Reducing the risks of cyclone storm surge inundation on the atolls of Tokelau

Fakaofo

NIWA Client Report: HAM2006-077
March 2006

NIWA Project: UNS05201

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Prepared for

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Executive Summary

On 25 February 2005 Tropical Cyclone Percy affected the atolls of Tokelau. The cyclone was of category 3 intensity as it passed around 100 km to the south west of Tokelau, intensifying further as it past through the northern Cook Islands with sustained winds measuring from 178 to 249 km/hr. The cyclone resulted in widespread damage, particularly on Fakaofo and Nukunonu. On Fakaofo the storm surge and large waves resulted in overwashing of part of the village on Fenuafala, particularly around the school and hospital. It also caused overtopping of seawalls inundation and damage of Fale. Inundation was also an issue on parts of Nukunonu and Atafu.

In the aftermath of Cyclone Percy, the United Nations Development Programme (UNDP) in Samoa commissioned NIWA to provide technical support to the Government and people of Tokelau to assist in the future reduction of coastal hazard risks, particularly associated with cyclone induced storm surge and wave overtopping and inundation (known as the Tokelau Seawall Project).

The main purpose of this document is to provide the UNDP with recommendations for potential priority assistance to Tokelau for reducing the risks associated with cyclone storm surge inundation. However, this has been developed within a more detailed strategic framework which aims to develop a set of guiding principles and options for consideration by the Fakaofo administration for the long-term reduction of the risks associated both with episodic cyclone storm surge inundation and longer-term adaptation to climate change.

In developing such a strategy for managing coastal hazard risk on Fafaofo it is important to note that:

1. **There is no "silver bullet"** i.e., no one option that will solve all the problems. A programme of reducing risk involves a range of inter-related activities, the composition of which will vary from location to location (e.g., between Fenuafala and Fale, the ocean to lagoon shore etc.) and over time.

2. **Reducing risk is a journey not a destination**. Reducing the risks of cyclone related erosion and inundation damage is hard work, requiring difficult decisions, and is a continuous and ongoing activity integral to development decision-making at individual, village (atoll), and national levels.

3. Building **adaptive capacity**, the ability of the coastline, the community and individuals to cope with, adjust, respond, or even take advantage of, variability and extremes in climate, including potential long-term climate change, is critical.

A series of recommendations were developed within four general risk reduction themes, which were:

1. Ensuring protection of the natural coastal defences (reef, reef flat, beach and coastal margin) and identifying the underlying causes of human impacts on reducing the effectiveness of these natural defences and how such impacts could be effectively reduced.

2. Options for land management planning both for future development and consideration of the potential for developing a long-term strategy for the movement of key infrastructural or other buildings from high risk areas.

3. How risks of damage to property and content could be reduced through building design, i.e., accepting that inundation is a natural occurrence (and will always be an issue on Fakaofo) and designing and constructing buildings and infrastructure to take account of this.

4. Development of a strategic approach to upgrading the standards of existing seawalls around Fale, taking in to account the present state of existing seawall structures, and requirements for future structural solutions with an emphasis on structures that: (1) enhanced the natural defences and are more sensitive to the important natural processes occurring on Fakaofo, (2) optimised to be more effective in reducing inundation, and (3) more sustainable in terms of both the length of time the structure is effective, and in terms of ongoing maintenance costs.

Based on the discussions held in Tokelau, and the resulting recommendations that have been developed, the following are suggested as priority areas for the UNDP to consider supporting:

1. Required materials for the maintenance and upgrading of existing sections of gabion seawalls on the ocean side of Fale and fronting the Administration Building on the lagoon side.

2. Seed money to assist the commencement of community planting initiatives and associated awareness programme on Fenaufala.

3. If sufficient funds are available, contributing funding to assist with the relocation of the oceanside bulk storage shed on Fale.

The series of recommendations outlined in this report are not intended to be a “quick fix” but rather a long term and sustained approach to reducing the risks to people, property and infrastructure of cyclone related inundation and erosion, long term coastal evolution of the motu, and any exacerbation of these impacts caused by global climate change. It is based on the growing evidence from around the Pacific region that integrating risk management of natural hazards in to individual / community / national decision-making is a far more cost effective strategy than a “wait and see” approach to managing both episodic disasters such as cyclones or longer term factors such as the consequences of sea level rise.

The approach presented in this report has attempted to complement and contribute to the suggested approaches to risk management of natural hazards (RMNH) in the Pacific region outlined in the recently published World Bank policy note *Not if but when: adapting to natural hazards in the Pacific Island region* (Bettencourt et al. 2006). Specifically, the recommendations involve actions at individual, community and national levels and associated coordination and interaction between these activities. They include actions that are highly visible (such as seawall construction) as well as actions that encourage changing behaviours and mindsets. As far as possible a "no regrets" approach has been adopted in the development of the recommendations, the aim of which is to ensure that as far as possible the communities of Tokelau will still be able to consider a range of risk reduction options in the future rather than being constrained to a narrow risk management approach due to past or present day decisions (which is the situation Fale is now in where future risk management options are now limited).

Whilst many of the risk reduction activities will be coordinated at atoll level, there is a need for coordination at national level:

- To mainstream these risk management measures into national economic and social planning, budgeting and decision-making processes.

- To provide support and guidance to the three atolls to continue to progress implementation of the recommendations.

- To provide coordination with donor and support agencies, such as the UNDP, New Zealand, SPREP, SOPAC and potential other sources of support.

- Encouraging donors to assist and support pro-active and long-term risk management activities rather than focus on episodic disaster recovery which needs to be fundamental aim of the Tokelau administration.

How this is best achieved (e.g., whether such responsibility lies within one unit, e.g., the Environment Unit, or within the whole of Government) will need to be determined by the Tokelauan decision-makers.

To underpin all future risk management activities in Tokelau is a need for a sustained program of public awareness activities, and capacity building at both community and national levels to support a proactive approach to reducing coastal hazard risk. Specifically this requires the development of support mechanisms within the National Government agencies to better empower each of the three

Tokelau communities to proactively manage natural hazard risks, to help identify and provide the resources needed to do so, and to move from intentions (suggested in this report) to actions. To begin with there is a need to disseminate, and discuss at community levels, the findings of the recommendations contained within this report, but in the longer term will need to include:

- Targeted information on hazard occurrence, climate variability and change for a range of audiences, e.g., Government policy and decision makers, community leaders and members, school children.

- Fostering of action plans in each community, based on the general recommendations and timelines suggested in this report, but with specific target actions and timeframes, and identification of who will do it.

- Training for national and community leaders in developing community approaches to reducing natural hazard risks. Whilst formal mechanisms such as on-island training courses will be integral there again needs to be a longer term focus with activities such as mentoring for technical support being introduced, and an emphasis on approaches that can be repeated and sustained.

1. Introduction

1.1 Background

On 25 February 2005 Tropical Cyclone Percy affected the atolls of Tokelau (Figure 1). The cyclone was of category 3 intensity as it passed around 100 km to the south west of Tokelau (the only wind measurement available was the 3 hourly recording at Nukunonu which recorded 59.3 km/hr at 03:00 NZST on the 27 February) with the cyclone going on to intensify as it past through the northern Cook Islands with sustained winds measuring from 178 to 249 km/hr. The cyclone resulted in widespread damage, particularly on Fakaofo and Nukunonu atolls. On Fakaofo the storm surge and large waves resulted in overwashing of many parts of the two inhabited motu[1]. On Fale, the southern of the two inhabited motu, the seaward bulk storage shed, and its contents sustained significant damage. On Fenuafala, much of the lagoon side of the motu was inundated where the second village, the school and hospital are located.

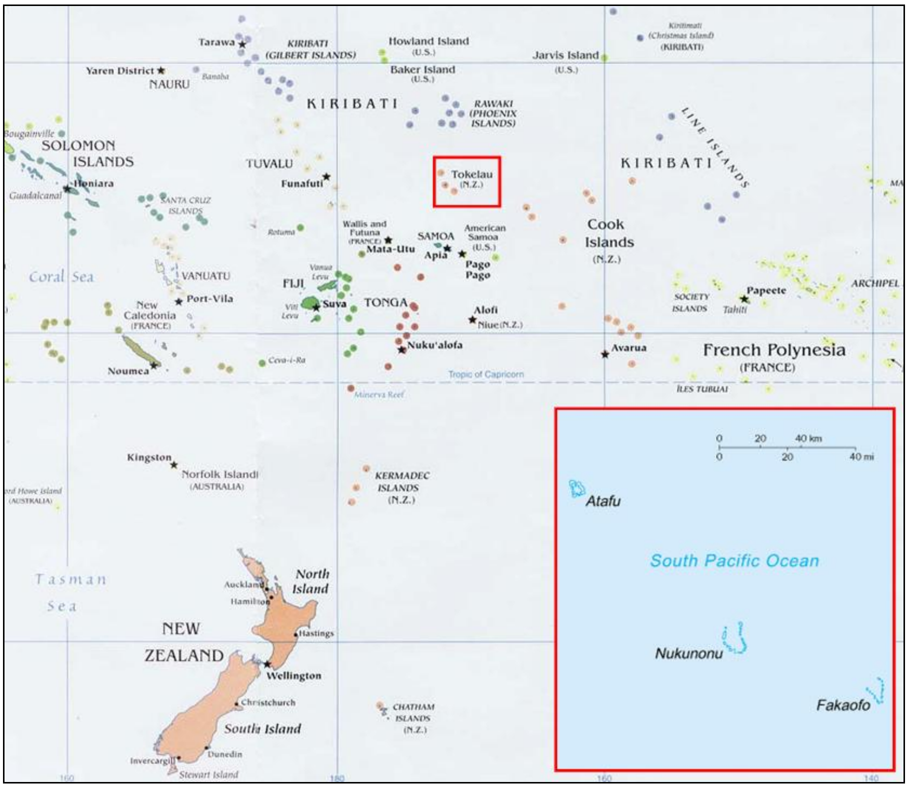


Figure 1: Location of the three atolls of Tokelau.

[1] Small islet on an atoll.

Further details of the damage caused by the cyclone are given in the UN Disaster assessment and Coordination (UNDAC) Damage assessment Report (Laurence & Hill, 2005).

In the aftermath of Cyclone Percy, the United Nations Development Programme (UNDP) in Samoa commissioned NIWA to provide technical support to the Government and people of Tokelau to assist in the future reduction of coastal hazard risks, particularly those caused by cyclone-induced storm surge and wave overtopping and inundation (known as the Tokelau Seawall Project).

Overall details of the project were summarised in the initial terms of reference for the project with the expected outcome to *"…. provide a sound mitigating response for Tokelau through appropriate seawall structures that will protect not only the existing infrastructure and resources on all the atolls but most importantly the lives of the people of Tokelau".*

This objective was reviewed and discussed with the UNDP as part of the project inception assessment and subsequently the scope was widened with the primary goal *to reduce risk to loss of life, damage to coastal infrastructure and coastal environmental areas from the devastating impact of storm surge from cyclones* (UNDP, 2005). Rather than focus primarily on seawall structures, the project was broadened to identify and optimize a range of both short term and longer term options for achieving a sustainable risk management approach. Whilst the focus is on reducing risks associated with cyclone-induced inundation and related coastal hazards, the approach adopted within the report aims to complement and contribute to the suggested approaches to risk management of natural hazards (RMNH) in the Pacific region outlined in the forthcoming World Bank policy note *Not if but when: adapting to natural hazards in the Pacific Island region* (Bettencourt et al. 2006).

The in–country consultation and assessments were conducted between 05 July and 13 July 2005 by Mr Doug Ramsay, NIWA, assisted during the visit to Tokelau, by Mr Heto Puka, Manager of Finance, Tokelau Apia Liaison Office. The scheduled passenger and cargo ferry MV Tokelau was used to transport the project team, with up to 2 days spent on each atoll. On each atoll an initial meeting was held with the Council of Elders (*Taupulega*), followed by discussions with the Women's Group (*Fatupaepae*), working or married men (*Aumaga* or *Taulelea* respectively) and a further, more detailed discussion, with the *Taupulega* at the end of the visit. A full walkover survey and collection of building and infrastructure information was also conducted. Details of the visit schedule and summary of the discussions are provided in the de-briefing report (Ramsay, 2005b).

1.2 Overview of the outputs of the study

This document is one of a series of reports prepared as part of the study, which include:

- An inception report completed prior to the trip to Tokelau (Ramsay, 2005a).
- A de-briefing report, summarising the visit and discussions held in Samoa and Tokelau (Ramsay, 2005b).
- A technical review of cyclone information and wave / water level design information covering all three atolls (Ramsay, 2005c).
- This report for Fakaofo (one of three, the other two covering Nukunonu and Atafu) which details options and recommendations for reducing cyclone storm surge inundation and other coastal hazard risks for both the short and long term.

1.3 Previous studies and ongoing activities

An assessment of damage due to wave overwashing and inundation caused by Cyclone Wini on the 28 February 1987 was conducted by Bakx (1987) and also summarised by Richards (1990, 1991). This detailed the physical conditions during the cyclone, the damage on all three atolls that occurred, and provided a series of recommendations, which included:

1. *"An immediate replanting programme should be initiated. Quick growing hardy species should be established just inland of the beach creast…..Based on observations on Atafu Island the vegetation barrier should extend for 20 m inland of the beach crest….."*
2. *"Buildings should be located as far back from the seaward facing shoreline as practicable and a "no development zone" established for any future construction along the coast."*

3. *"Wherever possible low and intermediate vegetation, of the type which has an extensive root network, should be established between buildings particularly within the central village area."*

4. *"Large bare areas of land such as used for the purposes of the playing fields or tennis courts, should be located away from built up populated areas and not in the central village area or on the seaward facing coastline."*

5. *"The establishment of a minimum building level should be investigated. This may necessitate raising the height of concrete foundations, within reason, to reduce either the likelihood or the impact of flooding of buildings."*

In the context of Fakaofo, these recommendations are more suited to the situation on Fenuafala than Fale, which given its long history of reclamation and protection using coral block walls, is now not a sustainable motu without such protection.

A programme of seawall construction, using gabion basket construction, was commenced following Cyclone Ofa (February 1990) by the New Zealand Defence Force (NZDF) and Tokelau based on designs developed by Maccaferri, the manufacturers of the gabion baskets, (Brockliss, 1990). Seawall construction was not completed before the NZDF departed, with Tokelau continuing the work.

To assist with completion of the project, UNDP funding (US$295,000) commenced in 1990 and lasted up to 1994. However, in December 1991, Cyclone Val damaged and destroyed many of the as yet uncompleted seawall structures. Hence a further UNDP funded Special Programme Resources project followed between 1992 and 1995 for limited reconstruction of the areas damaged by Cyclone Val.

By March 1992 (Brockliss, 1992), a total of 250 metres of gabion seawall structures had been completed on Fale or were under construction, including:

- 80 m mass gravity design using Terramesh gabion wall system to the south east of the boat channel.

- Commencement of a gabion wall to the north west of the boat channel, towards the foot bridge.

- Various sections of private gabion wall had been constructed along the lagoonside, with the gabions also used to construct boat shelters and for land reclamation. The report by Brockliss suggested that there appeared to be no systematic placement or design for the seawalls being constructed along the lagoonside, which will have had important bearing on the subsequent performance of the seawall, particularly with respect to the length of time that the gabion baskets have lasted before being damaged (see Section 3).

Concerns over potential adverse environmental impacts due to the seawall construction resulted in the UNDP/OTA commissioning a scoping environmental impact assessment (Shuma, 1992). This recommended that a detailed EIA be conducted to identify the likely long term positive and detrimental impacts of the seawall construction.

As part of the *Tokelau Environment Management Strategy* (TEMS) project (Toloa, 2000), Prof. Roger McLean was commissioned by the South Pacific Regional Environment Programme (SPREP) and the OTA to visit Tokelau and to undertake the EIA of the existing and proposed extensions to the gabion seawalls (McLean, 1993). However, no further external funding was provided to continue the coordinated construction of the seawalls based on the recommendations contained within the EIA. Despite this other ongoing *ad hoc* seawall construction, of varying construction standards has continued, typically relating to the reclamation of land on the lagoon side of Fale.

In addition to the EIA, McLean and d'Aubert (1993) prepared a report on the *Implications of climate change and sea-level rise for Tokelau* as part of a series of reports coordinated by SPREP. Both the EIA and this report are important documents within the context of the present study, with the overall discussions and findings contained within still highly relevant. This project aims to build on the findings of these reports.

In 2001, the NZ Ministry of Foreign Affairs and Trade (MFAT) commissioned an assessment of Tokelau's Infrastructure needs and priorities (Opus International Consultants, 2001) as a basis for future decision-making and funding allocation. This confirmed seawall repair and further construction, which had always been a high priority on Tokelau's development agenda, as such. However, the generic approach to the recommendations made for further seawall construction, and lack of consideration of other approaches to reduce such risks within the report raises considerable concern about the appropriateness, environmental consequences and sustainability of the recommendations.

A number of other activities have also been ongoing in Tokelau, particularly over the period since Cyclones Ofa and Val affected the atolls, which has contributed to the reduction in risk associated with cyclone storm surge inundation. Of most relevance has been the programme of housing re-development through a housing grants scheme which commenced in the mid 1980s. As a cost saving measure, water tanks tended to be built under the house, raising the floor level. This measure has resulted in the floor levels of the housing being generally raised above the level that would typically be inundated due to cyclone storm surge, or waves overtopping and overwashing the motu. This activity has resulted in a significant reduction in associated damage to individual property and their contents.

Recently, the UNDP have commenced funding a programme to strengthen disaster management and preparedness in Tokelau. Part of this project involves improving the equipment and capacity to receive and disseminate tropical cyclone warnings, development of a tropical cyclone operational plan and improved capacity to exchange information including redundancy within the system.

1.4 Scope of this report

The main purpose of this document is to provide the UNDP with recommendations for potential priority assistance to Tokelau for reducing the risks associated with cyclone-induced storm surge inundation.

However, this has been developed within a more detailed strategic framework which aims to develop a set of guiding recommendations and options for consideration by Tokelau's administration for the long term reduction of the risks associated with cyclone storm surge inundation. It is hoped that by developing a longer-term framework that this will help reduce the *ad hoc* approach to the reduction of coastal hazard risks that has occurred in the past and will help increase community resilience to future climate variability and extremes and the changes that will occur due to climate change including sea-level rise.

As such, this report aims to:

- Assess a range of strategic coastal hazard risk reduction options for reducing such risks on the people, developed infrastructure and property and natural environment of Fakaofo.

- Provide guidance for coastal hazard risk reduction policies to be integrated within economic and social planning functions and decision-making processes for future development and resource management over the next 10 to 20 years and longer.

- Identify opportunities for maintaining and enhancing the natural coastal environment, including the natural coastal defences on Fakaofo.

- Identify any necessary monitoring activities to aid future decision-making and to develop a set of risk indices to measure long term effectiveness of the risk reduction measures.

2. Natural coastal change on Fakaofo

2.1 Introduction

The motu on atolls are constantly changing and evolving in response to the natural processes that drive such changes (waves, tides, currents and the effects that climate variability and change has on these processes). A fundamental challenge for communities living on such motu is carry out development in a way that recognises and accommodates such change. It is often human impacts or interventions to these natural processes that can cause or exacerbate both short and longer term environmental problems.

On Fale, the natural beach system has largely been lost, with the island now essentially artificial, and the existence of the community there highly dependent on protection provided by seawall structures, (discussed in Section 3). Much of the remainder of this section is devoted to Fenaufala, which will have a very different approach to future management than that required on Fale. A critical issue in developing a long-term management approach to reducing the risks of coastal hazards to people on Fenaufala is an appreciation of the natural physical processes that are causing change at an atoll, motu and localised scale. Whilst it is appreciated that little geological or physical process studies have been conducted on any of the atolls of Tokelau, fundamental processes can be recognised based on observations and studies of other atoll environments.

It is not intended to provide a detailed overview of atoll processes and short and long term changes to motu but rather to summarise these as a series of statements and take-home messages to be borne in mind when considering: (1) appropriate risk mitigation options, and (2) future development projects. A more detailed discussion of such processes is provided by McLean (1993) and McLean and d'Aubert (1993).

2.2 An overview of key natural physical processes on Fakaofo

1. Motu are formed by cyclones

All land on Tokelau has been formed by deposits of sand, coral rubble and boulders that have been deposited on the reef flat by many cyclones over many years.

The motu are founded and anchored on a coral conglomerate platform which likely formed when sea levels were slightly higher (0.5 m to 1 m) between 2000 and 4000 years ago. These platforms (known as *te papa*), which are at a higher level than the present day reef flat, are exposed along the northern and north-western flanks of Fale, and western coastline of Fenaufala. The formation of the motu in roughly their present day form is partly related to a fall in sea level over the last 2000 years (sea levels began rising again about 150 years ago).

2. Cyclones are important for the continued growth of motu

Whilst cyclones can cause erosion and damage, their occurrence is vital to the long term future of the motu on Fakaofo as they continue to supply fresh sand and coral rubble to build the motu around the island. This counters the loss of sand and coral rubble that occurs from the motu, due to both natural processes, such as sand being transported in to the lagoon, and increasingly, and of greater consequence, due to human impacts, e.g., sand mining.

Around Fenuafala this fresh supply of sand and coral rubble can be seen in a number of forms: as banks of storm rubble on the reef flat which gradually migrate towards the beach, boulder tracts on the reef flat, or new accumulations of coral rubble or sand on the ocean beaches (which may only gradually appear in the weeks or months following a cyclone). On Fenaufala, such accumulations are most evident on the west and south coasts, and at the eastern point of the motu. Along much of the south coast, accumulations of coral rubble moved onshore from the reef flat have built up the active beach (Figure 2, left) increasing the natural ‘armouring’ of the beach system. Such accumulations do not tend to build up any significant increase in land, rather it provides a source of coral rubble to continue to maintain the active beach and the protection provided by it.

At the time of the visit, much of the beach along the western and southern (ocean) side of Fenuafala looked in a healthy state providing a high degree of protection to the land behind. Backing the beach was dense coastal vegetation with little evidence of significant human impact close to the beach.

The most significant accumulation of land is occurring at the eastern end of the motu (Figure 2, right). Substantial accretion of land has occurred in recent years, including in the aftermath of Cyclone Percy. Much of the sand-sized sediment that is produced or is deposited within the reef flat and beach system along the southern (Oceanside) coastline of Fenuafala tends to be transported to the eastern end of the motu (see below). However, as the eastern part of the motu is the most recent, it is also the lowest part (i.e., hasn't been built up by cyclones – see below) which makes it more vulnerable to overwashing and inundation. It is also the part of the island which the largest changes, in terms of the position of the shoreline, will occur for example during storm events.

Figure 2: The southern coastline of Fenuafala (left) showing accumulation of coral rubble on the beach in the aftermath of Cyclone Percy, and eastern end (right) where there has been long term accretion and build up of land.

On Fale, there is little natural supply of fresh sediment to maintain or build up the motu. This is due to both the morphological setting (lack of sediment available on the reef flat, and impediments to the transport of sediment, such as the *te papa* and steep drop off in to the lagoon, McLean, 1993) and due to the long history of human impacts on the natural beach and surrounding reef flat system. Rather the continued build up of land levels on Fale is conducted by coral rubble and sand brought in by hand for reclamation from other uninhabited motu.

3. Cyclones are important for building up the elevation of the motu

When water overtops and overwashes the ocean side of the motu, it transports sand and coral rubble from the ocean side and deposits it on to the land. Over time this builds up the motu. It is also part of the process that has supplied sand and rubble to build out the motu on the lagoon side. This is why the ocean side (southern) side of Fenaufala is much higher than the lagoon side, and why the older parts of the island (i.e., the Western part) is more stable and less prone to overwashing than the younger parts of the island (eastern end of the motu and lagoon shores).

Over time this can result in significant increases in the elevation of the motu. For example, archaeological surveys (Best, 1988) found evidence of communities on Fale and Atafu around 1000 years ago living on land levels between one to two metres lower than they are today:

> *"… the islets on which the present-day villages of Atafu and Fakaofo are situated were between one and two metres lower than the present surface, and thus more vulnerable to storm waves".*

This emphasises the importance of ensuring this long-term natural build up of the motu is allowed to continue particularly in the context of a future where sea levels will continue to rise. The construction of seawalls around Fale now prevents such a natural build up from occurring.

4. Beaches do not stay the same shape

The beaches around Fenuafala change in response to the size of the waves. This is a natural response during cyclones and large swell conditions and does not necessarily mean that erosion is occurring. In many cases the beach will gradually build back up after the cyclone (which is what is presently occurring on the west and south coasts of Fenuafala after Cyclone Percy) but this is a much slower process (see above) than the erosion that can occur over a period of a few hours during a cyclone.

The effects of large waves on the beaches around Fenuafala will vary depending on location:

- Along much of the western and southern (oceanside) coastlines, the beach is largely composed of large coral rubble (Figure 2 right). Such beaches are well adapted to dissipating large waves and protecting the land behind them. Their effectiveness can be substantially diminished if coral rubble (particularly the larger material) is removed resulting in the loss of land as the beach repositions landward (shown in Figure 3), for example as has happened on the ocean side of Atafu. However, at present this does not appear to be a significant issue on Fenuafala.

- The sandy beach along the eastern lagoon shoreline (eastern point to the school) is shallow sloping and characteristic of a relatively sheltered beach system which experiences little significant wave action (Figure 4, left). Due to its shallow nature, waves that reach the beach during cyclones dissipate over a very wide area including washing over the area behind the beach. As such a beach system rarely experiences large waves, considerable changes in the position of the beach can occur during cyclone events, particularly related to the longshore movement of sand (see below).

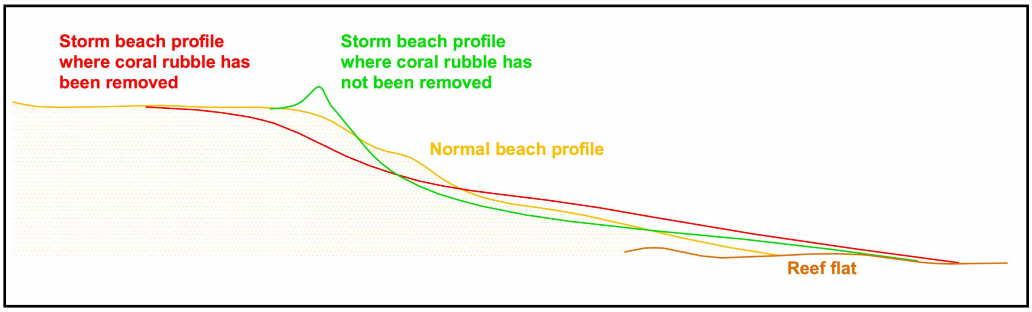


Figure 3: Beach profile change caused by large waves and the impact of removing coral rubble from the beach.

- Between the school and the north western corner of the island, the beach sediment characteristics gradually change from a sand beach to one where coral rubble dominates, reflecting the increase in wave energy away from the lagoon towards the ocean (Figure 4, right). As the wave energy experienced on the beach increases, this tends to winnow out the finer sand sized sediment and move it along shore to a less energetic location leaving behind the coral rubble. This can be a long term process or can happen quickly for example during a particular cyclone event. This change can lead to a retreat of the shoreline as the beach profile steepens due to the increase in dominance of the larger beach material and a dynamic-equilibrium is reached between the beach material and the wave energy climate.

Figure 4: Sand beach along the eastern end of the lagoon shoreline (left), mixed coral rubble / sand beach looking towards the western end of the lagoon shore (right).

5. *The movement of sand and coral rubble along the coastline is also important.*

Both cyclones and the day to day wave conditions also move sand and coral rubble back and forward along the shoreline. The dominant wave direction determines the main direction of the movement. If more beach sediment is transported from an area of beach, than is transported to the same area, then coastal erosion will occur. Activities that disrupt or change this natural movement of beach sediments, such as sand mining, building inappropriate seawalls that block sediment movement etc., normally leads to increased coastal erosion problems or loss of beach, (Figure 5). A good example of a structure of Fenuafala that does not disrupt longshore processes is the jetty structure.

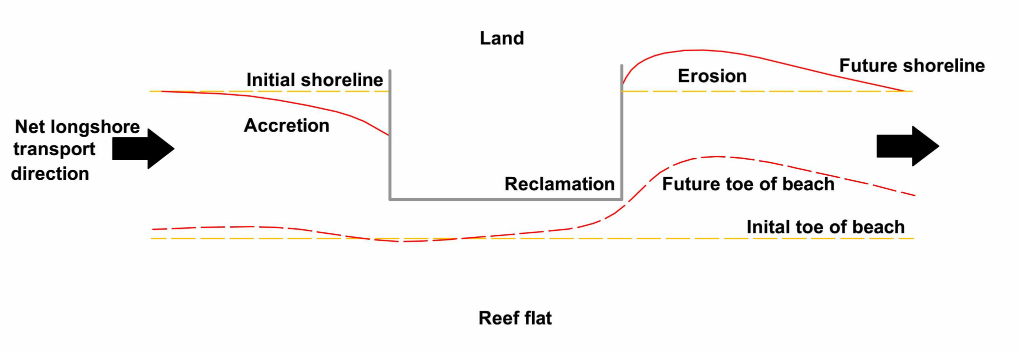


Figure 5: Impacts of reclamation or seawall construction on beach erosion where longshore transport is occurring.

On the southern (oceanside) of Fenuafala, sand and smaller cobble rubble tends to get moved to the east which contributes to the build up of land at the eastern end of the motu (Figure 6). Sand is also transported around the eastern end and is subsequently moved in a westward direction along the lagoon shore towards the school by waves generated within the lagoon by the prevailing easterly winds. However, along the western lagoon shore, ocean swell propagating over the reef tends to move sediment in an easterly direction. This 'meeting' of sediment being transported along the lagoon shore results in the 'bulge' in the coastline upon which the school is located. McLean (1993) also suggests that the lagoon shoals towards Fenuafala with sedimentation continuing to the west of Tuimanuka reef and along the motu's lagoon shore.

The largest changes in shoreline position (either accretion or erosion) during cyclone events tend to occur where the orientation of the coastline changes, such as at the eastern end, or "bulge" in front of the school.

Figure 6: Dominant directions of sediment movements along the coastline of Fenuafala and areas where longshore sediment transport pathways converge and accretion tends to dominate (red shaded areas).

6. *Natural vegetation on the coastline traps sediment and helps stop overwashing*

The natural vegetation found at the top of the beach plays a big part in reducing erosion and in reducing how far waves that overtop the beach travel inland. The roots of plants and trees help to hold sediment, especially sand in place. The deeper and more extensive the root system, the greater degree of stability. Undergrowth and low shrubs and bushes, helps trap sand and coral rubble being overwashed when large waves overtop the crest of the beach, reducing the amount of water and sediment entering village areas.

It was notable on all the atolls that the areas where overwashing was most severe during Cyclone Percy corresponded to the areas where the most significant clearing of vegetation had occurred (e.g., particularly the school playing field areas on Fenuafala, and on Nukunonu), Figure 7.

This is a pattern that has been evident when overwashing has occurred during cyclone to have affected the Tokelau atolls over the last century (e.g., the reports by Bakx, 1987 and Richards, 1990, 1991)

Figure 7: The school playing fields which experienced considerable inundation during cyclone Percy eroding much of the top layers of sand (right), and the lagoon coastline further west (left) which is backed by a well vegetated hinterland result in inundation being minimal.

3. The present day situation

3.1 Introduction

This section provides a snapshot of the current situation with regards to the status of the natural and built coastal defences on Fakaofo, and the risks to people, property and infrastructure. It provides a baseline for developing the future risk reduction recommendations discussed in Section 4. The summary is based on discussions and a walkover survey, part of which was conducted in the company of members of the *Taupulega*, during the visit to Fakaofo by the project team.

3.2 Natural coastal defences

The outer sections of the reef on Fakaofo are likely to be in a relatively healthy state, in terms of the protection it provides to the shoreline, with few human impacts likely to be of significance. However, short and longer term damage due to cyclone events has been noted in the past (Laboute, 1987) and also due to coral bleaching episodes related to higher sea surface temperatures during at least two strong El Niño periods over the last twenty five years.

The only place where human activities have significantly impacted on the natural protection provided by the reef and reef flat along the ocean side of Fale due to the construction of the reef channel and associated training walls. To the immediate south of the channel, the recent satellite image suggests that the spur and groove zone on the seaward edge of the reef is largely absent over about a 100 m length (compared to a well established spur and groove zone further south, and to the north of the channel). The cause of the lack of the spur and groove zone is not known, i.e., whether it has been deliberately removed (for example it is known that the *Lady Naomi* has previously dropped its bow door on to the edge of the reef at low tide to unload vehicles, which it wouldn't have been able to do with a spur and groove zone). There is some concern these activities may have exacerbated wave conditions experienced on the ocean side of Fale, particularly during cyclone events, and this may well be the case given the changes that have occurred here. With plans to develop a boat harbour and wharf at Fale, great care will need to be taken to ensure that any such structure does not further increase risk during cyclone events (discussed further in section 5).

Coral rubble removal from the beach and reef flat for construction projects and for the ongoing 'building up' of land levels and land reclamation on Fale has been ongoing for many years. Traditionally this will have been conducted from the closest beach and reef areas to the village. McLean (1993) notes that for the gabion construction of Fale that rubble was sourced from the boulder tracts to the north-west of the conglomerate area, the area to the south-east of the motu, and from a more distance source along the north-west coastline of the atoll (*Akau Loa*). The EIA recommended that no further rubble be taken from the sources close to Fale, with it likely that the long term removal of coral rubble from around Fale has been a contributing factor in the coastal issues experienced there.

The negative impacts of such past activities have now been recognised by the community with much sand and coral rubble for both community and private projects now generally collected from a “sacrificial” motu elsewhere on the atoll. However, during the visit some small-scale mining was observed at a number of locations on the lagoon side of Fenuafala (Figure 8). Despite this the natural coastal defences around Fenuafala are in healthy state (although their effectiveness along the lagoon side is reduced due to construction of buildings close to the shoreline) with it encouraging to note little apparent removal of coral rubble from, or human impacts on, the northern and western coastlines of Fenuafala which is vital to the ongoing protection of the motu.


Figure 8: The continued removal of sand (right) or coral rubble (left) from anywhere around the coastline of Fenuafala will have a detrimental effect on the level of protection provided to the village from the beach system.

The clearing of coastal vegetation, as people have built housing, along parts of Fenuafala also contributes to the reduced effectiveness of the natural defences. The areas of most significant inundation and scouring of the land surface during Cyclone Percy occurred along such areas (e.g., the school playing field).

3.3 Built coastal defences (seawalls)

Figure 9 summarises the extent of built coastal defence structures around Fale. The motu is surrounded by a variety of seawall structures, some have been well constructed, others less so. All these defences are in various states of repair, some still performing effectively but requiring maintenance, others beyond repair and providing little protection. Essentially the motu is now artificial with the community totally dependent on the protection provided by the seawall structures.

As on the other two atolls, coastal defences tend to be thought of as: 1) a community asset. The main sections are located to the immediate east of the boat channel and fronting the new Administration Building on the lagoon side, where construction is carried out as a community project, or 2) a private structure, built by property owners typically to reclaim land.

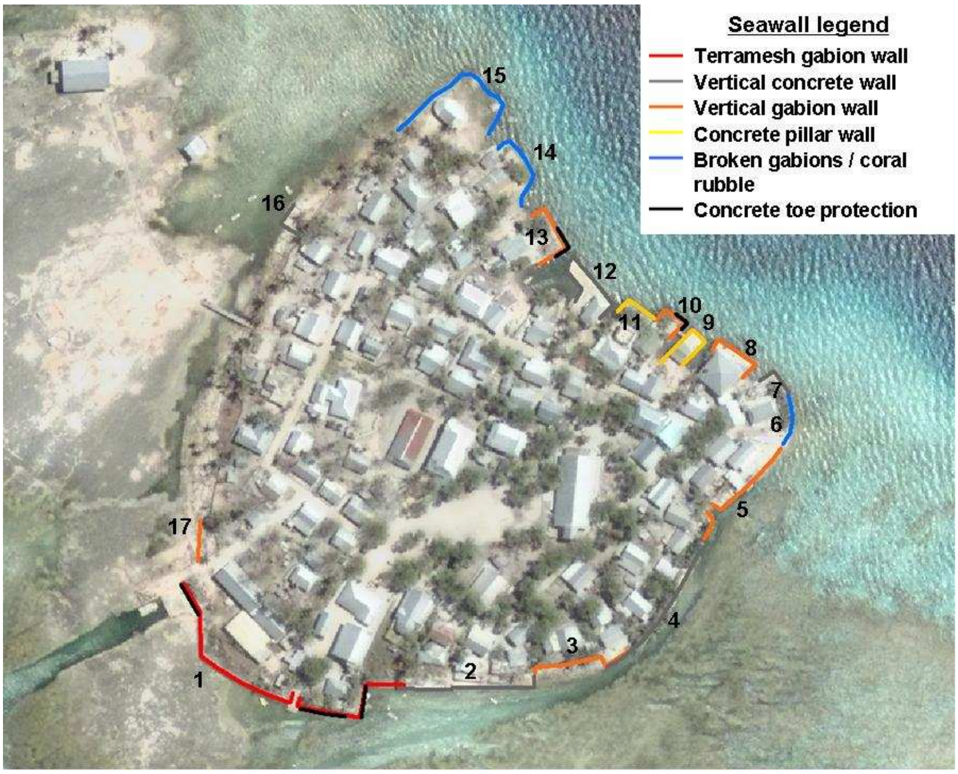


Figure 9: Summary of the location and type of seawalls constructed around Fale.

3.3.1 Community seawall sections

To the south east of the boat channel, a high vertical gabion wall (sections of both terramesh wall system and mass gravity) protects the southern side of the motu

(Figures 10 to 12). This is an important section of defence (Section 1, Figure 9). If it were to fail there would be a significant loss of land, and a number of community buildings potentially lost (bulk storage sheds, freezer facility) as well as a number of residential properties affected.

Figure 10: Gabion wall (Section 1) immediately south of the boat channel on Fale. Note the concrete beam protecting the toe of the structure along part of the length (left) and the split baskets on the top layer (right).

Maintenance activities have been periodically carried out including stitching unformed gabion baskets to the structure to repair baskets that have split (Figure 11, left) and installing concrete toe beams (Figure 11, right), reflecting that much of the damage to the gabions occurs along the lower sections that are within the range of the tide. The concrete toe beams have been constructed in two ways: (1) the bottom gabion has been faced with a layer of concrete (Figure 11, right), or (2) a thin reinforced concrete face is backfilled with coral rubble (Figure 12, left). Both construction methods are not robust and can be damaged relatively easily in storms as has happened at a number of locations (Figure 12, right).

Figure 11: Gabion wall along the southern coast of Fale

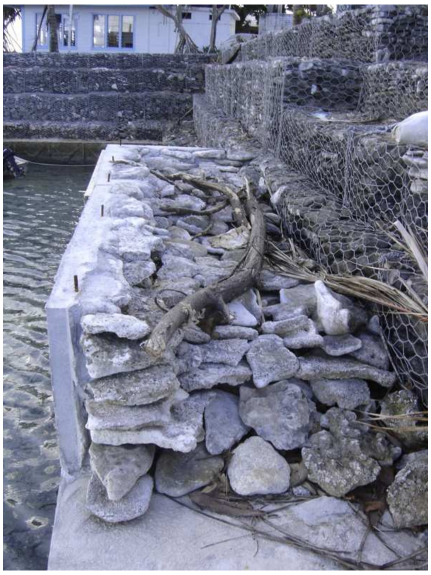
 

Figure 12: Typical concrete and coral rubble construction (left) and resulting damage (right).

The other main section of community defence fronts the new Administration building is located on the south east corner of Fale (Section 8, Figure 9). The building is fronted by a gabion seawall, that has been well constructed and is reasonable condition apart from some gabion damage at the southern end (Figure 13, left). However, the gabions have been stacked to create a vertical wall, rather than stepped, which is resulting in the wall tilting seawards (poor foundation of the structure may also be contributing to this) due to the forces created by the backfill behind the wall. There have been a number of attempts made to stabilise the toe with concrete, none of which have been successful.

Figure 13: Gabion wall fronting the Administration Building. The picture on the left shows the damaged gabions at the southern end of the wall. Note the *Piorities Sp*. coral heads in the foreground which have been collected from live coral bommies (*Akau*) within the lagoon. The use of such coral heads is not recommended, both on environmental grounds and because they are not well suited for either filling gabion baskets or used as fill given that they do not pack well.

3.3.2 Private seawall sections

Much of the remaining southern and eastern (lagoon) shoreline of Fale has been reclaimed and protected by privately constructed seawall structures. The traditional coral block walls have now been replaced by either vertical concrete walls (either concrete facing to gabions or coral block walls), vertical gabion structures, or a composite of the two with concrete foundations topped by gabions.

Along the southern coastline, the two main sections of vertical concrete wall (Sections 2 and 4, Figure 9) are substantial (Figure 14) with frequent variations in profile to accommodate access and boat tie up areas. The walls have typically been constructed using a thin concrete facing over gabions or coral block walls rather than mass concrete. Whilst some damage to the concrete is evident, particularly along Section 2, (e.g., shown in Figure 12 right) the walls are still functioning effectively. However, once the concrete facing is damaged, deterioration of the wall could be rapid during periods of large waves with the potential for much of the concrete facing to be lost and the wall significantly damaged.

Figure 14: Vertical concrete walls along Section 2 (left), and Section 4 (right).

On the lagoon side land reclamation has occurred right out to the edge of the back reef where the water depths begin to increase into the lagoon. Hence waves within the lagoon are not dissipated by the back reef flat before reaching the seawalls making them more susceptible to wave damage. For the gabion sections of seawall (Sections 6, 8 (discussed above), 10 and 13) and shown in Figures 15 and 16:

- The water depth, even at low tide, has resulted in it being more difficult to adequately found the walls during construction resulting in sections of localised wall failure due to poor foundations.

- The constant immersion and wave action on the lower sections of the wall has resulted in accelerated breakdown of the lower level gabion baskets.

- The vertical construction of the walls (rather than the gabions being stacked in a stepped manner landwards), in conjunction with the foundation issues, has significantly compromised the long term structural performance of the seawall sections.

With the exception of the vertical construction of the gabion baskets, the walls have generally been well built (the exception being the section around the ongoing reclamation at the northern end on the lagoon shore (Section 15, Figure 9)). The crest of the gabion seawall sections have typically been built no higher than the land level backing the wall, reducing the potential for damage to the baskets at the crest, and the gabions have been well packed with coral rubble of a suitable size and shape (which will be suitable for reuse when the seawalls need to be replaced).

Figure 15: Gabion wall sections 5 (right) and 10 (left) showing damage due to a combination of stacking gabion baskets vertically and foundation damage due to poor construction and basket deterioration.

Figure 16: Well-built section of gabion (Section 13) but now experiencing deterioration of the bottom layers (left) and, poor construction and inappropriate use of gabion baskets to form the boundary of a reclamation at the northern end of the lagoon shore (Section 15).

A number of wall sections have employed the use of concrete pillars or posts either in front of gabion baskets (Section 11, Figure 17, left) or, using fuel drums to provide the formwork, to construct either a vertical concrete wall (Section 9, Figure 17, right), to provide the foundations for a reinforced concrete wall (Section 7, Figure 18, left) or to provide toe protection to existing gabions (part of Section 13, Figure 18, right, and attempted at Section 5)

The predominant use of the fuel drums for formwork was to ease the placement of concrete underwater. It is a relatively robust methodology provided the pillars are well founded on the underlying reef and certainly a preferable method than simply facing a coral rubble blockwork wall or gabion baskets with concrete as has occurred on the southern side of the island. However, such a construction method will still be relatively prone to damage during large waves and is likely to have a similar lifespan to a well constructed gabion wall along such a coastline. Whilst the gaps in the wall, backed by the coral rubble / gabions may have a small influence in reducing wave reflections compared to a solid concrete wall, both the wall and any surface behind the wall are more likely to experience damage due to high wave-induced pressures within the backfill during large wave conditions.

Figure 17: Seawall section 11 (left) where concrete pillars have been placed in front of gabion baskets, and Section 9, (right), where the wall has been constructed using fuel drums for formwork with coral rubble fill behind the wall.

Figure 18: Concrete pillars constructed using fuel drums for formwork to provide the foundations (Section 7, left) and to provide toe protection to damaged gabion foundations (Section 13, right).

Gabions, that have been poorly constructed and have largely rotted away, have resulted in piles of coral rubble fronting a number of sections (Section 6, Figure 19 and 14). Whilst not intended as a coast protection structure the coral rubble does provide a level of protection, and where it occurs along with gabions built further landward, as has occurred at Section 3 provides a good example of improved approach to placement of the gabions, (Figure 19, left). At Section 3, the gabions have been built further up the beach with the bottom layer above the high tide level. Past gabions seaward of this have broken up and the coral rubble scattered over the beach. This helps protect the gabion baskets from wave attacked and as the founding layers of gabions are above normal inundation levels, and increases the time before the gabions degrade.

Figure 19: Concrete pillars constructed using fuel drums for formwork to provide the foundations (Section 7, left) and to provide toe protection to damaged gabion foundations (Section 13, right).

The wharf area of the small boat harbour (Section 12) is an example of a well constructed concrete structure which has been in place for a considerable period or time.

Along the northern shoreline some attempts have been previously made to construct a low gabion wall at the (noted in McLean, 1993) towards the toe of the beach but this has largely been destroyed. A small section of reclamation has commenced and is fronted by a narrow vertical concrete wall (Section 16, Figure 20 right). The wall is not of a suitable construction for a seawall structure.

Less land reclamation has occurred along the north-western shoreline with the shallow sloping beach still evident. However, housing and other associated buildings are built on the upper beach making them susceptible to wave damage during storm surge events when water levels are above level of the large area of *te papa* upon which the pig pens are located. Coral rubble, from a boat access channel excavated in the *te papa* and from other sources covers a substantial part of the beach and provides useful armouring that helps dissipate waves reaching the northern shoreline.

Figure 20: Northern section of coast (left) showing ongoing section of reclamation (to the left of the picture) and coastline east of the bridge, and (right) west of the bridge.

3.4 Community buildings

The building survey recorded use, wall type, foundation type and approximate floor level for each of the Government and community buildings on Fakaofo. Based on this survey, a relative appraisal of the potential risk of each building was made. This was defined as a combination of:

- Location risk (i.e., based on where the building was located) where:
    - Low – little risk of storm surge or wave overtopping reaching building.
    - Medium – occasional inundation and / or generally low water levels.
    - High – inundation occurs during most cyclones and / or inundation depths are high.
- Building risk (i.e., based on essentially the floor elevation relative to the surrounding ground level) where:
    - Low – floor level is well above likely inundation levels and / or foundations unlikely to be damaged due to water depth or velocity.
    - Medium – floor level likely to be above all but the most severe inundation levels.
    - High – inundation of building possible due to inundation levels likely to be experienced during cyclones and / or foundations potentially susceptible to damage due to water depth or velocity.

Details are summarised in Tables 1 and 2 with a spatial representation of overall community building risk, shown in Figure 21.

Table 1: Summary of storm surge inundation risk to government and community buildings on Fale.

Infrastructure	Location risk rating	Building design risk	Overall risk associated with storm surge inundation
Guest House	High	Medium	**Medium risk:** Located right on lagoon shore and dependent on seawall for protection. Floor level well above potential inundation levels.
Bulk storage shed (village)	Medium	Medium	**Medium risk:** Located on ocean side but inland with floor level above inundation levels likely to be experienced during low to moderate events.
Bulk storage shed (petrol)	High	High	**High risk:** Located on low lying land on ocean side. Protected by the other bulk storage shed but still considerable potential for inundation and related damage.
Bulk storage shed (building)	High	High	**High risk:** Located on very low lying land opposite the boat channel. Experienced considerable inundation and damage during Cyclone Percy.
Freezer facility	High	High	**High risk:** Located at the ocean side. Protected by the bulk storage sheds but potential for inundation related damage.
Catholic Church	Medium	Low	**Medium risk:** Loss of seawall would result in potential damage to church. Floor level sufficient to prevent significant inundation.
LMS Church	Low	Low	**Low risk:** Located in centre of motu with high floor level.
Admin building (Hakava)	High	Medium	**Medium risk:** Located right on lagoon shore and dependent on seawall for protection. Floor level well above potential inundation levels.
Family store	High	Medium	**Medium risk:** Located right on lagoon shore protected by new concrete pillar seawall.
Village store/Admin	Low	Low	**Low risk:** Located in centre of motu with high floor level.
Meeting fale	Low	Low	**Low risk:** Located in centre of motu .
Generator building	High	High	**High risk:** Located in very vulnerable location. Building has been well constructed and has survived past cyclones.
Public Works building (deserted)	High	High	**High risk:** Located in very vulnerable location. Building has been well constructed and has survived past cyclones.

Table 2: Summary of relative storm surge inundation risk to government and community buildings on Fenuafala.

Infrastructure	Location risk rating	Building design risk	Overall risk associated with storm surge inundation
Hospital	High	Medium	**Medium risk:** Located in an area subject to inundation during cyclone events but floor levels sufficient to prevent inundation during low to moderate events.
Doctor's house	High	High	**High risk:** Located right on the lagoon shore with low floor levels.
Generator building	Low	Medium	**Low risk**: located well inland.
Teletok office	High	Medium	**Medium risk:** Located on the lagoon shore subject to inundation and potentially wave damage. Floor level likely to be above inundation levels during low to moderate events.
Church	High	Medium	**Medium risk:** Located on the lagoon shore subject to inundation and potentially wave damage. Floor level likely to be above inundation levels during low to moderate events.
School	High	Medium - high	**High risk:** Buildings along the lagoon shore could potentially be damaged due to wave action. Inundation likely on building with low floor level. **Medium risk:** buildings further landward still in an area subject to inundation. Floor level on main building low.

The location of key community buildings on Fakaofo are split between Fale and Fenuafala. Some, such as the power station on Fenuafala are well sited in low risk areas inland. On Fale, the power station (Figure 22), located in one of the raised buildings on the *te papa* to the north west of village, is at very high risk to cyclone damage, either directly to the building or to the power link to the village being damaged, due to its exposed location. However, it is planned that power generation for Fale will be transferred to Fenuafala in the near future and supplied by an undersea cable which is already in place. The bulk storage sheds on Fale (Figure 22) are both high risk due to both their location and the low floor levels, particularly the shed closest to the boat channel. The UNDAC Cyclone Percy damage assessment (Laurence & Hill, 2005) noted that the shed suffered considerable damage, including loss of doors, and despite contents being placed on shelves, there was much damage to stored goods such as cement.

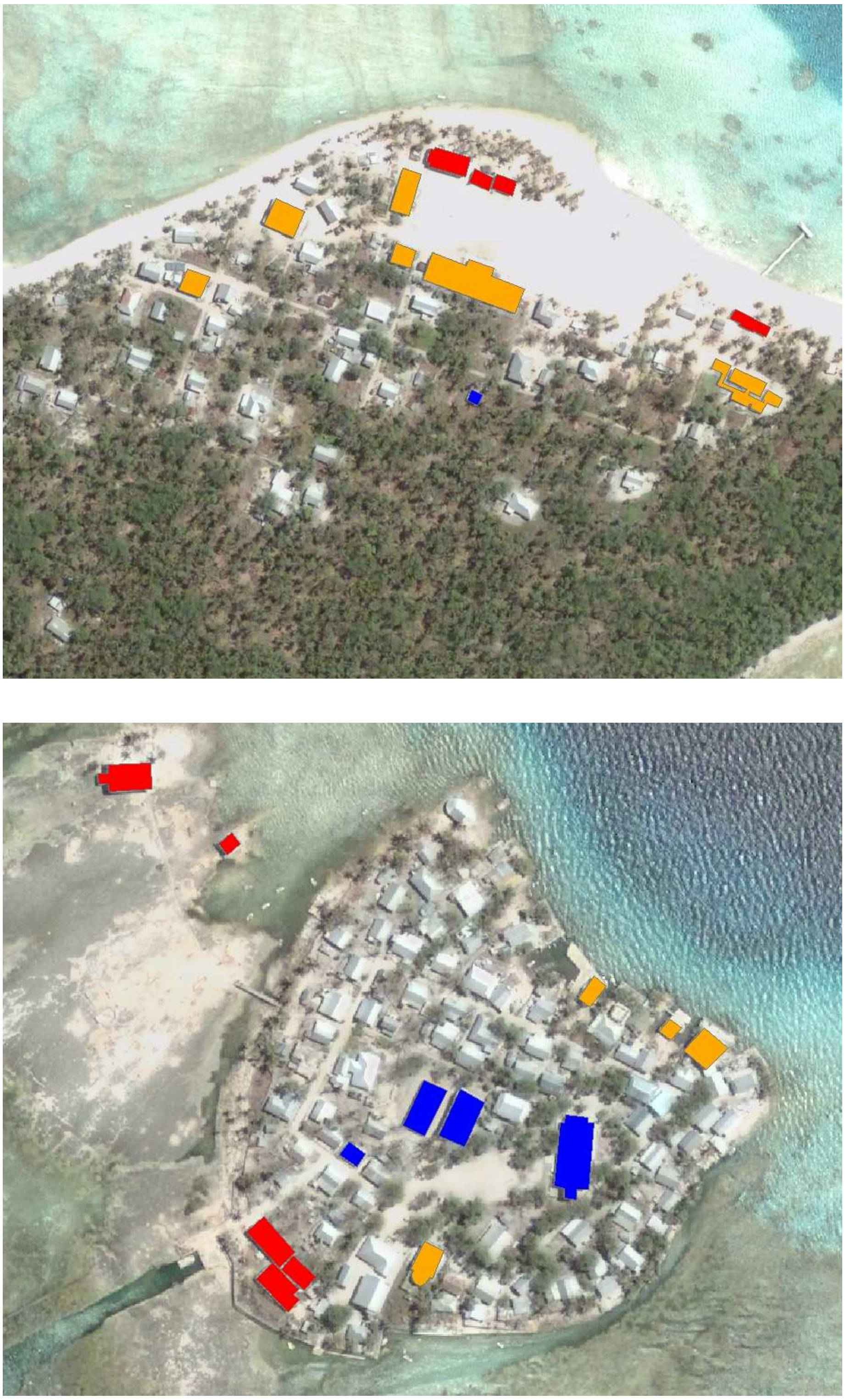


Figure 21: The relative risk of inundation or damage to community buildings on Fenuafala (above) and Fale (below) due to overwashing waves. Red = high risk, Orange = medium risk, Blue = low risk.

On Fenuafala, the school buildings are all located on low-lying land close to the lagoon shoreline which, given its location and elevation, would be expected to be inundated during cyclone-induced storm surge conditions. However, the potential for damage has been significantly exacerbated by the lack of vegetation to stabilise the surrounding land areas. The relatively low floor levels in a number of the buildings resulted in water entering them but contents had been removed beforehand so losses were minimised.

The damage assessment also noted that inundation around the hospital caused septic tanks to overflow and contamination to the drinking water supply. Damage also occurred to the Doctor’s house, which is located right on the lagoon shore and to the nurse’s quarters.

Figure 22: The bulk storage sheds (left) and power generation building (right) on Fale both at very high risk from cyclone damage.

3.5 Housing

There did not appear to be significant inundation-related damage to the main housing stock during Cyclone Percy, with little noted by the damage assessment team or raised with the project team during this visit. Some erosion and scouring around the corners and foundations of the buildings located right on the lagoon shore to the west of the school on Fenuafala occurred, with damage to one property’s foundation water tank and an outside toilet being swept away. Damage due to the effects of wind was generally much greater (e.g., roofing, broken louvres, etc. although sea spray did damage furniture and other possessions particularly in housing located close to the shoreline).

The building survey identified 45 and 76 primary housing units on Fenaufala and Fale respectively (but cook houses or sleep-outs attached to the main house were not included). Of this number, four were deserted (families moved abroad), one was being used as a store, with 14 being of two storeys, and one three storey house which was under construction.

It was noted on all atolls that the level of damage to domestic property and contents was much less during Cyclone Percy than during past cyclone events that have caused substantial inundation of the inhabited sections of the motu. This is largely due to the practice following the introduction of the housing grant scheme, of raising floor levels either by constructing the water tank under the house, or raising the floor level with concrete piles or a raised concrete slab. Figures 23 to 24 summarise the number of houses and their approximate floor elevations (relative to the surrounding ground surface) for both Fale and Fenuafala.

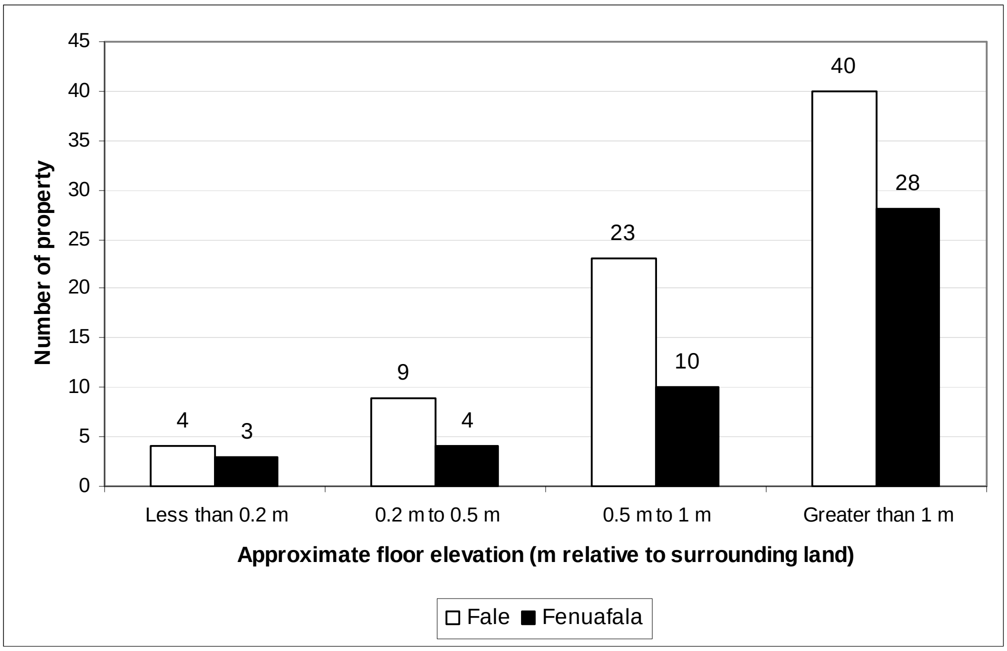


Figure 23: Summary of the number of houses with various floor levels on Fale and Fenuafala.

Figure 24: Floor levels of all buildings relative to surrounding ground levels. Red = < 0.2 m, Orange = 0.2 – 0.5 m, Yellow = 0.5 – 1 m, Green = 1 – 2 m, and Blue = > 2 m.

3.6 Extent of inundation during Cyclone Percy

From the damage assessment report, and our own discussions with the *Taupulega* and other members of the Fakaofo community, Figure 25 attempts to summarise the total extent of the inundation during Cyclone Percy on Fenuafala.

Figure 25: Approximate areas on Fenuafala (lagoon shore) inundated during Cyclone Percy. Note inundation will not have occurred at the same time at all locations. Overtopping of the beach crest is likely to have occurred along much of the ocean shore but does not appear to have caused inundation for any significant distance inland.

The main location where significant inundation occurred was along the lagoon shoreline of Fenuafala, particularly around the school. Given the low lying nature of the lagoon shore, which is a typical characteristic of such motu, inundation due to storm surge during cyclone events will occur, potentially up to around 1 m in depth above land level under most events (and potentially greater during a very severe event). During Cyclone Percy, the lack of vegetation resulted in much of the sand being stripped off the surface of the rugby pitch and surrounding areas.

On Fale, waves overtopped most of the seawalls. The main areas of inundation occurred within the lower lying areas around the bulk storage sheds opposite the boat channel and along the low lying northern coastline. However, with the exception of the bulk storage sheds, there appeared to be minimal inundation of buildings or damage to other property.

3.7 Cyclone damage estimates

There is some information on repair costs in the aftermath of Cyclone Percy for Fakaofo, detailed in Table 3 below. However, there is no systematic and quantified estimate of direct or indirect damage and whether such damage was attributable to either wind or inundation. In addition to Table 3 it would appear most direct costs, in the order of around $40,000, related to:

- The supply of provisions in the aftermath of the event.
- Labour costs associated with the clean-up.

Table 3: Summary of available details of repair costs of Fakaofo following Cyclone Percy.

Details	Costs (NZ$)
School repairs	
Materials (mainly roofing)	$6,605
Plumbing	$1,962
Doctor and Nurses housing	$4,768
Bulk store repairs & replacement of contents	
Roofing	$1,219
Replacement of 412 bags of cement	$5,541
Meeting house repair (wind related)	$1,636
Supplies for general maintenance of village	$20,913

In addition there will have been considerable indirect costs, such as ongoing loss of agriculture production, and also direct and in-direct intangible impacts on the Fakaofo community but no assessment has been made.

Damage estimates of previous cyclones, quoted in the *Tokelau Infrastructure Study* (Opus International Consultants, 2001) provide damage estimates for the whole of Tokelau from previous cyclones as:

Cyclone Wini (may also include Tusi?)	USD$500,000
Cyclone Ofa	USD$2,400,000 (NZ$4,000,000)

Cyclone Val	USD$750,000

Again, there are no estimates of the relative contribution of damage caused by wind and by inundation or erosion, with the majority of damage typically caused by the former. Developing a system and templates for systematically recording and quantifying damage following a cyclone is something that would be of considerable benefit.

4. An overview of the future management of coastal hazard risks on Tokelau

4.1 Introduction

Episodic cyclone events will continue to cause damage on Fakaofo in the future. On average a cyclone event that has the potential to cause significant disruption and damage (due to wind and / or wave inundation) appears to occur about once every 10 years with the greater risk during periods of El Niño periods. However, their actual occurrence is variable, e.g., from occurring on consecutive years as happened in 1990 and 1991 (Ofa and Val), or with longer gaps, e.g., the 14 years between Cyclone Val and Percy.

This section provides an overview of the approach adopted to the development of a long-term and sustainable programme, described in Section 5 to 9, for reducing cyclone and other climate related coastal hazard risks facing Tokelau. Many of these recommendations had been stated before (e.g., Bakx, 1987). However, it is important to note that, even with effective and continued implementation of all the recommendations in this report, small atolls such as Tokelau will still have residual risks associated with cyclone events. Whilst it is possible to reduce the damage and impacts associated with such cyclones (discussed in this and subsequent chapters), there will always be more severe events, likely to occur around every 30 to 50 years, where substantial external assistance will be required to Tokelau in the aftermath.

4.2 A strategic approach to reducing risk

Cyclone related risks are not just caused by the occurrence of the cyclone, and its hazardous characteristics (e.g., high winds and / or storm surge and large waves with associated inundation and erosion); risk is also a function of:

1. The nature of the elements (people, property, community infrastructure etc.) at risk from the hazards created by the cyclone.

2. How vulnerable (or resilient) these elements are (e.g., building location, construction or condition; state of the natural coastal defences; socioeconomic conditions etc.).

This highlights the fact that coastal hazard risk is a combination of both natural and human factors. Indeed, in most coastal locations of the world, coastal hazard problems typically have their origins in human actions rather than "abnormal" coastal behaviour (Dahm, 2005). However, historically the management of such risks has focussed on attempting to adjust the natural coastal processes, typically through engineering structures such as seawalls to "hold the line" rather than considering adjusting human behaviour and approaches to developing the built environment.

In many cases such human actions have exacerbated or caused further problems, reduced the long-term adaptive capacity of the natural coastal defences, and over the longer-term is often the most expensive (both in terms of capital and maintenance cost) form of risk reduction (but not the most effective). Such an approach has also lead to: (1) a narrow management focus, (2) a reactive approach to managing coastal hazard risk, (3) ignoring the human dimension of the problem, often leading to increasing intensification of development in hazard-prone areas, and the problem becoming more complex and difficult over time (Dahm, 2005).

The limitations of such a management approach has led to increased realisation that a more proactive and strategic approach incorporating a wide range of social and environmental objectives, is required for the development of more resilient communities exposed to coastal hazards. Embodied in such an approach is the need for a strong emphasis on awareness, information and communication through a participative process, and the need for both a bottom up and top down approach.

In developing such a strategy for managing coastal hazard risk on Fafaofo it is important to note that:

- **There is no "silver bullet"** i.e., no one option that will solve all the problems. A programme of reducing risk involves a range of inter-related activities, the composition of which will vary from location to location (e.g., between Fenuafala and Fale, the ocean to lagoon shore etc.) and over time.

- **Reducing risk is a journey not a destination**. Reducing the risks of cyclone related erosion and inundation damage is hard work and is a continuous and ongoing activity integral to development decision-making at individual, village (atoll), and national levels.

- It is critical to build **adaptive capacity**, which is the ability of the coastline, the community and individuals to cope with, adjust, respond, or even take advantage of, variability and extremes in climate, including potential long-term climate change.

4.3 Sustainable economic development

Implementing such a strategy for managing coastal hazard risks should also consider and contribute to Tokelau's economic development aspirations. In 2002 the Council of Faipule developed a vision for sustainable economic development on Tokelau, defined as "*our people improving the quality of their lives on Tokelau*". As part of this vision, six goals were developed:

1. A self-sustaining process of economic growth.

2. Creation of jobs at acceptable wages with appropriate benefits and career progression.

3. Producing goods and services that meet the social needs like affordable housing, reliable energy supplies at lower costs, better health care and education.

4. Community control, accountability and participation in the process of making decisions.

5. Broadening business and asset ownership within the community.

6. Respect for our unique cultural heritage and traditional ways.

Episodic natural disasters, such as cyclones on Tokelau, can result in high degrees of economic and social consequences in the months and years following such events which impact directly on the goals outlined above. Introducing pro-active (rather than re-active) risk reduction approaches into the development planning process is a well established and effective approach to reducing such consequences and will contribute directly to the goals and aspirations outline above. All recommendations outlined in the following sections have been developed taking account of the above goals.

4.4 Developing a risk reduction programme on Fakaofo

Episodic cyclone events will continue to cause damage on all of the Tokelau atolls in the future. During the discussions on Fakaofo, a range of potential options to reduce the risk of damage were discussed. This not only included reducing the risks associated with cyclone related inundation, but also discussing ways of reducing the impacts of potential longer-term coastal changes including those associated with long term climate change.

The approaches to reducing cyclone-related risks on Fakaofo will differ considerably between Fale and Fenaufala. Fale is now essentially an artificial island. The existence of the community on Fale totally dependent on the protection provided by the seawall structures that largely surround the motu, with future risk reduction options available to the motu limited to either: (1) continued maintenance and upgrading of the seawall structures, or (2) relocation to Fenaufala for the majority of the population.

Fenaufala has a much wider range of options and the opportunity, through effective land management planning, to enable a “no regrets” approach and to avoid the situation that Fale now finds itself. During the consultations it was emphasised that the focus of the project was not just on seawalls but on a wide range of options for reducing storm surge inundation risk with the aim of developing a strategic approach involving both short and long term objectives and options. Coastal defences such as seawalls built to ‘hold’ or ‘advance the line’ are often viewed as ‘solutions’ to coastal hazard problems. Unfortunately such actions tend to be reactive and are rarely the most effective solutions in the long-term, often leading to other environmental damage, e.g., loss of beach, and an expectation that such defences will maintained *in perpertuum* leading to ever increasing financial commitment to maintain and upgrade such defences. This is the situation that Fale now finds itself in.

As Fale has discovered with the gabion seawall and other approaches attempted, coastal defences constructed to reclaim land or to ‘hold the line’ have a limited lifespan, at best probably around 20 years given the limited types of construction and equipment available (and even then with considerable maintenance likely to be required). Whilst Fale has few other options other than continue to build and rebuild seawall structures, in general such an approach is an expensive option, can typically only ‘buy some time’ and should only be used as a last resort where assets are at direct risk and there are no other options to reduce this risk. Whilst on small motu such as Fakaofo, there is always considerable pressure to reclaim land, such activity is rarely consistent with reducing coastal hazard risk.

Options discussed and developed included:

- Ensuring protection of the natural coastal defences (reef, reef flat, beach and coastal margin) and identifying the underlying causes of human impacts on reducing the effectiveness of these natural defences and how such impacts could be effectively reduced.

- Options for land management planning both for future development and consideration of the potential for developing a long-term strategy for the movement of key infrastructural or other buildings from high risk areas.

- How risks of damage to property and content could be reduced through building design, i.e., accepting that inundation is a natural occurrence (and will always be an issue on Fakaofo) and designing and constructing buildings and infrastructure to accommodate this.

- Protection measures focussing on Fale, including the needs of both existing seawall structures, and requirements for future structural solutions with an emphasis on structures that (1) enhance the natural defences and are more sensitive to the important natural processes occurring on Fakaofo, (2) optimised to be more effective in reducing inundation, and (3) more sustainable in terms of the longevity of the structure, and in terms of ongoing maintenance costs.

In developing such an approach, the emphasis during the discussions on each atoll was placed on identifying activities that:

- Could be initiated and implemented at individual and island-community levels without the need for significant external assistance from the donor community.

- Could build on past on-island experience of implementing measures to reduce the risk of cyclone related inundation.

- Could be easily implemented using equipment that would realistically be expected to be available on Tokelau (e.g., could be built using an excavator rather than specialist equipment) and on-island skills (rather than rely extensively on external contractors).

- Looked for ways to reduce or streamline the need for large amounts of manual labour to implement solutions.

Outlined in the next sections are a series of recommendations for consideration by the decision-making process within the Fakaofo community. Also provided is a suggestion as to how these recommendations could be implemented, priority, and the timeframes over which the recommendations would be implemented (in terms of short-term, < 5 years, medium-term, 5-10 years, and long-term, > 10 years) and over which the benefits would be achieved. Also noted are potential equipment, labour and material requirements as well as a brief summary of the anticipated environmental, social and economic benefits and costs of the overall recommendations, how sustainable the recommendations are, and how they contribute to Tokelau's overall sustainable economic development goals.

5. Protecting and enhancing the natural coastal defences

5.1 Overview

The careful management of the natural coastal environment, and the resources found there, is the single most important coastal defence policy for Fakaofo. This is particularly relevant to Fenuafala, where management of the natural coastal defences and effective land planning will be integral to reducing future risk of damage due to cyclones, climate variability and climate change. On Fale it is critical to ensure that human impacts do not further impact the natural defence provided by the outer reef edge, reef flat and *te papa* outcrops on the oceanside and adjacent to the motu, through for example an inappropriately designed boat harbour and wharf or further land reclamation.

On Fenuafala along the ocean side of the motu, the reef, reef flat, beach and vegetated beach crest are all critical components of the natural coastal defence protecting the motu. This buffer has experienced little human impact and it is important that this natural defence be allowed to continue to provide this protection with minimal human impact. One way to achieve this is for the community to adopted this buffer as a vital community asset. Detrimental activities, such as sand and coral rubble removal from the beach or reef flat, clearing of natural vegetation, building housing or reclaiming land close to or over the beach, or building seawall structures, will all act to substantially reduce the effectiveness of this natural defence, to the detriment of the Fenuafala community (see Section 2).

The beach and backshore system on the lagoon side of Fenuafala is also an important community asset. Whilst the natural system will not prevent inundation due to high lagoon water levels during cyclone events, maintaining the beach and natural coastal vegetation along the shoreline will help reduce:

1. The extent of inundation.

2. The scouring of the sand/soil surface.

3. Reduce the potential for damage to buildings as waves washing over the land are dissipated by the vegetation along the shoreline.

Developing effective approaches to reducing the impacts of detrimental activities on the natural defences and addressing the underlying socio-economic causes of such activities is vital to maintain the effectiveness of these defences. The Fakaofo community is already making such efforts, for example reducing the impacts caused by sand and coral removal from the beaches of the inhabited motu (although sand removal from the lagoon beach continues on Fenuafala). The majority of sand for community and construction projects is now sourced from a 'sacrificial' motu elsewhere on the atoll. However, this is a time consuming and labour intensive activity not only on Fakaofo but also on Nukunonu and Atafu where typically it takes 10 men about 4 hours to collect 2 tonnes of sand which is transported back using the barge. In most other Pacific Island nations, developing an alternative source of sand is the critical component in reducing the impacts of beach sand mining. This is discussed further in Section 8.

The following recommendations are made:

Recommendation 1: The removal of sand and coral rubble from the beach and reef flat along the coastline of Fenuafala, and any further coral rubble from the surrounding reef flat to the north and south of Fale needs to be regulated by the community.

Recommendation 2: The clearing of natural vegetation be discouraged for at least 50 m behind the vegetation line around the entire shoreline of Fenuafala.

Recommendation 3: A rolling programme of repairing the natural coastal defences, through replanting natural shoreline vegetation, to help trap and bind the sands along the lagoon shore on Fenuafala, be initiated as an ongoing community project along the village frontage.

Recommendation 4: Reclamation of land or the construction of seawalls seaward of the vegetation line at any location on Fenuafala should be avoided.

Recommendation 5: That the environmental impacts and potential impacts on cyclone related risk on Fale of any proposed boat harbour and wharf be fully assessed by qualified professionals.

5.2 Implementation of the recommendations

Recommendation	Priority	Implemented over:			Risk reduction benefits over:		
		< 5	5 - 10	10+	< 5	5 - 10	10+
1	High						
2	High						
3	High						
4	High						
5	High	Wharf concept stage					

Implementation of *Recommendations 1 and 2* (and potentially *4*) could be achieved through a combination of developing village rules to be exercised by the *Taupulega*. A programme of community awareness to highlight the impacts and promote good practice will be an integral part of this, and all other risk management activities.

The responsibility for developing and implementing a community re-planting programme (Recommendation 3) could be carried out by a number of community groups (*Amaga*, *Fatupaepae*, youth, school project) under the direction of the *Taupulega*. One possible way is to have community planting days on the anniversaries of major cyclone events (Percy, Val, Ofa, Tusi, 1966, 1914 etc.) as a way of reminding the community about the impacts of past cyclones and the purpose of the activity.

The planting should focus primarily on establishing coconut and pandanus in a 20 to 30 m (minimum) strip from the current vegetation line:

- The methodology for planting of coconuts and other plants should be developed on the advice of community experts knowledgeable in such activities.
- Fertiliser may need to be used to help establish new plants and a suitable traditional mulch around the plants to minimize wind and water erosion and help the soil retain moisture.
- Regular watering may need to be conducted initially to help the plants establish.
- Access points from the village to the beach should be limited as much as possible.
- Leaves, fronds and branches deposited by the trees within the strip should not be swept up but allowed to remain.
- Periodic planting will be required to replace plants that haven't grown or have been affected by future cyclone events (it is important to appreciate that the plants in this area are sacrificial and re-establishing vegetation cover will be required after cyclone events).

Other natural shoreline vegetation, particularly the creeping vine (*totolo*) which is a good sand binder and low shoreline shrubs should also be established in the areas close to the current vegetation line. It is suggested that the initial focus on Fenuafala should be on the area in front of and to the east of the school along the front of the hospital and medical staff residential buildings, followed by extending the initiative to the west of the school. The full benefits of the scheme will only begin to be realised over the longer term (i.e., beyond 10 years) as the plants mature.

The need for land reclamation or seawall construction at present on Fenuafala can be avoided (*Recommendation 4*) through proactive implementation of recommendations 1 to 3 and development of appropriate community land planning measures (see next section).

A full environmental impact assessment, including detailed hydrodynamic assessment, (Recommendation 5) should be an integral component of any harbour/wharf design development on Fale.

5.3 Main constraints to implementation

- Potential conflict between an individuals rights as a land owner (to clear vegetation, collect sand from the beach in front of their property, prevent vegetation being planted on their property, reclaim land, build seawalls etc.), versus the best interests of the overall community (Recommendations 1, 2, 3 & 4).

- Long-term maintenance of community enthusiasm for ongoing replanting initiatives (Recommendation 3).

- Difficulty of enforcing village rules related to sand mining and vegetation removal (Recommendations 1 & 2 and potentially 4).

- Lack of sufficient funds to carry out sufficiently detailed hydrodynamic impact assessment as part of the environmental impact assessment of any wharf / harbour (Recommendation 5).

5.4 Summary of expected benefits and costs

	Benefits	Costs
Environmental	• Long term increase in the natural resilience of the natural coastal defence on the ocean side (Rec. 1,2,3). • Ensures no exacerbation of erosion potential due to impacts of structures (Rec. 4). • Ensures any proposed harbour/wharf will not increase cyclone risk to Fale (Rec. 5).	
Social	• Long term benefit to the Fakaofo community in assisting the reduction of risks associated with cyclone inundation (Rec. 1,2,3,4,5).	• Ongoing continual community labour commitment for replanting exercise, (Rec. 3).
Economic	• Limited external / materials costs (Rec. 3). • Complements other risk management measures in reducing economic impacts of cyclone disasters.	• Moderate and continual labour costs, (Rec. 3). • Requires external assistance for EIA of any wharf structure (Rec. 5).
Sustainability of recommendations	• Dependent on community motivation but requires little external funding, equipment or assistance for ongoing implementation, (Rec. 1,2,3).	
Contribution to sustainability development	• Contributes to long-term reduction of impacts on individuals, community and economy during cyclone inundation and coastal hazards. • Enables community control, accountability and participation in risk reduction measures (Rec. 1,2,3 & 4).	

6. Village planning to avoid coastal hazards

6.1 Overview

Incorporating coastal hazard considerations in to both the individual and community decision-making process when considering the location of new or re-built infrastructure, community buildings and residential property is an extremely effective way of reducing the risks associated with coastal hazards and a vital component in avoiding or reducing future risk associated with cyclone or other long-term coastal hazards. This is particularly important on Fenuafala where there is considerable potential to reduce future cyclone-related damage through a combination of maintaining the full effectiveness of the natural coastal defences (previous section) and effective community land planning. Developing effective and acceptable methods for addressing the often conflicting issues of individual land use rights with long-term community risk reduction measures will be a key challenge to each Tokelau community.

6.1.1 Future buildings and infrastructure

One of the most effective ways to reduce risk is avoiding building or locating essential infrastructure in areas that have been inundated during past cyclone events. From the inundation caused by Cyclone Percy, and from discussions with the community of inundation extents during previous cyclones, Figure 26 summarises for Fenuafala and Fale, in a simple format, the main areas within the villages that can be considered high hazard zones.

These are areas that could or have experienced inundation during past cyclones and can expected to be the areas most likely to be affected in future events. (Note: this does not mean that the areas that are not highlighted will not experience inundation, particularly in a future with accelerated sea-level rise).

On Fale the main damage is due to wave overtopping of the seawall structures. It is suggested that a 10 m wide zone landward from the crest of the seawall (or beach crest where it still remains, or seaward edge of land reclamation) be considered high risk and that the focus needs to shift from any further land reclamation activities to upgrading the standards of defences protecting the existing landmass.

Figure 26: Summary of land areas within Fenuafala (top) and Fale (bottom) at high risk from inundation. This does not imply areas not highlighted will not experience inundation.

The following recommendations are made:

Recommendation 6: On Fenuafala no further community buildings, infrastructure development or residential buildings (including land reclamation and seawall structures) should be constructed within the either the high hazard (red) zones or within 30 m of the ocean shoreline (south and west coasts).

Recommendation 7: As far as possible on Fale that no further land reclamation activities are conducted with a future focus on improving the standard of defence protecting the existing landmass.

Recommendation 8: As far as possible on Fale that no community buildings, land based infrastructure development or residential buildings be constructed with 10 m of the existing high water mark or seawall crests (high hazard red zone shown in Figure 26 above).

Recommendation 9: That the Fakaofo (Fenuafala) community discuss, develop and implement a community based land development planning process (with assistance from land-use managing planning experts) which aims develop a workable compromise between reducing further residential building development within the high hazard red zones and the many other social, economic and environmental factors and needs of both the community and the individual landowners.

6.1.2 Existing buildings and infrastructure

Whilst many of Fakaofo's community buildings and infrastructure are well located with respect to coastal hazard risk (e.g., the power plant on Fenaufala) there are a number of buildings that are highly susceptible to inundation damage (Tables 1 & 2). In the short term the main focus needs to be on reducing the risks to the seaward bulk storage shed and the power generator building on Fale, and in the longer-term the hospital and school on Fenuafala.

On Fale damage to residential property under moderate cyclone events due to wave overtopping of the various seawalls tends to be relatively minor. There was no significant inundation of property noted during Cyclone Percy. Rather the majority of damage tends to be wind related (removal of roof corrugated iron, broken louvres etc.). On Fenuafala, a number of residential properties located on low-lying land on the lagoon shore, particularly to the west of the school, experienced damage (e.g., to a foundation water tank) and inundation. Given that these properties are located right on the lagoon beach, the risks to these building and inhabitants will continue to increase over time.

Recommendation 10: The seaward bulk storage shed should be relocated to the centre of Fale to avoid future building and content damage. Re-construction of the building would ideally also incorporate flood proof walls (up to about 1 m high) and the ability to quickly flood proof the access points (e.g., stored sandbags).

Recommendation 11: Given the limitations on available land on Fale, the landward bulk storage shed should remain in place, but flood proof walls (up to about 1 m in height) should be constructed around the building and the ability to quickly flood proof the access points (e.g., stored sandbags) should be considered.

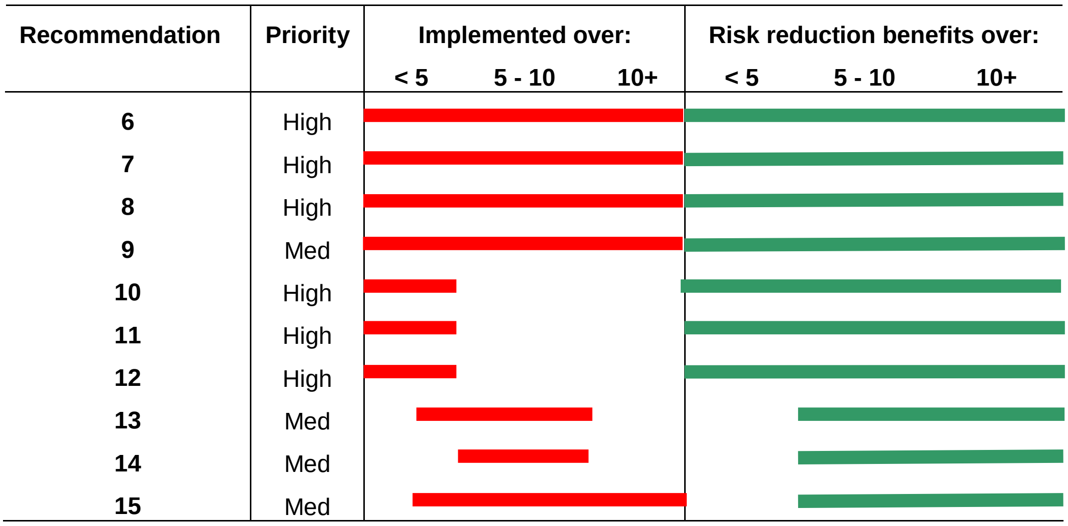
Recommendation 12: The planned relocation of power generation for Fale to the generation plant on Fenuafala should be implemented as quickly as possible.

Recommendation 13: That planning commence (leading to a staged implementation) for the relocation of the hospital and associated buildings further inland on Fenuafala away from the zone of high risk inundation. Consideration should also be given to establishing an emergency medical presence on Fale (for example located in the Administration Building) to deal with any medical requirements during cyclone events when access between Fale and Fenuafala is not possible.

Recommendation 14: That planning commence to relocate the school building constructed close to the lagoon shoreline in the medium to long term away from the zone of high risk inundation.

Recommendation 15: That the Fakaofo community discuss and develop an approach and method of implementation within a community land planning framework that addresses the needs of both the community and the individual landowners, to enable individual land / property owners located in high risk areas on the lagoon shoreline of Fenuafala to relocate either landward within their property, or to a suitable new safer site.

6.2 Implementation of the recommendations



Developing appropriate and effective land management and planning policies and practices that meet both individual and community (atoll) aspirations is never an easy task. The *Tokelau Environmental Management Strategy (TEMS)* identified the development of such a policy (Programme Profile 1), with the associated strengthening of an Environment Unit to implement such measures (Programme Profile 2). It is suggested that these recommendations fit well with the framework of the Tokelau Integrated Environment Management Project (TIEMP), also being funded by the UNDP, which has a core objective of developing an Environmental Policy and Management plan and associated capacity building and awareness activities.

In terms of recommendations 6, 7, 8, 9 and 15, the planning and management framework process needs to consider, develop and implement, within: (1) a Tokelauan context and (2) that meets the needs of both individual and community aspirations, some or all of the following:

- Restrictive zoning mechanisms.
- Design controls (see next section).
- Building set backs.
- Community reserves (e.g., community natural coastal defence buffer zones along the shorelines of Fenuafala).
- Land swaps and transferable development rights (to aid landowners with little alternative options to locate property outwith high risk zones, or where construction would increase the overall level of risk to the community through environmental damage).

Developing such a framework will take time to reach an effective consensus and will require outside assistance to facilitate its development. Associated with this will need to be a programme of awareness and capacity building at both Government and community decision-making level as well as awareness building at general community level. An important aspect will concern how such a land planning and management framework would be implanted in practice on each atoll (e.g., via the *Taupulega* or some form of development review / community planning forum) and the relative role of any national Environmental Unit. It will need to include an appropriate and well defined conflict resolution process.

A number of the recommendations outlined above, particularly relating to relocation of community infrastructure (Recommendations 10 to 14) can be implemented directly by the *Taupulega*, through allocation within the annual budget process (or through negotiated donor support).

The relocation of the bulk storage shed closest to the boat channel is considered the most urgent. Given the scarcity of land on Fale relocating this building may not be an easy task, a possible site being close to the present meeting house. An assessment will need to be carried out as to how much of the existing building could be re-used, e.g., complete structure, or recycled, e.g., the broken up foundation of the existing building used as foundation fill for the new one. The building should aim to have a higher floor level (relative to the surrounding land) than at present, although it is appreciated that this would be expensive for such a large building. An alternative may be to construct flood resistant reinforced concrete block walls (up to 1 m high) all around the structure with a temporary flood barrier at the entrance. Once relocated, it is suggested that coastal vegetation be established in and around the area where the bulk storage shed was located to aid protection to the second (landward) bulk storage shed.

Given the limited land on Fale, it is suggested that the second bulk storage shed, which is located on higher ground, remain. However, it is suggested a 1 m high reinforced concrete block wall be constructed around the building, with a demountable temporary flood barrier located at access points, to reduce the risk of inundation to the building and damage to the structure due to overtopping waves.

In the medium to longer term the relocation of the most seaward buildings at the school and hospital on Fenuafala should be implemented. These are both critical pieces of community infrastructure particularly during cyclone events and need to be located away from areas of such high inundation risk.

6.3 Main constraints to implementation

- Limited land out with private ownership for infrastructure development (Recommendations 8 to 14).

- High density of development on Fale increasing pressure for continued reclamation and development in high hazard zones (Recommendations 7 & 8).

- Land parcels already allocated on Fenuafala (and half the motu in private ownership) leading to potential conflict between an individuals rights as a land owner (to build on their land etc.), versus the best interests of the overall community (Recommendations 6, 9, 13, 14, 15).

- Potential social (and potentially financial) impacts relating to relocation recommendations (Recommendations 5, 7, 9, 10, 11, 12, 14, 15).

- Lack of funding (either from donors or within Tokelau budget) to facilitate the relocation of community infrastructure currently located in high risk locations (Recommendations 10, 11, 12, 13, 14).

6.4 Summary of expected benefits and costs.

	Benefits	Costs
Environmental	• Long term increase in the natural resilience of the natural coastal defence on Fenuafala (Rec. 6, 9, 13, 14).	
Social	• Long term benefit to the Fakaofo community in assisting the reduction of risks associated with cyclone inundation to key infrastructure, buildings and housing. • Improved awareness and incorporation of coastal hazard risk considerations within individual and community development decision-making.	• Potential for significant impacts on a number of individual land / property owners (Rec. 6, 7, 8, 9, 15).
Economic	• Should be the primary risk management tool on Fenuafala with the most significant financial and economic benefits in the long term.	• External assistance required over a relatively long time frame to enable the development and introduction of appropriate planning frameworks. • Potential high costs associated with relocation options, with benefits only realised over a long period. • Potential financial impact on individuals currently located in high hazard areas.
Sustainability of recommendations	• Dependent on (1) continual political will for integrating risk management in to decision-making process, (2) continued community awareness and support to promote changing public behaviour.	
Contribution to sustainability development	• Contributes to long-term reduction of impacts on individuals, community and economy due to cyclone inundation & coastal hazards. • Enables community control, accountability and participation in risk reduction measures (Rec. 9 & 15).	

7. Risk reduction through building design

7.1 Overview

The activities by the community in Fakaofo, as on the other two atolls, over the last ten to fifteen years, in building housing with: (1) concrete water tanks under the property, and (2) in a few cases on concrete piles, has had the greatest impact in terms of reducing risks to property and content damage due to storm surge inundation. In discussions on Fakaofo, damage to buildings and their contents due to water inundation was minimal compared to events that happened prior to the construction of such housing (e.g., the damage caused by the cyclone in 1966)

Typically construction or upgrading of two to three houses a year are commenced through the Housing Grant Scheme (either a replacement for an existing house or construction of a new house).

The following recommendations are made:

Recommendation 16: That the Housing Grant Scheme be continued (and potentially accelerated).

Recommendation 17: That coastal hazard risk reduction (through implementation of the relevant Recommendations 1 to 9 and 15 above) is an integral component to the plans for recipients of a housing grant. In other words, recipients of Government funds should not increase the potential for coastal-related damage, either to the particular property or to the general Fakaofo community).

The majority of damage to residential property and other buildings during Cyclone Percy was due to wind damage. Whilst outwith the scope of this report, it is suggested that an assessment of current building design practice is carried out by a suitably experienced engineer to identify potential improvements in the wind resistance of buildings in Tokelau.

7.2 Implementation of the recommendations.

Recommendation	Priority	Implemented over:			Risk reduction benefits over:		
		< 5	5 - 10	10+	< 5	5 - 10	10+
16	High						
17	High						

Implementation of *Recommendation 16* can be easily achieved by the *Taupulega* through continuation of the Housing Grant Scheme. If possible the emphasis should be on:

1. Relocating housing built close to the lagoon beach (including the doctor and nurses housing) on Fenuafala, particularly the three properties with floor levels less than 0.5 m above the surrounding land levels (the last property at the western end of Fenuafala is not used as a residential house rather for storage when the MV Tokelau is unloaded at the alternative boat channel)

2. Rebuilding (or preferably relocating) housing located around the perimeter of Fale with floor levels less than 0.5 m. There are approximately six properties (one of which is deserted).

At present the Housing Grant Scheme provides $11,000 for construction materials, $9,000 for the water tank, and $3,500 for sanitation. In total a normal sized house costs around $40,000 with the excess being provided by the family constructing the house.

Ensuring that recipients of housing grants do not increase or exacerbate coastal related risk, *Recommendation 17*, (either to themselves or the community) could be achieved through a series of general guidelines that grant recipients must adhere to. These guidelines would be based on the relevant recommendations 1, 2, 4, 6, 7 and 8.

Observations of damage to buildings in Asia affected by the Boxing Day tsunami highlighted that buildings elevated on well founded piles generally experienced less damage than buildings with solid walls or foundations due to the reduced restrictions on water flows (i.e., water was allowed to flow under the buildings). Significant and widespread damage to solid foundations due to overwashing flows during a cyclone event is only likely to occur during the most severe cyclone events. However, under more moderate events damage to such foundations could occur to specific property where there is a high volume of debris in the water or the building is located very close to the beach.

Whilst it cannot be stressed strongly enough, it is vital to ensure that further residential property is not constructed within the high hazard zones identified in Figure 26. If for a particular reason this cannot be avoided consideration should be given to the use of piled foundations, ensuring that the piles are well founded to withstand overwashing forces, braced where necessary, and have sufficient structural connection to the main structural frame of the house.

7.3 Constraints to implementation

1. Pressure on Tokelau budget to continue funding the housing loan scheme and lack of funds to accelerate it (Recommendation 16).

2. Potential conflict between an individuals rights as a land owner (to build on their land etc.), versus the best interests of the overall community (recommendation 17).

3. High density of development on Fale and lagoon coastline on Fenuafala increasing pressure for reclamation and development in high hazard zones (17).

7.4 Summary of expected benefits and costs.

	Benefits	Costs
Environmental	• Should reduce further property development in the immediate coastal zone assisting long term increase in the natural resilience of the natural coastal defence on Fenuafala (Rec. 16 & 17).	
Social	• Continued improvement in housing standards. • Substantial reduction in cyclone damage to, and inundation of, housing and associated tangible direct property damage and intangible impacts on household members.	
Economic	• Much improved housing standard with reduction in potential for structural and contents damage.	• Continued financial commitment to support the Housing Grant Scheme
Sustainability of recommendations	• Well established programme incorporated within the Tokelau budget process.	
Contribution to sustainability development	• Contributes to long-term reduction of impacts on individuals, community and economy due to cyclone inundation & coastal hazards. • Enables community control, accountability and participation in risk reduction measures.	

8. Risk reduction on Fale through protection measures

8.1 Overview

As discussed in Chapter 4, coastal defences such as seawalls built to 'hold' or 'advance the line' are often viewed as 'solutions' to coastal hazard problems. Unfortunately such actions tend to be reactive and are rarely the most effective options in the long-term, often leading to other environmental damage and an expectation that such defences will maintained *in perpertuum* leading to ever increasing financial commitment to maintain and upgrade such defences.

As Fale has discovered, coastal defences have a high maintenance requirement and a limited lifespan, at best probably around 20 to 25 years given the limited types of construction and equipment available. In a general context, seawalls such as these are an expensive option, typically only 'buy some time' and should only be used as a last resort where assets are at direct risk and there are no other options to reduce this risk. Whilst on small motu there is always considerable pressure to reclaim land, such activity is rarely consistent with reducing coastal hazard risk, particularly on the ocean side.

For Fale, continued reliance on seawall structures is now locked in and has become a necessity. On Fenuafala there are more appropriate long term risk reduction methodologies (discussed in the previous sections). For Fale a critical aspect will be to: 1) develop a long term strategic approach to developing and maintaining a more consistent standard of defence around the entire motu; and 2) develop more appropriate and effective forms of seawall design (both in terms of their performance in reducing inundation and cyclone related damage but also in terms of their functional lifespan). These designs need to be developed in the context of the existing seawall structures which are still providing a functional level of service and, with appropriate maintenance or upgrading will continue to provide an appropriate level of service for the short to medium term future. The approach recommended below (and for the future) also aims to ensure that upgrade activities form the basis of the replacement structure to the gabions when they do eventually deteriorate and require replacement.

8.2 Lessons learned for future seawall maintenance and construction

The Fale community has a long experience of constructing seawall defences and adapting designs based on what has and hasn't worked. However, this has resulted in a varied collection of wall types, standard of construction, and standard of protection around the motu. Whilst the use of gabion type materials to construct seawalls are far from ideal in a environment where large waves reach the seawall structure, they do have advantages in the context of Tokelau given the limitations in construction materials and methods available, local experience and knowledge, and cost considerations.

However, the longevity and performance of such defences could be improved. Based on the discussions held with the Fale community and observations during the visit, a number of general guidance criteria have been identified:

- A strategic or "community" approach needs to be adopted to ensure both a more consistent standard of defence construction and level of protection for the entire motu rather than ad hoc defence sections (e.g., where the performance of one section of well-built defence is compromised by adjacent sections of poorly-built defences).

- Gabion walls should not be used to define the boundaries for ongoing reclamations.

- Breakdown of gabion basket occurs primarily at the crest of the structure, at the toe (particularly when the toe is below normal high tide levels) and at the corners. As such:

    - The crest height of any gabion structures should not be above the level of the land backing the structure. To increase the height of any gabion structure also needs to involve the building up of land levels at the same time.

    - Where seawall foundation will be below high tide level, a mass concrete rather than gabion foundation should be used.

    - Where foundations are above high tide level (e.g., along sections fronted by *te papa* a concrete toe beam should still be constructed.

- All foundations whether gabion or mass concrete need to be keyed in to the underlying reef rock.

- The effectiveness of the gabion seawalls (both structurally and in terms of the level of protection they provide) along many sections has been reduced due to the front face having been built vertically as a retaining wall (to maximize reclaimed land). Any future gabion walls should not be built vertically faced as retaining structures but be stepped (or sloping) and optimized to provide a coast defence function.

- Gabion structures are preferable to wholly mass concrete structures as they are more effective at dissipating wave run-up, overtopping and wave reflection.

- The front face of all new gabion seawall sections should have an additional layer of PVC coasted wire mesh laced to the underlying baskets to increase the durability of the baskets and help prevent splitting.

- Gabion baskets filled with flat, slabby shaped coral rubble, which has been well packed, have been much more effective and long lasting than ones filled with more rounded and less well packed coral rubble.

- Concrete facing of gabions or use of lightly reinforced thin concrete walls backed by coral rubble will withstand commonly occurring wave conditions but are not sufficiently robust to withstand wave impacts during cyclone events. Whilst reinforced concrete can be used for seawall construction, this generally requires considerable technical expertise in design and construction. Rather, mass concrete, despite the capital costs being much more expensive, is a more appropriate long term approach.

- Consideration needs to be given as to how damaged gabions can be disposed of. Severely damaged baskets pose a significant health and safety hazard around the coastline, and present a debris hazard during cyclone conditions.

8.3 Developing a seawall upgrading strategy for Fale

Fale is going to require a considerable annual financial commitment to maintain, upgrade and replace existing seawall structures as well as construction of new structures along the northern coastline over the foreseeable future. Based on the lessons above this strategy aims to develop a framework (that would be implemented over a period of 10 years or longer), for upgrading the level of protection to Fale (Recommendation 18). This will ensure properly upgraded coastal defences that:

- Are more effective at reducing overwashing and overtopping, and protecting land from erosion, during the more commonly occurring cyclone conditions experienced

- Will reduce the level of structural damage to the seawall structures after a cyclone event and increase the structural stability and longevity of their serviceable life.

At present, it is not cost effective to completely replace existing defences that can still perform a useful function (with appropriate maintenance and upgrading). Hence a key component in the overall strategy for existing defences is to implement upgrade measures that will form the basis of the replacement structure to the gabions when they do eventually deteriorate and require replacement.

However, the construction of structural protection measures cannot reduce all the risk due to cyclone related inundation on Fale. Given the nature of motu there will still be considerable residual risk to Fale, particularly related to extreme, less frequent cyclone events which will have significant potential to cause damage to both the defences and to infrastructure and property behind the defences.

It is also important to note that the recommendations and seawall designs outlined in this section, are not appropriate solutions for Fenuafala or the other Tokelauan atolls.

8.3.1 Equipment requirements

The designs outlined below build on Fakaofo’s experience of constructing seawalls with limited equipment. However, some basic equipment will be required (either purchased or hired) to reduce the amount of manual labour required including:

- An excavator, particularly for the construction of new defence sections along the northern coastline.

- A compressor and jackhammer to enable the mass concrete toe to be keyed in to the underlying *te papa* or reef.

- A reasonable sized concrete mixer.

- A larger barge to assist with collection of coral rubble and sand from other areas on the atoll.

The designs also require a significant amount of sand. As discussed previously this is now being collected from a 'sacrificial' motu elsewhere on the atoll. However, this is a time consuming and labour intensive activity not only on Fakaofo but also on Nukunonu and Atafu where typically it takes 10 men about 4 hours to collect 2 tonnes of sand which is transported back using the barge.

Sand deposits within the lagoon at Fakaofo represent a much more sustainable source of sand than current sand sources. Acquisition of a small generator powered sand pump mounted on the barge to suck sand from relatively shallow areas in the lagoon (< 10 - 15 m deep) would provide a readily accessible sand resource, at a much reduced labour cost and time commitment. This has previously been identified as a requirement for all three atolls within the *Tokelau Infrastructure Study* (Opus, 2001) with both high environmental and developmental benefits resulting.

Whilst there are various types of pumps for dredging sand, most have a capacity well in excess of that required on Fakaofo. Low capital cost and maintenance requirements are also important. From discussion with pump suppliers an air operated diaphragm pump was recommended (e.g., the AOD series of pumps from Price Pump Co[2].). This pump has the advantage of being oil free, has minimal parts for maintenance, and has proven reliability.

This pump would be located on the barge, powered by a small petrol driven air compressor, and would "hoover" sand from the seabed. Some modifications to the barge would need to be done to provide fixings for the pump and generator and to allow the sand to be sieved in to the barge, and the water returned to the lagoon.

However, given the deep depth of the lagoon in Fakaofo it is recommended that an assessment of resource potential and ecological impacts be carried out (for example, with assistance from SOPAC who assist other Pacific Island countries in this area) before acquisition of any such equipment for Fakaofo.

It is assumed that all the equipment outlined above have considerable community benefit in addition to their use associated with future seawall construction. Hence any associated costs have not been included.

[2] www.pricepump.com

8.3.2 Environmental issues related to construction

Given future seawall structures will be generally replacing existing structures on Fale, the main environmental issues relate to:

- The source of sand for concrete production. As discussed above this needs to be sourced from a ‘sacrificial’ motu well away from Fale or Fenuafala or from shallow areas within the lagoon, if such a resource is viable (although the sand may not be of as good quality), again away from Fale or Fenuafala.

- Further coral rubble for the filling of gabion baskets. Whilst a substantial amount of coral rubble from the old gabion baskets can be re-used, there will be a need for some fresh material. This was discussed by McLean (1993) who recommended that no further coral rubble should be removed from deposits on the reef flat to the immediate north and south of Fale. Indeed it is recommended that no rubble be collected from any part of the reef flat from around Fale, between Fale and Fenuafala, and around and to the immediate east of Fenuafala.

  McLean (1993) recommended that all coral rubble be collected from an existing source, *Ahaga Loa*, along the north-western rim of the atoll and potential sites at *Nukumatu* and *Kauahua O Kupaga* to the south of Fale but would need to be investigated. During this study there was insufficient time on Fakaofo to investigate these sites but the recommendations remain valid.

Other specific issues are discussed in the following sections.

8.3.3 Outline designs for Fale

Given the limitations in construction materials and equipment on Fale, future seawall structures will rely heavily on the continued use of gabion structures and mass concrete. Other potential options, such as the use of rock armour, concrete armour units, or reinforced concrete all have significant technical and / or financial constraints and are unlikely to be feasible options for Tokelau.

Different seawall sections will be required at different points around Fale, depending on whether it is a lagoon shoreline or ocean, is fronted by *te papa* etc. Figure 27 summarises the four main sections and, based on the lessons learned (detailed above) and from relevant technical publications[3] [4], Figures 28 to 32 present indicative designs aimed at addressing the two objectives in the previous section.

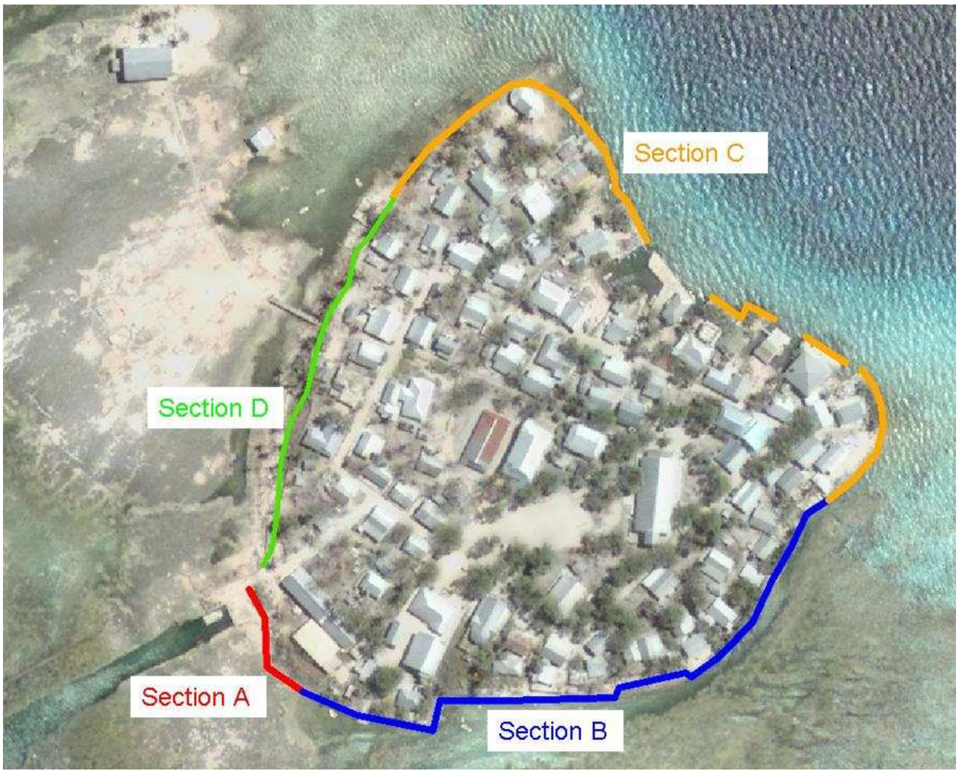


Figure 27 Summary of defence sections for different seawall design profiles around Fale (See Figures 28 to 32 for details)

For structural stability of the seawalls, reduction in wave related damage to the seawalls, and increased longevity it is suggested:

- All gabion structures have a stepped or sloping front face rather than vertical.
- The use of 0.5 m high gabion baskets which tend to keep their shape, provide more structural support and experience less stone movement (Opus, 2001) rather than 1 m square ones. In a sloping revetment situation having two layers of 0.5 m thick gabion baskets rather than one 1 m thick layer ensures the bottom layer remains intact even if the top layer becomes damaged.

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[3] HR Wallingford (1999) Wave overtopping of seawalls. Design and assessment manual. R & D Technical Report W178.
[4] McConnell, K. (1998). Revetment systems against wave attack – a design manual. Thomas Telford Publishing

- All gabion defences, where the toe of the structure would be below the level of normal high tides, needs an in-situ concrete toe beam cast to provide protection against scour and accelerated damage to the lower gabion units.

- The toes of all seawall structures (whether gabion or mass concrete) need to be keyed in (by around 300 mm) to the underlying reef or beach rock.

- The crest of any seawall be no higher than the land levels backing the structure. Hence potential damage to the structure due to overtopping is likely to still be an issue requiring additional crest protection such as landward extension of the gabion baskets, and an in-situ concrete crest beam.

- The front face and crest of all gabion structures be faced with an additional sheet of PVC coated wire meshing.

Section A: Ocean side to the south of the boat channel

This section is located on top of the raised reef rock (*te papa*). As the toe is founded on the *te papa* it is above normal high tide levels. However, a small, stepped concrete toe beam located in front of the existing gabion wall and keyed in to at least 300 mm in to the *te papa* will be required. The gabions should be stacked to form a stepped profile with at least a 500 mm tread (larger if possible, such as shown in Figure 28).

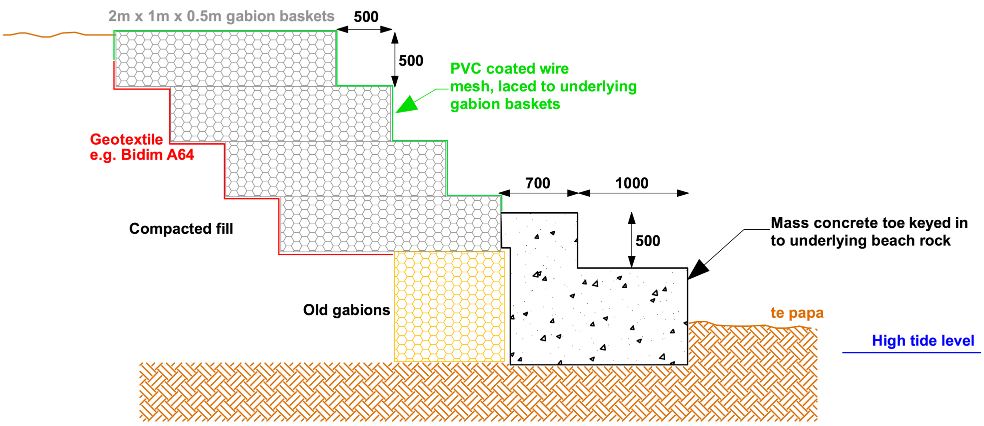


Figure 28: Proposed outline design cross-section along Section A of the Fale shoreline. Dimensions in mm unless stated.

The gabions profile could be extended higher as long as land levels behind the defence were also raised to be level with the top of the seawall. A concrete crest beam (similar to that shown in Figure 29) could also be placed to further improve structural stability at the crest but again should extend much above the land level behind the wall.

Underlying existing gabion baskets could remain and provide the core of the structure where suitable. Elsewhere the core underneath the gabions should be well compacted. Existing coral rubble fill from the existing gabion baskets can be re-used

Cost: $1,131 per linear metre ($1,390 with mass concrete crest beam)

Costs exclude labour costs associated with construction, equipment purchase or hire, and assume 25% of the coral rubble requirements will need to be freshly sourced. Costs associated with the collection of sand and coral rubble are included.

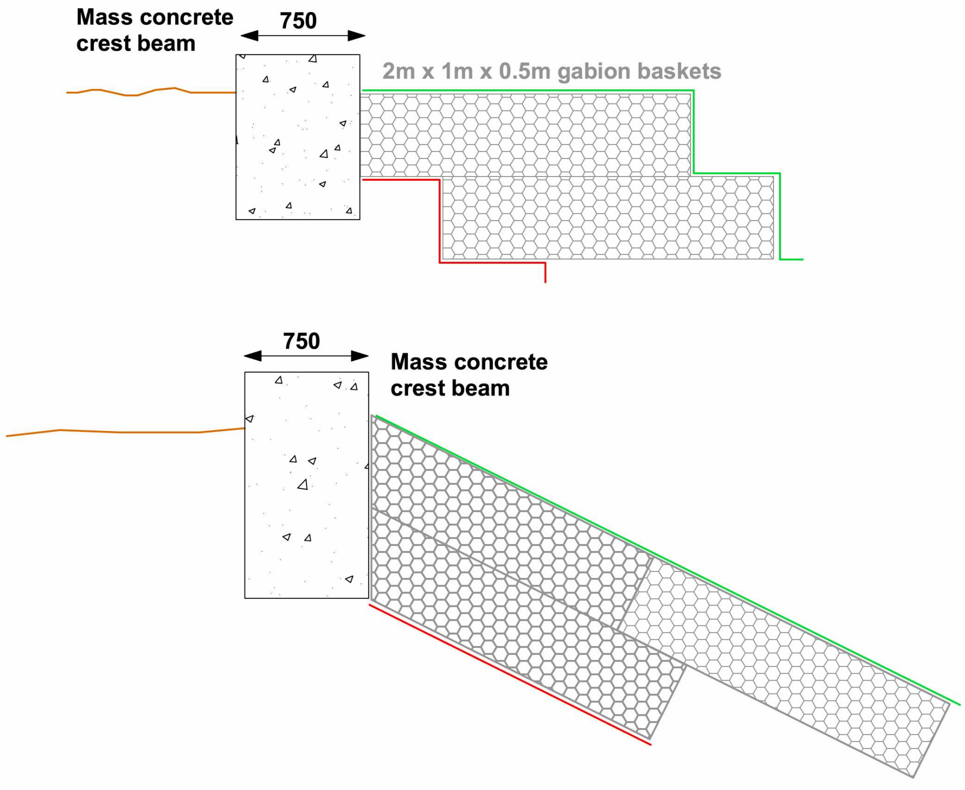


Figure 29: Examples of the use of a mass concrete crest beam to increase stability of the gabion crest.

Section B: Southern coastline

Section B extends from the southern end of the *te papa* outcrop, along the entire southern coastline until land levels begin to reduce towards the southern corner of the motu on the lagoon side. Some parts of the seawalls along this section (notably the concrete walled sections) may be sufficiently robust not to require upgrading for some considerable time, with the main focus likely to be on upgrading and replacing the existing gabion sections towards the ocean side.

Due to the toe of the structure being below water at all stages of the tide, a more substantial toe beam is required to help reduce deterioration of the lower gabion baskets and to help dissipate potentially larger waves that can reach the wall in due to deeper water at the wall.

To allow the concrete toe beam to be properly founded in the underlying reef rock some thought may need to be given to constructing temporary cofferdams around the foundation area being constructed to allow the excavation and pouring of concrete to occur in the dry. This could be achieved by carrying out such work over a low tide by building a sand bag bund faced with plastic sheeting and pumping or bailing out the water inside.

Construction of the gabions could either be stepped (Figure 30 top as described in Section A above) or sloping (Figure 30 bottom). The sloping structure is less prone to damage and easier to maintain but may be more difficult to construct initially. The slope should be at least 1:2 with two layers of the 0.5 m thick gabions used. However, it is important to appreciate that the sloping option will take up more land.

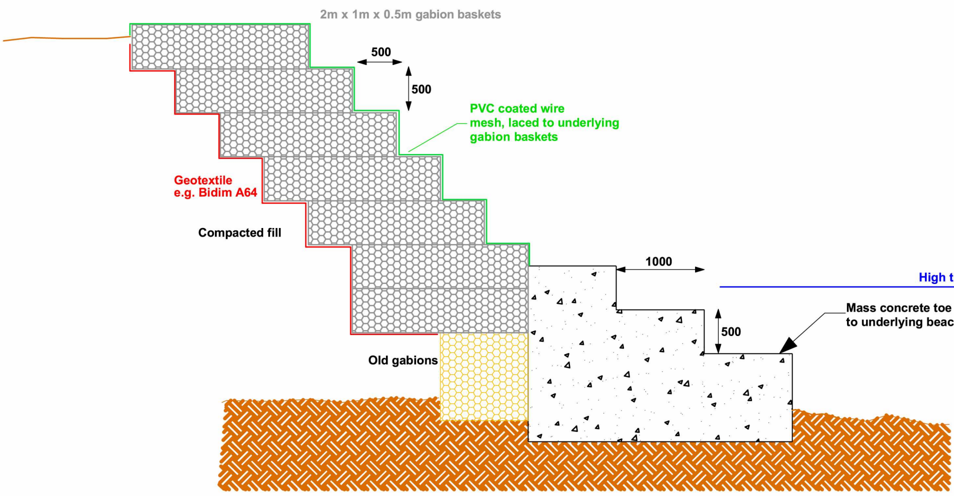
As with Section A, the gabions profile could be extended higher as long as land levels behind the defence were also raised. A concrete crest beam (similar to that shown in Figure 29) could also be placed to further improve structural stability at the crest.

Costs per linear metre will depend on the volume of fresh coral rubble required. For the purpose of the costing below it is assumed that there will be a requirement of 25% fresh material to the sections with existing gabions:

Cost (stepped profile): $2,384 per linear metre ($2,643 with mass concrete crest beam)

Cost (sloping profile): $2,547 per linear metre ($2,806 with mass concrete crest beam)

Costs exclude labour costs associated with construction, equipment purchase or hire, and assume 25% of the coral rubble requirements will need to be freshly sourced. Costs associated with the collection of sand and coral rubble are included.



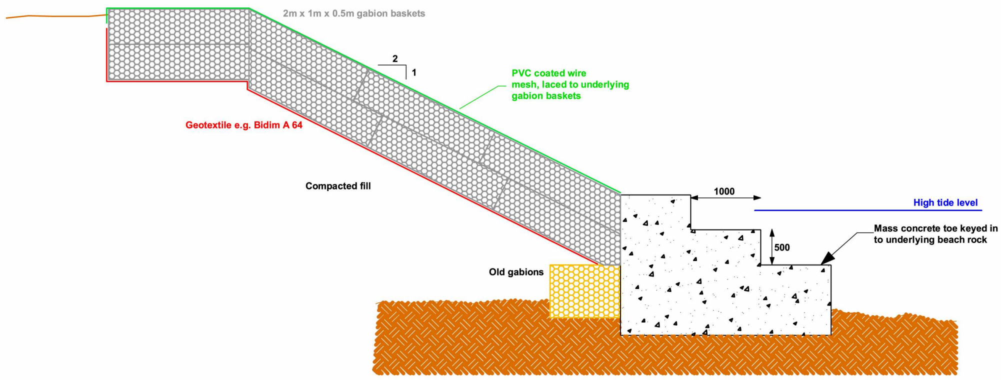


Figure 30: Proposed outline design cross-section along Section B (Fale) for a stepped gabion profile (top) and a sloping gabion profile (bottom). Dimensions in mm unless otherwise stated.

<u>Section C: Lagoon coastline</u>

The lagoon section extends from the south east corner, along the lagoon shoreline and around the north eastern corner of the motu to approximately the location where reclamation over the natural beach ends.

The extent of reclamation out towards the edge of the back reef has resulted in the toe of the defences being in relatively deep water making them difficult to found properly and more exposed to wave damage. However wave conditions generated within the lagoon will tend to be less damaging than those experienced on the ocean side. As a result a steeper stepped mass concrete toe is suggested than that outlined in section B above.

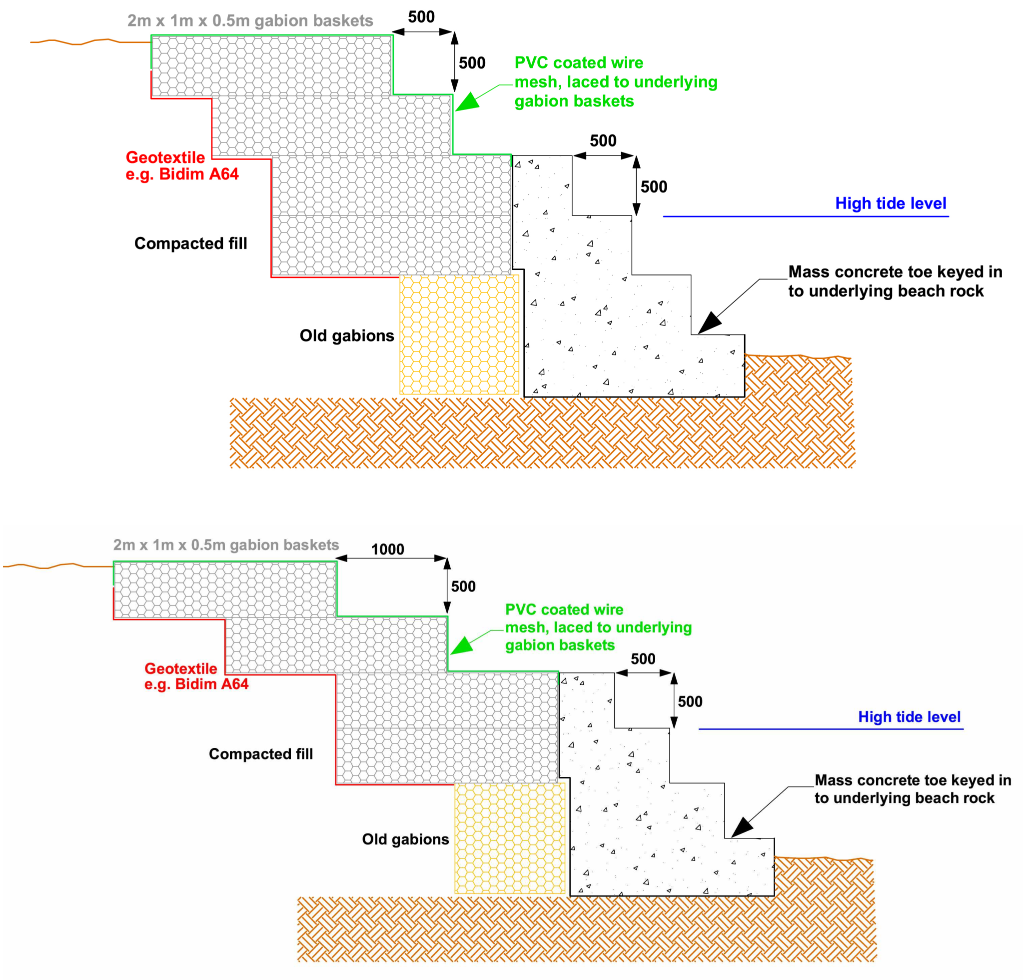


Figure 31 Possible configurations of defences along the lagoon shoreline (Section C) with the main difference being the tread of the upper gabions. Dimensions in mm unless otherwise stated.

As with the other sections, the gabions could either be stepped or sloping, the degree of which depending on available land and could be extended higher as long as land levels behind the defence were also raised. A concrete crest beam (similar to that shown in Figure 29) could also be placed to further improve structural stability at the crest.

Costs per linear metre will depend on the volume of fresh coral rubble required. Along sections already fronted with gabions, where coral rubble can be reused it is assumed that a there is a requirement of 25% fresh material. Other sections assume that all coral rubble will need to be resourced although this is likely to be an overestimate as there are substantial amounts located along unprotected sections, such as at the north-eastern end.

Cost: $1,389 per linear metre ($1,648 with mass concrete crest beam)

Costs exclude labour costs associated with construction, equipment purchase or hire, and assume 25% of the coral rubble requirements will need to be freshly sourced. Costs associated with the collection of sand and coral rubble are included.

Section D: Northern coastline

Most of the northern coastline is not protected by any seawall structures with a shallow sloping beach along much of its length. Housing backs the beach, and in some places extends on to the upper parts of the beach as do a number of cook houses. Whilst a raised area of *te papa* provides protection to the beach along this section of coast (apart from at the eastern lagoon end), wave run-up and overtopping of the beach crest resulted in inundation during Cyclone Percy. Whilst there did not appear to be significant inundation or damage to property during Cyclone Percy, wave overwashing did extend into this section of the village. The potential for damage caused by wave overwashing is limited somewhat by the protection provided by the *te papa* and large blocks of coral rubble scattered over the beach, which help to reduce the potential for loss of sand during cyclone events. However, there is still considerable potential for scouring and undermining of the foundations, leading to structural damage, of the first line of housing under such events in the future

Figure 32 summarises potential design cross sections for the northern coastline. The primary aim is to provide increased protection to the properties along this coastline from potential scouring of foundations of significant wave damage. It does not aim to reclaim land over the beach, with the lower section of the beach being an integral component of the scheme.

The toe of the defence should be around 2 m above the level of the reef flat (above the level of normal high tides). The toe needs to be buried by at least 0.75 – 1 m or down to any underlying beach rock to prevent any toe scour resulting in damage to the structure. Given the relatively low elevation of the land upon which the first row of properties are located it is suggested that the fill excavated from the foundation be used to build up land levels behind the defence to allow the crest elevation of the structure to be increased. A wider crest and concrete crest beam will help prevent damage to the crest and help reduce overtopping volumes.

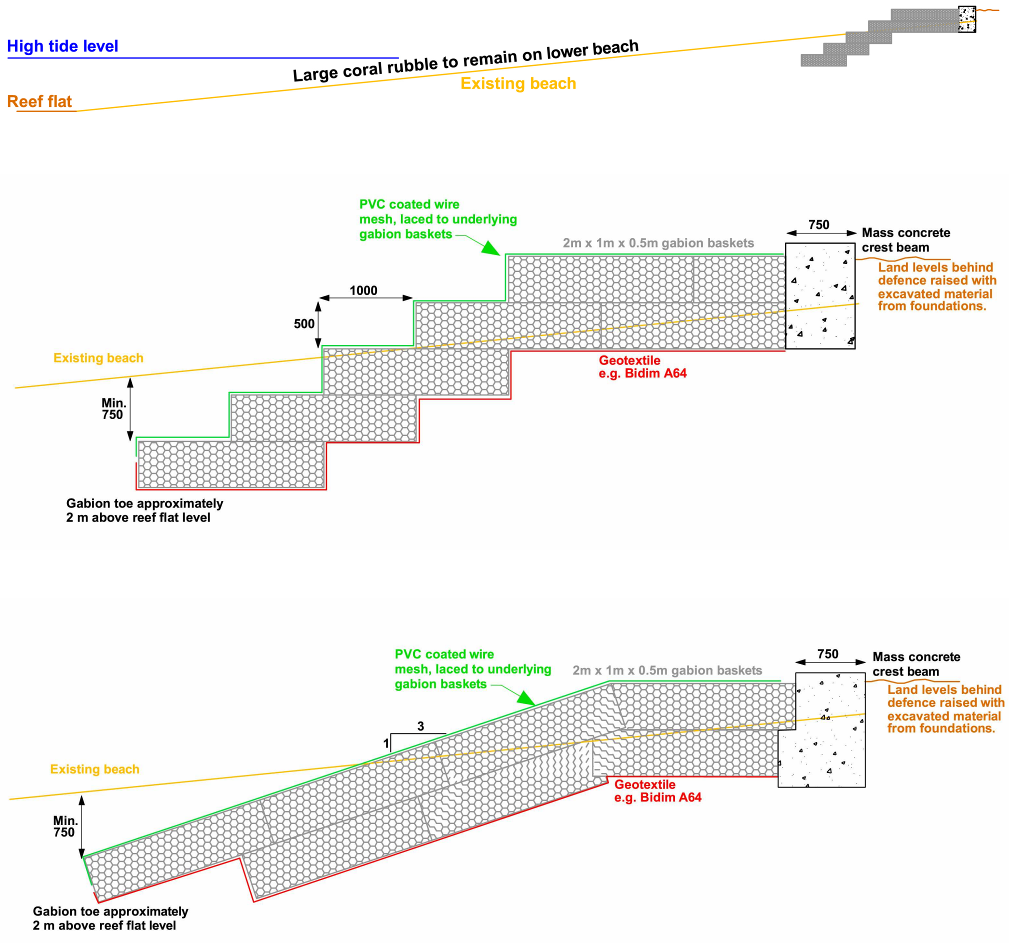


Figure 32 Potential defence cross-sections along the northern coastline of Fale (Section D). The top figure shows the location of the defence relative to the beach and reef. The defence can be constructed using either a stepped (middle) or alternatively a sloping (bottom) gabion profile. Dimensions in mm unless otherwise stated.

The gabion defence could be either stepped or sloping but it is recommended that a consistent cross-section be used along the entire length of the defence.

It is assumed that all coral rubble will need to be resourced.

Cost (stepped profile): $1,835 per linear metre

Cost (sloping profile): $1,758 per linear metre

Costs exclude labour costs associated with construction, equipment purchase or hire, and assume 25% of the coral rubble requirements will need to be freshly sourced. Costs associated with the collection of sand and coral rubble are included.

It is appreciated that this defence may need to constructed in a number of phases. It is suggested that construction commence at the ocean side and work towards the lagoon. The ends of the defence are particularly prone to damage if exposed to wave action such as under cyclone conditions. If there is planned to be a substantial length of time between construction of parts of the defence it is suggested that the revetment curve back landwards into the existing ground, or that wing walls, i.e., gabions are used to create a wall back in to the ground behind the defence at 90º to the seaward face of the wall.

8.3.4 Further measures to reduce overtopping of seawalls

Given the available elevation of the land backing all the defence sections, there is potential for considerable volumes of water to still overtop during peak cyclone conditions. Whilst raising the crest level is the most effective way to reduce overtopping volumes, to prevent damage to the seawall structure and to prevent the potential for ponding behind the structure, it is recommended that the crest of the seawall does not rise above the level of the land backing it.

There are a number of other ways to further reduce the volume of wave overtopping seawall structures. In general sloping, permeable structures reduce the volume of overtopping compared to comparable solid sloping or vertical walled structures. Overtopping volumes can be further reduced by:

- Reducing the slope of the structure which increases the slope length. An ideal slope is 1:3 and should not be more than 1:1.

- Introducing a berm (or flat area) mid-way up the front face of the structure. This can result in a substantial reduction in overtopping, the extent of which is dependent on the width of the berm and height relative to the water elevation (the higher the berm is above the water level the more effective it is).

- Widening the crest of the structure.

However, all these measures take up a greater amount of land and unlikely to be able to be accommodated given the limited space available and the proximity of buildings and property around the shoreline of Fale.

8.4 Implementing the future upgrading and maintenance of seawalls around Fale

As noted above, Fale is going to require considerable annual financial commitments to enable the upgrading and maintenance of seawall structures. This can only be achieved over the medium to long term with a need for such a commitment to be recognized and accounted for in annual budgets. Outlined below is a suggested strategy for the upgrading of seawall structures around the entire motu based on the suggested designs detailed in the previous section. **These need to be implemented within the context of other risk reduction measures, (for example such as relocating the bulk storage shed, ensuring no further buildings are constructed in the high hazard zones detailed in Figure 26) detailed in the previous sections**.

Given the size of the motu of Fale, and the importance of seawall structures to the protection of the entire community, it is suggested that future upgrading or provision of seawall structures become a community responsibility rather than a combination of community defence sections and a range of privately constructed sections. This would ensure a more consistent standard of defence construction and level of protection rather than the present *ad hoc* approach.

How this may be adopted and implemented will need to be agreed on by the Fale community. Potential mechanisms could include:

- Seawall upgrading and construction becomes entirely a community based activity with all material and labour provided and priorities decided either by adopting the recommendations below or through the *Taupulega*. This has the advantage of ensuring technical construction skills developed by the *Aumaga* are applied consistently to all defence sections resulting in a likely better standard of defence and level of protection.

- Off-island materials for the construction of the recommended seawall profile are provided (either directly or via some form of seawall grant scheme) but labour for construction and on-atoll sourced material (such as sand and coral rubble) are provided by the individual landowner. This has the advantage of not being reliant on the *Aumaga*, who also have many other work commitments, but may not result in as well-built seawalls as experience gained will not always be passed on.

In deciding on priorities, it is recommended that the focus within Fale be on commencing a programme of upgrading existing seawalls to permit these structures to continue to perform a useful function over the short to medium term but where the upgrade work, such as strengthening the toe of the defence, will form the basis of any replacement structure when the present gabions do eventually deteriorate beyond a state that can effectively be maintained. It is suggested that the priority for such work should be the community sections of seawalls which are protecting important community infrastructure.

Outlined below is a suggested programme of seawall upgrading for the next five year period. This period of five years (and the subsequent programme for the period 2011 to 2015) may need to be adjusted depending on available funding and on-island labour availability. Future events, such as the next severe cyclone, may also change the suggested priorities.

8.4.1 Seawall upgrading programme 2006-2010

Figure 33 Suggested programme of defence upgrading between 2006 and 2010. Note red = first priority, orange = second priority, and green = third priority

Year	Section	Length	Details	Cost ($)
06-07	1 & Part of 2	170 m	Construction of mass concrete toe beam, replacement of broken gabions at crest, and additional protection to front face of gabion with PVC coated mesh sheeting. Suggested UNDP priority (see next section)	$99,400
06-07	8	33 m	Construction of mass concrete toe beam, replacement of broken gabions at crest, and additional protection to front face of gabion with PVC coated mesh sheeting. Suggested UNDP priority (see next section)	$21,800
08-09	5	55 m	Construction of mass concrete toe beam (see Figure 31) to stabilize toe of existing gabion seawall.	$50,800
08-09	10	24 m	Reconstruction of entire gabion seawall as shown in Figure 31	$33,400
08-09	13	32 m	Construction of mass concrete toe beam (see Figure 31) to stabilize toe of existing gabion seawall.	$30,000
08-10	17 & new	160 m	Construction of new seawall based on design shown in Figure 32	$294,000
09-10	6 & 7	52 m	Construction of new seawall based on design shown in Figure 31	$72,300

8.4.2 Seawall upgrading programme 2011-2015

Figure 34 Suggested programme of defence upgrading between 2011 and 2014. Note red = first priority, orange = second priority, and green = third priority. The section of defence along the south-eastern section of coastline may require upgrading within this period and any need should be reviewed in the future.

Year	Section	Length	Details	Cost ($)
11-12	15, 16 & new	160 m	Construction of new seawall based on design shown in Figure 32 but requires existing reclamation to be completed.	$222,200
12-13	1 & Part 2	170 m	Replacement of the gabion baskets above the previously constructed mass concrete toe based on the design profile shown in Figures 28 and 30. Replacement of present day mass concrete toe.	$236,500
12-13	11	23 m	New mass concrete toe based on design in Figure 31.	$35,600
12-13	8	33 m	Replacement of the gabion baskets above the previously constructed mass concrete toe based on the design profile shown in Figure 31.	$20,300
13-15	5	55 m	Replacement of the gabion baskets above the previously constructed mass concrete toe based on the design profile shown in Figure 31.	$33,900
13-15	9	20 m	New mass concrete toe based on design in Figure 31.	$18,5000
13-15	13	35 m	Replacement of the gabion baskets above the previously constructed mass concrete toe based on the design profile shown in Figure 31.	$21,600
> 2015	Part 2, 3 & 4	150 m	Potential need to upgrade seawall. Will require future review.	-

8.5 Constraints to implementation

1. Need for considerable commitment for funding either within Tokelau's annual budget and / or with donor support.

2. Acceptance by Tokelau's other atolls that a considerably greater amount of money will be required to be spent on Fale to reduce hazard risk due to its reliance on seawall structures.

3. Potential conflict from landowners to restrictions on further land reclamation and suggested seawall designs.

4. Lack of available on-island labour for long-term construction projects.

5. Lack of availability of required equipment, notably an excavator and sand pump.

6. Future events, such as another severe cyclone may changes priorities.

8.6 Summary of expected benefits and costs

	Benefits	Costs
Environmental		• Requires substantial volumes of sand and coral rubble to be sourced from a sacrificial motu elsewhere on the motu.
Social	• Substantial reduction in cyclone damage to, and inundation of, housing and associated tangible direct property damage and intangible impacts on household members.	
Economic	• Reduced potential for inundation and damage to property and infrastructure. • More resilient structures with reduced maintenance commitment to maintain serviceable performance.	• Requires considerable financial commitment over the next 10 years to upgrade defences.
Sustainability of recommendations	• Needs to be: 1) integrated in to Tokelau's annual budget, and 2) strategic approach to upgrading the defences needs to have support of donor community.	
Contribution to sustainability development	• Contributes to long-term reduction of impacts on individuals, community and economy due to cyclone inundation & coastal hazards. • Enables community control, accountability and participation in risk reduction measures.	

9. Immediate priorities and future implementation

9.1 UNDP priorities

A primary purpose of this report is to identify priorities for the most effective and efficient use of current UNDP funding to help reduce future risks associated with cyclone related coastal erosion or inundation, within the context of the recommendations developed in the previous Chapters.

Based on the discussions held with both Tokelau and the UNDP the following are suggested as priority for funding assistance:

1. Required materials for the maintenance and upgrading of existing sections of gabion seawalls on the ocean side of Fale and fronting the Administration Building on the lagoon side.

2. Seed money to assist the commencement of community planting initiatives and associated awareness programme on Fenaufala.

3. If sufficient funds are available, contributing funding to assist with the relocation of the oceanside bulk storage shed on Fale.

The available budget will only be able to tackle the most important sections of existing sea defences. The future financial commitment for maintaining and upgrading the range of sea wall structures around Fale will be considerable (and well beyond the present budget). There will need to be a significant allowance in Tokelau’s annual budget for ongoing maintenance and upgrading of the seawall structures around Fale as discussed in the previous section.

9.1.1 Priority 1: Upgrade of the existing community gabion seawalls.

Chapter 8 outlines a long term approach to upgrading the seawall structures around the entire coast of Fale. It is based on a process of upgrading existing defences that can still perform a useful function over the short to medium term, and where the upgraded components form the basis of the replacement structure for the existing gabions when they do eventually deteriorate and require replacement.

Southern coast of Fale (Ocean side)

Given the importance of this exposed section of defence, maintenance and upgrading the vertical gabion seawall over a length of 200 m south east of the boat access channel is a high priority before it deteriorates beyond repair. It is suggested this would involve:

- Replacement of gabion baskets on the top layer (including keys), where they are split (or close to splitting). Replacement baskets should be galmac coated with a PVC sleeve (The existing baskets are only zinc coated – the galmac coating and PVC sleeve will provide additional protection increasing the lifespan of the baskets from rusting through by about 1.5 times compared to the existing baskets). There should be sufficient coral rubble available from the existing baskets to fill the replacements. However, if more rubble is required it should be flat and slabby rather than rounded and sourced from the locations recommended in the original EIA (See Section 8.3.2).

- Covering of the entire structure with continuous sheets of PVC and zinc coated wire mesh, contoured and laced to the baskets underneath (Figures 35 & 36)

- Construct a mass concrete toe along the sections of gabion wall where such toe protection does not presently exist and upgrading of the existing concrete toe beam:

  1. Along the section fronted by raised beach rock (*te papa*) immediately to the south of the boat channel and landing area the toe beam should be similar in construction (slightly wider and stepped) to the short section that has recently been constructed (Figure 35). Total length is approximately 36 m. The level of the top of the toe beam should be around one third of the way up the second layer of gabions and the toe of the beam should be keyed in approximately 300 mm into the underlying beach rock. This will form the first stage of a replacement for the gabion wall in the future (see Figure 28 for details in section 8.3.3)

     Between the southern extent of the beach rock (*te papa*) to the end of defence Section 1 (Figure 9), a more extensive toe should be constructed as shown in Figure 36 and based on defence section B as shown in Figure 30. The height of the toe should be about one third of the way up the third layer of gabions to protect the gabion baskets from wave interaction during normal wave / water level conditions (Figure 36). Along the short sections with an existing small toe beam already constructed, this existing beam should form part of the structure.

This section of wall would serve two purposes. Firstly it will protect and reinforce the bottom two layers of gabions (where are generally in the worst state of repairs due to them being within the intertidal zone), and (2) as stated above it is intended that the mass concrete wall (which should last considerably longer than the gabions) will form the foundation for the replacement for the gabion wall once it does reach the end of its serviceable life.

It is suggested that the wall be stepped on its front face to improve wave dissipation and should be keyed in to the underlying bedrock to at least 300 mm. To assist with construction it is suggested that a temporary sand bag cofferdam be used and a submersible pump hired to dewater the working area.

Towards the eastern end of defence section 1, a large coral rubble and concrete faced wall fronts the gabions. As previously discussed this type of construction is prone to damage. Should this occur, removal of the coral rubble fill and extension of the mass concrete toe beam should be considered.

The maintenance suggested above should extend the life of the structure over the short to medium term depending on the frequency and severity of cyclone events in the coming years and volume of beach fronting the structure. Maintenance to repair split mesh should be conducted periodically and should be a priority before any further new construction work is carried out.

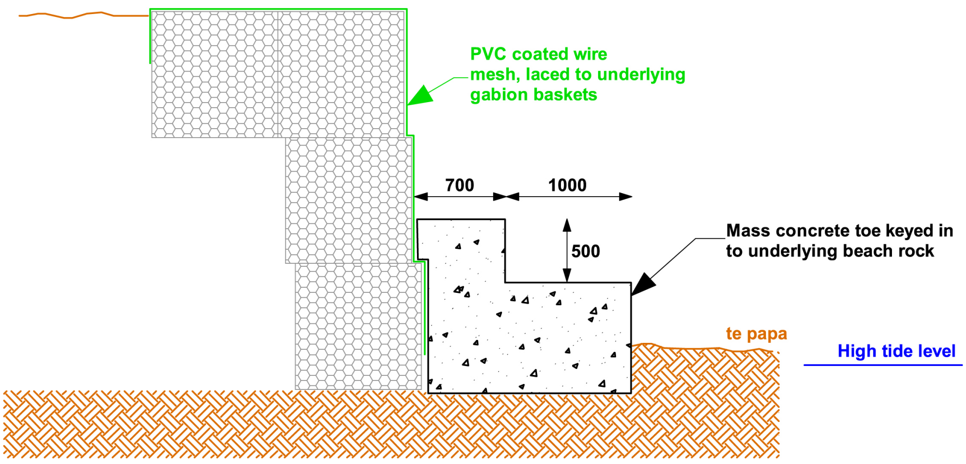


Figure 35: Repair details to Section 1 of the gabion seawall along the southern side of Fale. Dimensions in mm

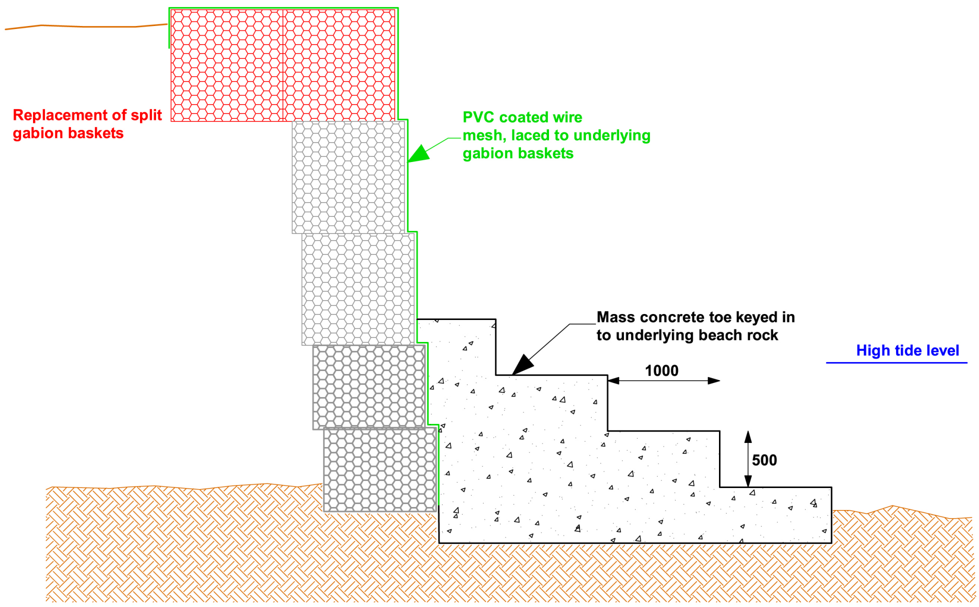


Figure 36: Repair details to Sections 2 and 6 along the southern side of Fale. Dimensions in mm.

Associated costs for maintenance activities described above are:

Gabion basket repairs	$
150 No. 2 m x 1 m x 1 m galmac and PVC coated gabion baskets @ $55 per basket (ex Apia)	8,250
20 No. roles (2 m x 50 m) of galmac and PVC coated mesh @ $135 each (ex Apia)	2,700
Lacing wire and miscellaneous	7,000
Mass concrete toe beam	
241 m^3 sand @ $120 per m^3	28,920
2892 No. bags of cement @ $14 per bag	40,488
Formwork and miscellaneous	12,000
TOTAL (materials)	**$99,358**

Labour costs associated with repair activities / construction of the mass concrete toe beam, (with the exception of the supply of sand), and fuel costs for the excavator, have not been included in the above costs.

Additional environmental impacts caused by the maintenance works are considered to be minimal as there should be sufficient coral rubble from the existing baskets to fill the replacements. If further coral rubble is required it should be sourced from the more distant sites identified in the EIA (such as *Ahaga Loa* area along the northwestern rim of the atoll), (McLean, 1993) and should be flat and slabby rather than angular or rounded. Live *porites* coral taken from the *akau* within the lagoon (as has been used to fill gabions at some locations on Fakaofo) should not be used.

The gabion baskets and mesh proposed are more durable and rust resistant than the original zinc coated wire used gabion baskets. With the maintenance suggested it is anticipated that the structure would continue to provide a similar level of protection for between another five to fifteen years, the lifespan depending largely on the frequency and timing of cyclone events over the coming years and on ensuring periodic maintenance to repair split mesh is carried out in the future. However, the inclusion of the larger sections of mass concrete toe will last much longer and along these sections provide the foundation for replacement defences for the existing gabion structures.

Administration Building (lagoonside)

The new Administration building is located on the south east corner of Fale. The building is fronted by a gabion seawall (defence Section 8), that has been well constructed and is reasonable condition apart from some gabion damage at the southern end. However, problems with undermining of the toe of the gabion wall, and tilting of the defence, possibly due to the proximity of the Administration building, has seen a number of attempts being made to stabilise the toe with concrete, none of which have been successful.

Given the importance of this building, it is suggested that repair and upgrading of the gabion wall, in a similar manner to that proposed for the ocean side defences above, is carried out. This would involve:

- Replacing the broken gabion baskets.
- Covering of the entire structure with continuous sheets of PVC and zinc coated wire mesh, contoured and laced to the baskets underneath (Figure 38).
- Construct a mass concrete toe along the lagoon facing sections of gabion wall similar in form to that suggested above (Figure 37). It is suggested that the top of the concrete toe should be above the level of the high water mark, approximately the base of the top gabion layer. Again the concrete toe should be keyed in to the underlying bedrock.

Again the construction of the mass concrete toe would form the basis of an upgraded wall when the existing gabions reach the end of their serviceable life.

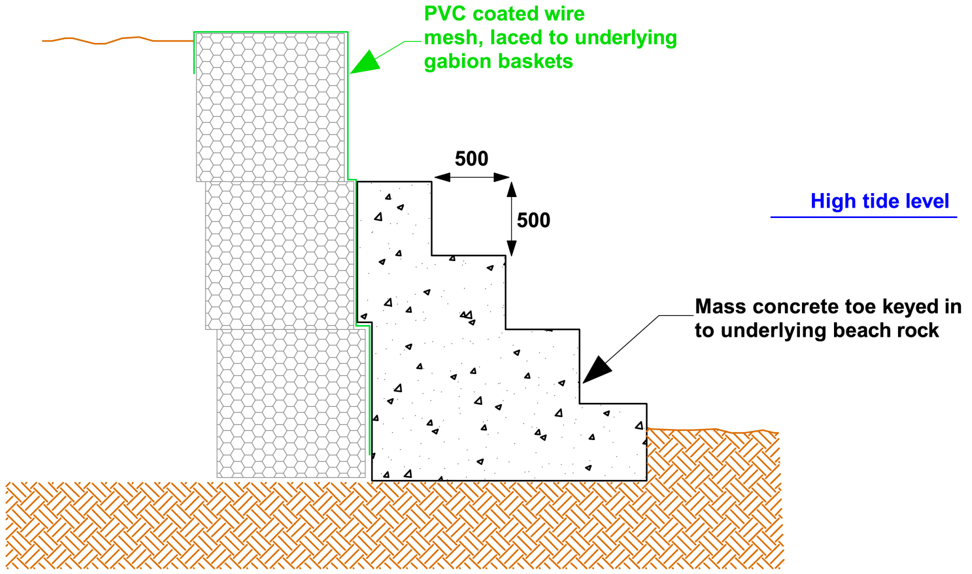


Figure 37: Repair and upgrade details to the section of gabion seawall fronting the Administration Building. Dimensions in mm.

Associated costs for maintenance activities described above are:

Gabion basket repairs	$
20 No. 2 m x 1 m x 1 m galmac and PVC coated gabion baskets @ $55 per basket (ex Apia)	1,100
6 No. roles (2 m x 50 m) of galmac and PVC coated mesh @ $135 each (ex Apia)	810
Lacing wire and miscellaneous	1000
Mass concrete toe beam (21 m)	
55 m^3 sand @ $120 per m^3	6,600
660 No. bags of cement @ $14 per bag	9,240
Formwork and miscellaneous	3,000
TOTAL (materials)	**$21,750**

Labour costs associated with repair activities / construction of the mass concrete toe beam, (with the exception of the supply of sand), and fuel costs for the excavator, have not been included in the above costs.

9.1.2 Priority 2: Initiation and ongoing management of the natural coastal defences on Fenaufala (Recommendations 1 to 4)

On Fenaufala, the careful management of the natural coastal environment, and the resources found there, along with effective land management planning, are the most important and effective elements of a coastal defense policy for the motu. Key to the long term reduction in cyclone-induced inundation risk is the need to ensure that human interference with the functioning of the natural coastal defences is reduced with a long-term programme of aiding the repair of past impacts initiated.

It is suggested that funding be provided to support community awareness activities associated with the development of village rules to address detrimental issues such as sand mining, vegetation clearing and land reclamation or seawall construction of Fenuafala (Recommendations 1, 2 & 4). It is also suggested that assistance (seed funding) be provided in the setting up of a community programme for repairing the natural coastal defences through a rolling program of replanting natural shoreline vegetation (Recommendation 3) as outlined in Section 5.2 with a focus on the lagoon shoreline of Fenuafala shown below.

Figure 38: Suggested priority area for community replanting initiatives on Fenuafala.

Recommendation	Description	$
1 & 2	Assistance and materials for development of awareness programme for school and community use.	$2,500
3	Hand tools (wheel barrows, spades, gloves) for community replanting programme	$1,000
3	Fertiliser	$1,000
	TOTAL	**$4,500**

9.1.3 Other potential priorities

There are a number of other priority areas that require consideration by the decision-makers on Fakaofo. Given the financial requirements detailed above, there is unlikely to be any significant additional funding for further work in Fakaofo under the current programme. However, one of the most pressing is the relocation of the bulk storage shed closest to the boat landing. This is on low-lying land and sustained considerable structural and content damage during Cyclone Percy.

Given the scarcity of land on Fale relocating this building may not be an easy task. A possible relocation site is close to the present meeting house. An assessment will need to be carried out as to how much of the existing building could be re-used, e.g., complete structure, or recycled, e.g., the broken up foundation of the existing building used as foundation fill for the new one. The aim should be to raise the floor level of the building above that of the surrounding land, although it is appreciated that this would be expensive for such a large building. An alternative may be to construct flood resistant walls (up to 1 m high) all around the structure with a temporary flood barrier at the entrance. Once relocated, it is suggested that coastal vegetation be established in and around where the bulk storage shed was located.

Relocating or re-positioning this building, and a number of critical pieces of infrastructure currently located in high risk areas will be a fundamental component of future risk reduction activities on Fakaofo.

9.1.4 Linkages to other UNDP programmes

Two other relevant UNDP programmes are currently being implemented in Tokelau, the Strengthening Disaster Management and Preparedness project (SDMP), and the Tokelau Integrated Management Project (TIEMPS). The risk management objectives suggested in this report are of direct relevance to the aims and objectives of these two programmes.

Table 4 summarises the recommendations detailed above of direct relevance to the two programmes and identifies areas, mainly related to awareness and capacity building activities which could be linked.

9.2 Future implementation

This study has attempted to develop a pragmatic range of coastal hazard risk reduction measures to reduce the impacts of cyclone related inundation and erosion and longer term impacts associated with climate variability and change.

The series of recommendations outlined in the sections above are not intended to be a “quick fix” but rather a long term and sustained approach to reducing the risks to people, property and infrastructure from cyclone-related inundation and erosion, long term coastal evolution of the motu, and any exacerbation of these impacts caused by global climate change. It is based on the growing evidence from around the Pacific region that integrating risk management of natural hazards into individual / community / national decision-making is a far more cost-effective strategy than a “wait and see” approach to managing both episodic disasters such as cyclones or longer term issues such as sea-level rise.

Table 4: Summary of linkages between the recommendations in this report and the Strengthening Disaster Management and Tokelau Integrated Environmental Management programmes.

Recommendation	SDMP	TIEMPS	Details
1	●	●	• Public awareness activities
2	●	●	• Public awareness activities
3		●	• Public awareness activities
4			
5			
6		●	• Incorporation of recommendations within Environment Policy and Management Plan development & associated public awareness and capacity building activities
7		●	
8		●	
9		●	
10		●	
11		●	
12		●	
13		●	
14		●	
15		●	
16			
17	●	●	• Public Awareness activities
Seawall strategy	●		• Public awareness activities

The approach has attempted to complement and contribute to the suggested approaches to risk management of natural hazards (RMNH) in the Pacific region outlined in the forthcoming World Bank policy note *Not if but when: adapting to natural hazards in the Pacific Island region* (Bettencourt et al. 2006). Specifically, the recommendations involve actions at individual, community and national levels and associated coordination and interaction between these activities. They include actions that are highly visible (such as seawall construction) as well as actions that encourage changing behaviours. As far as possible a "no regrets" approach has been adopted in the development of the recommendations, the aim of which is to ensure that the communities of Tokelau will still be able to consider a range of risk reduction options in the future rather than being constrained to a narrow risk management approach (for example Fale on Fakaofo is now in the situation where future risk management options are now locked in and very limited).

Whilst many of the risk reduction activities will be conducted at atoll level, there is a need for coordination at national level:

- To mainstream these risk management measures into national economic and social planning, budgeting and decision-making processes. Regional organisations such as SOPAC and tools such as the Comprehensive Hazard and Risk Management (CHARM) program may have a role to play.

- To provide support and guidance to the three atolls to continue to progress implementation of the recommendations.

- To provide coordination with donor and support agencies, such as the UNDP, New Zealand, SPREP, SOPAC and potential other sources of support.

- Encouraging donors to assist and support pro-active and long-term risk management activities rather than focus on episodic disaster recovery which needs to be fundamental aim of the Tokelau Administration.

How this is best achieved (e.g., whether such responsibility lies within one unit, e.g., the Environment Unit, or within the whole of Government) will need to be determined by the Tokelauan decision-makers.

To underpin all future risk management activities in Tokelau is a need for a sustained program of public awareness activities, and capacity building at both community and national levels to support a proactive approach to reducing coastal hazard risk. Specifically this requires the development of support mechanisms within the National Government agencies to better empower each of the three Tokelau communities to proactively manage natural hazard risks, to help identify and provide the resources needed to do so, and to move from intentions (suggested in this report) to actions. To begin with there is a need to disseminate, and discuss at community levels, the findings of the recommendations contained within this report, but in the longer term will need to include:

- Targeted information on hazard occurrence, climate variability and change for a range of audiences, e.g., Government policy and decision makers, community leaders and members, school children.

- Fostering of action plans in each community, based on the general recommendations and timelines suggested in this report, but with specific target actions and timeframes, and identification of who will do it.

- Training for national and community leaders in developing community approaches to reducing natural hazard risks. Whilst formal mechanisms such as on-island training courses will be integral there again needs to be a longer term focus with activities such as mentoring for technical support being introduced, and an emphasis on approaches that can be repeated and sustained.

9.3 Monitoring how risk changes

The measures outlined above are intended to provide some ideas and suggestions for consideration by the *Taupulega* and communities of Tokelau to help reduce risks due to cyclone storm surge and other coastal related hazards in both the short and longer term. Such risks to the community in Fakaofo will change with time. Some activities or decisions will increase such risks, other activities will reduce them. An important aspect to help inform decision-making is to monitor and assess how such risks are changing over time and whether the relevant decisions that have previously been made have been effective in helping reduce coastal hazard related risks.

Outlined below is an initial attempt at developing a set of pragmatic quantifiable measures that could be used to assess how the risks associated with cyclone storm surge inundation and other coastal hazards change over time. It is by no means a complete list and may well require further refinement in the future. By carrying out an assessment of the relevant factors that will increase or decrease risk on say an annual basis, the progress that Fakaofo makes in reducing their risks to coastal hazards can be monitored (or conversely increase the risk).

No	Increasing risk	Present	Decreasing risk
1	Sand / coral rubble removed from beach or reef flat around Fale or Fenuafala within last 6 months	Yes	No sand / coral rubble removed from beach or reef flat around Fale or Fenuafala within last 6 months
2	Vegetation cleared within 30 m of the vegetation line on Fenuafala within last 6 months	Yes	No vegetation cleared within 30 m of the vegetation line of Fenuafala within last 6 months
3	Replanting of natural vegetation along the village (lagoon) coast of Fenuafala within the last year	No	No replanting of natural vegetation along the village (lagoon) coast of Fenuafala within the last year
4	Reclamation activities or seawall structures built on Fenuafala	No	No reclamation activities or seawall structures built on Fenuafala.
5	Further land reclamation activities conducted on Fale in last year	Yes	No further land reclamation activities conducted on Fale
6	New housing, community buildings or infrastructure built within high hazard (red) zone on Fenuafala	??	No new housing, community buildings or infrastructure built within high hazard (red) zone on Fenuafala
7	New community buildings, infrastructure or property built in high hazard (red) zone on Fale	0	No new community buildings, infrastructure or property built in high hazard (red) zone on Fale
8	Bulk storage sheds in high risk zone	2	Bulk storage sheds moved out of the high risk zone
9	No planning commenced for the relocation of the hospital buildings on Fenuafala out of the high risk zone	No	Planning commenced for the relocation of the hospital buildings on Fenuafala out of the high risk zone
10	No planning commenced for the relocation of the school buildings on Fenuafala out of the high risk zone	No	Planning commenced for the relocation of the school buildings on Fenuafala out of the high risk zone
11	No environmental planning awareness and capacity building activities carried out within the last year	No	Environmental planning awareness and capacity building activities carried out within the last year
12	Consideration and development of planning mechanisms to aid individuals to reduce their own risk levels	No	No mechanisms to aid individuals to reduce their own risk levels
13	More houses with floor levels less than 0.5 m above land level	19	Less houses with floor levels less than 0.5 m above land level
14	No Housing Grant awards over the last year to families with existing houses with a floor level less than 0.5 m	?	Housing Grant awards over the last year to families with existing houses with a floor level less than 0.5 m
15	Guidelines for integrating coastal hazard risk reduction measures are not developed and implemented within the Housing Grant Scheme	No	Guidelines for integrating coastal hazard risk reduction measures are developed and implemented within the Housing Grant Scheme
16	No inspection and repair of damaged seawall sections carried out in last year	No	Inspection and repair of damaged seawall sections carried out in last year
17	No progress in implementing seawall upgrade strategy on Fale within last year	No	Progress in implementing seawall upgrade strategy on Fale within last year

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