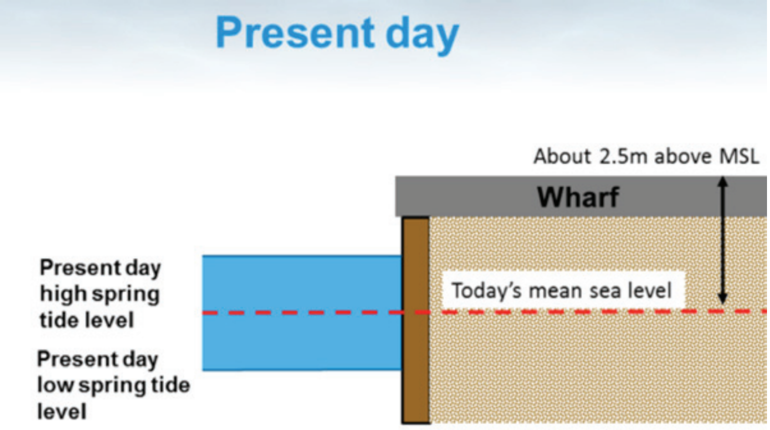



*Figure 22: Current mean sea level (MSL 2011), Pangai wharf. The mean spring tidal peak-to-peak amplitude is 1.4 m.*

In another generation's time — that is, 25 years — and assuming little tolerance for risk, the mean sea level may have risen to 0.4 m above what it is today.

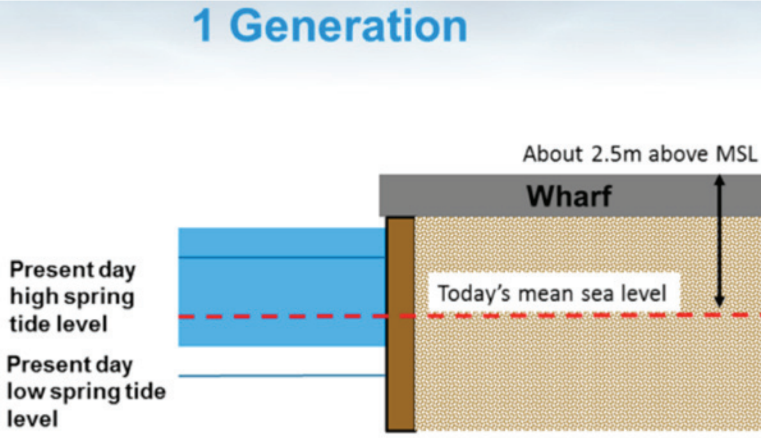



*Figure 23: Envelope of tidal levels by 2036*

In two generations' time (about 50 years), the mean sea level may be some 0.9 m higher than it is today.

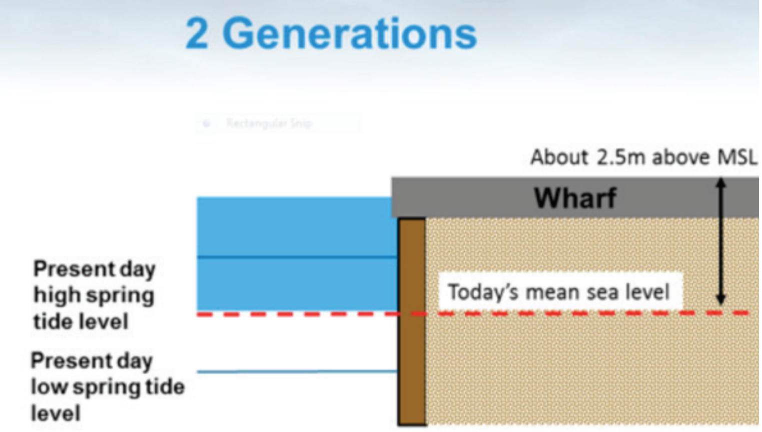



*Figure 24: Envelope of tidal levels by 2036*

In three generations' time (75 years), the mean sea level at the Pangai wharf may be 1.5 m higher than it is today.

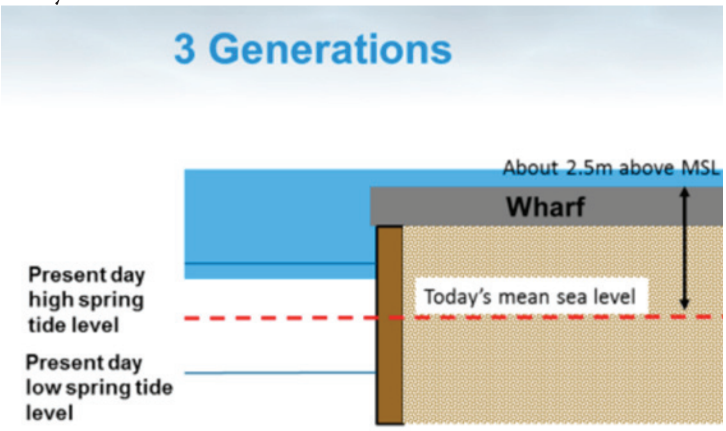



*Figure 25: Envelope of tidal levels by 2086*

In four generations — that is, by 2111 — we may see the sea level approach the level of the wharf's surface, or 2.4 m higher than it is today.

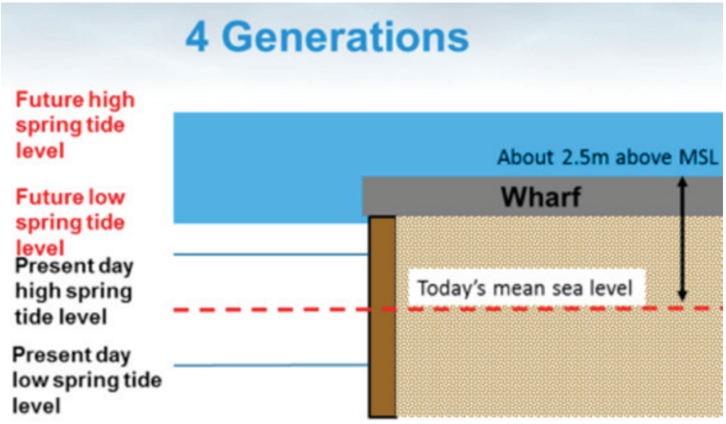



*Figure 26: Envelope of tidal levels by 2111*

## Water-level scenarios by 2100

Such scenarios incorporate technical information that has been gathered in the past about sea-level change worldwide, as well as information about Lifuka's coastal and social environments, and use it to make well-informed projections about the situation in the future. An intermediate–high scenario depicts the likely situation in 2100, based on projected global warming and the impact of melting ice sheets. The highest scenario reflects projected global warming and the maximum plausible contribution of ice-sheet loss and glacial melting. As an example, below is the water-level scenario in 2100 for Pangai:

It shows the results of 'bucket-fill modelling', which is the simplest form of inundation modelling of the mean sea level to the end of this century. This does not include intermediate flooding and associated risks due to higher-frequency events such as storm surge and wave setup during tropical cyclones.

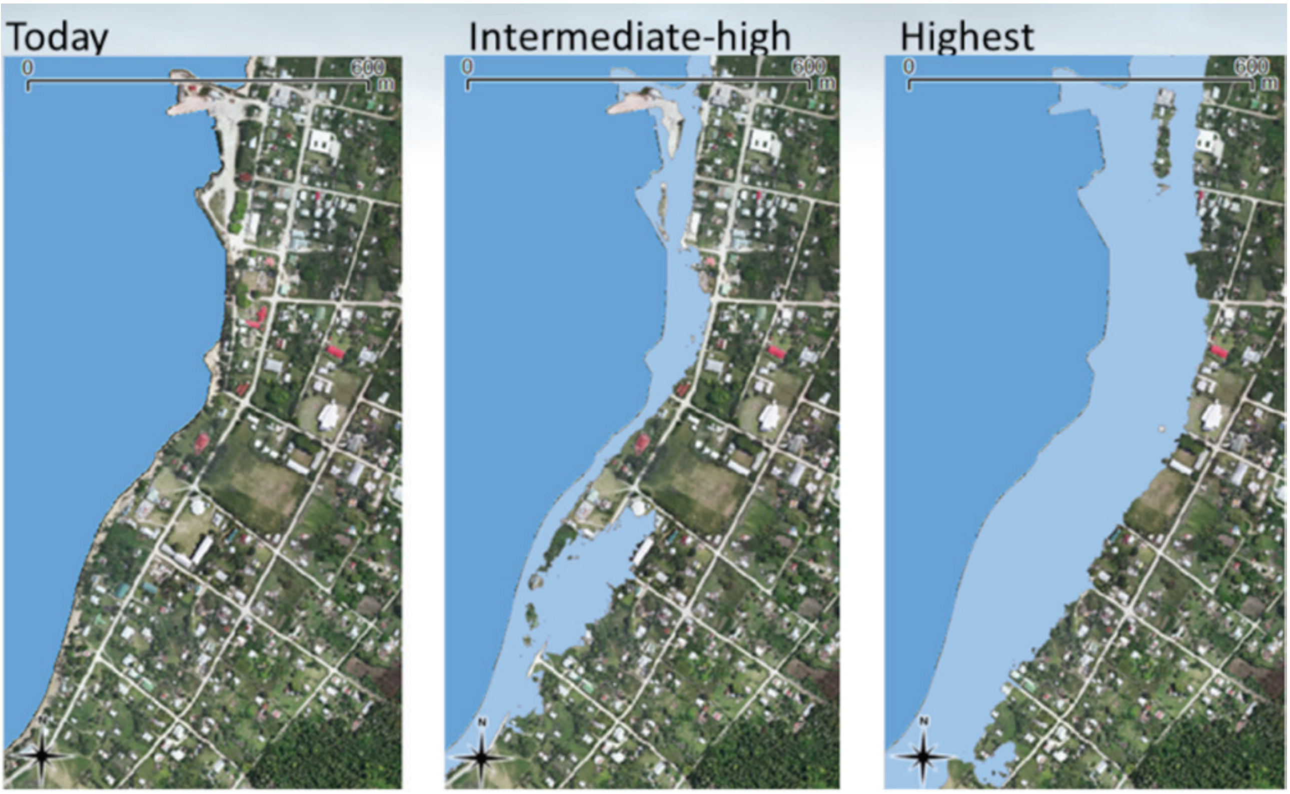



*Figure 27: Water-level scenario in Pangai in 2100*

## Stormwater levels

The schematic below shows how storm winds and air pressure influence water levels on Lifuka's western coast.

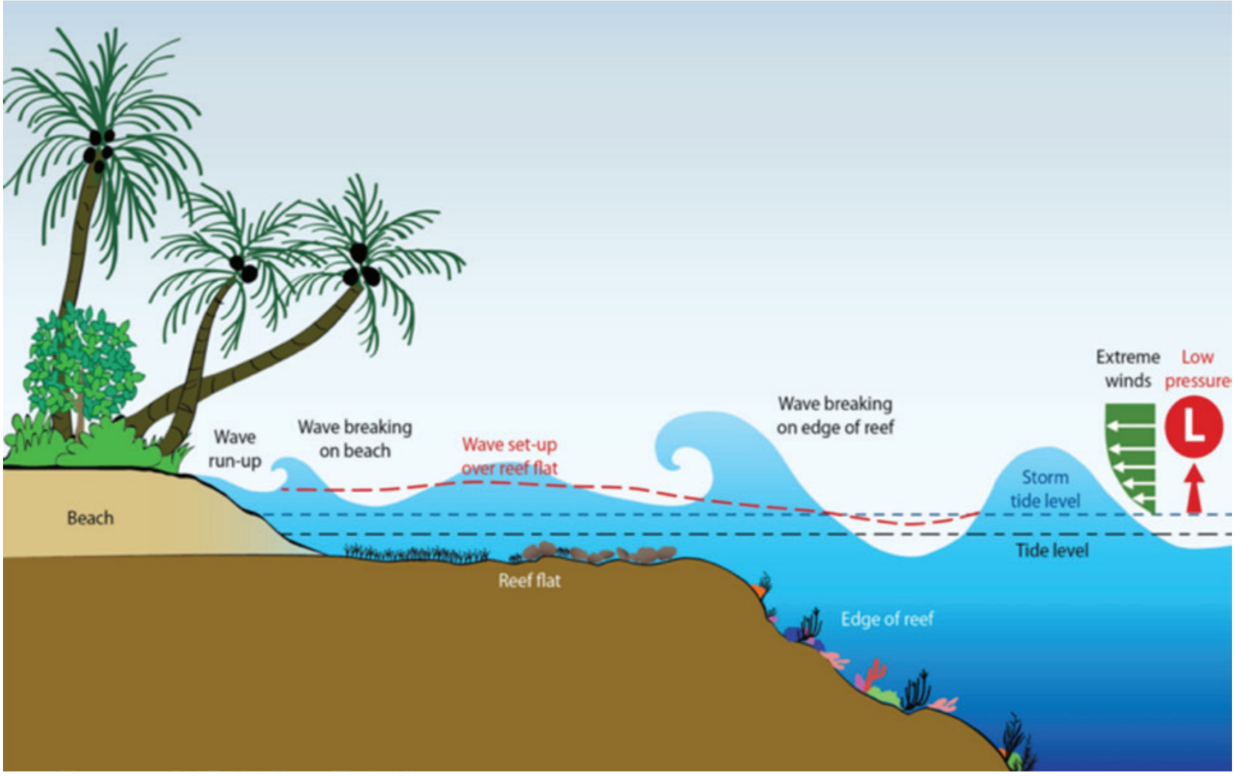



*Figure 28: On steep shorelines like Pacific islands, surface waves generated by storms are the dominant contributor to coastal sea-level extremes via wave set-up. (Source: NIWA)*

At present, under extreme tropical cyclone conditions, Pangai wharf can be flooded as illustrated below.

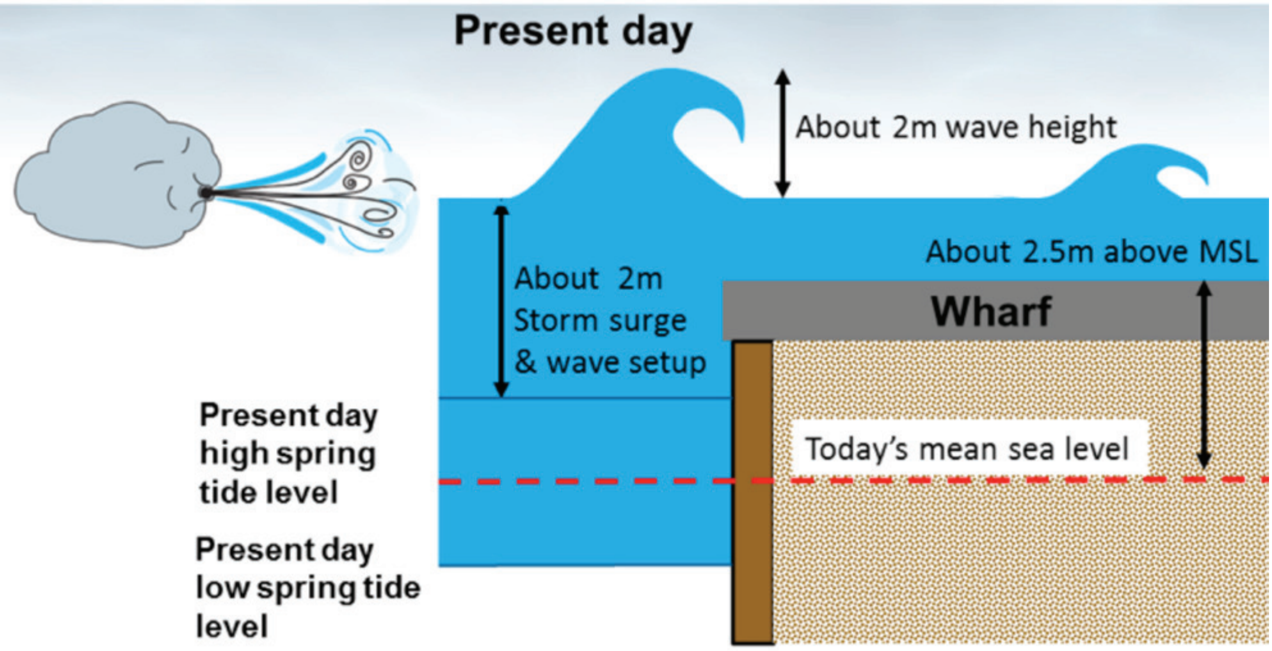



*Figure 29: Schematic showing the effects of an extreme tropical cyclone storm on seas at Pangai wharf, present day*

## Inundation scenarios: Sea-level rise coupled with a category 5 tropical cyclone

As part of this project and at the request of the Government of Tonga, SPC modelled the possible storm surge associated with a tropical cyclone with a one-in-one-hundred years return frequency (1:100 year event). Such an event — equivalent to a tropical cyclone category 5 — would be expected to be highly damaging to the lives and livelihoods of the Lifuka community.

The extent of damage would depend on a number of factors, including location on stable or unstable (erosive) land, proximity to the foreshore, the speed of waves, the elevation of the houses and depth of flooding. However, it is clear that without any adaptation, local people would be very likely to suffer injury from flooding and waves, the loss of personal possessions, and harm to critical amenities such as the police station, fire station, hospital, telecommunications facilities, power utilities, several schools and churches.

Based on the modelling conducted, several key zones have now been identified around Lifuka:

| | |
|---|---|
| Null zone | Areas around Lifuka island that would not be susceptible to inundation in a 1:100 year tropical cyclone event |
| Hazard zone | Areas that would be inundated during a 1:100 year event and that could be subject to wave action of waves <1 m in height |
| High hazard zone | Areas that would be inundated as a result of a 1:100 year event and that would be subject to damaging waves of =>1 m in height |
| Coastal setback zone | Area that is subject to long-term coastal erosion (Figure 47). |

The map next page shows the hazard areas that take into account both slow-onset hazards such as sea-level rise and erosion, and rapid-onset hazards such as extreme storm tides and inundation.

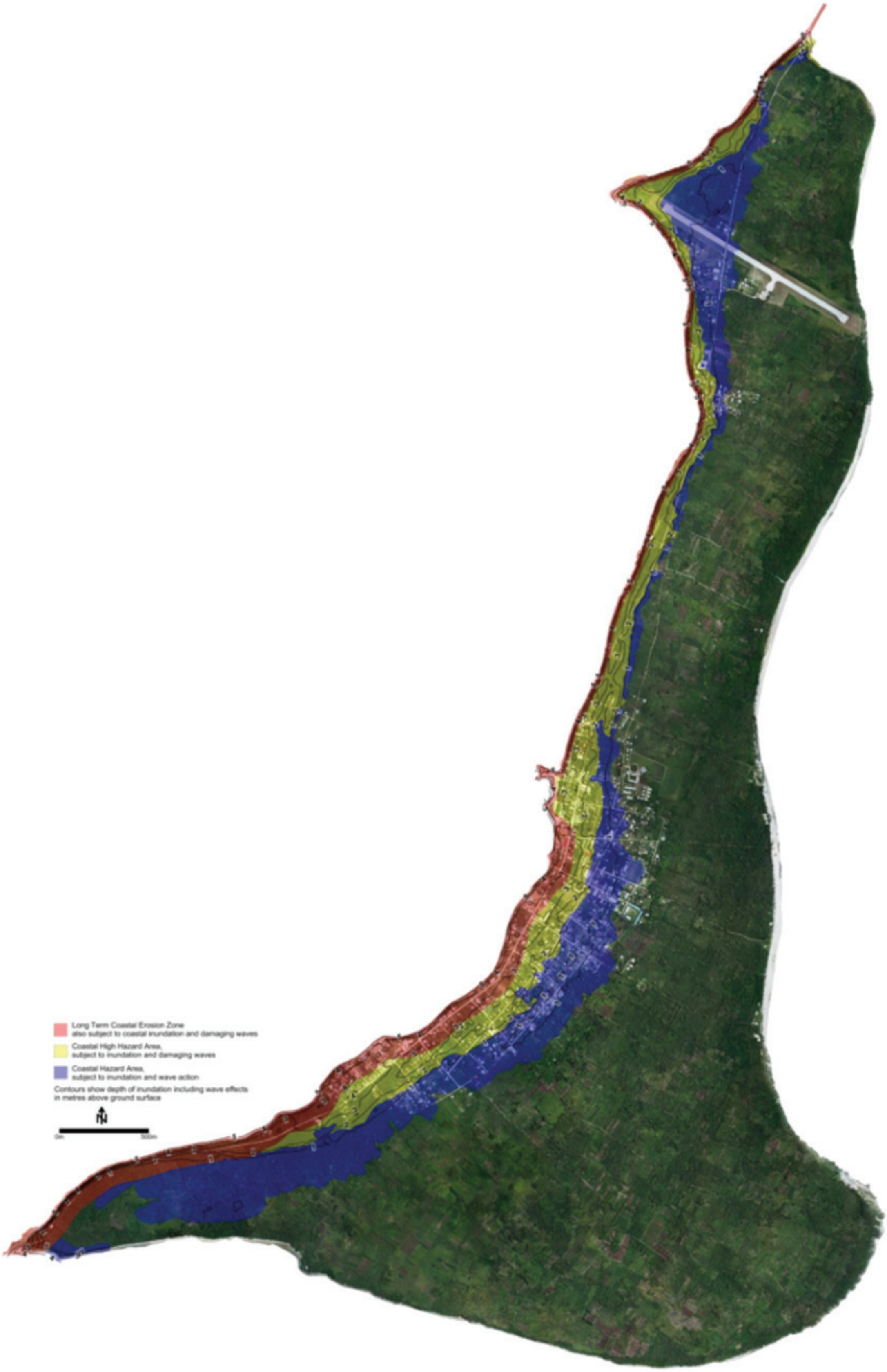



*Figure 30: Hazardous zones in Lifuka in a 1:100 year storm event (equivalent to a category 5 tropical cyclone). See the report Coastal Hazards for methodology.*

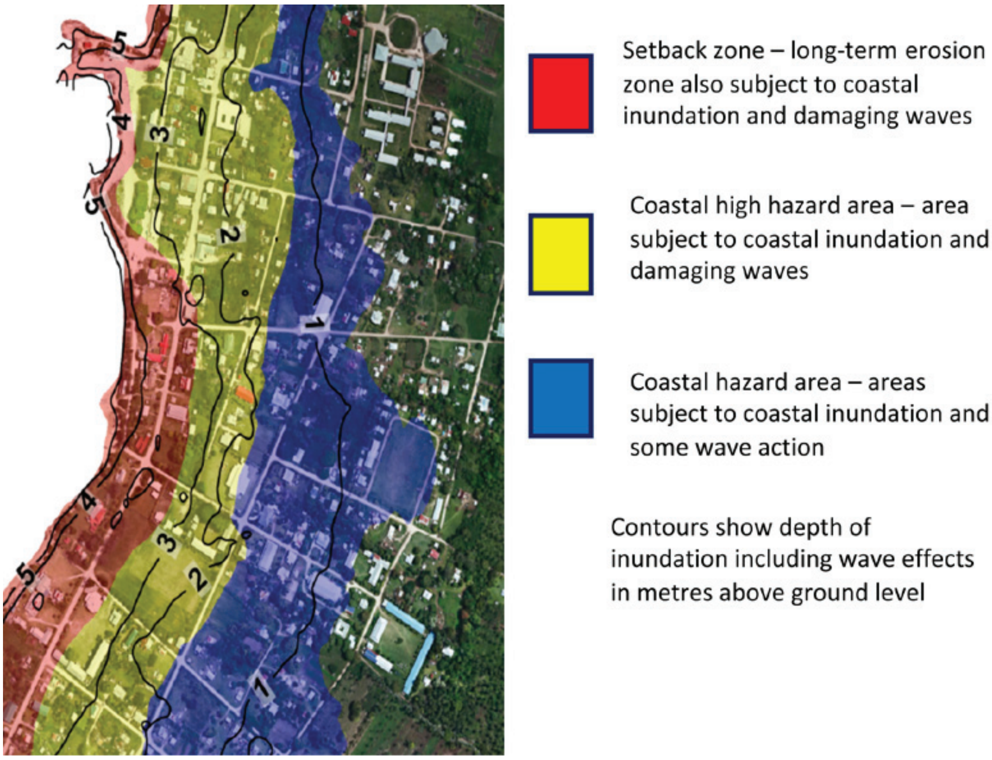



*Figure 31: Hazard zones on Lifuka: a closer look*

The following diagrams show how an intermediate–high sea-level rise (1.2 m by 2100) coupled with a cyclone in 2100 would affect Koulo and Holopeka. The numbers represent the depth of flooding, including the processes shown in Figure 45, in metres above ground level. Also considered were interannual variabilities in the regional sea levels due to ENSO (+0.18 m), as well as mean high-water spring tides (+0.71 m).The dark red area depict the coastal high hazard area subject to inundation and damaging waves. The light red area refers to coastal areas that are subject to inundation and some wave action. The contours show depth of inundation including wave effects in metres above ground level.

*Figure 32: Koulo and Holopeka flood depths in metres, 2100, based on an intermediate–high sea-level rise scenario and severe tropical cyclone conditions (see text for details)*

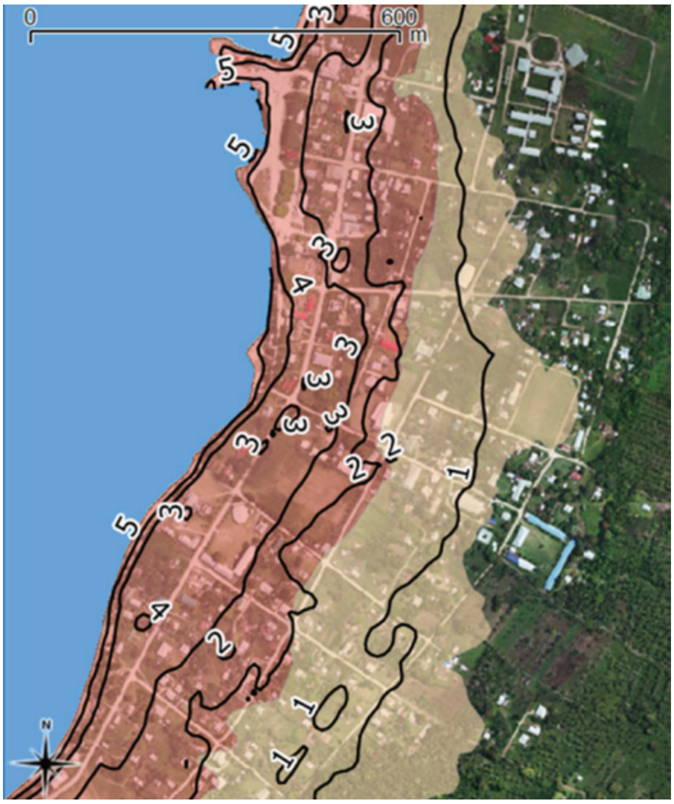



*Figure 33: Pangai flood depths in metres, 2100, based on an intermediate–high sea-level rise scenario and severe tropical cyclone conditions (see text for details)*

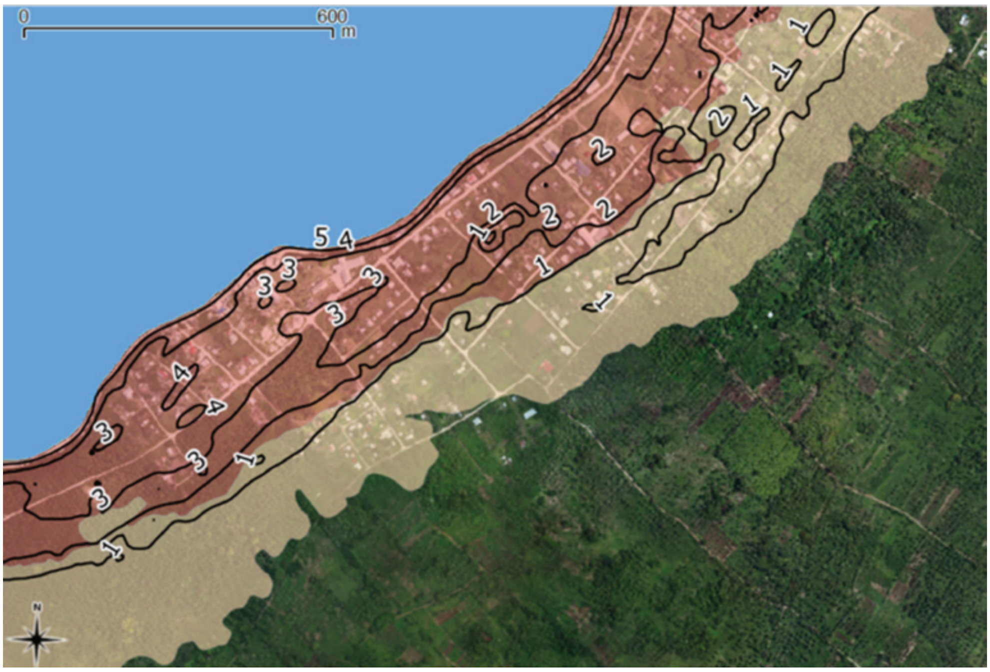



*Figure 34: Hihifo flood depths in metres, 2100, based on an intermediate–high sea-level rise scenario and severe tropical cyclone conditions (see text for details)*

## 1.2 Community values, concerns and exposure to risk (outputs 9, 15, 17)

Refer to B 2.2: Community Values and Social Impact Analysis

# SECTION D: ADAPTATION OPTIONS AND COMMUNITY STRATEGIES

## 1.0 Coastal rehabilitation – engineering options (outputs 13, 14, 16)

### Basic shoreline protection options

In mitigating coastal erosion, there are two broad options: 1) retreat, by gradually moving infrastructure to higher ground inland, or 2) protect, generally by engineering works. Consultation with the people of Lifuka found minimal support for retreat, with the majority of households identifying some form of protection as the most appropriate option.

Conceptual designs for three coastal erosion adaptation options for 2.2 km of Lifuka's western foreshore were developed.

1. Revetments using local coral
2. Revetments using geotextile sand containers
3. Groynes and sand nourishment.

***Option 1: Revetments using local coral***

Revetments are sloping structures that are covered with an erosion-resistant 'armour' and are flexible enough to absorb incoming wave energy. (Seawalls are often vertical and reflect wave energy.)

Major features of revetments are, from the surface down, a stable armour layer, an under-layer, filter layers and toe protection. The filter layer and the under-layer supporting the armour allow water to pass through. Toe protection prevents undercutting and provides support.

***Revetment footprint***


*Figure 35: The space that would need to be taken for the construction of a rock revetment in (left) Pangai, and (right) Hihifo*

Worldwide, rock armour revetments typically use igneous rock (rock formed from magma or lava).

*Figure 36: Rock revetment, Nuku'alofa*

However, as Lifuka has no local igneous rock, coral-based rock would need to be used.

Figure 21 below is an example of what could be built at Lifuka. The existing embankment would have to be regraded.

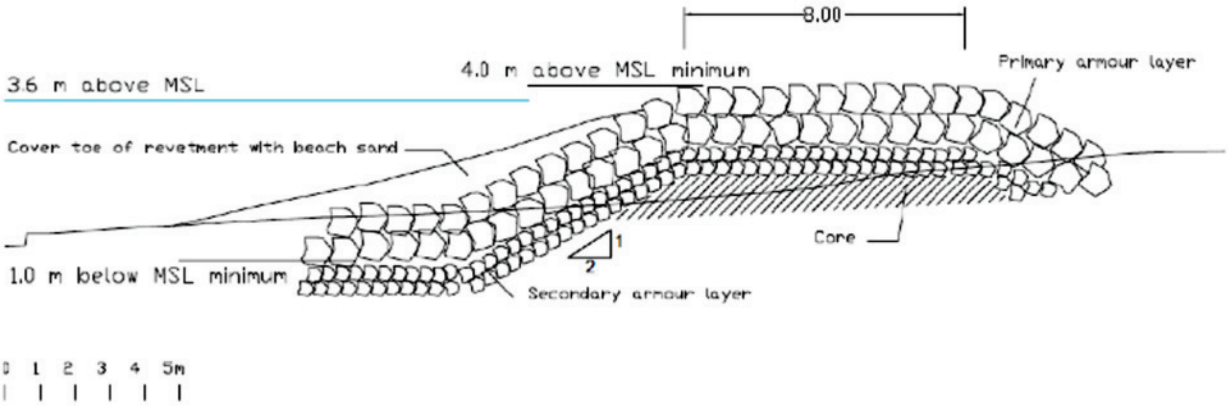



*Figure 37: Example of the type of revetment that could be built at Lifuka*

*Advantages of revetments*

- They can be effective in protecting landward infrastructure from erosion.
- They can be covered with sand, and vegetation can be planted on them to reduce their visual impact.
- They absorb wave energy and thereby help to reduce erosion on the seaward side of the structure. (They can still cause erosion on the seaward side of the structure, however, depending on the slope.)
- They would allow continued development on the coast because they reduce the risk to properties.

*Disadvantages of revetments*

- They can be costly to construct.
- They may not necessarily mitigate inundation, and may provide a false sense of security.

- They can detract from the appearance and use of the beach if they are not covered with sand.
- They have a large footprint and can disturb a large area of embankment during construction.
- They can result in higher rates of beach erosion at the ends of the revetment, which would require bringing in replacement sand.
- They require ongoing maintenance.

*Option 2: Revetments using geotextile sand containers*

Geotextile bags are made of permeable fabrics, usually polypropylene or polyester, that are resistant to puncture, abrasion and the effects of the sun. Filled with sand, they are built into a barrier. The bags generally come in standard sizes of 0.75 $m^3$ or 2.5 $m^3$, and are used in coastal protection worldwide. Below is a typical sand-filled geotextile container revetment at Byron Bay, New South Wales, Australia.

*Figure 38: Sand-filled geotextile container revetment at Byron Bay, New South Wales, Australia*

The main differences between rock revetments and geotextile revetments are:

- geotextile revetments have a more limited lifespan than rock structures because of sun damage and wave attack;
- geotextile revetments are generally cheaper to build than rock; and
- geotextile containers need to be filled with local sand (or can be pre-filled with sand from elsewhere).

Figure 23 shows a geotextile revetment design that could be used on Lifuka.

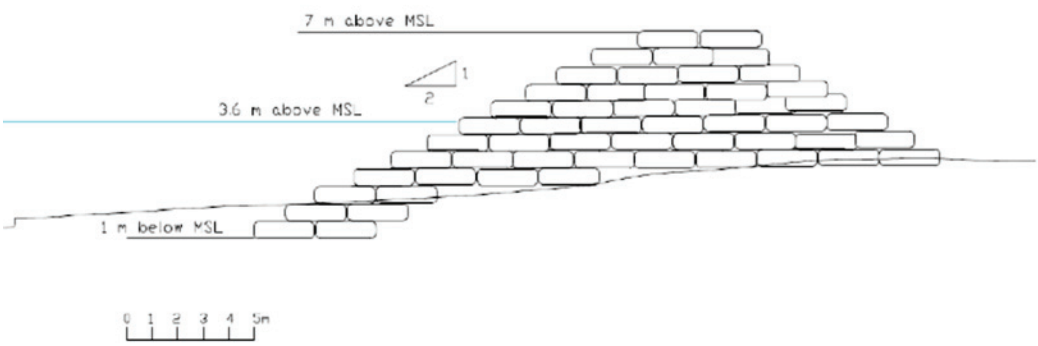



*Figure 39: Example of a geotextile revetment design*

***Option 3: Groynes and beach nourishment***

*Groynes*

Groynes are walls of sand-filled geotextile bags, rock or even wood built at right angles to the shoreline to trap sand and stop it drifting away. In the case of Lifuka, we are considering sand-filled bags.

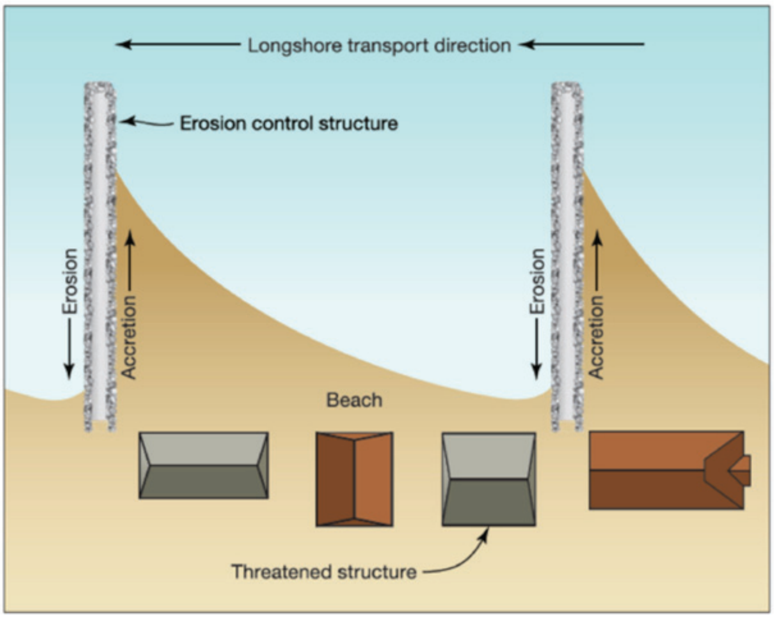



*Figure 40: How groynes work*

On Lifuka, groynes would need to be accompanied by 'beach nourishment', which involves trucking in sand to create a dune. About 15 groynes (each 50 m long) would be needed on Lifuka.

Below is a photo of groynes at Botany Bay, New South Wales, Australia showing how they have prevented sand from washing away.

*Figure 41: Groynes at Botany Bay, New South Wales, Australia*

Below is a groyne made of geotextile bags.

*Figure 42: Groyne made of geotextile bags*

Advantages of groynes:

They are effective in creating a usable beach on the updrift side (the side of the groyne where sand collects) if there is a strong rate of longshore drift (that is, a swift movement of sediment such as clay, silt, sand and shingle out from the beach).

- They can increase the width of the beach berm and, thus, provide an area of beach for public use.
- They allow the beach to grow on the updrift (higher) side, providing a buffer of sand to protect infrastructure against storm erosion.
- They can be installed as temporary geotube structures to determine their effectiveness and optimise their location.

Disadvantages of groynes:

- They can be costly to construct.
- They can detract from the appearance and use of the beach.
- They can cause erosion on their downdrift sides (the sides of the groynes where sand levels are lower).
- They can create a hazard to swimmers at their seaward end.
- They require careful design and detailed understanding of coastal processes.
- They can cause loss of sand from the beach system if they are too long.
- They require ongoing maintenance, especially after large storms.
- They cannot guarantee full or continual protection of the coastline from erosion. In severe storms, any sand that has piled up will be transported away from the beach, and wave action from a lengthy storm will continue to erode the coastline.
- They can generate rip currents, causing sand to be transported seaward.

Figure 43 is an example of a coral rock groyne that could be built on Lifuka.

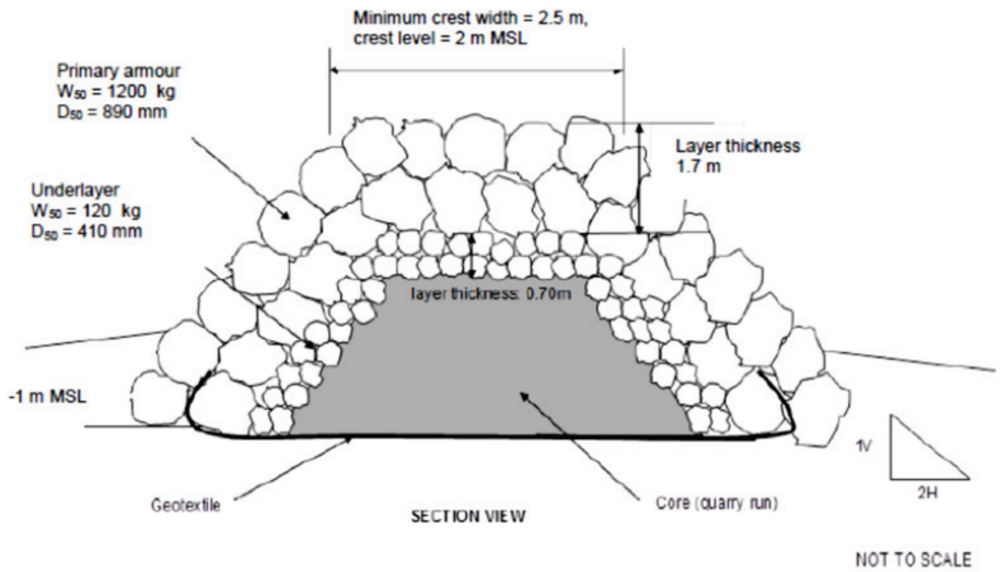



*Figure 43: Diagram of a coral rock groyne*

Figure 44 is an example of a geotextile bag groyne that could be built on Lifuka.

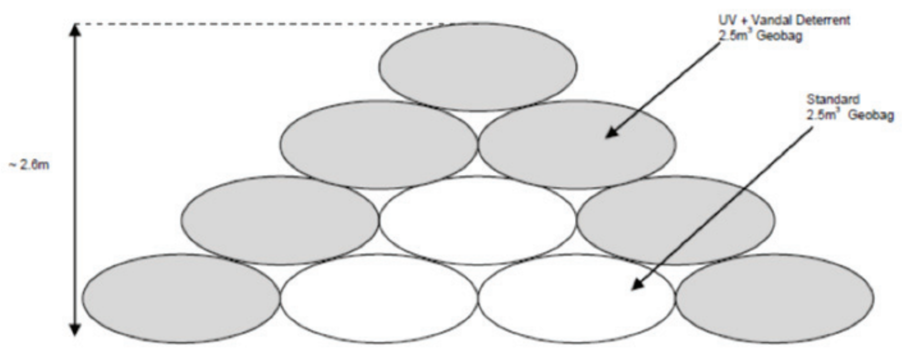



*Figure 44: Design of a geotextile bag groyne*

A note of caution about groynes:

Groynes work best in conditions where there is a high rate of sediment movement along the shoreline. The technical data collected suggest that this is not the case on Lifuka, which means groynes may not be the most technically effective solution.

If the groyne option is adopted, it is suggested that groynes be built out of geotextile bags in a trial location, such as near the telecommunications tower or the hospital, so that their effectiveness can be assessed over time.

*Beach nourishment*

Beach nourishment involves trucking in sand in order to create a dune that acts as a storm buffer. Below is an example of a completed beach nourishment project at Jimmy's Beach, Port Stephens, New South Wales, Australia.

*Figure 45: Beach nourishment project at Jimmy's Beach, Port Stephens, New South Wales, Australia*

Nourishment works best when the sand that is placed on the eroded beach closely matches the grain size and characteristics of the native sand. SPC has provided sediment sieve analysis of sands at various locations around Lifuka to help determine the best matches (see 1.5, Beach Sediment Assessment).

A wooden fence can be constructed at the top of the dune to enhance stability, and vegetation can be planted to help stabilise the dune and capture the sand.

Advantages of beach nourishment:

- It can work with, rather than disrupt, the natural coastal processes to replace sand on the beach.
- It provides a buffer of sand to help protect infrastructure.
- It can improve the appearance and use of the beach by providing a new area of sand.
- It can allow revegetation and rehabilitation of dune vegetation.
- It can provide a mechanism to allow the movement of sand that is currently trapped updrift by the artificial structures, including the causeway and Pangai Harbour breakwaters.

Disadvantages of beach nourishment:

- Beach nourishment conducted in isolation could result in sand being transported rapidly out of the beach system.
- It can be costly to implement.
- Beach nourishment sand can be lost in storms, so top-ups and maintenance would be needed.
- If the trucked-in sand is unsuitable, it could lead to large losses of sand from the beach during storms.
- In some cases, it can temporarily and negatively affect water quality due to fine material being released into the water.
- It cannot guarantee full or continual protection of the coastline from erosion or storms.

*Combinations of Options 1–3*

Combinations of Options 1–3 could be implemented.

- A combination of a revetment and beach nourishment. This option would involve burying the revetment along the foreshore and building a dune on top of it. The revetment would be exposed only following storm-related erosion, and would provide additional protection to infrastructure on the west coast.
- A combination of a buried revetment and a dune, in addition to groynes.

*Costs*

Below is the estimated indicative cost and maintenance of each option. (ARI = annual recurrence interval storm event; TOP = Tongan pa'anga.)

*Table 5: Estimated cost and maintenance of presented options*

| Adaptation | Cost TOP$ | Maintenance costs | Maintenance Frequency | Total cost over 50 years |
|---|---|---|---|---|
| Coral revetmant (100 year ARI) | $12,340,000 | $24,680 | Annual* | $13,574,000 |
| Coral revetment (1 year ARI) | $7,100,000 | $710,000 | Annual* | $42,600,000 |
| Geotextile revetment (100 year ARI) | $18,000,000 | $1,800,000 | Annual* | $108,000,000 |
| Geotextile revetment (1 year ARI) | &10,000,000 | $1,000,000 | Annual* | $60,000,000 |
| Groynes (coral rock, 15 x 50m long) | $10,500,000 | $210,000 | Annual* | $21,000,000 |
| Beach nourishment | $374,400 | $374,400 | Every two years | $9,360,00 |

* Maintenance would occur after a major storm causes damage – cost have been annualised for ease of calculation

In summary, whichever option is chosen, protecting the infrastructure on Lifuka's western coast requires a large and costly structure. Other strategies for coastal protection, such as beach nourishment, and relocation of critical infrastructure inland, warrant further consideration.

For technical data on the coastal processes affecting Lifuka which underpin these conceptual designs, see 2.0 Coastal Rehabilitation Tonga – Lifuka Island, Engineering Options Report.

## Managed retreat

- Managed retreat, the option recommended by the project, could involve several components:
- The delineation of a coastal setback zone in which building activity is restricted in order to mitigate risk, and families in the most hazard-prone areas retreat inland
- Building standards that favour elevation of coastal buildings to protect people and property
- A 'living shorelines' approach that favours the maintenance of healthy coastal habitats.

Managed retreat recognises that coastal hazards negatively impact the shoreline and that this is likely to worsen with climate change. Over time, it will become harder for the community to maintain infrastructure, with roads, water supplies, electricity and private buildings becoming increasingly exposed to coastal erosion and inundation. Eventually, if no action is taken, the structural integrity of coastal buildings will be compromised, and properties will have to be abandoned as they become unsuitable for human habitation.

A community that has the capacity to implement managed retreat is likely to be more resistant to impacts or able to recover more readily from extreme events and conditions.

*Coastal hazard zones and buildings at risk*

On the basis of the modelling and satellite-image analysis conducted, an estimated 272 homes (79%) are located in the coastal setback zone, hazard zone and high hazard zones identified around Lifuka. These homes are under threat from inundation and storm damage to varying degrees.

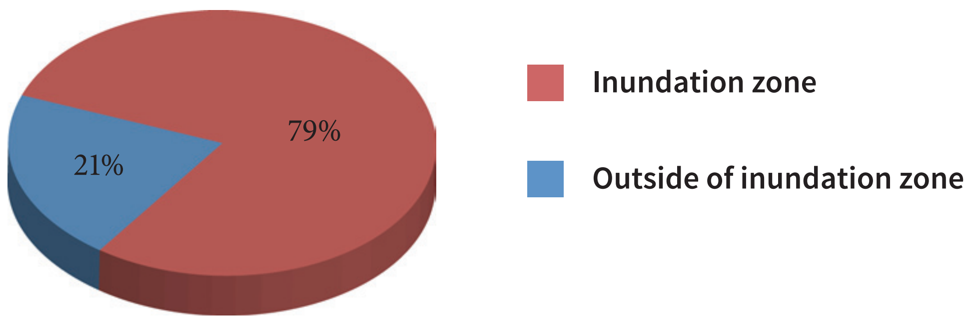



*Figure 46: Percentage of buildings within the inundation zone, as identified by the hazard map. A large proportion (79%) of all the buildings in Lifuka are situated within coastal hazard areas subject to inundation.*

Families located in the coastal setback and high hazard zones are at severe risk of personal injury and loss of property and possessions in a severe storm. Retreat involves families moving inland — either immediately, perhaps over a generation (gradual retreat) or as homes deteriorate (voluntary retreat).

*Table 6: Building recommendations for coastal setback zones*

| Zone | Hazard | Recommendations |
|---|---|---|
| Long-term coastal erosion zone – setback zone | This is the zone subject to erosion as well as the most intense forces from tropical cyclones and extreme storms, with high-velocity wave action from damaging waves of 1 m or greater. | Any construction in this zone is to be avoided. All buildings* (new construction, substantial improvement, and repair of substantially damaged buildings) should be located landward of the reach of the zone. Critical infrastructure in this zone should be considered for relocation. Removing sand or vegetation may increase potential flood damage and erosion. This zone should, instead, be vegetated and allowed to maintain its natural integrity. |
| Coastal high hazard area | This area is subject to inundation from tropical cyclones and extreme storms with strong waves of 1 m or greater. | Building critical facilities in this area is to be avoided. All other buildings* should be constructed on an open foundation (posts or columns) and the top of the lowest floor must be above the depth of inundation. Consider extra freeboard to add a margin of safety. Enclosed space below the lowest floor must be free of obstructions. |
| Coastal hazard area | This area is subject to flooding from tropical cyclones with waves big enough to damage structures built on shallow or solid-wall foundations. | Building critical facilities in this area is to be avoided. All other buildings* should be constructed on an open foundation (posts or columns) and the top of the lowest floor must be above the depth of inundation. Enclosed space below the lowest floor of buildings* must be used for storage or parking only, and the walls must be of open design to allow entry and exit of water. |

* Technical guidance and recommendations concerning the construction of coastal residential buildings can be found in the Home Builder's Guide to Coastal Construction (www.fema.gov/library/).

We are likely to see the major coastal hazards of erosion, inundation and flooding described earlier occur in a time period spanning three generations (the shared lifetimes of a family including parents, children and grandchildren). At least 13 tropical cyclone disaster events have been officially reported to have hit the Ha'apai Group in the last 100 years.

In technical terms, a cyclone event with a recurrence interval of 100 years has, on average, a 63% chance of occurring over a planning period of 100 years, and is therefore likely to happen. Similarly for erosion, the southwest coastline of Lifuka has experienced rates of erosion averaging 70 cm per year, and some parts have lost 40–50 m of land in the last four decades. This must be taken into account when considering critical infrastructure such as power plants or hospitals, or places of high cultural values such as churches or cemeteries. However, there will always be residual risk, and the level or risk that is not offset by flood-resistant design or moving buildings must be accepted by the community or owner of the building.

As the risk varies along the coast, the width of the coastal setback zones varies.

Coastal setback zone, Hihifo

The Hihifo coastal setback zone would be 110 m wide.


*Figure 47: Coastal setback zone, Hihifo*

Coastal setback zone, Koulo

The Koulo coastal setback zone would be 25 m wide.


*Figure 48: Coastal setback zone, Koulo*

***Building standards that favour elevation of coastal buildings to protect people and property***

Coastal setback zones needs to be coupled with elevation of buildings in the hazard areas, as shown below. By raising the floor height of buildings by at least a metre, either using concrete columns or wooden poles, the area below is left open to allow ocean water to flow under the building, reducing structural damage to the building or its contents in the event of an extreme flooding event.

This is best done by establishing and enforcing building standards such as minimum building heights to accommodate severe storms and a long-term zoning plan in which development in the most hazard-prone areas is minimised and new developments are located on safer, higher ground. However, construction in the coastal setback zone should always be avoided since this land is unstable and subject to continual change.

*Managed retreat: A schematic view*

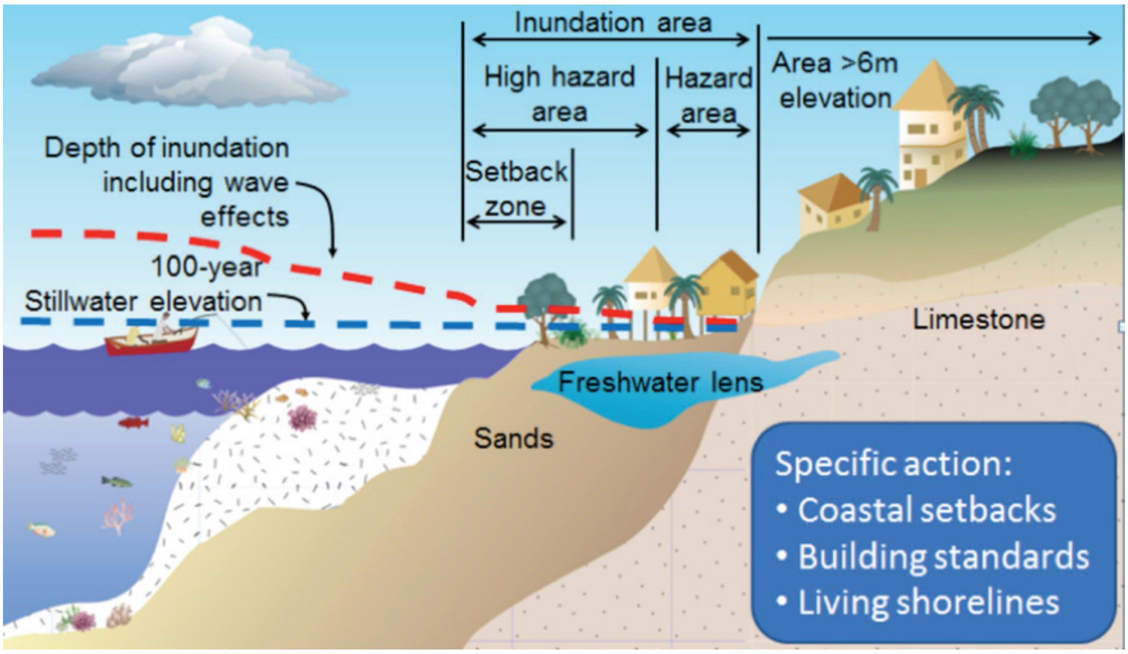



*Figure 49: Schematic view of managed retreat. The shoreline should be vegetated and allowed to undergo natural adjustment. Building in the coastal setback zone should be avoided. Houses in the hazardous areas should be elevated. Critical infrastructure with a long lifetime should be built on higher ground, at least 6 m above mean sea level.*

*Managed retreat: Appraisal*

Advantages

- Low start-up costs
- Locates new developments away from hazards
- Provides a long-term solution to manage climate-based risks
- Maintains ecosystem services
- Reduce the need for costly shoreline stabilisation.

Disadvantages

- Limits buildable area
- A certain amount of land will be lost
- Often controversial, so needs discussion and incentives for home-owners
- Results can be unpredictable.

## 2.0 Least–cost analysis (outputs 13, 14, 18)

*Introduction*

This least-cost analysis forms the first part of a preliminary economic assessment of adaptation options to address coastal threats in Lifuka. The analysis describes a provisional costing of several possible options to address the coastal threats arising from a single 1:100 year storm event.

## Method

As agreed by the government, the potential costs of three options were specifically provisionally estimated:

- Revetment (as a means to protect the foreshore);
- Relocation inland of families in the most hazard-prone areas;
- Elevating houses in the most hazard-prone areas.

To form the basis for costings and comparisons, several scenarios were provided:

To form the basis for costings and comparisons, several scenarios were provided:

- Six revetment possibilities;
- Two relocation possibilities;
- Two elevation possibilities.

## Key findings

Provisional costing indicates that the cheapest option after 50 years would likely be the establishment of a short coral-block revetment, such as exists along the main coastline of Tongatapu. By comparison, elevating houses in the hazard zones by building new (elevated) ones would be expected to be the most costly.

*Table 7: Provisional costing indicating options after 50 years*

| | Cost after 50 years | Cost per capita | Rank (cheapest first) | Other costs |
|---|---|---|---|---|
| *Short rice-bag revetment | 4.7 m | 1,601 | 4 | Possible environmental damage; Possible enhanced erosion in localised areas |
| *Short block revetment | 0.7 m | 229 | 1 | |
| *Long rice-bag revetment | 22.8 m | 7,686 | 8 | |
| *Long block revetment | 3.3 m | 1,101 | 3 | |
| *Long combination revetment | 18.8 m | 6,325 | 7 | |
| *Highly resilient coral-block revetment | 12.3 m | 4,159 | 6 | |
| Build new higher buildings (total) | 36.6 m | 12,321 | 11 | |
| Build new higher buildings (extra) | 2.2 m | 744 | 2 | |
| Elevate existing buildings | 9.2 m | 3,125 | 5 | |
| Immediately relocate | 34.7 m | 11,700 | 9 | |
| Gradually relocate | 34.7 m | 11,700 | 10 | |

* Length and form of revetments are detailed in Grujovic et al 2013 (Outputs 14, 18)

These provisional costs barely tell half of the story and are insufficient to determine the best adaptation strategy for Lifuka for several reasons:

Environmental costs associated with the cheapest options have not been costed. Revetments could, in fact, exacerbate coastal erosion in some areas along the Lifuka coast and the scale of these negative impacts could be large or small. Accordingly, an environmental impact assessment — as per Tonga's Environmental Impact Assessment Act of 2003 — would need to be conducted to identify any negative impacts and plan for their mitigation (such as attaching environmental conditions to the works).

Costs are not necessarily reflective of the ability of the options to protect the community. As an example, depending on the design, revetments may still permit the permeation of water to low land, with the effect that the community may still become inundated. This compares with elevating houses or relocating inland where communities would not be exposed to the same degree of hazard. Accordingly, it may be practical to consider elevation or relocation of infrastructure away from the most hazard-prone areas. Alternatively, combinations of options (such as partial revetments and partial relocation) may be the most effective to combat coastal inundation and harm to livelihoods. It is therefore critical that an assessment of the possible benefits from the options is considered before options are selected. Options that do not protect the community and livelihoods should not be pursued.

In the long term, infrastructure may need to be renovated, replaced or newly established around Lifuka. In the interests of protecting possessions, lives and livelihoods, the government should consider establishing and enforcing:

- building standards such as minimum building heights to accommodate severe storms;
- a long-term zoning plan in which development in the most hazard-prone areas is minimised and new developments are located on safer (elevated) ground;
- gradual relocation of critical amenities to safer ground;
- existing development controls such as the minimising of beach mining in sensitive areas.

To adapt to a 1:100 year storm event and in the face of climate change and rising sea levels, it is improbable that any single adaptation option will be a 'silver bullet'. The desirability of options will rely not only on affordability but also on (1) the effectiveness of the option to protect lives and infrastructure, (2) the attitudes of the community, and (3i) different combinations of options.

## 3.0 Cost–benefit analysis (output 18)

### Introduction

For the full report, see 4.0, Cost–Benefit Analysis, Assessing Vulnerability and Adaptation to Sea-Level Rise, Lifuka Island, Ha'apai, Tonga.

This cost-benefit analysis forms the second part of a preliminary economic assessment of adaptation options, building on and extending the least cost analysis described above. The cost-benefit analysis was based on the potential contribution that options could make to mitigate the impacts of a single 1:100 year storm event in Lifuka.  As agreed by the government, the potential value of revetment, elevation of homes and retreat from the coastline were specifically estimated and considered in light of the estimated costs.

### Method

***Impact of a 1:100 year event***

For this project, SPC has modelled the possible storm surge associated with a 1:100 year storm event in Lifuka (Kruger and Damlamian, 2013, output 13). The model indicates that a 1:100 year event would likely inundate, to varying degrees, the majority of the occupied district around Lifuka Island, since most buildings and amenities are located along the lowest lying part of the western coast.

Based on the modelling conducted, several major impact zones were identified. For the purpose of the cost-benefit analysis, these were considered as: (1) a hazard zone that would be inundated as a result of a 1:100

year storm event; and (2) a *high* hazard zone that would be inundated as a result of such a storm, but which could also be subject to the effect of damaging waves. This area also includes a coastal setback zone that is subject to long-term coastal erosion.

Drawing on a household and technical building survey also conducted as part of the project (Sinclair et al. 2013al, output 10) it would appear that around 272 homes (the majority of homes) around Lifuka are located in hazardous/highly hazardous (including erosive) areas. Without any adaptation, the local community would then face the unconstrained impact of the storm, which would likely include damage and injury from flooding and wave action, losses arising from damage (such as loss of personal possessions), as well as harm to critical amenities in the area, such as the police station, fire station, hospital, telecommunications facilities, power utilities, several schools and churches.

No engineering assessment was available from which to calculate the cost of a 1:100 year event on the community of Lifuka. Drawing on an assessment of severe storm events occurring elsewhere, the potential damage to homes in the hazard zones was determined to provide a basis from which implications could be considered.

The minimum cost of structural damage affecting homes in a 1:100 year storm event was thus estimated to be in the vicinity of TOP$0.6–20.8 million. This range reflects assumptions of whether housing damage had a lower, middle or higher impact. Nevertheless, the range of costs estimated is highly conservative. The costs estimated do not include damage to other sectors (such as damage to agriculture, fisheries and utilities), personal possessions, nor losses such as trauma and injury. Moreover, these costs do not include the likely costs of damage from wind shearing. This may be extensive in a community housed predominantly in wooden homes. Nevertheless, the values estimated provide a useful basis from which to consider adaptation.

In addition to the storm hazard, the community of Lifuka faces an ongoing erosion hazard along the coastline. Based on historical erosion rates, this has cost the community an average of around TOP$25k per year in lost land values over the last 40 or so years.

## Types of adaptation

Revetments, elevation of homes and retreat could take any number of forms. As a means to draw implications on the suitability of each option for Lifuka, several basic scenarios for adaptation were considered in this analysis.

*Table 8: Scenarios for adaptation*

| | |
|---|---|
| Revetments | Short revetment near the central business district of Lifuka where coastal erosion has been particularly active (coral block; cement-filled rice bag)<br>Long revetment along the whole shoreline of Pangai and Hihifo (coral block; cement-filled rice bag; combination of cement-filled rice bag *and* coral block; coral block revetment designed to withstand a 1:100 year tropical cyclone event) |
| Elevation of houses | Extra design feature of houses (cost on top of house building) in the hazard zones<br>Retrofitting existing houses in the hazard zones |
| Retreat | Immediate relocation (permanent evacuation) from all the hazard zones, where families have to face all costs of relocation<br>Gradual retreat from all the hazard zones over one generation, where families have to face all costs of relocation<br>'Natural' retreat from hazardous zones where families do not renovate their homes where they are (in situ) but instead establish replacement home elsewhere. In this case, economic costs are lower |

Assumptions around the nature of these scenarios were later varied in sensitivity analysis.

## Estimated returns on investment

Returns on investment were based on assumptions of the potential range of inundation damage (low, medium, high) to homes that would occur if a single 1:100 year event occurred. Most returns are likely to be underestimates (see table below) because they do not include benefits to buildings other than homes (such as schools) or other sectors (such as utilities). Moreover, the benefits valued reflect only those related to a single 1:100 year event. The adaptation options could also provide ongoing benefits as other events occur over time. Nevertheless, the values still raise critical issues that need to be considered in selecting and designing the final adaptation strategy for Lifuka and elsewhere.

Using the initial scenarios described above, no single adaptation method appears to offer sufficient valued benefits (that is, those benefits attributed with a monetary value) to cover costs, regardless of the scale of magnitude of costs from a 1:100 year event. This likely reflects in part the fact that not all benefits from the options could be valued during this assessment. Nevertheless, voluntary retreat of families away from all of the hazard zones consistently offers the highest net benefit (lowest net cost) for all damage scenarios. Bearing in mind that not all the benefits from retreat have been valued (such as protection of possessions and likely reduction in injury and or trauma), it is possible that voluntary retreat could become economically efficient once these benefits are considered. If conditions are varied so that retreat from the high hazard (and erosive) area only is considered, voluntary retreat almost pays off with the benefits that are estimated. It is possible that if all other benefits such as protection of possessions are included, this option would be economically efficient.

*Table 9: Estimated payoffs after 50 years TOP$m (base case)*

| 10% discount rate | Low-level damage scenario | | Medium-level damage scenario | | High-level damage scenario | | Comment |
|---|---|---|---|---|---|---|---|
| | Net present value * | Benefit: cost ratio * | Net present value * | Benefit: cost ratio * | Net present value * | Benefit: cost ratio * | |
| Short rice-bag revetment | –0.9 | 0.22 | –0.9 | 0.22 | –0.9 | 0.22 | No impact on housing damage included<br>Benefits from land protection only |
| Short block revetment | –0.4 | 0.43 | –0.4 | 0.43 | –0.4 | 0.43 | |
| Long rice-bag revetment | –5.6 | 0.05 | –5.6 | 0.05 | –5.6 | 0.05 | |
| Long block revetment | –2.7 | 0.09 | –2.7 | 0.09 | –2.7 | 0.09 | |
| Long combo revetment | –5.0 | 0.05 | –5.0 | 0.06 | –5.0 | 0.06 | |
| Highly resilient revetment | –12.0 | 0.02 | –11.1 | 0.10 | –11.5 | 0.07 | Assumed to reduce housing damage by 25%** |
| Build new buildings 1 m higher (total) | –36.5 | 0.00 | –36.4 | 0.00 | –35.4 | 0.03 | Benefits underestimated<br>Does not include value of protected possessions, reduced injury or trauma |
| Build new buildings 1 m higher (extra) | –2.2 | 0.01 | –2.0 | 0.08 | –1.1 | 0.52 | |
| Elevate existing buildings 1 m | –9.3 | 0.00 | –9.1 | 0.02 | –8.1 | 0.22 | |
| Immediate retreat | –34.6 | 0.00 | –30.8 | 0.11 | –32.4 | 0.07 | |
| Gradual retreat | –13.0 | 0.00 | –12.9 | 0.01 | –12.9 | 0.01 | |
| Voluntary retreat over time | –0.1 | 0.02 | –0.0 | 0.97 | –0.1 | 0.57 | |

* Net present value = total value of estimated benefits *less total value of estimated costs (all in 2013 terms); Benefit: cost ratio = total value of estimated benefits divided by total value of estimated costs (in 2013 terms) — an indication of payoff per dollar invested*

** For illustrative purposes only

It is probable that the prospect of ongoing renovation of homes in the hazard areas is likely to be more appealing to families than the prospect of establishing new homes away from the rest of the community. Consultations conducted indicate that retreat is not favoured by the community. Furthermore, access by families to new land away from the township is likely to be a major challenge. It should also be noted that retreat away from the existing township cannot be considered in isolation from the amenities and infrastructure needed to sustain lives. Families would require power, telecommunications, roads and other essential infrastructure in order to maintain standards of living in a new area. The effort involved to provide these would likely be substantial for the government.

Drawing on the initial scenarios, the next most efficient option after voluntary retreat is short revetments. Short revetments are estimated to generate losses over 50 years of around TOP$0.4 million but, in the process of so doing, protect the land from ongoing erosion, which is important to the community. (The benefits valued from this form of adaptation option thus take the form of land values). Additionally, there may also be future benefits from preventing subsidence (where erosion has been halted) to buildings.

Nevertheless, it is important to recognise that this option is not expected to protect homes or contents, because it will not prevent inundation. (Revetments commonly incorporate a permeable filter layer as part of their structure which would, by definition, allow water to flow up and onto the land.) It is unclear if the community recognises this limitation to revetments. Furthermore, the estimates provided for revetments do not include certain costs, such as the cost to the community of the land that would need to be surrendered to make room for the structure, nor any impact of the revetment upon the coastal ecosystem. (Revetments would interrupt existing dynamic processes and also potentially have a negative impact upon the continuation of seagrasses and related fisheries). The existence of revetments would also act to impede public access to the beach. Any revetment would logically — and by law— require an environmental impact assessment to be undertaken and to inform mitigation of negative effects. This would presumably increase the costs (and reduce the payoffs) from this adaptation option.

When assumptions are varied, other options become economically viable. In particular, if a high-damage scenario is considered with a low discount rate, immediate relocation from the high hazard zone becomes the most efficient option, followed by elevation of houses. Elevation of houses offers the highest payoffs as floor heights are raised higher still (e.g. 2 m instead of 1 m) for houses in the high hazard (and erosive) zone.

## Key findings

From the initial assessment, it appears that no one strategy to adapt to coastal hazards in the face of climate change offers either a positive payoff over time (based on benefits valued). Additionally, all options come with complications:

| | |
|---|---|
| Revetments | Will prevent ongoing erosion of the land but the land protected (and the homes and amenities on it) would continue to be exposed to inundation. Homes, possessions and infrastructure would continue to be damaged by inundation. Furthermore, since sea-level rise is ongoing, it would be expected that, in the long term, even revetments would cease to protect the land. |
| Retreat | Would be disruptive and likely involve highly complicated land access negotiations. Retreat is unpopular with the community. |
| Elevation of houses | Relies on families either already planning to rebuild their houses or asking them to consider it. In any event, ongoing sea-level rise and erosion rates would suggest that homes currently situated within the highly erosive area would end up in the intertidal zone, which is unsustainable. |

These complications suggest that it might be wise to consider a combination of approaches to adapt to coastal hazards in the face of climate change. For example, short-term options might be used to buy time while planning for a longer-term strategy to adapt to climate change. The strategy could involve a combination of 'no-regrets' and other options.

## Recommendations for consideration

### *'No-regrets' options*

- The storm modelling and shoreline change analyses conducted provide new information on the hazards threatening the Lifuka community. The information should be used as the basis for the establishment of a new town plan that guides where construction and development work may occur and how.
  - New building codes should be established that reflect the potential hazards identified in this project (such as the potential depth and speed of inundation). For example, these might include storm-proofing and minimum floor heights. Existing standards concerning floor heights and storm-proofing, etc. should also be emphasised and enforced. Enforcement will likely take time and resources.
    - Buildings in the high hazard (and erosive) zones are exposed to both inundation and damaging waves in the event of a severe storm. The potential speed and depth (over 4 m) of inundation in some parts is alarming. Furthermore, much of the land on which buildings in the high hazard zone are located is highly dynamic, with the effect that some buildings may be at risk of being damaged in the medium term (should erosion continue at its historical rate). Logically, no new developments should occur in this area unless they are structured to accommodate emerging risks and hazards. The community might also need to recognise that choosing to establish new structures in this high hazard (and erosive) zone may ultimately generate costs for which they would be responsible.
- A number of amenities are located in the hazard zones that are critical for human protection in the event of a severe storm. These include the hospital and the fire station. Damage to these buildings during a storm would result in needless harm to community members. The government could draw on the models to establish a long-term plan to relocate critical amenities away from the hazard zones to a permanent safe location. This may ultimately require the establishment of supporting infrastructure (roads, power links etc.). The establishment of these facilities may act, subsequently, as an incentive for community and business members to reconsider their own location.

### *Other adaptation options*

- Families located in the high hazard zone are at severe risk of damage and personal injury in the event of a severe storm. The government should lead discussion with communities to develop a plan to support their retreat from the high hazard zone for their personal safety.
- A short coral-block revetment would provide assurance to the community of government commitment to addressing community concerns regarding coastal protection. This measure may prevent future subsidence of highly exposed buildings and buy time for some families and businesses. However, to ensure that the community members do not gain a false sense of security from this measure, the community will need to be educated on the scope of benefits and durability of this approach. Second, rule of law should be applied to revetment developments (and any other structural solutions) to ensure that (1) the environmental and other impacts of the structure are

assessed through a fully public and transparent environmental impact assessment, and (2) any negative impacts are suitably managed in design.

- Government and community representatives need to discuss options to provide access to land for businesses and families who are at risk in their present locations and who wish to retreat from the hazard zones.
- The government may need to consider the need for incentives/financial assistance to families and businesses to understand and meet new building codes.
- Families and businesses are located in the areas they are in now for good reasons. This may include access to schools, work and business. Restrictions in land development in the hazard zones may consequently negatively affect families and businesses. The government and land owners must conduct consultations to identify the financial and other implications of land-use changes and find workable solutions to ensure the security of the community.

## The community response (outputs 19, 20)

### Introduction

This section documents the Technical Working Group's presentation of several adaptation options to Lifuka's communities and district officials in late April and early May, 2013. The main purpose of these public consultations was to clearly present the proposed mitigation measures, give people the opportunity people to discuss their advantages and disadvantages while expert help was available, and then choose a preferred option.

### Method

After discussion with the Government of Tonga, the options presented to the community for consideration were:

Option 1: Rock revetments to protect the foreshore (similar to an existing revetment at Nuku'alofa)

Option 2: Sand replenishment and groynes (using Waikiki Beach in Hawai'i as an example)

Option 3: Managed retreat.

It should be noted that Option 2 was not subject to an economic assessment.

### Key findings

Groups were divided into women, men and young people to discuss preferred options. Each group then presented their preferred option and the reasons for its selection to the entire meeting.

Workshop convenors originally planned that each presentation would start with discussion of options in the order above. However, convenors noted at the first meeting, at Hihifo, that people appeared to lose interest once the rock revetment option was discussed, suggesting that some had already made up their minds. It was decided to present in reverse order in order to focus attendees' attention.

Throughout the presentations, it was clear that a rock revetment was the preferred choice. Young people and women appeared more concerned about the impacts of each option on the environment and their livelihoods than were men. It is pertinent to note that young people in Koulo and Holopeka felt that sand replenishment would be more appropriate for their area because coastal erosion was not as severe as on other parts of the coast, and they still enjoyed beautiful beaches that would be affected by a 2 km-long rock revetment. The male groups' rejection of planned retreat appeared to be influenced primarily by a perceived lack of household finance for such an option and a perceived lack of land available for relocation.

## Climate impacts monitoring system (output 21)

### Introduction

The purpose of an Integrated Climate Impacts Monitoring System (ICIMS) for Lifuka is to provide a framework to observe and record environmental and social changes following the implementation of adaptation strategies.

This project proposed a system in which community members would select relevant indicators and would be able to collect information on them, thus generating awareness of climate change, engaging community members in decisions affecting them, and promoting their ownership of, and responsibility for, climate-change adaptation.

### Method

***Indicators for a project of this nature need to be:***

- easily obtained
- reproducible over time
- inclusive of the community in their collection and interpretation
- effective
- cost-effective, and
- of a nature that promotes government and community dialogue and participation.

In March 2013, the project technical team presented a range of indicators to a community meeting. Feedback was favourable, but limited, and it was not possible for the meeting to select which indicators would be monitored. Additional consultation will be required between the community and local and national government; however, the resources required for such consultation are beyond the scope of this project.

***Possible starting points***

The project team has outlined a complete list of indicators in the full version of this report, Integrated Climate Impacts Monitoring System (Output 21), December 2013. However, to provide guidance and a starting point, it has provided a table of accessible indicators that reflect existing practise and that would enable community participation (Table 10).

*Table 10: Indicators and potential importance for inclusion in development of an Integrated Climate Impacts Monitoring System*

| Issue | Indicator | Importance |
|---|---|---|
| Coastal erosion | Volume of sand taken from designated sites | High |
| | Coastline changes | High |
| | Beach profiling changes | Medium |
| Coastal inundation | Inundation levels | High |
| | Impacts to selected infrastructure | High |
| | Relative water-level changes | Medium |
| Subsidence | Change in elevation | Low |
| Water | Salinity and usage monitoring of TWB wells and galleries | High |
| | Thickness of the freshwater lens | High |
| | Drought management monitoring | High |
| | Bacteriological water quality (*E. Coli*) in wells and supplied water | High |
| Social/Economic | % of occupied households in the setback zone that have moved out of the zone | High |

Monitoring can be undertaken by the community

Monitoring requires specific skills (Tonga Government or SPC)

Monitoring can be undertaken by Island Council

## Conclusions

An Integrated Climate Impact Monitoring System should form part of the overall strategy for developing awareness of the effects of climate change and coastal erosion and documenting both climate-related change and the impact of adaptation activities.

However, the development of a robust monitoring system is dependent on the resources of government and the community to both introduce and sustain it. Existing monitoring systems that are already in place, such as rainfall monitoring and water quality, should be strengthened and the information they supply, in combination with other monitored indicators, used to make inferences.

It is recommended that the dialogue around indicators started between the government and the community be continued.

# SECTION E: CAPACITY BUILDING AND KNOWLEDGE SHARING

## 1.0 Capacity-building activities (output 24)

Capacity building involves strengthening the skills, competencies and abilities of people and communities so they have the tools to solve their own problems. Capacity building is a key component of overarching strategies for climate change adaptation in the Pacific, including the Pacific Islands Framework for Action on Climate Change (PIFACC) 2006–2015, Tonga's own Joint National Action Plan on Climate Change Adaptation and Disaster Risk Management 2010–2015, and this project, Assessing Vulnerability and Adaptation to Sea-Level Rise Lifuka Island, Ha'apai, Tonga. In particular, the Lifuka project aimed:

- to support the capacity of the Government of Tonga, and relevant NGOs, to conduct assessments of coastal and social vulnerability and the gender perspective of vulnerability and adaptation to sea-level rise.

This report summarises the capacity-building activities carried out.

*Table 11: Individual capacity-building*

| Position | Department | Activity description |
|---|---|---|
| Principal Surveyor | Lands Dept. Pangai, Ha'apai<br>Ministry for Lands, Survey, Natural Resources and Environment and Climate Change (MLSNRECC) | Trained on using automatic level for beach profiling<br>Collection of tide-cycle data<br>Sessions with levelling runs in deriving mean sea level |
| Senior Geologist | Department of Geology, MLSNRECC | Trained on using automatic level for beach profiling<br>Sediment sampling<br>Use of handheld GPS in shoreline mapping<br>Use of Trimble RTK GPS in coastal mapping<br>Preparation of sediment samples for analysis<br>Training on sand sieve analysis<br>Processing, analysing and reporting of sieve analysis<br>Point count analysis<br>Geophysics, EM34 surveys and resistivity surveying<br>Water quality sampling<br>Household survey techniques |
| Geologist | Department of Geology, MLSNRECC | Household survey techniques<br>Water quality sampling |
| Senior GIS Officer | Division of GIS, MLSNRECC | Use of Trimble RTK GPS in collecting ground control points<br>Training with Global Mapper on Image rectification<br>Use of Quantum GIS in Household Mapping<br>Use of Quantum GIS in creating metadata for household survey data. |
| Head of Aquaculture Research and Development and Inshore Resources Assessment | Fisheries Division of Ministry for Agriculture, Forestry, Food and Fisheries | Familiarisation with habitat mapping techniques<br>Preparation of habitat survey, discussions with local fishermen on their habitat knowledge<br>Transects using underwater camera and handheld GPS<br>Boat transects using drop video camera |
| Lead Hand<br>Senior Water Engineer | TWB Lifuka<br>TWB Tongatapu | Water quality sampling and monitoring |
| Enumerators | | Household survey techniques |

## 2.0 Knowledge-sharing activities (output 26)

**Development of manual on methodology for community work, 5–6 October and 13–14 October 2011. Venue: Ministry of Environment, Nuku'alofa, Tonga.**

Facilitators: Participants: Emeli Esau, TCDT; Brigitte Leduc, HDP, SPC

Objective: Building the capacity of project partners to work with communities

Outcomes: Manual on the methodology for working with communities developed

TCDT and SPC worked together to develop appropriate methodology and tools for use in the project Assessing Vulnerability and Adaptation to Sea-Level Rise, Lifuka Island, Ha'apai, Tonga. It provides a set of participatory tools and questions to guide discussions during focus-group discussions and interviews. The manual is entitled Assessing Vulnerability and Adaptation to Sea-Level Rise, Lifuka Island, Ha'apai, Tonga. Working with Communities: Methodology.

**Working with Communities Workshop, 7–9 October 2011. Venue Ministry of Environment, Nuku'alofa, Tonga.**

Facilitators: Emeli Esau, TCDT; Brigitte Leduc, HDP, SPC

Objective: Strengthen the capacity of project partners to use a participatory approach in their work with Lifuka communities throughout the project. The outcomes were (1) Imparting a common understanding of key concepts and approaches for working effectively with communities on sea-level rise and environmental change; and (2) Establishing a methodology to engage the Lifuka community in the project Assessing Vulnerability and Adaptation to Sea-Level Rise, Lifuka Island, Ha'apai, Tonga.

Attendees: Twelve people from governmental institutions and civil society organisations directly involved in the implementation of the project. Four participants were from Lifuka.

The first day of the workshop was dedicated to developing a common understanding about the concepts and approach promoted by the project. During the workshop, 14 participatory tools for working with communities were introduced. They are:

(All focus-group work)

1. Village map and land-use map
2. Historical timeline
3. Seasonal calendar
4. Seasonal dependency matrix
5. Food security assessment
6. Inventory of natural resources and changes in biodiversity
7. Division of labour and activity matrix
8. Impacts of coastal erosion, water stresses, and climate variability on natural resources and livelihoods
9. Management of fresh water
10. Institutional mapping and Venn diagram
11. Community values
12. Causes and impacts of vulnerability to coastal erosion and water stresses
13. Priority ranking
14. Planning adaptation.

Participant evaluation revealed a high level of satisfaction with the content of the workshop and the approach proposed. For many, these participatory tools were new and they believed such tools would enhance their capacities in their work.

**Presentations at Science and Technology Advisory and Resources (STAR) Network, 3–6 November 2012, Noumea, New Caledonia.** '*The science of a changing world: addressing Pacific issues through the 21st Century*'.

SPC's team leader for oceanography, Jens Kruger, presented the work undertaken to map shoreline change and devise setback options for Lifuka. He described how historical shoreline-change analysis of Lifuka was undertaken using historical aerial photographs, satellite imagery and a digital images spanning the period from 1968 to 2011. He described how coastal setback zones of 140 m for the southwest shoreline and 50 m for the northwest shorelines were proposed, and further subdivided into four separate risk zones to aid a staggered approach to the implementation of a managed retreat. He described how an alternative adaptation option using hard structures such as seawalls and revetments was also being considered.

STAR was founded in 1984 as a vehicle to assist the international research community to provide advice to SOPAC. A strength of STAR has been its ability to mobilise science to address the national needs of Pacific island nations and provide, as an independent and voluntary body, an important scientific and advisory role.

**SOPAC Division meeting, 6 November 2012, Noumea**

The presentation was titled Tonga: Lifuka Island — an integrated and multi-disciplinary approach to adaptation and coastal threats in the Ha'apai Group. It described how SOPAC had partnered with SPC's Human Development Programme (HDP) to characterise the vulnerability and impacts with a view to developing solutions and appropriate climate change adaptation responses. It demonstrated how, in implementing this project, SPC used an integrated and multi-disciplinary approach that recognised the complexity of the issues being faced. Hydrological work provided improved understanding of the groundwater resources and the impacts of rapid sea-level rise caused by subsidence. The vulnerability of the shoreline to erosion and potential inundation was assessed, with the evidence shared with the Lifuka community to assist their discussion of the options and their decision-making. HDP was instrumental in this regard as it had collected critical information about the community to understand its capacity to adapt.

Committee of Representatives of Governments and Administrations (CRGA), 12–16 November 2012, Noumea, New Caledonia.

Audience: Representatives of SPC member governments and development partners from around the region.

Purpose: To raise awareness among SPC member country representatives about the Lifuka project, in particular the dual scientific/community approach; to update development partners on the progress of the initiative; to build understanding of the effects of climate change, how these effects can be assessed, and how solutions can be found.

Two presentations were made:

i. An 18-minute documentary by SPC Water and Sanitation Communications Advisor Tiy Chung and SPC's Regional Media Centre, called *Rising Oceans, Changing Lives: Adapting to climate change on Lifuka Island, Tonga*. It introduces the problems facing Lifuka and outlines the project, underlining the importance of marrying scientific assessment and community involvement in assessing the impact of climate change and exploring adaptation options
ii. Posters explaining the project were set up in the foyer of the SPC conference room for public viewing.

**2013 Joint meeting of the Pacific Disaster Risk Management Platform and Pacific Climate Change Roundtable, 8–11 July 2013, in Nadi, Fiji.** Oceanographer Jens Kruger presented the findings.

# List of knowledge products (output 26)

## Documentaries

***Rising Oceans, Changing Lives***

**Length: 19 minutes**
**Credits: Scripter, camera operator and director: Tiy Chung.** Narration: Lauren Robinson. Video editor: Dovi Ikanivere, SPC Regional Media Centre. Executive Producer: Larry Thomas, SPC Regional Media Centre

Online at http://vimeo.com/53200521

***Lifuka Island – The Coastline of a Future Pacific***

Length: 25 minutes

Script: Steve Menzies; Camera: Kelepi Koroi; Editor: Amol Lal; Narration: Lenora Qereqeretabua; Direction: Steve Menzies

A Pasifika Collective Production

***Footage provided to television companies***

**TV One News, Television New Zealand. Footage provided to Pacific Affairs Correspondent Barbara Dreaver.** http://tvnz.co.nz/world-news/low-lying-island-threatened-rising-sea-levels-video-5498764

Press releases

**16 March 2012:** Lifuka Island, Tonga, at the forefront in understanding climate change impacts on small islands

(In French) http://www.spc.int/fr/library/869-lifuka-island-tonga-at-the-forefront-in-understanding-climate-change-impacts-on-small-islands.html

***Posters***

Adaptation Options for a Managed Retreat (A0)

Marine Habitat Map (A0)

# SECTION F: LESSONS LEARNT (output 25)

This project involved a wide range of stakeholders. It was innovative compared to other climate-change adaptation projects, where social mobilisation and technical assessment is usually disconnected and done separately. This project focused on both the social dimensions of adaptation to climate change and sea-level rise as well as its scientific aspects. Highlighted here are insights from team experience that will inform future projects of this focus and scale.

## Project design

**Multi-disciplinary teams can deliver benefits.** The Lifuka project was ambitious in the way it brought together different disciplines working in close collaboration, and this delivered a range of benefits. From a technical point of view, one was a breaking down of the barriers that often exist between different fields, with team members able to tap into a wide range of perspectives ranging from economics to oceanography. We believe that the multidisciplinary approach can, and has, facilitated holistic, pragmatic and people-centred policy approaches.

**Everyone needs to be at the table at project-design stage.** SPC has identified that its earlier involvement would have enhanced project design and project management. At the time SPC became involved, the project had already been designed and budgeted by a different implementing agency. Both the project document and budget required revision, a process that took at least six months and resulted in extra budget being allocated. Time and resources would have been saved had SPC been involved in project design and costing from inception.

**An effective, adequately resourced communications strategy is essential.** Project design should include a communications function with adequate resourcing. The Lifuka project, as well as helping local people drive their own response to sea-level rise and climate change, aims to be a blueprint for action for other low-lying nations. As insights emerge in a project of this nature, they need to be effectively communicated through a number of different means and platforms. In this case, creating two documentaries and banners was especially helpful in communicating scientific data to the communities, while the 'problem trees' helped the government to better understand the views of the community.

**Land-ownership issues need to be understood before project design begins.** Land tenure in the Pacific is often complex, and this project highlighted the importance of understanding land ownership systems before design begins. Activities were well advanced when it became apparent that Lifuka land was largely in private hands and rarely traded, severely limiting options for managed retreat and impeding the economic assessment of options that involved land transfer.

**Activity-based design limits flexibility.** This project was activity-based and prescriptive rather than outcome-based, which imposed some constraints and limited flexibility, particularly when aiming to meet targets around deliverables. For instance, from the perspective of a multi-disciplinary team, the question such a project should ask is, 'Where do we want to be at the end of this process, and how do we get there?' rather than aiming to deliver against a predetermined template.

**Gender mainstreaming is a process rather than an output.** Gender mainstreaming is a process rather than an output, and the project implementation team reflected this in its integration of gender mainstreaming in the Community Values and Social Impact Analysis. Firstly, mainstreaming ensured that all involved developed a clear overview of the perspectives of men and women on the causes of coastal erosion, its impacts, and potential solutions. It was clear that women and men had similar points of view on certain issues but differed in other areas, and we could see how men's and women's concerns and experiences varied according to their different roles in their households and the community. However, as reporting from the field was inconsistent, it was difficult to conduct a thorough gender analysis.

Secondly, the Lifuka project ensured that women had the same amount and quality of information as men in order to be able to offer informed comment, and the project team ensured, through a range of tools and techniques, that women's voices were clearly heard throughout the consultation.

The value of having separate breakout groups of men, women and young people should be highlighted here, and it is recommended that this approach be adopted for future projects. Had it not been for breakout groups, it might have appeared that Lifuka's people were almost universally against retreat when, in fact, young people and women were often in favour.

**Attitudinal insight is a valuable companion to scientific assessment.** The attitudinal data gathered from Lifuka's people was valuable in guiding the development of viable adaptation options. In some projects, a community may have little or no control or influence over the outcome, which risks rendering adaptation options useless or unachievable within reasonable time frames. Seeking the views of the community and identifying their preference for options/solutions and the social, historical, practical and political context from which these preferences sprang helped the team to present the options in ways that were relevant, informed and reflected local realities.

## Implementation

**Large, multi-disciplinary projects require full-time managers.** Although this project was rare in that nearly all of the technical expertise came from within one organisation, the project still involved multiple locations, with team members based in New Caledonia, Fiji and Tonga. This presented problems in management, integration, communication, coordination and monitoring. Project coordination was managed from within SPC but because the project had not initially been designed by SPC and was inherited for execution within a short time frame, management tasks were imposed on top of existing work plans. In future, a project as ambitious as this requires at least one dedicated, full-time manager who can maintain a firm focus on multiple activities and timelines.

**Good communication is critical for team cohesion.** Large projects with scattered, multidisciplinary personnel also need time and resources for face-to-face team meetings. Better use could have been made of video-conferencing facilities, given the time and cost of travel in the Pacific. Nevertheless, regular face-to-face meetings need to be budgeted for in future projects where team members are scattered.

Having a fully staffed PMU office in Tonga was critical to the success of the project, as there are unique challenges in managing an activity with the project team spread out in three different locations and on-the-ground implementation taking place in the remote outer island of Lifuka. In addition, the multi-disciplinary nature of the team required constant communication across the team and in particular between the Noumea- and Tonga-based managers.

**Community expectations need to be managed.** The depth of community consultation was one of the great strengths of this project. However, community expectations need to be managed when an assessment project of this scale is implemented in partnership with a government. It is important to stress that despite the amount of activity on the ground, final decisions belong to the partner government.

**Committed staff, partners and donors are critical to success.** This project enjoyed a great deal of support and engagement from PASAP and the Government of Tonga as well as Lifuka's people. Project team members had strong technical skills and were dedicated, despite facing time constraints and, at times, limited local expertise.

**There were a few missed opportunities.** Project design did not anticipate the need for certain data such as engineering assessments of the ability of certain structures to withstand wave impacts and inundation. These could have been obtained earlier in the assessment process through the services of a structural engineer and expedited the economic analysis.

The project design included an economic assessment of coastal hazard management options. However, in retrospect, benefits could have been achieved from an economic analysis of water management options. Since these were not budgeted for, it was not practical to include a preliminary assessment at the last minute. In the future, these opportunities could be exploited.

**Good data and data analysis is critical.** A weakness of the project was poor record keeping during field activities and poor time management in some areas. We also faced some restrictions in processing shoreline analysis data as the software used (ArcGIS 10.1, an unlicensed, trial version) proved not to be the appropriate choice. Historical imagery needed was either not available or missing.

In future, opportunities exist to better manage a large database. For example, inconsistences in data recording were identified during the project that required effort to fix, and this could have been avoided if all staff were familiar with the use of a single large database. (At present, staff commonly use different data manipulation software). This can be easily addressed in future.

**NGO partners may struggle with workloads.** Large-scale community-based adaptation projects require a firm and trusting partnership between the implementing organisation and its local NGO partner. However, stability and sustainability can be difficult for small NGOs to maintain, and the Tonga Community Development Trust (TCDT), which was contracted to undertake various tasks in the community assessment component of the project, suffered at times from capacity and management issues. SPC was required to step in at several critical stages to ensure the project continued to conform to required standards and timelines. However, the work that was carried out with TCDT remains with the trust and will inform its valuable work with Lifuka's communities in the future.

**Other challenges.** Other challenges worth noting are the overwhelming demands on MLSNRECC as well as the NGO implementing partner, TCDT, in relation to many other projects on climate change being implemented in Tonga. This raised the issue of donor coordination early on in project implementation. There was a need for a clear communication strategy and regular and proactive engagement with stakeholders on the activity by both the National Project Director and the National Project Coordinator. An additional challenge from the outset was the very tight timeline for the delivery of project activities, which highlighted the need for close engagement between MLSNRECC and the Tonga-based PMU and stringent management and regular communication across all the members of the team.

## Outcomes

**Local people's technical capacities have been developed.** Local people were trained in using equipment to carry out activities such as sediment analysis, surveying and boat transects (the latter a new survey method). The project led to the establishment of a soil laboratory for Tonga, which will be useful for future coastal surveys, and could become a source of income for the Tongan Government. At least five people from Lifuka developed their capacity to conduct social assessment and use a participatory approach to mobilise communities.

**A wealth of information with future application has been generated.** Many of the datasets that were generated in the course of this project can be used for multiple purposes by multiple users. Habitat maps produced could be used to define marine protected areas. The digital shorelines analysis used in the project will eventually become open-source. The methodology used for inundation modelling could be applied to other islands that have LiDAR data, such as Tongatapu.

The project established important technical baselines, but these may become purposeless if monitoring work does not continue. The digitisation of aerial photographs needs to be continued for these to be effective resources in future. The historical imagery that has been so useful in this project also needs to be adequately archived and stored.

# SECTION G: CONCLUDING COMMENTS

## Government feedback

This section summarises feedback from project partner the Government of the Kingdom of Tonga.

***Expected outcomes***

- There now exists an informed basis for selecting adaptation response to sea-level rise and storm surge in the western coastal zone of Lifuka. Three main adaptation options have proposed to the government and the Lifuka community, based on scientific and community assessment.
- There is improved community understanding of climate change impacts in the western coastal zone of Lifuka relating to future sea-level rise and storm surge.
- There exists increased capacity in relevant agencies in the Tonga Government to conduct assessments of coastal and social vulnerability in relation to adaptation to coastal erosion and sea-level rise. Dedicated training, where possible and appropriate, was organised and implemented.
- There is improved regional awareness and understanding of the potential impacts of climate change on coastal zones. Awareness is hard to measure, but we are still early in the process. Findings were shared through various processes captured in this overview report, with particular reference to Section E 2.0 (two documentaries). Both received wide coverage both in Tonga and in the region and at regional events, and have been made available to communities in Lifuka.

***Unexpected outcomes***

- Video documentaries, maps and field-day events all led to closer engagement of the community in all aspects of the process and contributed to awareness-raising around the science and the social impact issues of coastal erosion and sea-level rise.
- The final workshop in Nuku'alofa fostered closer engagement of local community representatives with local, central and higher-level Government decision-making bodies.
- Interaction was strengthened through joint activities, such as those between Tonga Water Board, MLSNRECC and Health.
- Communities developed their own community action plans.

***Expected long-term benefits***

- Resource mapping will contribute to future planning and development in Lifuka.
- Information and reports generated in the course of this project are being used by other development partners. For example, Asian Development Bank is considering establishing emergency shelters outside the hazard zones.
- The government confirms that the reports generated will be good reference for the future development of project proposals with donors and development partners for Lifuka, Ha'apai. This has already occurred with the data and findings from this project being used in other proposals.
- The government confirms that topographic and groundwater resource mapping together with LiDAR data will be useful for future planning, infrastructural development and decision-making in Lifuka, Ha'apai.

*Strategies for sustainability*

A range of issues need to be taken into account when considering strategies for sustainability; if not given due consideration, the successful follow-through of project recommendations can be put at risk.

These issues include:

- the need for strong political will and commitment to follow through on recommendations and to use evidence-based solutions in continued close consultation with communities in designing and implementing adaptation options;
- recognition of the importance of addressing land tenure and ownership issues;
- ensuring access to resources; and
- community acceptance of technical solutions.

All of these risks lie outside of the sphere of influence of the project.

Continuing commitment from the government needs to take into account all of the above and bring into focus relevant policy, legislative, institutional, management or human resource considerations.

Planning and aid proposals need to be based on, and use, information generated by the project. The community of Lifuka needs to be regularly updated on developments through local government mechanisms.

*Implementation issues*

There was a delay implementing the socio-economic component under the PASAP. This was a result, principally, of the Tonga Community Development Trust's lack of commitment to and lack of technical skill in effectively and efficiently carrying out tasks that it had been specifically assigned. The Project Monitoring Unit had to step in and complete these tasks.

There should be a Phase 2 (implementation phase) under PASAP and AusAID. The Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education should confirm the availability of funds for implementation of the recommended action.

*Lessons learned from the perspective of the Government of Tonga*

- The importance of establishing the policy, scientific and analytical basis for climate change adaptation in Lifuka, Ha'apai
- The necessity to increase Lifuka communities' understanding of and awareness of climate change and its impacts on the island's natural and socio-economic systems
- The value of enhancing local capacity to assess vulnerabilities and risks, formulate adaptation strategies and mainstream adaptation into decision-making
- The value of many useful practices (such as tools/methodologies, institutional arrangements, management arrangements, monitoring and evaluation frameworks and the like) adopted by PASAP, which will be replicated in assessment/implementation of future projects in other vulnerable communities in Tonga
- The importance of good partnerships between relevant stakeholders: PASAP, the government, NGOs, the Governor of Ha'apai, the Ha'apai Development Committee, the district and town

officers of Lifuka and the Lifuka community

- The need to build synergies with other climate change and disaster-risk programmes/projects and related initiatives (JNAP, PACC, GIZ CCPIR, MESCAL, National Communication, NBSAP, IIB, IAS, and DRM) within government and NGOs
- Confirmation that the engagement of regional experts from regional organisations such as the SPC to work with the local counterparts is a cost-effective mechanism that exchanges and transfers skills and knowledge.

***Recommendations for further engagement***

In agreement with the Government of Tonga, it is suggested that there is follow-up after 24 months to ascertain whether:

- the recommendations have been implemented;
- the training resources; the data, the monitoring and impact assessment tool, and soil laboratory are being used;
- the Integrated Climate Monitoring System has been taken on board and indicators are being measured; and
- data and information from the project have been used in the design and implementation of other climate change adaptation projects in Tonga.
- In considering adaptation options, the community should not rely upon future shoreline protection to compensate for poor location or design decisions. A reliance on hard structures (such as revetment) or beach nourishment to protect coastal sites and residential buildings is not a good substitute for appropriate site selection and construction; storm waves can easily spill over the top of a revetment and damage buildings.
- A managed retreat from the shoreline also favours a functional coastal ecosystem that is more resilient to climate change and variability, and provides goods and services that are critical to livelihoods.

# SECTİON H: BİBLİOGRAPHY (output 1)

## Lifuka project literature and data review

### *1. Tonga and Lifuka information*

#### *1.1 Demographics*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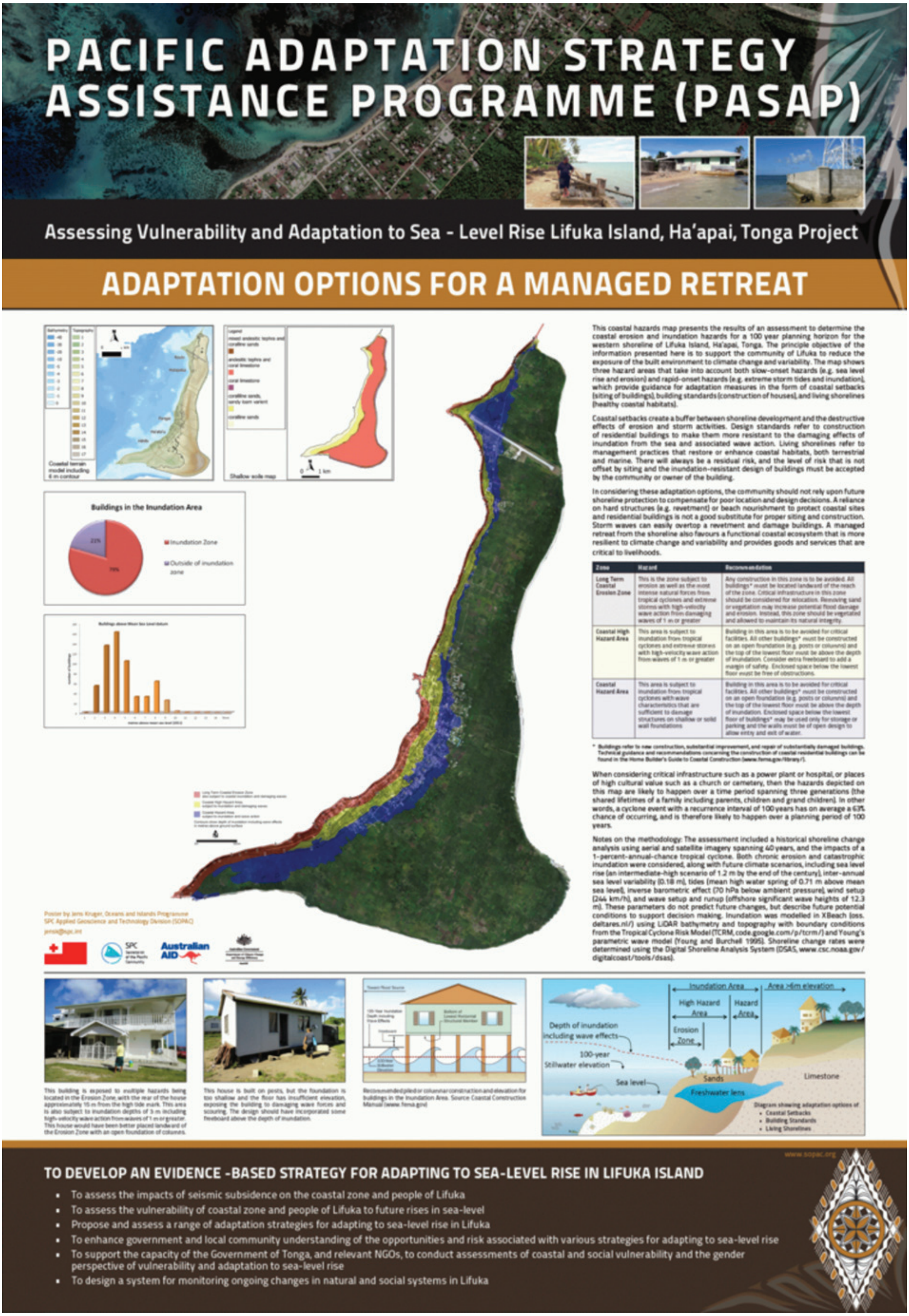
# Annex 1: A poster explaining coastal hazard zones



# Annex 2: Key activities and stakeholders relating to this project at the time of design

| Project Title | Description | Stake-holders | Time-frame | Geographic focus |
|---|---|---|---|---|
| Initial National Communication | Report on measures being taken or planned to implement the UNFCCC. USD325,000 | UNDP, GEF | 2005 | National |
| Second National Communication (SNC) | Consultations and stocktaking started (2006). USD405,000 | UNDP, GEF | 2006–2010 | National |
| National Capability Self-Assessment (NCSA) | Assist countries to strengthen their capacities to manage their priority environmental issues. USD200,000 | UNDP, GEF | 2008 | National |
| Pilot programme for Climate Resilience (PPCR) | Mainstream climate change adaptation into national development planning through a long-term programmatic approach. USD6–8 million | CIF, ADB | 2010–2015 | National |
| Pacific Adaptation to Climate Change (PACC) Project | Improve effectiveness of climate change response (technical skills, policy). Water resource management pilot activity in Hihifo District, Tongatapu. USD750,000 | UNDP, SPREP | 2009–2014 | Tongatapu |
| Pacific Climate Change Programme | Risk assessments, mainstreaming, inclusion of adaptation into infrastructure projects. | ADB | 2010 | Regional |
| Integrated Water Resource Management Project (IWRM) | Strengthen governance structures and frameworks to mainstream IWRM and water-use efficiency into national planning processes. USD7 million | EU, SOPAC | 2012 | Regional |
| Pacific Regional Infrastructure Facility | Data gathering exercise for urban development across Tonga | AusAID | | Regional |
| Pacific Islands Climate Prediction Project (PI-CPP) | To enhance the ability of National Meteorological Services to provide seasonal climate prediction services. | AusAID | 2004–2010 | Regional |
| South Pacific Sea-Level and Climate Monitoring Project: Phase IV | Tide gauge was installed at the Queen Salote Wharf, Nuku'alofa in 1993 to measure sea-level rise. | AusAID | | Regional |
| Pacific Islands Global Climate Observing System (PI-GCOS) | This project intends to strengthen the meteorological and climatological capacities to plan and respond to climate variability and extreme weather events. | | | Regional |
| National Foreshore Protection Programme | Foreshore protection constructed against future erosion and saltwater intrusion to Nuku'alofa areas. This project was funded by Japan and Tonga. | JICA | | Nuku'alofa |
| Coastal Protection, Houma village | Coastal trees replanted at Houma village, Western District, Tongatapu as protection from saltwater spray and climate change impacts along coast of Houma. | SPREP, MAFF | | Tongatapu |
| Ha'apai Conservation Area Project | Coastal tree replanting in Lifuka Island and remote areas of Ha'apai. | | | Ha'apai |
| Tonga Environmental Planning and Management Project | Included replanting of mangroves and coastal trees. | AusAID | | Tongatapu |
| Coping with Climate Change in the Pacific Island Region (CCCPIR) | Capacity building, energy, mainstreaming, REDD, tourism, adaptation. | GIZ, SPC | 2009–2015 | National, Lifuka Island |
| Causeway rebuilding, Ha'apai | German grant to rebuild causeway linking Lifuka and Foa Islands. Total cost TON3 million. Due for completion by December 2011. | MOW, MLSNRECC | 2010–2011 | Ha'apai |
| International Water Infrastructure Project | Consultancy "Ecowise" developed a water management system after assessing location, quantity and quality of groundwater in Lifuka. | TWB, AusAID | 1999 | Lifuka Island |
| Mangrove Eco-System for Climate Change and Livelihood | USD2.297 million | IUCN | 2014 | |
| Renewable Energy Projects | Installation of solar panels in Ha'apai outer islands. | IUCN | 2008–2010 | Ha'apai |

# Annex 3: Summary of PASAP project activities, outputs, personnel, and training

| Step | Outputs | Personnel | Training | Timing |
|---|---|---|---|---|
| 1. Project set-up including literature and data search and review | 1. Annotated bibliography<br>2. Agreed project implementation plan developed through an inception meeting<br>3. PMU positions in Tonga advertised/appointed | 1. Four members of the project team (PMU) each committing two weeks (8 weeks in total)<br>2. MLSNRECC and TWG members | 1. On the use of key word searches, searchable databases, and analysis of sources<br>2. Through an inception workshop on the goals and objectives of the program | Months 1–2 |
| 2. Topographic and groundwater resource mapping | 1. Report on coastal mapping<br>2. Report on geophysical investigations and monitoring bore rehabilitation<br>3. Report on quarterly shoreline and groundwater surveys | 1. Control point surveying: TBC<br>2. For LiDAR: n/a<br>3. Fieldwork for surveying: 4 people for 8 days to establish initial island surveys, repeat surveys, quarterly, 2 people, 2 days.<br>4. Two days for 2 people for surveying of the groundwater bore network repeat surveys, quarterly 2 people, 2 days<br>5. Geophysical survey investigations and monitoring bore rehabilitation 8 days for 4 people plus two local labourers | 1. On relevant survey techniques<br>2. On the use of the GIS software<br>3. On identifying locations for profile sections<br>4. On field geomorphic interpretation<br>5. On use of geophysical survey techniques and equipment and monitoring bore rehabilitation | Months 3–14 |
| 3. Assess sensitivity to coastal, freshwater, and social changes<br><br>A. workshop with NGO and government partners — capacity building and methodology development (10 days)<br>B. Temporal imaging analysis<br><br>C. Focus groups<br><br>D. Household surveys | 7. Workshop report which includes methodology and a participatory strategy for community engagement<br><br>8. Report of shoreline dynamics, including maps of shoreline position over several decades and rates of shoreline movement<br><br>9. Report on analysis of social impacts including a gender perspective<br><br>10. A report on the collected household survey data, its analysis and presentation of results including water resources assets and reliance on different water sources | PMU (incl. 3 SPC staff members); NGO partner(s); government partners<br><br>1. Ground truthing of image rectification: 2 people 5 days. For aerial image analysis: 1–2 people familiar with operation of ArcGIS, for 8–12 weeks<br><br>2. Household survey design: 3 people to design, administer and analyse the interviews, for 2 weeks (3 PMU)<br>3. Household Survey Field work: 4 people (two teams of two) over 3–4 weeks (1 additional team first week) (PMU)<br>4. Analysis and report of data: PMU staff 2 weeks with additional input from SPC Stats and Demography staff — 1 week | Vulnerability and adaptation<br>Participatory approach<br>Gender analysis<br>Interview and group discussions<br><br>On identifying features on aerial photos/satellite imagery<br>On photo rectification into a usable format in GIS<br>On interview design, implementation and analysis<br>On water resource survey techniques | Months 3–4<br><br>Months 3–15 |
| 4. Understand the sediment system | 11. Report on the island sediment system including maps of surface benthic zonation and sediment composition | 1. Field work: 3–4 people for 5 days<br>2. Laboratory: 1–2 people for 14 days<br>3. Mapping of zones: 1–2 people familiar with operation of ArcGIS, for 10 days<br>4. Assistance with field data collection | 1. Field training on sample selection and basic sedimentological techniques as well as identification of reef-island biogeo-morphological zones | Months 7–11 |

| Step | Outputs | Personnel | Training | Timing |
|---|---|---|---|---|
| 5. Analyse process dynamics | 12. Installation of current meters and wave gauges<br>13. Report on the process dynamics of the reef system from the reef crest to shoreline and inundation modelling<br>14. Report, concept drawings, and preliminary costing on basic shoreline protection options | 1. Two people over a 1 week field programme<br>2. One person for 2 weeks to analyse field data<br>3. Consultant engineer to advise on shore protection options<br>4. Inundation modelling — 3 month analysis (SPC) | 1. On the deployment and maintenance of oceanographic equipment | Months 10–15 |
| 6. Community values analysis | 15. Report describing community values | 1. For collection and analysis of existing reports: 3 people for 3 weeks<br>2. For conduct and analysis of key informant and focus group interviews: 3 people for 3 weeks | 1. On analysis of existing data<br>2. On focus group interviews | Months 4–6 |
| 7. Analysis of exposure to risk | 16. GIS database on infrastructure<br>17. Report identifying community concerns and exposure to risk, including maps<br>18. Cost–Benefit analysis report | 1. For the climate change scenarios: PCCSP assistance will be sought to provide training and model application<br>2. For mapping: MLSNR will be required and updated information from household surveys. One PMU staff member for 4 weeks<br>3. For the review of census data, development plans, and past studies, and interviews population projections, analysis of development plans, focus group interviews to develop scenarios of future social change: 2 project staff members for 2 weeks and an additional staff member for 1 week (5 weeks in total)<br>4. Cost–Benefit analysis: SPC resource economist for 10 days | 1. On the use of the Climate Futures tool<br>2. On the development of scenarios of social change through focus groups | Months 9–16 |
| 8. Vulnerability synthesis and adaptation strategies | 19. A workshop report that describes the project's method, presents data and findings, identifies a range of adaptation strategies, and details the communication strategy for community outreach extension | 1. For the workshop: up to 10 members of the project team for 5 days<br>2. For writing: up to 4 members of the project team for 1 week each (PMU to compile report) | N/A | Month 16 |
| 9. Community engagement | 20. A report describing the community engagement process including the methodology used, the level of community engagement, the preferred adaptation strategy and the lessons learned from the process | 1. The local MLSNRECC officer and other local partner organisation personnel will need to be present and available to members of the community<br>2. The leader of each of the coastal and social research teams associated with this project will be present for each series of community meetings, and should lead discussions on radio<br>3. One additional staff member from the project team may be required to assist with community meetings<br>4. For interviews with individuals: 2 additional PMU staff members working for 1 week a month for 2 months | N/A | Months 17–18 |

| Step | Outputs | Personnel | Training | Timing |
|---|---|---|---|---|
| 10. Integrated Climate Impacts Monitoring System | 21. A report describing a proposed Lifuka Integrated Climate Impacts Monitoring System | 1. PMU (2 members from each of the coastal and social assessment teams), local NGOs and MLSNRECC staff members, each for 1 day | 1. A day-long workshop on best practices in the use of indicators | Months 16–18 |
| 11. Final report | 22. Report collating each output report into a synthesis document for the project, including in Tongan language. | 1. PMU (two members from each of the coastal and social research teams), each for 3 days | 1. A day-long workshop to review the milestone reports, structure and develop a final report | Month 18 |
| 12. Finances and administration | 23. Six monthly financial and narrative reporting on project progress | PMU and 1 project officer 0.60 of times (based in Noumea) | | Months 6,12,18,21 |
| 13. Monitoring and evaluation | 24. A report which summarises the capacity building initiatives undertaken during the course of the project<br>25. A report which provides an assessment of project management arrangements<br>26. A compilation of communication and advocacy materials including a project video documentary | Project Management Unit throughout the project | | Upon comple-tion |

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