Reducing Risks of Coastal Hazards in Tokelau

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Coastal Hazards Study

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Document history and status

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1	19/06/2019	Final Report Issue	JJ	DC	DC
2	19/06/2019	Final Report Issue (minor edits to clarify model parameters adopted in SWASH modelling)	JJ	HL	HL

Tidal Constituents	Individual components that represent a periodic variation in water-level due to either the relative position of the earth, sun and moon, or other physical phenomena. Tidal water-levels can be predicted and described based on individual 'constituents'.
Tide	the rise and fall of the sea water level due to gravitational forces, primarily the sun and the moon.

1. Introduction

1.1 Background

Tokelau is a non-self-governing nation located in the South Pacific Ocean, approximately 500km north of Samoa. It comprises of three small coral atolls (Atafu, Nukunonu and Fakaofo) that lie between latitudes 8 and 10 degrees south and 171 and 173 degrees west.

The population of approximately 1,500 residents inhabit five narrow, low lying islets, which have a combined land area of approximately 12 square kilometres. These islets are typically not more than 200 metres wide and generally less than 3m above high tide.

Due to this setting, the nation is highly exposed to coastal hazards. Cyclonic events have caused substantial damage to the villages in the past and are a recognised risk among residents of Tokelau. In the last 50 years, at least 6 cyclone events have caused major damage to the atolls.

Future climate change effects, while uncertain, predict rising sea levels, potential increases in frequency and intensity of tropical cyclone events and changes in the dominant El Nino / La Nina cycles. Such changes will exacerbate existing coastal hazards and could potentially have significant implications to the livelihood of the villages.

The Government of Tokelau has recognised the vulnerability of its communities to existing and potential future coastal hazards and has formulated a national strategy to enhance the resilience of Tokelau (LivC 2017-2030). A key element of the LivC strategy is to better understand and respond to coastal hazards risks.

The New Zealand 's Ministry of Foreign Affairs and Trade (MFAT) is supporting the Government of Tokelau with the implementation of the strategy and has commissioned Jacobs to prepare a coastal hazard risk mitigation plan for Tokelau.

This document outlines the outcomes of a key step towards the development of this risk mitigation plan. It outlines the investigations that have been undertaken by Jacobs to assess the risks to the villages from existing and potential future coastal hazards, taking into account the likely impacts of climate change.

1.2 Study Objectives

The main objective of the Tokelau Coastal Hazards Study is to provide definition of likely hazards and associated impacts relating to coastal processes. This will provide the basis for the development of a long-term Coastal Hazards Risk Mitigation Plan for Tokelau.

The Coastal Hazards Risk Mitigation Plan shall provide appropriate guidance on managing existing and future risks from coastal hazards. Therefore, this Coastal Hazards Study provides the technical information on hazard likelihood together with their potential consequences (impacts on the village communities and their assets) from which management actions can be formed.

1.3 Risk Assessment Process

A risk-based approach has been adopted to develop the risk mitigation plan. A risk based approach provides a transparent and logical basis for making decisions about whether a coastal hazard risk needs to be treated or what the most appropriate risk treatment strategies may be.

The adopted risk management process is based on the International standard for risk management (ISO 31000:2018), and is presented schematically in Figure 1-1. The coastal hazard study deals with the risk assessment components of the risk management process.

In accordance with international standard, risk is defined as the combination of 'likelihood' of occurrence of an event and the 'consequence' if the event occurs.

The likelihood of risks is related to the extent and magnitude of coastal hazards, now and in the future. A coastal hazard assessment (Section 3) was undertaken to assess the hazard levels across the village motus for a range of likelihoods ('Almost certain', 'Possible', 'Unlikely' and 'Rare'). The likelihood of coastal inundation and shoreline erosion and recession has been defined for three planning horizons (immediate, 2050, 2100). Coastal hazards considered in the coastal hazard assessment include coastal inundation and coastal erosion.

The consequence of the risks relates to the impact of the hazards upon the communities. This is largely linked to effects of the hazards on assets and people. The key assets that may be impacted by coastal hazards were identified (Section 4) and allocated a risk consequence (Section 5.2). The outcomes of the risk assessment are presented in section 5.3.

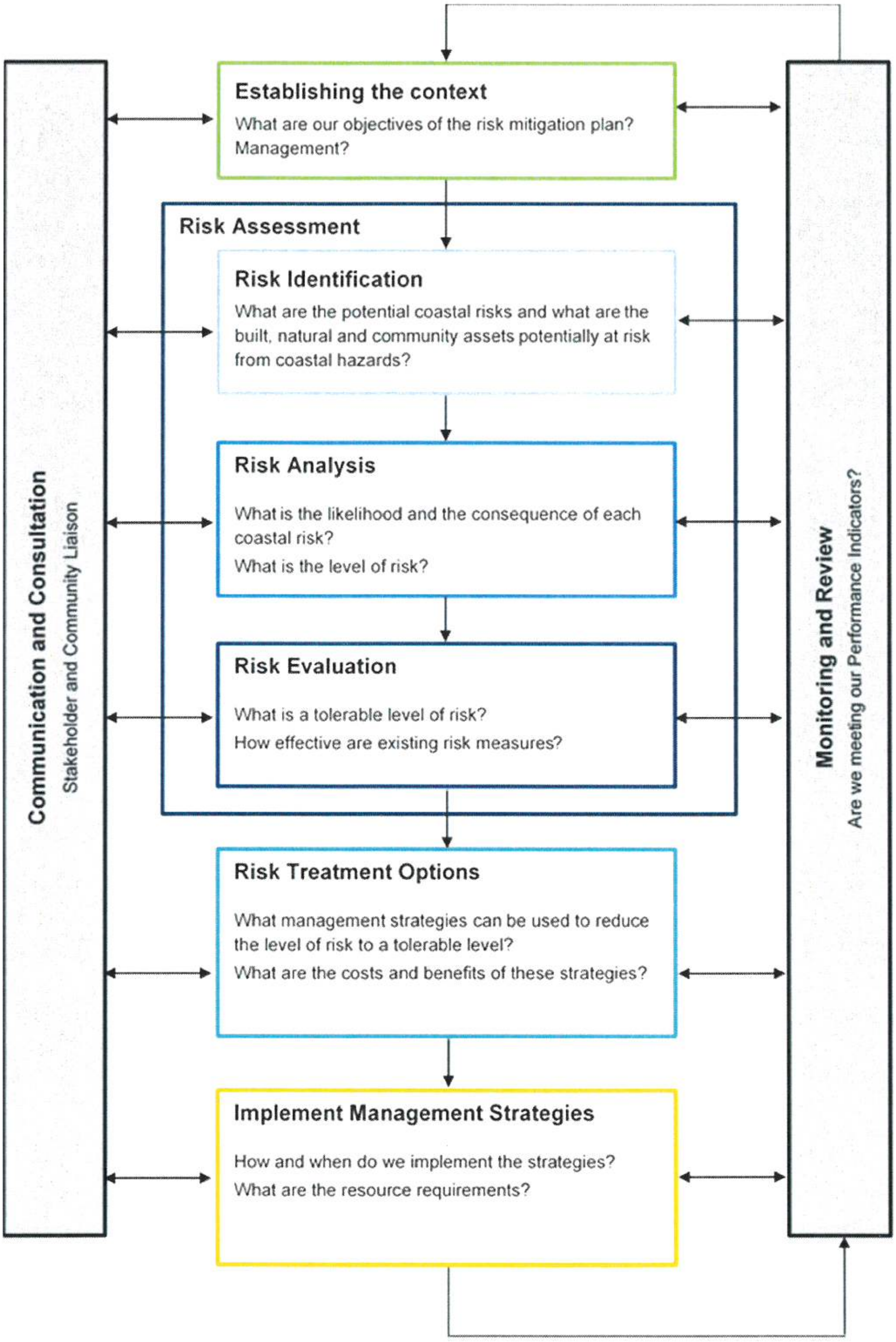


Figure 1-1 Adopted Risk management framework for managing coastal hazard risks in Tokelau (adapted from ISO 31000:2018)

1.4 Previous Studies

There have been various initiatives undertaken previously relating to the management of coastal hazard risks in Tokelau. These include studies into the impacts of past cyclones, possible impacts of tsunamis and a number of strategic documents and management plans, including:

- Government of Tokelau Asset Management Plan 2015-30 (Waugh, 2014)
- Living with Change (LivC): An Integrated National Strategy for Enhancing the Resilience of Tokelau to Climate Change and Related Hazard, 2017-2030 (Government of Tokelau, Office of the Council for the Ongoing Government and LeA International Consultants, 2017)
- Living with Change (LivC): Implementation Plan (Government of Tokelau, Office of the Council for the Ongoing Government and LeA International Consultants, 2017)
- Reducing the risk of cyclone storm surge inundation on the atolls of Tokelau: An overview of cyclone-related coastal hazards (NIWA, 2005A)
- Reducing the risk of cyclone storm surge inundation on the atolls of Tokelau: Atafu (NIWA, 2005B)
- Reducing the risk of cyclone storm surge inundation on the atolls of Tokelau: Nukunonu (NIWA, 2005C)
- Reducing the risk of cyclone storm surge inundation on the atolls of Tokelau: Fakaofo (NIWA, 2005D)
- Tsunami hazard potential for the atolls of Tokelau (NIWA, 2013)

These studies have been reviewed and referenced throughout the development of the Coastal Hazards Study.

2. Physical Setting

2.1 Site locations

Tokelau is located in the South Pacific Ocean approximately 500km north of Samoa and approximately 500km south of Kiribati (the Phoenix group of islands). It comprises three coral atolls (Fakaofo, Nukunonu and Atafu), arranged in a southeast-to-northwest line. Fakaofo is the southern-most atoll (9°21'S 171°12'W), then Nukunonu (9°12'S 171°51'W) is to the north of Fakaofo and Atafu is the northern-most atoll (8°33'S 172°30'W).

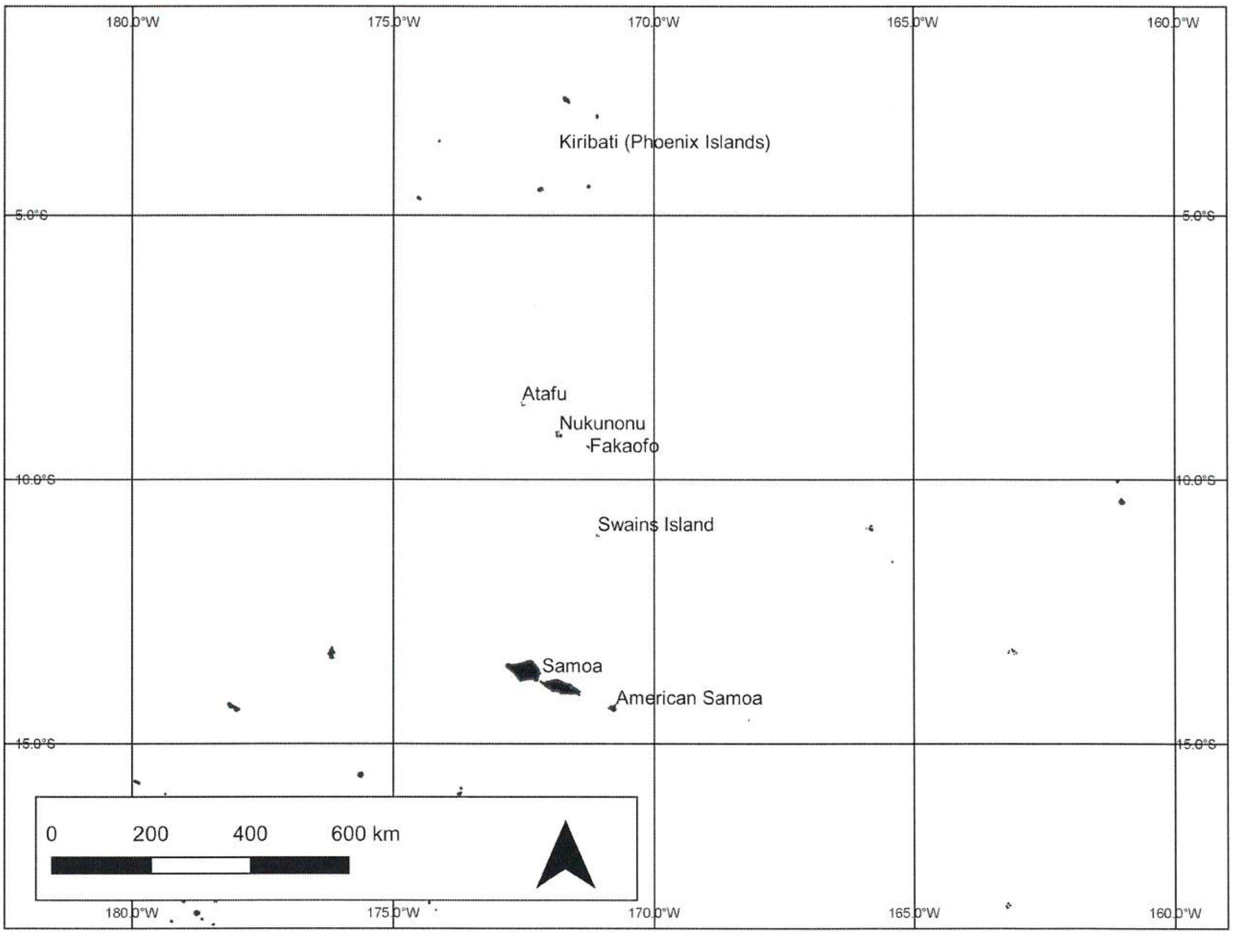


Figure 2-1 Location of the three atolls of Tokelau

2.2 Geomorphology

Each atoll consists of numerous islets (motus), located on a reef that surrounds a lagoon (See Figure 2-2 to Figure 2-4). The lagoons are more or less horse shoe shaped with water depths in excess of 60m in some parts while shallow and dotted with coral outcrops in other parts. The lagoon of Atafu is smaller than the lagoons of the other two atolls and is about 5km by 6km, compared to about 8km by 10km for Nukunonu and Fakaofo.

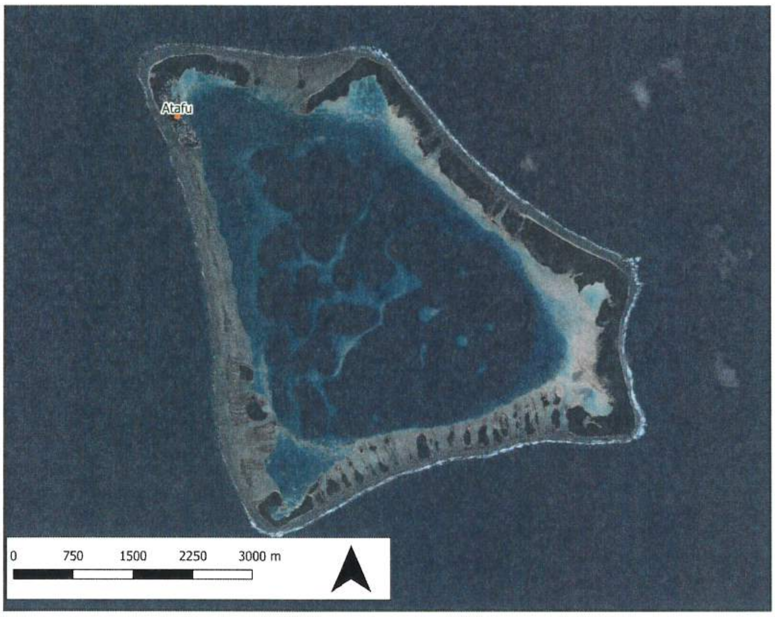


Figure 2-2 Aerial photograph of Atafu atoll

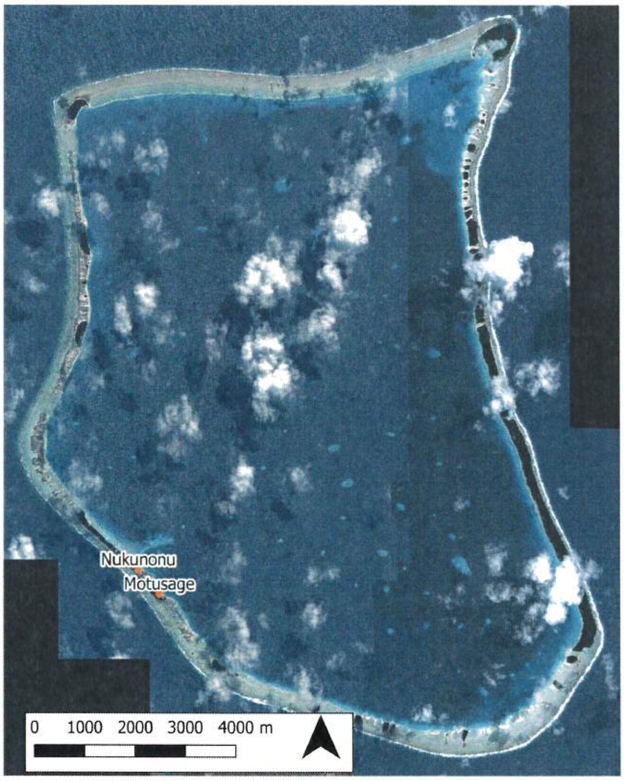


Figure 2-3 Aerial photograph of Nukunonu atoll

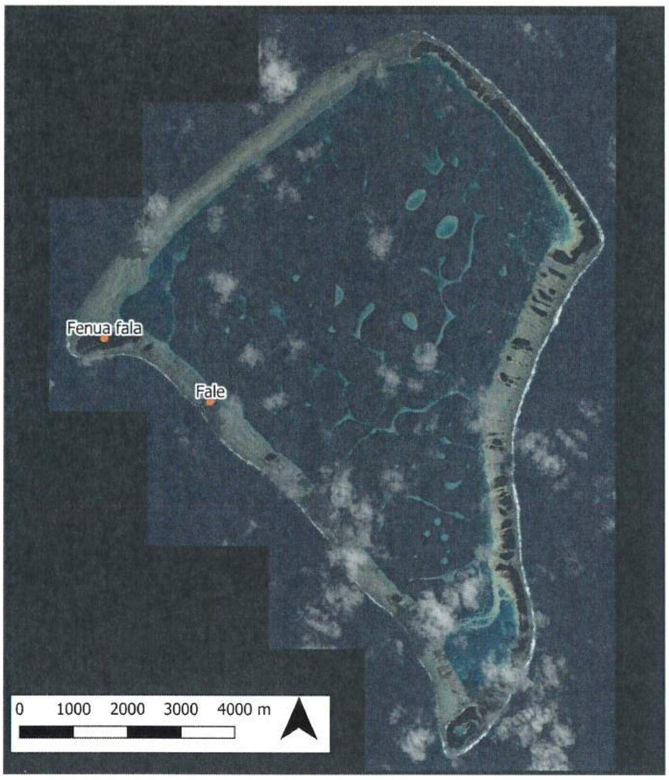


Figure 2-4 Aerial photograph of Fakaofo atoll

The reef of each atoll is continuous and hydraulically disconnects the lagoon from the ocean during low tides. There are no passages in any of the reefs, and thus the lagoons are inaccessible by ocean going vessels. The reefs are made of a conglomerate of cemented coral and other biogenic sediments and are rarely more than 400 m wide. Seaward of the reef, the seabed falls off sharply to depths of more than 3km.

The five inhabited motus of Tokelau (Atafu, Nukunonu, Motusage, Fale and Fenua Fala) are located on the south or western side of the atolls, on the opposite side of the prevailing wind and wave directions. The motu are typically situated on outcrops of conglomerate that are slightly higher than the present reef flat (known as *te papa*) and often located about 100 to 150m from the fringing reef. These outcrops were likely formed when sea levels were slightly higher (0.5 to 1m) between 2,000 and 4,000 years ago.

The motus are primarily made of biogenic sediments that are derived from skeletal remains and breakdown of calcareous organisms that live on the fringing reefs of the atolls. These biogenic sediments are largely supplied to the motus in response to cyclone events when material broken during the storm is gradually transported towards the shoreline. This fresh supply of the sediments is typically seen in a number of forms: as banks of storm rubble on the reef flat, boulder tracts on the reef flat or new accumulations of coral rubble or sand on the ocean beaches (NIWA, 2015B). In some instances, these accumulations have created new land, as occurred following the Great Cyclone of 1914 when substantial accretion of land occurred along the southern part of Atafu (Note that this area is still amongst the lowest parts of Atafu – see also section 2.2).

Storm activity also plays an important role in building up the elevation of the village motus. When water overtops the ocean barrier of the motu during storm events, it transports sand and coral rubble from the beach and deposits it onto the land, which over time builds up ground elevation across the motu. NIWA (2005A) quotes archaeological research by Best (1988) to suggest that the motu were the present-day villages of Atafu and

Fakaofo are situated were a thousand years ago between one and two metres lower than the present levels, suggesting that coral production of the fringing reef would have been in the order of 0.2 to 0.4m^3 per metre per year.

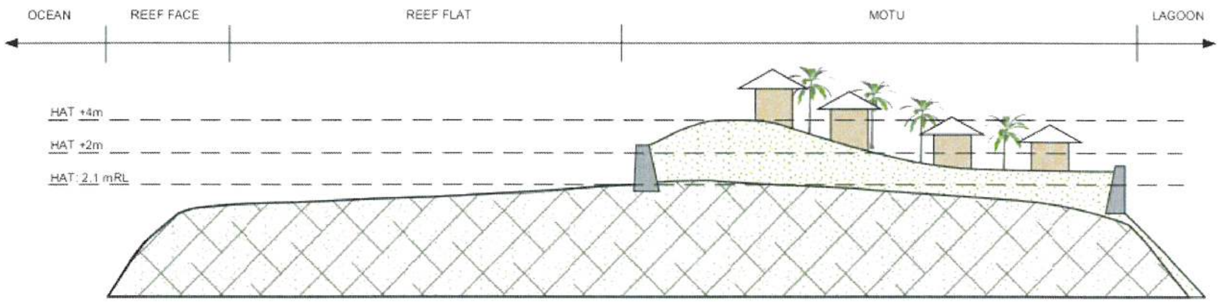


Figure 2-5 Schematic cross-section of a typical motu in Tokelau

2.3 Topography

A ground level survey of the village motus was undertaken by AVMAP in November and December of 2019. The ground level surveys were carried out using aerial survey techniques with remotely operated aircraft. Ground control points were established on each of the atolls to ground truth the aerial survey.

Digital elevation models (DEMs) containing the ground levels were developed for Atafu, Nukunonu, Fale, Fenua Fala, Pataliga Island and Te Afua o Pope Island, which are presented in Appendix A.

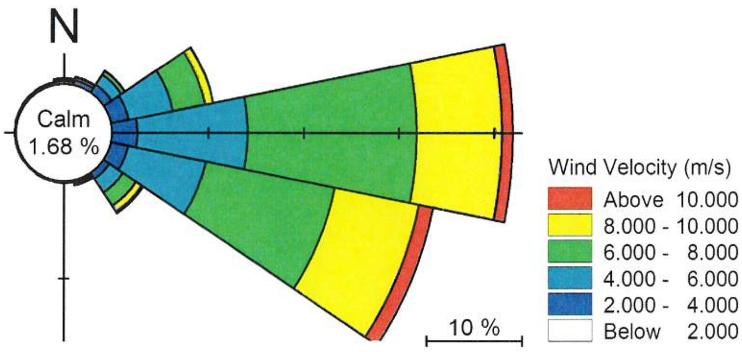
These DEMs show that generally the ground level on each motu slopes relatively steeply up to a defined crest from the reef-flat on the ocean side, after which the ground tends to slope mildly back down towards the lagoon. Crest levels on the motu are typically about 3 to 4m above HAT (highest astronomical tide level). The ground levels on the lagoon side are generally less than 2m above HAT, with some areas on Nukunonu and Atafu less than a metre above HAT. Typically, the reef flat around the motu has an elevation between mean sea level and the high-water mark.

2.4 Meteorology

Tokelau experiences a hot, humid tropical climate that generally remains stable year-round. Air temperatures are on average approximately 30°C, with only small seasonal changes usually less than 1°C.

Ambient wind conditions are dominated by the prevailing trade winds that predominantly blow from the south to southeasterly direction during the dry season (May to October) and the north-east to easterly direction during the wet season (November to April). Wind speeds are typically between 4 and 8 m/s (refer to Figure 2-6).

El-Nino Southern Oscillation (ENSO) effects have a strong influence over the climate on Tokelau. During El Nino events, the South Pacific Convergence Zone (SPCZ) moves closer to the equator, which results in warmer and wetter conditions on the atolls, together with a weakening of the trade winds. In addition, the likelihood of tropical cyclones increases significantly during El Nino conditions (NIWA, 2005A).



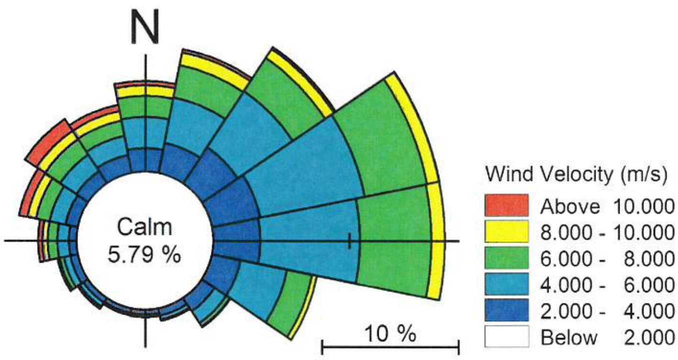


Figure 2-6 Ambient wind climate around Nukunonu, based on NCEP's CFSR2 data (1979- 2010) - Dry season (top) and wet season (bottom)

2.5 Tropical cyclones

A tropical cyclone is a rapidly rotating storm system with an intense low pressure centre and strong winds that circle around the eye of the cyclone in a clockwise direction (on the southern hemisphere). The eye is the area at the centre of the cyclone with the lowest atmospheric pressure at sea level, typically 20 to 50 km in diameter. Tropical cyclones can generate strong winds over extended areas of the ocean as cyclones can cover areas well over 1,000 km in diameter.

NIWA (2005A) provide an analysis of historical cyclones which indicates that about 33 cyclone events have passed Tokelau within a 600km radius during the period between 1969 and 2005, and of these events, approximately six events have caused major damage to the village motus. They observed that there are two generic cyclone trajectories that have led to major damage on the village motus:

- The first trajectory type is characterised by historical events as TC Tusi, Ofa, Val and Percy and two cyclones that affected Tokelau in 1941. These tend to form to the west of Tokelau between Tokelau and the southern atolls of Tuvalu and start tracking in an easterly direction towards Tokelau before turning and moving in a south easterly direction, passing within 500km from Tokelau. These events typically generate strong north to north westerly winds and large waves that mostly affect the western and north-western parts of the atolls.

- The second trajectory type is characterised by historical events as TC Esau and Wini and the cyclone of January 1966. This type of cyclone is more distant, and tracks in a general easterly direction, well south of Tokelau (around the latitude of Wallis and Futuna, Samoa and American Samoa). These events rarely cause damaging strong winds on the atolls, but can result in large waves generated by winds enacting over the large open fetches to the west of Tokelau. These events typically generate waves that affect the atolls for a considerable period of time (multiple days).

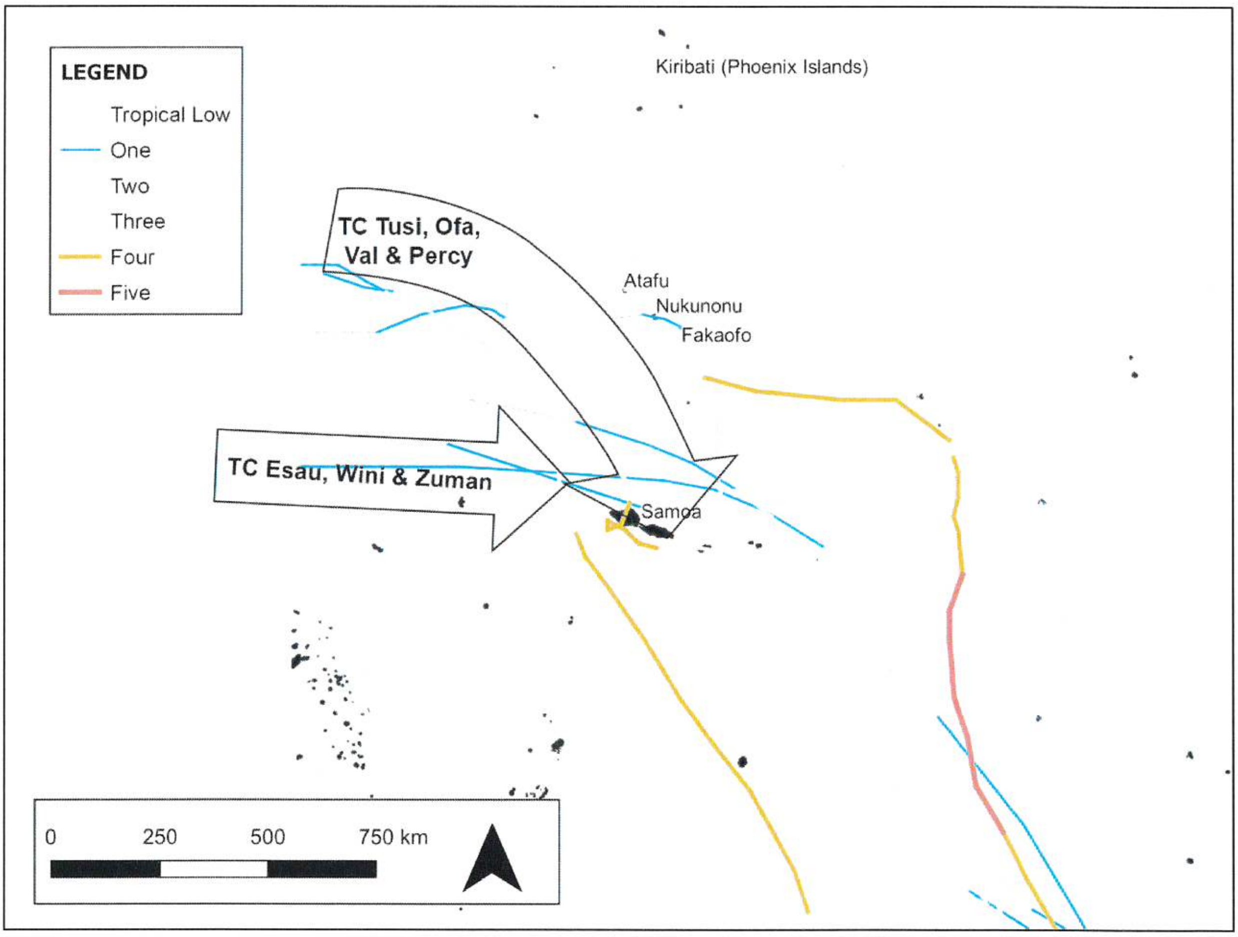


Figure 2-7 Summary of cyclone trajectories that have led to major damage on the village motu (From NIWA, 2005A)

2.6 Wave climate

There are no known wave measurements anywhere close to Tokelau. However, the general wave climate can be obtained from global wave models, such as NOAA's Wave Watch III global hindcast model.

Figure 2-8 presents wave rose plots of the seasonal wave climate in terms of significant wave height and direction for an offshore location around the atolls. These wave roses demonstrate that the wave climate in Tokelau is dominated by waves generated by the prevailing trade winds and occasionally influenced by tropical storms and cyclones.

There is a distinct seasonality in the ambient offshore wave climate, with shorter period waves (peak period of 6 to 10 seconds) from south to southeasterly direction being dominant during the dry season (May to October) and somewhat longer period (8 to 14 seconds) from a more variable direction prevalent during the wet season (November to April). Significant wave height typically ranges between 1 and 2m, and rarely below 0.5m.

Waves with a significant wave height above 3m are relatively rare and generally occur only during the wet season.

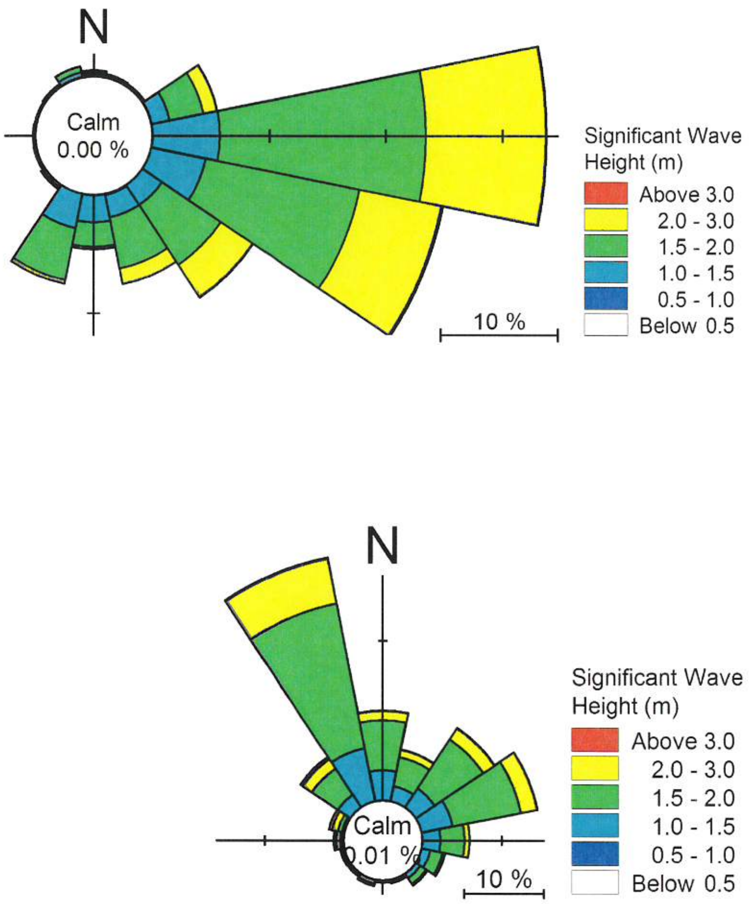


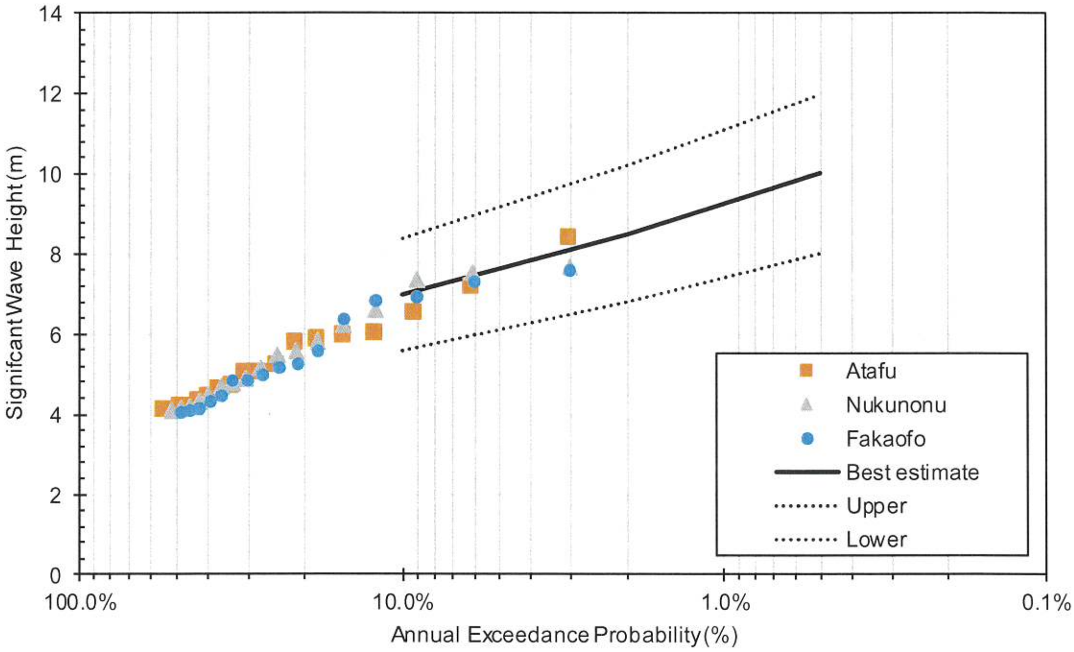
Figure 2-8 Ambient offshore wave climate around Nukunonu, based on NOAA's Wave Watch 3 data (1979- 2010) – Dry season (top) and wet season (bottom)

2.6.1 Extreme wave climate

Extreme offshore wave conditions were estimated by analysing a dataset of the major wave events that have occurred in Tokelau between 1979 and 2010. The dataset was created by supplementing wave events captured by NOAA's Wave Watch III global hindcast model with wave conditions during selected cyclone events, modelled with a cyclone wind-wave model (Refer to Appendix C).

Figure 2-9 presents a plot of the non-directional offshore wave height statistics, based on this dataset.

Figure 2-9 Non-directional offshore extreme wave height statistics for village motus



2.7 Water level fluctuations

2.7.1 Tides

As part of this study, water level loggers were installed at the ocean-side and lagoon-side of each atoll. Water level data recorded at Fakaofo during the period between 21 November 2018 and 8 March 2019 and at Atafu during the period between 28 November 2018 and 18 February 2019 was analysed to determine tidal water level fluctuations at the atolls and establish the main tidal constituents that comprise a tide.

Figure 2-10 shows the water level recordings at Fakaofo and Atafu during a selected period in December 2018, illustrating that the tide in Tokelau is semi-diurnal with a moderate inequality between successive highs. The tidal range on the ocean-side is typically about 1.0m during spring tides and about 0.6 m during neap tide conditions. The tidal range at Atafu is marginally larger than that at Fakaofo.

The tidal range in the lagoons is significantly smaller due to the controlling effect of the reef flat which forms a barrier at approximately 1.3-1.4mRL (roughly mean sea level in the ocean).

The Highest Astronomical Tide (HAT) in Atafu is estimated to approximately +2.1mRL.

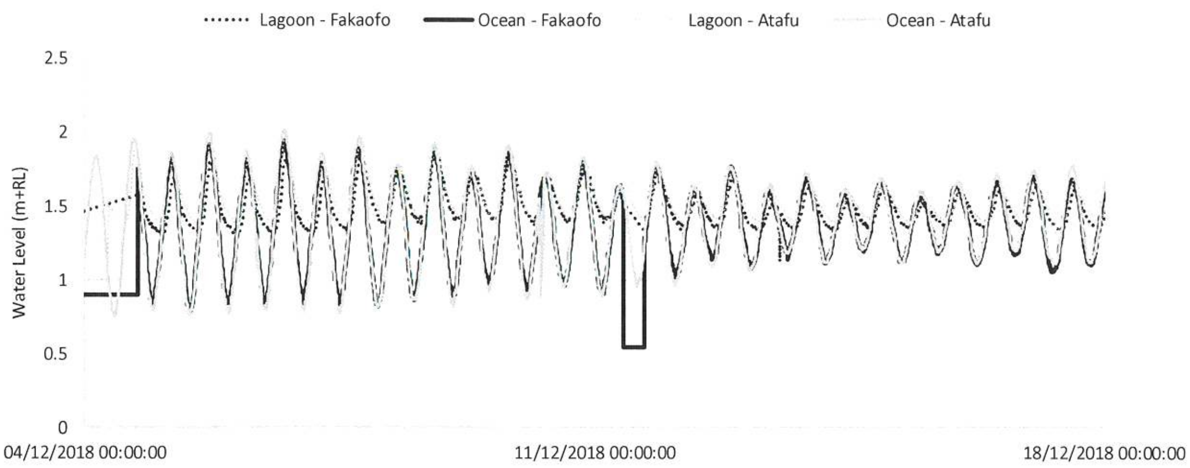


Figure 2-10 Recorded water levels at Atafu and Fakaofo during December 2018

2.7.2 Long-term fluctuations in mean sea levels

El-Nino Southern Oscillation (ENSO) cycles not only have a strong influence over the climate on Tokelau, they also have a notable influence on sea surface temperatures and mean sea levels in the region. Strong El Nino events result in a lowering of the mean sea level. El Nino – La Nina cycles tend to last between 2 and 5 years.

The Interdecadal Pacific Oscillation (IPO) is similar to ENSO in that it is a change in climate related to sea surface temperatures. However, IPO events tend to last much longer, 20-30 years, and the changes manifest themselves mainly in the northern and southern Pacific with only secondary characteristics experienced in the tropics, the opposite to ENSO.

Long-term sea-level fluctuations have previously been analysed by NIWA (2015A). They concluded that mean sea levels around Tokelau may experience fluctuations of up to about 0.5m due to long-term variability in the climate. Figure 2-11 presents the recorded monthly-mean sea levels at Funafuti in Tuvalu and shows a similar variability. The figure also shows that water levels at Funafuti during the period between November 2018 and March 2019 were above the long-term average sea water level at this location.

Based on this, it is not likely that the mean water level at Tokelau during the period when the water levels shown in Figure 2-10 were collected were significantly below their long-term average sea water level.

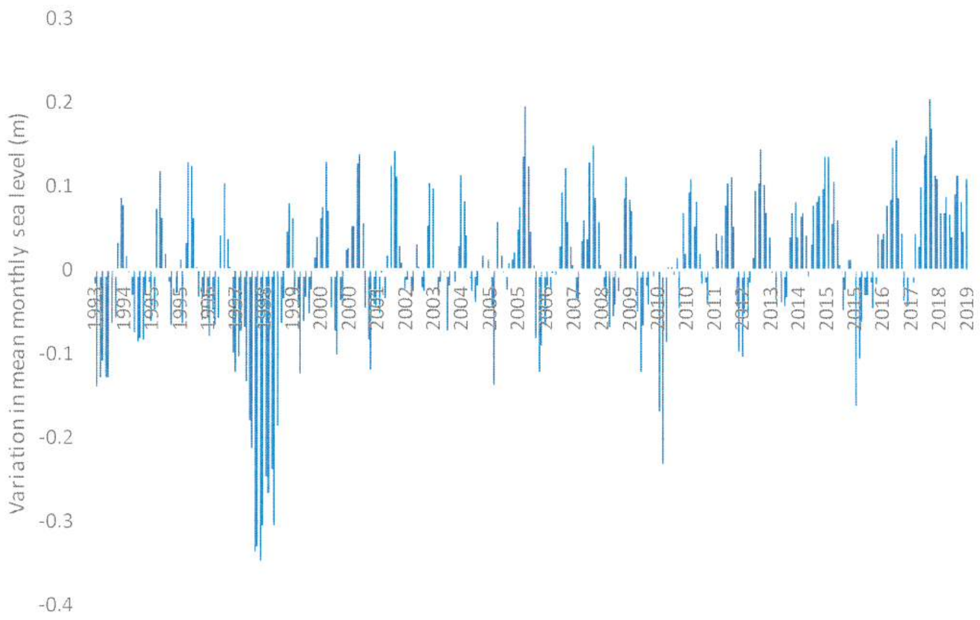


Figure 2-11 Variation in the monthly mean water levels at Funafuti (Tuvalu) between 1993 and 2019

2.8 Sediment transport

NIWA (2005B, 2005C and 2005D) provide a description of the overall sediment transport regime at each village motu.

The primary natural source of sediment for the village motus are the fringing reefs. This supply of the sediments is generally greatest following severe storm events and can be seen in a number of forms: as banks of storm rubble on the reef flat, boulder tracts on the reef flat or new accumulations of coral rubble or sand on the ocean beaches (NIWA, 2015B).

Once supplied to the nearshore areas, the sediment becomes subject to littoral transport processes, which largely can be regarded as involving cross-shore and longshore sediment transport processes.

Cross shore transport involves erosion from the upper beach ridge during episodic storm events, with the sediment being transported to the reef flat as well as back onshore towards land. Generally, the sediment that is deposited on the reef flat will gradually be transported back to the beach after the event. However, the sediment that became deposited behind the upper beach ridge is much more unlikely to return to the beach system, and plays a key role in building up the elevation of the village motu.

Longshore sediment transport results predominantly from waves on the reef flat breaking at an angle to the shore. Wind and ocean currents may also contribute to the generation of longshore sediment transport. In principle, waves during storm events as well as ambient (day-to-day) conditions both play a role in the movement of sediment along the shore. However, along many shoreline locations in Tokelau, sediment is usually confined to beach areas above high tide level, and therefore sediment transport at these locations is generally limited during day-to-day conditions.

A beach may remain stable (without net recession or accretion) where the longshore sand transport is uniform along the coast. However, where there are differentials in the rates of longshore transport, including any interruption of the sand supply to an area, then the beach will erode or accrete in response. Activities that disrupt or change the longshore movement of sediment include building seawalls at inappropriate locations (so they interrupt the alongshore movement of sediments) and the mining of beach material.

3. Coastal Hazards Assessment

3.1 Introduction

A coastal hazard assessment is an essential component of identifying and understanding coastal risks in the context of overall risk management. This chapter outlines the coastal hazard assessment that has been undertaken by Jacobs to delineate areas on the village motus that may be exposed to coastal hazards and determine the level of exposure. Coastal hazards considered in the coastal hazard assessment include coastal inundation and coastal erosion.

The definition of coastal hazards inherently involves uncertainty relating not only to coastal hazard processes but also to climate change variables. Irrespective of climate change, coastal hazards have always presented a challenge to land managers given the infrequent nature but potentially devastating impacts of events. Existing coastal hazards at the village motus are particularly complex, due to the dominance of coastal inundation events and the complexity of the physical processes and interactions that results in elevated water levels and wave overtopping.

Given the complexity of the coastal inundation processes, in combination with limited meteorological, oceanographic and topographic data, careful consideration is required in terms of the expected level of uncertainty in hazards identification and prediction. Added to this is the uncertainty regarding expected future climate conditions and the timeframe over which climate variables may change, as well as the uncertainty of response by the atolls to these changes.

A risk-based approach has been adopted to assess the coastal hazards risks in Tokelau, as such an approach is useful when dealing with high degrees of uncertainty in processes and information. The approach allows consideration of a range of events, their likelihood, consequence and thus the overall level of risk, rather than providing a single answer with absolute and potentially unfounded accuracy.

As coastal hazards are likely to change over time as a result of climate change effects, hazard levels have been assessed for a number of planning periods in this study. The adopted planning horizons are immediate (2019), 2050 and 2100.

3.2 Scale of likelihood

Based upon the best practice guidelines for risk management, including ISO 31000:2018 and AS5334:2013, this coastal hazard study has adopted a scale of likelihood that covers four likelihoods: 'almost certain', 'possible', 'unlikely' and 'rare'. A description of the likelihood classes is provided in Table 3-1.

It is important to recognise that the likelihood scale reflects a qualitative interpretation of hazard occurrence because there are no suitable methods for defining quantitative probabilities for coastal hazard levels in Tokelau due to limitations of available data and a lack of understanding of the key physical processes that are responsible for coastal inundation in the study area.

Table 3-1 Description of likelihood classes

Likelihood	Event-related risks	Long term risks (eg. risks related to climate change effects)
Almost certain	Events that occur 'frequently' (i.e. about every year or so	Has a greater than 90% chance of occurring in the identified time period if the risk is not mitigated
Possible	Events that occur 'sometimes' (i.e. there is about a 50/50 chance of occurrence with a 10-year period)	Has an approximate 50/50 chance of occurring in the identified time period if the risk is not mitigated
Unlikely	Events that occur 'very infrequently' (i.e. less than once in a lifetime).	Has a 10–30% chance of occurring in the future if the risk is not mitigated
Rare	Events that are 'highly unlikely' to occur, except in extreme circumstances (i.e. less than once in a 200 years).	May occur in exceptional circumstances, i.e. less than 5% chance of occurring in the identified time period if the risk is not mitigated

3.3 Climate change projections relevant to assessment of coastal hazard risks

The fifth Assessment Report (AR5) provides the latest projections of potential changes in the climate by the Intergovernmental Panel on Climate Change (IPCC, 2013).

The projections in AR5 are based on a hierarchy of climate models and a set of anthropogenic settings, called Representative Concentration Pathways (RCPs). The RCPs are labelled according to the range of radiative forcing values in the year 2100 relative to pre-industrial values and represent the likely climate futures under a range of possible greenhouse gas emission scenarios:

- RCP2.6 applies a radiative forcing value of +2.6 W/m^2 by 2100 and represents a scenario of reduced GHC emissions.
- RCP4.5 and RCP6 apply radiative forcing values of +4.5 and +6.0 W/m^2 by 2100 and represent stabilisation scenarios.
- RCP8.5 applies a radiative forcing value +8.5 W/m^2 by 2100 and represents a high emission scenario.

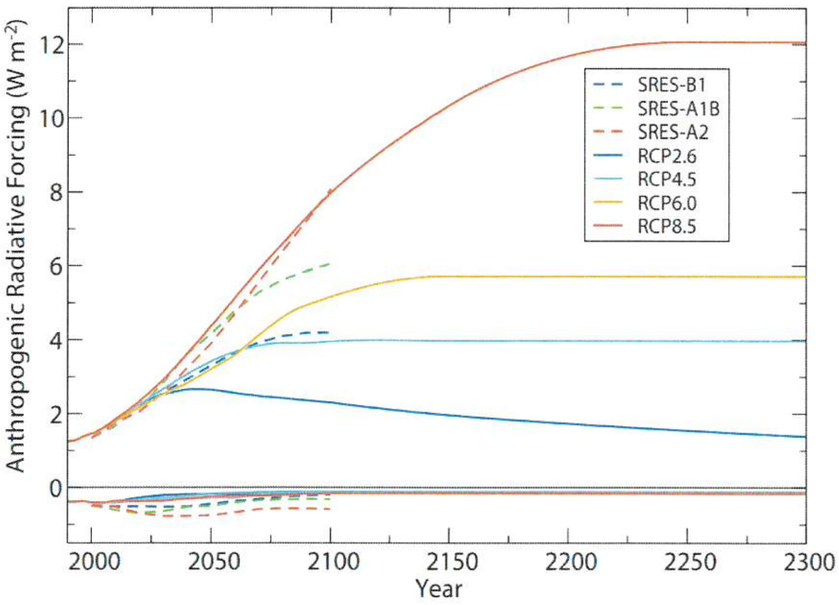


Figure 3-1 : Anthropogenic radiative forcing trajectory of each RCP (source: IPCC, 2013)

3.3.1 Mean sea level rise

The global average rate of sea level rise measured over the last century was 1.7 mm/year (Church et al., 2010), but has been rising at a higher rate during recent decades. CSIRO/ARECRC (2012) analysed global tidal gauge data and satellite observations, and found that the average rate of mean sea level rise has been approximately 3.1 ± 0.4 mm/year since 1992.

Figure 3-2 presents the global sea level rise projections for the four principal greenhouse gas emission scenarios, as provided in AR5. Projections for 2100 (relative to 1986-2005 levels) are in the ranges of 0.28 to 0.61 m for RCP2.6, 0.36 to 0.71 m for RCP4.5, 0.38 to 0.73 m for RCP6.0, and 0.52 to 0.98 m for RCP8.5.

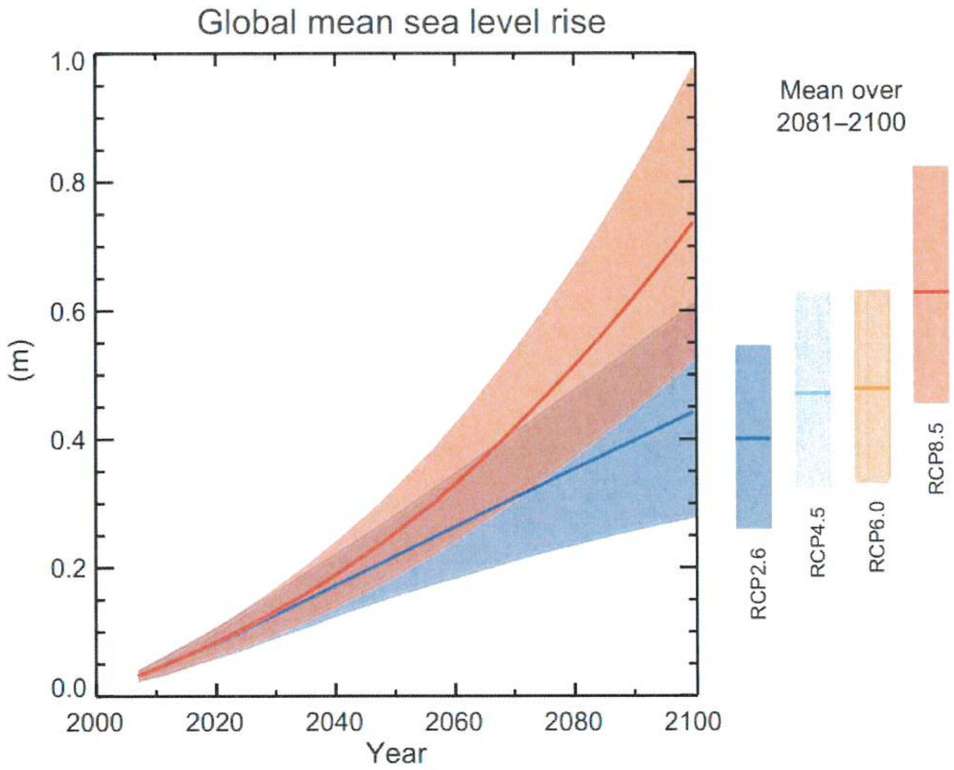


Figure 3-2 Projected global mean sea level rise during the 21th century (source: IPCC 2013

Table 3-2 Multi centennial global mean sea level rise projections (IPCC, 2013)

Scenario	2200	2300
'Low' GHG concentration	0.35 to 0.72 m	0.41 to 0.85 m
'Medium' GHG concentration	0.26 to 1.09 m	0.27 to 1.51 m
'High' GHG concentration	0.58 to 2.03 m	0.92 to 3.59 m

Regional sea level changes may differ significantly from a global average, showing complex spatial patterns, which result from dynamic ocean processes, movements of the sea floor, and changes in gravity due to water mass redistribution (land ice and other terrestrial water storage) in the climate system. Analysis of recent mean sea levels have indicated that sea level rise within the Tokelau region has been somewhat higher than the global average in recent decades (Hoegh-Guldberg and Bruno, 2010, Church et al., 2006, Figure 3-3). It has been suggested that rates of mean sea level rise could be higher at low-to-mid latitudes (IPCC, 2013), however considerable uncertainties remain in the regional distribution of global sea level rise effects.

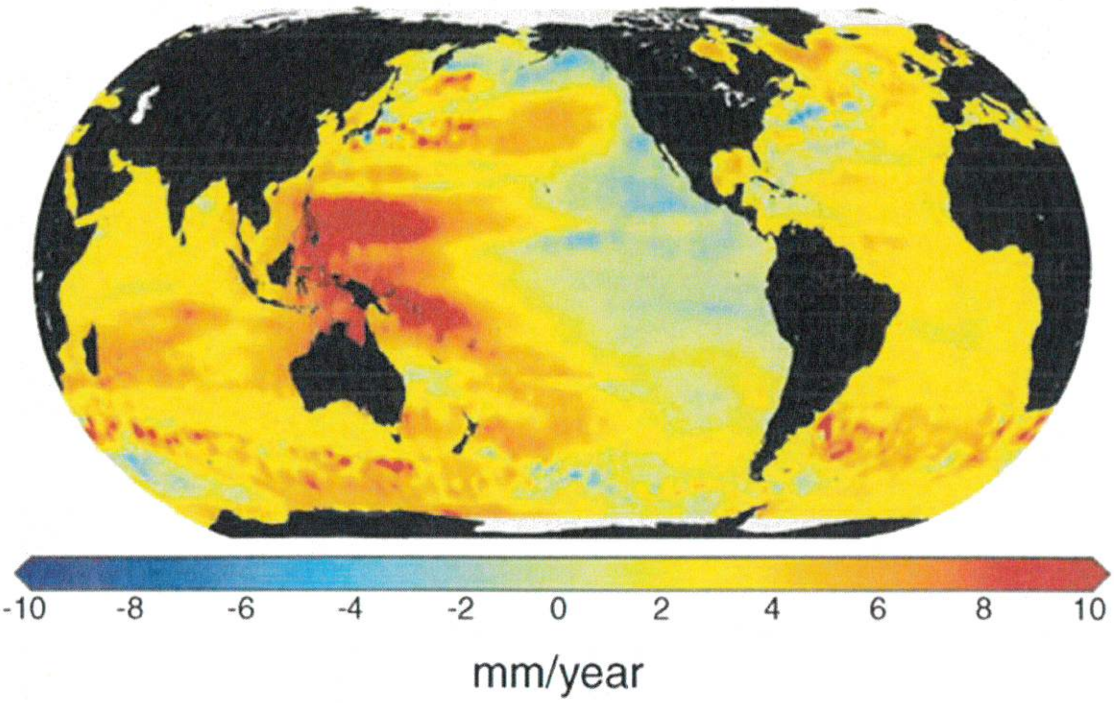


Figure 3-3 Estimates of recent sea level rise across the world (Hoegh-Guldberg and Bruno, 2010)

Considering the above information, the sea level allowances presented in Table 3-3 have been adopted in this coastal hazard study. The 'almost certain' sea level rise estimates have been based on the lower bound projections (5th percentile) of the low emission scenarios in AR5, the 'possible' estimates on the mean of the high emission scenario projections, and the 'unlikely' estimates on the upper bound projections (95th percentile) for the high emission scenario.

There is a chance that sea level rise may exceed the range of current IPCC projections. As such, a higher sea level rise value should also be investigated for design of essential infrastructure that is highly incompatible with coastal hazards (e.g. cyclone shelters and hospitals). A 50% faster rate than the 'unlikely' projections is considered an appropriate 'worst case' or 'rare' estimate for the purposes of this study.

Table 3-3 Adopted mean sea level rise values (m relative to 2019 levels)

Likelihood	2050	2100
Almost Certain	0.17m	0.28m
Possible	0.30m	0.74m
Unlikely	0.38m	0.98m
Rare	0.57m	1.47m

3.3.2 Tropical Cyclones

Any increase in intensity or frequency of tropical cyclone in the region due to changes in the climate could mean that the atolls become more exposed to coastal hazard events. Increases in storm intensity are likely to increase wave heights and water levels during such event, and coupled with a rise in sea level, could exacerbate coastal inundation levels and result in beaches experiencing greater erosion of sand during individual storms.

AR5 suggests that it is likely that the global frequency of tropical cyclones will either decrease or remain essentially unchanged while the mean storm intensity is projected to increase. Based on analysis by Knutson et al. (2010), AR5 suggests an increase of +2 to +11%. in the mean intensity by 2100 (as measured by maximum wind speed).

Considering the above, the allowances presented in Table 3-3 have been adopted in this coastal hazard study to incorporate the potential effects of changes in the tropical cyclone climatology during the 21st century.

Table 3-4 Adopted allowances for potential increases in tropical cyclone intensity (%relative to 2019 levels)

Likelihood	2050	2100
Almost Certain	0%	2%
Possible	0%	4%
Unlikely	2%	7%
Rare	5%	11%

3.3.3 Wave Climate

Changes in ocean wave conditions are determined by changes in the major wind systems.

The Tokelau region is projected to experience a marginal reduction in prevailing average significant wave height, combined with a slight clockwise rotation of the mean wave direction and a reduction in the mean wave period. The average significant wave height during the period January-March (when north-north-west is the dominant direction) is projected to decrease by approximately 5% whilst the average significant wave height during the period July-September (when east is the dominant direction) is projected to increase by approximately 5%, albeit there is low confidence in these projections (IPCC, 2013).

Given this lack of confidence, changes to ambient wave climate as a result of climate change impacts during the 21st century have not been investigated as part of this coastal hazard study. However, potential changes in the extreme wave heights associated with projected increases in the tropical cyclone intensities have been included in this study.

Numerical modelling undertaken as part of this study (Refer to Appendix C) has indicated that extreme offshore wave heights could increase by up to 20% by 2100, compared to present-day climate conditions. The effects of such changes in the extreme wave climate have been incorporated in the coastal hazard assessment.

3.3.4 Fringing Reef

The fringing reef of the atolls have a significant influence on the exposure of the motus to wave action. The reef provides the dominant source of sediment supply to the motus. Each motu is predominantly made of sediments that are derived from skeletal remains and breakdown of calcareous organisms, such as coral and coralline algae that live on the fringing reefs.

The major climate-related impacts on the fringing reef are predominantly driven by sea level rise, ocean warming, and ocean acidification. The impact of sea level is related mostly to the capacity of coral to keep up with the vertical rise of the sea. The potential vertical growth rate of coral reefs is strongly influenced by the types and health of coral living on the reefs, both of these aspects are largely unknown for the fringing reefs of

Tokelau. However, it is understood in general that many coral reefs will be unable to keep growing fast enough to keep up with rising sea levels (IPCC, 2013).

Ocean warming and acidification have synergistic effects in several reef builders (Reynaud et al., 2003; Anthony et al., 2008). They will increase coral mortality, reduce calcification and the strength of calcified organisms, and enhance skeletal dissolution (Manzello et al., 2008; high confidence). When atmospheric carbon dioxide is absorbed into the ocean, it reacts to produce carbonic acid, which increases the acidity of seawater and diminishes the amount of a key building block (carbonate) used by coral to make their skeletons and may ultimately weaken or dissolve them. Ocean acidification has a number of other impacts, many of which are still poorly understood

Warmer temperatures cause coral bleaching, which weakens those animals and makes them vulnerable to mortality. Coral bleaching and mortality is projected to increase in frequency and magnitude over the next decades (very high confidence).

Considering the above, the coastal hazard assessment has considered the effects of two reef development scenarios with respect to the fringing reef, namely

- the fringing reefs are able to keep up with rising sea levels and thus the reef crest of the fringing reefs grows at a rate equal to the rate of mean sea level rise; and
- the fringing reefs remain at their present level (around mean low water springs), as coral growth is substantially hampered.

In both reef development scenarios, it is assumed that the overall morphology of the remaining atoll will remain unchanged during the 21st century (i.e. It is assumed that there will be no significant changes in the layout and levels of the motus into the future).

3.4 Coastal Inundation

Coastal inundation is the flooding of motu land by sea waters. There are two impacts from coastal inundation that comprise the coastal inundation hazard:

- **Temporary inundation by storms:** During storm events, elevated sea water levels may directly result in the inundation of low-lying land, or cause ocean waves to run up against and overtop the existing coastal barriers. This type of inundation is episodic and so is not expected to result in prolonged flooding, but the forces of moving water, particularly where significant wave action exists, can be a hazard to people, and cause damage to buildings, coastal defence infrastructure and other structures;
- **Permanent tidal inundation:** Permanent tidal inundation refers to flooding of coastal land by tidal water levels. At present, parts of the village motus flood during high tide. With projected sea level rise, it is expected that high tides will become higher. Increased high tide levels will affect a number of low-lying parts of the study area that are hydraulically connected with the ocean or lagoon. Due to the persistent nature of such shift in tidal water levels, permanent tidal inundation represents a distinctly different hazard compared to the episodic nature of temporary inundation, likely requiring a different risk management approach.

The magnitude of the hazard to the community and its assets associated with coastal inundation can be described by using thresholds related to

- the stability of people as they walk through flood waters (ie the capacity to evacuate),

- the potential damage that flood water may cause to buildings and other built assets, and
- the ability of critical infrastructure to maintain service.

Such thresholds are typically defined by a combination of the depth of flooding, the magnitude of the flow discharge (so called 'depth-velocity products') and the flow speed of the overland currents. In this study, the flood hazard classification presented in Table 3-5 and Figure 3-4 has been used to define coastal inundation hazards. This flood hazard classification is based on a flood risk management guideline by the Australian Government (2014).

Table 3-5 Adopted Flood Hazard Categories

Hazard category	Description
Low hazard	Adults can wade, evacuation typically possible, structural damage limited
Moderate hazard – Wading Unsafe	Wading unsafe, structural damage limited
High hazard - Depth	Unsafe to people, structural damage possible
High Hazard– Floodway	Unsafe to people structural damage possible
Extreme hazard – Depth	Very unsafe to people, damage to structures possible, most building types vulnerable to failure
Extreme Hazard– Floodway	Very unsafe to people, damage to structures highly likely, most building types vulnerable to failure

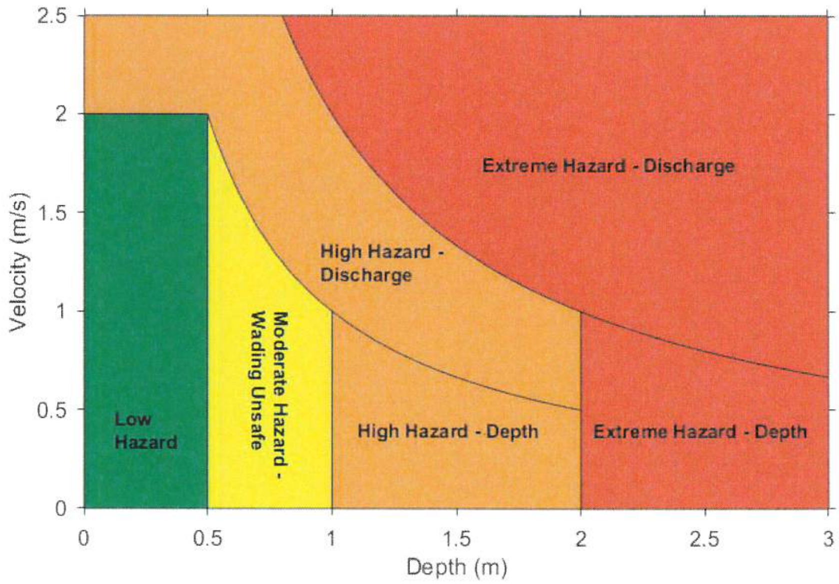


Figure 3-4 Definition of Adopted Flood Hazard Categories

3.4.1 Temporary coastal inundation by storms

For atoll islands such as Atafu, Nukunonu and Fakaofo, the primary forces driving temporary coastal inundation are tides and ocean waves with the largest impacts occurring when large waves coincide with high sea water levels. When waves break on fringing reefs, they generate wave setup, which raises mean water levels over the reef, and contributes to the generation of low-frequency waves on the shoreline called surf beat (water level fluctuations with typical periods of around 1 to 5 minutes, associated with wave grouping).

Other factors influencing temporary inundation, to a smaller extent, are elevated sea levels due to interdecadal and decadal influences such as El Nino Southern Oscillation (ENSO) and Interdecadal Pacific Oscillation (IPO) cycles and storm surge (i.e. the increase in sea level due to the reduction in atmospheric pressure combined with the influence of wind stress during storm events).

At the shoreline, the maximum vertical elevation reached by the sea depends on wave run up (or swash). Where the crest height of the coastal barrier is less than the wave run-up level, ocean waves will overtop the shoreline and may cause flooding of the land behind. The process of wave overtopping is very random in time and volume. When large waves coincide with a peak in the surf beat, a large amount of water may be pushed over the crest in a short period of time, less than a wave period, whilst during lower water levels or lower waves no overtopping occurs. Wave setup on the reef flat has the potential to drive substantial currents over the reef and can generate elevated water levels in the lagoon.

To allow the hazards associated with temporary coastal inundation by storms to be assessed, numerical modelling using the wave-flow modelling software SWASH was undertaken to simulate wave propagation (i.e. short and infragravity waves) and water levels across the reef in order to estimate extreme water levels along the shoreline and determine the wave overtopping regime for a range of storm conditions and motu geometries. Details on the SWASH modelling are provided in Appendix C.

The SWASH modelling indicates that mean wave setup on the reef flat during minor storm events (i.e. "almost certain" likelihood events) may be in the order of 1.0m and up to 2.5 - 2.7m during severe events (i.e. "rare" cases). Extreme wave setup values (2% exceedance values) are predicted to be in the order of 2m during minor storm events (i.e. "almost certain" likelihood events) and up to approximately 4.5m during severe events (i.e. "rare" cases).

Due to the magnitude of the wave setup on the reef flat, freeboard at the ocean barrier can become little to none. This can result in very large overtopping rates over the island's crest with modelled extreme flow discharge rates well above $1m^3/s/m$ at the crest during some simulations (refer to Figure 3-5). The SWASH model results further illustrate that extreme overtopping rates generally reduce significantly behind the crest, as overland waves are attenuated, and a more constant (in time) flow establishes.

The wave setup on the reef flat is likely to also significantly elevate water levels in the lagoon. For the purpose of assessing the temporary coastal inundation hazards, extreme water levels in the lagoon have been conservatively assumed to be equal to the mean water level on the reef flat.

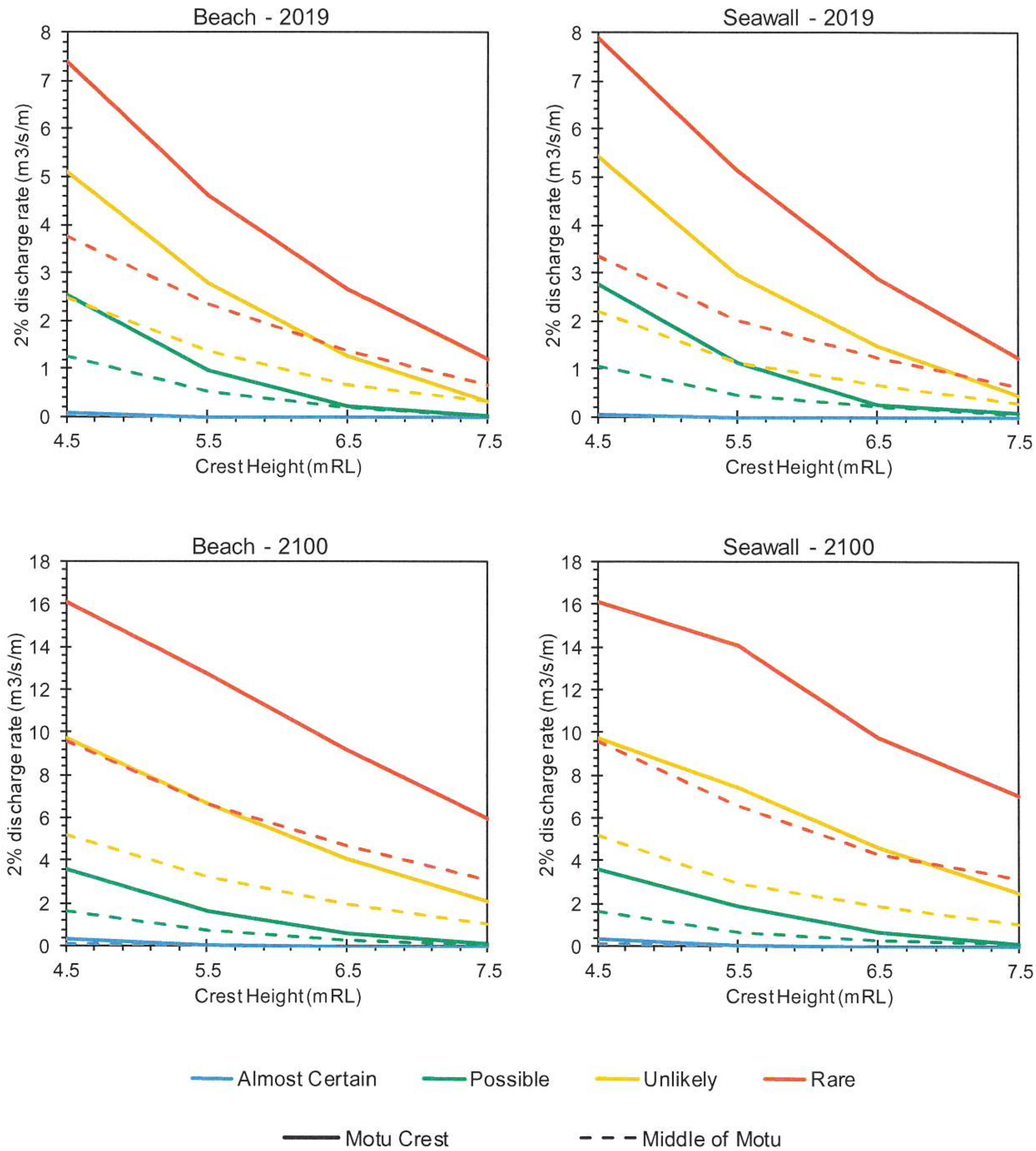


Figure 3-5 Extreme (2%) overtopping discharge rate (m3/s/m) at the motu crest and at the middle of the motu

Based on the SWASH modelling, the three flood zones can be distinguished on the motus during severe storm events (also see Figure 3-6), namely:

- **A wave impact zone:** The zone seaward and immediately behind the barrier crest where water is highly dynamic due to the presence of waves. Often, this zone is hazardous to people and buildings due to the large instantaneous flow currents.

- **An overwash discharge zone:** The zone located behind the wave impact zone that drains the water that washes over the crest of the motu. The flood conditions in this zone show significantly less temporal variability compared to the wave impact zone.

- **A backwater flooding zone:** The zone on the leeward side of the motu where flood conditions are dictated by elevated water levels in the lagoon. The flood conditions in this zone are generally characterised by lower flow velocities and larger flood depths.

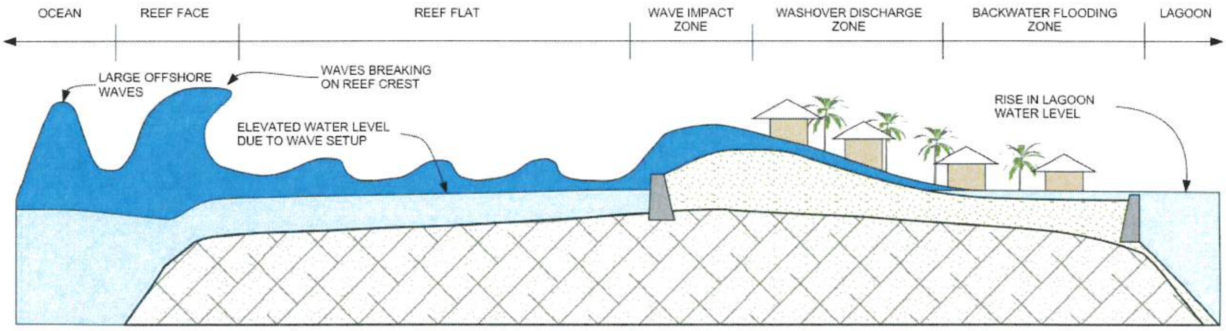


Figure 3-6 Flood zones across the motu during severe storms

Temporary coastal inundation hazard maps were compiled by extracting the overtopping flow discharge rates, depth and water levels from the relevant SWASH model results and using these to define flood conditions across the motu. The values associated with the 2% overtopping rate (i.e. the discharge which is exceeded 2% of the time during the peak of the storm) were used for this purpose. The water level associated with the modelled mean wave setup was superimposed to account for potential backwater flooding from the lagoon. The temporary coastal inundation hazard maps are presented in Appendix D.

These hazards maps show the following:

Atafu

- Under present-day climate conditions, parts of the village motu could experience some flooding during minor storm events ('Almost certain' likelihood). However, flood conditions are generally such that they don't present an acute hazard to people or buildings, except a narrow zone directly behind the ocean and lagoon shoreline, parts of the peninsula between the school and the hospital and the area around the Matagi hotel.

- During moderate storm events ('Possible' likelihood), an increasing part of the motu is predicted to experience a high flood hazard. This includes most land south of the Henetenali Hall and a substantial zone along the ocean and lagoon shoreline. These areas will be unsafe to people and buildings are likely to experience damage.

- During a once-in-a-lifetime event ('Unlikely' likelihood case), the vast majority of the village is predicted to be high or extreme hazards, meaning that most areas are unsafe to people and buildings are likely to experience damage.

- During an extreme event ('Rare' likelihood case), virtually the entire motu is predicted to be extreme hazard and thus most buildings in the village will experience substantial damage or fail.

- Climate change impacts are predicted to exacerbate existing hazard levels. In particular, the impacts of a once-in-a-lifetime event ('Unlikely' likelihood case) is likely to worsen significantly.

Nukunonu

- Under present-day climate conditions, parts of the village motu could experience some flooding during minor storm events ('Almost certain' likelihood). However, flood conditions are generally such that they don't present an acute hazard to people or buildings, except a narrow zone directly behind the ocean and lagoon shorelines, including areas around the Hagato Maletino Tepole Talikilagi (meeting hall) and Luana hotel.

- During moderate storm events ('Possible' likelihood), parts of the motu, including substantial parts of Motusage and areas to the north of the cemetery are predicted to experience a high flood hazard. These areas will be unsafe to people and buildings are likely to experience damage.

- During a once-in-a-lifetime event ('Unlikely' likelihood case), the majority of the village is predicted to be high or extreme hazards, meaning that most areas are unsafe to people and buildings are likely to experience damage.

- During an extreme event ('Rare' likelihood case), virtually the entire motu is predicted to be extreme hazard and thus most buildings in the village will experience substantial damage or fail.

- Climate change impacts are predicted to exacerbate existing hazard levels. In particular, the impacts of a once-in-a-lifetime event ('Unlikely' likelihood case) is likely to worsen significantly.

Fale

- Under present-day climate conditions, parts of the village motu could experience some flooding during minor storm events ('Almost certain' likelihood). However, flood conditions are generally such that they don't present an acute hazard to people or buildings, with the exception of a narrow zone directly behind the ocean and lagoon shorelines and the areas around the storage sheds near the wharf.

- During moderate storm events ('Possible' likelihood), a zone of about 40m behind the motu's sea defence line is predicted to experience a high or extreme flood hazard. These areas will be unsafe to people and buildings are likely to experience damage.

- During a once-in-a-lifetime event ('Unlikely' likelihood case), the majority of the village is predicted to be high or extreme hazards.

- During an extreme event ('Rare' likelihood case), virtually the entire motu is predicted to be extreme hazard and thus most buildings in the village will experience substantial damage or fail.

- Climate change impacts are predicted to exacerbate existing hazard levels. In particular, the impacts of a once-in-a-lifetime event ('Unlikely' likelihood case) is likely to worsen significantly.

Fenua Fale

- Under present-day climate conditions, parts of the village motu could experience some flooding during minor storm events ('Almost certain' likelihood). However, flood conditions are generally such that they don't present an acute hazard to people or buildings, with the exception of a narrow area immediately behind the wharf and a strip of land between the church and the school.

- During moderate storm events ('Possible' likelihood), some buildings around the lagoon are predicted to experience a high flood hazard. These areas will be unsafe to people and buildings are likely to experience damage.
- During a once-in-a-lifetime event ('Unlikely' likelihood case), the majority of the village is predicted to be high or extreme hazards.
- During an extreme event ('Rare' likelihood case), virtually the entire motu is predicted to be extreme hazard and thus most buildings in the village will experience substantial damage or fail.
- Climate change impacts are predicted to exacerbate existing hazard levels. In particular, the impacts of a once-in-a-lifetime event ('Unlikely' likelihood case) is likely to worsen significantly.

The adopted methodology to assess and map the temporary coastal inundation hazard levels assumes that storm inundation is fundamentally a cross shore process that can be represented by a series of shore perpendicular cross sections. It is recognised that both the hydrodynamic processes on the reef flat as well as the overland flooding will not always be completely a one-dimensional phenomenon, particularly in areas where there is significant alongshore variability in the reef or land configuration. Whilst the hazard maps will provide a reasonable indication of the overall exposure of the motu to coastal inundation, the maps should not be used to identify the degree of inundation throughout localised areas. More detailed analysis would be required to refine the accuracy of the hazard maps to make them suitable for this purpose.

3.4.2 Permanent tidal inundation

Permanent tidal inundation refers to flooding of coastal land by tidal water levels.

In addition to daily water level fluctuations due to the tide, long-period fluctuations in the mean sea levels should be considered in the assessment of permanent tidal inundation hazards. Mean sea level rise (SLR) due to climate change is an important consideration for the assessment of the future coastal inundation hazards across the atolls.

Mapping of the permanent tidal inundation hazards has been compiled by assessing the areas inundated by the tidal inundation levels presented in Table 3-6. A bathtub approached has been applied in the mapping, meaning that all areas at or below the tidal inundation level are mapped as inundated.

The temporary coastal inundation hazard maps are presented in Appendix E. The maps show that whilst the extent of the permanent tidal inundation hazards is relatively modest at present, the hazard is predicted to become more significant for the future planning periods due to sea level rise. Should sea levels rise at the 'Unlikely' rate or faster, significant parts of the village motu will become inundated regularly by 2100 due to tidal water level fluctuations.

Table 3-6 Permanent tidal inundation levels

Likelihood	Immediate	2050	2100
Almost Certain	2.1m RL	2.27m RL	2.38m RL

	HAT based in current measurements	Present-day HAT plus 0.17m of SLR	Present-day HAT plus 0.28m of SLR
Possible	2.3m RL HAT plus 0.2m for long-term sea level fluctuations	2.6m RL Present-day HAT plus 0.2m for long-term sea level fluctuations plus 0.3m of SLR	3.04m RL Present-day HAT plus 0.2m for long-term sea level fluctuations plus 0.74m of SLR
Unlikely	N/A	2.68m RL Present-day HAT plus 0.2m for long-term sea level fluctuations plus 0.38m of SLR	3.28m RL Present-day HAT plus 0.2m for long-term sea level fluctuations plus 0.98m of SLR
Rare	N/A	2.87m RL Present-day HAT plus 0.2m for long-term sea level fluctuations plus 0.57m of SLR	3.77m RL Present-day HAT plus 0.2m for long-term sea level fluctuations plus 1.47m of SLR

3.5 Coastal Erosion

3.5.1 Overview

The general perception is that low-lying atoll islands are very susceptible to erosion in response to measured and future sea-level rise. However, results from a quantitative assessment by Webb and Kench (2010) of 27 atoll islands in the central Pacific showed that only 14% of the islands experienced a net reduction in area over periods ranging between 19 to 61 years, with 43% showing a net increase in area. Similar mixed shoreline change results were found by Yates et al (2013) for 47 atoll islands in French Polynesia, with the study conclusion being that sea level rise did not appear to be primary control of shoreline processes on these islands.

Webb and Kench (2010) go on to note that these results contradict existing paradigms of island response and have significant implications for the consideration of island stability under ongoing sea-level rise. The study found that the islands are geomorphologically persistent features on atoll reef platforms and can increase in area despite sea-level change, they are dynamic landforms that undergo a range of physical adjustments in responses to changing boundary conditions, of which sea level is just one factor, and that erosion of island shorelines must be considered in the context of physical adjustments of the entire island shoreline as erosion may be balanced by progradation on other sectors of shorelines. This is borne out by the finding that although net area changes were small (range 0.1 to 5.6ha), gross planform changes were larger involving ocean shoreline erosion, lagoon shoreline progradation and extension of the ends of elongate islands. As a result, 65% of the studied atolls experienced a net lagoon ward migration of the islands.

Coastal erosion of the open ocean shorelines of the atolls is linked to coastal inundation, being episodic during cyclone events due to the combination of elevated water levels and high waves overtopping the natural beach berms resulting in landward movement of beach sediment, retreat of the beach position, damage to coastal vegetation and structures (including protection structures). However, as pointed out by NIWA (2005a), the occurrence of such events has historically been important for supplying the motus with sediment to build up the elevation of the land. This is an important offset for the loss of sand and coral rubble naturally transported across the motus into the lagoon by overland flow and increasingly loss to human activities (e.g. sand mining). Best (1988) suggests, based on archaeological evidence on Atafu and Fakaofo, that about 1,000 years ago the village motus would have been about one to two metres lower than the present ground elevations, and thus more susceptible to coastal inundation.

As the SWASH modelling has demonstrated (Refer to Appendix C), the reef flat plays a vital role with a feedback loop between water level and waves in determining storm impacts on the open ocean beaches. Large ocean waves driven by cyclonic events break on the outer edges of the reef and reform into smaller waves that are height limited by the water depth over the reef flat, and therefore the wave conditions impacting on the beach during a storm event are inherently associated with fluctuations in the water level associated with wave grouping (so-called "surf beat").

During the presence of 'surf beat' surge, significant wave heights at the shoreline could reach up to 1.0m during minor storm events (i.e. 'Almost certain' event, immediate planning horizon) and 1.8m during a major storm event (i.e. 'Unlikely' event, immediate planning horizon).

During storm events, finer sized sediment is also moved seaward from the beach to be spread over the reef flat, which combined with the losses due to sediment washing over the dunes and results in erosion of the beach front. Erosion of the beach front is generally reduced by the presence of natural vegetation as the foliage has a reducing effect on the wave overtopping velocities and distances, and root systems can provide greater resistance to landward sediment disturbance. While the front line of this vegetation tends to suffer some root exposure and loss during cyclone events, they typically recover following events, with beaches also building back up with finer sediment moving back to shore from the reef flat over time.

However, the human removal of coral rubble from the beach for construction purposes has lowered beaches, resulting in increased overtopping and greater seaward land movements during storm events.

From this brief erosion process assessment, it would be reasonable to be assume that the retention of beach sediment and natural back beach vegetation cover is the easiest way to reduce ocean shoreline movements, and that the construction of seawalls to reduce overtopping and coastal inundation hazards would also address erosion hazards on the ocean beaches. However, although longshore sediment transport rates are low, activities that disrupt or change these movements, such as building seawalls at inappropriate locations on the beaches so that they block these sediment movements have also been associated with increased coastal erosion problems or loss of beach widths at shoreline locations downdrift of these structures.

Because large wave events are the principal driver for both storm erosion and wave overtopping, storm erosion and coastal inundation tend to occur simultaneously with the hazard levels and extent dominated by coastal inundation, both now and into the future. However, the issues around sea wall structures disrupting sediment transport are most likely going to increase in the future with sea level rise.

In relation to sea level rise impacts, based on the evidence from numerous atolls in the western Pacific and Indian ocean Woodroffe (2008) concluded any erosion of ocean beaches were localised and periodic as a result of one or more extreme events, and that it is generally inappropriate to infer that such events are related to sea level rise or subsidence. As reported in IPCC (2013), part of this inappropriateness is due to the human induced changes to beaches masking any clear evidence of climate change impacts.

Woodroffe (2008) further noted that the response of the rim of coral atolls to sea-level rise is inadequately understood at present with several different processes operating at significantly different rates, and contradictory responses have been proposed. For example, many Indo-Pacific reef flats presently occur at elevations too high to be suitable for coral growth (due to relative sea-level fall during past millennia largely as a result of isostatic adjustment) so that emergent reef flats may be re-colonised by coral and flourishing reefs may undergo further keep-up growth, providing further sediment that is likely to be transported to the oceanward shore. A contrary view is that greater water depth over the reef flat will result in greater wave energy reaching shore, especially following disintegration of degraded reefs after coral bleaching, and that this will accelerate shoreline erosion. Also unclear is what effect increased wave runup will have on reef islands. It may build the ridge crest higher; or alternatively waves overtopping of the crest ridge may increase. Although Woodroffe considered that the reef atolls appear to have a morphological resilience to sea level rise, he also notes that there is some critical threshold of rise beyond which the reef growth will not be able to keep up.

3.5.2 Assessment Outcomes

Coastal erosion assessments generally involve the following three components:

1. Review of historical shoreline positions to determine patterns, rates, and trends of movement. This commonly involves the digitising of a shoreline reference position (e.g vegetation line, reef flat -beach interface etc) from a series of historical aerial photographs over as long a time period as possible, generally in minimum of 30 years.

2. However, for Tokelau the only available aerial imagery is from 2010 and 2019 (Refer to Appendix B), a period of 9 years which is too short to interpret anything other than short-term fluctuations in shoreline position, and human activities. Overlaid on the imagery in Appendix B are the areas of loss and gains of beach area on each of the atolls over the 9 year period. However, the majority of the losses are as a result of vegetation clearance and majority of gains are a result of new seawalls. The only areas where the mapped shoreline changes are as a result of natural coastal processes are generally ocean coast locations away from settlements It is also important to note that this period has been dominated by La Nina conditions and Tokelau was not impacted by any cyclones, therefore mapped shoreline movements may not be representative for El Nino conditions.

3. Estimate future shoreline recession with sea level rise using a simplistic geometric model such as the Bruun Rule (Bruun, 1962). However, a number of authors note that the impact of sea level rise on sandy beaches is inappropriate for atolls and reef island beaches due to the distinct break in topography and sedimentologly at the beach system of reef islands, and because the sediment pathway is predominantly from reef to land (Woodroffe, 2008; Webb and Kench, 2010). The Bruun rule assumes that the lower shoreface is reshaped over the timescale of the sea level rise, and fixing a depth of closure for sediment motion is a key requirement. Defining this position for ocean and lagoon-facing beaches on atolls is difficult because the sandy island is perched on a solid reef platform, which is inconsistent with traditional application of the Bruun rule.

   Conceptually, it can be expected that the ocean-facing beaches will maintain their present slope around the water line, the reef platform will either maintains its present elevation or grows vertically at the same rate as the rise in sea levels, and foredunes and crest ridges will be constructed by swash processes at a similar level above mean sea levels as at the present conditions. Under these assumptions, the resulting shoreline recession would be in the order of 10m per metre of sea level rise. Current projections are that this magnitude of rise would occur over the next century.

4. Estimation of the storm bite, being the magnitude of retreat of the upper beach ridge that may be experienced as a result of a severe storm). This analysis commonly involves one or both of the following methods:

   - Mapped or anecdotal evidence of magnitude of storm erosion in a known event. However, no such evidence appears to be available for past Tropical cyclone events impacting Tokelau. No reference to erosion distances in Cyclone Percy or any other earlier cyclone is given in NIWA (2005A, 2005 B, 2005C).

- Modelled erosion from design storm event. No such numerical modelling using computer modelling has been undertaken for past tropical cyclone events at Tokelau, Empirical modelling equations for gravel beaches (van der Meer, 1988) were also not appropriate due overtopped of the beach crest by design storm wave run-up calculated from the SWASH modelling.

  Based on first principles, past experience and a lack of evidence to the contrary, a conceptual estimate of storm bite for un-protected ocean coasts is given as a maximum of 5m for most storm events, and up to 10m for rare events. As indicated above, this erosion is short-term, with beach profile and vegetation recovery following damaging events.

  For sections of the open coast protected by seawalls, this magnitude of short-term erosion will not occur, unless the wall fails in the storm event. Depending on the cross-shore location of the wall, the above retreat may be greater adjacent to ends of the wall due to the reflection of storm wave upwash energy from the wall.

  Lagoon coasts are unlikely to suffer from short-term short bite due to a lack of exposure to an energetic storm wave climate, potential supply of sediment from overland flow, and large extent of seawalls to deal with lagoon inundation issues.

Based on the above considerations and lack of data, there is considerable uncertainty in the magnitude of current coastal erosion hazards on the village motus of Tokelau, but the area potentially prone to erosion is estimated to be in the order of 5m from the existing vegetation line. This uncertainty also extends to future erosion hazards with sea level rise, however the area may increase by an additional 10m over the next century. Based on these estimates, the extent of any coastal erosion zone would be included completely within the wave impact zone for storm inundation hazards, and temporally will occur at same time due to both hazards being driven by cyclonic conditions. The extent of future erosion hazards will be dependent on the types, location and design of the methods used to address the storm inundation hazard.

4. Asset identification

4.1 Introduction

The values associated with the village motus were investigated as part of this study through review of existing reports and data, site inspections and consultation with the Coastal Resilience Working Group in order to develop a database of the key built, community and natural assets on the village motus. The outcomes of the values assessments have been used to determine the likely consequences of coastal hazards impacting on the communities (Refer to section 5.2).

4.2 Environmental and Cultural Values

A desktop study, based on existing studies, was undertaken to provide an overview of the main environmental and cultural values of each atoll. As environmental (both terrestrial and marine) and cultural values are inherently linked to the well-being of local communities, an ecosystem services-based approach has been used to describe the values identified.

Ecosystem services comprise the benefits that communities derive from ecosystems (International Finance Corporation, 2012). There are four types of ecosystem services:

- Provisioning services (the products people obtain from ecosystems) e.g. food, freshwater, timber, fibres, medicinal plants;
- Cultural services (the non-material benefits people obtain from ecosystems) e.g. surface water purification, carbon storage and sequestration, climate regulation, protection from natural hazards;
- Regulating services (the benefits people obtain from the regulation of ecosystem processes) e.g. natural areas that are sacred sites and areas of importance for recreation and aesthetic enjoyment; and
- Supporting services (the natural processes that maintain the other services) e.g. soil formation, nutrient cycling, primary production.

4.2.1 Terrestrial Environment

Pierce et al. (2012) identified a number of terrestrial biodiversity values as well as threats from invasive / pest species. Figures 3.1, 3.2 and 3.3 below provide the key findings of the study for each of three atolls. It should be noted that the Key Biodiversity Areas (KBA) as indicated in each of figures below are the interpretation from the study and therefore are not designated areas which are afforded protection. In addition, as the study was focussed on terrestrial biodiversity values only the figures do not represent the full biodiversity value of the atolls which would include the marine environment. Using this study and others, a summary of the terrestrial and marine environmental values of the atolls are discussed in this section.

Figure 4-1 Key Biodiversity Areas (blue) and Areas of High Invasive Species (red) of Atafu - Source: Pierce et al (2012)

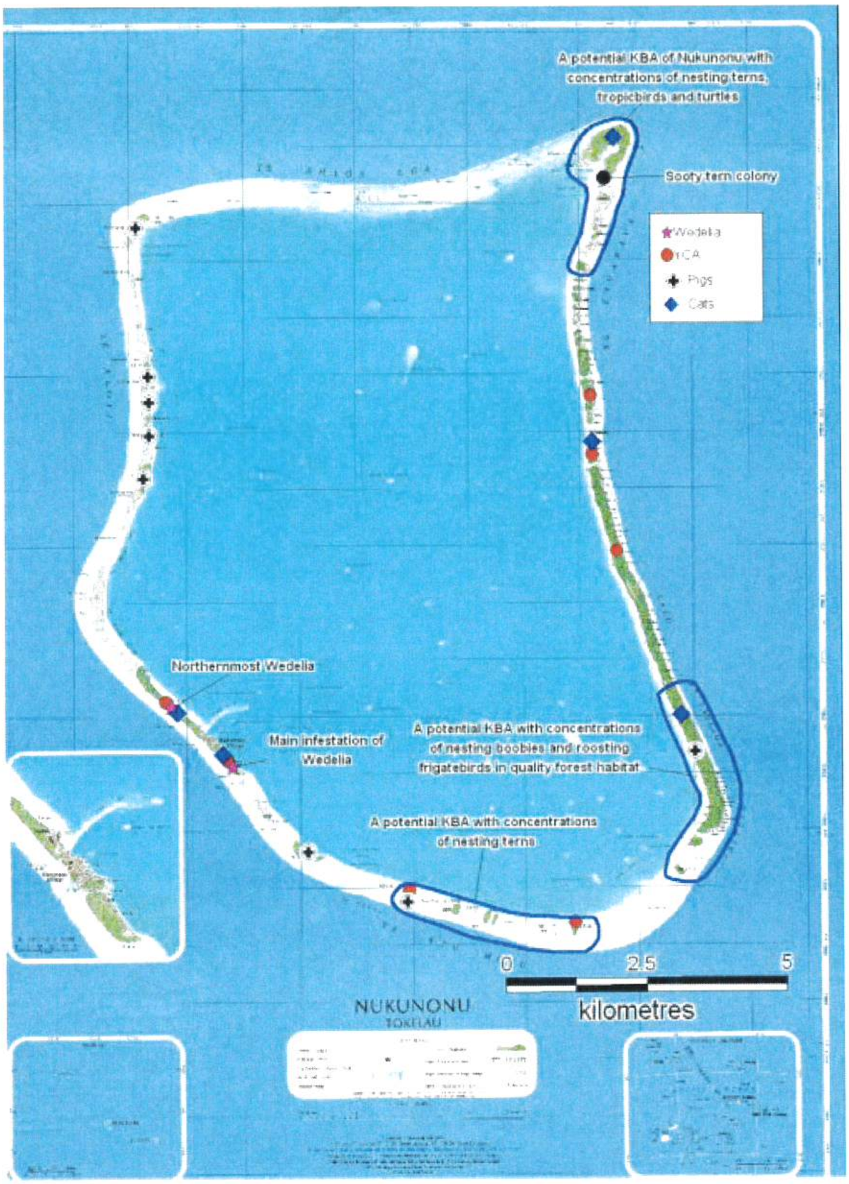


Figure 4-2 Key Biodiversity Areas (blue) and Areas of High Invasive Species (red) of Nukunonu - Source: Pierce et al (2012)

Figure 4-3 Key Biodiversity Areas (blue) and Areas of High Invasive Species (red) of Fakaofo - Source: Pierce et al (2012)

Vegetation

The vegetation of Tokelau is understood to be low in diversity and dominated by planted and regenerating coconuts (*Cocus nucifera*) and a small number of other tree species including *Pandanus tectorius*, *Tournefortia argentea, Pemphis acidula* and *Asplenium nidus*. At the ground level seedlings of these species as well as ferns dominate. Within the villages of Atafu, Nukunonu and Fakaofo a number of weed species are present including *Wedelia* (Pierce et al, 2012). No endemic plant species are noted as present in Tokelau (SPREP, 1994).

Other plant species including the flowering tree (*Cordia subcordata*) and pandanus have been heavily relied on in the past for traditional craft-making as well as for food and drink (provisioning service). Forest resources are still used for house and canoe building, construction of pig-pens and a variety of traditional uses such as wood-craft, weaving, dyes and traditional medicines (SPREP, 1994).

Avifauna

SPREP (1994) states that avifauna on Tokelau is relatively rich with at least 26 species present (15 species of seabirds, 8 are shore birds and 3 land birds). Pierce et al (2012) identified 20 species of indigenous birds comprising 14 seabirds, 1 heron, 4 waders and a pigeon. Locally breeding birds particularly noddies, terns and pigeons have traditionally been hunted for meat and eggs. At certain times of the year the Kaleva or long-tailed koel is present as well as species of duck. Key species noted include the following:

- The black noddy, brown noddy and white tern have the largest populations across all three atolls.
- The pacific pigeon is noted in the larger forested motus of Atafu but are rare on Nukunonu and Fakaofo.
- Smaller populations of the lesser frigatebirds and black-naped terns.
- Evidence of mynas (*Acridotheres* sp.) has been noted.

Based on a comparison against similar studies conducted in the 1970s, Pierce et al (2012) concludes that many of bird species observed across Tokelau have increased across the period.

Reptiles

Four species of terrestrial reptile have been noted across all three atolls snake-eyed skink (*Ablepharus boutonii*), blue-tailed skink, (*Emoia cyanura*), black skink (*E. nigra*) and house gecko (*Hemidactylus frenatus*).

Mammals

The Polynesian rat (*Rattus exulans*) is common across all three atolls although prevalence is highest on the inhabited motus versus uninhabited. Management controls of rat populations is ongoing. Domestic animals common across the atolls include the following:

- House cats;
- Pigs;
- Goats; and
- Chickens.

Insects

A total of 150 species of insects in 83 families including several agricultural pests have been recorded (SPREP, 1994). Pierce et al (2012) found three species of butterfly across the atolls: meadow argus (*Junonia villida*) (common and widespread across all three atolls), blue moon (*Hypolimnas bolinas*) (common on Atafu only) and crow butterfly species (*Euploea* sp.) recorded only at Atafu Village motu.

Several other insect groups have also been recorded during the 2012 survey (Pierce et al., 2012) including the following:

- Spiders (orb web and huntsman) and possibly an endemic species A. beavis;
- Moths;
- Red coloured dragonfly;
- Neuropterans or net-winged insects;
- Mosquito;
- Rhinoceros beetle;
- Whitefly; and
- Yellow crazy ants.

Of particular note is the yellow crazy ant which is extremely prevalent across the atolls and considered a pest species and management of their populations are ongoing.

Crustaceans

The coconut crab and large land crab (Cardisoma crabs) are widespread across the atolls and are frequently harvested by the local communities. It has been noted that crab sizes are in general declining due to unsustainable harvesting.

4.2.2 Marine Environment

Whilst the terrestrial environment is somewhat low in biodiversity the opposite is true of the marine environment surrounding Tokelau. The lagoon, reef and deep-sea resources are rich and varied with fishing the mainstay of both the Tokelauan diet and livelihood. Fish forms the major component of the diet, with the lagoon reef fishery accounting for 55% of all animal protein consumed (SPREP, 1994).

All three atolls are characterised by partly shallow lagoons with patch coral reef and fringing coral reefs surrounding the vast majority of the atoll. Lagoon water exchanges via tidal movement and oceanic swell/waves with the open ocean via shallow passages between motus.

The coral reefs which surround all three atolls are the traditional foundations upon which Tokelauans are able to support their subsistence living and provide livelihood means. The coral reefs ecosystem provides the rich fish and invertebrate food source that the Tokelauans rely so heavily on. In recent years climate change induced effects such as coral bleaching has been noted as occurring more-or-less on an annual basis leading to degradation of the coral reefs both within the lagoon and outside which has a direct knock on effect on the quantity and quality of food supply from the inshore fish population. Extreme weather conditions have also contributed in disrupting the life cycle of lagoon fish which has result in decreases in some species of fish from the lagoon (Fergusson, 2015).

Marine resources in Tokelau are generally open for community use and management of each atoll's resources is the responsibility of the respective Tapulega (island governing authority). Restrictions for fishing certain areas are sometimes enforced for days or months to ensure sustainable management of the fish populations. In addition, harvesting of certain species is also prohibited for periods of the year e.g. giant claims between March to October and for the coconut crab export from Nukunonu and Fakaofo is completely prohibited (Pasilio *et al*, 2013).

Fish and Molluscs

Fisheries comprise an inshore lagoon and reef fishery and an offshore pelagic and deep-water fishery. The lagoon fishery is used mainly for domestic consumption and comprise species such as: the great trevally, bigeye scad, goatfish, reef cod, garfish, parrot fish and surgeon fish. A survey undertaken in 2012 at Nukunonu identified 143 species of fish from the lagoon reefs (Fergusson 2015). The offshore and deep-water fishery is used mainly for commercial purposes and comprises tuna, snapper, shark, grouper and emperor species (SPREP, 1994).

The gastropod mollusc, trochus shells are commercially the most important species. However, other species including octopus, lobsters, crabs, giant clams and other gastropods also form an important food resource for Tokelauans. The triton shell was traditionally used to call communities for gatherings or communal events and cowrie shells have been used for crafts and jewellery (cultural service) (Pasilio *et al*, 2013).

Sea cucumbers (bêche-de-mer) although not a traditional food source for Tokelauans have in recent years been of increasing commercial value. The Tapulega approved a joint venture company to process and export sea cucumbers.

Marine Mammals and Turtles

Numerous species of whales and dolphins are sighted in Tokelau, but little is known on species, distribution and sighting numbers. Three species of turtle are found in Tokelau, the most common is the green turtle (*Chelonia mydas*). The green turtle has traditionally been an important provisioning service to the local communities providing both meat and eggs (during breeding season), however, populations have generally been noted as declining in recent decades. The hawksbill turtle (*Eretmochelys imbricata*) and loggerhead turtle (*Caretta caretta*) have also been recorded on all three atolls. The other reptile species also noted as present is the sea snake which is common the lagoon reefs.

4.2.3 Cultural

Tokelauan lifestyle relies heavily on traditional communal self-sufficiency. The 'inati' system of equal sharing of food and wealth to all families is still actively maintained which encourages the whole community to work together more closely. Traditional foods still form a major proportion of the diet with a strong reliance on marine resources, coconuts, pandanus, bananas, breadfruit, pawpaws, 'pulaka' and taro.

In recent years, access to improved methods of food gathering as well as the introduction of modern technology such as washing machines, kerosene stoves have changed Tokelauans lifestyles to being less physically intensive but also providing time for other tasks. Those tasks include employment on construction activities such as coastal hazard protection e.g. sea walls as well as community facilities such as schools, hospitals, septic tanks and rainwater collection tanks. Traditional tools such as adzes, fishing hooks and handicrafts are no longer required but are kept in family collections.

With the urbanisation, modernisation and external influences across the Pacific island nations, traditional cultural values are under threat. In Tokelau this is now being realised, and policies have been implemented to strengthen the cultural values 'faka-Tokelau' of the nation, this includes:

- Promotion of Tokelau at Pacific cultural events such as the South Pacific Arts Festival;
- Use of the Tokelauan language for teaching primary and secondary school students;
- Sending scholarship students to South Pacific countries such as Fiji (University of the South Pacific), rather than New Zealand;
- Teaching traditional values and lifestyles methods in schools and non-government community organisations;
- Voluntary cessation of the Resettlement Scheme in New Zealand to maintain numbers of able-bodied men for communal village responsibilities such as fishing, food preparation and construction;
- Recording the Tokelauan language and culture in written and video format;
- Retaining the Council of Elders (Tapulega) as the overall governing bodies for each village; and
- Retaining the 'inati' system of equal sharing of food and wealth to all families.

Religious belief across Tokelau is strictly Christianity and plays a significant role in the Tokelauan way of life. A church is located on each of the three atolls. In Nukunonu the main denomination is Roman Catholic, in Atafu protestant (Congregational church) and on Fakaofo there is a split between both. Christian missionaries arrived in Tokelau in the mid-1850s, prior to this, belief focussed on gods or spirits of which little is known. There are still ties to pre-Christianity beliefs such as the pillar associated with a god of old, Tui Tokelau, which is located in the meeting house on Fakaofo and is culturally acknowledged by the local community.

The handicapped, disabled and aged are not institutionalised in Tokelau, all necessary care and supervision is provided within the family group and access to medical services is free for all Tokelauans. Tokelauans have access to a New Zealand pension and working men receive dispensation by the Taupulega.

Land in Tokelau is owned by family members. Many of the motus are individually owned whilst the motus where the village centres are located, are split up into parcels of land which are also owned by family members. This land parcel is often sub-divided for family members. This land ownership structure has led to a lack of collective action with respect to managing coastal protection from natural hazards and in some cases conflict with neighbours. Many families have been building their own form of sea defence extending seawards, this has also allowed them to expand their land ownership. However, with few options in terms of land use the land extension serves no real function for day to day life.

4.3 Asset Database

Based review of existing reports and data, surveys (see Appendix A) and consultation with the Coastal Resilience Working Group, a geospatial database was developed of the key built, community and natural assets on the village motus. The database contains a variety of asset types, as listed in in Table 4-1.

Figure 4-4 to Figure 4-7 present maps of the assets incorporated in the risk assessment.

A survey was conducted to collect information with respect to the buildings and seawalls. The building survey collected information such as building type and purpose, foundation type, building age, number of habitable floors, height of lowest habitable floor, the number of occupants and the size (roof area). The seawall surveys collected information such as seawall type, seawall length, structure height, crest elevation and type, foundation type and age. A total of 577 buildings and 110 seawalls (with a total length of approximately 4824m) were identified (See Appendix A).

Replacement unit costs in the Government of Tokelau Asset Management Plan 2015-30 (Waugh, 2014) were used to provide an estimate of the replacement cost of the private property on the atolls. The estimated replacement cost of private property in Tokelau is approximately NZ$ 39.4 million, roughly evenly spread across the three atolls.

Table 4-1 Asset types identified in the study area

• Residential houses • Administration buildings • Meeting halls, • Police stations • Guesthouses and hotels • Commercial buildings (banks / finance buildings, shops, bars/pubs • Storage facilities: food (incl. freezer house), bulk., fuel, equipment • Education: schools, kinder gardens, universities, • Hospitals • Churches	• Road infrastructure: bridges, pathways • Maritime infrastructure: wharves/jetties, shipping channels • Utilities: electricity, telecommunication, water • Recreational facilities: Sport facilities, parks, playgrounds • Seawalls • Cemeteries • Pig pens • Beaches

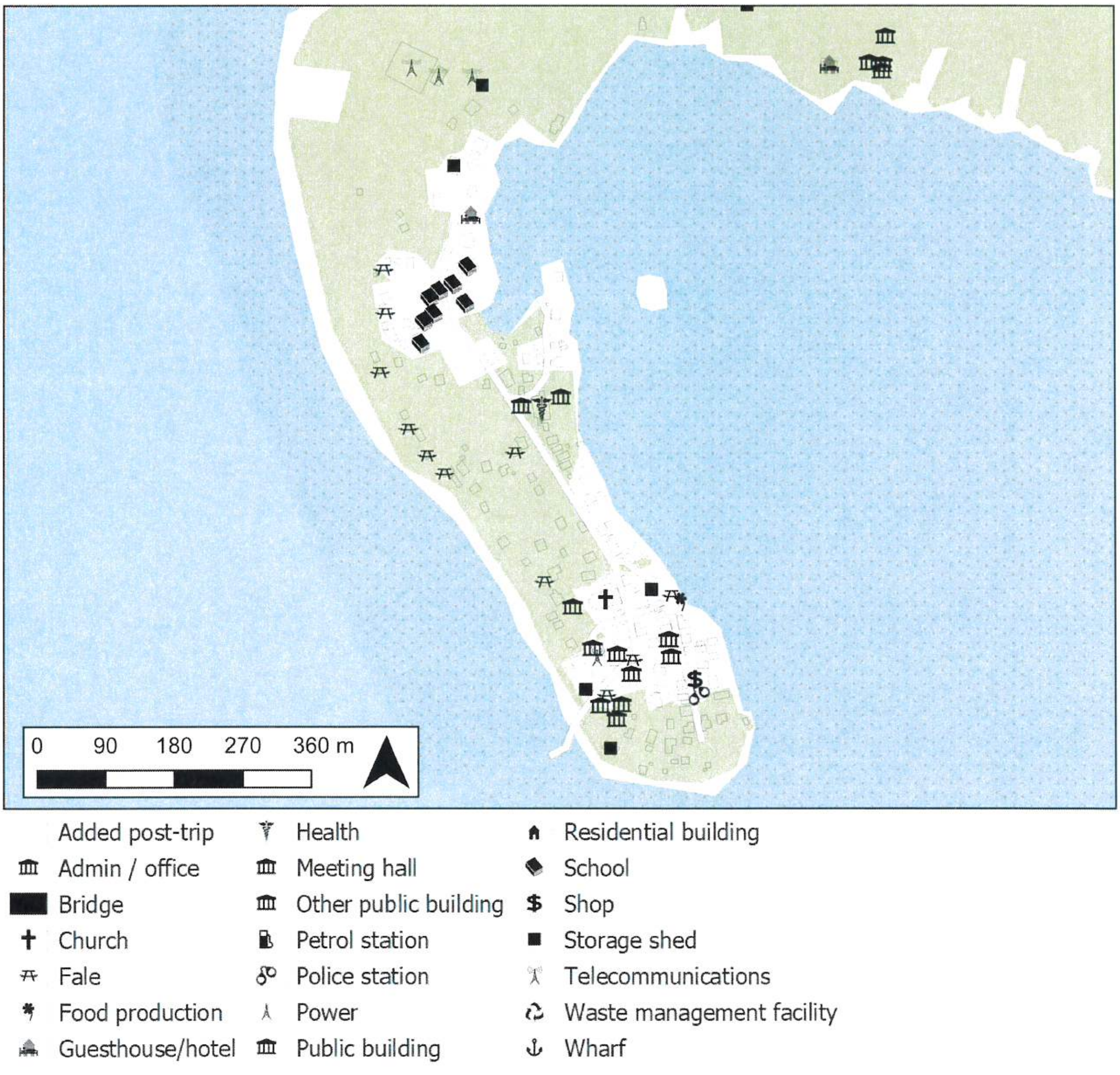


Figure 4-4 Assets incorporated in Risk Assessment- Atafu

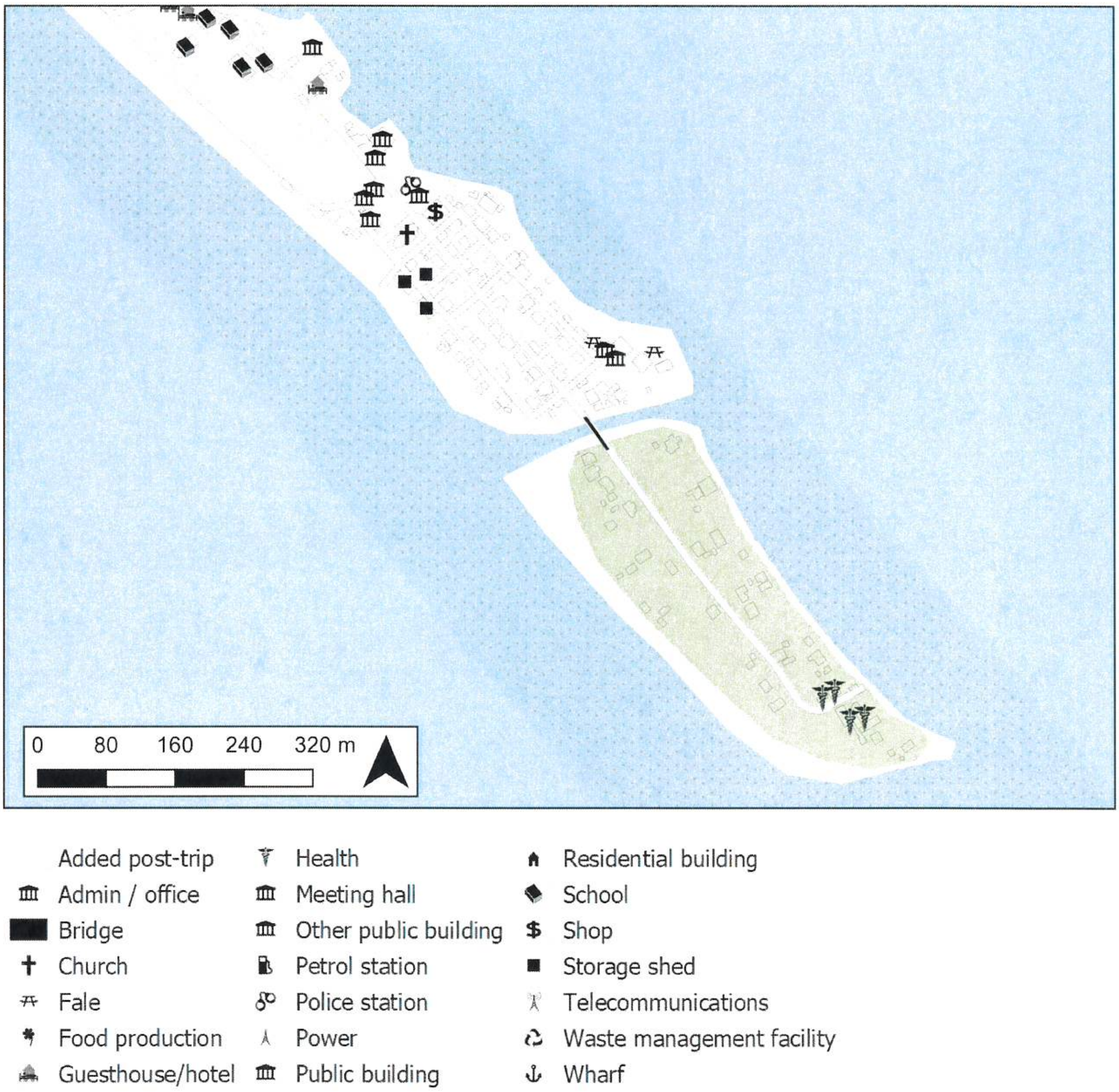


Figure 4-5 Assets incorporated in Risk Assessment- Nukunonu

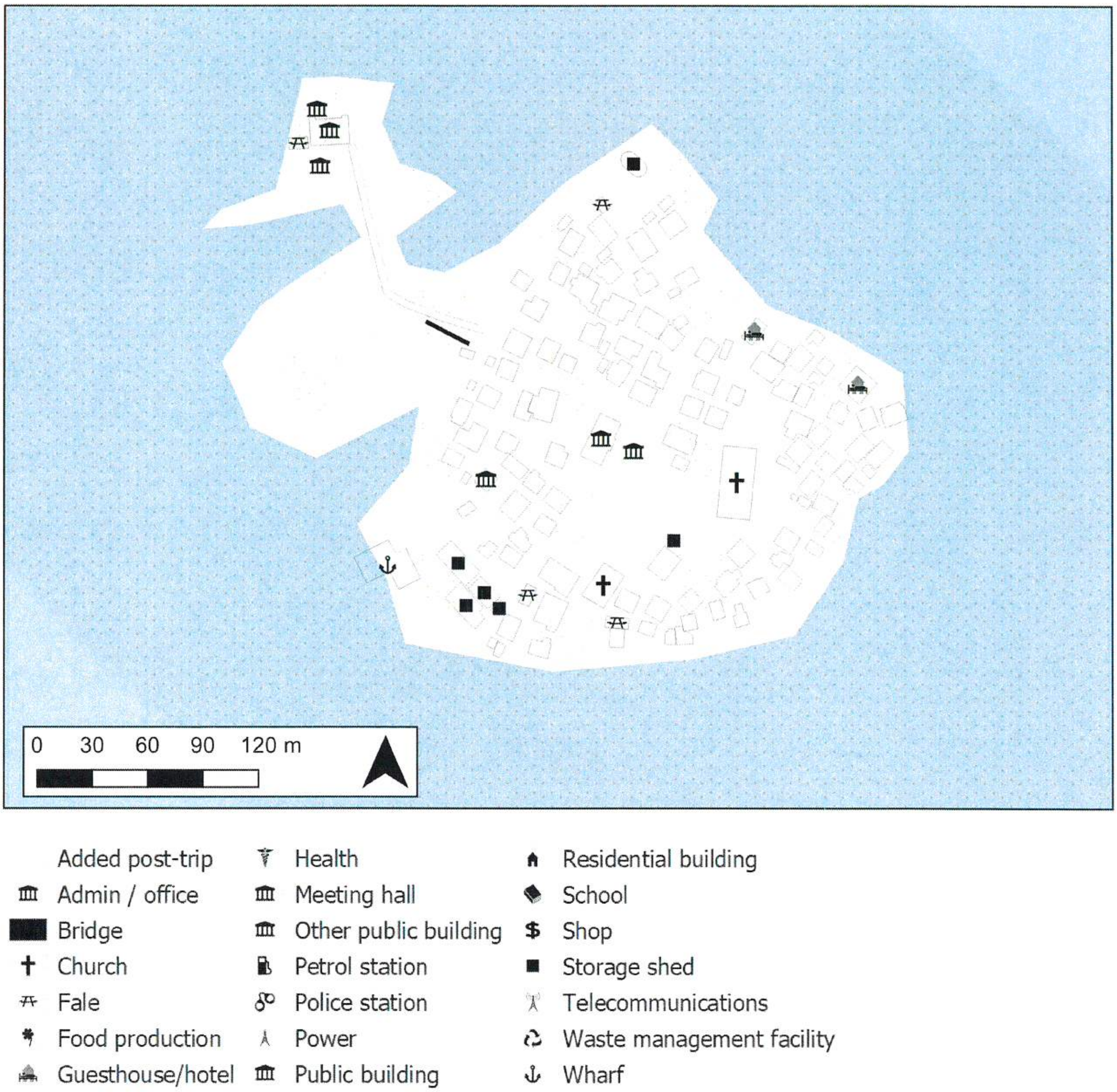


Figure 4-6 Assets incorporated in Risk Assessment- Fale

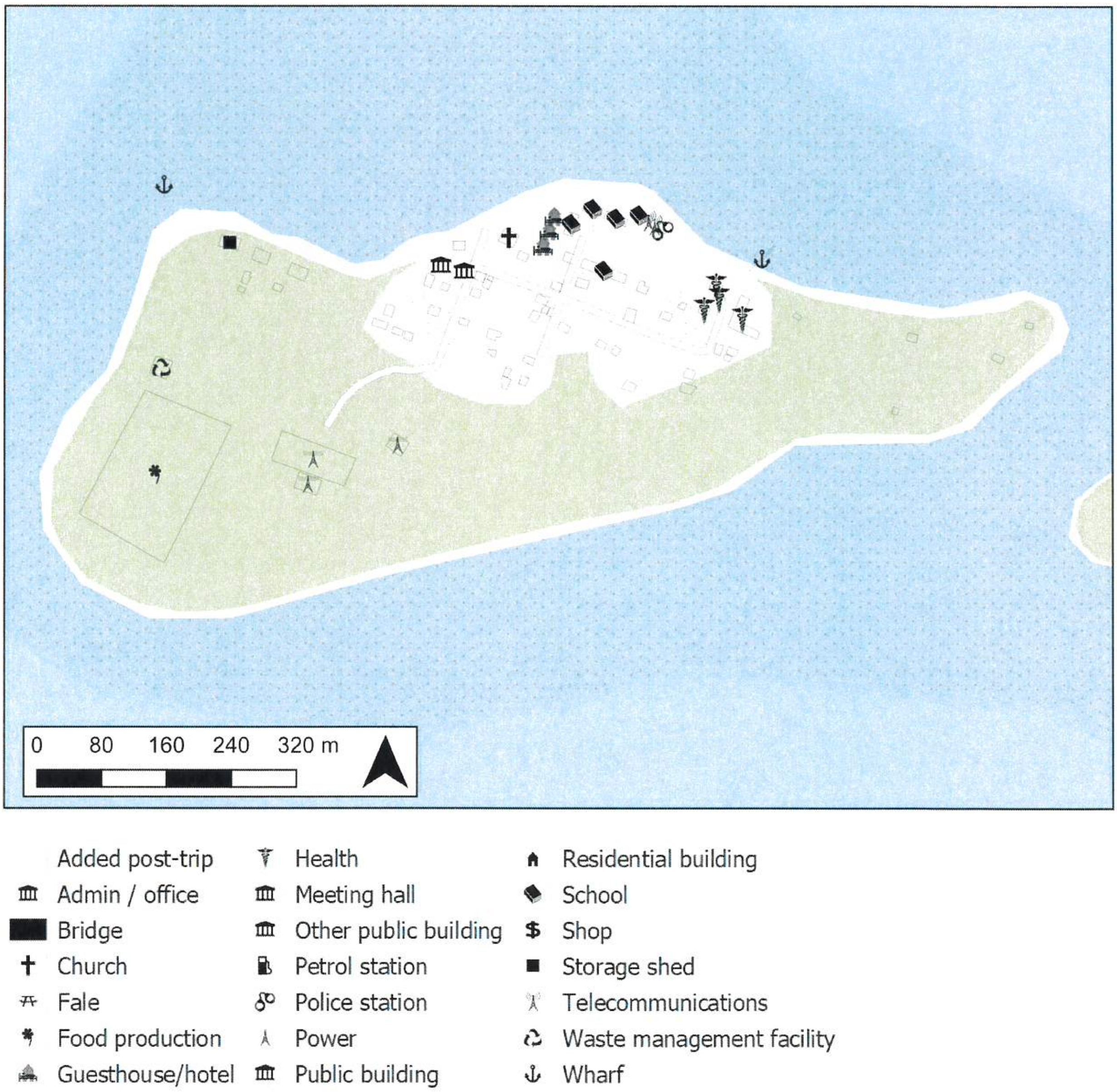


Figure 4-7 Assets incorporated in Risk Assessment- Fenua Fala

5. Coastal Hazard Risk Assessment

5.1 Introduction

A risk assessment for the immediate (2019), 2050 and 2100 planning periods has been carried out for the village motus. This risk assessment was carried out with reference to the hazard mapping done for each of the three planning periods.

Broadly, the risk assessment process involved the following steps:

1. Define likelihood categories (Hazard probability classes) and planning timeframes (Section 3.2);
2. Determine coastal hazards that could impact on the study area and how climate change could affect these hazards (Section 3.3);
3. Assess and map coastal hazard levels for selected likelihood categories and planning timeframes (Section 3.4 and 3.5);
4. Identify key assets on the village motus that could be impacted by coastal hazards (Section 4);
5. Define consequence ratings for each asset types (Section 5.2);
6. Allocate for each planning period the consequence of the risk occurring to specific assets and people's wellbeing, and determine the risk levels by combining risk likelihood and consequence (Section 5.3);
7. Evaluate the risks, based on the acceptability (and tolerability) of the risk and the community's capacity to adapt the risks.

5.2 Rating of Risk Consequence

The consequence of the risks relates to the impact of the hazards upon the communities, which is largely linked to the effects of the hazards on assets and people's wellbeing.

In consultation with the Coastal Resilience Working Group, a risk consequence scale was developed which provides a benchmark for the potential consequences of coastal hazard risks on a national level. The consequence scale is based on a triple bottom line approach and considers the potential consequences along three dimensions (social/community, environmental and economic). This consequence scale has five consequence ratings, as shown in Table 5-2.

Guided by the national risk consequence scale, a risk consequence rating was assigned for each asset type. Consequence values were assessed separately for coastal erosion and permanent tidal inundation hazards and temporary coastal inundation hazards, because the types of impacts are different. The impacts from coastal erosion and permanent tidal inundation are permanent and largely irreversible, whereas the impacts from temporary coastal inundation may only result in a short period and often only temporarily disrupt the service of the asset (ie. during and immediately following the event).

The adopted consequence scale for temporary coastal inundation hazards is presented in Table 5-3, the consequence scale for coastal erosion and permanent tidal inundation hazards in Table 5-4.

In addition to the consequence rating for assets, a separate consequence rating was defined to rate the potential impacts of coastal hazards to people. The risk consequence to people relates primarily to the ability to safely walk through the overland flood waters. The adopted consequence scale for risk to people is summarised in Table 5-1.

Table 5-1 Adopted consequence rating – Risks to people

Consequence description	Consequence rating
Wading unsafe	Moderate
Unsafe to people (Stability of people likely compromised, drowning possible)	Major

Table 5-2 Risk consequence scale

Consequence rating	Social / community	Environmental	Economic
Insignificant	• Minor short-term (~hours) disruption to services, wellbeing, or culture of the community (e.g. up to 5 % of village community affected) • No adverse human health effects	• No/negligible adverse effects on natural environment	• Little financial loss or increase in operating expenses • No effects on the local economy
Minor	• Small to medium short term (~days), (reversible) disruption to services, wellbeing, or culture of the community (e.g. up to 10 % of village community affected) • no serious injuries, Isolated illnesses may occur	• Minimal effects on the natural environment • Environmental damage of a magnitude consistent with seasonal variability. Recovery may take one year.	• Localised service disruption / additional operational costs • No permanent damage. Some minor restoration work may be required. • Financial loss small (<10% of village economy) • Minor effect on the local economy due to disruption of services
Moderate	• Minor long term or major short term (~week), mostly reversible disruption to services, wellbeing, or culture of the community (e.g., up to 25 % of village community affected), • Isolated serious injuries, multiple illnesses	• Significant impact on the environment, including local ecosystems. • Recovery may take several years. Some remedial action may be required	• Moderate financial loss (10–50% of village economy) • High impact on the local economy, with some effect on the wider economy
Major	• Major permanent or widespread medium term (~up to 3 months), somewhat reversible disruption to community's services, wellbeing, or culture (e.g. up to 50 % of village community affected) • Isolated permanent physical injuries or fatalities may occur	• Very significant damage to the environment and local ecosystems. Semi-permanent loss of entire important habitat. • Recovery may take many years. Remedial action likely to be required	• Major financial loss (50–90% of village economy) • Serious effect on the local economy spreading to the wider economy
Catastrophic	• Widespread, (semi-)permanent impact to village's services, wellbeing, or culture (e.g., > 50 % of community affected), • National loss • Multiple total disabilities or deaths	• Widespread, devastating / permanent impact (e.g. entire habitat destruction) • May include loss of species, habitats or ecosystems Extensive remedial action essential to prevent further degradation. Restoration likely to be required	• Extreme financial loss (>90% of village economy) • Major effect on the national economy • Significant permanent damage and/or complete loss of infrastructure and the infrastructure service •

Table 5-3 Adopted consequence rating – Temporary coastal inundation

Asset Type	Insignificant	Minor	Moderate	Major	Catastrophic
Hospitals and health clinics			• Flood levels below habitable floors; and • Low or moderate flood hazard	• Flood levels below habitable floors; and • High flood hazard	• Flood levels above habitable floors; or • Extreme flood hazard
Emergency shelters/evacuation centres			• Flood levels below habitable floors; and • Low or moderate flood hazard	• Flood levels below habitable floors; and • High flood hazard	• Flood levels above habitable floors; or • Extreme flood hazard
Schools, churches, meeting halls	• Flood levels below habitable floors; and • Low or Moderate flood hazard	• Flood levels below habitable floors; and • High flood hazard	• Flood levels above habitable floors; and • High flood hazard	• Extreme flood hazard	
Fale	• Low, Moderate and High flood hazard	• Extreme flood hazard			
Other public and private buildings	• Flood levels below habitable floors; and • Low or Moderate flood hazard	• Flood levels below habitable floors; and • High flood hazard	• Flood levels above habitable floors; and • High flood hazard	• Extreme flood hazard	
Recreational facilities	• Low, Moderate and High flood hazard		• Extreme flood hazard		
Utilities (electricity, telecommunication, water)		• Flood levels below habitable floors; and • Low or moderate flood hazard		• High flood hazard	• Flood levels above habitable floors; or • Extreme flood hazard
Food production areas (ie. pig pens)	•	• Low or Moderate flood hazard	• High or Extreme flood hazard		
Transport infrastructure (wharves, bridges)	• Low, Moderate and High flood hazard		• Extreme flood hazard		
Cemeteries and significant cultural sites	• Low or Moderate flood hazard		• High or Extreme flood hazard		

Table 5-4 Adopted consequence rating – Permanent tidal inundation or coastal erosion

Asset Type	Insignificant	Minor	Moderate	Major	Catastrophic
Hospitals and health clinics					• Building affected by erosion; or habitable floor inundated by permanent inundation
Emergency shelters/evacuation centres				• Site inundated by permanent inundation	• Building affected by erosion; or habitable floor inundated by permanent inundation
Schools, churches, meeting halls				• Building affected by erosion; or habitable floor inundated by permanent inundation	
Fale		• Building affected by erosion; or habitable floor inundated		•	
Other public and private buildings				• Building affected by erosion; or habitable floor inundated by permanent inundation	
Recreational facilities			• Building affected by erosion; or habitable floor inundated by permanent inundation		
Utilities (electricity, telecommunication, water)					• Building affected by erosion; or habitable floor inundated by permanent inundation
Food production areas (ie. pig pens)			• Building affected by erosion; or habitable floor inundated by permanent inundation		
Transport infrastructure (wharves, bridges)				• Building affected by erosion; or habitable floor inundated by permanent inundation	
Cemeteries and significant cultural sites			• Building affected by erosion; or Habitable floor inundated by permanent inundation		

5.3 Assessment of Risk Levels

A series of risk maps have been prepared which indicate the level of risk (low, medium, high, extreme) to assets and people across the village motus. The risk levels were determined by combining the coastal hazard likelihood with the risk consequence ratings conform the risk matrix present in Table 5-5.

The risk maps, included in Figure 5-1 to Figure 5-12, depict the highest risk level of any combination of likelihood and consequence that an asset or area may be subject to within a planning period, independent of the hazard type (temporary inundation, permanent tidal inundation or erosion).

It should be noted that the risk maps present the risk levels for the three planning periods without consideration of any adaptation measures or risk controls that may already be in place at present, with the exception of the existing seawalls on the ocean side. For example, the effects of risk reduction measures outlined in the Tokelau National Disaster Risk Reduction Plan (Government of Tokelau, 2013) have not been incorporated in the risk maps.

Table 5-5 Adopted risk matrix

	CONSEQUENCE				
LIKELIHOOD	**Insignificant**	**Minor**	**Moderate**	**Major**	**Catastrophic**
Almost Certain	Low	Medium	High	Extreme	Extreme
Possible	Low	Medium	Medium	High	Extreme
Unlikely	Low	Low	Medium	High	High
Rare	Low	Low	Medium	Medium	High

The risk maps of the immediate planning period (Figure 5-1 to Figure 5-4) show that the current risk levels across all villages are high to extreme, with the exception of a number of isolated areas. Particularly noteworthy is the extreme risk level of the hospitals of Atafu and Nukunonu and the telecommunication equipment on Atafu. Risk levels are predicted to increase somewhat for the future planning periods as a result of climate change impacts.

Temporary coastal inundation by storm events is the dominant element in the risk profile of the village motus. For most buildings not located in the immediate vicinity of the lagoon, the damaging impacts of large waves overtopping the motu barrier during storm events is the primary risk factor.

5.4 Risk Evaluation

It is impractical to mitigate all risks. Priority should be given, however, to treating risks that are considered to be the most important. In most cases, it would be expected that low or medium risks can simply be monitored, rather than demand valuable management resources.

Determining which risks to treat as part of the project is based upon the community's tolerance for risk. Tokelauans have been living with the threats from the ocean for many decades and have a relatively high tolerance to coastal hazard risks.

In consultation with Coastal Resilience Working Group, it was decided that high and extreme risks within the immediate and planning timeframe are considered intolerable and need to be addressed, either through risk reduction or conscious acceptance of the risks (provided that the community understands the residual risks). Extreme risks for the 2050 timeframe, as determined in the risk assessment, are also considered intolerable.

For assets that are currently not high or extreme risks but may become this in the long term (beyond the 2050 planning horizon), it should be recognised that there is still uncertainty regarding when these risk manifest and the most appropriate management strategy is to monitor the risk and seek opportunities to avoid the risk from occurring in the future. This may include relocating assets from these areas at the end of their service life or adapting them to better cope with the impacts.

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