Assessing vulnerability and adaptation to sea-level rise: Lifuka Island

Ha'apai, Tonga

D: Adaptation options and community strategies report

SPC Secretariat of the Pacific Community

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Jens Kruger, Hervé Damlamian, Peter Sinclair, Fuka Kitekei'aho, Soana 'Otuafi

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Contents

List of technical report titles for the project:
Assessing vulnerability and adaptation to sea-level rise: Lifuka Island, Ha'apai, Tonga

The Australian Government's 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'.

The Lifuka 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) to develop an evidenced-based strategy for adapting to sea-level rise in Lifuka Island.

Rising oceans, changing lives: Final report is the overview report in a series of technical reports that have been written for the project on Lifuka Island. Accordingly the section titles in the final report correspond with the names of the respective technical reports. The full series of technical reports is listed below.

A: Rising oceans, changing lives: Final report

B: Mapping the Resources

B 1: Physical resources

1.1: Shoreline assessment

1.2: Groundwater resources assessment

1.3: Oceanographic assessment

1.4: Benthic habitat assessment

1.5: Beach sediment assessment

1.6: Household survey to assess vulnerabilities to water resources and coastal erosion and inundation

B 2: Community assessment

2.1: Community engagement strategy and community assessment manual

2.2: Community values and social impact analysis

C: Vulnerability and hazard assessment

1.0: Coastal hazards

2.0: Coastal rehabilitation – Lifuka Island, engineering options report

3.0: Preliminary economic analysis of adaptation strategies to coastal erosion and inundation: Lifuka, Ha'apai, Kingdom of Tonga: Volume 1 – Least cost analysis

4.0: Preliminary economic analysis of adaptation strategies to coastal erosion and inundation: Lifuka, Ha'apai, Kingdom of Tonga: Volume 2 – Cost benefit analysis

D: Adaptation options and community strategies

Executive summary

Dealing with coastal erosion on Lifuka Island has been identified nationally and locally as an adaptation priority. The region experienced an earthquake on 3 May 2006 that measured approximately 7.9 on the Richter scale. It caused subsidence of 23 cm of Lifuka Island – in effect, an instant sea-level rise.

In the past four years, the island has also experienced significant coastal erosion along a 3 km section of coastline, on which are sited the harbour, residential dwellings, government offices, a broadcasting tower, a church, police and fire services, and the Lifuka hospital.

Sea levels are likely to continue to rise during the 21st century due to climate change, and the resulting wave impact is likely to lead to further erosion and inundation. There is, therefore, a need for adaptation in preparation for the future. Accordingly, Tonga's Ministry for Lands, Survey, Natural Resources, Environment and Climate Change (MLSNRECC) and the Secretariat of the Pacific Community (SPC), with the support of the Pacific Adaptation Strategy Assistance Program (PASAP) funded by the Government of Australia, collaborated to develop an evidence-based strategy for adapting to coastal erosion and sea-level rise on Lifuka Island.

The objectives were:

- to assess the impacts of coseismic 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 on 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 non-governmental organisations (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.

The general objectives in assessing adaptation options for Lifuka were the following:

- reduce risks to human health and safety;
- reduce exposure and vulnerability of the built environment;
- maintain a functioning and healthy ecosystem;
- maintain livelihood opportunities.

Also considered were:

- local capacity to realise each adaptation option;
- the technical effectiveness of each option;
- the cost of each option;
- the benefits of each option.

Recommendations

Having assessed a range of scientific data and consulted with the Lifuka community on the social impacts of sea-level rise and erosion, the Project Management Team and the Technical Working Group of the Lifuka project believe it is inevitable that the community of Lifuka will have to stage a managed retreat to protect families and infrastructure that face the damaging impact of storm-driven waves. Managed retreat is considered to be the most sustainable way to adapt to inundation and erosion risk, with respect to both community and public infrastructure and people's livelihoods.

The team believes that such a retreat needs to incorporate a coastal setback zone in the erosive and highly-exposed coastal fringes. It therefore recommends that planning for coastal retreat and setback zoning starts immediately, and that this be supported by other strategies where suitable, such as the elevation of buildings in hazard areas.

It is recognised that the factors affecting development and implementation of an adaptation strategy depend on the palatability of the options financially and socially, and the level of risk the government and the community are willing to accept. Managed retreat touches on land-ownership issues, and the social and economic costs that would accompany such an option may not be easily embraced by the community. Relocation of houses and infrastructure and withdrawal from land along the coast would take time; it is, therefore, expected that managed retreat would be a staged response over a period of time, and that such a response would need to be planned and supported by the government.

Final community consultations were held in late April and early May 2013 to select an option. These meetings gave Lifuka's people the opportunity to discuss each option's advantages and disadvantages while expert help was available. Rock revetment was the preferred choice.

The construction of revetments and seawalls and raising houses above expected inundation levels does not remove risk; such activities would be expected to form part of a managed or staged response to the risk of inundation.

Whatever action is taken, there will be environmental, financial and social effects. By using indicators to measure ongoing changes in natural and social systems on Lifuka over time, we can map these effects. This report describes an Integrated Climate Impacts Monitoring System (ICIMS) to capture that information.

This project also found that fresh groundwater within the area of inundation, as well as the infrastructure providing this fresh water to the community, is under threat. A range of options is presented to help householders and the Tonga Water Board maintain an efficient and safe water supply. Monitoring and evaluation of water sources is also part of the proposed ICIMS.

1. Adaptation options for Lifuka

A range of options has been explored during this project, and summaries of these options follow. For full information, see C 2.0 Coastal rehabilitation – Lifuka Island, engineering options report; C 3.0 Least cost analysis; and C 4.0 Cost benefit analysis.

1.1 Revetment

Revetments are sloping structures covered with an erosion-resistant ‘armour’ that are permeable enough to absorb incoming wave energy (seawalls are often vertical and reflect wave energy).

Figure 1: Rock revetment, Nuku’alofa

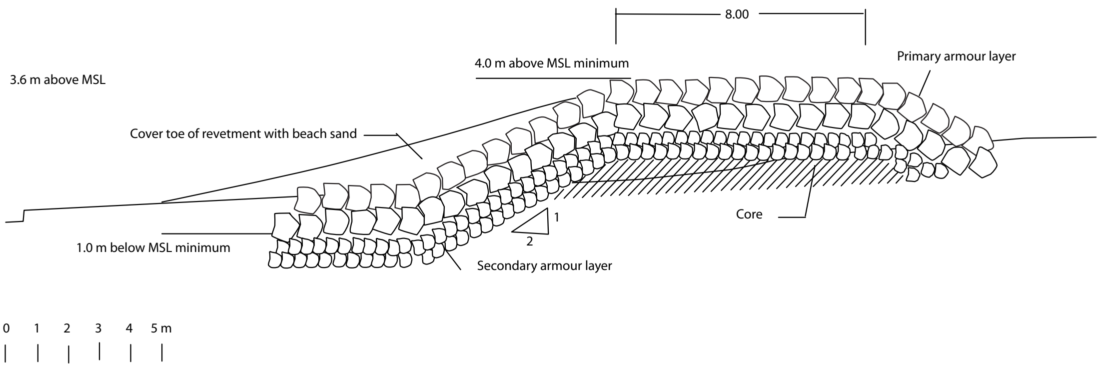


Figure 2: Design of a rock revetment sized for conditions on Lifuka’s western coastline

Rock revetment appraisal: advantages

- They can be effective in protecting landward infrastructure from erosion.
- Rock absorbs wave energy and reduces wave run-up and overtopping.
- They can allow continued development on the coast, as they reduce risks.

Rock revetment appraisal: advantages: disadvantages

- They are very costly to construct.
- They require ongoing maintenance.
- Their large footprints disturb a large width of the shoreline, as well as the ecosystem.
- The public loses access to the shoreline.
- They may not necessarily mitigate flooding, and may provide people with a false sense of security.

Revetment footprint

Figure 3: The space that would be taken by a rock revetment in (left) Pangai, and (right) Hihifo

1.2 Beach recharge

Another option is beach recharge, also known as sand replenishment, which is essentially trucking in sand to replace what is being lost. These examples of beach recharge are from Hawai'i.

Figure 4: Waikiki Beach, before beach recharge

Figure 5: Beach recharge work in progress

Figure 6: After beach recharge

Beach recharge on its own is, however, not an effective solution, as the forces that caused the beach erosion will simply continue to wash away new sand.

1.3 Beach recharge with groynes

Beach recharge needs to go hand in hand with a series of sand traps, or barriers, known as a groyne field. Groynes are walls of rock, wood or sand-filled geotextile bags, built at right angles to the shoreline to trap sand and stop it drifting away. They help contain sand that otherwise would be washed away.

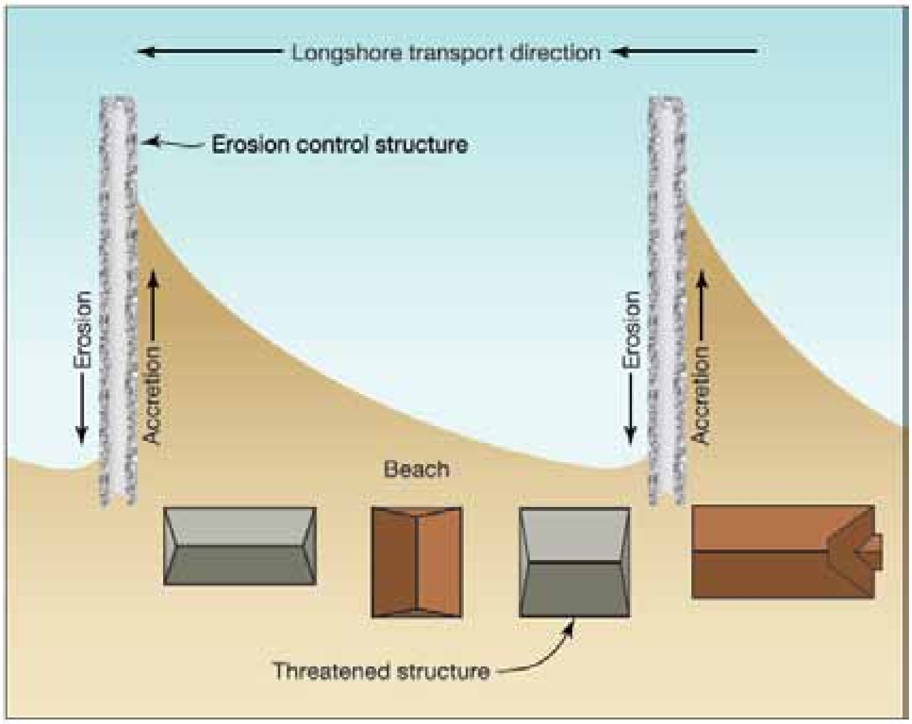


Figure 7: How groynes work

Figure 8: An aerial view of a groyne field that has successfully trapped sand to maintain the beach

Groynes work best in conditions where there is a high rate of sediment transport – the movement of the loose, erodible material in the sea – along the shoreline. The technical data collected suggests that this is not the case on Lifuka, which makes sand replenishment and a groyne field an ineffective adaptation option for the island.

Beach recharge appraisal: advantages

- It works with natural coastal processes rather than disrupting them.
- It allows rehabilitation of coastal vegetation.
- It provides a buffer of sand to help protect infrastructure.
- Sand trapped on the northern side of the Pangai wharf could be trucked to Pangai and Hihifo beaches, effectively by-passing the wharf structure.
- There is low reliance on imported materials.

Beach recharge appraisal: disadvantages

- It may cause environmental disturbance while work is being done.
- It requires periodic replenishment and maintenance, which can be costly.
- There is a relatively high level of uncertainty about how beaches perform during storm events, as new sand can rapidly be lost again.

1.4 Managed retreat

Managed retreat, the option recommended by the project, could involve several components:

1. The delineation of a coastal setback zone in which building activity is restricted in order to mitigate risk, and relocation of families in the most hazard-prone areas to safer areas inland.
2. Building standards that favour elevation of coastal buildings to protect people and property.
3. An ongoing '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 of extreme events and conditions and able to recover more readily from them.

1.4.1 Coastal hazard zones and buildings at risk

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

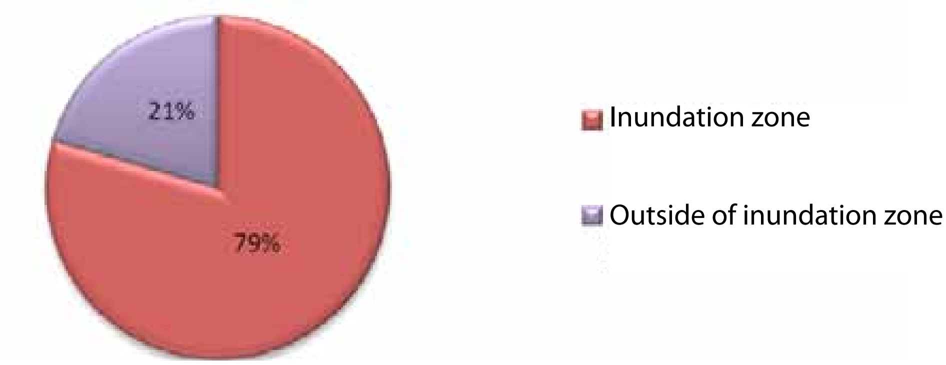


Figure 9: Percentage of homes located within the inundation zone

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 – immediately, over a generation (gradual retreat) or as homes deteriorate (voluntary retreat).

Hazards and recommendations for each zone are as follows.

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. Consideration should be given to relocating critical infrastructure in this zone. 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 of 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 raise the level further and 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 of 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.

Table 1: Building recommendations for coastal setback zones.

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

We are likely to see the impacts of the major coastal hazards of erosion, inundation and flooding (described in report C 1.0: Coastal hazards) occur in a time period spanning three generations (the shared lifetimes of a family including parents, children and grandchildren). Official reports show that at least 13 tropical cyclone disaster events have hit the Ha'apai group in the past 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. Erosion is already occurring; 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 value 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.

1.4.2 Coastal setback zone, Hihifo

The Hihifo coastal setback zone would be 110 m wide.

Figure 10: Coastal setback zone, Hihifo.

1.4.3 Coastal setback zone, Koulo

The Koulo coastal setback zone would be 25 m wide.

Figure 11: Coastal setback zone, Koulo

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

Coastal setback zones should be coupled with elevation of buildings in the hazard areas, as shown in Figure 12. Raising the floor height of buildings above the inundation levels depicted on the coastal hazard map (see report C. 'Vulnerability and hazard assessment' and also the poster version of this shown in the annex), either using concrete columns or wooden poles, leaves the area below open to allow ocean water to flow under the building, reducing structural damage to the building or its contents in 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, as this land is unstable and subject to continual change.

1.4.5 Design of elevated buildings

Figure 12 shows the recommended elevated, poled or columnar construction for buildings in the inundation area, including new construction, renovation, and repair of substantially damaged buildings.

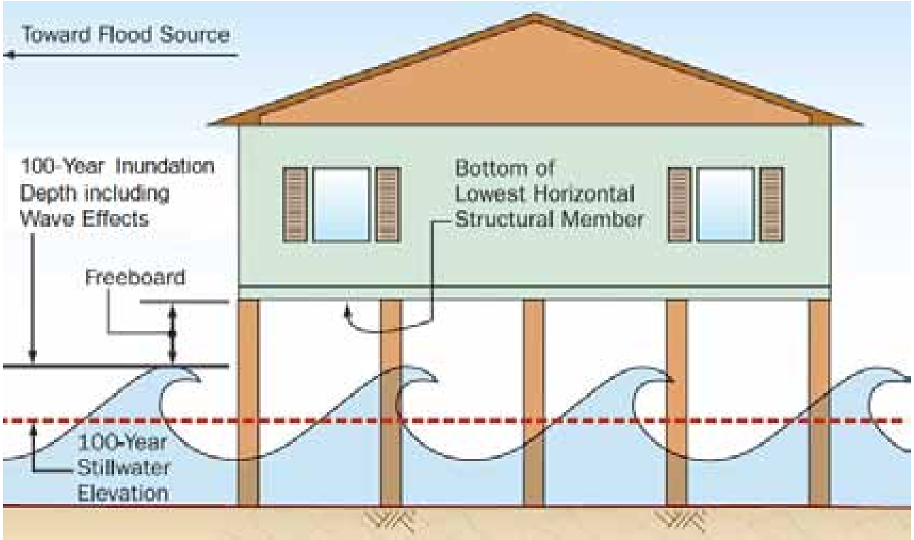


Figure 12: Source: Coastal Construction Manual, available at www.fema.gov

Examples of elevated buildings

Figure 13 shows a building in the USA that survived the destructive Atlantic tropical cyclone Katrina in 2005. It is an example of a successful, well-elevated and embedded pile-foundation building. Note the number of collapsed buildings in the background.

Figure 13: A successful, well-elevated and embedded pile-foundation building.

The example below is also from the USA. The buildings depicted are well elevated and structurally sound, but now uninhabitable because of erosion.

Figure 14: Sound coastal buildings rendered uninhabitable by erosion

The building shown in Figure 15 is in Nuku'alofa, Tongatapu, Tonga. It is not well set back from the revetment, being separated from it only by a public footpath. It is one of the very few elevated structures in the backshore of Nuku'alofa, and has been designed to allow storm waters to pass under the house without causing structural damage.

Figure 15: House in the backshore of Nuku'alofa built using a concrete stilt construction. Even though the house is elevated to mitigate against flooding and wave action during storm events, it is located in a vulnerable area close to the shoreline.

1.4.6 Managed retreat: A schematic view

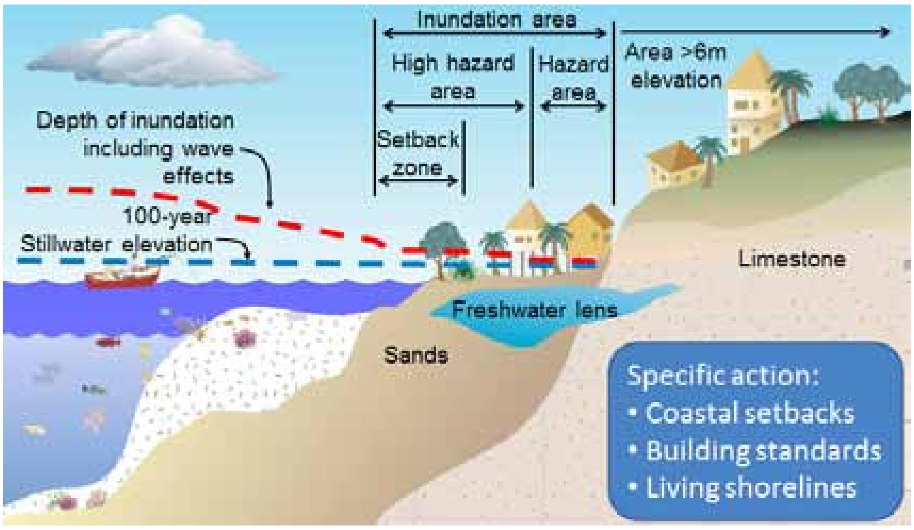


Figure 16: Schematic view of managed retreat. The shoreline should be vegetated and be allowed to undergo natural adjustment. Building in the coastal setback zone should be avoided. Houses in the hazardous areas should be elevated. Critical infrastructure with a long lifetime should be built on higher ground at least 6 m above mean sea level.

Managed retreat appraisal: advantages

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

Managed retreat appraisal: disadvantages

- Limits buildable area.
- Requires setting aside a certain amount of land.
- Often controversial, so needs discussion and incentives for home-owners.
- Results can be unpredictable.

2. Summary of economic assessment

For more detail, see reports C 3.0 Least cost analysis and C 4.0 Cost benefit analysis.

Several different adaptation options were assessed for their costs and benefits: revetment, retreat and the elevation of buildings. In practice, there is no single set formula for how these options might be implemented in Lifuka. The community and the Government of Tonga would need to consider the options that would best suit them. Nevertheless, to illustrate the kind of implications that each option would have, some scenarios were provided for revetment, retreat and elevation of homes. The community and the Government of Tonga can use this information to inform their future talks.

Based on discussions with the Government of Tonga and the availability of existing data, the total costs to implement revetment, retreat and elevation of houses were assessed (see report 3.0 Least cost analysis). A revetment using a short, basic design could be the cheapest option, although elevating buildings would be cheaper if elevation was built into the design of new buildings. Retreat would be costly if it included the cost of rehousing families and accessing new land on which to build new homes. In practice, however, these costs would be substantially lower if families voluntarily relocated when their existing homes required renovation and/or if only those families in the highly hazardous and coastal setback zones moved.

Potential payoffs

In reality, cost is only one consideration when selecting an adaptation strategy. The effectiveness of a strategy in preventing building damage and in protecting homes and businesses from harm is the critical issue. The values of revetment, elevation and retreat were thus estimated, based on their ability to protect homes and land in the event of a single 1:100 year tropical cyclone event. The values estimated are indicative only and are likely to be underestimates because they do not include benefits to buildings other than homes (such as schools) or other sectors (such as utilities). Moreover, the benefits valued only reflect 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 raise critical issues that need to be considered in selecting and designing the final adaptation strategy for Lifuka – and elsewhere.

Using a variety of scenarios for revetment, retreat and elevation of homes, no single adaptation method appeared to offer benefits of sufficient value (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 offered 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 area only is considered, the estimated benefits of voluntary retreat almost meet the costs. It is possible that – if all other benefits such as protection of possessions are included – this option would be economically efficient.

The next most efficient option after voluntary retreat was a short revetment. Short revetments were estimated to generate losses over 50 years of around TOP 0.4 million but, in the process of so doing, they protect the land from ongoing erosion, which is important to the community. (The benefits from this 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. (Revetment commonly incorporates a permeable filler layer as part of its structure which would, by definition, allow water to flow up and onto the land.) It is unclear if the community recognises this limitation to revetment. Furthermore, the estimates provided for revetment 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 revetment upon the coastal ecosystem. (Revetment would interrupt existing dynamic processes and also potentially have a negative impact on the continuation of sea-grasses and related fisheries.) The existence of revetment would also impede public access to the beach. Any revetment would logically – and by law – require an environmental impact assessment to be undertaken, with consideration of how to mitigate 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 1:100 year storm event led to severe damage, immediate relocation of families from the high hazard zone would become the most efficient option, followed by elevation of houses. Elevation of houses becomes increasingly efficient the higher they are elevated, and is particularly efficient for houses in the high hazard zone.

In considering adaptation options, the community should not rely on 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.

3. Water resource adaptation options

3.1 Adaptation options for households

The recommended water resource adaptation options for households are listed below.

1. A guttering maintenance programme to ensure adequate rain is being captured.

2. 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.

3. Targeted installation of plastic tanks to replace leaking cement tanks.

4. Boiling or chlorinating of water used for drinking water purposes.

3.2 Why are these options recommended?

The Household Survey (Report B. 1.6), undertaken as part of the Lifuka project, showed that 92% of Lifuka's households relied on rainwater for cooking, drinking and washing.

The majority of households (85%) had adequate roofing – usually made of corrugated iron – for rainwater harvesting. However, more than 85% of all households collected 50% or less of the rain falling on the roof. Furthermore:

- 75% of all houses required improvements to their guttering;
- 46% of all households did not have any screens to prevent debris entering water tanks; and
- 76% of households with screens needed to have those screens either repaired or replaced.

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. Just 5% of all households regularly boiled their drinking water to reduce the risk of illness.

At the time of the survey, there was 5.3 ML of storage averaging to 14,600 L/HH. However, this was not evenly distributed, and 34% of all households had less than 10,000 L of storage.

Water was stored in cement tanks (75% of all tanks connected to a rainwater harvesting system), cement cisterns, plastic tanks and fibreglass tanks. However, 50% of cement tanks were observed to be leaking or in need of repair.

3.3 Adaptation options for the Tonga Water Board

Lifuka's groundwater is a small and limited resource which is impacted by over abstraction and with a shallow water table that is susceptible to contamination. It is important to plan to safeguard quality and supply from existing threats of abstraction, contamination, an eroding shoreline, and future extreme events such as seawater inundation. Recommendations for the Tonga Water Board are listed below.

Reticulation

1. Reduce the high rate of lost and unaccounted-for water.
2. Adjust abstraction based on salinity in production wells; reduce the draw on any one individual well when salinity is high.
3. Improve water-quality sampling and adopt a pro-active response to the results.

Buffer zones

4. Create a 100 m buffer zone around TWB wells and abstraction galleries to protect groundwater from contamination. No animals should be allowed to reside in this zone. Wastewater disposal would be improved in this zone, and the storage and use of chemicals and fuels restricted.
5. Fence off an area 10 m around each well-head to limit contamination.
6. Fence off Tonga Water Board wells 4, adding a bund and improving surface drainage to direct surface water away from the well head.

Why are these options recommended for the Tonga Water Board?

Groundwater is an important water source for Lifuka. It is supplied by both the Tonga Water Board and private wells. But tests carried out as part of the household survey showed that 95% of groundwater samples tested positive for E. coli, which can cause illness if ingested.

This contamination was due to faecal matter from warm-blooded animals entering the groundwater system and migrating to wells. The high concentration of pit latrines and poorly-constructed septic tanks was a contributing factor, as was the high number of roaming animals, including pigs and dogs.

A total of 68% of Lifuka's households have access to water from the Tonga Water Board, and this provides an estimated 80% or more of the water needed by these connected households. However, they use it primarily for personal bathing, toilets and gardening.

Losses are estimated to account for 33% of total production, with unaccounted water, which includes losses and illegal connections, estimated to be as high as 51% of total water abstracted.

4. The community response

This section documents the Technical Working Group's presentation of three 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, and to give people the opportunity to discuss their advantages and disadvantages while expert help was available, after which they could choose their preferred option.

The options were:[1]

Option 1: Rock revetment 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

1 For more information on the technical aspects of options 1 and 3, see report C 2.0 Coastal Rehabilitation, Lifuka Island, Engineering Options.

4.1 Presentation to the Governor of Ha'apai, district and town officers and some church leaders

The meeting is summarised below.

Meeting with	Governor of Ha'apai, Honourable Havea Tu'iha'angana
Date	**Wednesday 1 May 2013**
Time	**9.30 a.m.**
Venue	**National Youth Centre**
Attendees (20)	Governor of Ha'apai, Honourable Havea Tu'iha'angana **Representatives of ministries and departments** Ministry of Fisheries and Agriculture Governor's Office Ministry of Infrastructure and Works Ministry of Lands, Survey, Natural Resources, Environment and Climate Change Ministry of Health Ministry of Education **Representatives of NGOs** Red Cross Tonga Water Board Youth Congress **Representatives of high schools** St. Joseph Community College Ha'apai High School **Representing young people** Ha'ato'u Hihifo Town officers District officer
Consultation team	**Representatives from** Tonga Community Development Trust Ministry of Works Ministry of Health Ministry of Lands, Survey, Natural Resources, Environment and Climate Change Tonga Water Board PASAP Project Management Unit
Welcoming and briefing	Fuka Kitekei'aho gave a quick summary of work completed to date, as below. **Results of community consultations and interview** (Tools 1–15) Koulo, Holopeka, Pangai, Ha'ato'u, Hihifo **Results of water assessments** Household survey Impacts of coastal erosion and sea-level rise on Lifuka's water sources (rainwater and underground freshwater lens) Assistance from the project to Tonga Water Board on renewal of water pipes **Results of coastal assessments** Scientific survey and results, causes of coastal erosion Future (return interval [RI] 100 yrs); affected areas not safe for settlement, etc. **Final consultation** Proposed options, determined from the results of the three components assessments and meeting with the technical team in Nuku'alofa: 1. revetment 2. sand replenishment and groynes 3. managed retreat. Advantages and disadvantages of each option

General discussion	
Comments	The governor thanked the team for its work and said that the results would be important in his upcoming meeting with the Ha'apai Development Committee (HDC). The governor said he was well aware of the project, and was aware of much community talk about the results of investigations to date. He was also aware of the problems his people were facing, and said he already had a fair idea of what was in their hearts. He had several questions: ***What did PASAP want from him and the people? Who made the decision about implementations of selected option(s)?*** Fuka Kitekei'aho replied that the project was coming to the final stages, and implementation of an option or options was up to the Government of Tonga. Therefore it is important that these results reached the right people (government, parliament, cabinet, prime minister, etc.) with strong backup from HDC. ***Was it possible to reduce the height of the revetment?*** The governor was advised that this was possible, but that lowering the height of the revetment would allow waves to spill over the top, which would lead to flooding. ***Was funding available for the option(s)? How long would it take to build a revetment?*** The governor was advised that funds were available through various climate-change and climate-adaptation programmes. However, for this to happen, the Government of Tonga would need to make the issue a priority. With full support and commitment from the government, work could be completed within one to two years. **GOVERNOR'S OPTION** The governor recommended rock revetment similar in size and design to a successful existing rock revetment in Nuku'alofa. It was apparent, he said, that the people of Lifuka desperately needed immediate action to minimise and alleviate problems. Revetment, he said, was his final decision.
Other comments from participants	The district officer of Lifuka conveyed his gratitude to the governor for standing with the people of Lifuka. He also emphasised that it was important that his decision reached the prime minister and his government, with full support and backup from his fellow members in the Ha'apai Development Committee. The town officer of Pangai and Ha'ato'u also recommended to the meeting the construction of two elevated town halls (similar in elevation to that proposed for managed retreat) as evacuation centres in case of tsunami or storm surge.
Closing	The governor thanked the team from Nuku'alofa, heads of departments and representatives from other organisations, schools and young people for making time to attend the meeting. He emphasised that the project needed to be fully understood by all stakeholders in Lifuka.

4.2 Community consultations

4.2.1 Methodology

The community was divided into groups of women, men and young people to discuss preferred options. Each group then presented its preferred option and the reasons for its selection to the entire meeting.

The community consultations are summarised below.

FINAL CONSULTATION WITH THE COMMUNITIES OF LIFUKA: ADAPTATION OPTIONS	
Villages	**Hihifo, (Tuesday 29 April); Holopeka and Koula (Wednesday 1 May); Pangai and Ha'ato'u (Thursday 2 May); Pangai-Navea (Friday 3 May)**
Time	**6.00 p.m.**
Venues	**SDA Church, Wesleyan Church Hall Koulo, National Youth Hall**
Attendees	Men, women and young people (Hihifo – 30 people; Holopeka and Koulo – 40 people; Pangai and Ha'ato'u – 30 people; Pangai-Navea – 30 people)
Consultation team	**Representatives of** TCDT Ministry of Works Ministry of Health Ministry of Lands, Survey, Natural Resources, Environment and Climate Change Tonga Water Board PASAP Project Management Unit
Welcoming and briefing	Fuka Kitekei'aho gave a quick summary of work completed to date, as below. **Results of community consultations and interview** (Tools 1–15) Koulo, Holopeka, Pangai, Ha'ato'u, Hihifo **Results of water assessments** Household survey Impacts of coastal erosion and sea-level rise on Lifuka's water sources (rainwater and underground freshwater lens) Assistance from the project to Tonga Water Board on renewal of water pipes **Results of coastal assessments** Scientific survey and results, causes of coastal erosion Future (RI 100 yrs); affected areas not safe for settlement, etc. **Final consultation** Proposed options – determined from the results of the assessments of the three components and meeting with the Technical Team in Nuku'alofa. 1. Revetment 2. Sand replenishment and groynes 3. Managed retreat Discussion of advantages and disadvantages of each option

Workshop convenors originally planned that each presentation would start with a discussion of options in the order above. However, it was 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.

4.2.2 Summaries of community meetings

The meetings held with Lifuka's communities are summarised in the table below.

HIHIFO		
Group Type	**Preferred option**	**Reason**
Young people	Revetment and managed retreat	Revetment is the best option; however, the map (revetment footprint) indicated that people living on the coast would still be affected as they need to relocate inland and give space for the revetment to be built. Therefore, these people should start thinking of areas to relocate to.
Women	Revetment and managed retreat	Revetment seemed to be the best option. But who would pay? The people or the government? Some felt that government decision-makers living in Nuku'alofa did not understand what Lifuka people are suffering, and would not unless they lived on the island. Building the revetment would give people time to retreat.
Men	Revetment	Reclaim about 10 m of land and then build a revetment. There was little at sea to protect. Priority should be the safety of the community (health, security). Private land was more important than protection of the ecosystem.

Comments on options

1. **Sand replenishment and refilling**

MEN: Replacing the sand already lost would be costly as it would need to be done at regular intervals. There was no guarantee that it would work. Is there enough sand available for replenishment?

2. **Managed retreat**

MEN: This option was affordable, but for whom? The government or the people? This option would be cheaper for the government but not for individual households, as households would bear many of the costs (looking for available land, resources for housing, etc). There was no guarantee that land would be available.

Final option for Hihifo

REVETMENT

Hihifo opted for revetment to give affected households time to gather the necessary resources for relocation.

HOLOPEKA and KOULO		
Group type	**Option**	**Reason**
Young people	Sand replenishment and replanting more trees	Sand replenishment would have less impact on the marine ecosystem, would help gain land already lost to coastal erosion and maintain sandy beaches, with livelihoods derived from the sea still intact. Young people emphasised that tree-planting should go hand in hand with sand replenishment to mitigate further erosion. They did not want to lose their beautiful sandy beaches.
Women	Revetment	Ensured security of people and land. A more expensive option, but gave the community safety for a longer period.
Men	Revetment	Felt that if something was expensive that meant it would last longer; therefore they felt that revetment was the best option. The other two options (sand replenishment and managed retreat) would still leave the community exposed to danger.

Comments on options

1. **Revetment**

YOUNG PEOPLE: Building a revetment would have a negative impact on the marine ecosystems, affecting livelihoods derived from the sea. Significantly, Koulo and Holopeka had beautiful sandy beaches and a revetment would ruin them.

2. **Sand replenishment**

MEN: Replacing the sand every three to five years was not ideal as there was no guarantee of this method working. It would be more costly than building a revetment.

WOMEN: Sand was gained and lost all the time, and safety from storm surge and coastal erosion was not guaranteed, unlike with a revetment.

3. **Managed retreat**

MEN AND YOUNG PEOPLE: Land was very scarce in Holopeka and Koulo, making this option unsuitable. Nearby high islands were not suitable or safe.

Other comments

Length/footprint of the proposed revetment

The Technical Working Group recommended that a revetment run from the wharf south to Hihifo, and that north of the wharf, around the villages of Holopeka and Koulo, sand replenishment is the best option. However, Holopeka and Koulo people were not satisfied, as they wanted the revetment to run from their villages right down the western coast of Lifuka. The men, in particular, were firm in their belief that a revetment was the best option for their villages, and explanations from the technical team did not change that perspective.

Water resources

Town officers reported that their water resources were about 5 m from the sea and highly vulnerable to sea-level rise and coastal erosion. Therefore they needed protection, and a revetment would offer this.

Women's group discussion

Prior to agreeing on the revetment, the women's group debated its final option, with 12 women voting for revetment and seven for managed retreat. Points raised by the latter seven members were mainly concerned with the impact of revetment on their sandy beaches, loss of their traditional fish ('otule) and the protection of historical sites on the coastline. The other 12, most of whom were living in the vulnerable coastal zone, said that while these were important issues, they were at risk and needed protection from storm surge and sea-level rise. After further discussion, the entire group agreed on revetment.

Final option for Koulo and Holopeka

REVETMENT

After presentations from all groups and further discussion, the communities of Holopeka and Koulo agreed on revetment. The communities weighed the options and their impacts and agreed that people's security and safety was more important than the ecosystem and other environmental impacts.

PANGAI		
Group type	**Option**	**Reason**
Young people	Revetment	There was no need to retreat now, without any protection to stop or prevent sea water from eroding the land. Therefore, it was better to build a revetment and give time for relocation. The revetment would also benefit the communities through job opportunities.
Women	Revetment	Revetment was the best option as there was no available land for relocation. Not only that, the financial stress of relocation would fall on households, unlike the cost of the revetment, which would be a government responsibility.
Men	Revetment	Revetment was cheaper than managed retreat, therefore land should be reclaimed from the sea to build a revetment.

Other comments on options

1. **Managed retreat**

MEN: This was not an option as there was no available land for retreat on Lifuka's eastern coast. This sector of the island was also undergoing coastal erosion and no one could guarantee a tsunami would not occur on the eastern side.

Other comments

Availability of rocks/boulders for a revetment

According to the representative from Ministry of Works and Infrastructure, there was a good supply of rocks to build the revetment.

Request for assistance.

Evacuation centre

The town officer recommended an elevated evacuation centre be built for communities that need to evacuate their homes.

New water source

The community requested another possible source of water for Lifuka other than the source at Hihifo.

Open the bottom of the wharf at the landward side

The community was keen to see sediment transported freely to the southern side of the wharf.

Final option for Pangai

REVETMENT

The community of Pangai opted for revetment, recommending the same slope as detailed in technical reports, but asking for the height to be lowered.

HA'ATO'U		
Group type	**Option**	**Reason**
Young people	Revetment	Sea level was reported to be rising every year, and there was no confirmation that the options of sand replenishment and managed retreat worked. Revetment would give people time to come up with the resources for retreating.
Women	Revetment and managed retreat	Revetment was the best option, but at the same time people occupying the coastal area should start thinking about relocation to safer areas. Some women were concerned about the footprint of the revetment and its impact on those living near the sea. They felt that if people were required to move, the government should offer assistance. The women also recommended replanting trees behind the revetment to minimise other impacts, such as storm-surge overtopping and inundation.
Men	Revetment	The negative impacts of a revetment were not important. What was important was the safety and security of people and protecting land from the sea.

Other comments on options

1. **Revetment**

WOMEN: Some of the women raised concerns about the impact of the revetment on their livelihoods, namely fishing and gathering sea cucumbers and shellfish, as well as their pandanus-related activities.

Other comments

Building an elevated town hall

As another adaptation option, the town officer requested the construction of an elevated community hall as proposed in the presentation. This building could be an evacuation centre for the community in case of a tsunami or a tropical cyclone. Lifuka currently had no evacuation centre.

Final option for Ha'ato'u

REVETMENT

After discussion, the community voted for revetment, prioritising human safety and security.

4.3 The community's choice

Throughout the presentations, it was clear that 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 two kilometre-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.

5. Integrated Climate Impacts Monitoring System (ICIMS)

5.1 Introduction

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

This project proposed a community-inclusive monitoring system to generate awareness of climate change, engage community members in decisions affecting them, and promote their ownership of, and responsibility for, climate-change adaptation. This approach promotes consultation with communities to identify a number of easily-understood indicators that would be used to document change.

5.2 Monitoring indicators

Indicators for a project of this nature need to be:

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

The first step is identifying the resources necessary to collect, analyse, disseminate and store data and information and ensure the sustainability of data collection. In this context, sustainability means that ongoing, regular data collection is achievable, and that even if data are collected irregularly, they remain useful.

5.3 Methodology

In March 2013, a number of possible indicators were presented to Lifuka community representatives to help generate discussion on what a monitoring system involved and how it could be implemented.

Feedback from community representatives was favourable, but limited. At that time, it was not possible to select which indicators would be monitored.

This selection process will require additional consultation between the community, and local and national government. The resources required for such consultation are beyond the scope of this project.

5.4 Integrated Climate Impacts Monitoring System (ICIMS) indicators

The following indicators have been identified for coastal erosion, inundation, subsidence, water resources and social impact. They are presented as possible options and it is not expected that all these options will be selected for monitoring.

Some of these indicators, such as rainfall, water quality (salinity and E. coli) and water usage are already being monitored. Wherever possible, monitoring of these indicators should continue, with additional resources dedicated to monitoring, and the insights communicated to the public.

Additional indicators should be chosen, based on their relevance to the community and for practical reasons such as ease of data collection, interpretation, presentation and storage.

5.4.1 Coastal erosion

Areas on the western shoreline of Lifuka are considered erosive, with average annual erosion rates south of the wharf of 0.7 m/year. It is expected that this erosion will continue. Revetments and hard structures would, at best, arrest this erosion, but would require careful design to avoid causing increased erosion on other stretches of the coastline.

Table 2: ICIMS indicator – coastal erosion

Indicator	Resources needed to collect and analyse information (skills and costs) Ability to collect and analyse information	Community accessibility and inclusiveness	Advantages	Disadvantages	Possible responsibility
Coastline changes	High-resolution imagery purchased, or Google Earth images can be used. A low-cost, unmanned aircraft system can also be used. Trained technicians required.	Information is visual, readily accessible and understandable (such as coastal outlines over time plotted on the present-day image).	Easily interpreted by community, very convincing, easily displayed. Images can be used for other aspects of planning and can be stored with the community or in island council offices. Does not require expensive software, and open-source and web applications can be used (e.g. QGIS and DSAS).	Community would rely on trained technicians to digitise the shoreline and analyse the data. Cost of imagery.	SPC, with hard copies of the maps held with the community

Changes in infrastructure	Designated locations captured over time from the same perspective with a digital camera of moderate quality. Dedicated community or government member to undertake photographic record on a regular basis, possibly at the same time every year and after and/or during significant events.	Information is pictorial and readily interpreted by all within the community. Provides a visual temporal record. Accessible through electronic and print media and easily shared.	Low-cost, community-inclusive, easy to interpret and effective in raising awareness. Sporadic records remain useful.	Relies on dedicated personnel in Lifuka to undertake the activity.	Community (local government, schools)
Beach profile changes	Surveys from the water's edge inland along a pre-existing transect. Could be undertaken after major events as part of inundation surveys. Requires skilled personnel and some surveying equipment.	Survey results presented as a profile would be accessible to the community.	Surveys can be compared over time.	Requires personnel trained in survey skills.	MLSNRECC
Volume of sand taken from designated sites	Recording the volume of aggregate that is removed and the number of people using aggregate from designated legal sources. Useful for monitoring changes in community behaviour over time. Requires management and record-keeping for quarry sites.	Community is included in survey and results are readily interpreted.	The information can be very useful, and its collection sends a message to the community that sand mining and protection of the coastline is taken seriously.	Requires resources and management of the quarry sites, and accurate and detailed movements of material from quarry sites. Will be useful for showing behavioural change related to aggregate mining.	Local government
Sand movement with causeway reconstruction	Monitoring of causeway and impact on sediment transport: use of satellite imagery to monitor over time, pre-reconstruction and then annually and after weather events.	Information is pictorial and readily accessible	Easily interpreted by community, very convincing, easily displayed.	Requires trained technicians and funding to purchase imagery.	MLSNRECC

5.4.2 Inundation

Table 3: ICIMS indicator – inundation

Indicator	Resources needed to collect and analyse information (skills and costs) Ability to collect and analyse information	Community accessibility and inclusiveness	Advantages	Disadvantages	Possible responsibility
Inundation heights on gauge plates, posts (e.g. church, steel post)	Survey of heights of inundation and dates tagged against specific events.	Community can be responsible for marking post, can have dedicated posts or gauge plates in all villages.	Very visible and accessible for the community	None identified	Community, local government
Register of inundation of buildings	Registry recording which buildings are inundated, their locations and the extent of damage or inundation.	Would be voluntary, with the community identifying key structures or their own structures for inclusion	Individual houses and impacts of inundation registered. Registry kept by district office; increased awareness of the value of capturing information across the island.	May result in people thinking that compensation is associated with registration. Uptake may not be high if voluntary. Nuisance flooding may not be recorded.	Local government and community participation
Infrastructure impacts	Parameters include frequency of inundation and the qualitative impact of inundation over time, e.g. the number of times inundation affects specific infrastructure such as council offices and the King's Palace. Public or private infrastructure that is regularly affected by inundation is selected for monitoring.	Record of prominent infrastructure impacts very relevant to the community	Useful to the National Disaster Management Office (NDMO), but would not replace an NDMO assessment	Requires consistent surveying of specific parameters over time.	Local government
Inundation surveys	In response to specific inundation events, SPC could undertake inundation surveying and could also incorporate beach surveys for erosion.	Not inclusive, but results will be very valuable regarding spatial and temporal effects of inundation and will provide additional quantification of impacts.	Validation of the existing model	Cost of travel for SPC team. Survey can also be undertaken by local lands surveyor.	MLSNRECC and SPC

Water level of ocean	Pressure sensor installed for long-term water level recording. Requires maintenance every 10–12 months. It is proposed that MLSNRECC geologists undertake this activity, with data stored on the SPC Applied Geoscience and Technology Division's Geonetwork survey.	Data not easily accessible to community without analysis and presentation by trained technician. Online access from Geonetwork useful to make information available.	Utility lies in identifying the water level in the oceans and wave and water-level heights in regard to storm and inundation events.	Ongoing costs of batteries and maintenance, coupled with annual visit by MLSNRECC Geology for water-resources auditing.	SPC and MLSNRECC Geology
Change in elevation	Utilise the existing GPS monument to allow a repeat of Global Navigation Satellite System (GNSS) elevations of measurement points.	Highly specialised equipment and trained staff required.	Deploy as required and when funds permit.	Cost of deployment of equipment	MLSNRECC

5.4.3 Water resources

Table 4: ICIMS indicators – water resources

Indicator	Resources needed to collect and analyse information (skills and costs) Ability to collect and analyse information	Community accessibility and inclusiveness	Advantages	Disadvantages	Possible responsibility
Salinity and usage monitoring of Tonga Water Board (TWB) wells and galleries	Recording of usage and salinity data from galleries and at exit from the water treatment plant to be carried out on a regular basis (ideally weekly, minimum monthly) by TWB. Data audited annually by MLSNRECC Geology. Information used to monitor the water provided by the galleries and to assist in the management of water resources.	Data would be held by TWB, with a copy provided annually to MLSNRECC Geology for storage and auditing.	Adaptive operational management of the groundwater for improved water supply using the salinity and abstraction data.	Some improvements in infrastructure may be required, such as variable flow-rate pumps or adjustments to abstraction rates.	TWB as part of normal operations; MLSNRECC Geology could undertake annual audit role

Thickness of the freshwater lens	Monitoring of salinity monitoring bores (SMBs) undertaken by TWB on a quarterly basis, with annual auditing by MLSNRECC Geology	Unlikely that community would be directly involved in the data collection; however, annual publication of results recommended.	Promote exchange of information between government departments. Is cost-effective.	Information requires some processing to be accessible to the community.	TWB to collect data; MLSNRECC Geology to audit; funding for collection and auditing required
Drought management monitoring	Daily and monthly rainfall totals recorded at the airport by Tonga Meteorological Service. Usage and salinity data from TWB, and monitoring data on the thickness of the freshwater lens.	Community would be involved in the application of the data and to consider appropriate responses to droughts for water conservation.	Promote exchange of information between government departments (Tonga Meteorological Service, MLSNRECC Geology, TWB, local government, health, National Disaster Management Office).	No disadvantages anticipated, but some challenges in ensuring that methodology is accepted by government; agencies cooperate with exchange of information; resources are in place to collect data and inform community of responses.	TWB, Tonga Meteorological Service, MLSNRECC Geology, National Disaster Management Office
Bacteriological water quality (*E. Coli*) in wells and supplied water	This activity is already undertaken by TWB to some extent with analysis of *E. coli* and free available chlorine undertaken in the laboratory at Nuku'alofa. It is recommended that analysis be undertaken by the Ministry of Health in Lifuka, which will result in a faster turnaround of results, be more inclusive, and provide greater transparency.	Unlikely that community would be directly involved in the data collection. However, quarterly publishing of results is recommended to inform community.	More responsiveness and greater transparency.	Cost of equipment at Ministry of Health and ongoing supplies.	TWB to continue to assist with sampling. Will require Ministry of Health to be funded with appropriate equipment, possibly some training, and ongoing costs of reagents

5.4.4 Social

Table 5: ICIMS indicator – social.

Indicator	Resources needed to collect and analyse information (skills and costs) Ability to collect and analyse information	Community accessibility and inclusiveness	Advantages	Disadvantages	Possible responsibility
Percentage of occupied households in the setback zone that have moved out of the zone	Would require specific survey work.	Task undertaken by Lifuka government offices.	Clear indicator of uptake of managed retreat and adherence to setback zones.	Requires resourcing by Lifuka government.	Local government (additional task)

5.5 Principles for prioritising indicators

The impact of an ICIMS and acceptance of it are influenced by the manner in which information is collected and how the results are presented to the government and the community. The following factors are useful in determining which indicator parameters are more critical, and how they may impact on proposed behavioural responses. They are:

- who collects and owns the information;
- how accessible the information is and by whom;
- how the information and indicator response is presented;
- where the information is stored;
- how the information on the monitoring of the indicator will be used; and
- who can act on the indicator trends and what enforcement is possible.

Table 6: Principles for prioritising indicators.

Indicator	Behavioural response and identified outcome	Climate resilience
Coastal erosion indicators		
Volume of sand taken from designated sites	Recording of truck movements and volume and type of aggregate extracted from beaches to indicate the change in community attitudes to beach mining and willingness to source aggregate from alternative designated on-land locations. Effectiveness of controlled aggregate mining.	Yes
Coastline changes	Delineating the coastline on satellite images or aerial photographs to identify changes. Useful for improving understanding and for identifying change due to certain activities or events such as tropical cyclones. Photographic records of coastline impacts and changes due to events – whereby a time-series of photographs of certain coastal features is created – develops awareness of seasonal changes and the possible impacts of human activity, and encourages action where impacts are negative. This could include documenting the sand movement and changes in coastal morphology as a result of the causeway reconstruction.	Yes
Beach profile changes	Repeat survey of established beach profiles. These surveys can be conducted by locally-trained people, and serve as ground-truthing for the remote-sensing options. This provides empirical evidence to confirm anecdotal accounts of erosion rates. In the event of continuing erosion, this would confirm the need for a coastal setback zone and managed retreat.	Yes
Inundation indicators		
Inundation levels	Following extreme events such as tropical cyclones, the distance from the shoreline (i.e. the erosional scarp of base of the beach) and depth of flooding are measured. Magnitudes of flooding will depend on the severity of the event, but results are to be made public and discussed within the community. These are to reinforce adaptation actions such as elevating houses and siting new constructions further inland.	Yes
Impacts of inundation on critical and public/ private infrastructure	Document and measure impacts of flooding on critical infrastructure and possible impact on the delivery of public services (e.g. closure of hospital and roads, outage of utilities). Including private residences in the hazardous zones in this process will further encourage adoption of adaptation options of managed retreat and building codes.	Yes

Relative water-level changes	Lifuka can undergo relatively rapid subsidence or uplift, especially in conjunction with earthquakes. Changes in vertical motion are measured by GNSS observations at the GPS monument. Repeat observations will determine if the island is undergoing rebound to the previous (pre-2006) levels. Evidence of relative changes in sea level confirms that observed changes in the shoreline of Lifuka are permanent and that appropriate adaptive action needs to be taken.	Yes
Water resources indicators		
Salinity and usage monitoring of TWB wells and galleries	Salinity threshold limits are determined in consultation with the community. Salinity of individual galleries is used as a guide to restrict the volume of water that the galleries can contribute to the overall water supply within the supply network. That is, a well/gallery that has a high salinity is restricted, and additional abstraction is taken from other areas where possible. Community to agree that if low-salinity water is available in insufficient qualities, supplies may need to be reduced to ensure continued quality. Usage data used to identify leakage in the water supply network. Leakage from individual structures that is considered high will result in specific leakage reduction action undertaken by the government and TWB.	Yes
Thickness of the freshwater lens	Monitoring of the SMBs is used to determine the freshwater lens thickness in response to abstraction and rainfall. Behavioural response is to use the monitoring of the lens to trigger water conservation measures as well as awareness raising, and possible restrictions in supply, and to guide drought-response action. Monitoring in average, low and high rainfall periods is used to characterise the water lens behaviour in normal, stressed and recovery conditions respectively.	Yes
Drought management monitoring	Using data already collected (or that have been recommended for collection) such as rainfall, usage and salinity, and monitoring bore data and existing methodologies, such as rainfall percentile indices, to identify the status of water resources relative to previous dry periods. The information will be useful to the government and the community alike to determine water-conservation responses and as criteria for assigning drought status. Will encourage cooperation and exchange of information between departments and will encourage informing the community.	Yes
Bacteriological water quality (*E. coli*) in wells and supplied water	Bacteriological content and salinity of the water is an important consideration in the potability of the reticulated water supply. Recommend community and government determine water-quality limits and agree on reporting and response actions. Behavioural response is to increase treatment and/or boil drinking water.	Yes
Social indicators		
Percentage of occupied households in the setback zone that have moved out of the zone	Measure over time the effectiveness of incentives to relocate households outside the setback zone.	Yes

5.6. Selection of indicators – recommendations

The technical team has provided a suggestion for prioritisation of indicators for guidance. This selection considers community involvement and accessibility.

Table 7: Indicators and potential importance in development of an ICIMS.

Issue	Indicator	Importance
Coastal erosion	Volume of sand taken from designated sites	High
	Coastline changes	High
	Beach profile changes	Medium
Inundation	Inundation levels	High
	Impacts of inundation on critical public/private infrastructure	High
	Relative water-level changes	Medium
Relative sea-level changes	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	Percentage 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 (Government of Tonga or SPC)

Monitoring can be undertaken by island council

5.7 ICIMS – the way forward

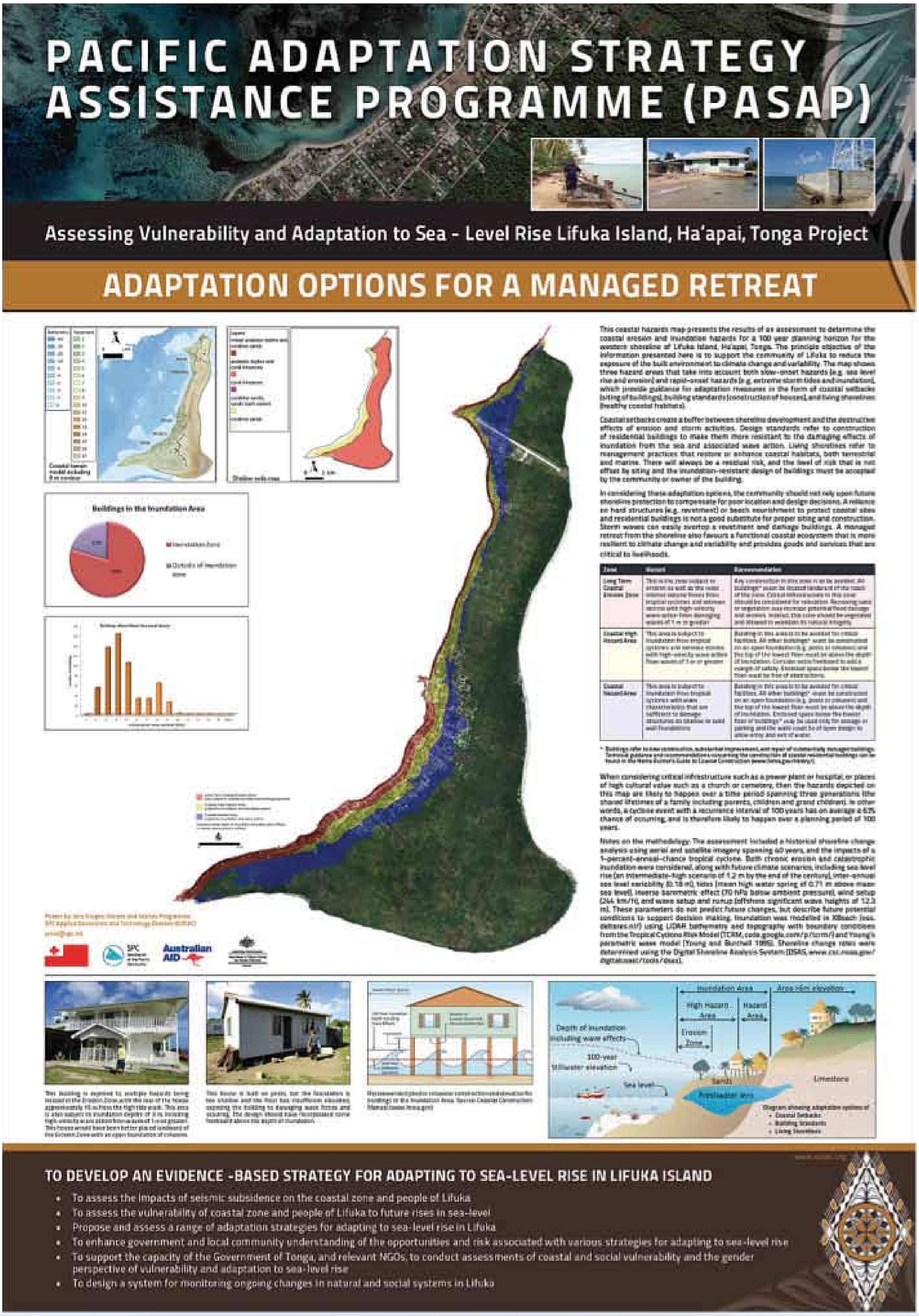
An Integrated Climate Impacts Monitoring System should form part of an overall strategy for developing awareness of the effects of climate change and coastal erosion and documenting both climate-related change and the impact of adaptation activities.

However, the development of a robust monitoring system depends 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 that was started between the government and the community under this project be continued. Specific and visible monitoring activities such as photographic records capturing inundation events, aggregate abstraction, and recording of impacts to critical or significant infrastructure are a good first step in building increased awareness of changes to Lifuka's physical environment and the possible community responses.

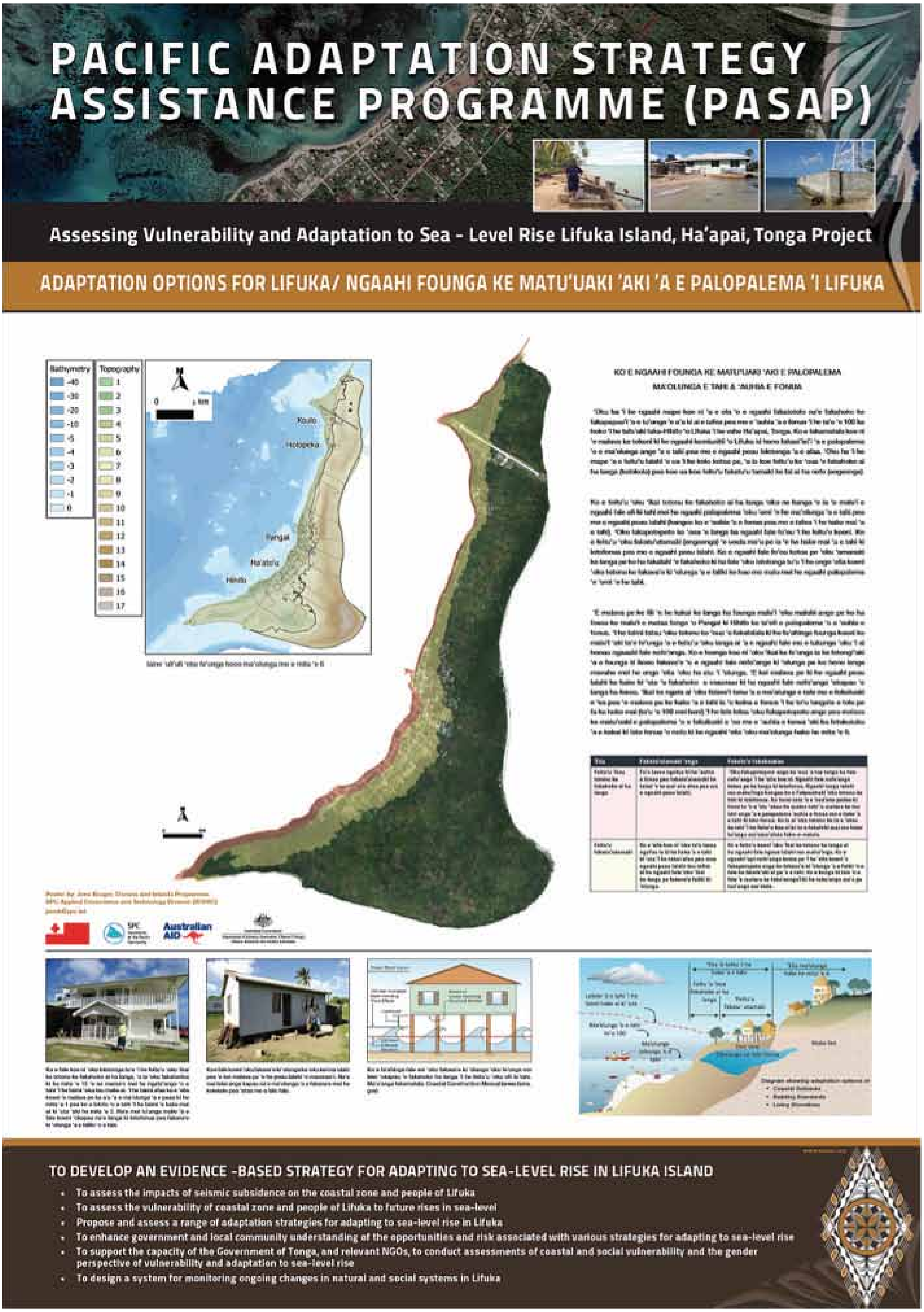
Appendix 1:

Coastal hazards poster used for government stakeholder consultations in Nuku'alofa, as well as project advocacy at meetings and technical workshops.



Appendix 2:

Tongan version of the coastal hazards poster. This version is a slightly simplified version with only two hazard zones (setback and inundation zones), and was widely used during the final community consultations in Lifuka.



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