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

# Nukunonu

**NIWA Client Report: HAM2006-078**
**June 2006**

**NIWA Project: UNS05201**

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*Prepared for*

United Nations Development Programme

NIWA Client Report: HAM2006-078
June 2006

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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 Nukunonu the storm surge and large waves resulted in overwashing of many parts of the motu. Inundation was also an issue on parts of Atafu and Fakaofo.

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 cyclonic 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 Tokelauan administration, and within this context of this report for the decision-makers on Nukunonu, 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 Nukunonu 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 Nukunonu and Motuhaga motus, 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 Nukunonu) 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 Nukunonu, 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 Nukunonu, (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 urgent maintenance of the existing gabion seawall and upgrading the protection of the bridge abutments linking Nukunonu with Motuhaga.

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

3. Contributing funding to assist with the relocation of the main school building.

The series of recommendations outlined in this report are not intended to be a "quick fix" 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 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 (e.g., the situation Fale is in where future risk management options are now 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.
- 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 such as whether responsibility lies within one unit, such as 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 three atolls of Tokelau (Figure 1). The cyclone reached a 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 km/hr at 03:00 NZST on the 27 February). The cyclone intensified further as it past through the northern Cook Islands with sustained winds measuring from 178 to 249 km/hr. The cyclone caused widespread damage, particularly on Fakaofo and Nukunonu. On Nukunonu the storm surge and large waves resulted in overwashing of many parts of the two inhabited motu[1] (Nukunonu and Motuhaga). Inundation was also an issue on parts of Atafu and Fakaofo

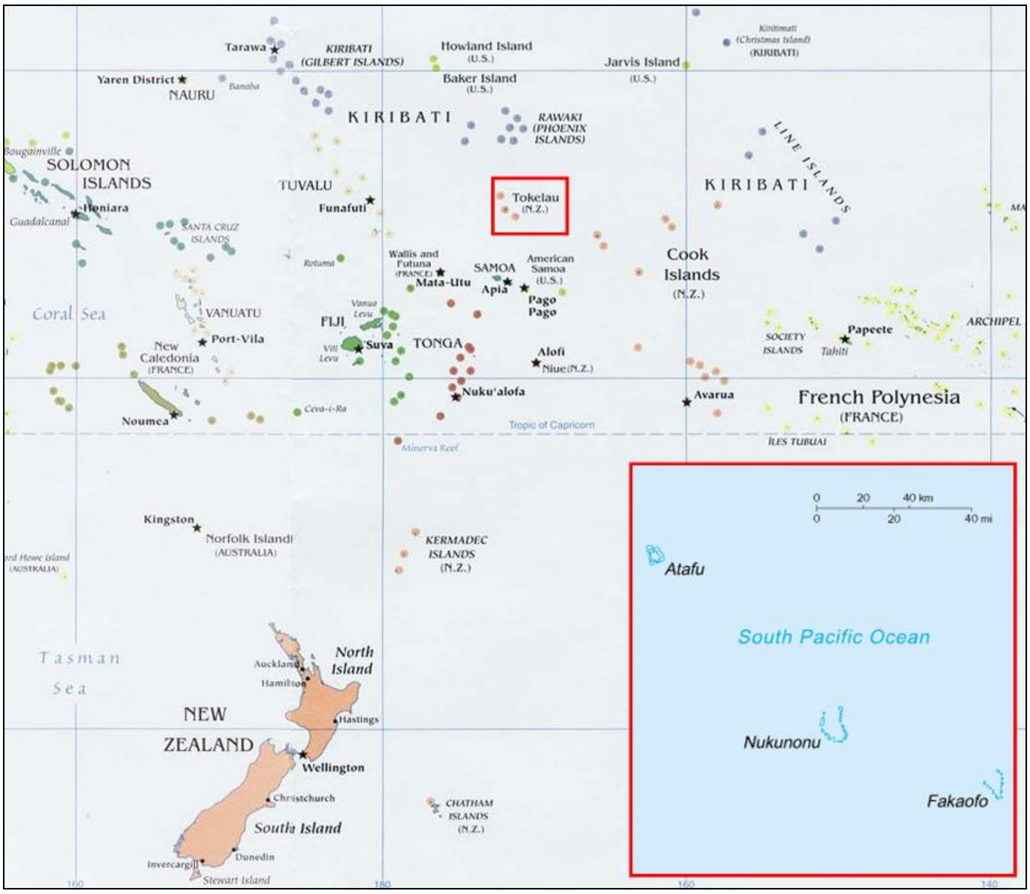


**Figure 1:** Location of the three atolls of Tokelau.

[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 <u>range</u> 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 Nukunonu (one of three, the other two covering Fakaofo 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 crest…..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."*

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, 275 m of gabion seawall had been constructed, or was in the process of being constructed, at four locations on Nukunonu, one on the ocean side at the southern end of Nukunonu towards the bridge, and at three locations on the lagoonside. An assessment by Maccaferri, commissioned on behalf of the UNDP and Office of Tokelau Affairs (OTA), (Brockliss, 2002) identified a further 1060 m of gabion wall was required, including continuation of the seawall north to the school compound with an access gap at the boat channel on the ocean side, 200 m at the southern end of Motuhaga around the hospital and a total of 500 m in length on the lagoon side. This report also raised concerns (noted in McLean, 1993) that the design recommendations had not been followed with the oceanside walls being built some 4 to 7 m further seawards than was recommended, with the private seawalls on the lagoonside some 12 m seawards in an endeavour to claim land. This issue has had an 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.

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 Nukunonu has continued.

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, 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 Nukunonu;

- 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 Nukunonu;

- 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 Nukunonu

## 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 these naturally occurring changes. It is often human impacts or interventions altering these natural processes that can cause or exacerbate both short and longer-term environmental problems.

Hence a critical issue in developing a long-term management approach to reducing the risks of coastal hazards to people on Nukunonu is an appreciation of the natural physical processes that are causing changes at an atoll, motu and localised scales. Whilst it is appreciated that little geological or physical process studies have been conducted on any of the atolls of Tokelau fundamental physical 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 Atafu

*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 of Nukunonu and Motuhaga 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 to the north and south and along the western coastline of Nukunonu and Motuhaga motus. The formation of the motu on top of these platforms 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 - 200 years ago). The *te papa* plays a vital role in "anchoring" the motu helping reduce magnitude of shoreline change from either episodic storm / cyclone events or longer-term processes. Without it, both motu would be very different, if present at all.

*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 Nukunonu 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 such as sand mining.

This fresh supply of sand and coral rubble are typically 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). However, around Nukunonu and Motuhaga motu, such accumulations are not as apparent in the aftermath of a cyclone event (which in part is due to their location on a long, straight section of atoll) as on Atafu or Fenuafala of Fakaofo. Despite this, cyclone events still have an important positive role to play in maintaining the dynamic balance of motu morphology.

On Tokelau the build-up of new land tends to occur at the southern end of the motu (evidence of which can be seen in the reduction in vegetation elevation towards the southern end of Motuhaga) and to a small extent in front of the gabion seawall at the southern end of Nukunonu. However, the rate of accumulation is much slower than has occurred at the southern end of Atafu or Fenuafala on Fakaofo. As the southern 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 vulnerable to overwashing and inundation. It is also the part of the island where the largest changes, in terms of the position of the shoreline, will occur for example during storm and cyclone events.

McLean (1993) also suggested that Nukunonu may have previously consisted of three or four islets, separated by channels similar to the one between Nukunonu and Motuhaga. These channels have subsequently been infilled either during cyclone events or due to longshore transport of beach material. The areas where such channel infilling has occurred may also be slightly lower in elevation and may be a factor in why some areas are more prone to overwashing during cyclone events.

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

When water overtops and overwashes from 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 beach crest on the ocean side of Nukunonu is much higher than the lagoon side.

Over time this can result in significant increases in the elevation of the motu. For example, archaeological surveys on the other Tokelau atolls (Atafu and Fakaofo), (Best, 1988) found evidence of these communities 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".*

A similar build up of land levels will have occurred on Nukunonu over this period and 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. Sea-level rise will cause physical changes in island shorelines but this does not always mean a loss of land. On a narrow motu, such as occurs on Nukunonu, cyclone events will wash sediment from the ocean side over the motu to the lagoon side raising land levels and causing the motu to slowly migrate, or rollover, towards the lagoon as it attempts to reach an equilibrium state with changes to coastal processes over the reef caused by the increase in sea level (Kench & Cowell, 2001). This is shown conceptually in Figure 2.

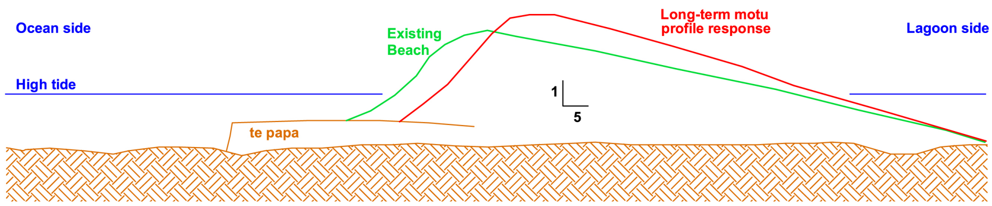


**Figure 2:** Conceptual model showing how a narrow motu such as Nukunonu or Motuhaga adjusts to cyclone events and to increasing sea levels.

*4. Beaches do not stay the same shape*

The beaches along the ocean side of Nukunonu changes 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 recover after the cyclone but such recovery is a much slower process.

The large waves that occur during a cyclone tends to erode the finer sand sized beach sediment from the beach and move it seawards over the reef flat or along the shoreline, to leave the larger coral rubble (essentially increasing the natural armouring on the beach). The changes to the shape of the beach will depend on the interaction between the amount and size of the coral rubble on the beach and the particular wave and water level conditions.

Where there is a lot of coral rubble (or smaller waves / lower water level) a storm berm will tend to build up with the upper part of the beach becoming steeper (green profile in Figure 3). An example of this is the beach on the ocean side of Fenuafala on Fakaofo (Figure 4; left). Where there is less large coral rubble, i.e., the beach has more sand or small coral rubble (or where people have removed the larger coral rubble), the beach crest will tend to move landward and the beach slope becoming more shallow (red profile in Figure 3). An example is the ocean beach along much of the Nukunonu frontage, (Figure 4; right) which is dominated by sand and smaller sized coral rubble possibly due to limited supply of larger material from the reef and also potentially long term removal for housing foundations and other uses. Such a situation makes wave overtopping and overwashing more likely to occur.

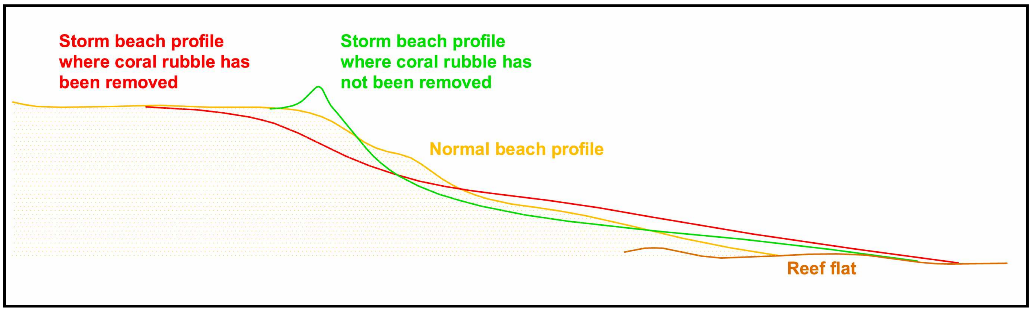


**Figure 3:** Beach profile change caused by large waves and the impact of removing coral rubble from the beach.

**Figure 4:** Storm ridge built up on the ocean side on the motu of Fenuafala (Fakaofo) where there is a healthy coral rubble beach with little overwashing occurring during cyclone Percy (left), and the beach at the northern end of Nukunonu (right) which is composed of smaller material which results in a flatter beach and a greater likelihood of overwashing during cyclone events.

*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 and building inappropriate seawalls that block sediment movement, normally leads to increased coastal erosion problems or loss of intertidal beach.

On the ocean side of Nukunonu and Motuhaga sediment tends to be moved south along the coast evident by the slow build-up at the southern end of Motuhaga, and a very small build-up in front of the gabion wall over the last 15 years at the southern end of Nukunonu. However, these rates of longshore transport and build up are very small and movement is most likely to occur just during storm or cyclone conditions. Beach sediment is also transported from ocean to lagoon side through the channel between Nukunonu and Motuhaga, typically during cyclone events, (Figure 5).

Sand that is moved around the southern end of the Motuhaga will tend to be deposited on the lagoon side and will either be transported into the lagoon or northwards along the lagoon shore due to the prevailing winds and hence waves within the lagoon. The effect of this can be seen mid way along the lagoon shore of Motuhaga (Figure 5) where a small section of reclamation/seawall has been built using coral rubble. This has resulted in the blocking of the northward movement of beach sediment causing a build up at the southern side (Figure 6; left) but accelerated "downdrift" erosion immediately to the north (Figure 6; right) and is shown conceptually in Figure 7. Beach sediments will also be moved in a net northward direction along the southern part of the lagoon coast on Nukunonu motu but the rate will be low given the amount of human modification on this shore. North of the Luana Liki Hotel the shelter provided by *Akau Loa* from waves from the east through south will result in a net southerly movement of beach sediment along the central part of the lagoon shore on Nukunonu motu (Figure 5).


**Figure 5:** Dominant directions of sediment movement along the coastline of Nukunonu and Motuhaga (adapted from McLean, 1993).

**Figure 6:** Build up of sand on the beach to the south of the seawall/reclamation mid-way along the lagoon shore of Motuhaga (left) and associated increase in erosion to the immediate north (right).

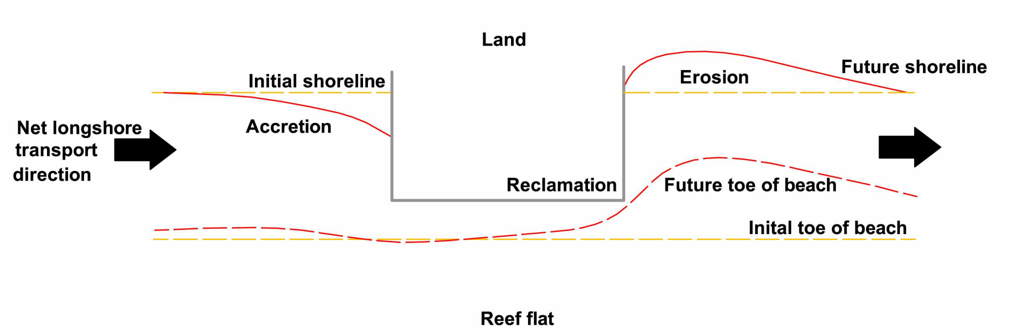


**Figure 7:** Impacts of reclamation or seawall construction on beach erosion on the lagoon side of Motuhaga

### 6 *Natural vegetation on the coastline traps sediment and helps reduce 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 or overwashing the entire motu.

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., the school areas at Nukunonu and around the area of the boat channel, Figure 8. This is a pattern that has been evident when overwashing has occurred during cyclones to have affected the Tokelau atolls over the last century (e.g., the reports by Bakx, 1987 and Richards, 1990, 1991).

**Figure 8:** Overwashing of Nukunonu motu at the location of the school (left) and at the location of the boat channel (right) was most severe during Cyclone Percy and most previous cyclones, exacerbated by the lack of vegetation.

# 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 Nukunonu, and the risks to people, property and infrastructure. It provides a baseline for developing the future coastal management 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 Nukunonu by the project team.

## 3.2 Natural coastal defences

The outer sections of the reef on Nukunonu are likely to be in a relatively healthy state in terms of the protection it provides to the shoreline, showing a well developed spur and groove zone. It is known that natural events have caused short and longer term damage in the past due to cyclone events (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 main area on the outer reef, where human impacts have caused a detrimental impact is at the boat channel. Figure 9 shows the impact of the channel on the pattern of waves translating over the reef flat and the effect this has on the shape of the coastline opposite the reef channel. The plan shape of the raised beach rock (*te papa*) along this section of coast suggests that there is likely to have been some form of natural channel on the outer part of the reef prior to the creation of the man-made one. However, the creation of the boat channel will have further influenced the way waves translate over the reef flat resulting in the indented shape of the coastline at this location.

The main problem with the boat channel is that the landward end has been built too close to the beach (see Ramsay, 2005c). Wave-induced currents over the reef flat result in beach sediments being eroded and transported seaward out through the channel. This effect increases as waves get larger. During cyclone conditions significant amounts of beach sediment can be lost either into the channel, or transported down the channel and lost off the seaward edge of the reef. Guidance to mitigate such impacts are summarised in Ramsay (2005c).

**Figure 9:** The reef channel at Nukunonu provides an example of the influence of waves translating over the reef flat and the resulting effect on the shape of the coastline.

Coral rubble removal from the beach and reef flat for construction projects has been ongoing for many years. Traditionally this will have been conducted from the closest beach and reef areas to the village (i.e., the shoreline in front of the village). The impacts from past sand and coral rubble removal has increased the susceptibility of the ocean beach fronting the village to cutback of the beach crest and overwashing during cyclone events. However, 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 collected from a “sacrificial” areas elsewhere on the atoll. For the gabion construction McLean (1993) noted that rubble was collected from the *Te Kama* to *Te Puka* area which is four to five kilometres to the northwest of the village.

Unlike the other two atolls, where small-scale sand mining and coral rubble removal from the beach is still occurring and observed during the visit, there was no evidence during the walkover of such activity occurring and no mention made of it being an issue.

Also contributing to the reduced effectiveness of this section of natural defence has been the removal of the natural vegetation, particularly the clearing of low bush and undergrowth. The lack of vegetation behind the beach around the area landward of the boat channel, and at the school playing fields directly contributed to the severity of the impacts caused due to waves overwashing the motu. As on the other atolls, the most severe inundation during Cyclone Percy occurred where such vegetation had been removed.

Little of the lagoon shore fronting the village on Nukunonu motu is in a natural state with sections of reclamation and seawalls constructed along significant sections (discussed in the next section). Less reclamation and seawall construction has occurred along the Motuhaga lagoon frontage. During the visit, sections of natural beach on the lagoon shore, particularly on Motuhaga, had recently built out slightly due to sand and small coral rubble that had been deposited at the southern end of the motu during Cyclone Percy being moved northwards along the lagoon shore due to the prevailing wind, and hence wave conditions within the lagoon.

## 3.3 Built coastal defences (seawalls)

Figure 10 summarises the extent of built coastal defence structures around both Nukunonu and Motuhaga. As on the other two atolls, coastal defences tend to be thought of as either a community asset or a private structure. The main sections of community defence are the gabion walls on the ocean side at the southern end of Nukunonu, and the wall around the meeting fale on the lagoon side. Construction of these defences is carried out as a community project. Private structures are built by property owners typically to reclaim land predominantly on the lagoon side.

### 3.3.1 Community seawall sections

Approximately 320 m of gabions have been constructed at the southern end of Nukunonu motu, extending from approximately 100 m south of the boat channel to the lagoon side of the channel at the southern end of Nukunonu motu. The potential long-term effectiveness of this section of wall has been reduced by changes to the recommended design by constructing the seawall between 4 to 7 m too far down the beach making it more prone to damage. This is particularly evident along approximately the northernmost 35 m of the defence (Figure 11; left) and at other localized other spots (e.g., immediately east of the bridge, Figure 11; right).

Build up of beach material along the ocean side at the southern end of Nukunonu motu has resulted in a thin beach forming at the toe of the structure (Figure 12; left), helping to protect it during more normal occurring wave conditions with mainly the top 3 to 4 gabions exposed.

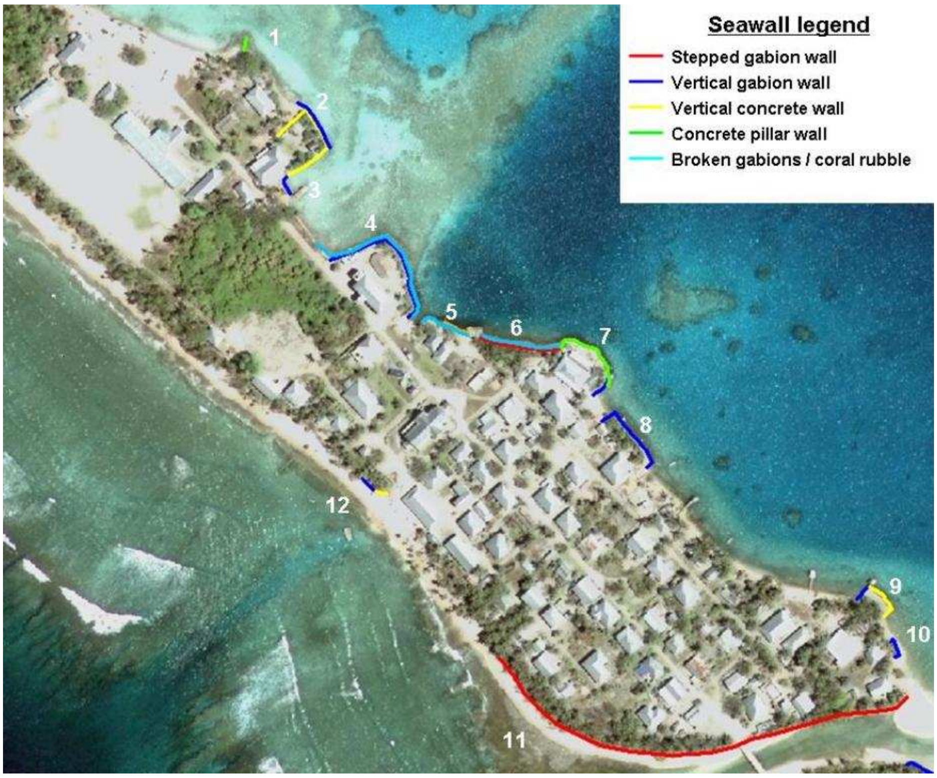



**Figure 10:** Summary of the location and type of seawalls constructed around Nukunonu motu (top) and Motuhaga motu (bottom).

**Figure 11:** Badly damaged section of the gabion wall at the northern end of the main structure (left) and to the immediate lagoon side of the bridge (right).

Whilst the tops of many of the gabion baskets have split, the shape of much of the structure remains (Figure 12, left), with much of the coral fill still in situ, along much of the length, with the exception of the 30 m section at the northern (oceanside) end. However, the structure will quickly deteriorate if no maintenance activities are carried out but can still perform a useful role over the short to medium term with appropriate maintenance.

On the lagoon side of the bridge, the gabions are still in a reasonable condition with the exception of a 20 m length immediately adjacent to the bridge where there is damage to the tops of a high percentage of the top three layers of gabions. A 75 m section also suffers from being undermined (Figure 12, right). The gabions are still in a reasonable condition, and if repairs to the foundation were made quickly could prevent further, more serious, damage to the defence at this section

**Figure 12:** Section of gabion wall with beach covering the bottom half of the structure along the ocean side showing the damaged tops to the gabions baskets (left) and undermining of the gabion revetment along the lagoon side of the channel (right).

A short length of vertical gabion wall has also been built on the ocean side between the northern end of the boat channel and the old power generation building (Figure 13; left). The southern end of the wall has been faced with cement to produce a smooth vertical wall. The wall has been built part way down the active beach and appears to have subsided due to lowering of the beach along the central section. This may well be due to the influence of the wall on the beach at this location and not only increases the risk of damage to the wall, but also increases the potential of overwashing of the motu at this location. The location of the wall and construction (vertical and with a concrete face) is far from ideal for the ocean side of the motu.

**Figure 13:** Gabion wall to the immediate north of the boat channel part of which has been faced with cement (left) and the gabion wall, with coral rubble toe protection around the area reclaimed for the meeting fale (right).

On the lagoon side, the new meeting Fale and Faiefa building has been built on an area of reclaimed land bounded by a vertical gabion wall with large coral rubble placed to provide toe protection to the wall (Figure 13; right). Despite being constructed vertically, the gabions are in good condition with the wall well built using a double layer of gabion baskets. The toe protection provides additional support reducing the potential for wave damage. It is a reasonable example of an appropriate and well built wall for this particular location.

### 3.3.2 Private seawall sections

Between the Luana Liki Hotel and the southern end of Nukunonu motu much of the coastline has some form of coastal defence structure. Typically these have involved the use of gabions or are mass concrete or concrete faced coral rubble using fuel or water drums to provide the formwork. The standard of private defences on Nukunonu are generally much less well built than occurs on Atafu or Fakaofo which may be a reflection of the more exposed nature of the lagoon coastline on Nukunonu and hence larger, more damaging wave conditions.

Around the hotel, a vertical concrete (sections of mass concrete and concrete faced coral rubble) retaining wall provides the boundary for the reclamation upon which the hotel is located. On the lagoon face two layers of gabions provide toe protection to the wall and appear to be well constructed and in a relatively good condition (Figure 14; left). The walls along the flanks of the reclamation are less well constructed but are not as exposed. Between the hotel and the reclamation on which the new meeting Fale and Faiefa building is located, there is a short stretch of gabion wall at the northern end and a large pile of rubble to the south (Figure 14; right).

**Figure 14:** Gabion lower wall and concrete upper on the lagoon side of the reclamation upon which the Luana Liki Hotel is located (left) and between the hotel and the reclamation upon which the meeting fale is located (right).

Most of the sections of gabion wall between the meeting Fale and the southern end of Nukunonu motu have been poorly constructed, many in a complete state of disrepair (Figures 15 & 16). This is due to a number of reasons including:

- A relatively exposed lagoon coastline with a narrow back reef.
- Vertically stacked gabion baskets that have been used to form the boundary of a reclamation failing due to poor foundations and the structure not being adequate to act as a retaining wall (Figure 15).
- Attempts to minimise costs by putting one single line of gabions which rapidly fall apart (Figure 16, right)

- Using the gabions for mooring boats and other uses which rapidly results in the baskets bursting and corroding away (Figure 16; left). Note the corroding lower gabions have resulted in piles of coral rubble fronting the gabions higher up the beach. Whilst not intended as a coast protection structure, the coral rubble over the lower beach provides effective toe protection to the higher gabions forming a relatively effective defence.

**Figure 15:** Gabions, poorly founded and constructed, being used for reclamation (Section 8 left; section 9 right).

**Figure 16:** Gabion wall where the lower baskets have rotted away (Section 6 left), and as a single line of gabions that provides virtually no protection to the land behind and is easily damaged (right).

A number of wall sections have used fuel or water drums to form the framework to construct a vertical concrete pillar wall (Figure 17; left) or front existing gabions. Mass concrete has also been used to cover over sections of gabion wall (Figure 17; right). These tend to be more substantial structures and typically have been used to support reclamations with higher land levels. However, the difficulty of founding the structures below low tide levels has resulted in displacement of some of the concrete units.

On the lagoon side of Motuhaga, less seawall construction has occurred although this is now changing with a number of sections now appearing. This is of considerable concern as any structure seaward of the vegetation line is going to disrupt the longshore movement of beach sands along this section coast, exacerbating erosion to the north (See Figure 4). At present the main section of defence/reclamation is little more than a pile of coral rubble. A number of other short sections of gabions have been built on the lagoon side, all of limited effectiveness due to either their construction or *ad hoc* nature.

**Figure 17:** Mass concrete pillar wall section (Section 7, left), and mass concrete with gabions underneath (Section 9, right).

### 3.3.3 Boundary walls

Boundary walls located around the church and satellite installation (Figure 18) also function as a coastal defence during cyclone conditions. If access points were sealed prior to cyclone events, the walls would reduce water entering the areas around these buildings under the more commonly occurring overwashing events (although the walls would be overtopped during severe events) reducing the risks of fast flowing water and debris around these buildings (see Figure 26 taken during Cyclone Percy). However, such a measure does result in overwashing water being channelled between the walls which can lead to fast flows and scouring. Despite this it is a good example of an effective structural solution reducing the risk of certain areas being inundated with little impact on the natural coastal processes, and is appropriate for locations in the centre of the motu such as around the church.

**Figure 18:** Boundary walls around the church and satellite installation.

A similar boundary wall is found around the pig pens towards the northern end on Nukunonu motu. However, the wall is relatively low and damaged in a number of places with inundation occurring of the pens during Cyclone Percy.

### 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 Nukunonu. 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) and how exposed it is to storm-induced inundation 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 Table 1 with a spatial representation of overall community building risk, shown in Figure 19.

Given the susceptibility of the motu on Nukunonu to overwashing, a relatively high number of community buildings are located in high risk areas. The most critical are:

1. The school buildings (Figure 20; left), which although built well back from the coastline are in an area that is susceptible to complete overwashing of the motu from both ocean and lagoon side (compounded by the removal of all vegetation to create the playing field). The floor elevations are close to the surrounding land levels and as a result inundation is a significant risk. During Cylcone Percy about 40% of books were lost as well as damage to other school equipment and to the buildings themselves (Lawrence & Hill, 2005).

2. The buildings (village store, Co-op, police/transport, finance and health offices) located to the lagoon side of the church (Figure 20; right), are also located in an area where overwashing appears to occur during most cyclones with the risk of damage high due to the low floor levels of these buildings.

3. The power (generator), fuel, fisheries and bulk storage buildings (Figure 21), which are all located on or close to the beach crest at the ocean side. All of these buildings, due to their location are at high risk from being damaged in the future, particularly if vegetation fronting the buildings is lost and beach levels are reduced. The power and fisheries buildings are relatively new, have been well built with high floor levels, and likely to be less prone to damage that the fuel and bulk storage buildings.

4. The hospital is located at the southern end on Motuhaga on some of the “youngest” land. As such land elevations tend to be lower. Whilst the hospital buildings did not appear to be inundated, significant inundation occurred all around the hospital. The damage report noted that the Doctor’s house at the hospital was severely damaged which is due to both its location and construction (e.g., low floor levels).

**Figure 19:** The relative risk of inundation or damage to community buildings on Nukunonu (top) and Motuhaga (bottom) due to overwashing waves. Red = high risk, Orange = medium risk, blue = low risk.

**Table 1:** Summary of relative storm inundation risk to government and community buildings on Nukunonu and Motuhaga.

| Infrastructure | Location risk rating | Building risk rating | Overall risk associated with storm inundation |
|---|---|---|---|
| School | High | High | **High risk:** Located in an area where significant overwashing occurs during cyclone events, with low floor levels. Risk exacerbated by the main building blocking the overwash flow path. |
| Faiefa building | Med | Low | **Low risk:** Located outwith an area where direct overwashing occurs. Water depths will be high during cyclone event but ground floor designed as meeting rooms with little to damage. |
| Luana Liki hotel (Private) | Med | Med | **Medium risk:** Located outwith an area where direct overwashing occurs. Water depths will be high around building. Main rooms are on first floor with a games room/bar on ground floor and susceptible to inundation. |
| Meeting fale | Low | Low | **Low risk:** Located outwith an area where direct overwashing occurs. Water depths will be high during cyclone but building open resilient to damage. |
| Health office | Med | High | **Medium risk:** Located in an area where overwashing occurs during cyclone events, and relatively low floor levels |
| Finance office | Med | High | **High risk:** Located in an area where overwashing occurs during cyclone events, and very low floor levels |
| Police / transport office | Med | High | **High risk:** Located in an area where overwashing occurs during cyclone events, and very low floor levels |
| Co-op store | Med | High | **High risk:** Located in an area where overwashing occurs during cyclone events, and very low floor levels |
| Village store (storage) | Med | High | **High risk:** Located in an area where overwashing occurs during cyclone events, and very low floor levels |
| Store (private) | Med | Med | **Medium risk:** Located in an area where overwashing occurs during cyclone events, and low floor levels |
| Bulk storage (building materials) | High | High | **High risk:** Located very close to the ocean side, with low floor levels |
| Falepa (old meeting house) | High | Med | **High risk:** Located very close to the ocean side, but open sides reduce potential for damage. |
| Catholic Church | Med | Low | **Medium risk:** Located in an area where overwashing occurs during cyclone events. High floor levels and surrounded by boundary walls |

| Infrastructure | Location risk rating | Building risk rating | Overall risk associated with storm inundation |
|---|---|---|---|
| Fisheries Facility | High | Med | **High risk:** Located very close to the ocean side and prone to damage if beach levels in front of the building reduce further. Floor levels are above most likely inundation levels |
| Fuel storage | High | High | **High risk:** Located very close to the ocean side and prone to damage if beach levels in front of the building reduce further. Floor levels are very low and building at high risk of inundation |
| Generator building | High | Med | **High risk:** Located very close to the ocean side and prone to damage if beach levels in front of the building reduce further. Floor levels are above most likely inundation levels |
| Can crushing facility | Low | Med | **Low risk:** Located in the centre of the motu surrounded by a well vegetated buffer zone. |
| Women's centre | Low | Low | **Low risk:** Located in an area of lower risk of inundation, with floor levels well above likely inundation levels. |
| Hospital | High | Med | **High risk:** Located on low-lying land that will be inundated during most cyclone events. Floor elevation sufficient to prevent inundation during less severe events. |
| Doctor's house | High | High | **High risk:** Located in an area at high risk from inundation with low floor levels. |

**Figure 20:** High risk community buildings including the school buildings (left) and the village store, Co-op, police, finance and health offices (right) which are located in areas prone to overwashing and also have low floor levels.

**Figure 21:** The generator building (left) and fuel storage building (right) are located right on the crest of the beach on the ocean side making them highly susceptible to damage.

### 3.5 Housing

The damage report indicated that around 80% of the buildings on Nukunonu reported some damage with at least five severely damaged. The majority of the damage will have been related to wind effects (e.g., roofing, broken louvres etc.). However, a small number suffered erosion around their foundations and subsequent cracking of walls (Figure 22). The majority of the structural damage due to inundation was a direct result of the particular buildings being located too close to the beach.

**Figure 22:** Damage to housing located too close to the beach on the lagoon side of Nukunonu.

The building survey identified 87 primary housing units (cook houses or sleep-outs attached to the main house were not included) on Nukunonu. Of this number, seven were deserted (families moved abroad) and 14 comprising two storeys.

It was noted on all atolls that the level of damage to 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, which largely began after 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 and 24 summarise the number of houses and their approximate floor elevations (relative to the surrounding ground surface). Note this is not the total the only factor influencing inundation as absolute land level is also a factor. Compared to both Fakaofo and Atafu, there is a much greater percentage of the buildings on Nukunonu having floor levels less than 0.5 m above the surrounding ground levels and therefore more exposed to inundation.

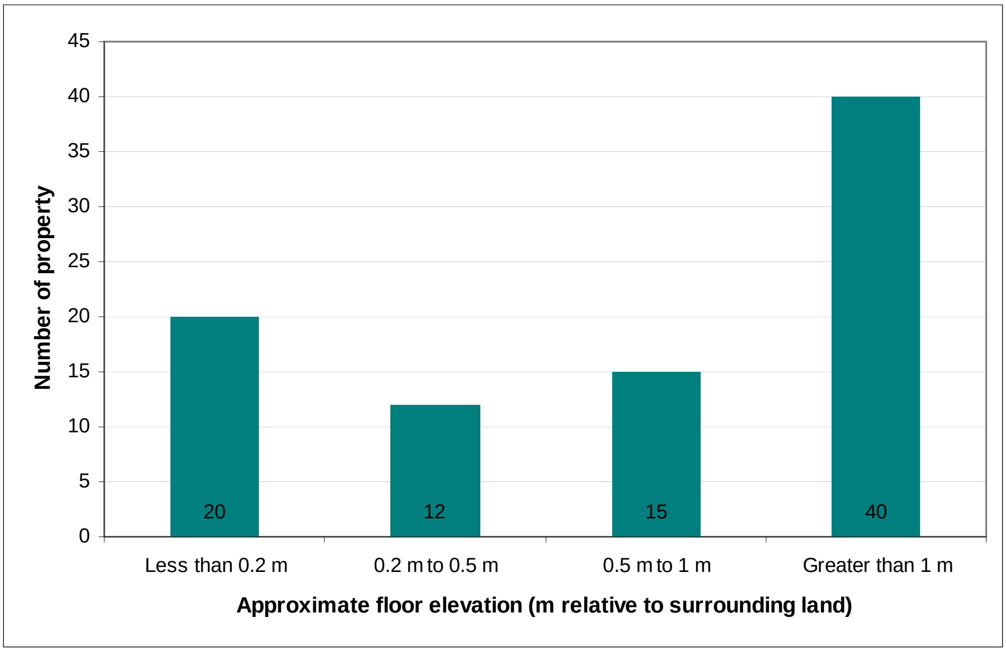


**Figure 23:** Summary of the number of houses with various relative floor levels on Nukunonu

**Figure 24:** Floor levels of all buildings relative to surrounding ground levels on Nukunonu (top) and Motuhaga (bottom). Red = < 0.2 m, Orange = 0.2 - 0.5 m, Yellow = 0.5 – 1 m, Green = >1 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 Nukunonu community, Figure 25 attempts to summarise the total extent of inundation during Cyclone Percy on Nukunonu.


**Figure 25:** Approximate areas on Nukunonu inundated during Cyclone Percy. Note inundation will not have occurred at the same time at all locations. Black arrows indicate main areas of overwashing from the ocean side. The extent of overwashing to the north of the school is uncertain.

The pattern of overwashing during Cyclone Percy appears to be similar to that experienced during other cyclone events, for example photographs in *Matagi Tokelau* (Anon, 1991) and TVNZ footage taken during a flyover by the Royal New Zealand Air Force after Cyclones Tusi in 1987, and descriptions of the extent of inundation during Cyclones Ofa and Val in 1990 and 1991 respectively.

Both the area around the school and at the boat channel appear to be highly susceptible to severe overwashing under most cyclone events. On Motuhaga the northern coastline bounding the channel and over the low-lying area at the cricket pitch is also an area that is highly exposed to inundation as is the lower-lying area at the southern end where the hospital is located. There has been some suggestions that the gabion defences at the southern end of Nukunonu have exacerbated the overwashing that occurred at the northern end of Motuhaga during cyclone Percy and may indeed have been a factor. Figures 26 to 28 show a number of images taken during Cyclone Percy.

**Figure 26:** Overwashing to the south of the church opposite the boat channel during Cyclone Percy (Photographs courtesy of http://www.mfat.govt.nz/foreign/tokelau/tokelau index.html).

**Figure 27:** Inundation damage in the school building (left) and inundation looking north (right) from the Luana Liki Hotel on the lagoon side (Photographs courtesy of http://www.mfat.govt.nz/foreign/tokelau/tokelauindex.html).

On the lagoon side, the 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 on land under most events (and potentially greater during a very severe event). The most significant depth of inundation appears to occur between the village store northwards to beyond the school. It would also appear that the area between the reclamations upon which the hotel and the meeting fale are located is an important drainage pathway for water overwashing the atoll from the lagoon side around the location of the boat channel. Reclaiming this area between the hotel and the meeting fale may impact on how water drains from the area behind the church.

**Figure 28:** Inundation from the lagoon side opposite the basketball court (right) and wave overtopping of the bridge (Photographs courtesy of http://www.mfat.govt.nz/foreign/tokelau/tokelauindex.html).

### 3.7 Post Cyclone Percy clean-up

One of the major problems during Cyclone Percy on Nukunonu was the amount of debris that was entrained in the overwashing water which substantially increased the risk of injury to people wading through the water. This issue was identified by many people during the consultations. A substantial amount of this debris at the time of the visit had still not been cleaned up (unlike Fakaofo and Atafu) and poses an additional risk to public safety if such an event were to occur in the near future. A major clean-up exercise is still required on Nukunonu to reduce the amount of potential debris and material that exacerbates risks during future cyclones. Reducing the amount of material, either lying around or unsecured that has the potential to become hazardous debris will be an ongoing task.

### 3.8 Cyclone damage estimates

No quantified estimate of direct or indirect damage has been made after Cyclone Percy. Nor has the damage been apportioned to either wind or inundation, or both. It would appear most direct losses related to:

- Structural damage to school and hospital and damage to school contents;

- Some inundation damage to the village store, Co-op, Police/Transport office, Finance and Health offices;
- The supply of provisions in the aftermath of the event;
- Labour costs associated with the clean-up;
- Damage due to inundation to a number of houses and some minor scouring of foundations;
- Damage to coastal defences;
- Damage to vegetation and crops.

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 Nukunonu community.

Damage estimates of previous cyclones, quoted in the *Tokelau Infrastructure Study* (Opus, 2001) provide loss 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 for systematically recording and quantifying damage and losses 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 Nukunonu in the future. Indeed of the three Tokelau atolls, Nukunonu, due to the narrow width of land, is the one where most damage is likely to occur (given similar cyclone conditions). 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, socio-economic 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[2] 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, and (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 Nukunonu 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 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 and is a continuous and ongoing activity integral to development decision-making at individual, village (atoll), and national levels.

[2] the ability of the natural coastline to cope with, adjust and respond to variability and extremes in climate, including potential long-term climate change

3. 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 Nukunonu

Episodic cyclone events will continue to cause damage on all of the Tokelau atolls in the future. During the discussions on Nukunonu, 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.

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 a mixture of short and long term objectives and options. As Nukunonu (and the other Tokelau atolls) have 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). There are sections of the Nukunonu coast that presently have few other options other than continue to build and rebuild seawall structures. However, in general such an approach is an expensive option, can typically only 'buy some time' (unless considerable maintenance and ongoing upgrading is conducted). Consequently seawalls 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 Nukunonu, there is always considerable pressure to reclaim land, such an activity is rarely consistent with reducing coastal hazard risk.

Options discussed and developed during the community meetings included:

- Ensuring protection of the natural coastal defences (reef, reef flat, beach and coastal margin) and identifying the underlying causes of human activities that reduce the effectiveness of these natural defences and how such impacts could be effectively reduced (Section 5);

- 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 infrastructure or other buildings from high-risk areas (Section 6);

- 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 Nukunonu) and designing and constructing buildings and infrastructure to accommodate this (Section 7);

- Protection measures, including the needs for both existing seawall structures, and requirements for future structural solutions with an emphasis on structures that: (1) enhanced the natural defences and were more sensitive to the important natural processes occurring on Nukunonu, (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 (Section 8).

In developing such an approach, the emphasis during the discussions on each island 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);

- Made most efficient use of limited local resources e.g., sand and coral rubble;

- 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 Nukunonu community. There are also suggestions on how these recommendations could be implemented, prioritised, and the timeframes for their implementation and accrual of benefits (in terms of short-term, < 5 years, medium-term, 5-10 years, and long-term, > 10 years). Potential equipment, labour and material requirements are noted 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 Nukunonu. Given that Nukunonu is generally more susceptible to inundation damage during cyclone events than the other two atolls, management of the natural coastal defences (and effective land planning, see Section 6) is even more critical as a means of reducing both future risk of damage due to cyclones and climate variability and change.

Along the ocean side of the motu, the reef, reef flat, beach and vegetated beach crest provides the natural coastal defence protecting the village. Whilst motu are "designed" to be overwashed under the most severe conditions, activities such as sand and coral rubble removal from the beach or reef flat, clearing of natural vegetation, building housing or reclaiming land close or over the beach, or building seawall structures, all act to substantially reduce the effectiveness of these natural defences in reducing the magnitude of such overwashing, to the detriment of the Nukunonu community (see Section 2).

The beach and backshore system on the lagoon side 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 their effectiveness. The Nukunonu community is already making such efforts, for example reducing the impacts caused by sand and coral removal from the beaches of the inhabited motu, with the majority of sand for community and construction projects is now sourced from a 'sacrificial' motu elsewhere on the atoll. Nukunonu was the only atoll of the three where there was no evidence of small scale sand or coral rubble removal occurring during the time of the visit. However, sourcing sand and coral rubble is a time consuming and labour intensive activity not only on Nukunonu but also on Fakaofo 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 beach sand mining impacts.

The following recommendations are made:

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

**Recommendation 2:** The clearing of natural vegetation be discouraged as far as possible over the entire motu and certainly within at least 20 m behind the vegetation line around the entire shoreline of Nukunonu and Motuhaga.

**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 ocean shore of Nukunonu, be initiated as an ongoing community project along the village frontage and at key locations on the lagoon side.

**Recommendation 4:** Any reclamation of land or the construction of seawalls <u>seaward</u> of the vegetation line around Motuhaga motu be avoided.

**Recommendation 5:** Any reclamation of land or <u>further</u> construction of new seawall structures <u>seaward</u> of the present vegetation line around Nukunonu motu be avoided (with the exception of protection to existing areas of reclamation on the lagoon side).

## 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 | | | | | | |

Implementation of *Recommendations 1 and 2* (and potentially *4 & 5*) 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 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 to reduce inundation overwash points;
- 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 should be on the area extending from the northern end of the existing gabion wall on the ocean side to north of the school, and on the lagoon side of the school (Figure 29). 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.

**Figure 29:** Suggested areas where replanting initiatives should be focused.

On Motuhaga the potential for reclamation or seawall structures built seaward of the vegetation line to exacerbate erosion is a considerable concern and needs to be avoided (*Recommendation 4*). Reducing inundation risks on Motuhaga can be more effectively managed through a combination of proactive implementation of recommendations 1 to 3, development of appropriate community land planning measures (see next section), and through building construction (Section 7) rather than structural defence measures.

On the ocean side of Nukunonu, seawall construction north of the boat channel is impacting on beach levels (*Recommendation 5*). Indeed any linear structure built along this part of the coast, seaward of the vegetation line will impact on beach processes which are important for the long term protection and development of this section of Nukunonu, and, given the types of construction material available on Nukunonu, such defences have a very short lifespan. This is discussed further in Section 8.

## 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 & 5).

- 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 & 5).

- Ongoing consideration that structural solutions such as seawalls are the only way to reduce coastal hazard risk (Recommendations 4 & 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).<br>• Ensures no exacerbation of erosion potential due to impacts of structures (Rec. 4, 5) | |
| Social | • Long term benefit to the Nukunonu 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)<br>• Compliments other risk management measures in reducing economic impacts of cyclone disasters. | • Moderate and continual labour costs, (Rec. 3). |
| Sustainability of recommendations | • Dependent on community motivation but requires little external funding, equipment or assistance for ongoing implementation, (Rec. 1,2,3,4,5). | |
| Contribution to sustainability development | • Contributes to long-term reduction of impacts on individuals, community and economy during cyclone inundation and coastal hazards.<br>• 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. It is also a vital component in avoiding or reducing future risk associated with cyclone or other long-term coastal change. This is particularly important on Nukunonu which is so susceptible to inundation and damage during cyclone events requiring considerable effort to maintain the full effectiveness of the natural coastal defences (previous section) and in effective community land planning to reduce such risk. 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 on Nukunonu and in the other Tokelau communities.

### 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 are known to experience inundation during cyclone events. From the inundation caused by Cyclone Percy, and from discussions with the community of inundation extents during previous cyclones, Figure 30 summarises for Nukunonu and Motuhaga motus, in a simple format, the main areas within the villages that can be considered high hazard zones.

These are areas that 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 - the narrow nature of the motu means that almost all areas are at some potential risk). Ensuring future buildings are located outside the areas that experience most severe overwashing will not be an easy task on Nukunonu given the lack of land and the many other social, economical and environmental factors that need to be taken in to account for effective land use management planning. However, there is scope, for example locating any new development on Motuhaga and north of the school on Nukunonu down the centreline of the motu (e.g., adjacent to the road) rather than at the coastline ensuring a well vegetated buffer zone is maintained. The recommendations below attempt to provide a framework, which in conjunction with the recommendations provided in Sections 5, 7 and 8 will over the long term help reduce inundation risks.

**Figure 30:** Summary of land areas within Nukunonu (top) and Motuhaga (bottom) at high risk from inundation. This does not imply areas not highlighted will not experience inundation. Note: areas inundated north of the school were not inspected but the same general buffer zones around both the ocean and lagoon side should be applied to any new development.

**Recommendation 6:** As far as possible no further community buildings, essential infrastructure or residential buildings be constructed in:

1. The high hazard zones on the ocean side of Nukunonu;

2. The high hazard zones on the lagoon side north of the Faiefa Building (for example north of the school any new buildings should aim to be located in a single line down the centreline of the motu);

3. The high hazard zones around Motuhaga (both ocean and lagoon sides).

**Recommendation 7:** On the lagoon side of Nukunonu motu to the south of the Faiefa Building, new or replacement community buildings or residential buildings be permitted as long as:

1. There are no other safer building locations available to the *Taupulega* or land-owner;

2. The building is located as far inland as possible;

3. Does not involve further reclamation of land;

4. The building is constructed to have elevated floor levels (at least 1 m above surrounding land levels) and foundations sufficient to withstand inundation of the surrounding land areas (see Section 7).

**Recommendation 8:** As far as possible on the lagoon side of Nukunonu motu that no further land reclamation activities are conducted south of the Luana Liki Hotel, with a future focus on improving the standard of defence protecting the existing landmass.

**Recommendation 9:** That the Nukunonu 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 any 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

Given the narrow nature of the motu on Nukunonu, almost all of the community buildings and infrastructure are at risk of damage during cyclone inundation. However, a number of these are at very high risk either due to their location and/or how they have been constructed (Table 1).

In the short term the main focus needs to be on reducing the risks to the main school building. In the medium term consideration may need to be given to relocating the power generator building, raising the floor levels of the hospital buildings (or relocating if a suitable safer site can be found), raising the floor levels of the various buildings located behind the church (e.g. Co-op, police building etc.), and in the longer term relocating the fisheries building, fuel and bulk storage sheds.

On the ocean shoreline the main areas of residential property at risk are currently located behind the gabion seawall at the southern end of Nukunonu motu which are reasonable well protected as long as the gabion wall is maintained. At greater risk are the buildings located close to the shoreline on the lagoon side at both the southern end of Nukunonu motu and to a lesser extent on Motuhaga. Foundation damage and cracking of a number of buildings occurred during Cyclone Percy (Figure 22) and 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 main school building (which runs parallel with the centreline of the motu) should be re-located on the property and incorporate a piled (or other raised) foundation to raise floor levels at least 1 m above surrounding land levels.

**Recommendation 11:** During the natural cycle of replacement/upgrading of the hospital buildings, remaining school buildings, village store, Co-op store, Police/Transport, Finance and Health offices, the floor levels of these buildings should be increased to at least 1 m (1.2 – 1.5 m for the hospital buildings) above surrounding ground levels. Consideration may also need to be given to relocating the hospital to a safer location in the longer term.

**Recommendation 12:** That planning commence (leading to a staged implementation) for the relocation (in order of priority) of the power generation plant, fuel storage shed, fisheries building, old Falepa building, and bulk storage shed back from the coastline.

**Recommendation 13:** In the short to medium term flood-proof walls (up to about 1 m in height) may need to be considered around the bulk storage shed and the ability to quickly flood proof the access points (e.g., stored sandbags) considered.

**Recommendation 14**: That flood proofing (e.g., stored sand bags or something more permanent) of the access points around the boundary walls to the church grounds and satellite area be considered to prevent water entering these areas.

**Recommendation 15:** That the Nukunonu 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 to relocate either landward within their property, or to a suitable new safer site.

## 6.2 Implementation of the recommendations

| Recommendation | Priority | Implemented over: | | | Risk reduction benefits over: | | |
|---|---|---|---|---|---|---|---|
| | | < 5 | 5 - 10 | 10+ | < 5 | 5 - 10 | 10+ |
| 6 | High | | | | | | |
| 7 | High | | | | | | |
| 8 | Med | | | | | | |
| 9 | Med | | | | | | |
| 10 | High | | | | | | |
| 11 | High | | | | | | |
| 12 | High | | | | | | |
| 13 | Med | | | | | | |
| 14 | Med | | | | | | |
| 15 | Med | | | | | | |

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 Nukunonu and Motuhaga);
- 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 12*) can be implemented directly by the *Taupulega*, through allocation within the annual budget process (or through negotiated donor support) as can flood proofing of the bulk storage shed (*Recommendation 13*) and the access points to the boundary walls around the church and satellite equipment (*Recommendation 14*).

Possibly the most pressing building to be relocated is the school building that runs parallel with the axis of the motu. This experienced considerable structural damage and damage to contents during Cyclone Percy due to inundation, with similar damage occurring during other cyclones to have affected Nukunonu. The extent of damage is largely due to two main factors:

1. the lack of vegetation in front of the school due to it being cleared to create the rugby field significantly increasing the susceptibility of

significant over washing during cyclone events (i.e., there is no vegetation to reduce the over washing flows); and

2. the very low-lying floor level of the building.

It is suggested that re-positioning the main school building should be seen as a high priority to reduce the potential for future damage which will occur every time a cyclone does impact on Nukunonu. Figure 31 summarises the suggested relocation of the building to run perpendicular to the coastline at the southern end of the rugby field. As part of the re-construction, the floor level of the school should be raised to at least 1 m above the surrounding ground level either by incorporating a water tank underneath the school, or by building the school on piles or raised concrete slab. Given the slope of the ground surface, the school may need to be built over a number of levels. The area will still overwash but hopefully the vegetated areas help reduce the damage to the playing field with the repositioned building (and contents) being much less susceptible to damage.

**Figure 31:** Suggested re-position of the main school building (red) and associated area of vegetation planting (green) to help reduce wave overwashing.

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.

### 6.3 Main constraints to implementation

- Limited land out with private ownership for infrastructure development (Recommendations 6 to 11).

- High density of development at the southern end of Nukunonu, and desire to reclaim land on the lagoon side of Motuhaga, increasing pressure for continued reclamation and development in high hazard zones (Recommendations 6 to 8).

- 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 to 10).

- Potential social (and potentially financial) impacts relating to relocation recommendations (Recommendations 6 to 10).

- 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 to 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 Nukunonu (Rec. 6 to 15). | |
| Social | • Long term benefit to the Nukunonu community in assisting the reduction of risks associated with cyclone inundation to key infrastructure, buildings and housing.<br>• 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 a key risk management tool on Nukunonu with 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.<br>• Potential high costs associated with relocation options, with benefits only realised over a long period.<br>• 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.<br>• 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 Nukunonu, 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 Nukunonu, 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). The new Faiefa Building is also a good example of a building where cyclone hazard considerations have been incorporated in to the design, with the ground-floor a meeting room with few contents to be damaged.

Typically 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, in the context of the whole of Tokelau, that additional emphasis be made on upgrading housing in Nukunonu due to the higher percentage of buildings with floor level less than 0.5 m compared to Atafu and Fakaofo.

**Recommendation 17**: That coastal hazard risk reduction (through implementation of the relevant Recommendations 1 to 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 Nukunonu community.

The majority of damage to residential property and other buildings during Cyclone Percy was due to wind damage. Whilst outside 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. However, as Nukunonu has a much higher percentage of existing buildings that have floor levels less than 0.5 m, and thus are susceptible to inundation, compared to the other two atolls it is suggested that additional assistance be provided to Nukunonu to accelerate the Housing Grant scheme.

If possible the emphasis should be on:

1. Rebuilding (preferably relocating) the first line of housing back from the beach (Both ocean and lagoon sides) that have floor levels less than 0.5 m above. There are approximately nine such properties on Nukunonu motu and five on Motuhaga (Figure 24).

2. Rebuilding (or preferably relocating) further housing to those identified above located in the high hazard zones with floor levels less than 0.5 m above the surrounding ground levels. There are a further four such properties on Nukunonu.

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, either to themselves or the community, *Recommendation 17*, 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, 5, 6, 7, 8, 9 and 15.

Observations of damage to buildings in Asia affected by the Boxing Day tsunami highlighted that buildings elevated on well founded piles with open ground floors 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 or through the ground floor). Significant and widespread damage to solid foundations or walls and associated scour 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 properties located very close to the beach and where there is potential for a high volume of debris in the inundating water.

Whilst it cannot be stressed strongly enough, how vital it is to ensure that further residential property is not constructed within the high hazard zones identified in Figure 29, if this can not be avoided consideration should be given to the use of piled foundations (rather than a water tank foundation). The piles need to be well founded, sufficient to withstand inundation flows, 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 at the southern end of Nukunonu motu increasing pressure for reclamation and development in high hazard zones and on Motuhaga (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 defences (Rec. 16 & 17). | |
| Social | • Continued improvement in housing standards.<br>• 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.<br>• Enables community control, accountability and participation in risk reduction measures. | |

# 8. Risk reduction on Nukunonu 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 Nukunonu has discovered with the gabion seawall, coastal defences constructed to 'hold the line' along the ocean beach 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). In general seawalls such as these are 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 Nukunonu, there is always considerable pressure to reclaim land, such activity is rarely consistent with reducing coastal hazard risk, particularly on the ocean side.

However, structural protection measures do have a role to play in such risk reduction through complementing and enhancing the activities outlined in Sections 5 to 7. Alternative approaches for construction of such protection measures on Nukunonu are discussed below. The approach recommended below (and for the future) is to ensure that all existing walls are properly maintained and functioning <u>before</u> considering construction of any new structures.

## 8.2 Lessons learned for future seawall maintenance and construction

The Tokelau communities have had long experience with the construction of 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 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 Nukunonu and other atoll communities, 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;

- Lines of single gabion baskets in the inter-tidal beach are not an effective form of coast defence and are easily destroyed;

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

- Gabion basket breakdown 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 need to involve the building up of land levels at the same time;

    - in beach locations (either ocean or lagoon side), the position of the gabion wall should be sufficiently far landward to ensure that the toe of the gabions are not exposed (i.e., are completely buried by the beach at all times);

    - where gabions front a reclamation on the lagoon side (and the wall foundation below high tide level) a mass concrete rather than gabion foundation should be used (on lagoon side only);

- The effectiveness of the gabion seawalls (both structurally and in terms of the level of protection they provide) along a number of reclaimed sections on the lagoon side on Nukunonu 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 is generally not sufficiently robust to withstand wave impacts during cyclone events. Vertical faced or mass concrete walls should not be used on the ocean side at all and only used on the lagoon side with much caution and certainly not where a beach is located in front of the defence, otherwise the beach is likely to recede;

- 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 Seawall repair

The potential long-term effectiveness of the gabion seawall at the southern end of Nukunonu has been reduced by changes to the recommended design by constructing the seawall between 4 to 7 m too far down the beach. Whilst this has allowed a narrow area of land to be reclaimed behind the wall it has resulted in the wall being much more exposed and hence much more prone to damage than intended in the original design. Rather than be the primary form of defence along this part of the coast (which gabions in any form are not well suited for in such a location), the gabion wall was intended to be constructed behind the current vegetation line and to act in conjunction with the beach, that is allow the beach to respond in a natural manner but with the gabion structure to help reduce overwashing and overtopping of the beach crest during storm or cyclone events.

The gabion seawall is viewed by the community of Nukunonu as an important community asset, and one which has played a role in reducing the magnitude of damage during Cyclone Percy at the southern end of Nukunonu motu. Loss of the structure would be of significant detriment to the general well-being of the southern

Nukunonu community and increase the risk of damage to the bridge connecting Nukunonu with Motuhaga (an important community lifeline particularly given the location of the hospital on Motuhaga). During Cyclone Percy, overwashing at both ends of the bridge resulted in outflanking which could have led to serious damage to the bridge. Whilst the tops of many of the gabion baskets have split, the shape of much of the structure remains, with much of the coral fill still in situ. Without repair the structure will quickly deteriorate but can still perform a useful role over the short to medium term and be more cost effective than building a new, more appropriate structure at this stage. It is suggested the main focus of such repair works be the sections either side of the bridge (which provides the predominant benefit for the entire community),

**Recommendation 18:** Maintenance of the existing gabion seawall, to extend its effective life, and to upgrade protection of the bridge abutments, is a priority activity before the defence degrades further and before any further protection works are considered.

On the lagoon side the wall around the reclamation upon which the meeting Fale and Faiefa Building) is located is in good condition and only some very minor patching currently required. However, with some proactive upgrading, there is potential to substantially increase the serviceable life of the structure.

**Recommendation 19:** The gabion seawall around the meeting Fale and Faiefa Building is sheathed with continuous sheets of PVC and galmac coated wire mesh, contoured and laced to the underlying gabion baskets.

On the lagoon side, most of the private wall sections are in a poor state of repair, are *ad hoc* and variable, with the more substantial structures developed in piecemeal fashion. All require repair but upgrading or replacement for most in due course are likely to be more appropriate. This is discussed in section 8.4

### 8.3.1 Implementation of the recommendations

| Recommendation | Priority | Implemented over: | | | Risk reduction benefits over: | | |
|---|---|---|---|---|---|---|---|
| | | Short | Medium | Long | Short | Medium | Long |
| **18** | High | | | | | | |
| **19** | Med | | | | | | |

Repair to the existing gabion defences would involve:

- replacement of gabion baskets on the top two or three layers which are substantially damaged (i.e., where the sides of the baskets are burst). 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;

- scraping off the coral rubble which is presently built up over the bottom half of the seawall, covering of the entire structure with continuous sheets of PVC and zinc coated wire mesh, contoured and laced to the baskets underneath (Figure 32), and **replacing the coral rubble back at the toe;**

- repairing the foundation of the structure that has become undermined along approximately 75 m at the lagoon end of the channel. Ideally this would be of mass concrete and keyed in to the underlying beach rock and extend underneath the bottom gabion basket to provide support (Figure 33);

- the northern (oceanside) end of the gabion structure should be curved landward away from the beach to ensure no scouring or outflanking behind the defence structure occurs.

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 <u>priority</u> before any further new construction work is carried out.

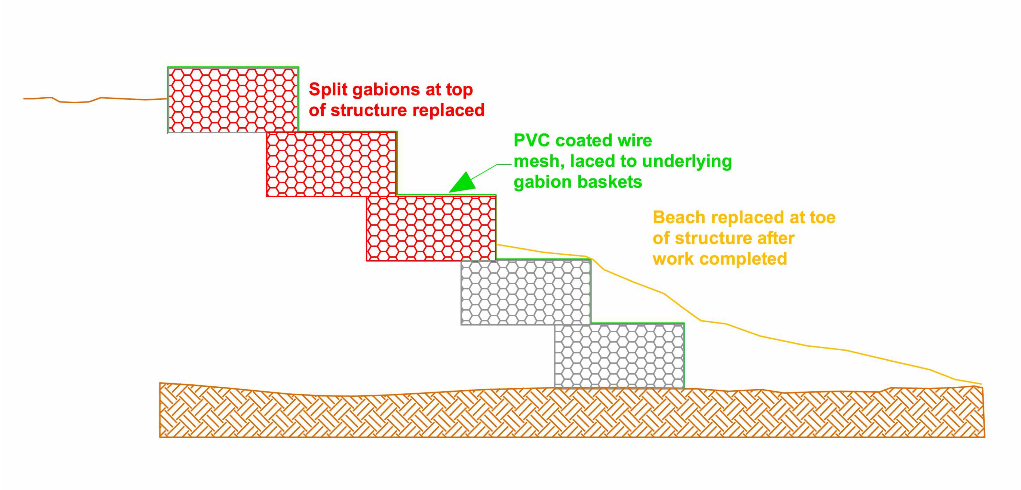


**Figure 32:** Repair details to gabion seawall along the ocean side and to the immediate lagoon side of the bridge.

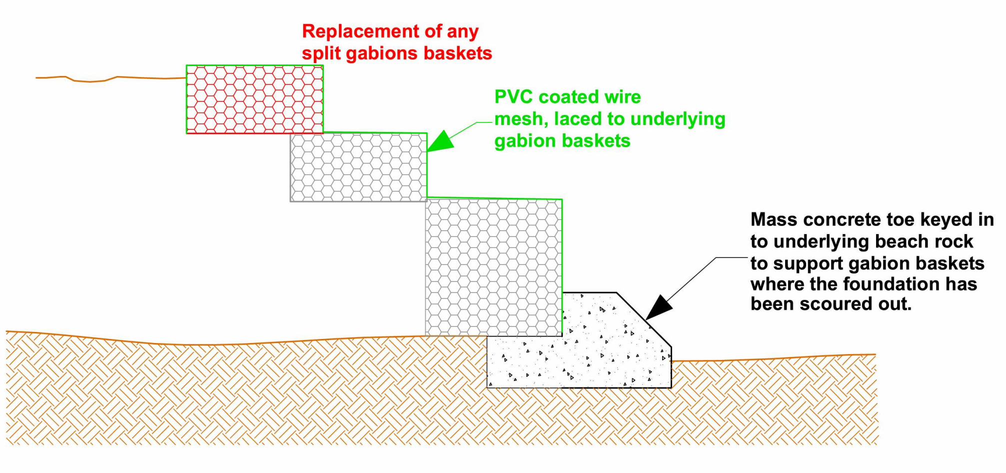


**Figure 33:** Repair details to gabion seawall along the section at the lagoon end of the channel currently being undermined (see Figure 12, right).

Particular focus should be placed on the immediate area around the bridge, ensuring that the gabion protection on the Nukunonu side has been well constructed. To reduce the risk of outflanking of the immediate approach to the bridge, the following is suggested:

- A mass concrete or reinforced slab be constructed to extend the bridge approach further landward (approximately 8 m would appear to be reasonable) on both the Nukunonu and Motuhaga sides.

- Gabions, with a geotextile filter layer, be keyed in to both flanks of the bridge approach and extended landward around 8 m (Figure 34) and excavated earth backfilled.

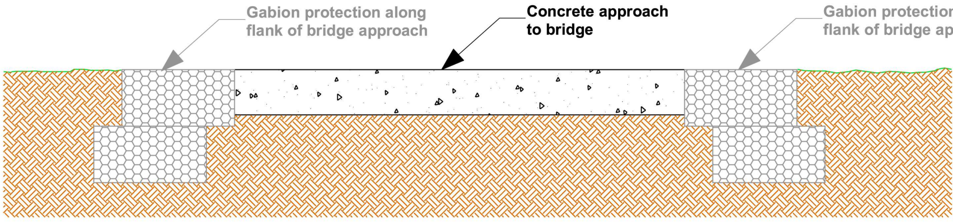


**Figure 34:** Schematic cross-section of the approaches to the bridge.

This should provide additional protection in the short to medium term. However, an assessment of a more permanent solution for the long term protection of the bridge abutments, particularly on the Motuhaga side, should be conducted by an experienced structural engineer.

## 8.4 Replacement / new structural protection measures

The recommendations outlined in Sections 5, 6 and 7 are intended to reduce the need for structural coastal defence solutions as a primary means of reducing the risk of inundation related damage during cyclone events. This is particularly the case of Motuhaga where implementation of the recommendations above will be a much more effective way of reducing such risk even at the northern end of Motuhaga where damage to the coastal edge and severe overwashing occurred during Cyclone Percy.

However, coastal defence structures will still have an important contribution to make in further enhancing the primary risk reduction activities outlined in sections 5, 6 and 7 at certain locations on Nukunonu. As with the other Tokelau atolls discussions concerning the need for future structural solutions focused on the primary objectives of:

1. reducing the frequency and / or magnitude of water overwashing and inundating the main inhabited areas of the village (rather than reclamation or protection of land);

2. reducing the level of damage experienced to such structures during a cyclone event.

During the community meetings other forms of defence structure were discussed, particularly relating to offshore structures located on the reef flat to help dissipate wave energy (for example breakwaters using concrete armour units such as those used to build the breakwater at the entrance to the port at Apia). Cost, environmental issues, and construction logistics all make such structures unfeasible in Tokelau's situation. Given the limitations in construction materials and equipment on Nukunonu, future seawall structures will rely heavily on the use of gabion structures, and on the lagoon side, also mass concrete.

For structural stability of the seawalls, reduction in wave related damage to the seawalls and reduced overtopping, 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;

- all gabion defences where the toe of the structure is exposed and below the level of normal high tides should have an in-situ concrete toe beam cast to provide protection against scour and accelerated damage to the lower gabion units;

- where founded on the underlying reef or *te papa*, the toes of all seawall structures (whether gabion or mass concrete) need to be keyed in (by around 300 mm);

- 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, 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.

Outlined below are a number of different designs developed conceptually in consultation with the Nukunonu community, the lessons learned detailed above, and from relevant technical publications[3] [4], which aim to complement the measures being recommended in sections 5, 6 and 7 aimed at addressing the two primary objectives detailed above. Figure 35 summarises the locations on Nukunonu where the different sea-wall sections detailed below are applicable.


**Figure 35:** Summary of defence sections for different seawall design profiles around the village on Nukunonu (Figures 36 to 39 for details). The position of the line shows the <u>minimum</u> distance the crest of the wall should be from the vegetation or shore line.

However, it is important to appreciate that the construction of further coastal defence structures may not significantly reduce risk of inundation on an atoll as susceptible to overwashing as Nukunonu. Indeed, there are some locations, such as at the school,

[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

where economically justifiable coastal defences will do little to reduce such risks, with other measures such as relocating/redesigning the school buildings a much more effective and longer lasting risk reduction measure.

**Recommendation 20:** Coastal defence structures are used to enhance rather than be the primary risk reduction measure on Nukunonu with the main objectives of such structures to reduce the potential for wave overtopping and overwashing, and to reduce the magnitude of damage to such structures during a cyclone.

### 8.4.1 Implementation of the recommendations: Ocean side on Nukunonu

Maintenance of the existing gabion wall at the southern end of Nukunonu should extend the serviceable life of the wall by 10 to 15 years unless there is a significant increase in cyclone events over this time. However, over this timeframe this defence will approach the end of its serviceable life and will require replacing.

The defences outlined below will still require a substantial amount of coral rubble to fill gabion baskets. The environmental implications are discussed in Section 8.4.3. However, associated with this there is a need for a larger barge to aid the collection of rubble from other motu around the atoll.

<u>Section A: Channel coast</u>

Along the flank of the channel there is little scope other than to rebuild the wall along its present realignment to ensure that the bridge connecting the two motu is adequately protected as well as the high density of residential property located behind the wall. However, it is sheltered from direct wave attack and hence does not experience the same level of damage as the more exposed section facing the ocean.

The concrete toe beam will provide additional stability to the toe and prevent the undermining as has happened along a section of the present defence. A proportion of the coral rubble needed to fill the gabions can be re-used from the existing gabion baskets.

Cost: $1,040 per linear metre

Costs exclude labour costs associated with construction, equipment purchase or hire, and assume 50-60% of the coral rubble requirements will need to be freshly sourced. Costs associated with the collection of sand and coral rubble are included.

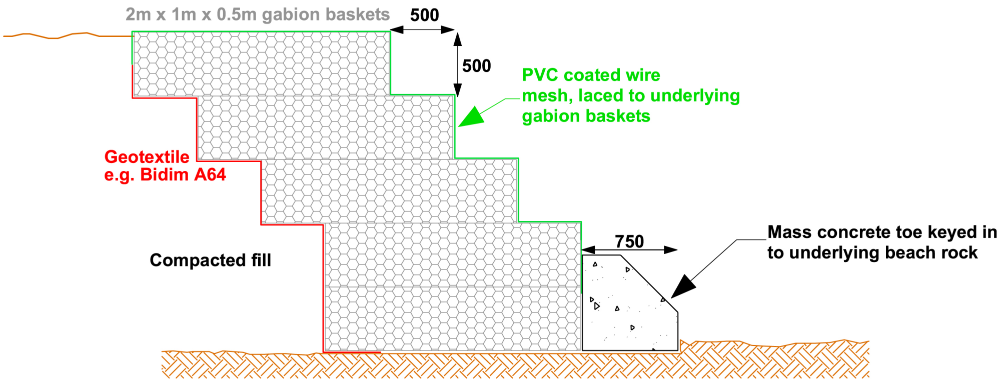


**Figure 36:** Proposed outline design cross-section along Section A (south side of Nukunonu).

Section B: Ocean coast (southern end of Nukunonu)

The original gabion design (Brockliss, 1992) required the seawall structure to be located behind the vegetation line with the subsequent reduced performance of the wall (as built) largely down to it having instead been built on the beach.

Rather than be used to reclaim land and to try to provide direct protection to the shoreline, the gabion structure (or any form of seawall structure on the ocean side) needs to be used to create a secondary defence landward of the vegetation line that acts in conjunction with the natural beach system. Such a system will more effectively reduce the potential for overwashing and help reduce the extent of damage to the wall during cyclone events providing a much longer serviceable life.

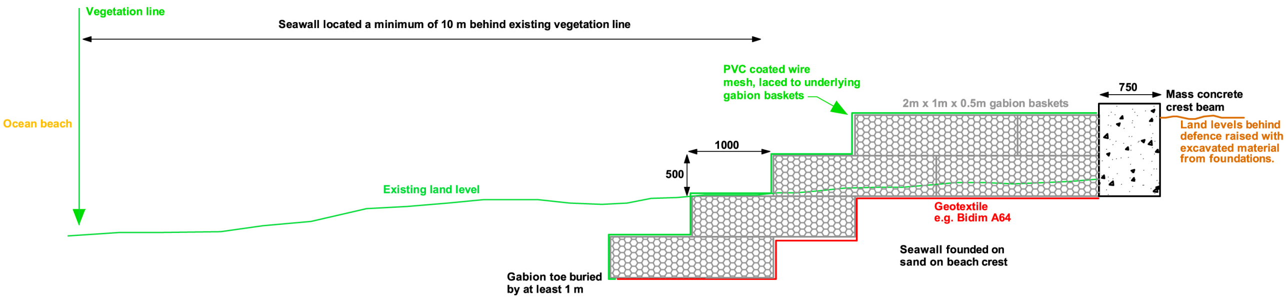


**Figure 37:** Proposed outline design cross-section along Section B (ocean side of Nukunonu).

The wall should be located around 10 m back from the current vegetation line (see Figure 35) but should not be beyond the highest point of the storm berm. At the southern end it should tie in with Section A, detailed above, and curve in behind the line of the existing wall. When the existing wall is removed (or falls apart) there will be some relocation landward of the vegetation line as the beach around the corner at the southern end of Nukunonu re-adjusts. One of the advantages is that the wall can be built whilst the existing one is still in place ensuring that there is no local decrease in the protection to the community at the southern end of Nukunonu during construction. The effectiveness of the beach / gabion system can be further enhanced by ensuring dense vegetation cover between the vegetation line and the new defence.

Again a proportion of the coral rubble needed to fill the gabions can be re-used from the existing gabion baskets.

If required, the line of the wall can be extended northwards towards the bulk storage shed (although the initial focus should be on ensuring a replacement for the existing wall).

Whether a wall should be built in front of the existing community buildings located on the ocean coast (from the bulk storage shed in the south to the generator building at the north) was discussed. Essentially this would require a seawall located in the active beach (i.e., in a similar position on the beach to the gabion wall further south). A gabion wall built in such a position is exposed, would be easily damaged, have high maintenance requirements, and have a similar serviceable life to the existing wall. Nor would it significantly reduce overwashing flows along this part of the coast as the height of the wall would also be constrained. It is suggested that a more effective use of funds would be to relocate the buildings (as discussed in Section 6) rather than spend it on a seawall in front of them. A more substantial wall, e.g., involving use of mass concrete, would have significant detrimental impacts on the ocean coastline and is certainly not recommended.

If the community buildings along the ocean coast are relocated (even by moving them 20-30 m landward) there is no reason that the gabion wall could not be extended northwards to around the location of the generator building (again with re-establishment of dense vegetation over the bare areas in front of the defence) in the long-term. However, it is not suggested that such a wall be extended along the school frontage due to the very narrow beach crest. This area is always going to be susceptible to overwashing and the recommendations made in Sections 5 and 6 are more suitable to reducing inundation risks for this location.

Cost: $1,480 per linear metre for a replacement wall ($1,610 per linear metre for new sections of wall).

Costs exclude labour costs associated with construction, equipment purchase or hire, and assume 50-60% of the coral rubble requirements will need to be freshly sourced for the replacement wall and 100% for any extended wall. Costs associated with the collection of sand and coral rubble are included.

| Section | Present Priority | Implemented over: | | | Risk reduction benefits over: | | |
|---|---|---|---|---|---|---|---|
| | | Short | Medium | Long | Short | Medium | Long |
| Section A | Low | | | | | | |
| Section B | Low | | | | | | |

### 8.4.2 Implementation of the recommendations: Lagoon side of Nukunonu

On the lagoon side further wall construction is likely to be related to the replacement of existing sections fronting reclamation areas and occur between the northern end of the Luana Liki Hotel and the southern end of Nukunonu motu. There is little justification for requiring seawall structures outside this section.

<u>Section C: Existing reclaimed areas on the lagoon shore</u>

Existing reclamation areas on the lagoon shore at the southern end on Nukunonu motu (particularly south of the Faiefa Building) extends the land out towards the edge of the back reef resulting in the defences being in relatively deeper water and more exposed to wave damage. As a result a combination of a mass concrete toe and stepped gabion upper is suggested.

Again where existing gabions have been used a proportion of the coral rubble needed to fill the gabions can be re-used from the existing gabion baskets.

Cost: $1,400 per linear metre

Costs exclude labour costs associated with construction, equipment purchase or hire, and assume 50-60% of the coral rubble requirements will need to be freshly sourced. Costs associated with the collection of sand and coral rubble are included.

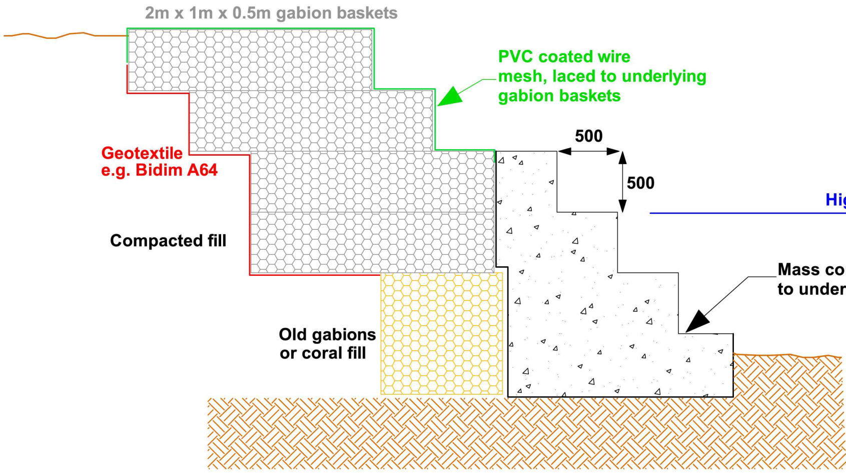


**Figure 38:** Proposed outline design cross-section along Section C (existing reclaimed areas on the lagoon shore of Nukunonu).

Section D: Other sections of lagoon shore on Nukunonu

Between the Luana Liki Hotel and the southern end of Nukunonu motu there are sections between the areas that have been reclaimed that have seawall structures, most of which have not been well built, and other areas where the lagoon beach can still be seen. Whilst further reclamation should be discouraged there may be a need to protect existing housing located close to the beach or to raise land levels slightly in lower lying areas. However, care needs to be taken in not raising land levels or seawall structures right along this lagoon frontage as this may reduce the ability of waves overwashing from the ocean side (which is still going to occur irrespective of risk reduction measures taken) to drain in to the lagoon potentially increasing inundation depths over the motu.

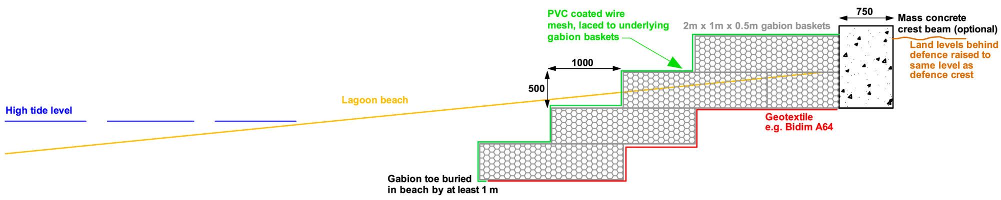


**Figure 39:** Proposed outline design cross-section along Section D (lagoon side of Nukunonu).

The section shown above is suggested as potential solution enabling land levels to be built up slightly and protection provided to residential buildings (in some cases the back edge of the seawall may need to be up against the wall of the building) whilst still providing easy access to the lagoon and a beach to moor fishing boats on

There are a number of sections (e.g., south of the Faiefa Building), where split gabion baskets have created an intertidal area of coral rubble. This is quite effective and it is suggested in such areas that the coral rubble remain to front any gabion construction.

Cost: $1,080 per linear metre ($1,300 with concrete crest beam)

Costs exclude labour costs associated with construction, equipment purchase or hire, and assume 100% of the coral rubble requirements will need to be freshly sourced. Costs associated with the collection of sand and coral rubble are included.

| Section | Present | Implemented over: | | | Risk reduction benefits over: | | |
|---|---|---|---|---|---|---|---|
| | Priority | Short | Medium | Long | Short | Medium | Long |
| **Section C** | Low | | As required | | | | |
| **Section D** | Low | | As required | | | | |

Upgrading seawalls on the lagoon side is typically the responsibility of the landowner with the designs outlined above likely to be more expensive than typical seawall construction protecting individual properties. However, on Nukunonu, given the narrow width of the atoll, the provision of such seawall structures does have a benefit to the wider community. It is suggested that to aid the uptake and implementation of the designs presented above that some thought may need to be given to a "seawall grants scheme" or other form of local government assistance to assist with the expense of constructing such defences. **Such assistance should only be available to landowners located between the lagoon side of the school and the southern end of Nukunonu and be based on agreed design standards.**

### 8.4.3 Environmental issues relating to constructions

Environmental impacts relating to further seawall construction as outlined above is primarily related to the collection of coral rubble. As there was insufficient time to inspect areas where coral rubble is sourced, the recommendations made in the EIA (McLean, 19993) should apply. This recommended that the rubble be sourced from the northern end of the motu (*Te Kamu* and *Te Puka* area 4 to 5 km northwest of Nukunonu), 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 Nukunonu) should not be used.

## 8.5 Constraints to implementation

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

2. Potential conflict from landowners to restrictions on further land reclamation, suggested seawall designs;

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

4. Future events, such as another cyclone 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 | • Ongoing reduction in cyclone damage to, and inundation of, housing and associated tangible direct property damage and intangible impacts on household members. | • Requires substantial human resources for construction. |
| Economic | • Reduced potential for inundation and damage to property and infrastructure.<br>• More resilient structures with reduced maintenance commitment to maintain serviceable performance. | • Requires higher level of financial commitment to upgrade defences (both community and private). |
| 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.<br>• 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 sections.

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 urgent maintenance of the existing gabion seawall and upgrading the protection of the bridge abutments linking Nukunonu with Motuhaga.

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

3. Contributing funding to assist with the relocation of the main school building.

However, there are a number of other critical activities that have been identified to reduce cyclone related risks on Nukunonu such as consideration of relocating key infrastructure.

### 9.1.1 Priority 1: Repairing the ocean side gabion wall (Recommendation 18)

Details of the repair to the gabion seawall around the southern end of Nukunonu motu are provided in Section 8.3. Without such repairs the structure will quickly deteriorate leading to an increased risk of damage or loss of the bridge between Nukunou and Motuhaga and an increase risk of inundation to housing located behind the wall (a number of which have low floor level relative to the surrounding land levels and are thus highly susceptible to inundation. Maintenance of the structure will provide time for commencing the implementation of longer-term strategies to manage such risks along this section of coast.

Associated costs for maintenance activities described above are:

| Gabion basket repairs | $ |
|---|---|
| 450 No. 2 m x 1 m x 0.5 m galmac and PVC coated gabion baskets @ $55 per basket (ex Apia) | 24,750 |
| 45 No. roles (2 m x 50 m) of galmac and PVC coated mesh @ $135 each (ex Apia) | 6,075 |
| Lacing wire and miscellaneous | 7,000 |
| **Mass concrete toe beam (75 m total @ 0.65 $m^2$/m)** | |
| 50 $m^3$ sand @ $120 per $m^3$ | 6,000 |
| 600 No. bags of cement @ $14 per bag | 8,400 |
| Formwork and miscellaneous | 5,000 |
| **Bridge approach and protection** | |
| 20 $m^3$ sand @ $120 per $m^3$ | 2,400 |
| 240 No. bags of cement @ $14 per bag | 3,360 |
| 40 No. 2 m x 1 m x 0.5 m galmac and PVC coated gabion baskets @ $55 per basket (ex Apia) | 2,750 |
| Formwork, filter cloth and miscellaneous | 3,000 |
| **TOTAL (materials)** | **$68,735** |

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 northern end of the motu as recommended in the EIA (*Te Kamu* and *Te Puka* area 4 to 5 km northwest of Nukunonu), (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 Nukunonu) 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 structural 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. The maintenance costs of around $140 per metre for the mesh repairs and $400 per metre for the section with the mass concrete toe beam (excluding labour) are significantly less than the cost of new defence structure at this stage.

### 9.1.2 Priority 2: Initiating community awareness and risk reduction programmes (Recommendations 1, 2 & 3)

Key to the long term reduction in cyclone induced inundation risk is the need to ensure that human impacts on the function of the natural coastal defences are 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 the village rules to address detrimental sand mining and vegetation clearing activities (Recommendations 1 & 2). 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). Areas to focus on are summarised in Figure 28 in Section 5.2 but the priority should be along the ocean and lagoon sides of the school playing field and carried out in conjunction with the relocation of the school building outlined below.

| 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 Priority 3: Relocation of the school (Recommendation 10)

It is suggested that re-positioning the main school building should be seen as a high priority to reduce the potential for future damage which will occur every time a cyclone does impact on Nukunonu. Suggested details are provided in section 6.2. 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.

It is unlikely that there will be sufficient funds within the current UNDP programme to completely finance the project but a contribution to the overall costs may be possible. Possible additional funding could be sourced from the remainder of the Cyclone Percy disaster relief fund. A full estimate of the cost of rebuilding the school will require more detailed consideration by the Nukunonu *Taupulega* and *Amauga*.

Where the present school building is located, it is suggested that vegetation is planted all along the lagoon side of the rugby field (as detailed in the section above) to help stop over washing waves, eroding the rugby field and depositing the sediment in the lagoon as detailed in Section 6.2.

### 9.1.4 Other potential priorities

There are a number of other priority areas that require consideration by the decision-makers on Nukunonu. Of most concern at the time of the visit on Nukunonu was the amount of debris that was still covering the island. As noted in Section 3.7, the amount of debris that was entrained in waves overwashing the motu during Cyclone Percy substantially increased the risk of injury to people wading through the water. A major clean-up exercise is still required on Nukunonu to reduce the amount of potential debris and material that exacerbates risks during future cyclones. Reducing the amount of material, either lying around or unsecured that has the potential to become hazardous debris will be an ongoing task.

In addition to the school, Nukunonu has other critical infrastructure that is at very high risk due to their location or the way they have been constructed. Examples include the power generating building, fuel storage shed, fisheries building, bulk storage, and the hospital. Consideration for relocating and/or upgrading these buildings, particularly the first three, to areas of less risk is suggested to be a high priority.

## 9.2 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 2 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.

**Table 2:** 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 | ● | ● | • Public awareness activities |
| 5 | ● | ● | • Public awareness activities |
| 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 |
| 18 | ● | | • Public awareness activities |
| 19 | ● | | • Public awareness activities |
| 20 | ● | | • Public awareness activities |

## 9.3 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 the consequences of sea level rise.

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 Nukunonu 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 (e.g., the situation Fale on Fakaofo is in where future risk management options are limited and expensive).

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 accessible following self-determination.

- 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.

## 9.4 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 Nukunonu 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 (based around the recommendations) 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 Nukunonu makes in reducing their risks to coastal hazards can be monitored.

| No | Increasing risk | Present | Decreasing risk |
|---|---|---|---|
| 1 | Sand / coral rubble removed from beach or reef flat around Nukunonu or Motuhaga within last 6 months | **No** | No sand / coral rubble removed from beach or reef flat around Nukunonu or Motuhaga within last 6 months |
| 2 | Vegetation cleared within 30 m of the vegetation line within last 6 months | **Yes** | No vegetation cleared within 30 m of the vegetation line within last 6 months |
| 3 | Replanting of natural vegetation along the ocean coast and key lagoon locations within the last year | **No** | No replanting of natural vegetation along the ocean coastal and key lagoon locations within the last year |
| 4 | New reclamation activities or ad hoc seawalls built in the last year | **Yes** | No new reclamation activities or ad hoc seawall structures built in he last year. |
| 5 | New community buildings or infrastructure built within high hazard (red) zone | **0** | No new community buildings or infrastructure built within high hazard (red) zone |
| 7 | New residential property built in high hazard (red) zone | **??** | No new residential buildings built in high hazard (red) zone |
| 8 | Number of community buildings at high risk | **17** | Number of community buildings at high risk |
| 9 | School buildings not relocated | **No** | School buildings relocated and rebuilt to improve resilience to inundation. |
| 10 | No planning commenced for upgrading of hospital, and community buildings located to the lagoon side of the church commenced) | **No** | Planning and upgrading commenced for upgrading of hospital, and community buildings located to the lagoon side of the church commenced) |
| 11 | No planning commenced for the staged relocation of the power, fisheries, fuel storage, old Falepa and bulk storage sheds. | **No** | Planning commenced for the staged relocation of the power, fisheries, fuel storage, old Falepa and bulk storage sheds. |
| 12 | 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 |
| 13 | 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 |
| 14 | More houses with floor levels less than 0.5 m above land level | **32** | Less houses with floor levels less than 0.5 m above land level |
| 15 | 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 |
| 16 | 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 |
| 17 | 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 |
| 18 | No progress in implementing seawall upgrade strategy on Nukunonu within last year | **No** | Progress in implementing seawall upgrade strategy on Nukunonu within last year |

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