Coastal protection along the north coast of Tongatapu, Tonga (CPS 20/140) Report 1

Desktop Assessment and Community Priority Issues

Prepared for the GCCA+ SUPA Project

and the Kingdom of Tonga:

eCoast
eTakutai

MOHIO - AUAHA - TAUTOKO
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Report Status

Version	Date	Status	Approved by
V. 1	11 December 2020	Final Draft	STM
V. 2	4 January 2020	Rev. 1	SDG

It is the responsibility of the reader to verify the version number of this report.

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Foreword and Acknowledgements

Due to the travel restriction caused by the CoVid-19 global pandemic, the project consultants (eCoast and PLANIT Pacific) have not been able to travel to Tongatapu for data collection and community consultation, and other restrictions such as limitations on numbers for group gatherings have also modified the way this project has been approached. However, with the aid of virtual meeting technology and the assistance of our project partners at Tonga's Ministry of Meteorology, Energy, Information, Disaster Management, Environment, Climate Change and Communications (MEIDECC), namely Manu Manuofetoa and Filimoeunga Aholelei, the compilation of local information and community consultation was still able to be undertaken to a high standard. We would like to acknowledge the input of our Tongan counterparts, which has been invaluable for carrying out this project during these interesting times.

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1 Assessment Overview

1.1 Project Background

The Kingdom of Tonga is located in the central South Pacific and it lies between 15° and 23°S and 173° and 177°W (Figure 1.1). Tonga has a land area of 649 km^2 and is an archipelago of 172 coral and volcanic islands of which 36 are inhabited. Tonga consists of four main island groups: (1) Tongatapu (260 km^2) (Figure 1.1) and ‘Eua (87 km^2) in the south, (2) Ha'apai (109 km^2) in the middle, (3) Vava'u (121 km^2) in the north and (4) Niuafo'ou and Niua Toputapu (72 km^2) in the far north. The population of Tonga is 101,436 (2016 census).

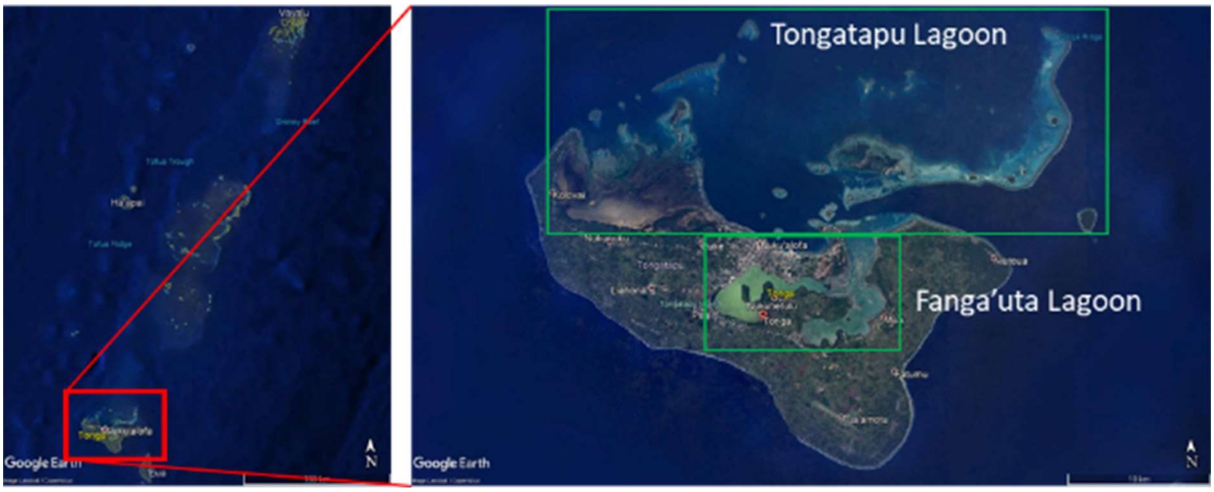

Figure 1.1 Location of the Kingdom of Tonga and Tongatapu home to the capital, Nuku’alofa.

Tongatapu has been experiencing beach erosion for many years now and although little quantitative evidence is available, it is most likely due to human activities. For example, in many places, mangroves are cleared for fuel wood and the resulting space is used for land reclamation and other purposes (NBSAP, 2010). Beach sand is mined and used as construction material and for the decoration of tombs. Accelerated sea level rise is contributing to beach erosion, which is, in turn, resulting in the wave overtopping being experienced on coastal roads in Tongatapu.

Over the last ten years medium-scale coastal protection works – revetments, groynes and offshore breakwaters – have been constructed at a few sites along the north coast of Tongatapu, at Talafo’ou, Manuka and Kolonga on the north-east coast, and Kolovai and ‘Ahau on the north-west coast, together with ecosystem-based measures involving coastal planting and mangroves. This is in addition to the “older” coastal protection measures protecting the capital, Nuku’alofa, which is a 1:4 (V:H) rock revetment and a number of port/wharf developments (Figure 1.2).

Figure 1.2. The Nuku’alofa coastline includes some 6.0 km of rock armour and port/wharf developments.

Under the Global Climate Change Alliance (GCCA+) Scaling Up Pacific Adaptation (SUPA) regional project, the Government of Tonga has selected coastal protection as the focus sector under Output 3. The GCCA+ SUPA project is funded by the European Union with €14.89 million, and implemented over the period 2019-2022, by the Secretariat of the Pacific Community (SPC) in partnership with the Secretariat of the Pacific Regional Environment Programme (SPREP) and The University of the South Pacific (USP) and the government and people of Cook Islands, Federated States of Micronesia, Fiji, Kiribati, Marshall Islands, Nauru, Niue, Palau, Tonga and Tuvalu. SPC is the lead organisation for the GCCA+ SUPA project.

Recognising the continuing and increasing challenges posed by climate change, the Government of Tonga wishes to adopt a holistic approach to coastal protection for the entire north coast of Tongatapu, from Niutoua in the east to Ha'atafu in the west, and including the coastline of the Fanga'uta Lagoon.

SPC has commissioned eCoast to (i) conduct an overall assessment of the northern coast of Tongatapu to include geomorphological, biophysical, engineering and social characteristics; (ii) prepare a conceptual design and preliminary costing for measures to protect the communities living within 2 km of the high water mark up to the 2030 and 2050 planning horizons; and (iii) prepare a feasibility study outlining prioritised options and their scheduling.

This document presents the first of the investigations; a desktop literature and data review to provide an overall assessment of the northern coast of Tongatapu, including the outcomes of community consultation meetings.

1.2 Project Setting

The island of Tongatapu is flat and low-lying with the highest elevation being 70 meters above sea level. The island spans 35 km in an east-west direction and 15 km in a north-south direction. The north-west tilting of Tongatapu coupled with the accelerated sea level drop (some 20,000 years ago) has caused land subsidence to most of the northern coastline, making all land and human development susceptible to inundation and flooding. Furthermore, tsunami modelling carried out by MLECCNR (2013) has demonstrated that under a scenario of a magnitude 9.0 earthquake origination from the east (Tonga Trench), coastal communities and properties would be vulnerable to a rapid onset tsunami event (McCue, 2014).

The south coast of Tongatapu boarders the deep ocean. In contrast, the north coast faces a large lagoon (412 km^2) known as Tongatapu lagoon (Figure 1.1), which has a mean depth of 13.0 m and a maximum depth of around 27.0 m depth CD. The lagoon is open from the north but mainly closed from the eastern and western sides by two barrier reefs. The eastern reef is open via a 500 m deep channel (Piha Passage) that is particularly wide.

The nearshore and intertidal areas of Tongatapu consist of a wide range of habitats including mangroves, rock terraces, sand beaches, saline wetlands, estuary and mudflats, reef flats and coral reefs (barrier, fringing and submerged). The Fanga'uta Lagoon provides additional intertidal areas and is of ecological and cultural significance. The lagoon is characterised as a 36.6 km^2 semi enclosed lagoon averaging 1.0 to 2.0 m depth and has a residency time of 23 hours with tidal mixing at only 12 % (very poor flushing) (Figure 1.1). The nutrient rich ground water essentially supplies the entire lagoon. (refer to Section 8: Annex F for further detail).

This report focuses on five sections of coastline (coastal units) on the northern side of Tongatapu and includes the Fanga'uta Lagoon (Figure 1.3). These coastal units are: (1) Ha'atafu to Foui to the north-west (red), (2) Foui to Sopu in the middle northern-west (yellow), (3) Sopu to Nuku'alofa in the middle of the northern side and includes the Fanga'uta Lagoon to the edge of Nuku'alofa city (blue), (4) Nuku'alofa to Nukuleka (Lagoon main component) (pink), and (5) Nukuleka to Niutoua (green). Basic coastal descriptions of these coastal units are presented below.

(1) Coastal Unit 1 - The north-western coastal unit faces north-eastwards and comprises the villages Ha'atafu, Kanokupolu, Ha'akili, Kolovai and Foui. This coastal unit experiences easterly and north-easterly wind events. Waves that are generated by these wind directions break offshore on the large barrier reef, and are also dissipated by the shallow western section of the Tongatapu Lagoon (Mead and Atkin, 2014). The northern areas of this coastal unit (i.e., Ha'atafu) are topographically higher than the southern areas and are thus less vulnerable to flooding inundation hazards (Figure 4.14). ~2,350 people reside in these villages that occupy this area (McCue, 2014).
(2) Coastal Unit 2 - This coastal unit comprises villages Foui, Masilamea, Nukunuku, Fatai, Sia'atoutai, Puke, and Sopu. This area is considered low lying and vulnerable to flood inundation risks (Figure 4.14). This costal unit is, however, somewhat protected by the adjacent Tongatapu Lagoon, which prevents large waves from penetrating to the coastline. ~2100 people reside in these villages that occupy this area (McCue, 2014).
(3) Coastal Unit 3 - This middle coastal unit comprises the capital city of (urban area) of Nuku'alofa, the area of which consists the northern armoured and non-armoured beaches and part of the Fanga'uta Lagoon. Topographically, this area is only 1–2 meters above sea level and is subject to periodic flooding during heavy rain (Figure 4.14). This coastal unit is home to some 30,000 people. The risk of coastal inundation and erosion is often intensified by development in the coastal area. Most coastal lands

have been significantly altered either through conversion to agriculture/plantation use and urban development of the villages that border the coastline.

(4) Coastal Unit 4 - This coastal unit extends from the south-western to north-eastern shores of the Fanga'uta Lagoon and includes the villages Pea, Ha'ateiho, Veitonga, Nukuhetula, Longoteme, Vaini, Holonga, Alkai, Mua and Hoi. The lagoon is shallow and almost closed off. It is an important breeding ground for birds and fish. The south-western shores are generally more low lying and are subject to greater inundation hazards (Figure 4.14).

(5) Coastal Unit 5 - The northeastern coastal unit comprises the villages Nukuleka, Makaunga, Talafo'ou, Navutoka, Manuka, Kolonga, Afa and Niutoua. This coastal unit is somewhat protected by a submerged fringing reef during high tide, with the reef edge being ~80 m from the beach at Niutou and increasing to >1,500 m further west at Navutoka. Topographically, the land from Kolonga towards Nukuleka (west to east) reduces in elevation. Most of the villages in this coastal unit are less than 3.0 m above sea level, which makes them vulnerable to the effects of climate change, disaster risk, sea level rise, storm surge and coastal erosion issues (Figure 4.14) (McCue, 2014). This area has been subject to some 50 – 70 m of coastal erosion since the 1960s. ~2,200 people reside in these villages that occupy this area. This coastal unit has been subject to various climate change resilience trials, which have seen the construction of sedi-tunnel groynes, detached breakwaters, and revetments

Detailed annexes on the specific components comprising this assessment (biophysical, coastal protection measures, climate projections, socio-economic characteristics and community priority issues) are provided in Sections 3 to 12 below.

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Figure 1.3 The five study sections along the northern coastline of Tongatapu, Kingdom of Tonga (Google Earth, 2020). Coastal Unit 1 = red, Coastal Unit 2 = yellow, Coastal Unit 3 = blue, Coastal Unit 4 = magneta and Coastal Unit 5 = green.

1.3 Bio-Physical Environment of the Northern Tongatapu Coast.

Tongatapu has long felt the effects of inundation and coastal erosion, as a result of human activities coupled with rising sea levels. A literature review assessing geomorphology, biology, engineering, and social characteristics of the northern coast of Tongatapu, including Fanga'uta Lagoon has been conducted to provide an overview of the state of the coastal communities and coastlines. For the purpose of this review, the northern coastline, including the Fanga'uta Lagoon, has been split in five geographical areas to allow for a more comprehensive review for specific coastal shorelines.

The island of Tongatapu is flat and low-lying with the highest elevation being 70 meters above sea level. The island spans 35 km in an east-west direction and 15 km in a north-south direction. The north coast on Tongatapu faces a large lagoon (412 km^2) known as Tongatapu lagoon (Figure 1.1), which has a mean depth of 13.0 m and a maximum depth of around 27.0 m CD. The lagoon is open from the north but mainly closed from the eastern and western sides by two barrier reefs. The eastern reef is open via a 500 m deep channel (Piha Passage) that is particularly wide. These coral reefs act to dissipate wave energy along the shorelines of Tongatapu. Where the reefs are narrow and deep, more wave energy penetrates to the shoreline. In contrast, where reefs are shallow and wide, less energy can penetrate to the shoreline with these areas more protected.

The predominant wind and wave directions are from the south-east, and as such the north coast is sheltered from most deepwater wave conditions although some areas are exposed to high winds. Tides range from 0.9 to 1.9 m. Sea level rise is in the order of 6.4 mm/yr since records started in 1993, which significantly higher than the global average (2.8 – 3.6 mm/yr). On average, Tongatapu experiences two cyclones per year, which can cause severe inundation and flooding to low-lying areas, which is predominantly all coastal urban developments including the capital Nuku'alofa.

The biodiversity of Tongatapu has yet to be fully explored, due to a lack to resources. Despite this, overharvesting and over exploitation of marine resources have been identified as being the greatest threat to marine biodiversity (Chin *et al.,* 2011; cited in NBSAP, 2014).

In general, the bio-physical environment of the northern Tongatapu shoreline has been highly modified, which has seen large mangrove stands, as well as natural coastal resilience structures and processes, reduced and\or removed. This, coupled with the low-lying topographic nature of the urban developments, has created many unstable and vulnerable shorelines to coastal inundation and erosion hazards. These hazards are likely to be exacerbated when coupled with predicted sea level rise and land subsidence. The shorelines of Tongatapu generally comprised of mangrove belts and pockets, sandy or coral beaches, and engineered structures to prevent coastal inundation and erosion.

The individual coastal units considered in this report are summarised below (refer Figure 1.3), and expanded on in Sections 5 to 9 (Annexes C to G):

1.3.1 Coastal Unit 1:

This section of coastline is mostly less than 2.0 m above high tide and is vulnerable to inundation hazards from northerly storms and susceptible to storm surge. The coastline faces east towards the shallow western section of the Tongatapu Lagoon, which helps dissipate incoming wave energy. This shallow area/lagoon is about 10 km east-west and 5 km north-south.

The nearshore environment largely consists of rocky reef flats of the shallow western section of the Tongatapu Lagoon. These rocky reef and sand flats are largely exposed to the north and are overlain by sediment to the south. The south is a low-lying, low energy environment and is suitable mangrove habitat.

The bio-physical environment has been greatly influenced by humans. The northern section, Ha'atafu, has a relatively high elevation and rocky coast, and so is not vulnerable to inundation and erosion like the rest of this coastal unit. A mangrove belt once fringed the entire coastal unit. Mangroves near villages have been removed for various reasons and land has been reclaimed. The development of a wetland in the northern portion occurred around ~1968 and a revetment/coastal road was soon after constructed. The wetland is currently disconnected from the open coast. Various climate change resilience projects have been implemented in this coastal unit, which has seen revetments constructed from Kanukupolu in the north to A'hau in the south to prevent inundation and coastal erosion; wooden groynes and fences to protect mangrove seedlings and prevent damage by foraging pigs in Kolovai and A'hau, and a seawall along the Kolovai road with discharge outlets to prevent inundation and sustained flooding. Mangrove stands and wetland exist in the south of the area.

1.3.2 Coastal Unit 2:

This section of coastline is very low lying and, like coastal unit 1, is vulnerable to inundation hazards from northerly storms surges. This coastline faces northwards towards the shallow western section of the Tongatapu Lagoon.

The nearshore environment largely consists of rocky reef and sand flats that are overlain by sediment to the west on the shallow western Tongatapu lagoonal area. To the east a fringing coral reef exists, beyond which the water depth increases rapidly.

The bio-physical environment has been greatly influenced by humans. A mangrove belt exists along the entire coastal unit but has been heavily modified for growing crops. There is little in the way of engineering or coastal protection measures along this section of coastline, with the exception of coastal protection measures (breakwaters/bunds) that have been built around Sopu along the eastern most section of this coastal unit.

1.3.3 Coastal Unit 3:

This coastal unit comprises a northern section (the north side of Nuku'alofa facing the Tongatapu Lagoon) and a southern section (the southern side of Nuku'alofa on the coastal of the Fanga'uta Lagoon). Nuku'alofa is the capital of Tonga and is highly populated. The coastline is entirely urban and very low lying with only two high ground areas. As such, this area is extremely vulnerable to inundation and coastal erosion hazards from storm events.

The northern section comprises a range of thin beaches backed by breakwaters\seawalls; some 6.0 km of rock armour and port/wharf construction is present between Albert Street in the west and the end of the barrier spit adjacent to Nukunukumotu in the east. The middle northern area comprises the Vuna and Queen Salote Wharfs, which have seen various upgrades over time. The nearshore environment is comprised of rocky reef flats, which extend ~550 m in the west to the ~300 m in the east. The fringing reef lies at the end of the rocky reef flats, beyond which the water depth significantly increases. Hence, the coastline along this area is highly exposed to northerly swells and storm surge.

In the north-eastern corner of this coastal unit, near the entrance to the Fanga'uta Lagoon, significant works have been carried, which have seen breakwaters/seawalls and drainage channels constructed both on the mainland (Nuku'alofa), as well as on Nukunkumotu Island, just east of Nuku'alofa. Mangroves line the channel between the mainland and island.

The southern section of this coastal unit comprises the northern shores of the Fanga'uta Lagoon. The coastline along this area is largely urban with small pockets of fringing mangroves. The is mostly only very low wave action within the lagoon due to the limited fetches, and as such coastal protection structures are largely non-existent with a few properties fronted by tipped rubble mound revetments.

The nearshore environmental consists of shallow lagoonal waters, which are subject to marginal flushing. The lagoon is highly eutrophic and prone to algal blooms. Little of the original mangrove stand exists along the lagoon edge of this coastal unit.

1.3.4 Coastal Unit 4:

This coastal unit comprises the southern shores of the Fanga'uta Lagoon. The southern shores of the lagoon are not typically subject to large wave conditions due to the low energy nature of the lagoon, offshore wind conditions (predominant south-easterly), and limited fetch. Therefore, coastal protection structures are virtually non-existent. Since 2011, the mangrove stands surrounding the lagoon have been protected by law. Despite this, mangrove removal has still occurred.

The lagoon is broken down into four sections. The Mu'a Sector is the initial sector near the entrance (3-6 m depth), water flows from here either south and then west into the Vaini Sector (1-2 m depth) or directly west into the Folaha Sector (3-6 m depth) before entering the Pe'a Sector (1-2 m depth).

The Fanga'uta lagoon is highly eutrophic due the low flushing that occurs (tidal residency of up to 140 days, depending on the sector of the complex lagoon system, with tidal mixing only 10-12%) and the significant amount of anthropogenic pollution and sediment that enters. Yet the lagoon remains an important breeding and nursey habitat for fish and birds. Furthermore, the lagoon has been a life-support system for communities, providing a wide range of marine and intertidal resources, such as mangrove wood (fuel), medicines, fish, seaweed, and shellfish for generations. The nutrients that sustain lagoonal fauna and flora are largely derived from the groundwater, which seeps into the lagoon.

The shorelines are a function of the environmental energy present in each area and range from dense aggregations of mangroves along sections that are shallow and sheltered, to thin stands along headlands and deeper sections that are exposed to higher current velocities and longer fetches. The mangrove belts are typically wider and continuous to the west of the coastal unit and broken to the east towards the more urbanised area of Alaki and Mua. A substantial quantity of mangroves have been removed between Veitongo and Nukuhetulu in the recent past.

The villages of Alaki and Mua are exposed to higher wave energy than other areas, and as such rocky reef flats exist with little sediment overlying. A small breakwater exists between Alaki and Mua, which has provided shelter for sediment accumulation and mangrove development.

In general, the village of Pea is most low-lying (<1 m) and susceptible to inundation hazards with elevations increasing eastward toward Mua (>4 m).

1.3.5 Coastal Unit 5:

This section of coastline is also very low-lying like the Nuku'alofa area, with much of the western part of this coastal unit less than 2.0 m above MSL. The coastline is protected from the prevailing south-east wind and associated wave conditions but is, however, exposed to the northerly storms and as such is susceptible to storm surge, inundation and coastal erosion hazards.

This coastal unit can be described as having a south-west facing Fanga'uta Lagoonal entrance component and north facing open Tongatapu Lagoonal component. The northern nearshore environment is characterised by a by intertidal rocky reef flats with a fringing barrier reef within the Tongatapu Lagoon. Beyond, the water level drops away rapidly into a deep channel. The south-western nearshore component is characterised by intertidal rocky reef flats within the entrance of the Fanga'uta Lagoon.

The shorelines are comprised of thin sandy beaches, backed by a coastal road along much of the length; this road is susceptible to over-topping during extreme events. Several climate change resilience projects have been constructed to prevent inundation and coastal erosion hazards. Between Makaunga and Talafo'ou, a groyne field has been constructed and beaches have shown signs of growth and stability during a recent evaluation. On the northern side, a combination of revetments and detached breakwaters have been constructed from west to east, respectively. Along the northern coastline, historical shoreline analysis has revealed that between 10 and 25 m of retreat/erosion has occurred since 1968 with most of it occurring after 1981.

1.3.6 Existing Coastal Engineering Structures

Coastal Unit 1

A revetment has been constructed from Kanukupolu in the north to A'hau in the south to prevent inundation and coastal erosion; wooden groynes and fences to protect mangrove seedlings and prevent damage by foraging pigs in Kolovai, and a seawall along the Kolovai road with discharge outlets to prevent inundation and sustained flooding are also present. All of these coastal protection measures have been undertaken with international aid funding.

Coastal Unit 2

This unit is mostly devoid of coastal protection measures and fronted by mangroves. Some intervention has occurred along the eastern most section (Sopu), low bunds and breakwaters constructed near and along the coastline.

Coastal Unit 3

The northern section of this unit along the coast of Nuku'alofa comprises a range of thin beaches backed by breakwaters\seawalls; some 6.0 km of rock armour and port/wharf construction is present. In the north-eastern corner of this coastal unit, near the entrance to the Fanga'uta Lagoon (Siesia and Popua), significant works have been carried out, which have included breakwaters/seawalls and drainage channels constructed both on the mainland (Nuku'alofa) as well as on Nukunkumotu Island, just east of Nuku'alofa (Siesia).

The southern section of this coastal unit comprises the northern shores of the Fanga'uta Lagoon, which is usually exposed to only very low wave action within the lagoon due to the limited fetches, and as such coastal protection structures are largely non-existent with a few properties entertaining tipped rubble mound revetments.

Coastal Unit 4

The southern shores of the lagoon are not typically subject to large wave conditions due to the low energy nature of the lagoon, offshore wind conditions (predominant south-easterly), and limited fetch. Therefore, coastal protection structures are non-existent.

Coastal Unit 5

Several climate change resilience projects have been implemented in this coastal unit. Between Makaunga and Talafo'ou, a groyne field has been constructed and beaches have been increased in width and stability. On the northern side (Manuka), a combination of revetments and detached breakwaters have been constructed from west to east.

1.3.7 Coastal Hazards

Coastal hazards and where they occur for each Coastal Unit are detailed in Section 11: Annex I. The most common hazard is inundation, which occurs in all 5 Coastal Units. This is to be expected due to the low-lying nature of Tonga's northern coastline, although is exacerbated by the removal of mangroves in many area (especially within Fanga'uta Lagoon).

The removal of mangroves and sand extraction have also resulted in coastal erosion (especially on the southern side of the Lagoon and along the north eastern coast, which also exacerbates inundation and over-topping, which has been defended with coastal structures in some cases, as summarised in the section above.

The information presented in Section 11: Annex I, in combination with the community's priority issues and the information compiled on the bio-physical nature of the northern Tongatapu coastline will be used for the development of the next phase of this project:

a) Overall conceptual design and costing for the entire length of coastline from Niutoua to Ha'atafu including the Fanga'uta Lagoon for the 2030 and 2050 planning horizons, and;
b) Specific conceptual design and costing for the minimum 10 small-scale hard and soft engineering measures for the northwest coastal stretch from Sopu to Ha'atafu to be considered for implementation during the period mid-2021 to end 2022.

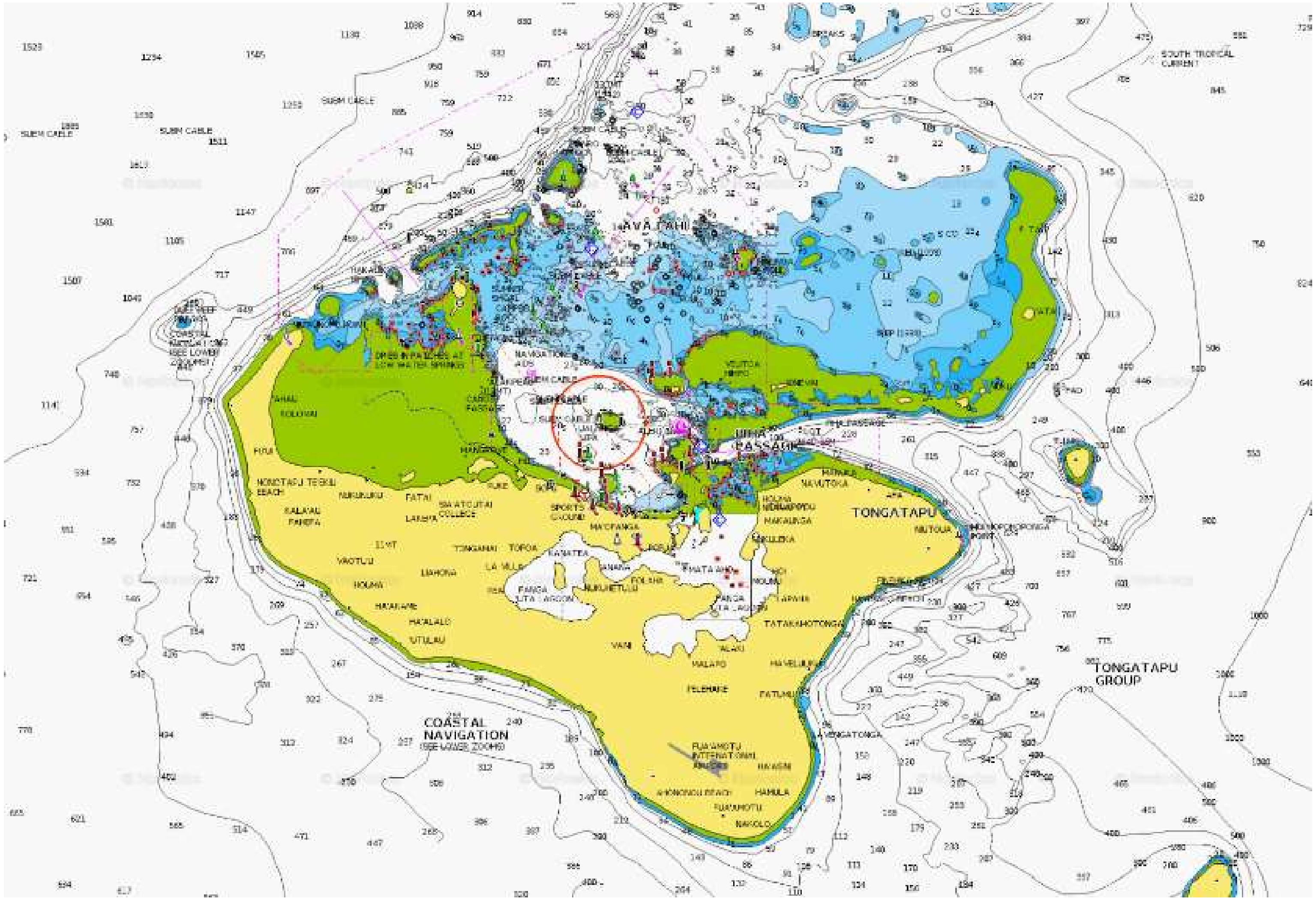

Figure 1.4. Nautical chart of Tongatapu[1].

[1] https://webapp.navionics.com/#boating/mapOptions@9&key=hk%7C_Cbcsj%60%40

1.4 Socio-Economic Characteristics and Community Priority Issues

The socio-economic assessment (Section 10: Annex H) was undertaken using the 2016 Census and related publications, community consultation meetings and a questionnaire, with the more salient results summarised here.

Socio Economic Value

Three areas were raised regarding the important features on the coastal zone that were seen as significant to their community and needed to be protected. All three areas of concerns were noted within the area fronting the foreshore (above the high-water mark).

- The first issue was regarding cultural/religious areas. The respondents noted that there had previously been four fishing areas, but that they no longer fished there.
- The second issue pertained to the natural areas, such as mangroves, that were used for medicinal and construction purposes.
- Finally, the respondents noted areas of concern in terms of their food sources, specifically mentioning the following fish/seafood: oo, tanutanu, koputu, ihe, unomoa, paka, feke, lomu, teepupulu, 'elili, takaniko, and mehingo, as well as food items such as carrots, tomatoes, cucumber, lettuce, cabbage, and onions.

The respondents did not indicate any concerns for water sources, access to the beach, or *any particular built structure* that might be in jeopardy.

Coastal Zone Hazards

80% of the respondents stated that they frequently visited the coastal zone and made use of coastal amenities, while the other 20% of respondents visited occasionally.

All respondents indicated having seen or experienced major changes to the beach front and/or within coastal watersheds. These changes included erosion/loss of land, loss/changes to engineered structures or roads, and loss of vegetation.

Further information on the coastal zone hazards faced by these communities are discussed in Section 11: Annex.

Disaster Response

No information was provided regarding the survey questions pertaining to disaster response, including information on early warning systems, disaster management procedures, location and the time it takes to get to the evacuation centre, and possible things that the respondents might give up in order to address the issue of overtopping.

Community Benefits

All of the respondents felt the need for improvements within the coastal zone fronting their community. These improvements included beach restoration, rock baskets, sea walls, reclamation, and planting of coastal vegetation.

It is of note that some of these improvements have already been implemented, and as such the survey participants have been able to see the value and benefit of these particular improvements.

The need to educate students and all levels of the community on coastal protection and better practices was also recognised.

Social Impacts

The social impacts identified during the community consultations and survey questionnaires included:

- Concerns based on rising sea levels that have increased inundation, flooding, and overtopping, as well as land reclamation by the sea;
- Concerns that flooding is causing road closures and damaging the road integrity;
- Concerns regarding the impacts to crops and their livelihoods due to flooding and overtopping;
- Concerns regarding deaths due to drowning caused by flooding for those with limited swimming abilities and a lack of knowledge of safe areas to cross channels during these times of flooding;
- Concerns surrounding the previous and continuous removal of mangroves, and other illegal activities including sand mining, that has a direct correlation to increased flooding issues, and;
- Concerns regarding lack of maintenance of previous coastal protections projects.

Recommendation and Mitigation Measures

The following are recommendations from a social perspective to help mitigate some of these impacts for those living along the coastal zones:

- Dedicated community liaison for disaster management to assist the communities by relaying information to them, as well as during natural disasters such as tropical cyclones or tsunamis providing current, up-to-date evacuation information and status;
- Increased monitoring of illegal activities, including sand mining, mangrove clearing, and pig roaming, including providing clear procedures on who and how to report these activities when observed;
- Working with local school and community groups to organize the replanting of mangrove and other coastal vegetation;
- Provide awareness training and programmes to communities to educate the communities on the coastal processes and the impacts of various activities, such as the removal of mangroves, sand mining, etc.;
- Installation of a monitoring programme to evaluate the effectiveness of the coastal measures and changes that are put in place;
- Installation and maintenance of culverts;
- Potential relocation for those communities who have no other effective coastal protection measure options.

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3 Annex A: Inception Meeting Report

GCCA+ SUPA Project Inception Meeting

Project Long Title	Consultancy to conduct an assessment, conceptual design and feasibility study for coastal protection along the north coast of Tongatapu, Tonga (Niutoua to Ha'atafu and including the Fanga'uta Lagoon). RFP19/108
Objective	To inform relevant stakeholders such as government officials, civil society, NGOs and the community about the project and its mandated activities with special focus on the work that is currently undertaken by the eCoast Consultant.
Date	10th September, 2020
Time	10am-1pm
Venue	Baha'i Church Hall, Nuku'alofa
Summary	• Meeting begun with a prayer followed by the welcome address by the Project National Coordinator, Manu Manuofetoa. • A group photo was taken before participants were called back to their seats to proceed with the meeting (see Appendix 1) • Manu delivered the introduction before he presented a PowerPoint on the following: a. Background information of the GCCA+ SUPA Project – a regional project funded by the European Union and implemented by SPC, SPREP and USP in partnership with 10 countries in the Pacific. b. Tonga's Coastal protection project and the four (4) Key Result Areas (KRAs) that the project covers. c. eCoast Consultant who has been engaged directly by SPC to undertake the overall assessment of the northern coast of Tongatapu. d. Coastal Protection– Issues in Tonga, Extreme Events, Sea Level Rise (SLR) and potential response to SLR e. Five (5) community meetings aimed at collecting more data for both the overall assessment of the northern coast of Tongatapu and the impact assessment of the coastal protection project implemented in eastern and western Tongatapu. • After the presentation a discussion forum and Q & A summarised below:

	➢ The discussion began with a question from Pea Town Officer (TO) who queried on confirmation if the project was going to be implemented or not. He specifically mentioned how he has been invited for project meetings, but they hardly received any assistance. Manu confirmed in saying that such a meeting is organised to commence the project and will be followed by 5 community meetings. Manu further asserted that meetings will only be called once certainty is confirmed, hence the purpose of the meeting today. ➢ Another question had been from the District Officer of Kolofo'ou, 'Alotaisa Takau who raised the question of whether the project is in line with government's long-term development goal. Manu responded by saying that all climate change projects are aligned to the Tonga Strategic Development Framework (TSDF 2015-2025) and the Climate Change Policy as well as Joint National Action Plan 2. ➢ There was also a question about the total value of the project and how the funds would be utilised. In response, Manu said that the total budget for the project is around 0.5million euro and has been allocated in 4 KRAs. Interestingly, while there were some who appreciated the EU and SPC generosity a few were saying that the budget is not sufficient to cover all villages in the entire north of Tongatapu. Manu clarified that the KRA1 was and is intended to cover the whole of northern Tongatapu. However, he said that he had mentioned in his presentation that small hard and soft option projects will only start from Sopu to Ha'atafu. Manu again informed the participants that once the report for KRA 1 is completed it will be used to prepare another proposal for a bigger project that will cover the whole northern coast of Tongatapu. This clarification from Manu brought smiles on the faces of those who had questioned the budget. Mr.Takau again thanked Manu for the clarification and turned to the participants and moved the motion that they should support the project's plans for small projects to be implemented from Sopu to Ha'atafu. He said the other communities will wait for the next project and everyone seemed happy and agreed with the motion by Mr.Takau. • The discussion then shifted to issues that the communities are facing. Among the issues reported was sea level rise, inundation, erosion, overtopping during cyclone and storm surges, lack of catches along the coast as compared to the past 10 years. • Also, the Town Officers from Talafo'ou and Makaunga reported that the sedi-tunnel groynes implemented along their coasts are taking time to bring about the result they anticipated. Manu clarified by saying that the project was a 'pilot' one and he said it had been explained to the community at the time that it will take time for sand to deposit due to the fact that there was only one source that provided sand for these coasts. According to Manu there is no sand

	coming from the deep ocean but rather brought through a channel by waves and wind along the north eastern sides of these communities. Manu further said that the GCCA+ SUPA project will evaluate the impacts of the previous project and from there it will determine if the sedi-tunnel groynes were working or not. • The Fua'amotu Town Officer reported that some parts of their beaches are heavily eroded and need urgent action. He asked if the project will be able to assist in solving this issue. Manu responded by saying that it was unfortunate that the project only covers the communities along the north coast of Tongatapu. However, he said he will bring up the issue up with the Director of Climate Change to see if the department could assist. • There was a concern regarding the sustainability of the project especially when the project is completed, some project sites are left unattended and no maintenance works have been conducted. This has led to some project sites either being damaged or becoming an eyesore. In his attempt to respond to this matter Manu acknowledged the concern raised is real. However, he mentioned that the main reason why donors partner up with government is because there is an expectation that the government will continue monitoring once the project is completed and due. Other methods used by the donor is to work in partnership with other donors so when one donor funded project is due the other donor will come in and proceed with what the other project had covered. He used the example of the partnership between the GIZ ACSE project and the GCCA+ SUPA project in Hihifo. • Prior to the closing of the meeting Manu requested for participants to fill the questionnaires provided by eCoast. • The closing prayer was conducted by District Officer of Nukunuku constituency, Sione Nuku Kata.
Outcome:	1. Participants were made aware of the GCCA+ SUPA Project and its mandated activities. 2. Communities were informed of the 5 community meetings that has been planned to soon. commence in their respective constituency. 3. Some information had been collected from the questionnaire that were given to the Participants.
Participants- full name and position (or if large national event- organisers only):	See Participants List in Appendix 2

Appendix 1: Images from the Inception Meeting

Appendix 2: Questionnaires and summary of answers

What happen during extreme events? Does over-topping occur on your property or somewhere nearby? If so, how often and to what extent (e.g.: spray onto the footpath, large volumes of discharge across the road and into your property, etc. Do you recall the dates? If so, please list them – this will help further determine the kinds of events in terms of metocean and conditions that lead to hazard?

Over-topping is an ongoing problem in our community. Usually, it happens during strong wind and cyclones but the current trend is that it's occurring on a regular basis and it's not only affecting those living along the sea but also those household residing further landward.

Over-toping exacerbated soil erosion and when soil erosion takes place it uproot coastal vegetation. Some of the lands that we used to plant before are now under water

Yes – we are experiencing over-topping almost every month especially the side to Lavengamalie in Tofoa as it is the lowest part of the community

Our home is not affected but our neighbors have been badly affected over the years.

Have you observed changes to the beach and the surrounding environment over time (e.g.: erosion/loss of sand, sand accretion, loss of vegetation, loss/changes to engineered structures or rocks? Please describe and indicate on the aerial poster

A lot of changes (negative changes) have been happening in our shores today. We experienced erosion, loss of sand, sand accretion and loss of vegetation. As for changes to engineered structures, some changes are cause by nature and some are caused by human activity

What do you value/what is important about the coastal setting and what do you not like/value. For example, the beach, beach access (where are these/which access), walking along the beach, collecting food, fishing, the aesthetic of the bay, built structure etc.

Important: Beach, walking along the beach, the aesthetic of the pay and fishing and built structure

Dislike: Littering along the beach

Which one would you prefer to give up in order addressing the increasing occurrence of over-topping due to sea level rise? For example, some views of the bay due to heighted protection structure, one lane of the road to accommodate a wider buffer zone etc.

There is no need to give up anything. Rather, we need to work together

Appendix 3: Participants List

GCCA +
THE GLOBAL CLIMATE CHANGE ALLIANCE PLUS INITIATIVE
Funded by the European Union
SCALING UP PACIFIC ADAPTATION (SUPA)

EVENT: Inception Meeting
PROJECT: GCCA+SUPA
COMPONENT: General/Component 1
LOCATION: Baha'i Hall, Fasi
OFFICER IN CHARGE: Manu Manuofetoa & 'Unga 'Aholelei
DATE: 10/09/2020

#	Name	Job/Agency/Community	Signature	Phone/email
1	Sosefo Hehea	Vaini Town officer	[illegible]	7759008
2	Lipi'ati Fohulu	Talafoou	[illegible]	7771692
3	Ofuhouna Nepot	Veitongo	ONepot	7715760
4	Sila Tautuiaki	'AHAU	[illegible]	7711343
5	Lafoaga Fahamokioa	Ideleki	[illegible]	7780695
6	Valeti Kaufo	Havelu T/Officer	[illegible]	22553.
7	Reynold 'Ofanoa	MOH	ROfanoa	8833179
8	Sela Akolo Fa'i	"	[illegible]	7714092
9	Paea Filimoehala	Haveluloto	[illegible]	7595157
10	Meleane Fakalolo	[illegible]	[illegible]	8608196
11	Siosua Holani	Pelehake/Kolonga	[illegible]	35525
12	FINE ANASI	LONGOTEME	[illegible]	7783139
13	Kelemesi Filikitonga	KOLONGA	[illegible]	77-74019
14	KAUFINGA LI	MANUKA	[illegible]	8451138
15	Taliuki 'U. Fusi'ahi	NUKUNUKU	[illegible]	8772211
16	Fuatakavu Tuionetoa	Talafo'ou	[illegible]	7714585
17	Sioape L. Fonokalafi	Makaunga	[illegible]	8768878
18	[illegible]	Kolofo'ou	[illegible]	7790265
19	ALOTAISI TAKAU	Kolofo'ou D/O	[illegible]	7717450
20	Daisy R. Anna	Popua	DRAnna	7704417 fkfofonga
21	Penu Havea	LLT	Penu H Havea	863-4432
22	S. Fuanaki Latu	Nukunukumotu	[illegible]	776823
23	SEMISI VEA	TUFOA	[illegible]	77-49174
24	NIALOLO TUPOU	PUKE	[illegible]	7760344
25	Sione Taumoepeau	FATAI	[illegible]	8703106
26	Paulo. Muller	T/O Matafonua	[illegible]	8737587
27	[illegible] L Lui	D/O TITONGA	[illegible]	8768330
28	SANGLIA LAUTAIMI	TATAKAMOTONGA	[illegible]	7714297
29	SAFEKI T. TANGI'A	Pea T/officer	[illegible]	8438323
30	MAILE AKAINA	LAPAHA	[illegible]	7740477
31	Viliami Sungā	D/O Vaini	[illegible]	7716371
32	METUI [illegible]	D/O KANOKUPOLU	[illegible]	7748226
33	Papiloa Bloomfield	Foliaki D/Director Tcdt	[illegible]	24199
34	Kalolaine Kavaefiafi	PM/Tcdt	[illegible]	7758453

34	Sione N Kioa	D/O Houma / Niuafo'ou		7754014 / 8
35	Malialosa Tapueluelu	Caritas Tonga		840-4931 / 26-8
36	Hanisi Fonua	TO - Fo'ui		7732407.
37	Sione Manumanu	DO - Hihifo		7717702
38	Viliami Faleafa	TO - Kolomotu'a		7784602
39	Aleki Kangafatai	TO - Hofoa		
40	Tevita Piukana	TO - Ha'atafu		8402902 / 8799909
41	Moala Aniseko	TO - Nukunuku		7719320
42	Mafiu Langi	TO - Nukuleka		8817002
43	Frances Sefini	GCF		7736243
44	Salote Samate	GCF-NAP		7740154
45	Akanesi Tofu	GCF-NAP	Tofu	7737719
46	Lazarus Vaipulu	GCF-NAP		77-12171
47	Pisila Kaianga	GCF - NAP		7796-406.
48	~~Salote Sam~~			
49	Ilaisaane Moala	GCF Phase 2		7774414
50	NUA VEILOFIA	CLIMATE FINANCE	N.V	26-514
51	Elizabeth Akauola	GCF		26514
52	Ma'ata Foliaki	JNAP Sec		7702268
53	Filimone Moli	Climate Change		7708366
54	Losana Latu	Climate Change		26514
55	Liliani Makasini	CLIMATE CHANGE		26-514
56	Gatton Tonga	MEIDECC		7756148
57	Kevini Falesiva	MEIDECC		7761913
58	Kalisitiane Koaneti	GCF-NAP Project		7728715
59	Manu Manuofetoa	GCCA+SUPA - NC		7736695
60	Filimoeunga Akolei	GCCA+SUPA - FA	Akolei	7798991
61	Siutaisa Fakahua	Climate Change		26814
62	Manu Manuofetoa	GCCA+SUPA	Manuofetoa	7733695
63				
64				
65				
66				
67				
68				
69	Filimoeunga A			

4 Annex B: Bio-Physical Environment of Northern Tongatapu

4.1 Geology

The Tongan archipelago is formed from western edge of the western Pacific Plate colliding with, and sliding below, the Indian/Australian Plate (Scholl and Vallier, 1985; Mimura and Pelesikoti, 1997; Department of Environment, 2005; Lao, 2007).

There are two parallel lines of islands: the eastern line, consisting of coral islands; and the western line consisting of volcanic islands (Wood, 1972; Scholl and Vallier, 1985; Mimura and Pelesikoti, 1997; Lao, 2007). East of the coral islands is the deep Tonga Trench, which extends to a depth of ~10,500 m (Wood 1972; Scholl and Vallier 1985; Stevenson *et al*., 1994; Lao, 2007). The islands that are located along the north-west to south-west axis (red line Figure 4.1) (e.g. Niuafoóu island (north west) to Áta island (south east), of Tonga are composed of fresh volcanic islands, and the islands that are located along the north-east to south-east axis (black line Figure 4.1) are uplifted limestone islands (e.g. Vavaú Groups main island (north-east) to Éua island (south-east) (Scholl and Vallier, 1985; Stevenson *et al.,* 1994; Lao, 2007). While founded on older volcanic substrates, the limestone islands are formed from coral (Scholl and Vallier, 1985, Stevenson *et al*., 1994; Mimura and Pelesikoti, 1997; Lao, 2007).

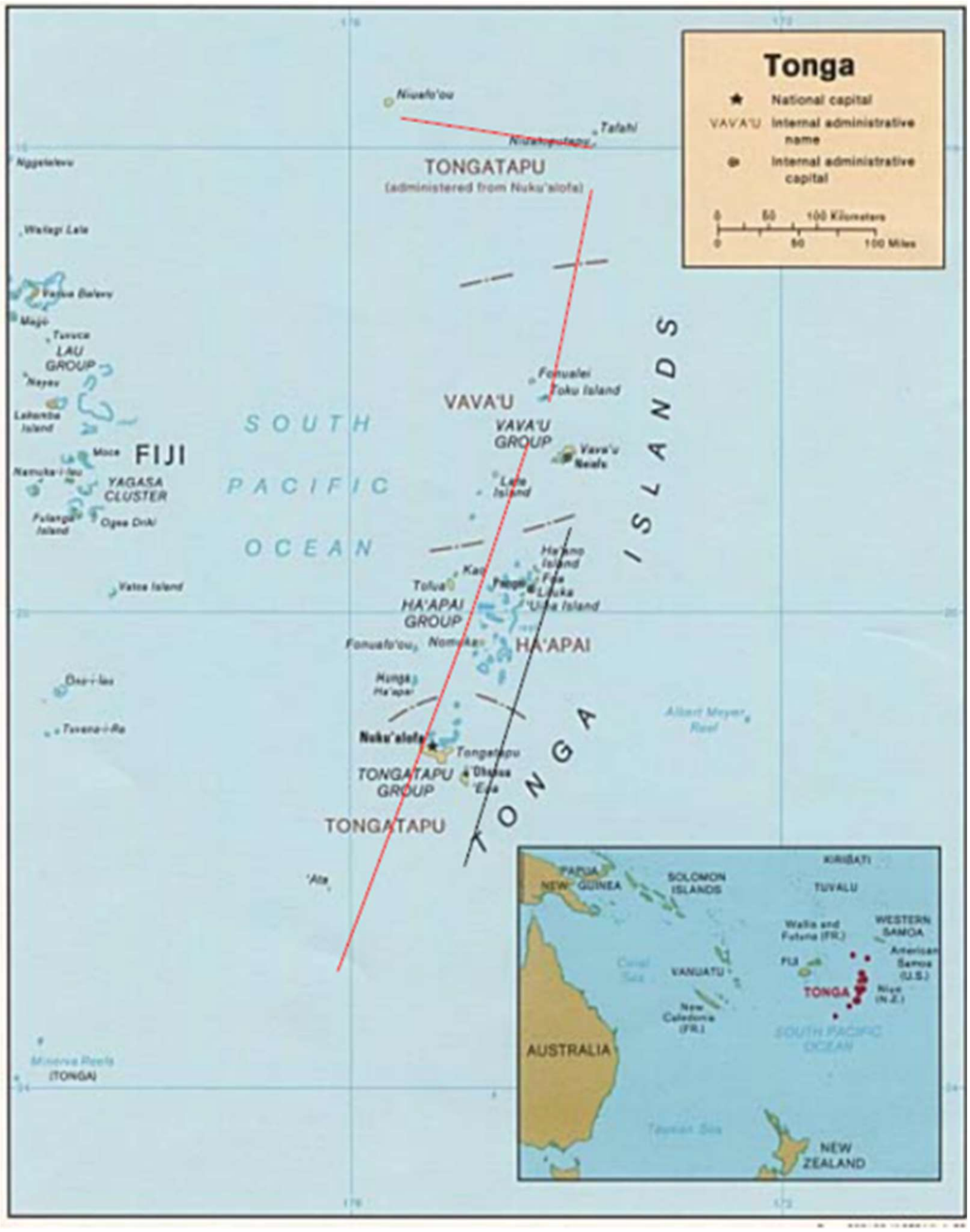

Figure 4.1 Map illustrating the different geological island groups, Kingdom of Tonga (Ministry of Lands, Survey, and National Resources, Nuku'alofa, Tonga, 2001; cited in Lao, 2007). The western line of islands are volcanic (red lines), and the eastern line of islands are coral (black line).

4.2 Island Elevation

The island of Tongatapu is flat and low-lying with the highest elevation being 70 meters above sea level. The north-west tilting of Tongatapu coupled with the accelerated sea level rise (some 20,000 years ago) has caused land subsidence along most of the northern coastline, making all land and human development susceptible to inundation and flooding in this area. The low-lying and consequently vulnerable land areas of the northern coast and the coastline around Fanga'uta Lagoon is very obvious in the 2012 LiDAR, which is presented for the 5 coastal units in Figure 4.2 to Figure 4.6. The red zero metre contour is set at mean sea level (MSL), with the 1.0 m contour (orange) being slightly above highest spring tides and the 2.0 m (yellow) contour representing a level close to maximum inundation during a strong tropical cyclone occurring at high spring tide (e.g., TC Harold in early April this year). The Nuku'alofa area (Coastal Unit 3) is particularly low-lying, with much of the topography between 1.0 and 2.0 m above MSL (Figure 4.4). Coastal Unit 5 also has a very low-lying coastline like the Nuku'alofa area, with much of the western part of this coastal unit less than 2.0 m above MSL (Figure 4.6).

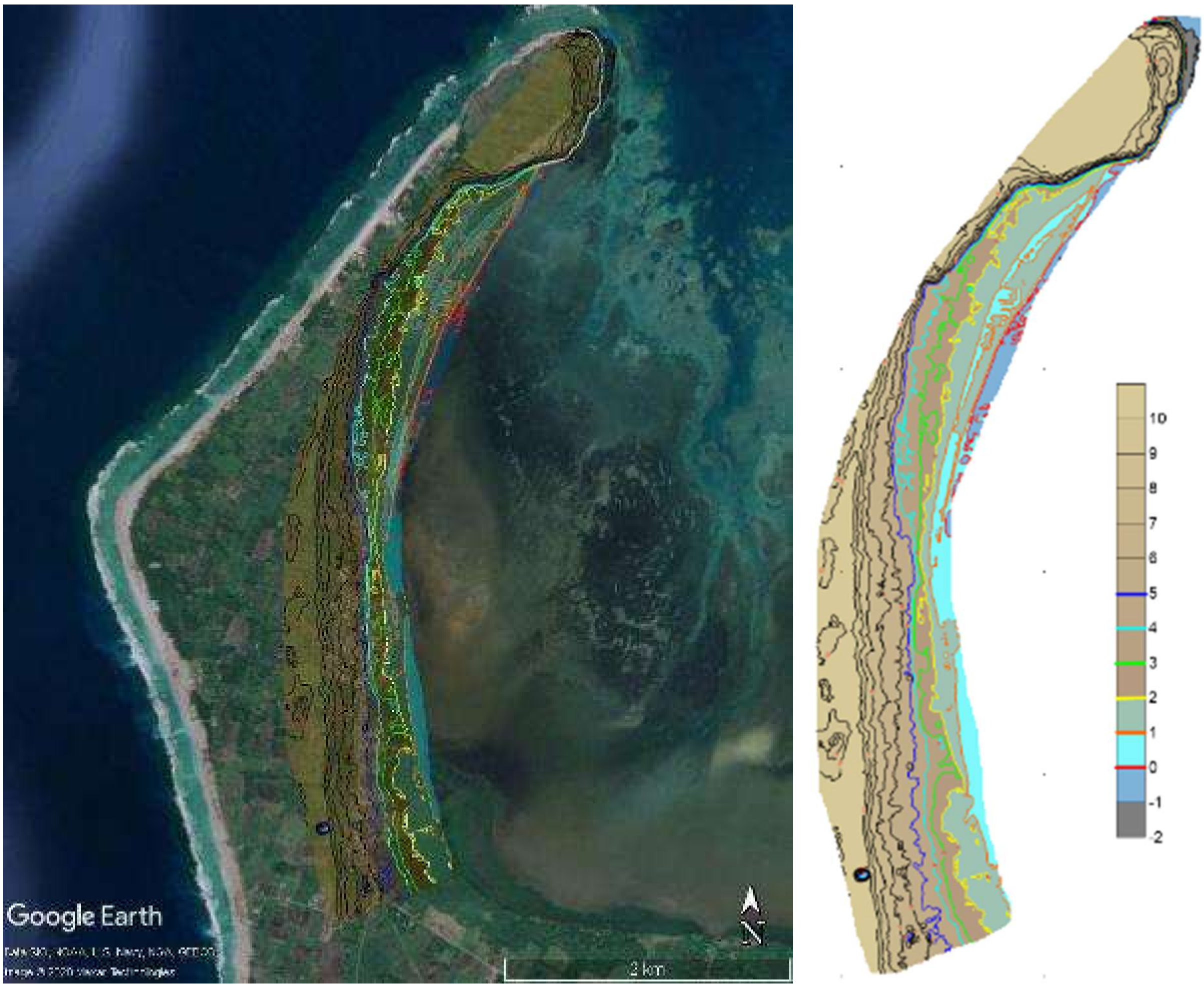

Figure 4.2. Elevation map of Coastal Unit 1. The red line represents MSL and the yellow line represents 2.0 m above MSL.

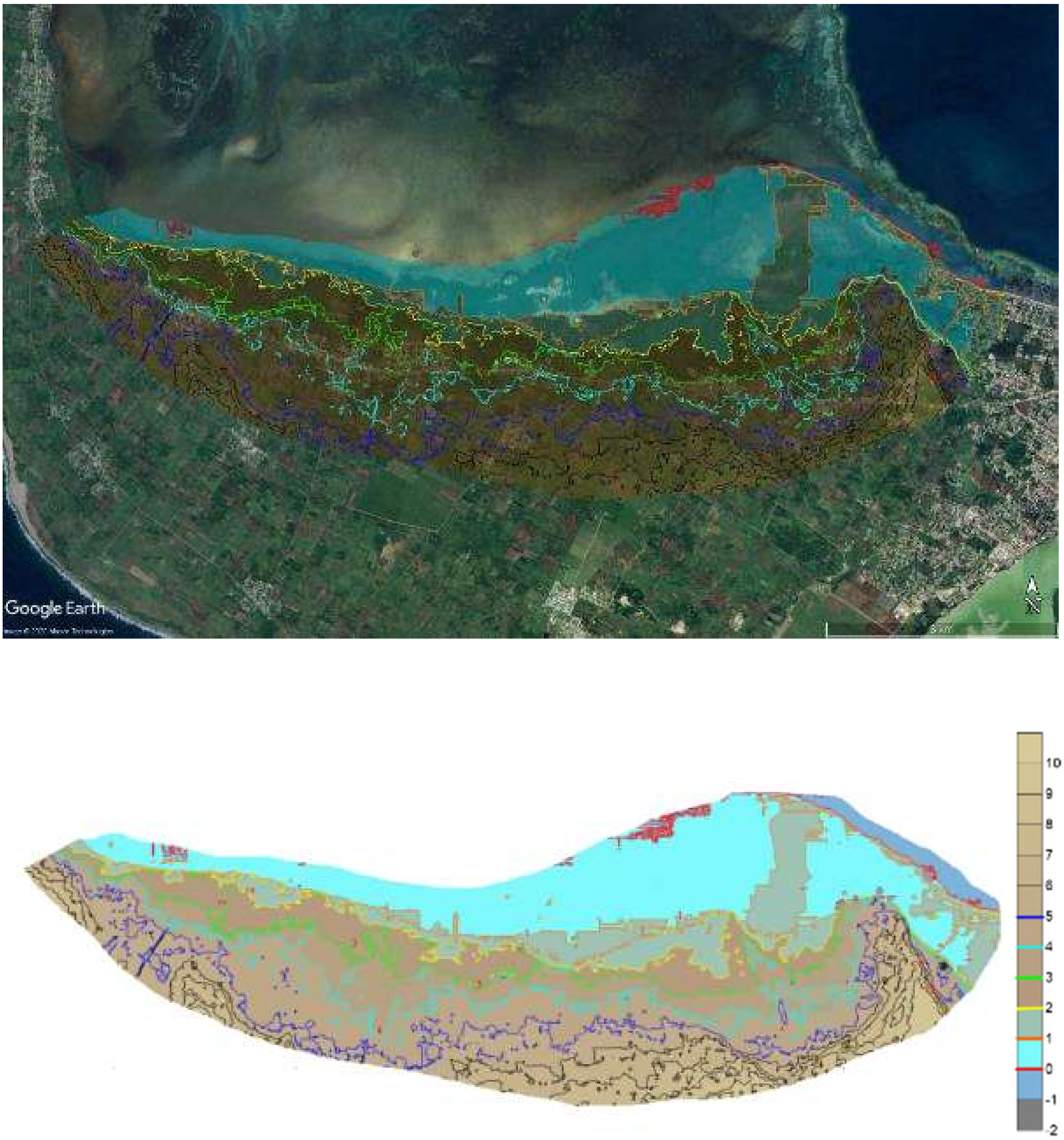

Figure 4.3. Elevation map of Coastal Unit 2. The red line represents MSL and the yellow line represents 2.0 m above MSL.

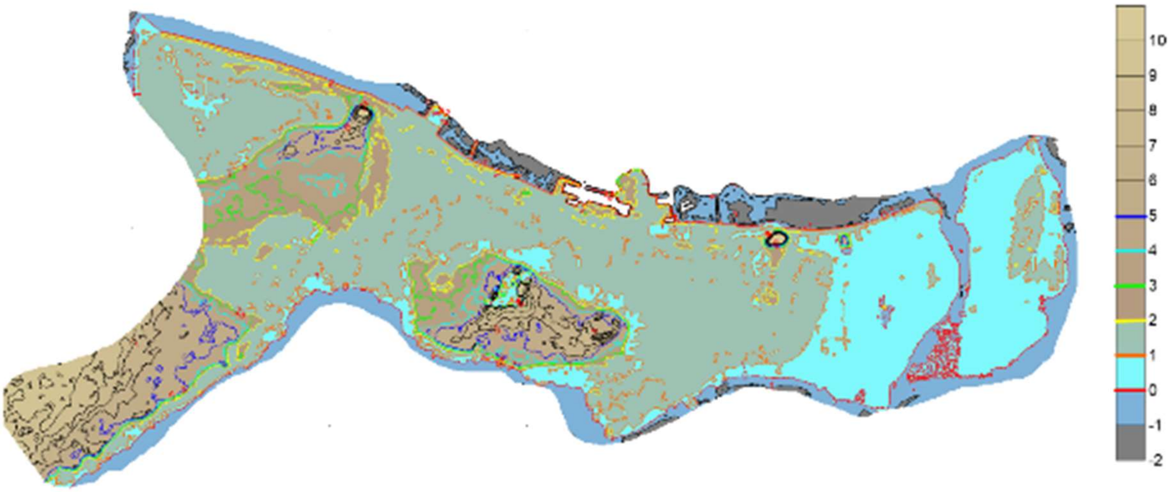

Figure 4.4. Elevation map of Coastal Unit 3. The red line represents MSL and the yellow line represents 2.0 m above MSL.

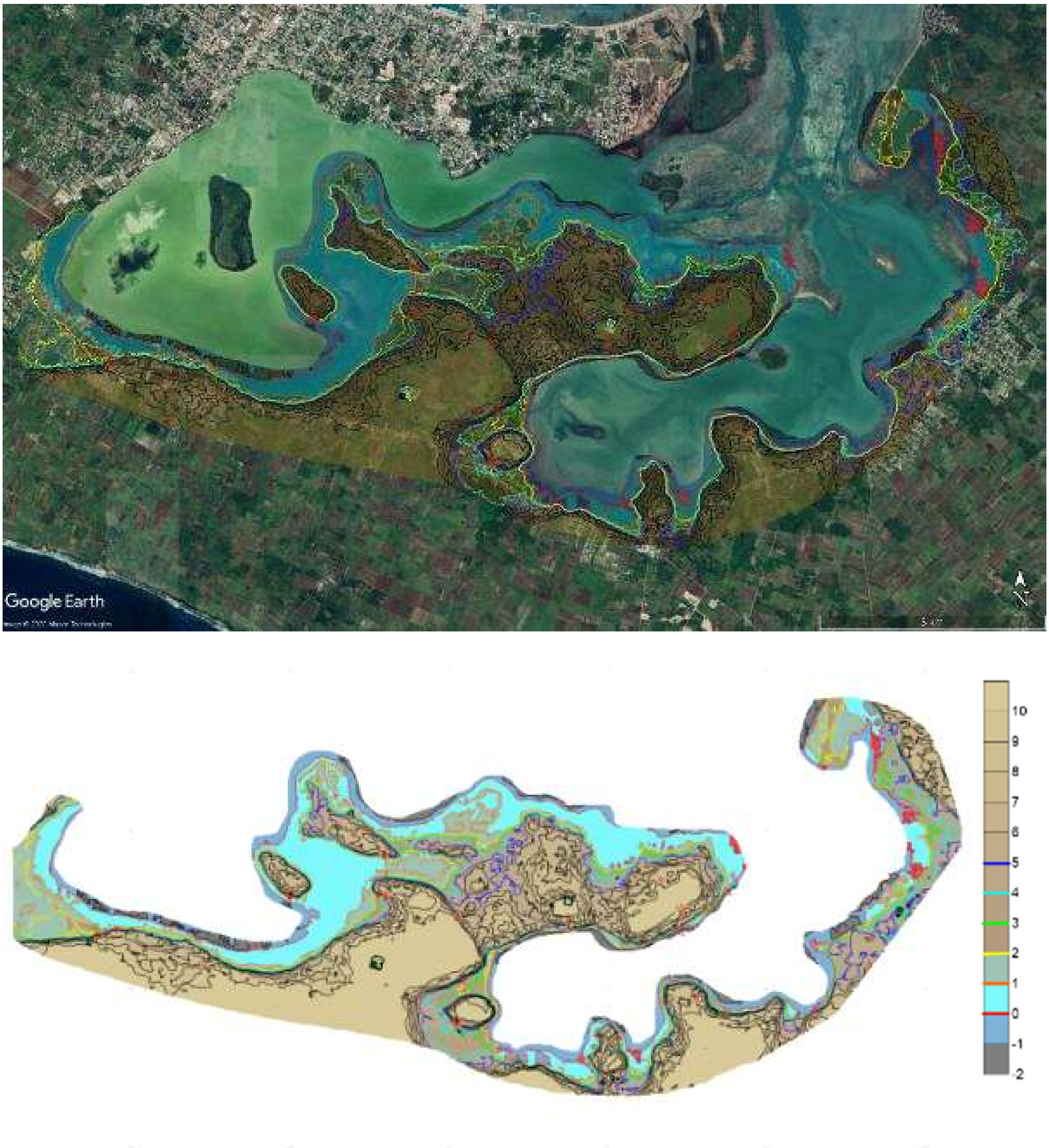

Figure 4.5. Elevation map of Coastal Unit 4. The red line represents MSL and the yellow line represents 2.0 m above MSL.

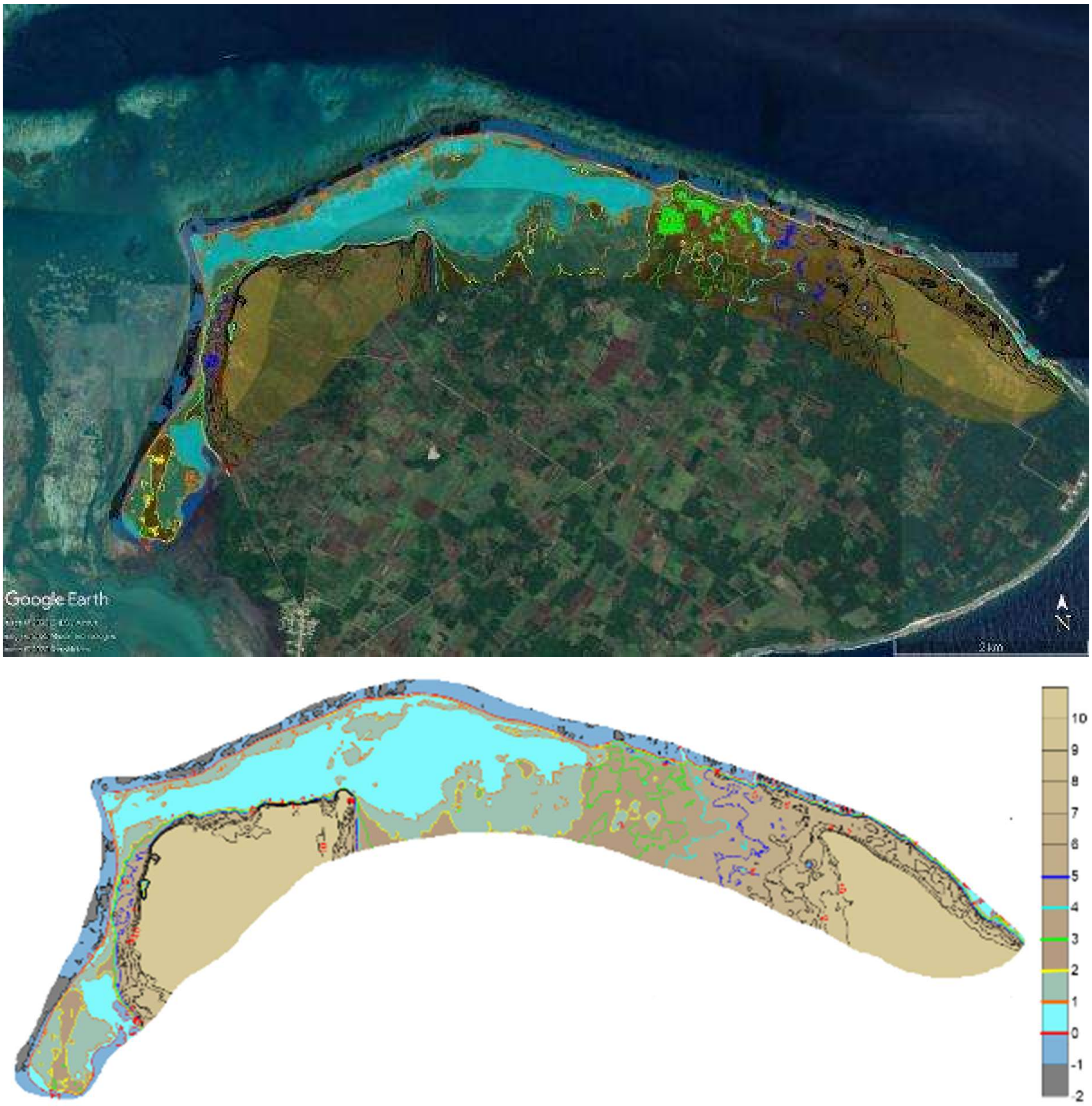

Figure 4.6. Elevation map of Coastal Unit 5. The red line represents MSL and the yellow line represents 2.0 m above MSL.

4.3 Wave and Wind Climate

Waves and wind-driven currents have the biggest impacts on coastal morphology in the study area. In 2013, wave and wind data were downloaded from eCoast's MDI (Metocean Data Interface) for a 5 year period between 2005 and 2010 to provide some background data on the wave and wind climates for northern Tongatapu (Mead *et al.,* 2013) – the data extraction site was to the north-west of Tongatapu in deep water beyond the fringing reefs.

The data shows the predominance of the south-easterly winds with the consequent short period waves from the south-east, and the longer period south-west swells that originate mostly from the Tasman Sea and Southern Ocean (Figure 4.7, Figure 4.8 and Figure 4.9). Therefore, the northern side of Tongatapu is more sheltered than the southern side, as the northern side of the Island is not exposed to the predominant wind and wave climate.

Given the orientation of northern Tongatapu, all studies areas are well protected from the dominant wave conditions, with local wind-waves from the eastern quarter leading to most wave activity in a gradient from the north to the south of the study site. Tropical cyclones, however, can produce very large waves and often approach from the north to north-west (e.g., Figure 4.8), thus the northern coast is exposed to these events, as noted in previous investigations, especially the capital city where there is little protection.

The wave climate along the north-western coast of Tongatapu (Ha'atafu to Sopu), is reduced due to the wide shallow lagoon that characterises that area. Waves along this section of the coast are estimated to be <1 m, except during tropical cyclone events. During tropical cyclone events, which occur on average 2 times per year within 400 km of Tongatapu and other extreme wind/wave events (i.e., tropical depressions), storm surge can allow larger waves to penetrate to the coast if they occur at full tide, although it is not expected that they would be significantly larger than 2.0 m due to effects of the wide shallow lagoon area (e.g., Gourlay, 1994). Under normal wave climate conditions, waves are estimated to get no greater 1.0 m along any section of the northern coastline.

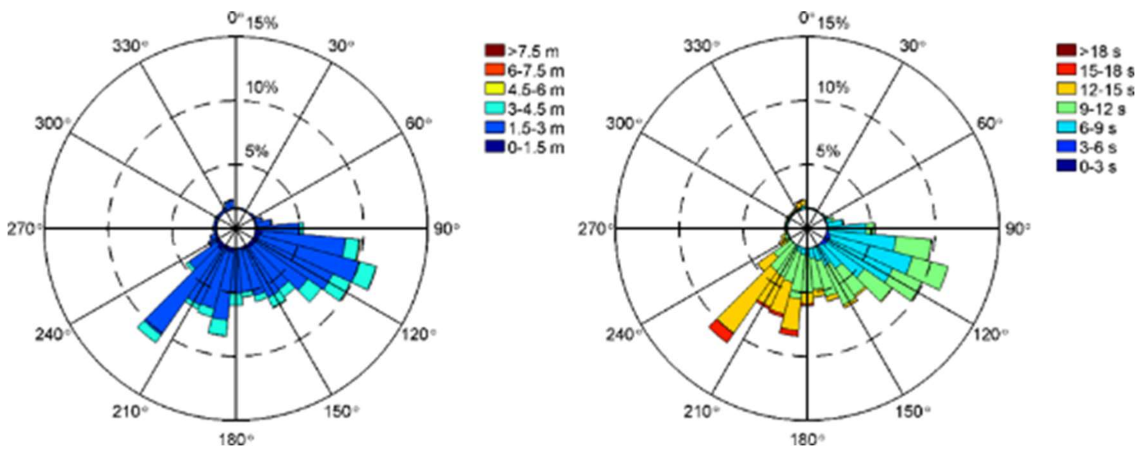

Figure 4.7 Roses of wave height (left) and period (right) for offshore north-west Tongatapu.

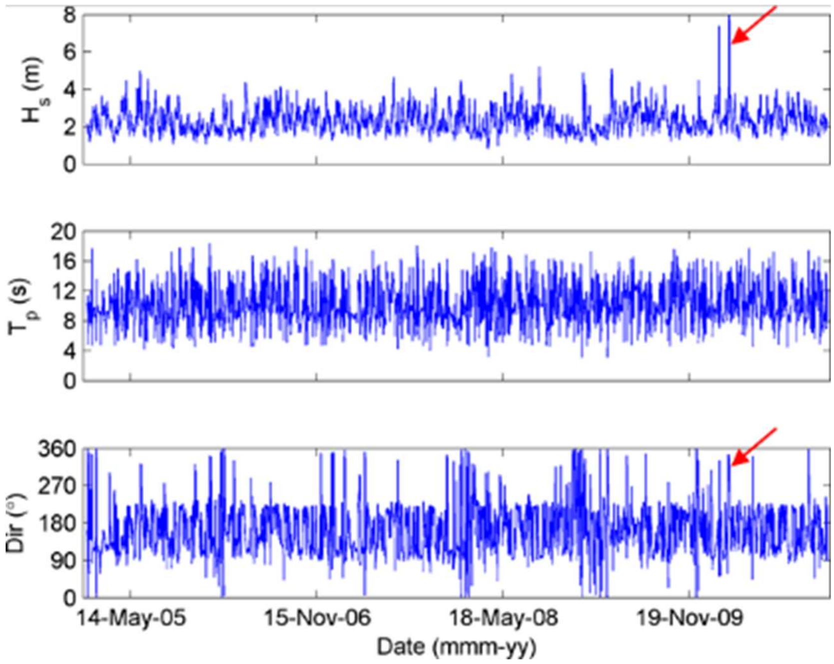

Figure 4.8. Wave time-series data for offshore north-west Tongatapu. A tropical cyclone event is highlighted by the red arrows, which show the extreme wave heights (top) and the approach from the northerly quarter (bottom).

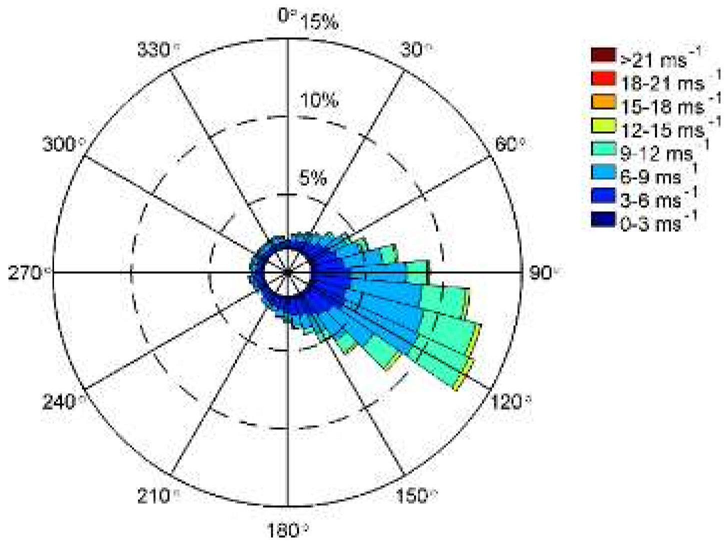

Figure 4.9. Wind rose for north-west Tongatapu.

4.4 Hydrodynamics of Fanga'uta Lagoon.

Damlamian (2008) carried out hydrodynamic modelling of the Tongatapu Lagoon, which was currently updated for the ADB Fanga'atu Lagoon Bridge project (Mead *et al*., 2020). Three current components were found to be involved in the water circulation: tides, winds and waves. The tidal current is dominant and is so during spring tidal phases on the flood, whereas wave and wind induced currents are less influential. During ebb tidal phases, the tidal current pushed the water out of the Tongatapu Lagoon (Figure 4.10). The water, however, is flushed into the lagoon across the south-east corner of the atoll rim, as the wave induced flux competes with the ebb current. Within the lagoon, the easterly wind generates the westward current. During neap tides, the tidal current decreases and the circulation in the lagoon is mainly controlled by the easterly wind (Figure 4.11) (Damlamian, 2008).

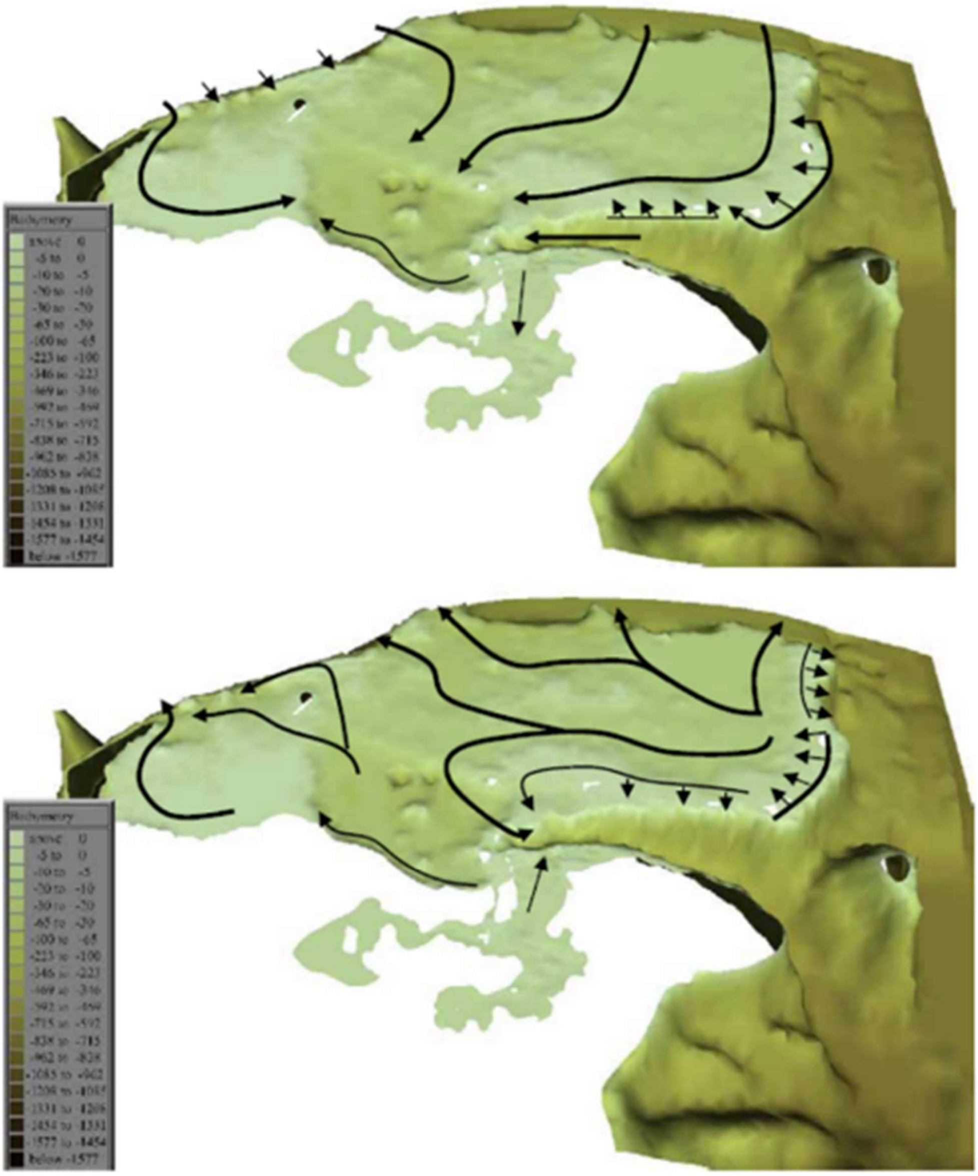

Figure 4.10 Current circulation patterns during flood (top) and ebb (bottom) spring tidal phases (Damlamian, 2008).

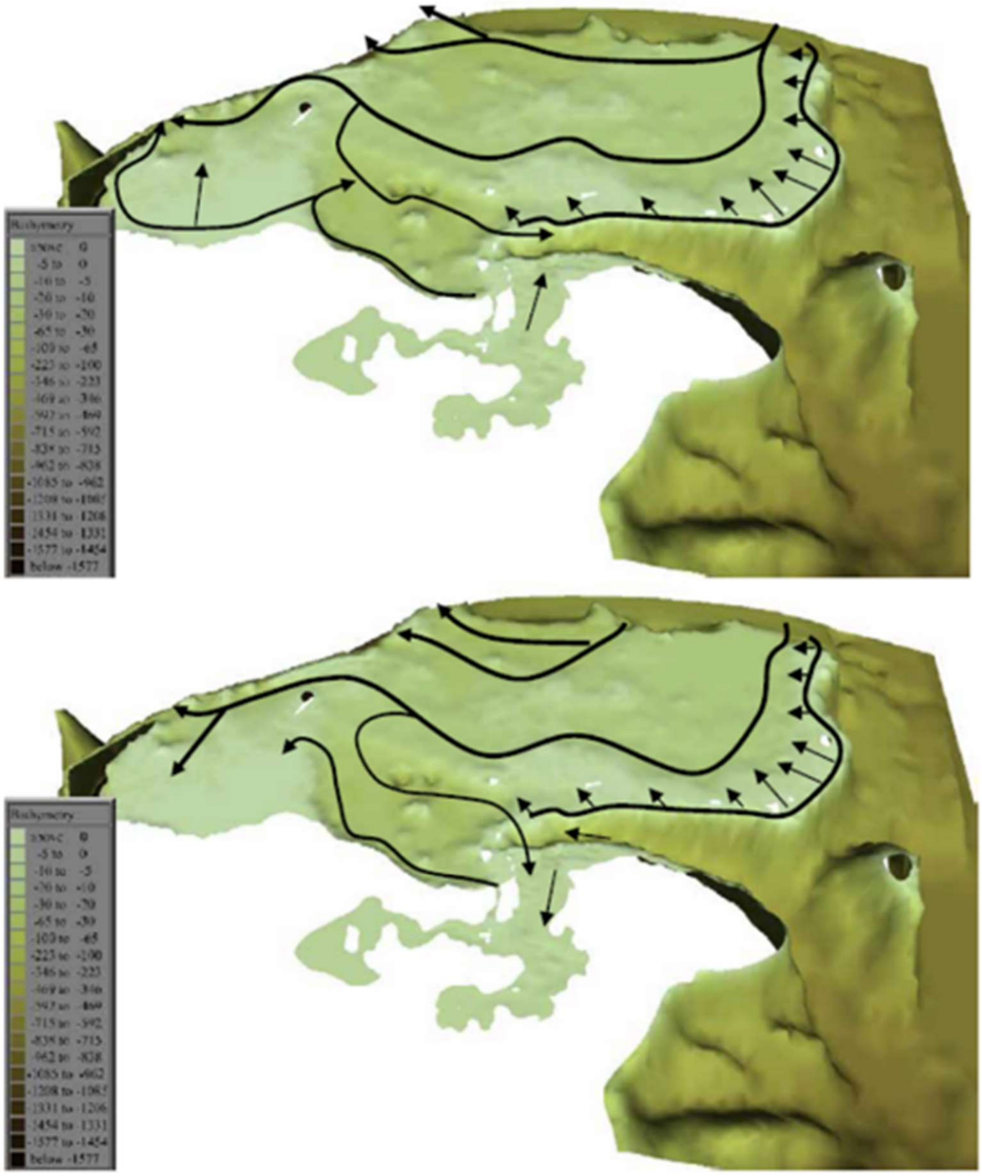

Figure 4.11 Current circulation patterns during flood (top) and ebb (bottom) neap tidal phases (Damlamian, 2008).

Mead *et al*. (2020) investigated flushing times of the Lagoon, and found that after the two-week modelling period (i.e., a spring-neap cycle), the northern arm had only flushed 10% of the initial numerical tracer, suggesting that complete flushing of the arm could take roughly 140 days. The differences between these estimations of flushing time and that of 29 – 30 days for the entire lagoon by Damlamian (2008) is that their calculations assumed that once water had left the system it could not return, while the tracer model applied here is likely to be closer to the reality of a tidal system that allows water to move into and out of a basin.

Similar results were found when 1 m of SLR was added to the model with respect to the impacts of the construction of the bridge (Mead *et al*., 2020). SLR itself has a far greater impact on lagoon flushing than the presence of the proposed bridge piles, with the increased depth and width of the lagoon entrance due to the increase in sea level resulting in quicker flushing of the lagoon (approximately 82 days for complete flushing as compared with 140 days for present-day conditions).

4.5 Tides

The tides of Tongatapu are semi-diurnal and range from 0.9 m to 1.9 m during neap and spring tides, respectively.

4.6 Over-Topping Inundation, Climate Change (CC) Projections and Sea Level Rise (SLR)

As shown in Figure 4.12, the total water level at any time is a combination of several factors. The primary component is of course the astronomical tide level. To this can be added any 'storm surge' which may affect the site, as well as wave setup and wave runup. The storm surge component in this context is assumed to contain both the effect of wind (wind setup), as well as the inverse barometer effect (pressure setup). When combined during extreme events, wave over-topping and inundation can occur, which will be exacerbated by SLR.

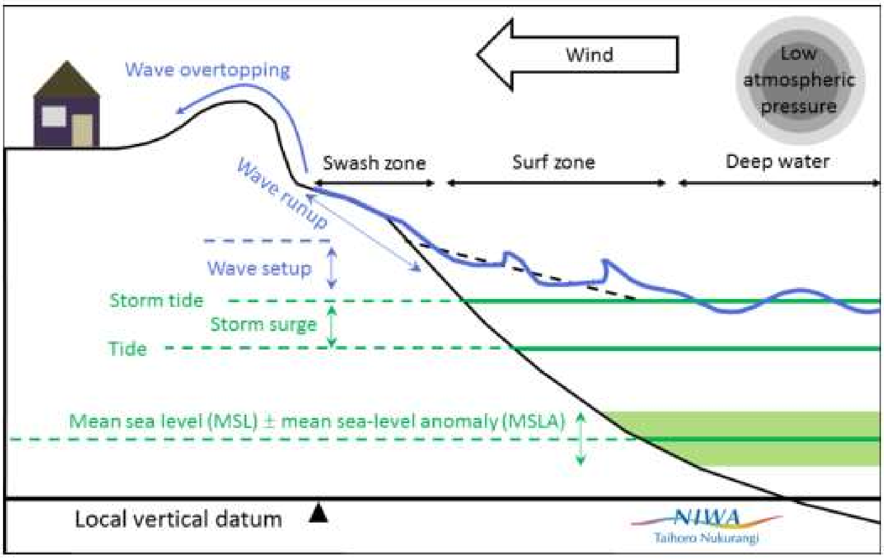

Figure 4.12. Components of the total water level.

Figure 4.13 illustrates four scenarios of New Zealand-wide regional sea level rise to the year 2150 from the IPCC AR5 cited in MfE (2017). The most extreme scenario (NZ RCP8.5 H+) indicates that in 100 years the sea level will rise by 1.34 m with the medium projections indicating SLR values in 100 years of 0.55, 0.67, 1.06 m for RCP2.6 m, RCP4.5 m and RCP8.5 m, respectively. The projections include a New Zealand-wide regional offset, with a small additional SLR above the global mean projections. Note: RCP refers to representative concentration pathways.

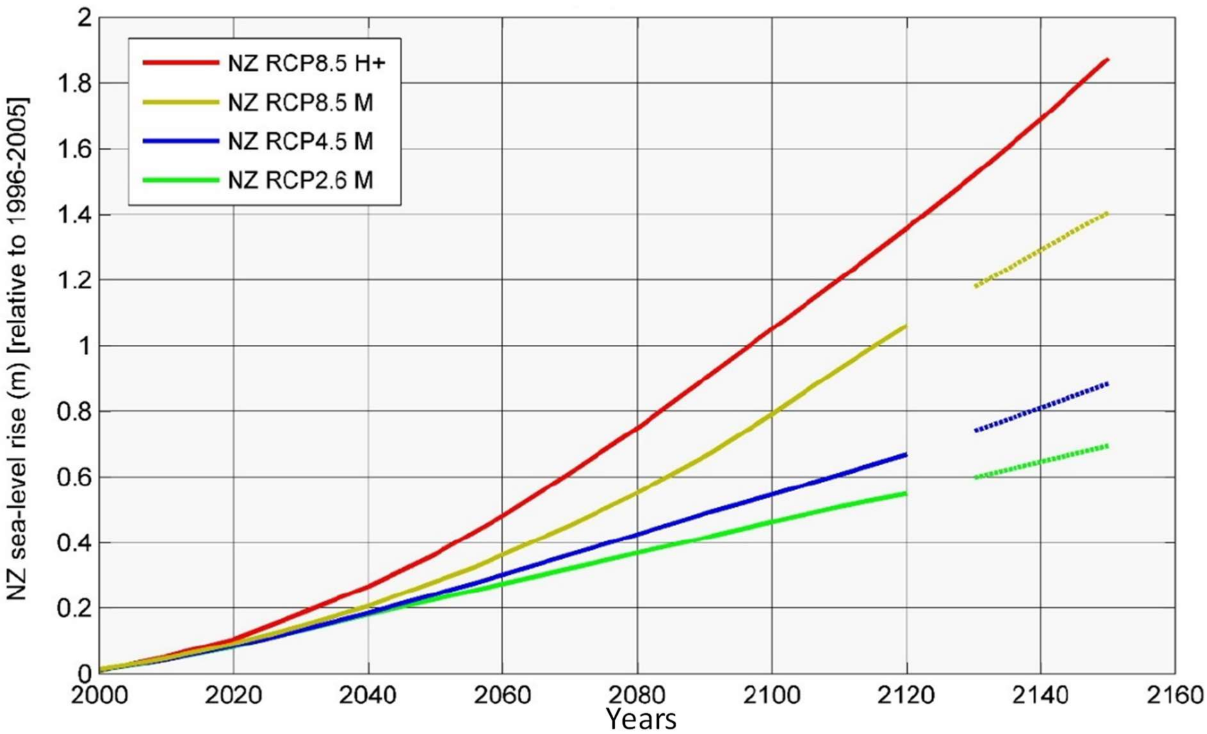

Figure 4.13. Four scenarios of New Zealand-wide regional sea level rise projections to 2150 based on Kopp *et al.* (2014) cited in MfE (2017).

The four sea-level rise scenarios are based around three RCPs (RCP2.6, RCP4.5 and RCP8.5). Three of the scenarios are derived from the median projections of global sea-level rise for the RCPs presented by the IPCC in its Fifth Assessment Report (AR5) (Church *et al*, 2013). These have been extended to 2120, to meet the minimum requirement of assessing risk over at least 100 years, as required by the NZCPS 2010. A further extension to 2150, using the rates of rise from Kopp *et al*. (2014), provides a longer view over 130 years (with a gap shown in Figure 4.13 between the two sets of projections). It is also a reminder that sea level will keep rising after 100 years, irrespective of actual future greenhouse gas emissions (MfE, 2017). Figure 4.13 indicates that there is a large range of uncertainty with respect to what the magnitude of SLR will be as time progresses, mostly due to how human's respond to the challenge of CO_2 reduction and how the uncertainties of ice-sheet mechanics. However, it is clear that in low-lying areas such as the northern Tongatapu coast, the impacts of SLR will lead to coastal hazard issues in the short to medium term (i.e., 10 to 30 years).

There is one tide gauge on Tongatapu. which shows a general increase in sea level rise in the order of 6.4 mm/yr since records began in 1993 (to 2007) (TMS Tonga, 2007;cited in McCue, 2014). Satellite data confirms that the rate of sea level rise is around 6.0 mm/yr since 1993 (to 2007) (PCCSP, 2011; cited in McCue, 2014). This rate of SLR is about twice the global average (2.8 to 3.6 mm/yr) and highlights the vulnerability of Tongatapu to coastal flooding, particularly around Hahake and Hihifo.

The University of the South Pacific carried out sea level rise modelling (Figure 4.14), which showed that increases in mean sea level of 0.3 m and 1.0 m would result in land loss of 3.1 km^2 and 10.3 km^2, respectively, which corresponds to about 2,700 and 9,000 people becoming displaced, respectively. In general, 20,000 people (McCue, 2014) are considered to live in low lying areas that are cable of being flooded by a 2.8 m storm surge (Tropical Cyclone Issac in 1982).

While the impacts of rising sea level can be envisaged, it is more difficult to determine what the combined impacts of climate change (CC) will be and how/when they will manifest. Tonga is highly vulnerable to the impacts of climate change due to its geographical location and its socio-economic characteristics (ADFAT, 2018). Tonga is susceptible to a wide range of climate change impacts in addition to SLR, including increasingly intense tropical cyclones, extreme rainfall events leading to flooding, coastal erosion, heat waves, drought and ocean acidification.

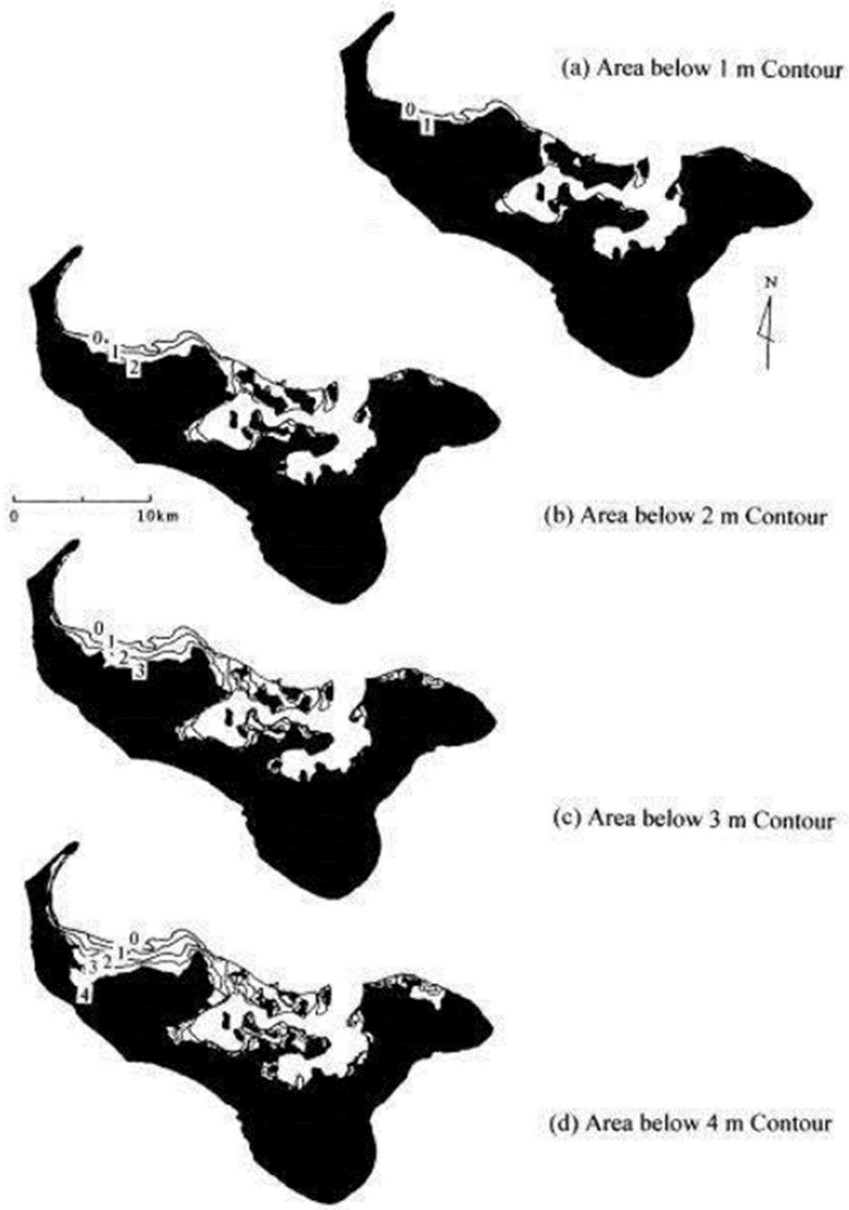

Figure 4.14 Shows the successive geographical areas of Tongatapu that are below 1.0 m, 2.0 m, 3.0 m, and 4.0 m elevation (above the present coastline level) (McCue, 2014). Note. Lowlands extend along the north shore, and the land is particularly low at Nuku'alofa, the capital.

4.7 Tropical Cyclones

In the South-West Pacific, tropical cyclones are seasonal phenomena from November through to April. On average, Tonga experiences 2 per year during El Nino phases of the Southern Oscillation. Since the 1960s, historical records indicate an increased trend in tropical cyclone frequency in the South-West Pacific. Between 1969 and 2010, 71 tropical cyclones passed within 400 m of Nuku'alofa (the capital of Tongatapu); Figure 4.15 shows the tracks of all known tropical storms and cyclones that have passed through the Tonga area since 1941. During El Nino years, tropical cyclones occur more frequently.

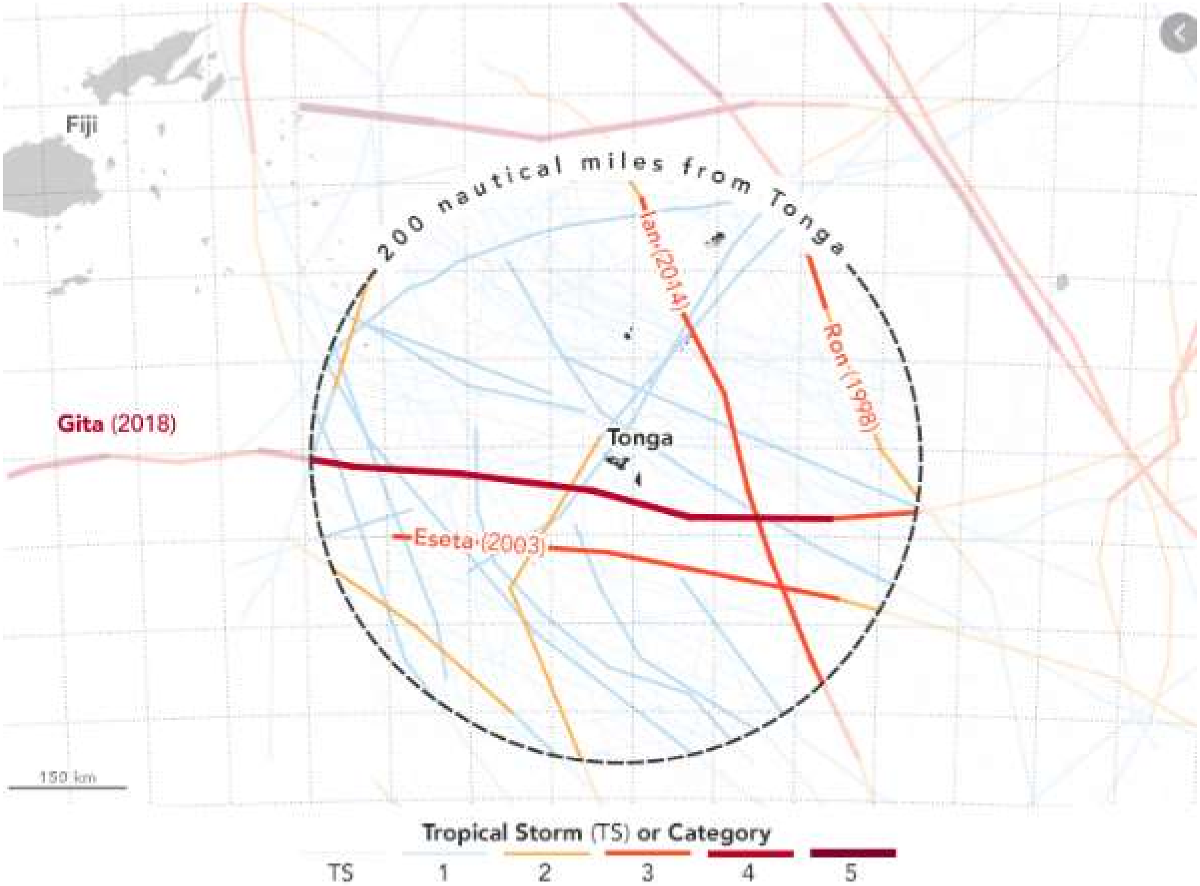

Figure 4.15. Tracks of all known tropical storms and cyclones that have passed through the Tonga area since 1941.

4.8 Status of Marine Resources and Biodiversity

NBSAP (2014) reported that the status of the marine ecosystems in Tongatapu, as a whole, has yet to be fully explored. A lack of resource assessment is major issue, with only a few selected fisheries known i.e. sea cucumbers and seaweed. Despite this, data is available on some fisheries and coral reefs. Overharvesting and overexploitation of the marine resources are identified as being the greatest implicating factors to marine resources. Tongan fisheries comprise both offshore (tuna, snapper, and groupers) and inshore fisheries (mullet). Both deep water and shallow water fisheries are vital to subsistence and are a source of income to many.

The population of Tongatapu has increased and with it the demand for marine resources. Recent studies suggests a change in local diet more towards marine protein-based products, which has put further pressure on marine resources (NBSAP, 2014). A 2011 analysis of *Reefs at Risk Revisited* study suggested that over a third of Tonga's coral reefs are threatened by overfishing (moderate risk or higher), and the 2005 UNEP/SOPAC Environmental Vulnerability and 2009 Pacific Ocean Synthesis reports also suggested that fishing possess an ever growing threat to the marine resources of Tongatapu (Chin *et al.,* 2011; cited in NBSAP, 2014).

In general, NBSAP (2014) reported that the overall status of harvesting resources has almost reached its maximum sustainable yield for certain marine species and the population trend for Tongatapu marine ecosystems remains unknown due to a paucity of data caused by lack of funding.

5 Annex C: Coastal Unit 1: Ha’atafu to Foui

5.1 Bio-Physical Environment

The coastal unit between Ha'atafu and Foui is characterised as having slightly higher topography in the north, which slopes southward down to Foui. This coastal unit faces north-eastwards towards the shallower western section of the Tongatapu Lagoon (Figure 5.1). As mentioned, this section of coastline experiences easterly and north-easterly wind events. Waves that are generated by these wind directions break offshore on the large barrier reef (McCue, 2014) and are also dissipated by the shallow western section of the Tongatapu Lagoon (Figure 5.1).

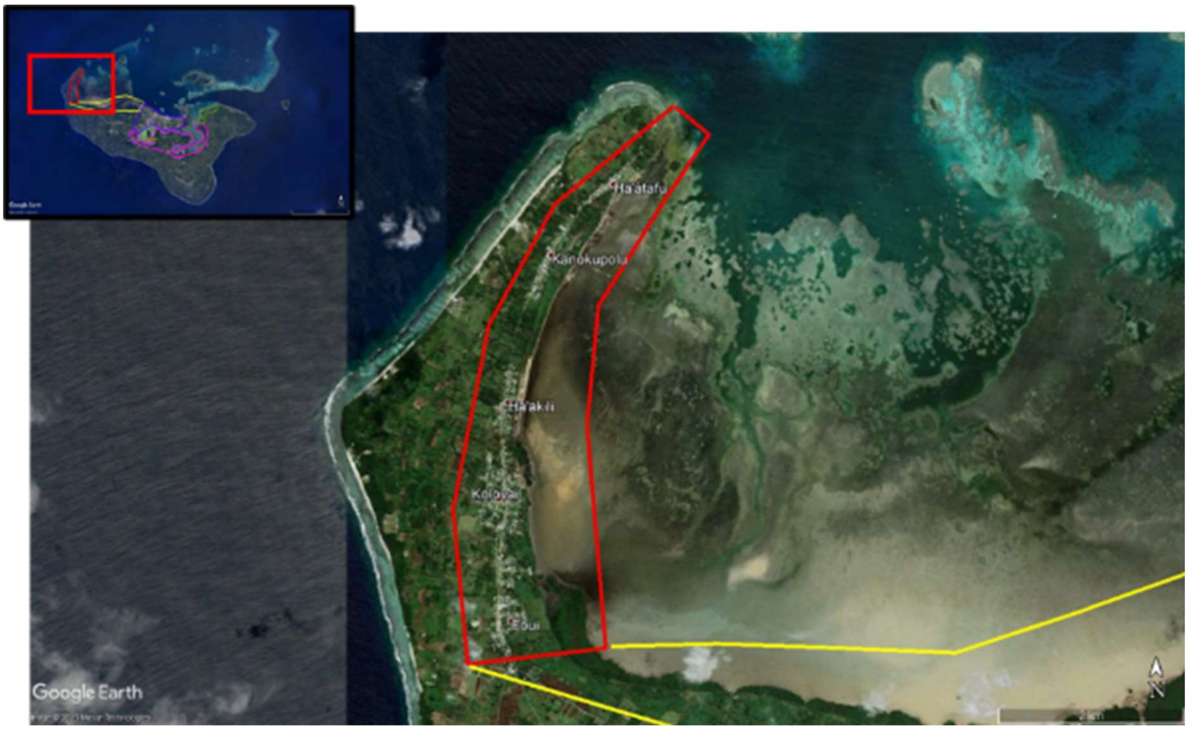

Figure 5.1 Location map of coastal unit 1 (red line) on the north-western coastline of Tongatapu between Ha'atafu to Foui (Google Earth, 2020) .

The bio-physical environment of the coastline along coastal unit 1 has been greatly influenced by humans. Originally, a mangrove belt lapped the entire coastal unit. Over time, mangroves near villages have been removed for various purposes and land has been reclaimed. The development of a wetland in the northern portion occurred around ~1968 and a revetment/coastal road was soon after constructed (Howarth, 1983). This section of coastline has been subject to many shoreline evaluation reports and also climate change resilience trials, the details of which are discussed throughout the various sections below.

Near recent LiDAR from 2012 confirms that the topography of the coastal unit is generally low lying except for the northern area (Figure 5.2).

- At Kanokupolu the whole village is very low (much <1 m above high tide).
- At Ahau most of the village is very low lying (<1-2 m above high tide).
- At Kolovai the village area east of the main road is very low lying (<1-2 m above high tide).
- The villages Ha'avakatolo and Fo'ui are mostly >2 m above high tide, except for a few properties that are most eastern on the mangrove fringe.
- Ha'atafu is located >4 m above high tide and is not considered vulnerable to coastal hazards.

Figure 5.2 2012 Lidar of coastal unit 1, Tongatapu, Kingdom of Tonga (modified from Mead & Atkin, 2014).

5.2 Ha’atafu

The nearshore environment of Ha’atafu is characterised by intertidal reef flats, which gives way to a thin veneer of sand directly adjacent to the centre of the village and a coastal revetment to extending southward from the village centre (Figure 5.3). Toward the north, the beach is comprised of small rocky outcrop features for a small section before giving way to light vegetation.

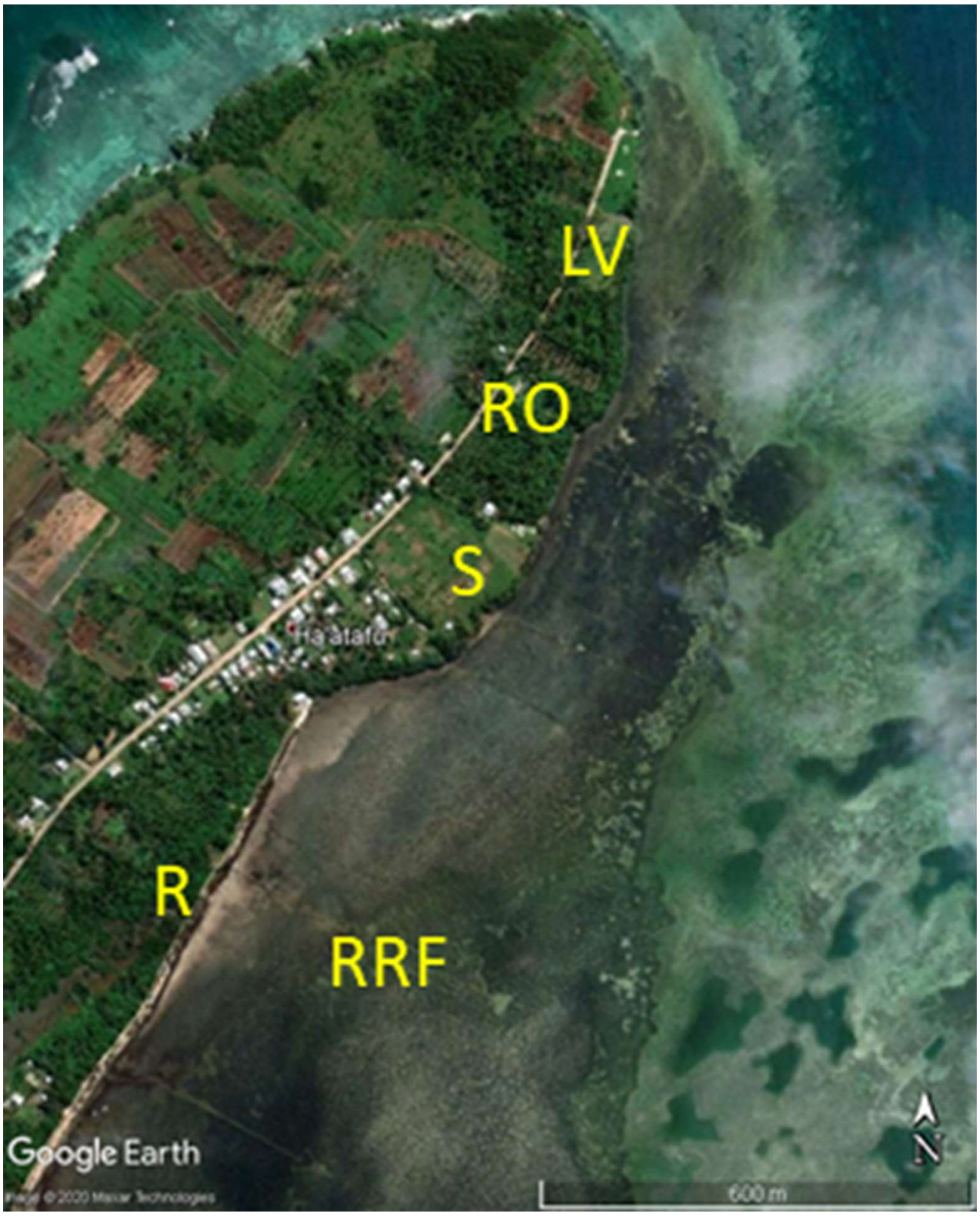

Figure 5.3 Image shows nearshore and shoreline bio-physical features of Ha’atafu, the northern most village of coastal unit 1, Tongatapu, Kingdom of Tonga (Image sourced from Google Earth, 2020). Note: LV = light vegetation, RO = rocky outcrops, S = sand, R = revetment, RRF = rocky reef flats.

5.3 Kanokupolu

The nearshore environment of Kanokupolu is characterised by intertidal reef flats, which gives way to a coastal revetment extending northward and southward (Figure 5.4). A tidal lagoon exists in front of the village, which formed between 1968 and 1979, although the exact date is unknown. The lagoon is 720 m long and ranges between 40 m and 70 m wide. Within the lagoon the small pockets of mangroves exist. As mentioned, the lagoon is physically closed by the revetment/road from the open coast, thus the nursery benefits to local fauna have been negated.

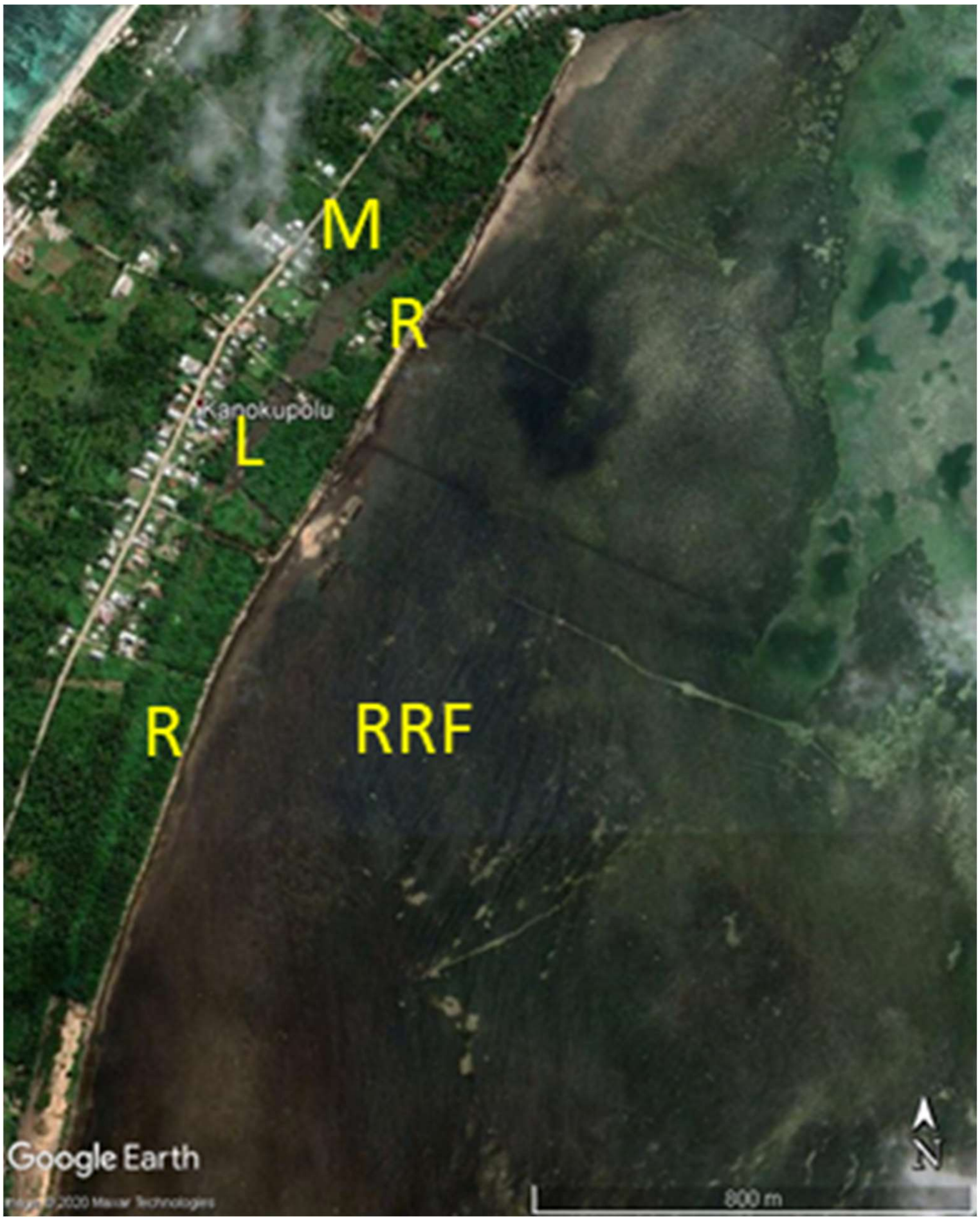

Figure 5.4 Image shows nearshore and shoreline bio-physical features of Kanokupolu village, Tongatapu, Kingdom of Tonga (Image sourced from Google Earth, 2020). Note: R = revetment, RRF = rocky reef flats, L = lagoon, M = mangroves.

5.4 Ha'akili (A'hau)

The nearshore environment of Ha'akili is characterised by intertidal reef flats, which appear to have a veneer of sediment overlying (Figure 5.5). This veneer increases in thickness southward toward the small mangrove stand boardering Kolovai village, which spans ~550 m long by 140 m at it widest. The area south from Ha'akili appears to be a sediment trap. Most of the shoreline to the north comprises a breakwater/revetment (A'hau Barrier), which was upgraded sometime between June 2018 and July 2019 (Figure 5.6). Behind this breakwater a small lagoon exists, which up until recently has been largely been closed off. Recent works have opened a southern entrance to the lagoon and widened the existing northern entrance (Figure 5.6).

Mead (2019a) carried out a construction evaluation of the western Tongatapu (Hihifo) climate change resilience trials. The construction involved: a) reinforcing the existing A'hau Barrier by the addition of armoured rock, b) opening to the southern entrance and widening the northern entrance to provide better flushing, and c) removing the access road across the middle of the of lagoon. In general, Mead (2019a) reported that the construction was progressing well and that the rock from the non-functional entrance had been removed, with the rock being used to armour and slightly heighten the seaward side of the barrier as well as to make a causeway road for construction (Figure 5.8). A detached breakwater once existed but has mostly been removed and the rock has been placed along the seaward side of the barrier (Figure 5.8).

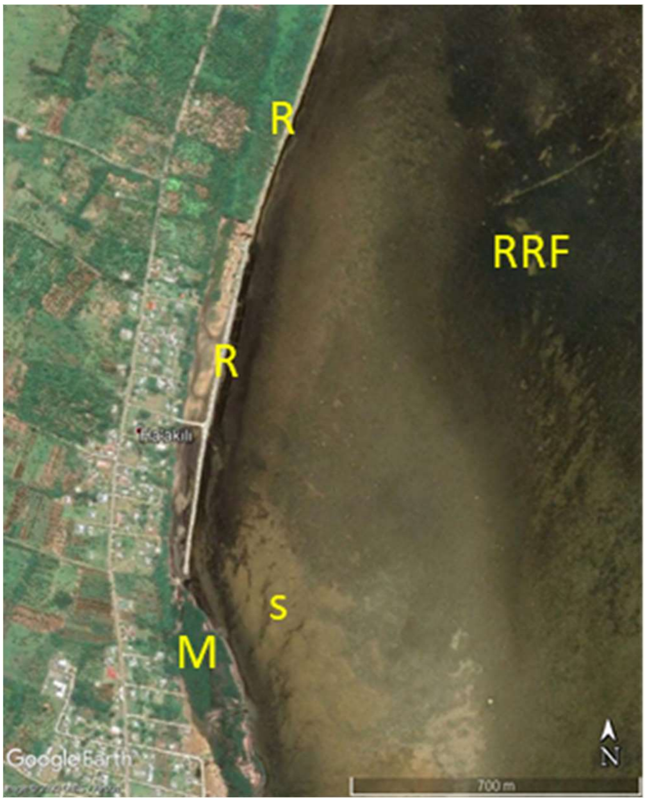

Figure 5.5 Nearshore and shoreline bio-physical features of Ha’akili village, Tongatapu, Kingdom of Tonga (Image sourced from Google Earth, 2020). Note: R = revetment, RRF = rocky reef flats, M = mangroves, and s = sediment.

Figure 5.6 Revetment/breakwater upgrade at Ha’akili Village. Left and right images are from June 2018 and July 2019 (Images sourced from Google Earth, 2020).

Figure 5.7 The temporary access road to the A'hau Barrier that requires complete removal on completion of the barrier project (Image sourced from Mead, 2019a).

Figure 5.8 Left - Armour rock from the non-functional entrance that has been removed and placed as armour along the A'hau barrier. Right - The trial detached breakwater (which proved to have low efficacy along this coast due to the almost complete lack of sand) has almost been dismantled and the armour rock is being used to heighten and widen the A'hau barrier (Images sourced from Mead, 2019a).

5.5 Kolovai

The nearshore environment of Kolovai is characterised by intertidal reef flats, which have an increasing veneer of sediment overlying (Figure 5.9). Again, the veneer increases in thickness southward toward Ha’avakatolo village. The mangroves in the north boarder Ha’akili village. The mangroves in the middle of the appear to have somewhat been removed.

On shore, Mead (2019a) carried out a construction evaluation of the Kolovai Seawall and flood mitigation additions, as part of the climate change resilience trials for this area. The works included a) building a seawall to reduce inundation of the properties during extreme events (440 m long by 0.9 m high by 0.4 wide with additional rock armour at the toe of the seawall to provide a buffer for wave reflection during extreme wind/wave events) b) ensuring that stormwater can be discharged to the sea (through the seawall) during extreme rain events to prevent flooding (250 mm diameter PVC flap valves) c) building a wooden stick groyne to provide a protected area for mangroves seedlings to better establish, and d) the placing of strategic fences to keep pigs out of the mangrove restoration areas. (Refer to Mead (2019a) for further details on the design specifications).

In general, Mead (2019a) reported that the works were progressing well with 80 m of the seawall footing prepared (Figure 5.10). Mead (2019a) also reported to have observed pigs that could not get around the new fence (to forage in the mangrove restoration area (Figure 5.10)). The wooden groyne was noted the be impressive and would serve the purpose of protecting mangrove seedlings well (Figure 5.11).

Mead (2019a) noted that several design specifications had been changed, which included:

- *Reducing the diameter of the drainage pipes and increasing the number of them;*
- *Incorporation steel reinforcing where the ground is soft;*
- *Increasing the 10 m spacing for the reinforcing buttresses, although greatly increasing the size of the buttresses;*
- *Inclusion of an access through the wall along the southern section, and;*
- *Realigning the wall around the house at the northern end of the project.*

Mead (2019a) reported that all the design specification were acceptable, although the following recommendations should be implemented:

- *With the decreased diameter of the drainage pipes, the increased number should only double (i.e. 10). This is because every drainage pipe represents a potential failure point in the design; that is, if a non-return valve fails (through blockage or breakage), seawater can come landward of the wall and inundate the area. Therefore, the more* *discharge points, the more potential failure points. With the reduced diameter of pipes, there will still be sufficient flushing capacity for heavy rainfall with 10 across the site (it may temporarily flood some land during extreme events, but this is freshwater, not salt);*

- *Steel reinforcing will reduce the chance of the wall failure where the soil is soft. However, ensure that it is well covered in concrete, since if it is exposed to saltwater by being only covered with a thin layer of concrete, it will expand as it rusts and also cause failure;*
- *At present, the access to the public/paper road is planned to have an approximately 30 cm wall across it and ramps either side. This should be monitored to determine whether it is overtopped during extreme events, and to what extent saltwater inundation occurs. The question should also be asked "Is it really necessary?". There has not been a road here previously, and it is basically a 'Road to Nowhere', as it goes to an area of mangroves and mangrove restoration which does not require vehicular access in any case. I would recommend considering a full height wall with steps up and over for pedestrian access (although again, is this really necessary?);*
- *The northern part of the wall has been moved seaward to incorporate the single house on the northern stretch of the seawall, where it was previously going to be located behind; this was at the request of the Minister, and it reasonable. The main thing to ensure is that the return at the end of the wall up the road on the other side of where it was previously proposed to ensure seawater inundation does not out-flank the wall. This may again cause issues to road access, although it is also to a mangrove restoration area, and so should not be required, and;*
- *The road has been raised, and as a result the flooding of properties by freshwater has been exacerbated. In the first instance, filling would be of aid, although it will require filling and levelling to at least the back of these sections. An alternative is to make a stormwater drain along the boundary of these sections (i.e. on the landward side of the road, 200-300 mm deep) to a central covered drain that goes under/across the road and discharges through the wall via a large diameter (at least 250 mm) non-return pipe. The location for the drain across/under the road should be at drainage pipe Location 3 (Figure 4 and Table 1 in the design report).*

Figure 5.9 Image shows nearshore and shoreline bio-physical features of Kolovai village, Tongatapu, Kingdom of Tonga (Image sourced from Google Earth, 2020). Note: RRF = rocky reef flats, M = mangroves, and S = sediment.

Figure 5.10 Left – Construction progress of the Kolovai Seawall. Right – One of the new pig exclusion fences to protect the mangrove restoration areas (Images sourced from Mead, 2019a).

Figure 5.11 Wooden groyne constructed to help protect mangrove seedling establish from the impacts of waves (Image sourced from Mead, 2019a).

5.6 Ha’avakatolo & Foui

The nearshore environments of Ha’avakatolo and Foui are characterised by intertidal reef flats, which have an increasing veneer of sediment overlying (Figure 5.12). The water depth in this area is slightly greater compared with the villages to the north with a channel running out toward the north-east and north to the open coast. A large mangrove stand begins at Ha’avakatolo and extends around to Sopu. The mangrove stand is ~450 m at its widest within this area and flushed tidally.

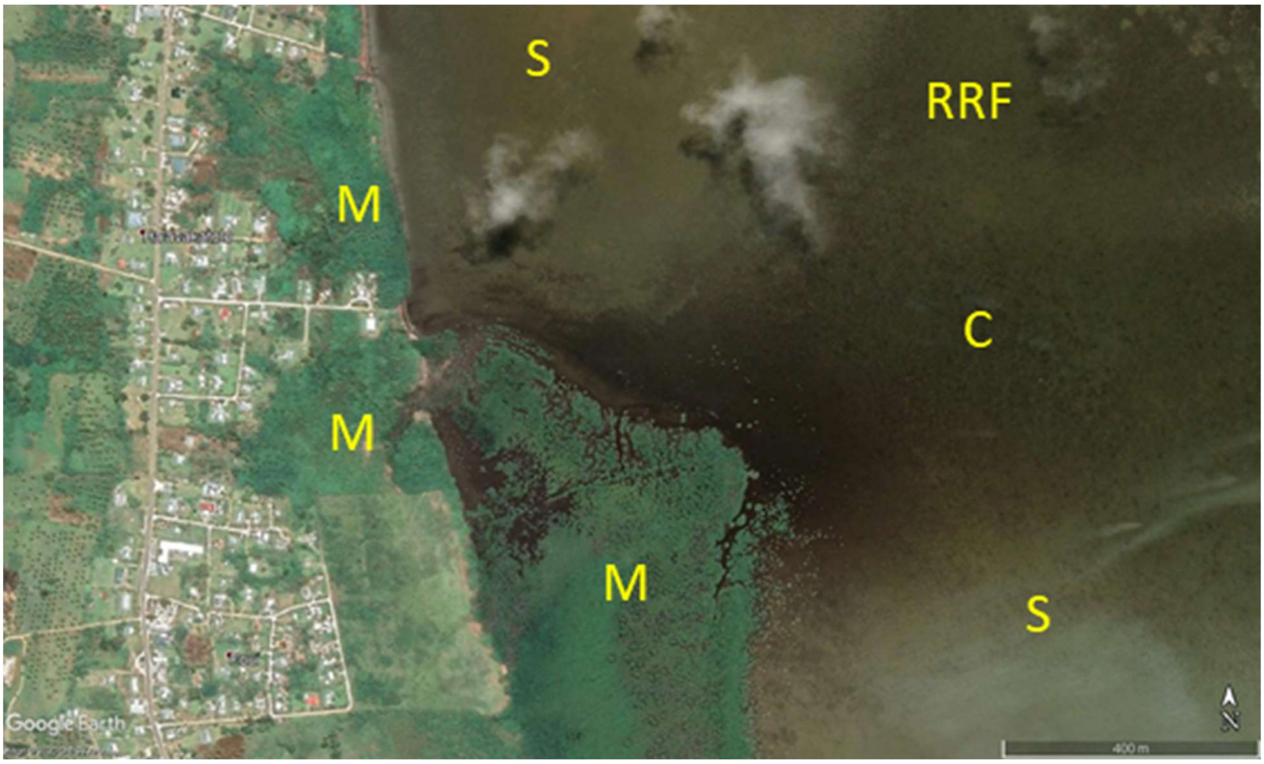

Figure 5.12 Image shows nearshore and shoreline bio-physical features of Ha’avakatolo and Foui villages, Tongatapu, Kingdom of Tonga (Image sourced from Google Earth, 2020). Note: RRF = rocky reef flats, M = mangroves, C = channel, and S = sediment.

5.7 Historical Shoreline Changes

Howarth (1983) carried out an evaluation of the Kanokupolu Beach shoreline. Howarth used historical land surveys (1910 and 1914), and aerial photographs (1968 and 1979) to determine morphological changes along the Hihifo coast. He found little evidence of permanent change in the ~80-year period due to the low energy environment – only in rare instances that permanent change takes place (e.g. due to an intense cyclone) (cited in Mead & Aktin, 2014).

The low relief of the coastal settlements was noted by Howarth (1983), with the entire Kanokupolu village area, which extends ~300 m inland from the high tide mark, <1 m (above the high-water mark). Ahau and Kolovai villages were found to be <2 m above the high-water mark. In contrast, Ha'atafu, Fo'ui and Ha'avakatolo villages were considered sufficiently elevated to be protected from coastal processes. Since Howarth (1983) evaluation, however, there has been seaward development of Foui and Ha'avakatolo (cited in Mead & Aktin, 2014).

The northern shoreline of Kolovai village has been flooded by high tides since at least 1968 and is frequently flooded during cyclones and other periods of bad weather. Cyclone Isaac in 1982 led to the entire village of Kanukupolu being inundated (cited in Mead & Aktin, 2014).

The main changes in the area were the development of the ~350 m long spit that developed southwards from the north end of Ahua village (it still remains, with a relief of less than one metre) and the development of the tidal lagoon in front of Kanokupolu village (which formed between 1968 and 1979, although the exact date is unknown). The lagoon was approximately 1.5 km long and averages 100 m wide at the time of writing (cited in Mead & Aktin, 2014).

Due to the small nature of the northern entrance of the lagoon, lagoon was unable to completely drain at low tides. Today the tidal lagoon entrance is blocked by the coastal road, and there is no regular water exchange.

Howarth (1983) indicated that a mangrove belt once extended along the entire coastal unit. Over time, however, mangroves have been selectively removed from the areas close to the villages. At Kolovai, coastal erosion of several tens of metres have been recorded since 1910 surveys. Since the process of mangrove removal, the erosion has accelerated (cited in Mead & Aktin, 2014).

Howarth (1983) did not recommend shoreline protection measures be constructed to protect against storm surge flooding, however, due to the nature of the extensive area being very low-lying and not of sufficiently high economic value. At the time, the morphology of the Kanukupolu-Kolovai area enabled storm surges to drain away quickly and freely. Reclamation of areas was suggested – especially the tidal lagoon and somewhat carried out. Today the lagoon is no longer tidally flowing due to the closure of the entrance and the development of the coastal road/revetment (Figure 5.13). This has resulted in issues with extreme rainfall and/or overtopping events, where water cannot drain out of the reclaimed lagoon area (cited in Mead & Aktin, 2014).

Figure 5.13 The coastal road/revetment that has halted erosion at Ha'atafu and Kanokupolu villages but closed off the lagoon that was naturally produced sometime between 1968 and 1979 (cited in Mead & Aktin, 2014).

5.8 Historical Coastal Engineering Reports

Mead *et al.* (2014) also carried out a review of recent coastal information pertaining to coastal geomorphology and coastal engineering climate change resilience feasibility and design for the coastal areas and villages of coastal unit 1. Three reports were reviewed:

- Sustainable Seas, 2014a. Consultancy to Conduct Coastal Feasibility Studies, Coastal Design and Costing for Six (6) Communities on the Western Side of Tongatapu. Report prepared for the Ministry of Lands, Environment, Climate Change and Natural Resources (MLECCNR).
- Sustainable Seas, 2014b. Consultancy to Conduct Coastal Feasibility Studies, Coastal Design and Costing for Six Communities on the Western Side of Tongatapu; Deliverable 2 – Final Coastal Design and Costing Report 2014. Report prepared for the Ministry of Lands, Environment, Climate Change and Natural Resources (MLECCNR).
- Geocare and Petroleum Consult, 2014. Environmental Impact Assessment of Five (5) proposed Coastal Engineering Interventions for Six (6) Communities on the Western Side of Tongatapu. Report Prepared for Ministry of Environment and Climate Change (MECC)

5.8.1 Sustainable Seas Ltd (2014a)

SSL (2014a) reiterated that there has been little evidence of permanent change in the past 80 years due to the low energy environment – only in rare instances that permanent change takes place. Aerial photography and discussions with local communities in Hihifo indicated that the coast has been subject to erosion of up to 20-30 m since the 1960's (0.25-0.5 m/year). This has been arrested with the construction of the coastal road/revetment (Figure 5.13), which is holding the line (cited in Mead *et al.,* 2014).

SSL (2014a) consider the new coastal road (i.e. the new main road through the Hihifo villages) a critical feature as both preforming a role as a coastal protection feature and also as the only route for the village people of Fo'ui, Ha'avakatolo, Ahau, Kolovai, Konokupolu and Ha'atafu to escape the area in the event of an extreme event (e.g. super-cyclone, tsunami). Despite upgrading in 2012, however, the coastal road itself is creating local drainage problems for the villages in Hihifo in many places, as culverts through the road and drainage was not introduced into the design for this road (this issue has been raised by all 6 Hihifo communities) (cited in Mead *et al.,* 2014).

SSL (2014a) report that the priority villages for climate change adaptation are Kolovai, Ha'avakatolo, Fo'ui and Ahau. Kanukupolu and Ha'atafu have been protected by the coastal road/revetment. The road effectively acts as hard barrier to waves and storm surges, and its ability to maintain this function is critical to the continued protection from erosion and inundation by the sea in this area. Although Kanukupolu Lagoon has changed, with the addition of the seawall (closure of the entrance), and mangroves have been removed. SSL (2014a) recommends that the areas should be replanted with plants that were originally there.

The frontages of the six villages are less than 2 m above sea level. This renders them highly vulnerable to the impacts of climate change, sea level rise, disaster risks (e.g. tsunami), storm surge and coastal erosion issues (Figure 5.2 - 2012 LiDAR survey overlaid on 2012 satellite image). The most low-lying villages are Kanokupolu, Ahau and eastern Kolovai (cited in Mead *et al.,* 2014).

SLL (2014a) state that in the southern parts of the study area, mangroves are being removed, land-reclaimed and the village is advancing seawards. Mangrove clearing and reclamation was observed in Kolovai and Ha'avakatolo during the recent site visit (Figure 5.14), and is clear on satellite images of the area. Reduction in the wetland and mangrove areas means that the land is more susceptible to flooding (cited in Mead *et al.,* 2014).

Figure 5.14 Mangrove clearing and reclamation for houses in eastern Kolovai.

SSL (2014a) also reiterate that the Hihifo coast has a very low sediment budget – this is evidenced by the lack of infilling of the excavation holes created by the extraction of sand and coral rock by the community since 1982. There is limited sediment and limited ability for the system to generate new sediment, which needs to be taken into account for any solution (cited in Mead *et al.,* 2014).

Due to the very low sediment budget, SSL (2014a) state that without improvement works, beach levels will continue to lower and the pressure on the road/revetment will increase resulting in further deterioration. It is likely that this process will eventually lead to the road/revetment breaching in a number of locations, which will result in significant flooding to the villages. The existing dynamics and pressures facing the area are likely to become further exacerbated by future sea level rise (SLR). SLR will increase the likelihood of direct tidal inundation of properties and the road network that connects the villages of western coastal Tongatapu (cited in Mead *et al.,* 2014).

The site is exposed to higher winds than most other parts of Tongatapu (Figure 5.15), with the north reaching peninsula being susceptible to the dominant E-SE winds. The Hihifo coast is also vulnerable to tsunami inundation due to its low topography (Figure 5.16) (cited in Mead *et al.,* 2014).

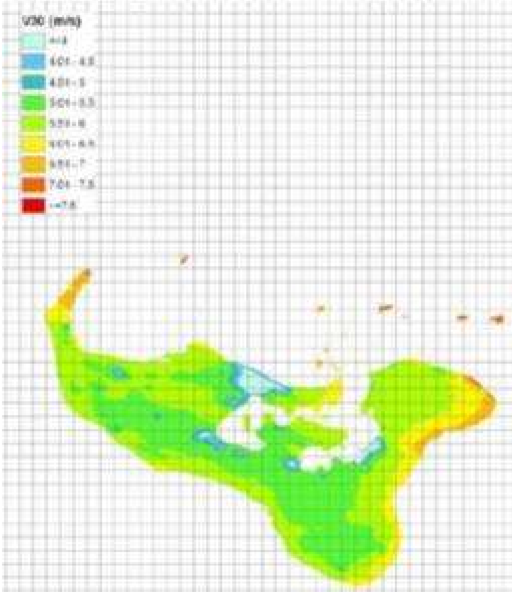

Figure 5.15 Wind speeds at 30m elevation (source: Winergy 2006 – cited SSL 2014a).

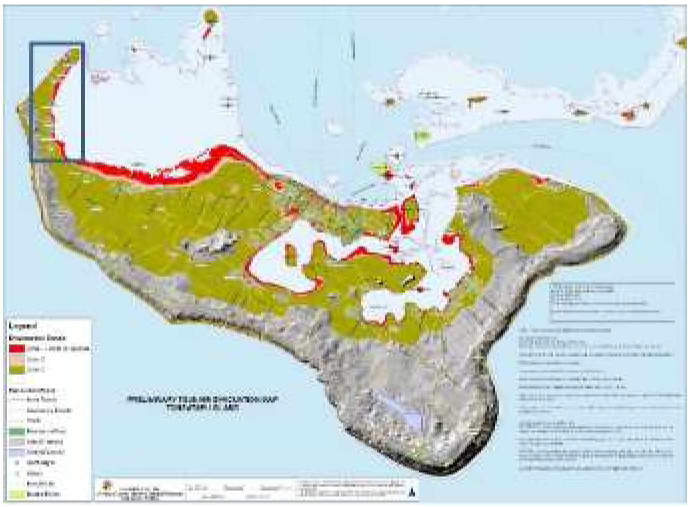

Figure 5.16 Evacuation map for Tongatapu Island showing the project area covers either the most vulnerable Zone 1 or Zone 2 categories. Kanokupolu, Ahau and part of Kolovai villages are categorised as "most vulnerable" Zone 1 (Source, SSL, 2014a).

SSL (2014a) state that the coastal (landward) habitats have been significantly altered by humans either through conversion to agriculture/plantation use and urban development of the villages that border the coastline. The report describes the importance of the artificial wetland in Kanukopolu based on the (1993), including fish and crustacean species. This area, however, is nowadays blocked off from the sea, therefore most marine species are unlikely to use the area as a nursery, and reclamation has been on-going since closure (Figure 5.17) (cited in Mead *et al.,* 2014).

Figure 5.17 The Kanokupolu lagoon in 2005 after closure by the construction of the coastal road/revetment (left), has been continually reduced in size (especially in the north and south) (right – April 2013).

SSL (2014a) describe how the impacts on the mangrove due to pigs foraging (observed during the site visit) leads to poor mud structure and consequently reduced growth rates and seedling success of mangroves. This indicates a need to control pigs if re-establishment of mangroves is to be successful (cited in Mead *et al.,* 2014).

SSL's (2014a) investigation of the nearshore marine ecology suggests that the reefs that supply sand to the area are in poor health (likely from over-fishing and land-use (e.g. run-off of sediment smothers the reef and reduces water quality). No seagrass beds were observed, likely due to a combination of sediment starvation, lack of sediment supply and poor water-quality. Algal mats are present, likely due to increased nutrients going into the sea (due to agricultural run-off, wastewater, etc.) (cited in Mead *et al.,* 2014).

SSL (2014a) concluded that development of an adaptive management strategy is required to address the stability and security of the coastline along the study area – to address erosion, flood risk and encourage sediment deposition at strategic locations along the frontage and potentially encourage restoration of habitat biodiversity (cited in Mead *et al.,* 2014).

Two coastal behaviour units were identified by SSL (2014a); Ha'atafu, Kanokupolu and Ahau in the northern unit, and Kolovai, Ha'avakatolo and Fo'ui in the southern unit. Accommodation and soft structure approaches for both units are recommended (cited in Mead *et al.,* 2014).

Mangrove replanting, a large part of SSL's (2014a) proposed intervention strategy, has been tried and has sometimes failed in Tonga; there is no clear understanding or guidance with respect successful implementation. SSL (2014a) suggest that there is a need to apply lessons learnt from previous successful mangrove replanting schemes (cited in Mead *et al.,* 2014).

SSL's (2014a) recommended strategy for the Hihifo District is set out below:

a) Promote a District wide "Green Buffer" coastal flood management intervention, involving a focused programme of mangrove planting.
b) Promoting the improved establishment of mangroves in higher energy environment locations through the use of bamboo breakwaters or groynes to help reduce wave energy and to encourage fine material settlement along the Hihifo nearshore zone to enable mangrove propagules and juvenile trees to establish themselves.
c) Encourage the promotion of mangrove "nurseries" within the newly created wetland systems for each village (community ownership and responsibilities being established).
d) Construct secondary backing defences through the use of large sandbags (partly filled with cement) to improve resiliency of the structure and for these structures to be placed in the quieter backwaters of the wetland lagoon areas of Kanukopolu and Ahau (cited in Mead *et al.,* 2014).

5.8.2 Sustainable Seas (2014b)

This report further expands on the recommendations of the Sustainable Seas (2014a) report for the application of solutions for the area. Rehabilitating mangroves for the whole area is recommended – development of a "green buffer" along the coast. This approach involves the following sub engineering components to ensure the integrated concept of the "Green Buffer" will work:

a) Improved community management of existing brackish wetlands at Kanukopolu and Ahau;
b) Improved engineering management of the existing community coral block wall (from south of Ha'atafu southwards to Ahau village) creating "flushing gaps" in the defence to allow improved tidal circulation which in turn shall encourage improved water quality and hence create a more suitable environment for mangrove rehabilitation;
c) Installation of bamboo groynes and breakwaters to act as "energy dampeners" along the coast to enable fine sediment accretion and thus help aid mangrove rehabilitation to occur in more higher energy tidal areas of the Hihifo coastline (namely southern end of Ha'atafu, Kolovai and Ha'avakotolo, Fo'ui);
d) Strategic placement of backing defences within the lagoonal areas (not high energy coastal areas) using large sandbag defences (or similar) (cited in Mead *et al.,* 2014).

The introduction of an improved "mangrove planting programme" is proposed to help promote a more "climate resilient approach" towards addressing the issue of reducing wave energy impacts along the Hihifo frontage. This is designed to help defend the existing coastal frontage from Ha'atafu through to Fo'ui. The approach is implementable in tandem with the bamboo groynes/breakwaters and intends to use (eventually) mangrove plants grown specifically in the two proposed mangrove nursery areas in the "green buffer" wetland areas at Kanukopolu and Ahau. SSL (2014b) indicate that local materials and seedlings shall be used and grown within the two proposed "nurseries" in Hihifo. This is hoped to have the full support of the community towards planting, conservation, construction, maintenance and monitoring of mangrove growth, which is likely to be a major benefit to ensure longer term success of the project (cited in Mead *et al.,* 2014).

SSL (2014b) consider the appropriateness of this approach, within this location, is that mangrove growth does occur in the district and has historically been the main line of coastal defence for Hihifo, despite the area being exposed to occasional high wave energies (during extreme events) and that mangroves grow more efficiently in protected more sheltered environments. In addition, the presence of mangroves on the western side of Tongatapu has, in the past, proven effective in saving stretches of coast from serious damage during cyclone events. SSL (2014b) state that the onset of mangrove clearance in the area, over time, has reduced the natural defence capability and this situation needs to be reversed (cited in Mead *et al.,* 2014).

SSL (2014b) state that the integrated "Green Buffer" coastal flood management approach is revolutionary to Tonga, and also the South Pacific, hence Tonga can seek to use this opportunity to pilot some new innovation in coastal protection and engineering. It is a cost-effective long-term solution, as opposed to the construction of hard seawalls along the Hihifo frontage. SSL (2014b) indicates that despite this, it can only be applied to areas where there is a clear understanding of sediment processes and budgets operating along the peninsula. Consequently, SSL (2014b) raises concerns with respect to a detailed understanding of the coastal processes (cited in Mead *et al.,* 2014).

While detailed investigations would be especially useful to further develop a solution, given the budgetary constraints and the scale of the project area (some 4 km of coast), such investigations cannot be undertaken. Even so, Howarth's (1983) review of morphological change and existing evidence indicates that the area is very low energy (except during cyclones) and previously had a green belt of mangroves. Therefore, the approach to re-establish the green belt makes good sense (cited in Mead *et al.,* 2014).

SSL (2014b) note that the approach is not designed to prevent all coastal flooding that occurs in the Hihifo villages, nor is this a total remedy for addressing tsunami risk (though international best practice does suggest that green buffers are the most sensible option to pursue for tsunami inundation mitigation as opposed to hard coastal defences). SSL (2014b) recommend that the integrated approach should be iterative, and should be designed to "act with nature" as more information becomes available through community and government funded monitoring programmes – the development of which is a part of this present consultancy (cited in Mead *et al.,* 2014).

SSL (2014b) states that it is important that the approach be implementable at the local community level, it must seek to use local materials (constructed or grown locally) and have the support of the community in terms of bamboo (or equivalent) groyne and breakwater construction, maintenance and monitoring of scheme performance. SSL (2014b) suggest that establishing village specific mangrove nurseries, that involve children from local schools planting new mangrove seedlings through to adults constructing the brushwood bundles within the bamboo groynes is likely to be an important social dimension to the project, and it is anticipated that this community engagement aspect is likely to be a major benefit to ensure longer term success of the project (cited in Mead *et al.,* 2014).

SSL (2014b) provide the following basic principles of establishing a greenbelt and associated nurseries in Hihifo which should be applied when designing to conditions laid down by the MLECC:

- Existing natural ecosystems should be preserved. In other locations, the natural terrain and vegetation should be restored as far as possible, keeping visual effects also in mind.

- The natural littoral woodland species will be the most used species because sandy shores border most of the peninsula.
- Wherever mangroves have been damaged or depleted, they should be rehabilitated and enhanced and wherever they have been destroyed, they should be restored.
- Introduced/exotic species should be excluded.
- Footpaths through mangrove forests should preferably be raised board walks, to ensure minimum disturbance to the mangroves.
- At least a 15 to 20m wide strip of natural littoral woodland and strand plants should be planted seaward of agricultural crops. Imitation of the typical plant species mix and distribution in the natural community would be the best, while natural vegetation should not be removed but integrated (cited in Mead *et al.,* 2014).

In addition, SSL (2014b) make recommendations to protect the new mangrove. Newly planted mangrove species within the nursery should be protected against strong winds, animals, pests and diseases, wilting, and nutrient deficiencies. Temporary fencing with bamboo posts and barbed wire, combined with windshields of brush wood, thatched coconut fronds or such other material on the windward side, could protect the plants from wind and animal damage (pigs, etc.). Plants should also be regularly checked for pests and diseases, and nutrient deficiencies, for the treatment of which the advice of an agriculturist should be sought, and promptly treated. Protection from the sun and watering during dry periods is also recommended (cited in Mead *et al.,* 2014).

Development of the green belt and artificial lagoon is supported by the construction of brushwood or bamboo structures to protect mangrove seedling and encourage sedimentation (Figure 5.18 and Figure 5.19). There is little difference between these structures and the fish traps that are present on this coast, and so construction should not pose an issue. Fish traps will need to be moved more seawards to accommodate the T-groyne structures, however, there is plenty of space available for this to occur (cited in Mead *et al.,* 2014).

Figure 5.18 An example of a bamboo/brushwood groyne (SSL, 2014b; cited in Mead *et al.,* 2014).).

Figure 5.19 An example of a bamboo/brushwood groyne and sedimentation field (SSL, 2014b; cited in Mead *et al.,* 2014).

Another component of SSL's (2014b) recommended strategy is managed realignment. Managed realignment (also referred to as "Setback") is a technique that is linked as being a key part to delivering the Green Buffer strategic coastal flood management approach**.** SSL (2014b) state that the strategic approach aims to eventually contribute towards creating a national land use planning designation "green buffer". This represents a strategically significant planning designation to better accommodate and integrate climate resilience into Tongan land use development. The purpose of this strategy is also to seek to accommodate accelerated sea-level rise or increased storm activity through managed and controlled coastal engineering whilst enabling coastal livelihoods and habitats to be sustained. This part of the SSL (2014b) strategy incorporates 3 locations for sandbag backstop walls:

1. Kanukopolo – circa 250m length

2. Ahau – circa 200m length
3. Fo'ui –circa 100m length.

A further component of the SSL (2014b) strategy is the development of an artificial wetland – the approach being proposed for this PACC project supports this concept as the technique seeks to maximize habitat and natural processes in a range of low to medium energy areas found along sheltered coastlines (cited in Mead *et al.,* 2014).

SSL (2014b) summarise the benefits of their recommended approach as:

- It saves "risk" areas from flood inundation;
- It helps to convert barren land into productive resource management areas;
- The approach introduces a method how to effectively use the voluntary role of coastal communities in delivering sustainable sea defence management;
- The approach increases the adaptive capacity through providing a sufficient additional income on top of any other routine livelihood activities.
- Due to recurrent income generation, the approach reduces the vulnerability of coastal communities to climate change.
- Establish up to 2500 hectares of mangrove to provide natural protection for the wetland areas (cited in Mead *et al.,* 2014).

SSL (2014b) provides a cost breakdown for the recommended intervention strategies. They estimate USD$380 for the application of the solution, with a total budget of US$650 for works and consultancy support. SSL (2014b) also includes a comprehensive Appendix on the application of the various strategies recommended (cited in Mead *et al.,* 2014).

5.8.3 Geocare and Petroleum Consult (2014)

This comprehensive report considers the impacts of the strategy proposed by SSL (2014b), provides a detailed environmental management plan (EMP) to address any potential negative impacts of the implementation of the strategy, and provides alternatives based on the feedback from the local people. The EIA also reiterates the importance of community buy-in to achieve a successful outcome (cited in Mead *et al.,* 2014).

As in the SSL (2014a) report, Geocare and Petroleum Consult (2014) describe the marine life in the Kanokupolu lagoon, and how it acts as a nursery for juvenile marine fish. These biological descriptions are likely from an earlier investigation (e.g. Scott, 1993), and are not currently relevant since the lagoon is blocked off from the sea and is a brackish area that is being reclaimed by vegetation (cited in Mead *et al.,* 2014).

The local people's preference for increasing coastal resilience is for a foreshore revetment like in Nuku'alofa. This, however, cannot be achieved in this project (cost is estimated at >$6M). When the components of the strategy of SSL (2014b) are considered along with a foreshore revetment most local people want all types of protection.

The alternatives to the SSL (2014b) strategy, which include rehabilitating the rock foreshore, relocation and doing nothing, are also examined by Geocare and Petroleum Consult (2014). The rehabilitation of the rock foreshore (road/revetment) is supported by the results of tsunami inundation modelling that indicate it is effective at reducing the impacts of waves (cited in Mead *et al.,* 2014).

6 Annex D: Coastal Unit 2: Foui to Sopu

6.1 Bio-Physical Environment

The coastal unit between Foui and Sopu is characterised by a thin mangrove stand that thickens from west to east (Figure 6.1). This area is low lying and very susceptible to inundation (Figure 4.3) with most of this coastal unit below 2.0 m. This coastal unit faces north towards the shallower western section of the Tongatapu Lagoon. The section of coastline is protected from the prevailing south-east winds but is exposed to northerlies. Similar to coastal unit 1, the wave climate along coastal unit 2 is considered to be small <1.0 m under normal conditions, as waves break on the offshore barrier reef system and wave energy is further dissipated over the shallow western section of the Tongatapu Lagoon.

Figure 6.1 Location map of coastal unit 2 (yellow line) on the north-western middle coastline of Tongatapu between Foui to Sopu (Google Earth, 2020) .

The bio-physical environment of the coastline along coastal unit 2 has been greatly influenced by humans but less so than coastal unit 1. The mangrove belt that extends from Foui to Sopu is ~12 km long and is ~1 km at its widest (eastern end). It is evident that land reclamation has occurred, which has resulted in the removal of mangroves. This mangrove removal is especially evident in the western section where a large area ~1.2 km^2 has been cleared is now brown (Figure 6.1) in the satellite imagery. Where houses reside next to the coastline, the mangroves adjacent, have been somewhat cleared, potentially to provide access to the lagoon and for materials.

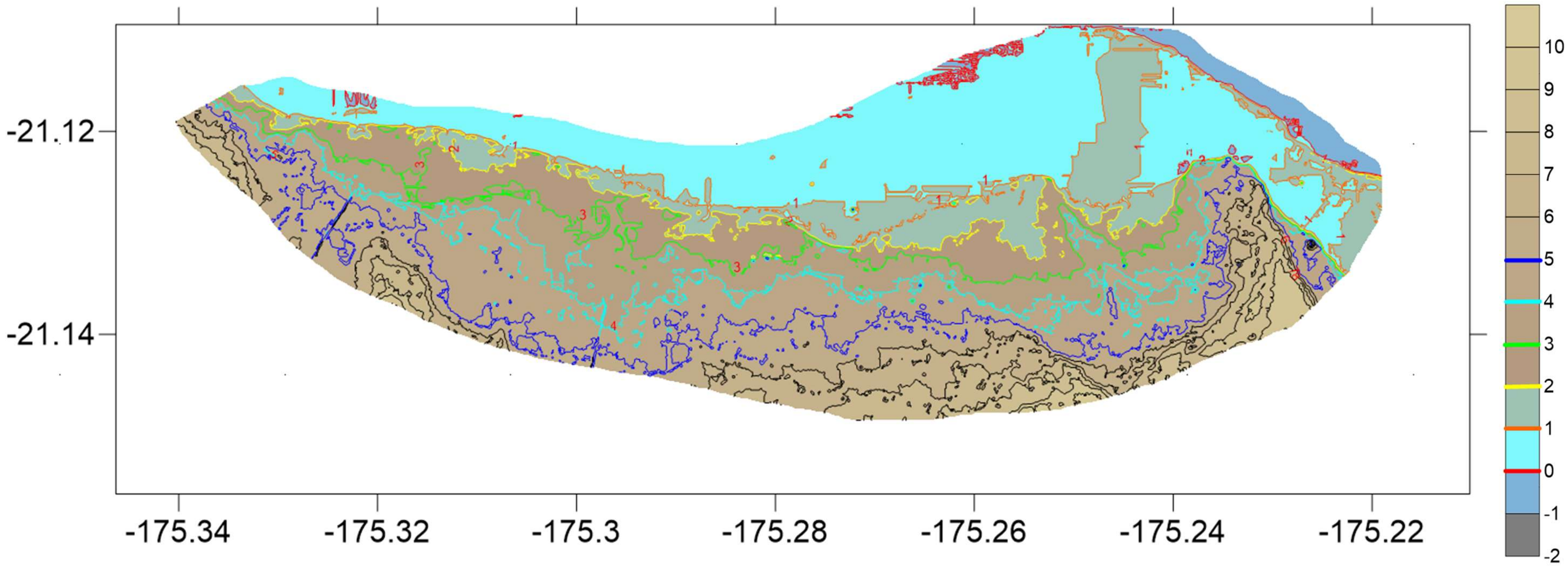

Figure 6.2 Contour plot of coastal unit 2. Note: Level refers to contours level (m) from MSL.

6.2 Masilamea, Teekiu & Nukunuku

The nearshore environment between Masilamea and Nukunuku villages is characterised by intertidal reef flats, which have a veneer of sediment overlying (thickness unknown) (Figure 6.3). The water depth in the western portion is slightly greater compared with the villages to the west with a channel running out toward the north-east and north to the open coast. The mangrove stand that extends around along this coastline is thinned out, only 230 m at its widest. The mangroves have been removed near the roads and houses that are situated adjacent to the coastline.

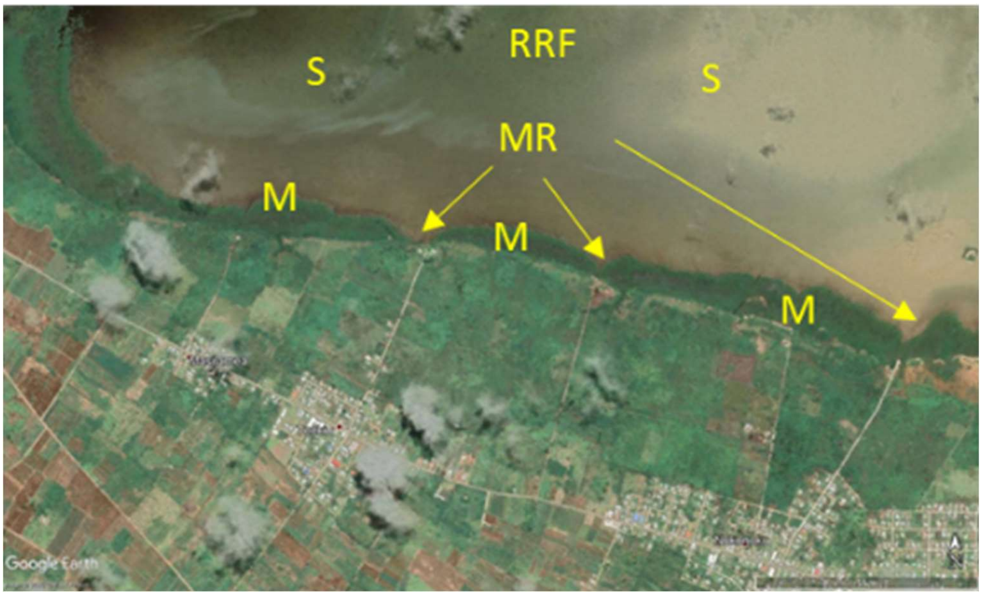

Figure 6.3 Image shows nearshore and shoreline bio-physical features between Masilamea, Teekiu and Nukunuku villages, Tongatapu, Kingdom of Tonga (Image sourced from Google Earth, 2020). Note: RRF = rocky reef flats, M = mangroves, MR = mangrove removal, and S = sediment.

6.3 Matafonua & Fatai

The nearshore environment between Matafonua and Fatai villages is characterised by intertidal reef flats, which have a veneer of sediment overlying (thickness unknown) (Figure 6.4). The mangrove stand that extends along this coastline begins to thicken from Nukunuku through to Fatai, where it is 800 m wide. There is evidence of mangrove removal along the coastline, which is indicated by the brown patches (Figure 6.4).

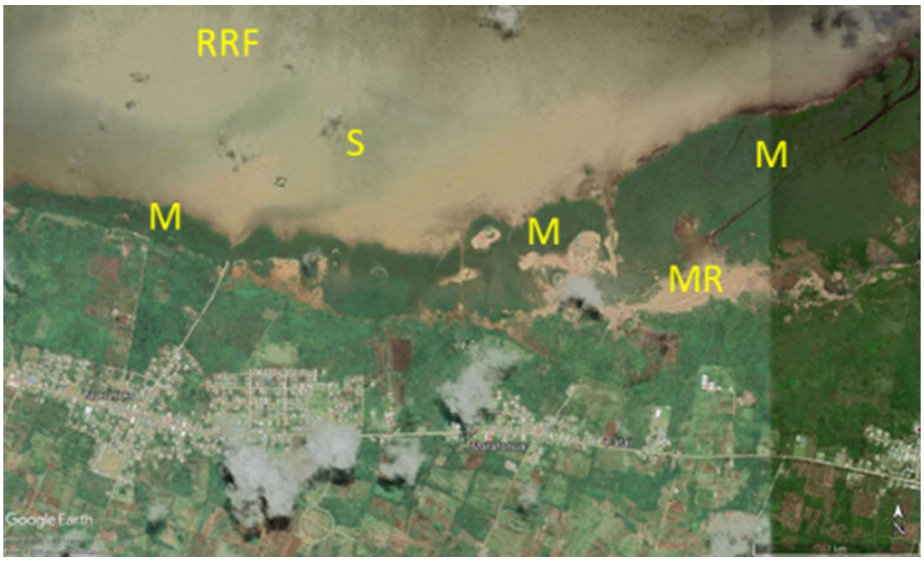

Figure 6.4 Image shows nearshore and shoreline bio-physical features between Matafonua and Fatai villages, Tongatapu, Kingdom of Tonga (Image sourced from Google Earth, 2020). Note: RRF = rocky reef flats, M = mangroves, MR = mangrove removal, and S = sediment.

6.4 Sia'atoutai, Puke and Sopu

The nearshore environment between Sia'atoutai and Sopu villages is characterised by intertidal reef flats, which have a veneer of sediment overlying in the western portion, which thins toward the fringing reef in the eastern portion (Figure 6.5). Beyond the fringing reef, the water depth drops away rapidly to about 27 m depth CD. Adjacent to Sia'atoutai, the mangrove stand is widest (~1.2 km). Just to the east of Sia'atoutai, however, mangrove removal is evident, which is indicated by the brown patches (Figure 6.5). A road extends from the coastline adjacent to Sopu toward a house in the clearing (Figure 6.6).

From the northern most tip of land, the shoreline changes from mangroves to the west to a broken sandy beach system to the east. This is indicative of a change in environmental energy from low to high. From where the above-mentioned road begins (Figure 6.6), a revetment has been constructed, which appears to be protecting a small land bridge connecting the road to the coastline adjacent to Sopu Village. Directly adjacent to Sopu village the shoreline is characterised by a thin beach, which extends to a groyne at Nuku'alofa.

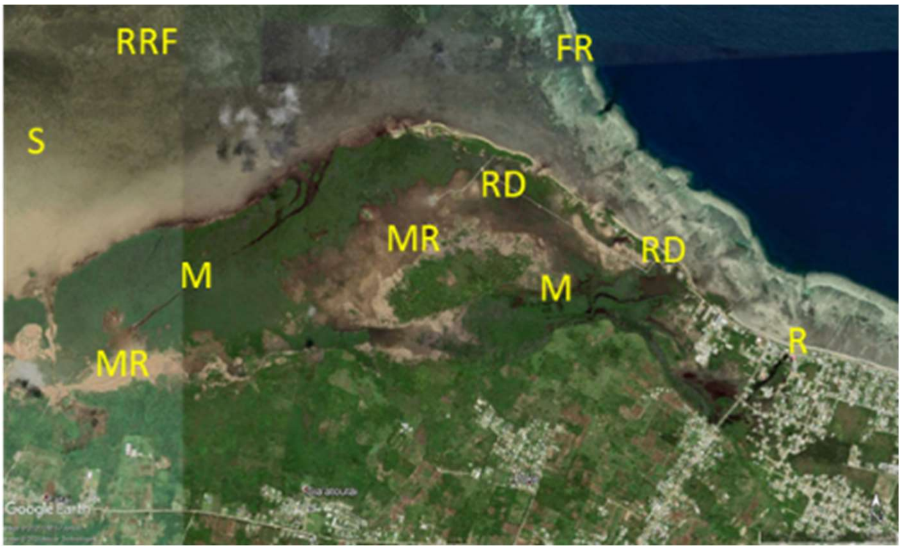

Figure 6.5 Image shows nearshore and shoreline bio-physical features between Sia'atoutai and Sopu villages, Tongatapu, Kingdom of Tonga (Image sourced from Google Earth, 2020). Note: RRF = rocky reef flats, M = mangroves, MR = mangrove removal, FR = fringing reef and S = sediment.

Figure 6.6 Image shows a road adjacent to Puke Village going to a house in the clearing, Tongatapu, Kingdom of Tonga (Image sourced from Google Earth, 2020).

7 Annex E: Coastal Unit 3: Sopu to the Nuku'alofa shore of the lagoon

7.1 Bio-Physical Environment

The coastal unit between Sopu and Nuku'alofa comprises two geographical components: a northern coastal area and a southern lagoonal area (Figure 7.1). The northern coastal area nearshore environment comprises a fringing reef, which drops off into the deep waters of the Tongatapu Lagoon. Similar to coastal unit 2, unit 3 is low lying and very susceptible to inundation (Figure 4.14). There are three pockets of higher ground that are greater than 2 m but most of this area is less than 2 m depth (

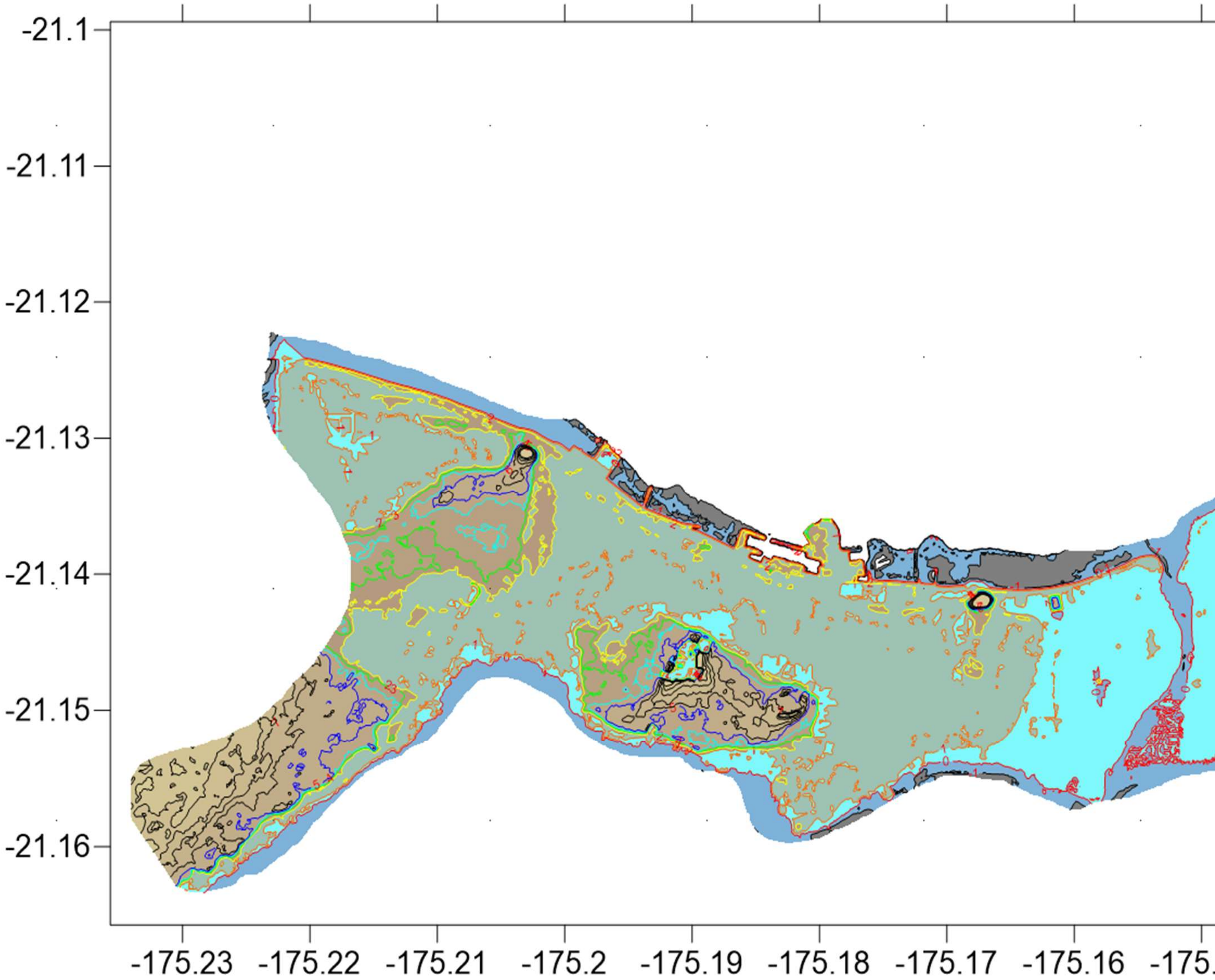

Figure 7.2). This coastal unit faces north towards the deep middle section of the Tongatapu Lagoon. The section of coastline is protected from the prevailing south-east winds but is exposed to northerlies. The wave climate along the northern coastal component of coastal unit 3 is considered small <1 m under normal conditions. Cyclones from the north, however, can produce larger waves and as this area is not directly protected by a barrier reef, this section of coastline is exposed and susceptible to storm surge.

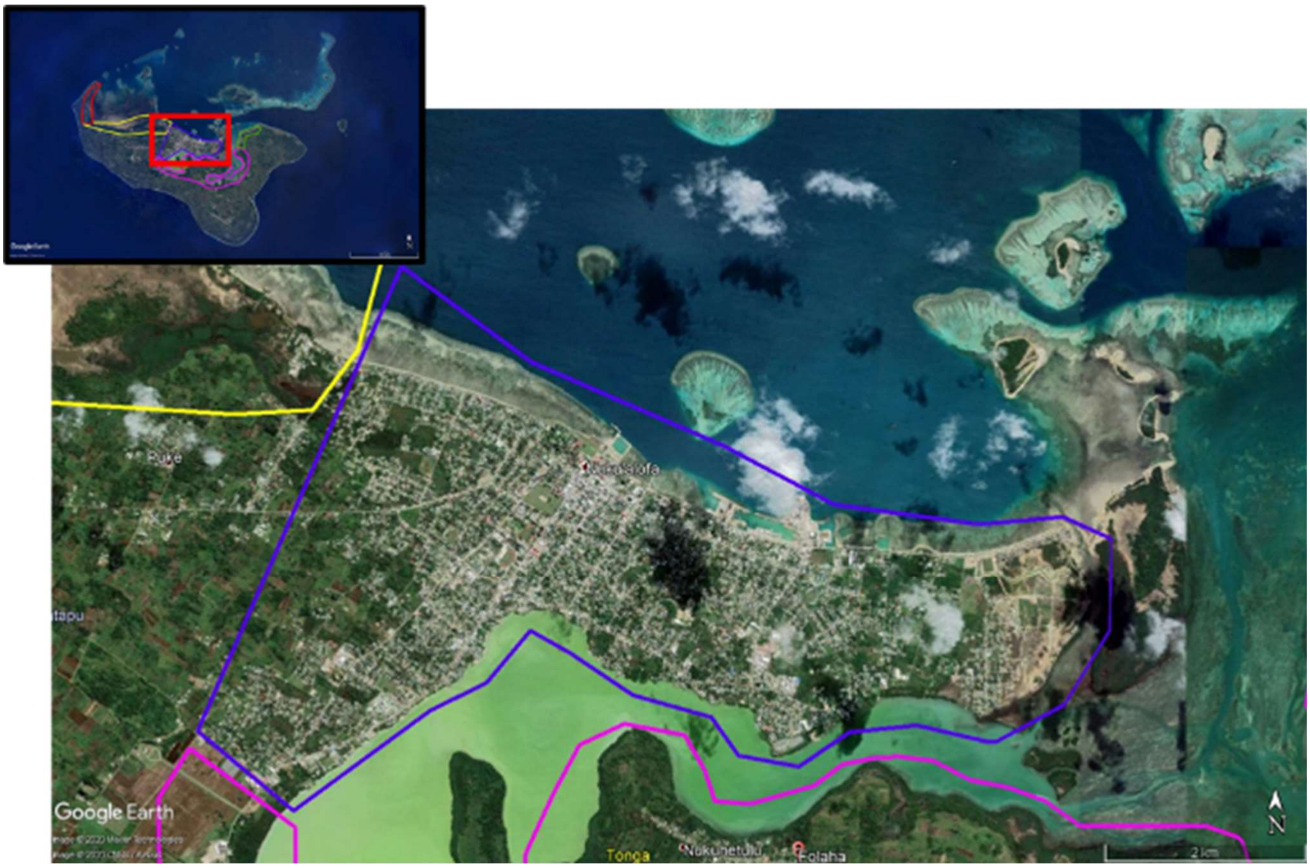

Figure 7.1 Location map of coastal unit 3 (blue line) on the northern most section of coastline of Tongatapu between Sopu and Nuku'alofa (Image sourced from Google Earth, 2020).

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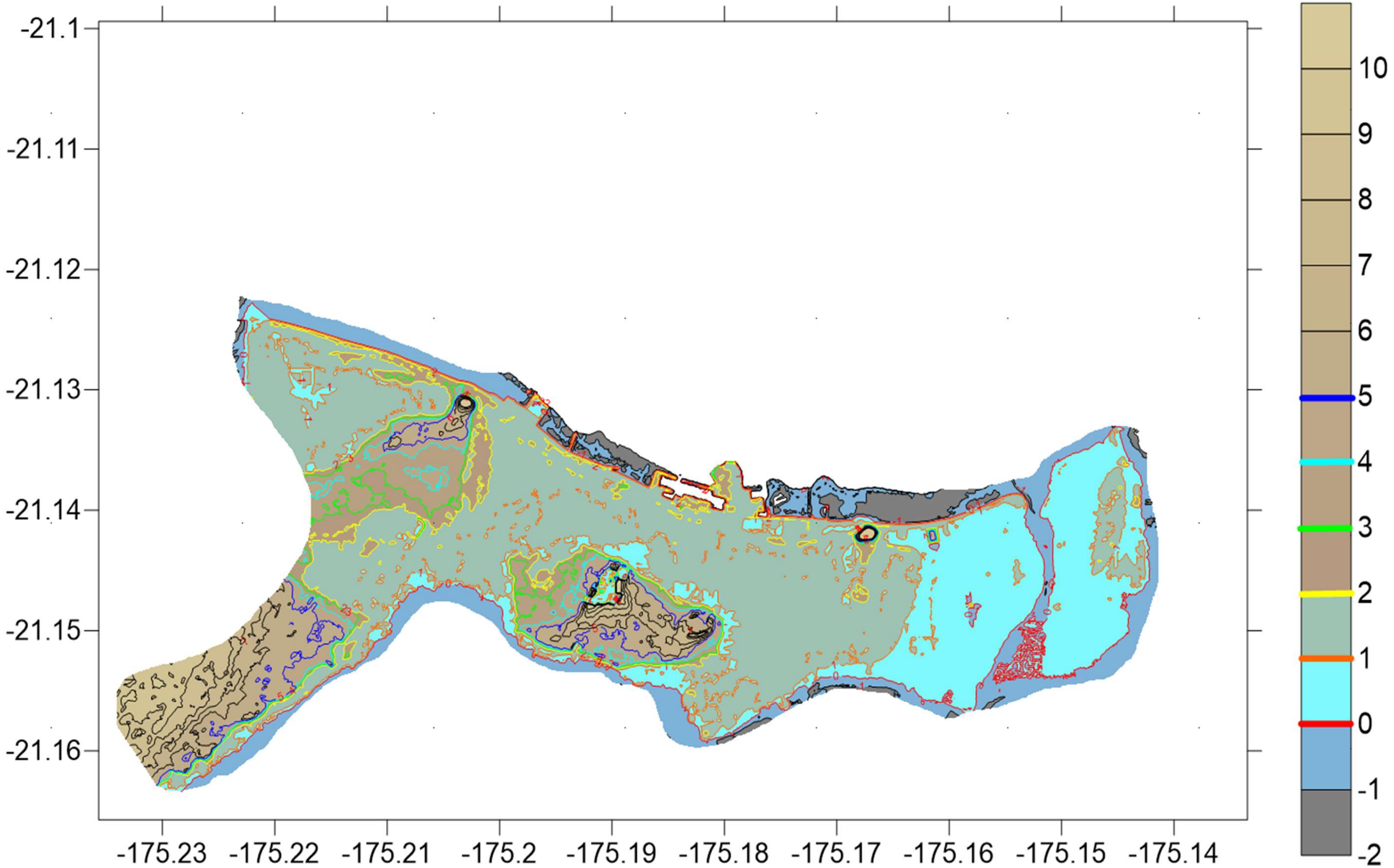


Figure 7.2 Contour plot of coastal unit 3. Note: Level refers to contours level (m). Three pockets of high ground are evident.

7.2 Northern Component

The western area of the northern coastal shoreline is characterised by the Nuku'alofa seawall (Figure 7.3). This seawall was first built in 1977 and rebuilt after Cyclone Issac in 1982. By 1986, the seawall was revamped to a total length of 3.4 km (Figure 7.4) (Mimura & Pelesikoti, 1997). Today the seawall extends from east of Sopu to Popua (>6.0 km).

The middle northern component is characterised by the Vuna and Queen Salote Wharfs (Figure 7.5) with revetments/ breakwaters constructed between these. Constructed sometime around the 1860s, the Vuna Wharf is one of the oldest ports of call in the South-Pacific and enabled early commerce with the British and Germans traders. In 1902, the Vuna Wharf was opened for international trading. For nearly 120 years Vuna Wharf endured earthquakes and cyclones and was later suspended. In 2012, Vuna Wharf was resurrected, redeveloped, and re-opened by His Majesty King Tupou VI (Figure 7.6). Currently, the wharf is opened to cruise liners, foreign naval ships and vessel (Ports Authority Tonga, 2017).

Queen Salote Wharf was open in 1967 by His Majesty King Taufa'ahau Tapo IV and Her Majesty Queen Halaevalu Mata'aho 'Ahome'e and serves cargo and shipping liners. In 2015, the Queen Salote Wharf was upgraded to include a domestic transport wharf (Figure 7.7).

Figure 7.3 Image shows close up of the western area of the northern coastline of coastal unit 3, Tongatapu, Kingdom of Tonga (Image sourced from Google Earth, 2020). Note: FR = fringing reef, R = Revetment, W = Wharf.

Figure 7.4 Nuku'alofa Seawall (Images sourced from Mimura & Pelesikoti, 1997 (left); Asian Development Bank – Flickr, 2020 (right)).

Figure 7.5 Image shows close up of the middle area of the northern coastline of coastal unit 3, Tongatapu, Kingdom of Tonga (Image sourced from Google Earth, 2020). Note: FR = fringing reef, R = Revetment, W = Wharf.

Figure 7.6 Images show progressive development (left to right) of the Vuna Wharf Upgrade. Images dated as 09/03/2002, 16/07/2009, and 17/06/2020 (Images sourced from Google Earth, 2020).

Figure 7.7 Images show progressive development (left to right) of the domestic transport upgrade for Queen Salote Wharf. Images dated as 18/07/2014, 02/06/2016, and 12/01/2018 (Images sourced from Google Earth, 2020).

The eastern area of northern shoreline component of coastal unit 3 is characterised by small pocket beaches broken by revetments/breakwaters at the western end and thin beach backed by a breakwater at the eastern end, which extends to the end of the Island. At the eastern extent, there is a revetment/breakwater protecting the peninsular (Figure 7.8 and Figure 7.9).

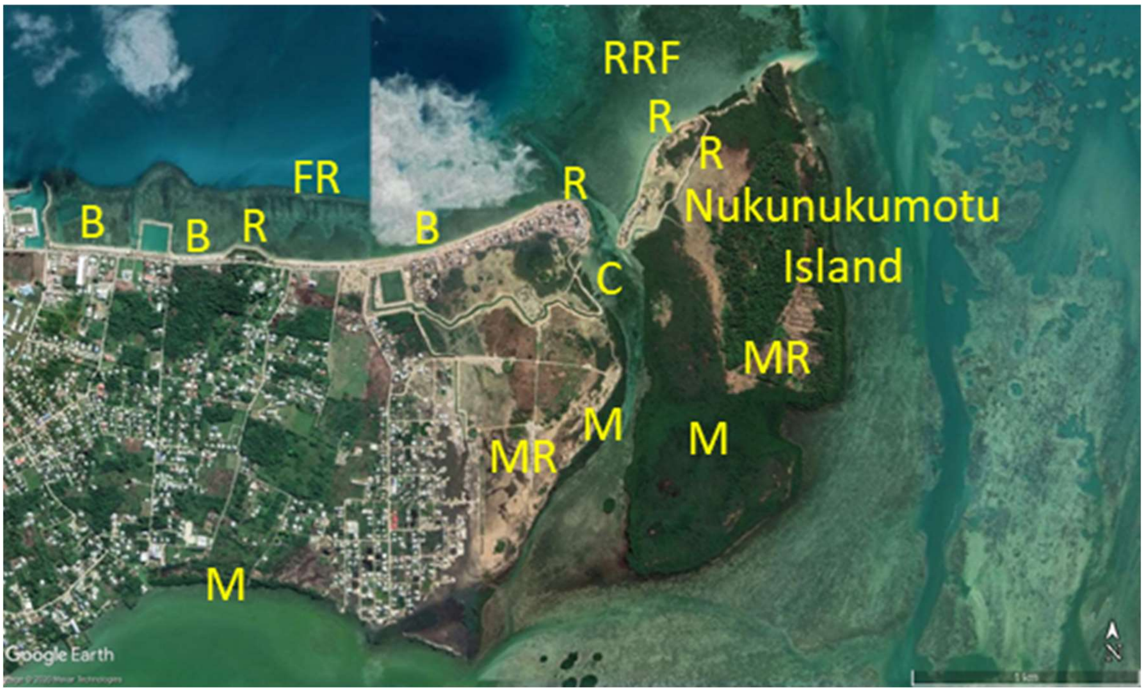


Figure 7.8 Image shows close up of the eastern area of the northern coastline of coastal unit 3, Tongatapu, Kingdom of Tonga (Image sourced from Google Earth, 2020). Note: FR = fringing reef, R = revetment, C = channel, MR = mangrove removal, and M = mangroves.

Nukunukumotu Island constrains the Fanga'uta Lagoon entrance on the western side. A small channel passes between the mainland (west) and Nukunukumotu Island (east). Mangroves line both sides of this channel, except a large portion has been removed on the Nuku'alofa side (Figure 7.8 and Figure 7.9).

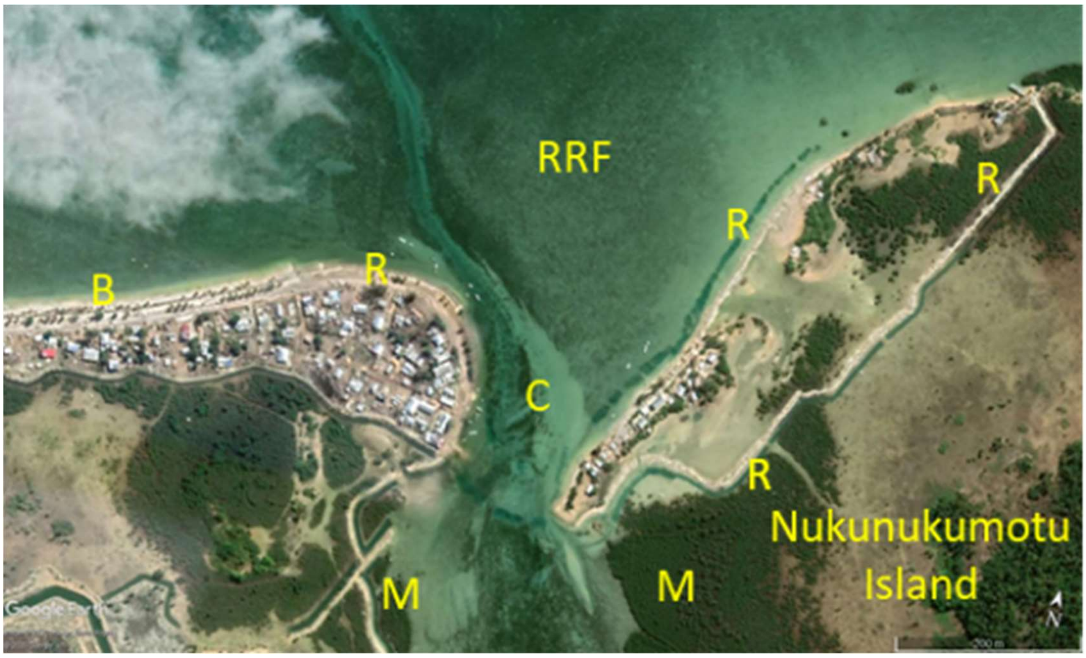


Figure 7.9 Image shows close up of the eastern area of the northern coastline of coastal unit 3, Tongatapu, Kingdom of Tonga (Image sourced from Google Earth, 2020). Note: FR = fringing reef, R = revetment, C = channel, MR = mangrove removal, M = mangroves, and RRF = rocky reef flats.

Along the southern urban boarder of the town at the eastern extent of the peninsula (Figure 7.10) revetments and bunds, as well as drainage channels have been constructed, between June 2016 and present. Furthermore, the small township on the western side of Nukunukumotu Island, Seisia has also had bunds constructed, sometime between September 2019 and April 2020, which area current still be under construction (Figure 7.9 and Figure 7.11), as discussed in Annex I.

Figure 7.10 Pre-(02/06/2016) and post- (12/01/2018) revetment and drainage channel construction images for the eastern most area of the northern coastline of coastal unit 3 Tongatapu, Kingdom of Tonga (Image sourced from Google Earth, 2020).

Figure 7.11 Pre- (29/09/2019) and post- (21/04/2020) revetment and drainage channel construction images for the western side of Nukunukumotu Island, Tongatapu, Kingdom of Tonga (Image sourced from Google Earth, 2020).

7.3 Southern Component

The southern lagoonal component of this coastal unit is characterised as the northern shores of the Fanga'uta Lagoon extending from the entrance through to the Pea Nuku'alofa boarder. This section is a low energy environment that is not subject to waves from the open coast, except for areas near the entrance. As such, few engineering structures exists along this section of the coastal unit. There does, however, appear to be a few tipped rubble revetments, which boarder a few coastal property boundaries.

Along the northern shores of the Fanga'uta Lagoon, urban development increases from east to west (Figure 7.8 and Figure 7.12).

The bio-physical environment of the coastline along coastal unit 3 has been greatly influenced by humans. Much of the coastline is characterised by urban development with considerable mangrove removal having occurred along both the northern and southern shores. Furthermore, the land nearest the entrance has been highly modified for urban development with significant mangrove removal.

Figure 7.12 Image shows close up of the southern area of coastal unit 3, Tongatapu, Kingdom of Tonga (Image sourced from Google Earth, 2020). Note: UD = urban development.

8 Annex F: Coastal Unit 4: Nuku’alofa to Nukuleka

8.1 Bio-Physical Environment

Coastal unit 4 between Nuku'alofa and Nukuleka comprises the southern shores of the Fanga'uta Lagoon (Figure 8.1). In contrast to the northern shores (Nuku'alofa), the southern shores are significantly less developed with considerable mangrove stands existing. The Pe'a and Folaha Sectors (northern arm of the lagoon) are more low lying than the Vaini and Mua Sectors to the south (see Figure 8.9 for lagoon sectors) and are thus more susceptible to inundation and flooding (Figure 8.2). The southern shores of the lagoon are not subject to large incident wave conditions due to the low energy nature of the environment and small fetch of the lagoon. Thus, coastal protection structures along the southern shore of the Fanga'uta Lagoon are effectively non-existent and little change has occurred except for mangrove removal. If mangroves were to be entirely removed, then coastal erosion would be more evident than it is currently.

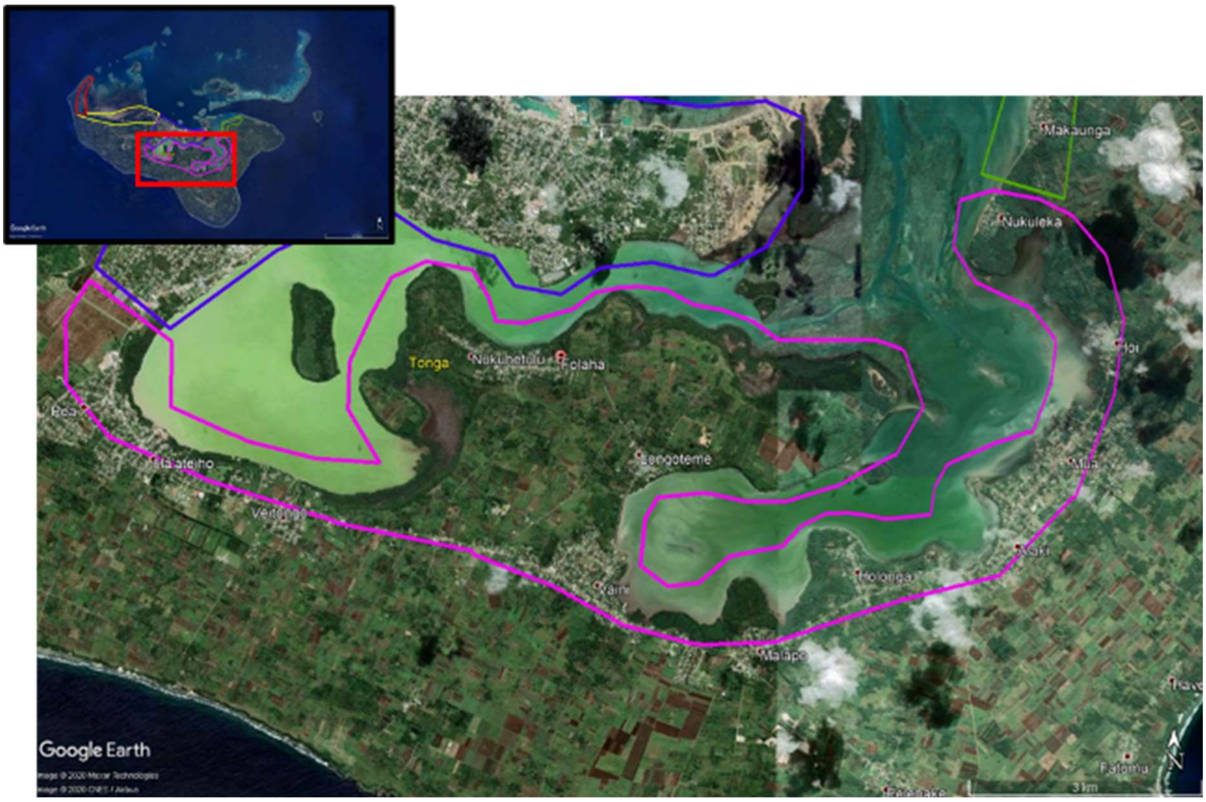


Figure 8.1 Location map of coastal unit 4 (magenta line) along the southern shores of the Fanga'uta Lagoon, Tongatapu between Nuku'alofa and Nukuleka (Image sourced from Google Earth, 2020).

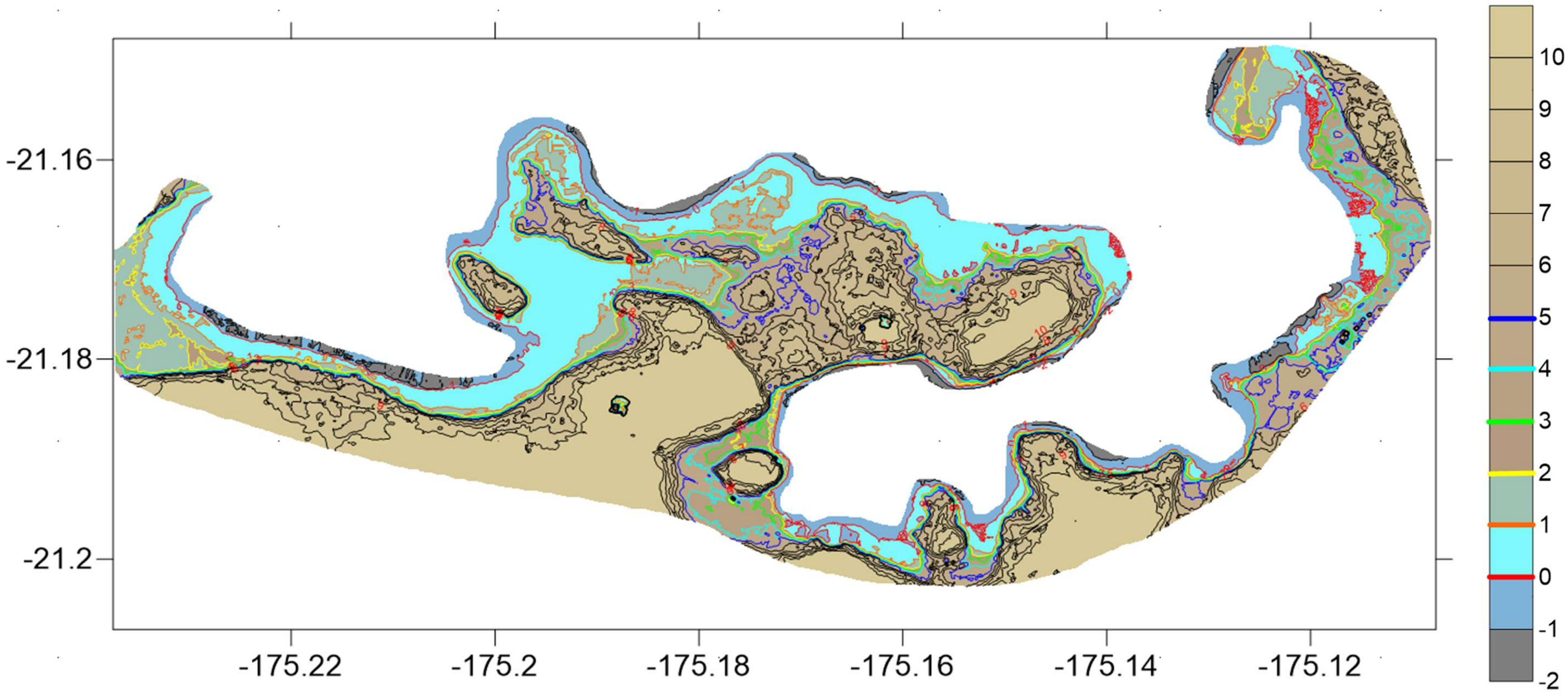


Figure 8.2 Contour plot of coastal unit 4. Note: Level refers to contours level (m) to MSL.

8.2 Pe'a, Ha'ateiho & Veitongo

The shoreline between Pe'a and Veitongo is characterised by pockets of mangroves, which are separated by villages encroaching on the lagoonal shoreline. The mangroves range from ~230 m wide at Pe'a to ~160 m to the east of Veitongo. Adjacent to Ha'ateiho, the mangroves are thinnest at ~130 m wide (Figure 8.3). The Pe'a village is particularly low lying (1 m or less) and more susceptible to inundation hazards compared to Ha'ateiho and Veitongo, which are between 3 and 4 m above present coastline level (Figure 4.14).

A detailed description of the nearshore environment and lagoon is presented in Section 8.7.

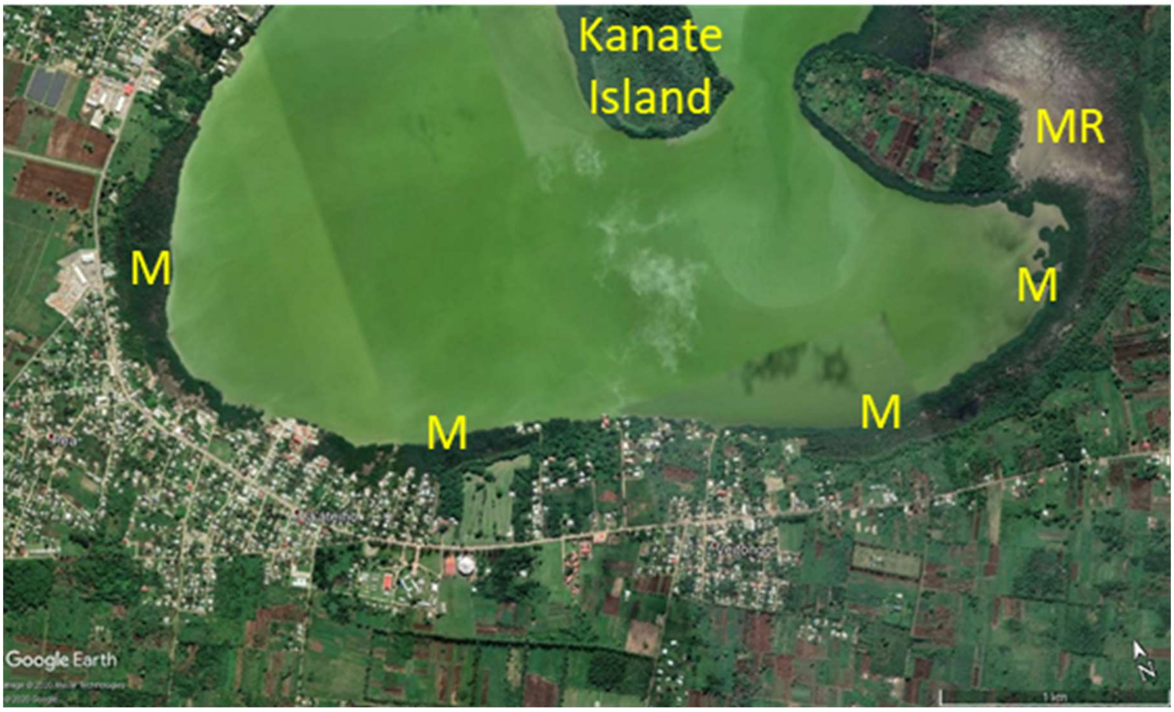


Figure 8.3 Image shows nearshore and shoreline bio-physical features between Pe'a and Veitongo villages, Tongatapu, Kingdom of Tonga (Image sourced from Google Earth, 2020). Note: M = mangroves and MR = mangrove removal.

8.3 Veitong & Nukuhetulu

The shoreline between Veitongo and Nukuhetulu is characterised by an unbroken mangrove stand, which varies in thickness due to mangrove removal. A large section of mangroves has been removed (~0.42 km^2) just south from Nukutehulu village (Figure 8.4). The mangroves become thin along the Nukuhetulu shoreline, which is most likely a result of the higher energy experience along this section, as well as the greater water depths limiting sediment accumulation. The topography of the area is a combination of low-lying mangrove hotspots (< 1 m) and high ground comprising headlands and Nukuhetulu village (>2 but <3 m). Folaha village is slightly lower between 1 and 2 m above present coastline levels (Figure 4.14).

A detailed description of the nearshore environment and lagoon is presented in Section 8.7.

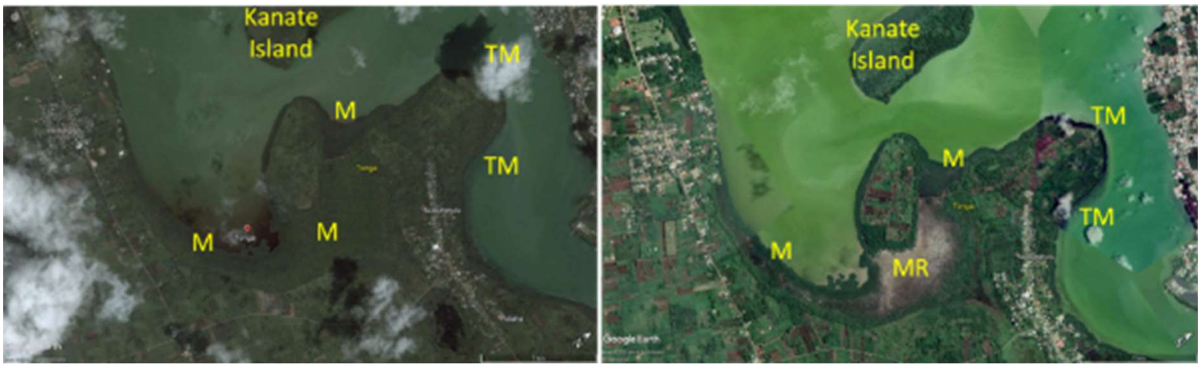


Figure 8.4 Image shows nearshore and shoreline bio-physical features between Veitongo and Nukuhetulu villages, Tongatapu, Kingdom of Tonga (Image sourced from Google Earth, 2020). Left – Image from 09/03/2002 showing little mangrove removal. Right – Image from 17/06/2020 showing substantial mangrove removal. Note: M = mangroves, TM = thin mangroves, and MR = mangrove removal.

8.4 Nukuhetulu, Folaha & Longoteme

The shoreline between Nukuhetulu and Longoteme is characterised by a northern and southern component (Figure 8.5). The northern component is characterised by an unbroken mangrove stand that extends to the end of the peninsular ranging from 50 to 200 m wide, which varies in thickness due to mangrove removal (0.18 km^2 removed directly east of Folaha village) and environmental energies at work. To the north-east, the nearshore environment consists of very shallow rocky reef flats, which give way to a deeper channel (3 to 6 m depth), to the west. Around the head of the peninsular and southward (southern component) the mangroves thin to Longoteme. The nearshore environment to the south-east of the peninsular head is characterised by deeper water (3 to 6 m depth) and is subject to higher current velocities. Further, this shoreline is exposed to the predominant south-easterly winds. Hence, mangroves are thin along this section of shoreline. The topography of the area is between 2 and 3 m above present coastline levels with the village of Longoteme above 4 m (Figure 4.14).

A detailed description of the nearshore environment and lagoon is presented in Section 8.7.

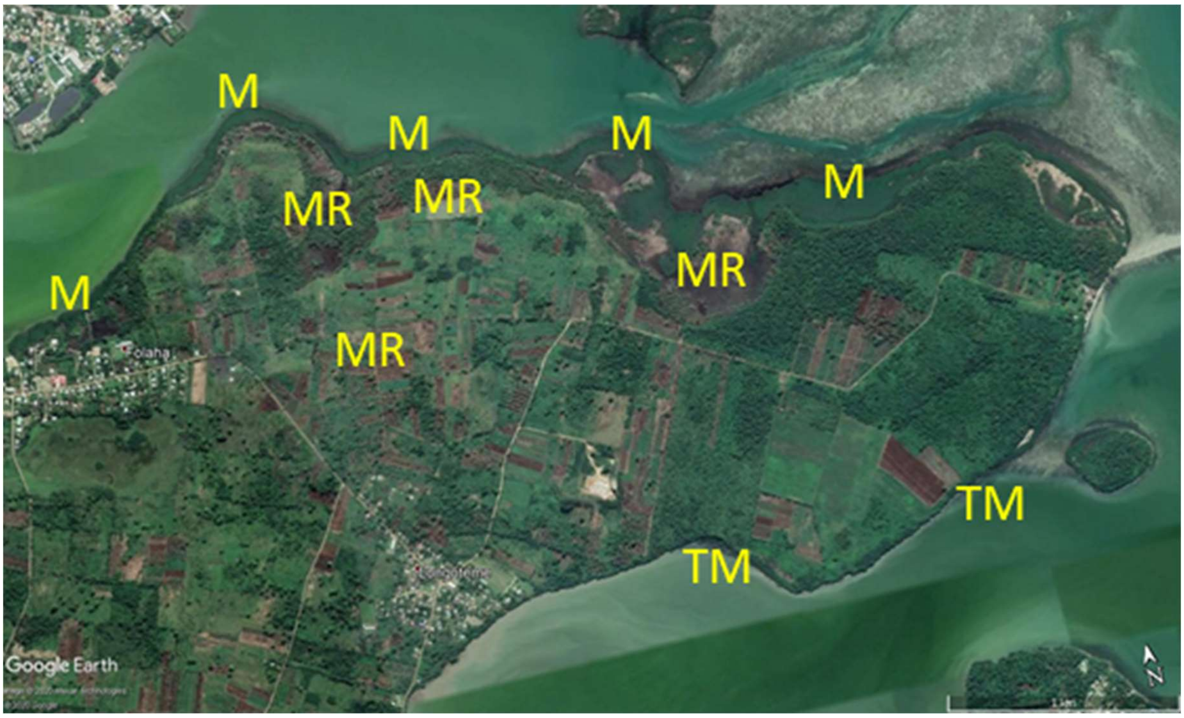


Figure 8.5 Image shows nearshore and shoreline bio-physical features between Nukuhetulu and Longoteme villages, Tongatapu, Kingdom of Tonga (Image sourced from Google Earth, 2020). Note: M = mangroves, TM = thin mangroves, and MR = mangrove removal.

8.5 Longoteme, Vaini, Malapo & Holonga

The shoreline between Longoteme and Holonga is characterised by urban development encroaching on the shoreline (Figure 8.6). Pockets of mangroves occupy the space between villages and lowland areas, while headlands are characterised by thin mangrove stands. The largest mangrove pocket lies westward of Malapo village at ~340 m wide. The nearshore environment is shallow (1 to 2 m depth) and sheltered from prevailing winds. Hence, mangroves. Vaini has is somewhat low-lying (2 and 3 m), with Malapo and Holonga situated at >4 m above present coastline levels (Figure 4.14).

A detailed description of the nearshore environment and lagoon is presented in Section 8.7.

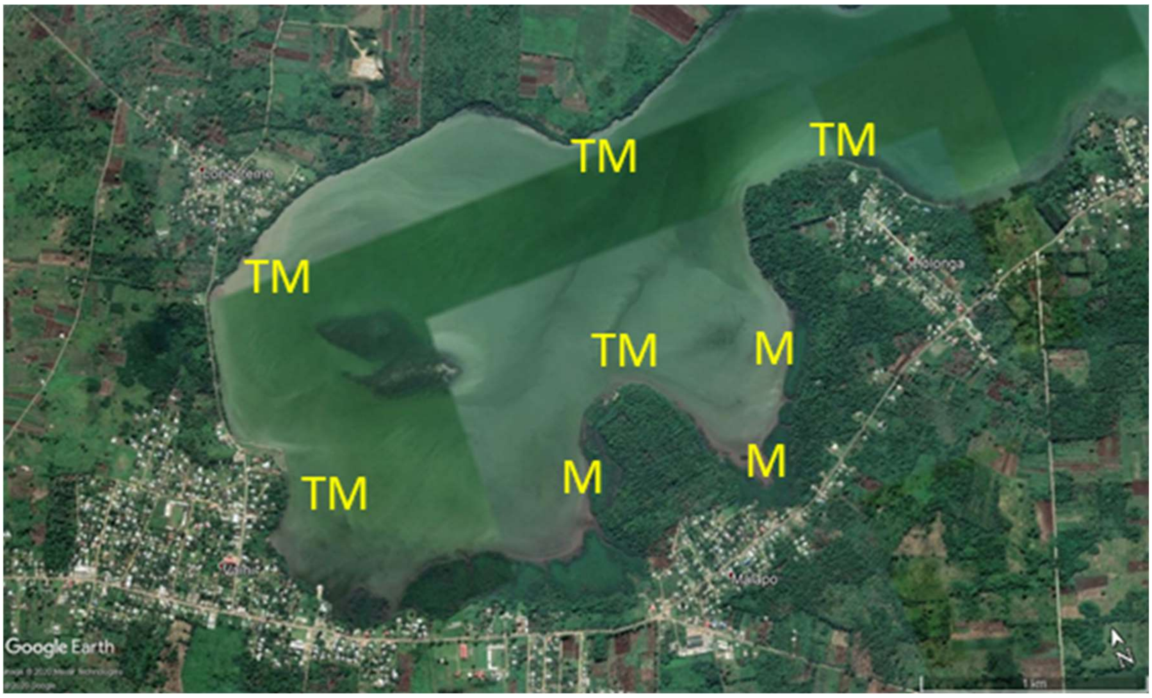


Figure 8.6 Image shows nearshore and shoreline bio-physical features between Longoteme and Holonga villages, Tongatapu, Kingdom of Tonga (Image sourced from Google Earth, 2020). Note: M = mangroves, and TM = thin mangroves.

8.6 Holonga, Alaki, Mua, Hoi & Nukuleka

The shoreline between Holongo and Nukuleka is largely characterised by thin mangroves, along a predominantly urban shoreline, to the south-east and thickening mangroves from the village of Hoi to Nukuleka (Figure 8.7). With urban development, however, mangroves adjacent to these villages have largely been removed. The nearshore water depth is between 3 to 6 m. It is evident, however, that a shallow rocky reef exists directly adjacent to the shoreline, which thickens and is more exposed at Mua village compared to Alaki. This suggests that wave conditions (directly in line with the open coast through the entrance) and tidal velocities, at Mua, may be greater along this section of shoreline, thus preventing sediment build up and mangrove development. This is evident as mangroves and sediment build up is observed on the lee (south) side of the breakwater, which is protecting a road (Figure 8.8). The topography between Holonga and Nukuleka is the highest of this coastal unit at >4 m above present coastline levels (Figure 4.14).

A detailed description of the nearshore environment and lagoon is presented in Section 8.7.

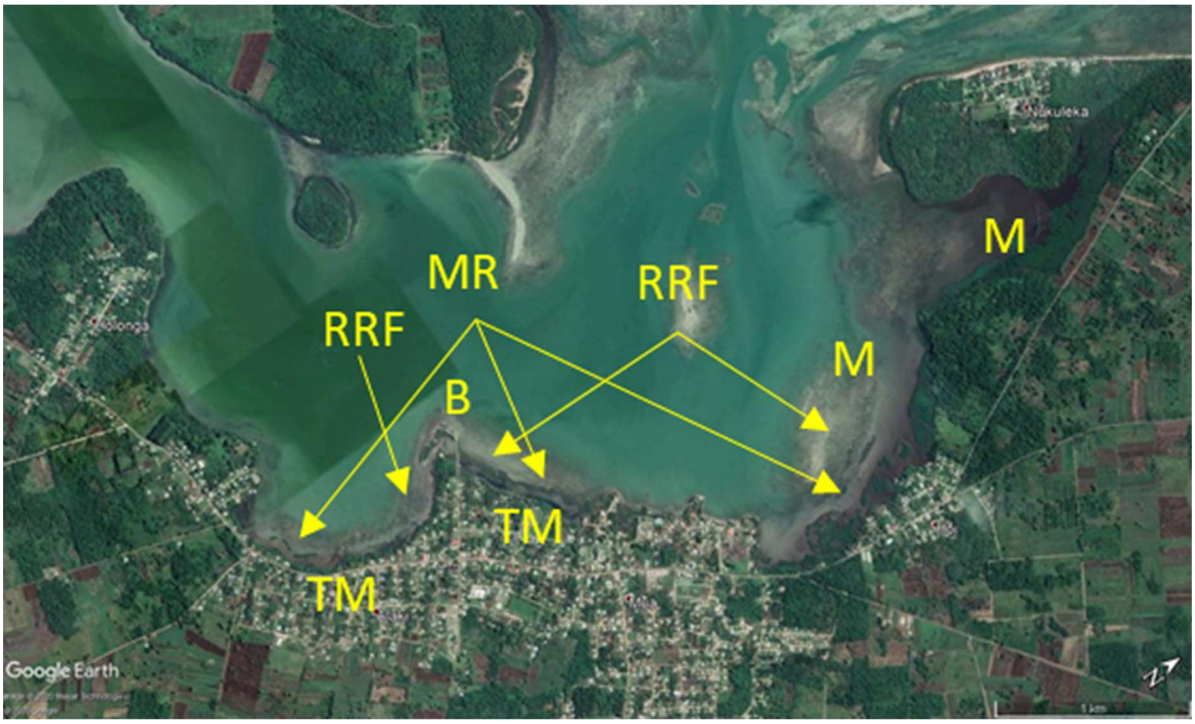


Figure 8.7 Image shows nearshore and shoreline bio-physical features between Holonga and Nukuleka villages, Tongatapu, Kingdom of Tonga (Image sourced from Google Earth, 2020). Note: M = mangroves, TM= thin mangroves, MR = mangrove removal, RRF = rocky reef flats, and B = breakwater.

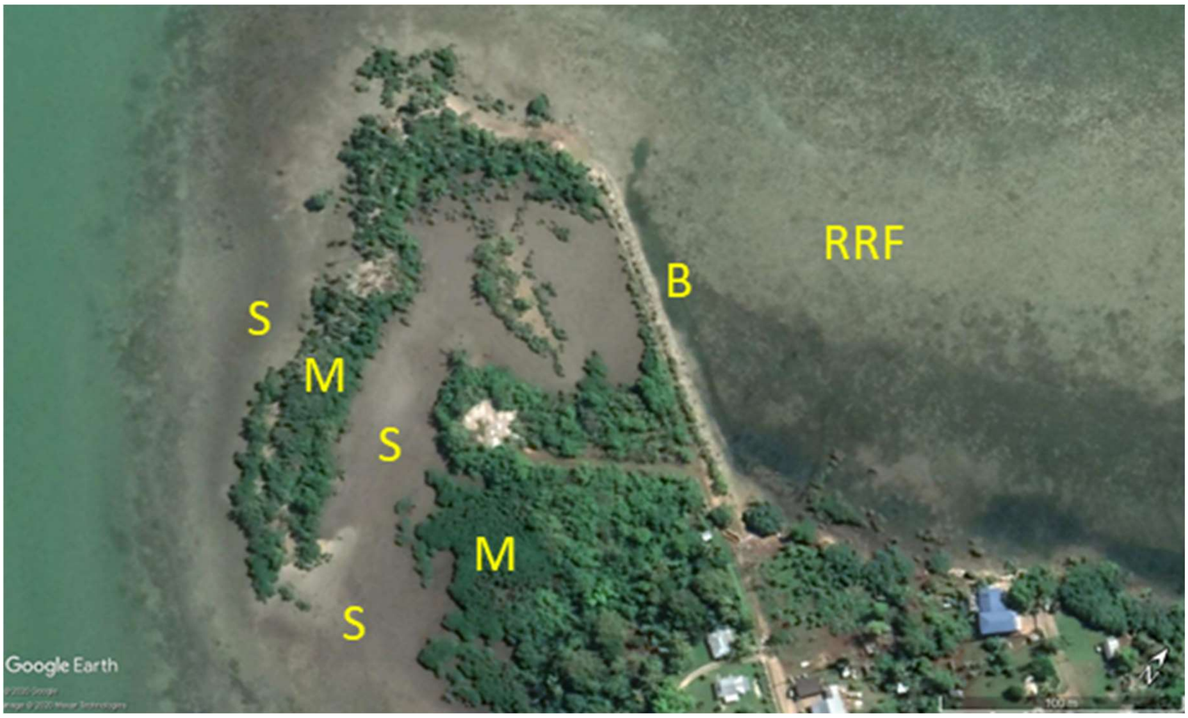


Figure 8.8 Image shows sediment accumulation and mangroves on the lee side of the breakwater, adjacent to Alaki village, Tongatapu, Kingdom of Tonga (Image sourced from Google Earth, 2020). Note: M = mangroves and B = breakwater.

8.7 The Fanga'uta Lagoon

The Fanga'uta Lagoon catchment area is home to over 55% of Tongatapu's population (over 40,000 people and 8,000 households) (GoT, 2011; cited in Talia'uli *et al., 2016*) (Figure 8.9). The importance of this area and its value to people is not always considered on a day to day basis, by national planners nor residents. Many of the communities within the lagoon area are dependent on the ecosystem services the lagoon provides for their livelihoods and wellbeing (Talia'uli *et al.,* 2016).

The lagoon is a life-support system for communities, providing a wide range of marine and intertidal values. The lagoon has provided goods such as mangrove wood (fuel), medicines, fish, seaweed, and shellfish for generations (Morrison and Kaly, 2010). In recent years, however, yields have dropped, and some species are no longer sustainably exploited. For example, mangroves have been exploited and areas reclaimed (Pelesikoti et al., 2001a; cited in Talia'uli *et al.,* 2016). Simply, the lagoon has been overfished, with yields declining, particularly mullet (IUCN, 1991).

Zann *et al.* (1984) described the Fanga'uta Lagoon as a shallow, almost enclosed estuarine embayment on the northern Tongatapu coastline. A complex system of reefs and channels separate the two main branches (Figure 8.9). The western most section, to the south of Nuku'alofa, is made up of a sinuous channel, the Folaha Sector, about 0.5 km wide, and a broad shallow basin, the Pe'a Sector, surrounding Kanate Island, roughly 2 km in diameter. The Mu'a Branch connects directly to the sea and can be subdivided into the Vaini Sector to the west (a shallow basin) and the deeper Mu'a Sector to the east. The water depth is considered shallow with Pe'a and Vaini only reaching 1-2 m depth while the Folaha and Mu'a Sectors have water depths of 3 m and 6 m, respectively. Naturally, the tidal circulation within the lagoon is constrained by the geometry of the reef flats and channels with a range of 0.13 m, compared to the open sea of 1.06 m. The lagoon has a residency time of between 29 and 140 days, depending on the sector, with tidal mixing only 12% efficient (MacIntosh, 2020). The lagoon tides lag some 3-4 hours behind the ocean tides with currents within the main channel of the lagoon reaching up to 1.5 m/s. The average daily freshwater input into the lagoon is 26 m^3/d, which is largely derived from the ground water lens, except for times of heavy rainfall (Zann *et al.,*1984).

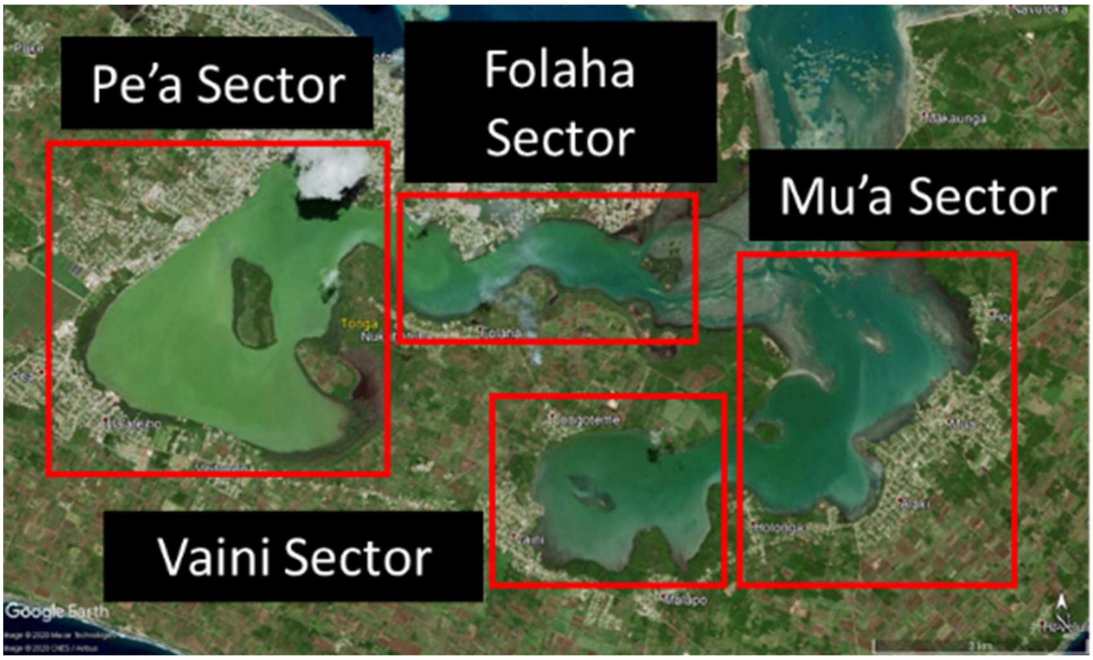


Figure 8.9. Sectors of the Fanga'uta Lagoon, Tongatapu, Kingdom of Tonga (Image sourced from Google Earth, 2020).

Zann *et al.* (1984) reports that the groundwater is rich in nutrients and essentially provides the entire nutrient supply for the lagoon. The long residency times allow the nutrients to become incorporated into living organisms, which contribute to basement sediments. Zann *et al.* (1984) argues that infill rate of the lagoon, due to the nutrient supply from the groundwater, is ~2 mm per century. The lagoon infill rates, however, are likely greater due to erosion and run-off during times of heavy rainfall. An uplift event of 20 – 40 cm, that occurred within the entrance area some 80 - 240+ years ago, created a damning effect. This uplift increased likely increased the rate of infill due to greater residency. The lagoon comprises several islands, including; Nukunuku Motu, Kanetea, Talakite, Mata'aho and Mo'ungatapu.

8.7.1 Ecology

The ecology of Fanga'uta lagoon has been investigated by Zann *et al.* (1984). This investigation included aspects of circulation and hydrology, water chemistry, plankton abundance and primary production; corals; fish and benthic communities; fringing vegetation; and fisheries. Since the initial ecological investigation by Zann *et al.* (1984), however, there has not been a comprehensive ecological investigation. Thus, the ecological state presented below may be outdated. The data and species, however, are still valid and can be used as a baseline from which to compare future studies.

Nutrient input, tidal exchange, water depth, and wind all control biological processes within the lagoon. In the Pe'a Sector, sea grass cover is low due to strong winds and shallow water, which creates turbidity and unfavourable growing conditions. In contrast, the Vaini Sector, which is also shallow but is more protected from the prevailing wind, has a far greater sea grass cover, which further stabilises sediments. Thus, the Vaini Sector is dominated by benthic processes, whereas the Pe'a Sector is dominated by plankton. In the Folaha and Mu'a Sectors, seagrass cover is restricted to the margins due the increased water depth. With respect to plankton, growth is more rapid in the Pe'a Sector compared to the Mu'a Sector. Zann *et al.* (1984) argues that this is likely due to the higher concentration of particulate matter, thus a higher nutrient availability.

Zann *et al.* (1984) reports that the principal sea grass species are *Halophila ovalis* and *Halodule pinifoliosa* Brock (1991; cited in IUCN, 1991) reported algae species including *Caulerpa serrulata, C. racemosa, Cladophora sp., Chlorodesmis spp., Halimeda discoidea and Gracilaria sp..*

44.5 km of the 58 km shoreline of the Fanga'uta Lagoon is covered by mangroves. The coverage is greatest in the Nuku'alofa branch (30 – 35 km), while the Mu'a branch has only ~14 km. This is due to the raised limestone on the southern coast of the Mu'a branch, which is less suitable for growth (Zann *et al.*, 1984).

In the Pe'a Sector, *Brugiera gymnorhyza* dominates along the water's edge with agallocha present as a secondary canopy. An abundant community of epiphytes and creepers is present. *Lumnitzaera lottoera* and *Xylocarpus granatum* are located shoreward, while *Hibiscus tiliaceous, Pandanus sp., Acrostichum* and *Ficus obliqua* scrubs lie further inland (Zann *et al.*, 1984).

At Alaki, *Rhizophora samoensis* dominates the shoreline community with *Acrostichum aureum* and *Xylocarpus tauer* ranging into the coastal or littoral forest behind (Zann *et al.*, 1984).

Lagoon-wide faunal species include; alpheid shrimp *Alpheus mackayi,* mantis shrimp *Squilla sp.* and *Lysiosquilla sp*. commercially important prawns *Metapenaeus ensis* and *Penaeus sensculcatus* and crabs *Scylla serrata*, *Thalamita prymna*, *Calappa hepatica* and several species of the Xanthidae family (Zann *et al.*, 1984).

The holothurian *Holothuria atra* is common in parts of the lagoon; *H. edulis, H. leucospilota*, *H. impatiens, Stichopus variegatus* and *S. chloronotus* are all found on the patch reefs near the lagoon entrance. Starfishes and *Astropecten sp*. are common on the intertidal flats and deeper soft-bottom areas of the Vaini, Mu'a and entrance channel regions. Blue starfish *Linckia laevigata* and sea urchins *Diadema setosum, Tripnuestes gratilla* and *Toxopneustes pileolus* are frequently seen on the entrance channel patch and fringing reefs. A small number of Capitellidae polychaete species are found in sediments. Sand-trapping chaetopterids are common on the patch and fringing reefs at the entrance. Several sponges are present on shallow fringing reefs, most commonly near the lagoon entrance.

Throughout the lagoon, there are a number of various bivalves. Small tellinids and *Gafrarium tumidum* are common in the sediments of all sectors; towards the lagoon entrance cockle *Anadara maculata*, strawberry cockle *Fragum unedo*, *Tellina tellin sp*., cockle *Periglypta sp*., *Lucina sp.* and scallop *Pecten sp*. are found, along with pinna *Atrina sp.* and pear oyster *Pinctada margaritifera*. Larger gastropods found near the entrance include ringed money cowry *Cypraea annulus*, money cowry *C. moneta*, milk spotted cowry *C. vitellus* and tiger cowry *C. tigris*, spider shell *Lambis lambis*, humpback *Strombus gibberulus,* and cone *Conus pidicarius*. Jellyfish *Cassiopea sp*. are very common in the Nuku'alofa branch of the lagoon, with local densities reaching 4 per sq. m. These species are harvested for consumption.

Zann *et al.* (1984) observed that diversity of coral declines from 10-15 genera at the lagoon entrance, to only one, Pontes, in the Mu'a Sector. Living coral coverage declines from 70% outside the lagoon entrance, to 15 - 30% at the entrance, to much less than 0.1% in the lagoon. This reflects the intolerance of coral species to hyposaline and turbid conditions. The proportion of dead coral increases further into the lagoon. A species list, including Scleractinia, Alcyonaria and Hydroidea taxa, is given in Zann *et al.* (1984).

Zann *et al.* (1984) observed a total of 96 fish species in the lagoon, with the greatest diversity occurring toward the seaward. Faunal species associated with fringing vegetation include mudskippers *Periophthalmus sp*., fiddler crab *Uca lactea*, nerites *Nerita plicata* and *N. undata*, whelks Clypeomorus and other invertebrates.

With respect to bird species, golden plover *Pluvialis dominica*, Australian grey duck *Anas superciliosa*, frigate bird *Fregata ariel*, abundant crested tern *Sterna bergii*, fairy tern *S. nareis*, reef heron *Egretta sacra*, in both white and grey morphs, bar-tailed godwit *Limosa lapponica*. Pacific swallow *Hirundo tahitica* and white-tailed swift *Apus pacificus*. Reptiles include banded sea-snake *Laticauda colubrina*, are all associated with the lagoon or seen off the outer lagoon patch reef (Zann *et al.*, 1984).

8.7.2 Mangroves

Tonga always has had cultural and historical affinities with mangrove ecosystems. Long before the introduction of modern technology and the industrial revolution, mangroves were part of Tongan life culturally and historically.

One of the mangroves species, which has almost reached extinction locally, is Lekileki – *Xylocarpus moluccensis* (Lamarck) (Ellison, 1998; cited in NBSAP, 2010). This mangrove species is culturally unique for Tongans as the bark is utilized for medicine as a treatment for internal bleeding among other injuries. This species, however, is also used for firewood, similar to *Lumnitzera littorea* (Hangale). The bark of another two mangrove species, Tongo Lei (*Rhizophora mangle*) and Tonga Ta'ane (*Bruguiera gymnorrhiza*) are mostly harvested by local people for making tapa cloth (Ngatu). Recently, a replacement product for these mangrove species' bark has proven very effective. Lekileki and Hanagle species, however, are at a very critical to endangered level (Ellison, 1998; cited in NBSAP, 2010). Table 8.1 shows the mangrove species present in Tonga, including rare species, such as *Lumnitzera Littoera* and *Xylocarpus Moluccensis* discussed above.

It should be noted, however, that none of these species are regarded as critical nor endangered on the IUCN Red List. In fact, all species are regarded as "Least Concern" on a global scale. This is of some concern, as clearly the IUCN Red List requires more information about these species at a local scale, rather than just global.

As part of the Ridge to Reef Project in 2014, a baseline survey was carried out which identified mangrove hotspots (damaged areas) and non-hotspot areas (undamaged). The results of the baseline survey are shown in Figure 8.10 which indicates that where the proposed lagoon bridge is to be constructed (purple line) the mangroves are somewhat healthy. Note this data is from 2015. Figure 8.11 and Figure 8.12 (NBSAP, 2014) provide an alternative interpretation. These maps indicate that the mangroves within this area have been removed and the lands reclaimed on the northern side where the proposed bridge is to be constructed. NBSAP (2014) suggest that the total mangrove loss around Fanga'uta Lagoon between 2004 and 2012 was 7.4%. This was based on an assessment using satellite imagery and LiDAR data.

Table 8.1 Shows the mangrove species present in Tonga (Prescott, Date Unknown).

Scientific name and nomenclature	Tongan name
Common	
Rhizophora mangle L. (Rhizophoraceae). (Pseudonym = *Rhizo*	Tongolei or Tongo
Rhizophora stylosa Griff. (Rhizophoraceae).	Tongolei or Tongo
Brugidera gymmorrhiza (L.) Lamk. (Rhizophoraceae)	Tongo ta'ane
Excoecaria agallocha L. (Euphorbiaceae)	Feta 'anu
Rare	
Luninitzera littorea (Jack) Voigt. (Combretaceac).	Hangale
Heritiera littoralis Dryand. (Sterculiaceae)	Mamea
Xylocarpus granatum Konig (Meliaccae).	Lekileki
Xylocarpus moluccensis (Lamarck) Roemer	Lekileki

Up until 2011, lands at the fringe of the Fanga'uta Lagoon were allocated to the public, which resulted in ~78 ha of land being reclaimed across the island, of which ~35% of these were within surrounding lagoon area. After the 2011, a decision was made to cancel the allocation and reclamation of lands to the public along the fringes or areas surrounding the lagoon. This decision has been noted to have had positive influences on biodiversity surrounding and within the Fanga'uta Lagoon, specifically the mangrove ecosystems (NBSAP, 2014). This is important, as the mangrove and seagrass provide vital nurseries for mullet and locally important subsistence fauna.

Figure 8.10 Shows areas identified as having mangroves around the lagoon. Pink stars show the locations of the monitoring sites, red areas are mangrove hotspots (damaged areas) and green areas are mangrove cover. Note the purple line delineates the approximate location of the proposed new bridge. The red line delineates the catchment boundary (modified from Talia'uli *et al.,* 2016).

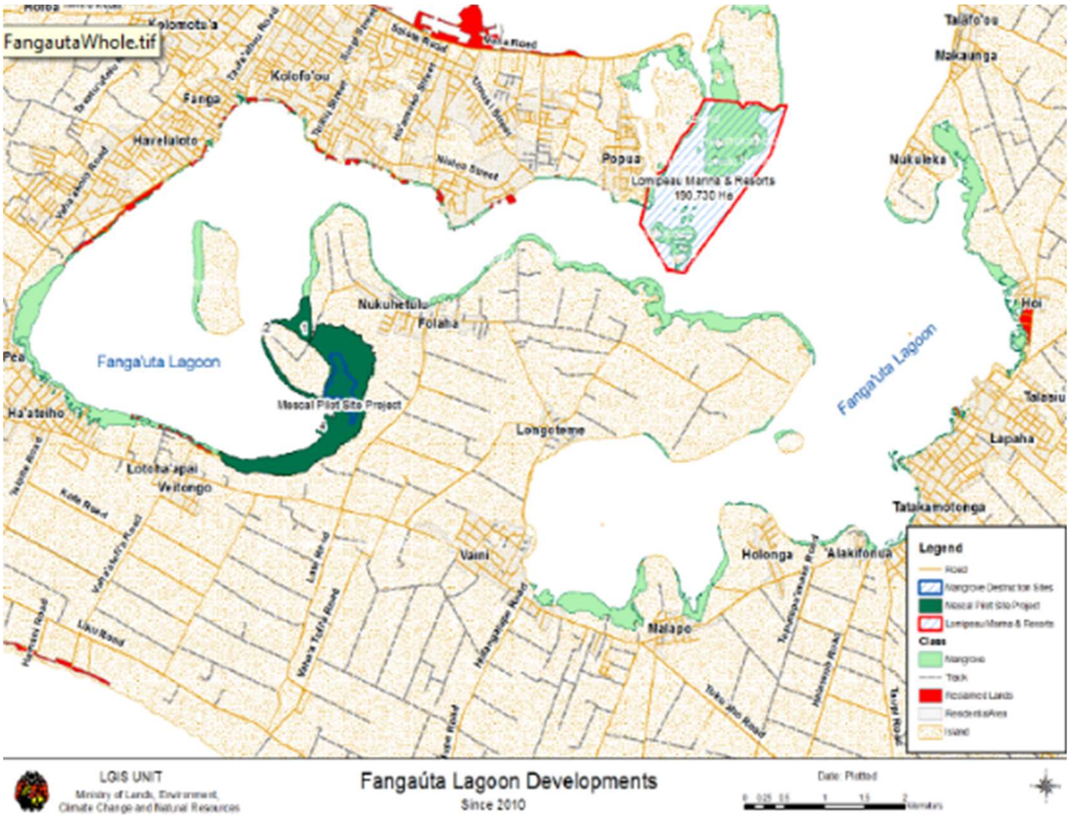


Figure 8.11 Shows developments at Fanga'uta Lagoon as well as remaining mangrove stands. Coastal areas including mangrove stands that have been reclaimed are represented by red, existing mangrove stands (light green), and the once proposed MSECAL Pilot Project area (dark green). Mangrove destruction sites are also noted blue, as per the image legend (NBSAP, 2014). Note the Lomipeau Marine and Resorts Project area (proposed developments have been stopped).

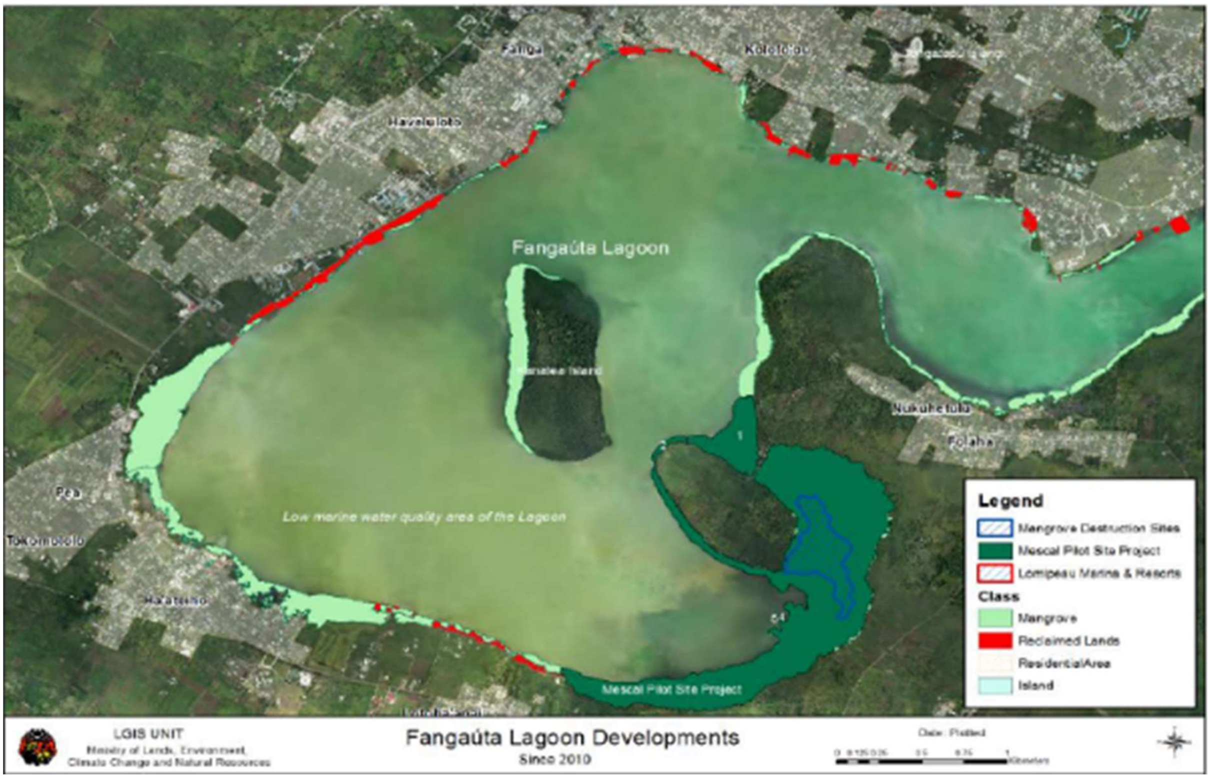


Figure 8.12 Locations of the Fanga'uta Lagoon developments and mangrove stands includingcoastal areas including mangrove stands that have been reclaimed (red), existing mangrove stands (light green), and the once proposed MSECAL Pilot Project area (dark green). Mangrove destruction sites are also noted blue, as per the image legend (NBSAP, 2014).

9 Annex G: Coastal Unit 5: Nukuleka to Niutoua

9.1 Bio-Physical Environment

The coastal unit between Nukuleka and Niutoua comprises the eastern and north-eastern shores of the Fanga'uta Lagoon entrance (Figure 9.1). This section of coastline is protected from the prevailing south-east winds in the west and becomes increasingly exposed to the east. Topographically, the land from Nukuleka to Manuka (west to east) is very low-lying, while Kolonga, Afa and Niutoua are relatively high, increasing from ~4 m to >8 m high (west to east). The wave climate along this coastal unit is considered small <1.0 m, as the predominant wave direction is from the south-east, however, the section of coastline is exposed to larger waves from the north produced by tropical cyclones. In general, the village of Nuitoua is most exposed and the villages within the entrance least exposed, although due to the increasing land height from west to east, vulnerability can be considered to trend in the opposite direction (east to west). The land from Nukuleka to Manuka in this coastal unit is 1-2 m above mean sea level, which makes them vulnerable to the effects of climate change, disaster risk, sea level rise, storm surge and coastal erosion issues (Figure 9.2) (McCue, 2014). This coastal unit has been subject to various shoreline reviews and climate change resilience trials, which have seen the construction of sedi-tunnel groynes, detached breakwaters, and revetments along the north-eastern villages, the details of which are discussed in the various sections below.

Figure 9.1. Location map of coastal unit 5 (green line) along eastern side of the Fanga'uta Lagoon entrance and the north-eastern coast of Tongatapu between Nukuleka to Niutoua (Image sourced from Google Earth, 2020).

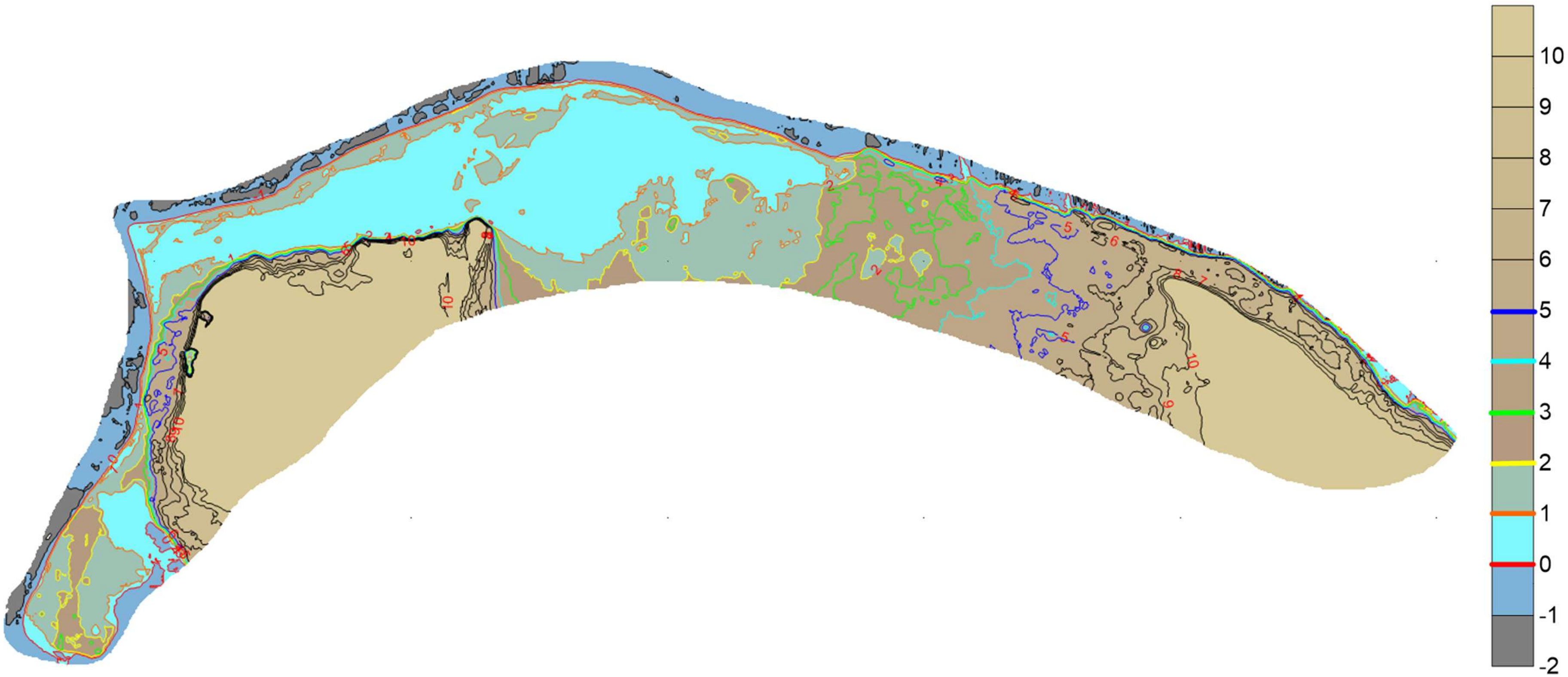


Figure 9.2. Contour plot of coastal unit 5. Note: Level refers to contours level (m) to MSL.

9.2 Nukuleka

The village of Nukuleka lies on the eastern side of the Fanga'uta Lagoon entrance. The nearshore is comprised of shallow sandy sediments with the shoreline of the village consisting of a thin beach. Along the southern tip, a small mangrove stand exists ~450 m long by 50 m wide with mangroves also located along the northern and eastern sides of the small inlet ~1.5 km long and 210 m at its widest (Figure 9.3). The existence of the sandy beach and the mangroves indicates the different energies within these environments with the sandy beach indicative of higher energies (due to the channel) and the mangroves indicative of low energies within the inlet.

Figure 9.3 Image shows nearshore and shoreline bio-physical features of Nukuleka village of coastal unit 5, Tongatapu, Kingdom of Tonga (Image sourced from Google Earth, 2020). Note: M = mangroves and B = beach.

9.3 Makaunga & Talafo'ou

Northward toward the Fanga'uta Lagoon entrance, the nearshore environment of Makaunga and Talafo'ou villages again comprises shallow sandy sediments within the channel with a thin beach system extending to the lagoon entrance (Figure 9.4). The beach system is thinnest southward and thickens toward the entrance. A groyne field has been constructed along this section of coastline to trap sediment and grow the beach system (Figure 9.5 and Figure 9.6). Mead (2019b) carried out a performance evaluation of the eastern Tongatapu climate change resilience trial constructions, which included an inspection of the mentioned groyne field. The findings were that:

- *All open and half open groyne were working well in the northern part of the site;*
- *The fully closed groynes resulted in the usual groyne effects with more sand on one side that the other;*
- *3x the length of the groyne for the gap between each one is the best spacing (similar to temperate groyne field design);*
- *The southern groynes, where there was/is less wave energy, are probably more suited to fully closed groynes, noting that sand transfer did not occur for these groynes;*
- *The groynes and associated beaches are being utilized by the local people, especially since there is now no scarp and rocks in these areas (they have been covered by the accumulated sand), and;*
- *Some of the end units have been dislodged, which is believed to be due to boats being moored to them (even though the units weigh 700 kg each).*

Mead (2019) made recommendations to:

- *Fill the gaps of 60 and 120 m spacing to have groynes at 30 m intervals along the beach;*
- *Use the half open configuration for all additional groynes;*
- *Rotate the half open units at the 6 southern groynes to be fully closed, and;*
- *Bring in an additional 3,000 m^3 of sand from the sand collection area to distribute in the areas of the additional groynes, and the southern areas of the site where none has yet been placed.*

Figure 9.4 Image shows nearshore and shoreline bio-physical features of Makaunga and Talafo'ou villages of coastal unit 5, Tongatapu, Kingdom of Tonga (Image sourced from Google Earth, 2020). Note: G = Groynes, B = beach

Figure 9.5 Image shows groynes along the coastline adjacent to Makaunga and Talafo'ou villages of coastal unit 5, Tongatapu, Kingdom of Tonga (Image sourced from Google Earth, 2020). Note: G = Groynes.

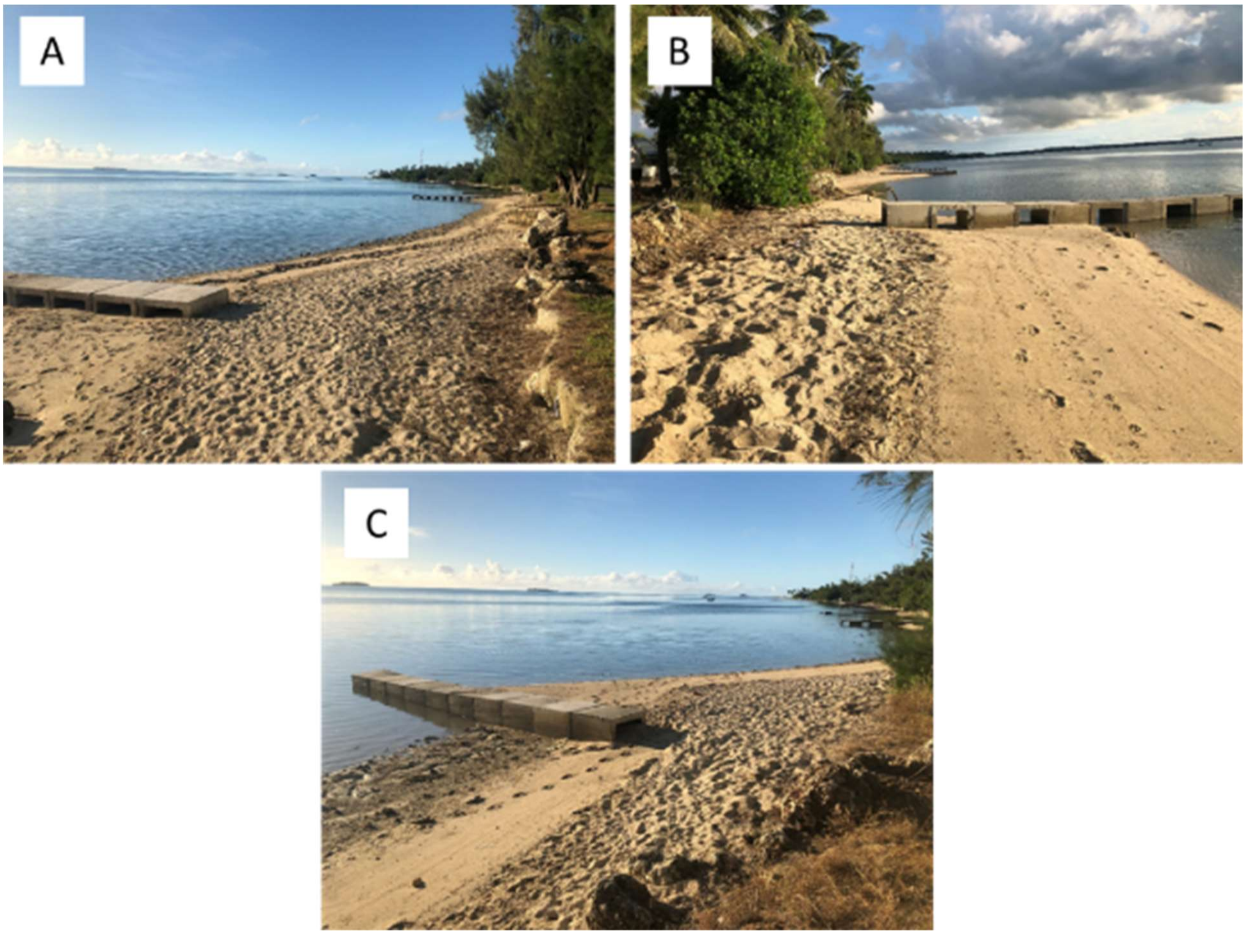


Figure 9.6 Image shows the three types of groynes that have been constructed on the beaches adjacent to Makaunga and Talafo'ou villages. A) fully open, B) half-open, and C) closed.

9.4 Navutoka & Manuka

East of the Fanga'uta Lagoon entrance are Navutoka and Manuka villages, the nearshore of which comprises intertidal reef flats with the shoreline characterised by a 2 km long breakwater/revetment (Figure 9.7, Figure 9.8, and Figure 9.9). At the eastern end of Manuka village is a series of detached breakwaters (Figure 9.10). This section of coastal unit 5 is far more exposed than the villages along the eastern side of the lagoon entrance but is still protected from the predominant south-east winds and swells. Cyclones from the north do, however, produce large waves which can penetrate this section of the coastline. Hence, the need for coastal protections structures which have been trialled.

Mead (2019b) carried out an inspection of the detached breakwaters and reported that they have been extremely effective at widening the beach to provide a buffer zone and stop over-topping on to the coastal road, which normally overtops 2-3 times year during storm events. Mead (2019b) reported that there is now 10-30 m of buffer zone and that a series of crescent shaped beaches have been produced (Figure 9.10). The trial proved that detached breakwaters with sand transfer are an effective solution to this part of the north-eastern coast. Interestingly, Mead (2019b) states that SOPAC were promoting this type of intervention some 26 years ago in 1994.

Figure 9.7 Image shows revetment/breakwater along the coastline adjacent to Navutoka and Manuka villages of coastal unit 5, Tongatapu, Kingdom of Tonga (Image sourced from Google Earth, 2020). Note: R = revetment/breakwater and RRF = rocky reef flats.

Figure 9.8 Left - Image shows original coastline (29/05/2018). Right – Image shows constructed revetment/breakwater along the coastline (2/05/2019) adjacent to Navutoka and Manuka villages of coastal unit 5, Tongatapu, Kingdom of Tonga (Image sourced from Google Earth, 2020).

Figure 9.9 Images show revetment/ breakwater along the coastline in front of Navutoka and Manuka villages of coastal unit 5, Tongatapu, Kingdom of Tonga (Images sourced from Mead, 2019b).

Figure 9.10 Left – Image shows no detached breakwater series (18/07/2014). Right and Bottom - Images show detached breakwater series along the same stretch of coastline at the eastern end of Manuka Village of coastal unit 5, Tongatapu, Kingdom of Tonga (Image sourced from Google Earth, 2020 and Mead, 2019b). Note: DBW = detached breakwater.

9.5 Manuka to Niutoua

Between Manuka and Kolonga, a low coastal road separates farmland that is lower than the road (Figure 9.1 and Figure 9.2). Overtopping onto the road occurs 3-4 times a year between Manuka to Kolonga, except where the detached breakwaters have been installed (Figure 9.10). From Kolonga to Niutoua, the coast is increasingly elevated where the natural 'tilt' of the island begins to increase height; together with the rocky nature of this area of coastline, this area is not susceptible to erosion or over-topping coastal hazards.

9.6 Historical Shoreline Changes

Ortho-aerial photographs dating back to 1968 were available from the Ministry of Natural Resources, and include 1968, 1981, 1990, 1991, 2010 and 2011. Mead *et al*. (2013) carried out a shoreline and foliage analysis of these aerial photographs. Scans of the aerial photographs were provided by the Ministry of Natural Resources, which were then geo-referenced and the beach position plotted for each. Foliage position was also considered because the resolution of various photographs and the seasonal variation of beach position (SOPAC, 1994) are both ambiguous and variable in some locations. It was concluded, however, that the beach positions provided were the most useful analysis.

The 1991 and 2010 aerials were not used as they were very similar to the 1990 and 2011 aerials, respectively, and the 1991 image resolution was all very low. The images are presented in Appendix A, while the beach and foliage positions are overlaid on a recent Google Earth satellite image for presentation below.

9.6.1 Nukuleka

Unfortunately, only the 2011 aerial photograph covers Nukuleka village, so no comparisons or historic shoreline positions could be made. This is unfortunate, since discussions with local people indicated that this area previously had a mangrove fringe and the beach was some 20-30 m further seaward. Indeed, it is likely that this whole western side of the study site had a mangrove fringe of this width, due to the low wave exposure and the existing mangrove fringe on the opposite side of the lagoon entrance (Figure 9.11 and Figure 9.12).

Figure 9.11 The entrance to the Fanga'uta lagoon. A mangrove strip is evident on the unpopulated western side, while it is absent on the eastern side where the villages are – this is more evident in Figure 9.12 below (Mead *et al*., 2013).

Figure 9.12 The western side of the lagoon entrance (top) has a 20-40 m wide mangrove fringe, which is absent on the eastern side (bottom), except on the southern tip of the peninsula below (Mead *et al.*, 2013).

Between Nukuleka and Makaunga/Talafo'ou villages, there is little evidence of change between 1968 and 2011 (Figure 9.13). In 1968, there is evidence of the beginnings of settlement of Makaunga and the road is already present also already present at this time in the same location as today.

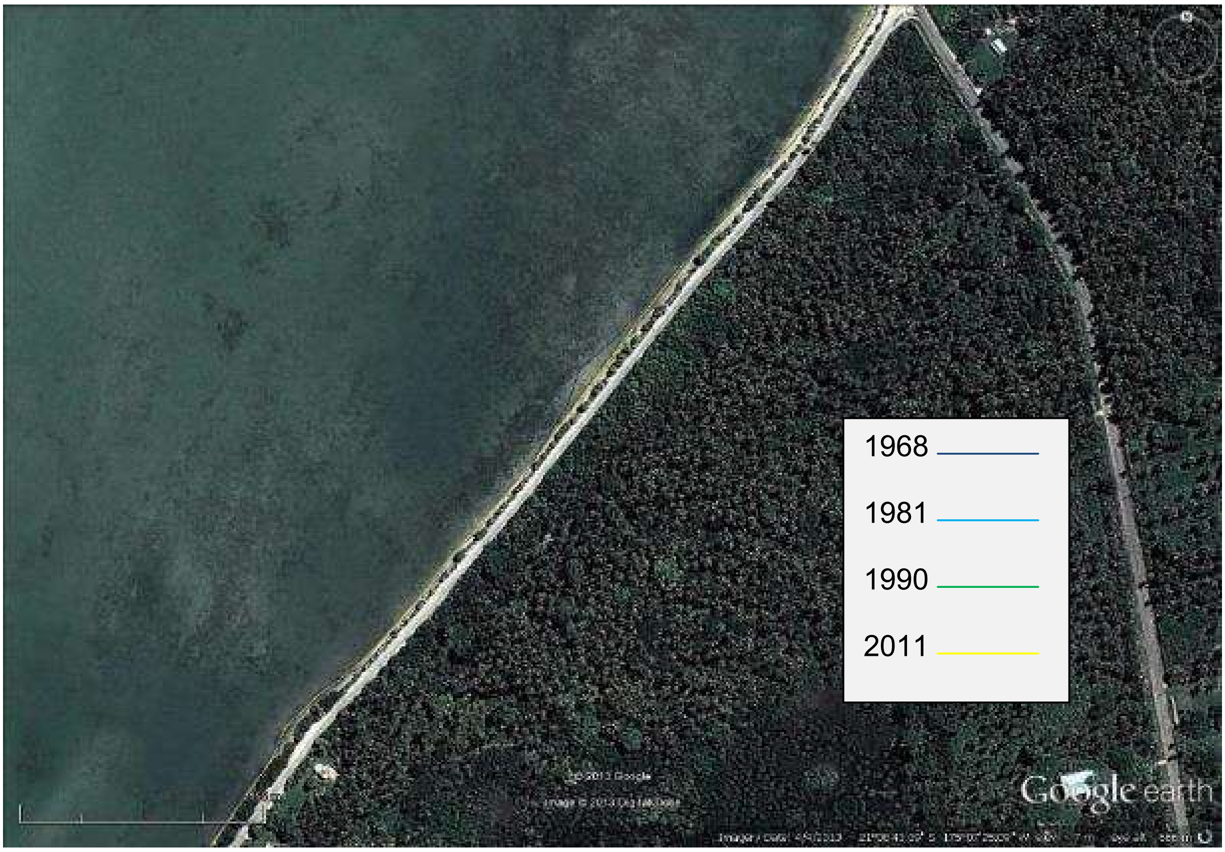


Figure 9.13 Beach position between 1968 and 2011 (1981 and 1990 aerials do not cover this area) below (Mead *et al*., 2013).

9.6.2 Makaunga/Talafo'ou

Along the waterfront of Makaunga/Talafo'ou villages, the beach has retreated between 10 and 25 m since 1968, with most of it occurring post 1981 and the greatest retreat in the northern parts of the village (Figure 9.14).

Between Makaunga/Talafo'ou and Navutoka villages, the beach has retreated some 30 m on the western side of the point and some 25 m on the eastern side (while the seawards position of Whitehouse Point has remained unchanged)(Figure 9.15). The extent of retreat diminishes ~5 m at the western end of Navutoka (Figure 9.15). The period of greatest retreat was between 1968 and 1980, and while there was some accumulation of sand on the western side of

Whitehouse Point (5-10 m) between 1980 and 1991; since 1991 the beach has retreated back to the 1980 position (Figure 9.15).

Figure 9.14 Beach position along Makaunga/Talafo'ou villages between 1968 and 2011 below (Mead *et al*., 2013).

Figure 9.15 Beach position between Makaunga/Talafo'ou and Navutoka villages between 1968 and 2011 below (Mead *et al.*, 2013).

9.6.3 Navutoka

The beach has retreated between 10 and 20 m along the waterfront of Navutoka since 1968, with the largest retreat in front of the row of dwellings on the seaward side of the road (Figure 9.16). There was mostly little change in beach position between 1980 and 1991 in this area, with the most active erosion periods being 1968-1980 and 1991-2011 (Figure 9.16).

9.6.4 Manuka

An area of up to 25 m retreat between 1968 and 2011 is evident on the western part of Manuka Village, while the position of the beach on protrusion in the coast on the eastern side of the village has changed little since 1968 (Figure 9.17). Similar to Navutoka, little change in beach position occurred between 1980 and 1991 in this area, with the most active erosion periods being 1968-1980 and 1991-2011 (Figure 9.17).

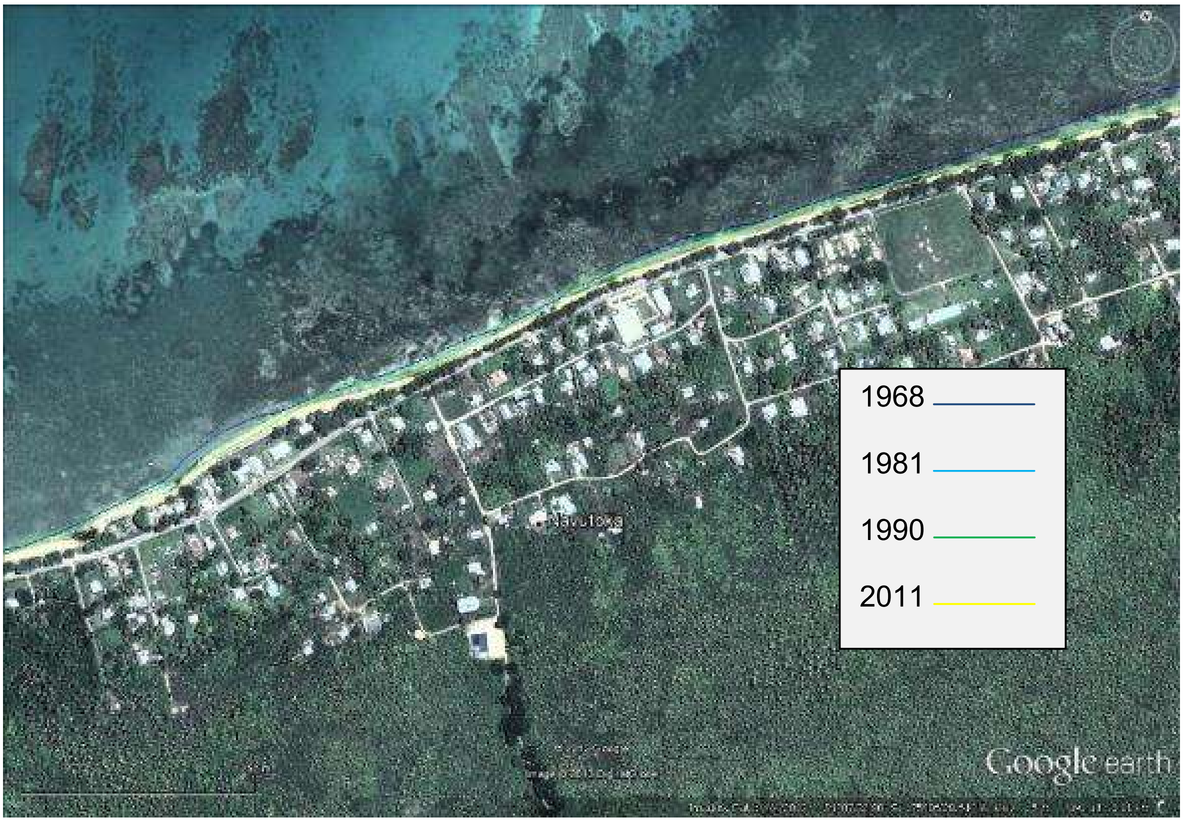


Figure 9.16 Beach position along Navutoka Village between 1968 and 2011 below (Mead *et al.*, 2013).

Figure 9.17 Beach Position along the beach at Manuka Village between 1968 and 2011 below (Mead *et al.*, 2013).

Between Manuka and Kolonga Villages, the beach has retreated between 5 and 15 m since 1968 (Figure 9.18 and Figure 9.19). To the west, the greatest retreat generally occurred between 1968 and 1980 (Figure 9.18), while to the east of this stretch significant retreat also occurred between 1991 and 2011 (Figure 9.19).

Figure 9.18 Beach position along the western part of the coast between Manuka and Kolonga between 1968 and 2011.

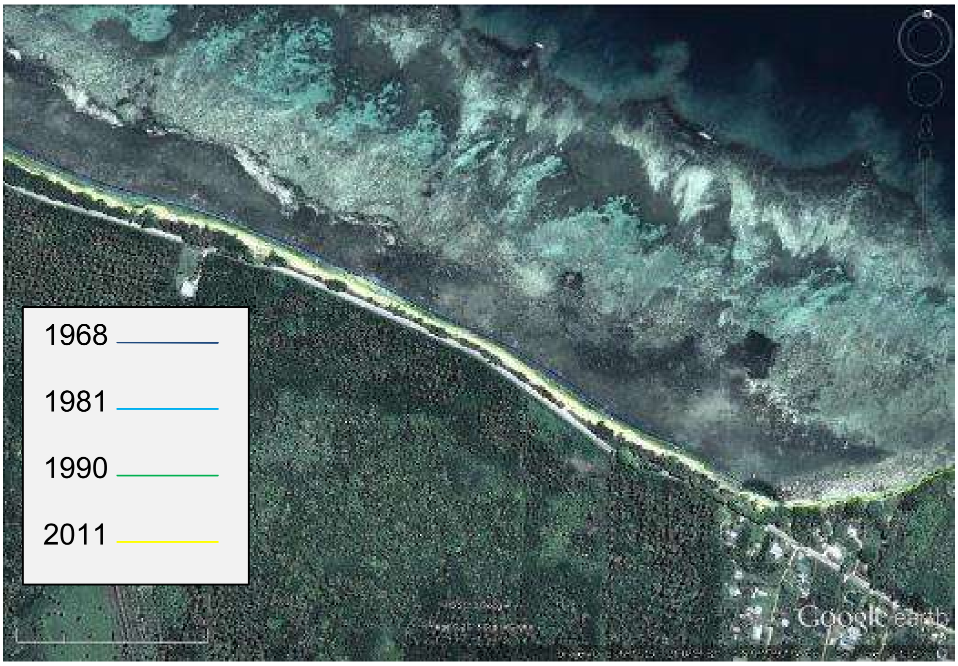


Figure 9.19. Beach position along the eastern part of the coast between Manuka and Kolonga between 1968 and 2011.

9.6.5 Kolongo to Nuitoua

As noted above, Kolonga, Afa and Niutoua are relatively high, increasing from ~4 m to >8 m high (west to east – Figure 9.2), and the coastal morphology is mostly uplifted limestone reef. As such, these villages are not vulnerable to coastal hazards in the next 10 to 30 year timeframe.

9.7 Historic Coastal Engineering Reports

Mead *et al.* (2013) carried out a review of recent coastal information pertaining to coastal geomorphology and coastal engineering climate change resilience feasibility and design for the coastal areas and villages of coastal unit 5. Three reports were reviewed:

a) CTL (2012a). MECC Consultancy to conduct Coastal Feasibility Studies, Coastal Design and Costing, of Six Communities on the Eastern side of Tongatapu: Report of Coastal Feasibility Studies March 2012.
b) CTL (2012b). MECC Consultancy to Conduct Coastal Feasibility Studies, Coastal Design and Costing, of Six Communities on the eastern side of Tongatapu: Report of Coastal Design and Costing March 2012.
c) MEC (2013). Environmental Impact Assessment of Four Proposed Coastal Engineering Interventions for Five Communities on Eastern side of Tongatapu, June 2012.

9.7.1 CTL (2012a;b)

The CTL (2012a) report proposes short (0-5 year) and longer (5-20 years) term pilot studies for research and further model testing. The main conclusion based on exiting information is that sand-mining, removal of mangroves and damage to the fringing reef ecology has reduced beach height and removed sediment from the system faster than it can be replenished. This has been exacerbated by the reduction in the health of the fringing reefs, likely due to over-fishing, which consequently reduces the system's ability to generate new sand (cited in Mead *et al.,* 2013).

CTL (2012a) also found no nearshore wave data, and present offshore wave data at a location close to the Tonga Ridge (which was provided to CTL by eCoast). As noted, south-easterly waves dominate due to the predominant south-easterly trade winds, and cyclones generate waves over 5 m and often approach the site straight on (i.e. from the north-west) (cited in Mead *et al.,* 2013).

The anecdotal evidence is that the road is over-topped some 3-4 times a year, with large waves being the cause on the northern side of Whitehouse Point and storm surge due to cyclones on the western and southern parts of the study site (cited in Mead *et al.,* 2013).

From discussions with local people, CTL (2012a) concluded that all villages suffer from flooding. In addition, while the road can form a barrier to prevent over-topping (and hence flooding) due to waves and storm surge, when over-topping does occur the road prevents the flood water from draining back into the sea and prolongs the problem. Apart from the culvert at Nukuleka, there is no provision for drainage across the road.

The CTL (2012a) report provides a good summary of the numbers of people and households at threat, the variety of beach erosion measures that are in place along the extent of the site, and provides a range of options to provide coastal protection to different areas of the study site that are broken into areas based on geomorphology and wave exposure. Through the application of a variety of tables, CTL (2012a) narrow down the selection of the most appropriate options. This is a valid and useful method to apply in the absence of any data and information on the coastal processes of the sites with which to develop designs (cited in Mead *et al.,* 2013).

Manyof the options analysis are valid and practical. However, some of the conclusions are not supported and lead to further consideration of the most appropriate options to trial:

- Area A3 (Kolonga to Manuka) is not conducive to mangrove plantation pilot studies alone, i.e. the proposed option cannot be considered a soft-option, it requires re-building of the failed seawall. This area is not a low exposure area, rather it is the most exposed site compared with the others under consideration. It is noted that the presence of mangroves in this area is due to the protection from waves and modification of soils caused by the sand/sediment retention provided by the failed seawall that is acting as a series of semi-emergent breakwaters.
- Sediment recycling from C1 (Whitehouse Point to Talafo’ou) to C2 (Talafo’ou to Makaunga) is not in support of the sediment transport regime as described by CTL (2012a). Sand is moving from north (C1) to south (C2), and so, moving sediment from C1 to C2 artificially is not re-cycling (or back-passing as it is often referred to), rather it is accelerating the sediment transport rate and will lead to increased erosion of the C1 area, which aerial photograph analysis indicates is not a sediment sink. Back-passing should occur from a site south of the at-risk areas. Even so, given the absence of settlement in this area, and the distance from the road, it could provide a source for sand in a system that has little capacity to generate new sand.

- Revetments will protect the road and the few properties seawards of the road from erosion, but do not provide a great deal of climate change resilience to the sites. The proposed revetment design with a sloping face that terminates at 'natural ground level' will likely lead to increased over-topping in comparison to the present vertical structures, and do not address increased resilience. They will, however, reduce erosion/damage to the land/road behind them.
- Detached semi-emergent breakwaters are considered an uncertainty and therefore dropped from the list of possible solutions. However, the failed seawall at Manuka provides very good evidence that this method can be applied along the northern part of the study site. Sand/sediment is retained, and coastal vegetation can be established. It is notable that there are large holes in front of these structures (Figure 9.20), which have likely impacted on the coast to the west. These features may be restricting alongshore sediment transport to the west and hence the reason for the scoured beach adjacent to them.

Figure 9.20. Deep holes in the nearshore zone are present at the western end of the failed seawall project, which may in part account for the adjacent scoured beach (Mead *et al*., 2013).

The accommodation approaches as described in CTL's (2012a) assessment tables, rather than in the generic strategies figure, as well as some protection strategies, are the most valid for the development of climate change resilience in this area. An approach that increases buffer zones (i.e. managed advance) and road/revetment height increases, are the best methods presented for increasing climate change resilience along this coast in the short to medium term. Indeed, CTL (2012a) recommend that the majority of the study site applies an accommodation approach for the longer term (20 year) measures, which we are in strong agreement with (cited in Mead *et al.,* 2013).

Finally, CTL (2012a) provide a concise summary of recommended options and recommendations for the implementation of engineering options. While most of the recommended options make sense although there are some areas where different options may be preferable (which will be addressed in the detailed design and costing phase of this project), the recommendations for the required technical datasets, mitigation against risk of project failure and raising awareness amongst the stakeholders, are all important considerations (cited in Mead *et al.,* 2013).

CTL's (2012b) report describes design and costs for the 4 recommended trials that were considered – detailed design and costing of 2 pilot options. The report provides some very useful information, while also highlighting the concerns expressed above, some of which relate to the specific approach for short-term (0-5 years) solutions, and not implementation of longer-term accommodation approaches (i.e. CTL's ToR). The ToR for the study was to consider trial engineering solutions that will lead to learning and the development of best-practise engineered coastal protection systems for vulnerable coastal areas in Tonga and elsewhere in the Pacific Islands Region, and so a longer-term view is required (cited in Mead *et al.,* 2013).

With respect to the recharged groyne trials for unit C2, in the first instance the sediment is not being recycled, it is being moved down the coast at an accelerated rate and may lead to consequent accelerated erosion of unit C1 – although it is noted that MEC (2012) consider sediment transport along this coast is in the opposite direction (up the coast, south to north). Given that there is no settlement in this area and it is relatively distant from the road, however, this site may still provide a source for sand recharge to help protect developed areas since there is little capacity for the generation of new sediment. Given the north to south sediment transport along this stretch of coast, back-passing/recycling should occur from the south to the north. While outside the scope of this current project, the sediment deposits to the east of the mangrove fringe on the southern tip of the peninsula (Figure 9.12) could be a more sustainable sand source with lower environmental impacts due to removal (cited in Mead *et al.,* 2013).

The downcoast impacts on unit C3 would be significant based on 3 very long groynes if designed following conventional methods (i.e. groynes are normally 2-3^{rds} the length of the spacing between them (Basco and Pope, 2004). Given the length of coast and the consequent spacing for 3 compartments is ~900 m, then 100 m long groynes (at a ratio of 1:3) will be required, will have little if any bypassing function to the south and will accelerate erosion in this area. On this coast, the application of groynes should be subtle, as is demonstrated in Plate 2.1 of the CTL (2012b) report to reduce/prevent downcoast impacts, and the 4 groynes that CTL (2012b) have designed fit this category (they are only 10 m long and semi-permeable). This designed solution, however, is not sustainable or sensible; the groynes are likely too few by an order of magnitude. It is noted that the 1:3 design ratio was not developed for coral sand/reef situation, and that given the relative shelter from wave activity, larger spacings may be applicable and could be tested either in this project or by the ADB (cited in Mead *et al.,* 2013).

CTL (2012b) proposes surge management for Nukuleka by increasing the length and height of the seawall adjacent to the road. Although this approach doesn't protect the beach in front of the seawall, CTL (2012b) only considered short-term applications, and, as CTL (2012a) have indicated, longer-term widening of the buffer zone is required in most areas. In addition, 3 culverts are proposed to drain the properties behind the road if over-topping still occurs in extreme events (cited in Mead *et al.,* 2013).

While gabions are likely a lower cost option than rock, and are applicable for a short-term (0-5 years) solution, as noted by ADB (2013) a rock design will have a longer design life. In addition, ADB (2013) consider moving the seawall 5 m further seaward and establishing a planter strip of mangrove – this will both reduce the impacts of over-topping and provide settling ponds to reduce sediment run-off into the sea during heavy rain events (cited in Mead *et al.,* 2013).

In the section addressing wave impacts along the northern coast (Navutoka to Manuka), CTL (2012b) suggest a hard and a soft engineering approach, although both are hard engineering approaches with one incorporating sand recharge and mangrove planting behind a reinstated seawall (a hybrid approach). Mead *et al*., (2013) interpretation of these areas is to do nothing to the area of failed seawall that has led to the development of tombolos and establishment of mangroves at this stage. Rather, it would be preferable to incorporate this area into the monitoring programme and use the current situation to first learn more about how this has occurred on the coast in order to apply elsewhere. This fortunate accident has provided a buffer zone that also incorporates habitat for marine species and is suitable for mangroves. It is noted that re-building the seawall along the full length of the site may lead to the reduction of the suitability of this area for mangrove survival if good flushing is not incorporated (cited in Mead *et al.,* 2013).

To the west, CTL (2012b) propose to increase the width and height of seawalls. Mead *et al., (*2013) were of the opinion that a similar establishment of further buffer zones should be trialled, rather than the construction of a larger seawall with a splash wall. The failed seawall to the east has indicated that semi-emergent detached breakwaters are effective in this area, and by moving the protection further seawards of the road, over-topping by waves will occur seawards of the road and have less potential to effect properties. Furthermore, seawalls will exacerbate beach erosion, while a beach can be created in the lee of detached structures (cited in Mead *et al.,* 2013).

Mead *et al.,* (2013) stated that the MEC (2012) document was very useful for considering additional costs for mitigation of impacts during construction and will be used to support the selection of 2 options and the development of costings for construction. It concludes that all 4 of the CTL options would pose minimum environmental impact to the coastline if the suggested mitigation measures are strictly adhered to. This is especially useful, since the availability of a sand source is likely to be imperative for the application of some options (cited in Mead *et al.,* 2013).

Similar concerns as raised by the ADB (2013) with respect to the longevity of gabion baskets are also raised by MEC (2013). This most likely stems from the short versus long-term approach (cited in Mead *et al.,* 2013).

9.7.2 MEC (2013)

MEC (2013) highlight the uncertainty with respect to coastal processes along the study sites, where their interpretation of sediment transport regime along the Makaunga, Talafo'ou and Nukuleka coastline is opposite to that defined by CTL (2012a). The morphology of Whitehouse Point indicates that it could be the convergent zone of two opposing sediment transport pathways, while the build-up on the northern side of Makaunga groyne indicates a southern transport regime. Mead *et al.,* (2013) stated that it is feasible that the southern half is southwards and the northern half is northwards, with overlapping/reversing regimes in the middle section (waves versus tidal currents) leading to the protruding coastline at Makaunga. Similarly, it could be the remnant coastal terrace from paleo sea level stands (as indicated in Figure 24 of MEC (2012)). Comprehensive monitoring and subsequent monitoring should lead to a better understanding along this coast (cited in Mead *et al.,* 2013).

The beach replenishment of Makaunga and Talafo'ou villages is also considered from the tourism aspects by MEC (2012), which was also highlighted in discussions with Ministry of Natural Resources. There is a reasonable amount of recent work that indicates sandy beaches have a great deal more value for tourism income than scoured beaches in front of seawalls. Thus, managed advance should be kept in mind for all sites (cited in Mead *et al.,* 2013).

10 Annex H: Socio-Economic Characteristics and Community Priority Issues

10.1 Introduction

PLANIT Pacific Pte Ltd was engaged by eCoast for this project to carry out the social characteristic study by way of a desktop review of the socio-economic characteristics of communities living within 2 km of the coastline, due to the travel restriction caused by the CoVid-19 global pandemic. The socio-economic characteristics of the northern coast covers population dynamics, occupations and socio-cultural considerations. Also included, the results of household community surveys which were undertaken by government partners to assess community priority issues and their needs based on past community consultations, as well as recent consultations that have recently been conducted within the communities living along the northern coastline.

The desktop review of the socio-economic characteristic is based on Tonga's 2016 National Census, while the assessment on collating community priority issues and their needs was collected through recent community consultation meetings and household survey questionnaires. Much of the analysis is based on the Tonga 2016 Census of Population and Housing Volume 2: Analytical Report. One of the challenges with using this census data is selecting the appropriate spatial analysis over the boundary; that is using Tongatapu census data to base it over the communities located along the north coast. In rapidly changing communities, short-term intercensal variations are sometimes not captured noting that it is now year 2020 with major changes from the 2016 census. Despite these limitations, the census data provide appropriate information for Tongatapu and Tonga holistically in some sections where information is not specific to Tongatapu.

In addition to the census data, this report utilises material from other sources including Tonga Labour Force Survey 2018: Analytical Report providing labour market statistics and Tonga Disability Survey Report 2018, assessing and documenting persons with disability.

This report also relied on gathering more information from the community consultation, household survey questionnaires and incorporating the information/data of the biophysical nature of the of north coast for the development of an overall conceptual design and costing for coastal protection measures of the coastline from Niutoua to Ha'atafu

10.1.1 Assessment Objectives

The objective of the Socio-Economic Characteristics Assessment is to gather the community's perception and concerns and identify some community-based protection measures for north coast communities. The Socio-Economic Characteristics Assessment will be used to guide the conceptual design and possible implementation ensuring that the impacts identified is considered.

10.1.2 Purpose of the Assessment

Specifically, the report comprises of:

- Reviews of the population size and growth in Tongatapu;
- Provides an outline of the population dynamics with determining factors such birth, death, immigration and emigration ;
- Reviews the socio-cultural factors such as ethnicity, race and religion;
- Examines the socio-characteristics of the population in terms of education;
- Summarises the major characteristics of the labour force, including employment and unemployment;
- Reviews of disability among the people of Tonga;
- Assesses community priority issues and needs based on the community consultation meetings conducted, and;
- Provides social impacts and recommendations and mitigation measures to reduce any impacts that the proposed project may have on the surrounding environment and the communities living along the coastal zones.

10.2 Social Environment

10.2.1 Demographics

The Kingdom of Tonga lies between 15° and 23°S and 173° and 177°W in the South Pacific. Tonga consists of five administrative island divisions: Tongatapu (260km^2), Eua (87km^2) in the South, Ha'apai (109km^2), Vava'u (121km^2) and Ongo Niua (72km^2) which spread over an area of 360,000km^2 with total land area of 749km^2. Nuku'alofa, the capital is located on the island of Tongatapu and is the most populous division when compared to the rest of the island divisions (Figure 10.1).

The study area is located on the north coast of Tongatapu with areas mostly flat and low-lying as the island is built of coral limestone. At the south coast of Tongatapu, the height reaches an average of 35 meters and gradually decreases towards the north.

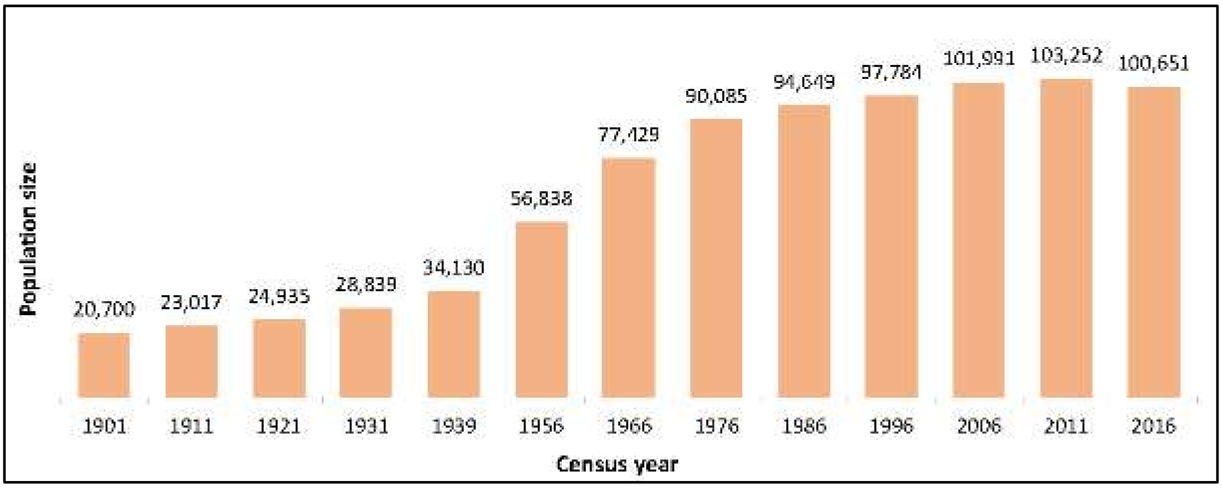
Figure 10.1. Map of Tongatapu including the 4 divisions.

10.2.2 Population

According to the 2016 Census, the total population of Tonga (5 divisions) was 100,651 people with 50,255 males and 50,396 females while the total population in 2011 was recorded as 103,252. Over the course of 5 years from 2011 to 2016, there was a decrease in population by 2,601.

From the first census that took place in 1901; up until 2011 the population of Tonga showed a continuous increase with the strongest growth between 1939 and 1966. However, for the first time during the census year, there was a decline in population between 2011 to 2016 by 2601 (Figure 10.2).

The report had noted that the population growth varied extensively by division and district and while the overall Tonga population declined between 2011 and 2016, Tongatapu population also decreases at a rate of -0.2%.



**Information Provided by Tonga 2016 Census of Population and Housing Volume 2 pg 15*

Figure 10.2. Total population size, Tonga 1901-2016

Table 10.1. Total population size and growth for Tongatapu, 2006, 2011 and 2016.

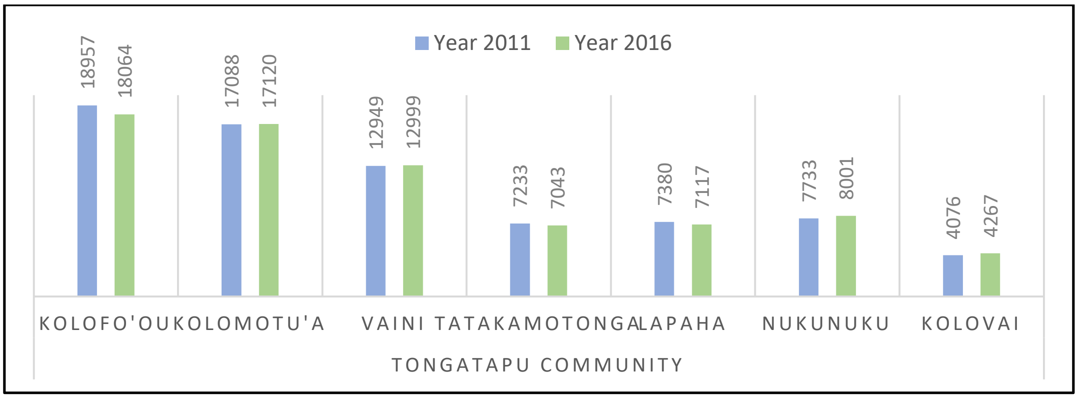
Division/District	Census total population			Population change					
				(in numbers)		(in %)		(Annual growth rate)	
	2006	2011	2016	2006-11	2011-16	2006-11	2011-16	2006-11	2011-16
TONGA	**101,991**	**103,252**	**100,651**	**1,261**	**-2,601**	**1.2**	**-2.5**	**0.2**	**-0.5**
Tongatapu	**72,045**	**75,416**	**74,611**	3,371	-805	4.7	-1.1	0.9	-0.2
Kolofo'ou	18,463	18,957	18,064	494	-893	2.7	-4.8	0.5	-1.0
Kolomotu'a	15,848	17,088	17,120	1,240	32	7.8	0.2	1.5	0.0
Vaini	12,594	12,949	12,999	355	50	2.8	0.4	0.6	0.1
Tatakamotonga	6,969	7,233	7,043	264	-190	3.8	-2.7	0.7	-0.5
Lapaha	7,255	7,380	7,117	125	-263	1.7	-3.6	0.3	-0.7
Nukunuku	6,820	7,733	8,001	913	268	13.4	3.9	2.5	0.7
Kolovai	4,096	4,076	4,267	-20	191	-0.5	4.7	-0.1	0.9

**Information Provided by Tonga 2016 Census of Population and Housing Volume 2 pg 17*

Within the Division of Tongatapu, it consisted of a number of different districts and looking at Table 10.1 above and Figure 10.3 below, 2 districts i.e. Kolofo'ou and Kolomatu'a out of the 7 districts has high number of populations since both are located in the urban area which form the township of Nukualofa.

As explained already that Kolofo'ou has the highest number of populations in Tongatapu and between 2011 and 2016, the growth rate for Kolofo'ou slightly decreases while Kolomotu'a district continues to increase gradually from 17088 to 17120.

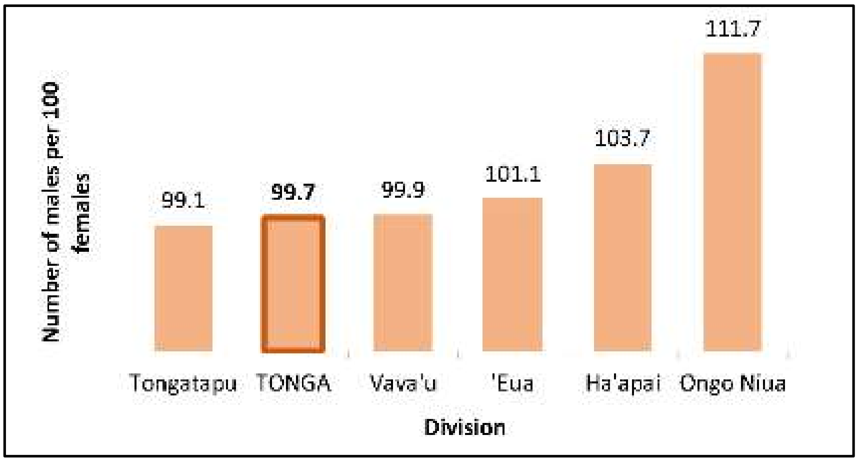
In the rural areas of Tongatapu, the district of Vaini has a high number of population when compared to the other 4 rural districts. The growth rate for Vaini increased from 12949 in 2011 to 12999 in 2016. For Kolovai district despite having the lowest population of around 4000 plus, the district continued to increase with a growth rate from 4076 to 4267. The 2 districts that gradually decreases in population were Tatakamotonga and Lapaha.



**Information Provided by Tonga 2016 Census of Population and Housing Volume 2 pg 17*

Figure 10.3. Census total population for 2011 & 2016

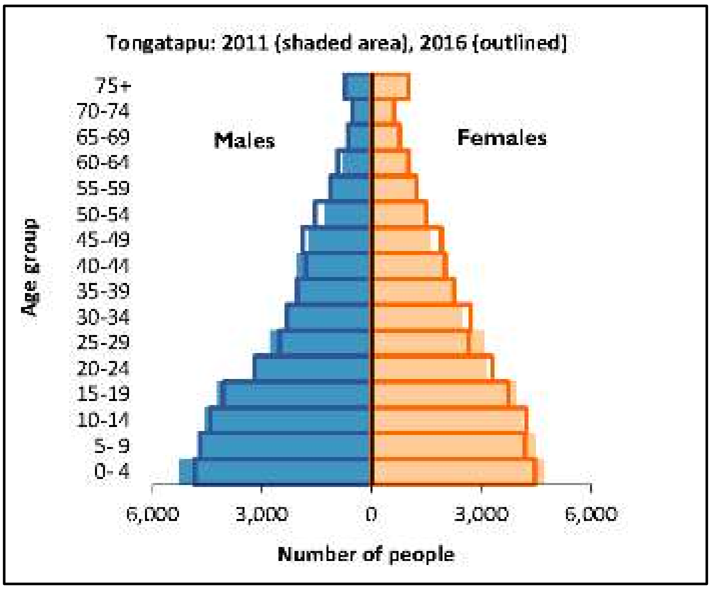
10.2.3 Population Structure



**Information Provided by Tonga 2016 Census of Population and Housing Volume 2 pg 19*

Figure 10.4. Tonga sex ratio by division for year 2016

There was a slight decline in the number of males per 100 females from 101 to 99 in Tongatapu and according to the 2016 Census, the decrease was due to higher number of out-migration from the outer islands, high number of overseas migration and slow improvements in life expectancy for males that females.



**Information Provided by Tonga 2016 Census of Population and Housing Volume 2 pg 20*

Figure 10.5. Tongatapu: 2011 (shaded) & 2016 (outlined)

The population pyramid of Tongatapu in Figure 10.5 above indicates that there is a large percentage of people in the younger age group. This is a sign of high fertility rates with high number of births per women.

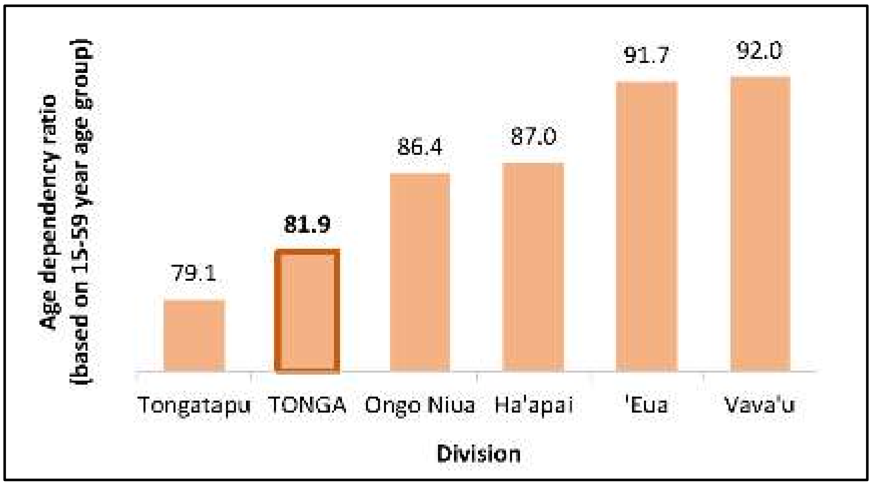
Table 10.2. Population Distribution by broad age group, dependency ratio, median age and sex ratio, Tonga 2011 & 2016

Division	Year	Proportion of population by broad age group (in %)				Age dependency ratio (15–59)	Median age (years)	Sex ratio (males per 100 females)
		0–14	15–24	25–59	60+			
TONGA	2011	37	19	36	8	84	21.3	101
	2016	36	19	36	9	82	21.9	100
Tongatapu	2011	37	19	36	8	81	21.4	101
	2016	36	19	37	8	79	22.0	99

**Information Provided by Tonga 2016 Census of Population and Housing Volume 2 pg 21*

In 2016, the population of Tongatapu has a young age structure younger than 15 years of age at 36%, a decline from 37% in 2011 while only 8% of age above 60 years remains between 2011 and 2016. Population age structures changed gradually over time and with little difference in median ages between 2011 and 2016. However, as a result of out-migration of young adults, the median ages were higher in the rural divisions of the outer islands in 2011 as compared to 2016.

The population's age structure is described using the age dependency ratio comparing the economically dependent component of a country's population with its productive component mainly expressed as ratio of young people from the age of 0-14 years and old age from 60 years above to 99 people working age from 15-59 years (Figure 10.6). The high dependency ratio indicates that more young and older people require to be supported by the working age population while a low dependency ratio will show that the working population are young and able to support the older population.



**Information Provided by Tonga 2016 Census of Population and Housing Volume 2 pg 22*

Figure 10.6. Age dependency ratio for Tongatapu, Tonga 2016

From the graph above, the most favourable dependency ratio was noted for Tongatapu with only 79 dependent people per 100 people of working age however, between year 2011 and 2016 censuses, there was a decline of dependency ratio in all divisions.

10.2.4 Fertility and Mortality

The 2016 census only present birth and fertility as well as mortality for the entire population of Tonga and not specific to each division nor district.

10.2.4.1 Fertility

For the entire population of Tonga, the total number of children born alive to the 32,840 women at the age of 15 years and older was 79,238 with an average number of 2.4 children per women born alive (average parity) by all women.

Comparing the average number of children reported by the women of Tonga that were ever born over the last three censuses, showed a decline in fertility that occurred in the country over the last two decades and this is evident in every age group.

Table 10.3. Number of births reported during the one-year period before the census (December 2015 to November 2016) by age group of mother, Tonga 2016

Age group	Number of women	Number of births			Age-specific fertility rate
		Male	Female	Total	
15–19	5,053	87	50	137	0.0271
20–24	4,128	266	254	520	0.1260
25–29	3,467	259	264	523	0.1509
30–34	3,527	267	240	507	0.1437
35–39	2,941	128	148	276	0.0938
40–44	2,716	47	43	90	0.0331
45–49	2,581	7	8	15	0.0058
Total	**24,413**	**1,061**	**1,007**	**2,068**	**TFR = 2.9**

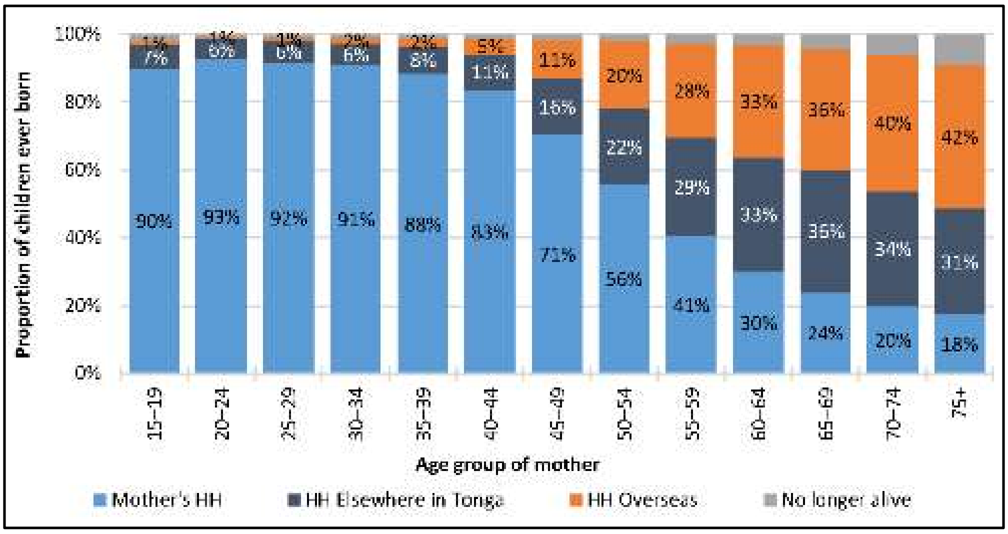
TFR = Total Fertility Rate. This is the average number of children a woman living in Tonga can expect to have during her childbearing years, if she experiences the current age specific rates of fertility.

**Information Provided by Tonga 2016 Census of Population and Housing Volume 2 pg 24*

According to the 2016 census, a question was raised regarding the date of birth of the last child born and was noted that 2,068 children were born during a one-year period before the census and that is between December 2015 and November 2016. This count was compared to the 2,279 children younger than one year old that was enumerated during the 2016 census and was found that there was some under-reporting of births.

Based on the reported births and looking at Table 10.3 above, there is still a continuation of fertility decline that was observed over the recent decades due to undercounting in the census birth data. The mismatch in birth counts suggest that a number of women did not report the birth of their child during the year before census whereby they did not accurately report the exact date of birth of their children or they were possibly out of the country during the census day. Multiple births such as twins or triplets were also not captured by the last child born question in the census.

Also included as part of the census question was whether the children still live with their mother in her household or elsewhere and whether they reside in Tonga or overseas. It was gathered that there was a decrease in children living with their mother as they age and when they grow older, they leave their parent home to form their own household. Not only that, but they also leave to form their own household, as about more that 40% of children to mothers aged above 70 years, now live overseas.



**Information Provided by Tonga 2016 Census of Population and Housing Volume 2 pg 26*

Figure 10.7. Proportion of children ever born and whether mother's children live in the same household as mother, Tonga 2016

10.2.4.2 Mortality

In 2016, of all the children that were ever born to women aged 15 years and older stands at 79,238. Of the total that were born, 97% of children (77,081) were still alive with more surviving females than males while 2,157 of children had passed on. The number of females were slightly higher than that of males.

With regards to death in a household, 12 months prior to the 2016 census, the total death reported was 382 which was significantly lower than 692 deaths in 2016 calendar year and in 2015 calendar year with 675 deaths reported.

In comparison of the registered deaths where the date of death was in the period of 2013 to 2016, showed some under reporting of infant and child deaths in Tonga's Civil Registration data and under reporting of deaths in the older age groups in the census data.

10.2.5 Migration

One year prior to the 2016 census, it recorded around 93,620 people (96% of resident population one year and older) who had not moved division of residence. Only 2,651 people had mentioned living elsewhere in Tonga while 1,752 lived in overseas.

The 2016 census then further looked into divisions and noted that Tongatapu had more net gain of people migrating from the other divisions like Vava'u, Ha'apai, Eua and from Ongo

Niua during a one year period before census. Based on the 2011 census, Tongatapu also gained more population through migration from the outer island divisions. These divisions slowly loose its population through rural to urban drift.

In terms of lifetime migration (i.e., number of people by current place of residence compared to place of birth), the direction of internal migration flows was mainly towards Tongatapu. Tongatapu also had the highest number of residents that were born overseas so those choosing to return to Tonga from offshore, mainly chose to reside in Tongatapu, the urban centre.

10.2.6 Religion

Methodism is the dominant religion in Tonga with 35% of the population or 35,082 members affiliated with the Free Wesleyan Church and according to the 2016 census, there was a decrease from 40,371 members in 1986 till 2016.

10.2.7 Ethnicity

According to the information collected and based on the number of people by ethnic origin, Tonga has a very homogenous population of 97% who are of Tongan origin and another 1% of part-Tongan origin while other ethnic origin population other than Tongan or Part-Tongan is less than 2%.

Table 10.4. Total population by ethnic origin, Tonga 2016

	Total	Urban	Rural
Tongan	97,662	21,873	75,789
Part - Tongan	793	244	549
European	251	74	177
Fijian	306	191	115
Fijian Indian	117	80	37
Chinese	731	369	362
Other Pacific Islander	201	67	134
Other Asian	192	133	59
Not elsewhere classified	70	35	35
Other	302	129	173
Total	**100,625**	**23,195**	**77,430**

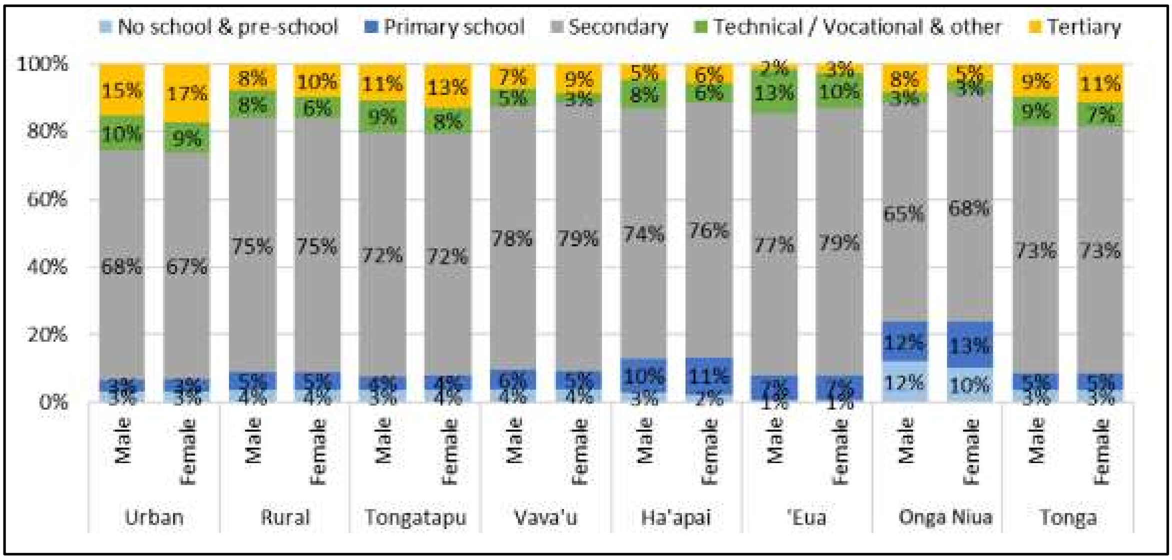
**Information Provided by Tonga 2016 Census of Population and Housing Volume 2 pg 38*

The 2016 census had noted that other ethnic origins is slightly higher in Tonga's urban area where 5% are not Tongan or Part-Tongan, 2% are of Chinese origin, 0.3% are of European origin and a further 1% are of Asian descendant.

10.2.8 Education

In Tonga, it is compulsory for children to attend school from the age of 6 to 14. The formal education system is divided into three stages: Primary, Secondary and post-Secondary. The primary school begins from Class 1 to Class 6, then secondary education covers Year 7 to 13 during which students are generally at the age of 13 to 17. Students in secondary have various options of where to study and these range from government funded, mission or non-government private schools.

The 2016 population census identified that a total of 31,338 people from the age of 6 years to 16 were enrolled in school with more females (16,331) than males (16,007). At the age of 16 and above, the enrolment rates slowly decrease and a further small population (3%) from the age of 6 years old were recorded to have never been to school. At the primary school level, more boy was recorded to have attended schools while there was a gender equivalence at the secondary level.



**Information Provided by Tonga 2016 Census of Population and Housing Volume 2 pg 45*

Figure 10.8. Population aged 15 and older by sex and educational attainment (%) by Urban/Rural

In terms of educational attainment, around 3% of the population at the age of 15 years and older were reported to have received no formal education attended. Nearly three quarter of the population at the age of 15 and older had at least secondary education and was consistent with the 2011 census. The technical vocational education attainment was also reported at 7% of the population while 10% had tertiary education as per the 2016 census. Interestingly there were no major differences between males and females in educational attainment, although a slightly higher proportion of females had attained tertiary qualification.

There were more people from the age of 15 years and older living in urban areas had higher education attainment when compared to those in rural areas. Looking at the previous census, there has been a major improvement in educational level in Tonga for both urban and rural areas which reflects how important and valuable education is to the community. Unfortunately, the level of education is low outside of Tongatapu.

For educational qualifications, the proportion of the population aged 15 and above with a primary qualification having achieved at least Class 6 to Form 6 was 76% for females and 77% for males and this was identified to be the most common highest qualification in Tonga. For students that have completed Form 7 as their highest grade was 5% females and 4% males. The low rate suggests that a lot of Tongans did not complete their secondary level. For those that have completed their secondary level, they continue to further their education and completed their tertiary level with 12% females and 10% males. It was noted that there were more qualified population living in the urban area than in the rural areas.

10.2.9 Employment

10.2.9.1 Labour Force

The labour force is composed of the employed and the unemployed population aged 15 and above. According to the 2016 census, those people who are defined as being employed stands at 33,973, with paid workers recorded to be around 23,323 and subsistence workers at 7,470. Looking at the Tonga Labour Force Survey that was carried out in 2018, the total Tongan labour force stands at 63,189 which is an increase from 2016 census. It was noted that majority of the labour force was located in Tongatapu rural with a total of 33,024 people followed by Tongatapu urban with 16,527 people and an even lesser percentage of labour force accounted for in the outer islands.

According to the TLFS 2018, Tongatapu has the majority of the labour force (14,203 persons) that have completed their secondary education. The labour force further includes around 5,032 persons who completed primary education and around 2,941 persons who have started or completed their tertiary education. Only an estimated of 37 workers in the labour force have up to primary education level only. It was noted that there are more women than men that have started or completed tertiary education while there were more men than women who have completed primary or secondary education.

10.2.9.2 Employed Population

In terms of employment population, a total of 28,598 persons were recorded as having employment in the 2018 Tonga Labour Force Survey, of which 16,153 were men and 12,445 were women. This was an increase from the 2016 census; i.e. a total of 23,323 employed persons of which 14,008 were males and 9,315 were females. More than half of those employed were located in Tongatapu urban while a quarter was located in Tongatapu rural.

According to the 2018 TLFS, the distribution in the employment industry showed that the largest industry in terms of employment was the manufacturing sector, followed by agriculture, forestry and fishing. The other large sectors in terms of employment were administrative and support services activities and construction. Women had recorded the highest in the manufacture sector while more men recorded being employed under the agriculture, forestry and fishing sectors.

In comparison to the 2016 census, the main industries that make up the highest employed workers were in the field of agriculture, forestry and fishing still dominant by males and in the manufacturing sector, it was still female dominant. Other sizeable industry groups with significant proportion of being employed were trade, public administration and defence, education and construction while other remaining industries represented very low number. With regards to employed worker by occupational group, the largest employed workers were mainly men in the Skilled Agriculture Forestry & Fishery Worker category, followed closely by craft and related trade workers with more females than males recorded.

10.2.9.3 Unemployment & Labour Force

According to 2016 census, around 6,650 people at the age of 15 years and above did not work and they were available and willing to start work if jobs were offered to them. This level of unemployment represents 16.4% in labour force.

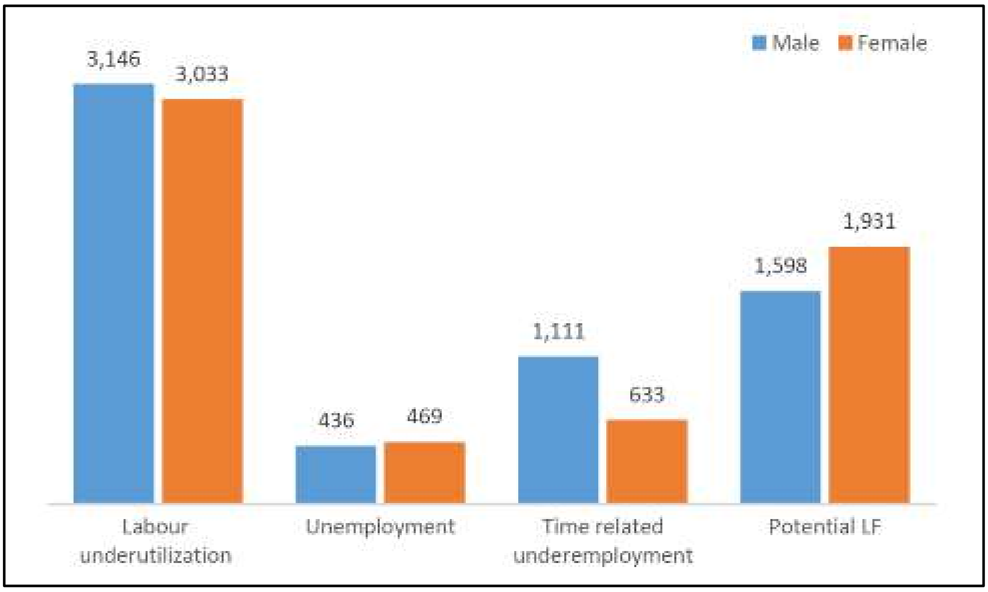
The total number of people that were classified as not in the labour force in the 2016 census was 23,129 people. The total number of people not in the labour force in 2016 was significantly lower than 2011 due to a decrease in the total number of people from non-labour who were available and keen to work. The number of people in the labour force increased and there was a decrease in the non-labour force.

Table 10.5. Population aged 15 and older not in the labour force, Tonga, 2016

Non labour force	Male	Female	Total
Student	4,530	4,779	9,309
Home responsibilities or domestic duties	2,472	7,740	10,212
Retired or too old	947	1,077	2,024
None or did not work due to various reason	612	331	943
Physically / Mentally disabled	378	263	641
Total	**8,939**	**14,190**	**23,129**

**Information Provided by Tonga 2016 Census of Population and Housing Volume 2 pg 56*

According to the TLFS 2018, around 906 people were unemployed including 469 women and 437 men with a total of 563 those unemployed people being from Tongatapu rural. At the ages between 15-24, the number of unemployed youngsters were 405. Around 6,180 people experienced labour underutilization which affected men and women to the same extent.



**Information Provided by Tonga Labour Force Survey (TLFS 2018) Analytical Report pg 33*

Figure 10.9. Labour underutilization by sex Tonga Labour Force Survey, 2018

The 2018 TLFS reported that females are more likely to be in the potential labour force and males are more likely to be in employment but wanting more hours of work. Most of those that experienced labour underutilization were those in the potential labour force. Tongatapu rural accounted for the highest share of those that experienced labour underutilization.

10.2.10 Disability

According to the 2016 census, around 5% of the population were reported to have one or more forms of disability. It was expected that population of disability increases with age. Among school children, around 3.5% were reported living with a disability and has increased to 12.7% for those 50 years and above. Overall, there was very little difference in the number of males and females with disability.

In both moderate and severity of functionality limitation, difficulty in mobility was commonly recorded at a total of 1,888 with more females (1,018) being disabled than males (870) followed by difficulties in selfcare at 1,652 people, difficulties in communication (1,210), difficulties with seeing (807), difficulties with memory (787) and the least is difficulties with hearing (672).

A recent study was carried out in 2018 specifically for disabilities in Tonga. The report was prepared by the Statistics for Development Division of Pacific Community, Tonga Statistic Department and UNICEF, with the assistance of Australian Government's Department of Foreign Affairs & Trade (DFAT), Washington Group and Pacific Disability Forum. Results from the study, showed that disability is prevalent at every age level for children from ages between 2-4 years at 2.2%, ages 5-17 at 2.0% and 11.4% at 18 years and above. Out of the total population with disabilities, Tongatapu rural recorded the highest prevalence rate with 47.1% and Tongatapu urban at 21.3%.

As indicated from the study, disability in Tonga is largely associated with illness and age. A substantial rate of those with disability occurring early in life were results of preventable diseases and medical conditions. Those with vision impairment, around 13.9% use personal companion to assist them with their mobility while 6.6% use a walking stick/cane to assist them. With regards to hearing impairment, 35.9% are able to use assistive products for reading lips and pronunciation, 10.6% uses cochlea implants while 10.3% use sign language to communicate. For those aged 5 and above with walking impairment, 54.4% use walking sticks/canes, 37.2% requires someone else to assist them, while 34.5% use either wheelchair or scooter to move around.

The 2018 study revealed that households with persons with disabilities recorded at 23.7%, almost one in every four of households with seven or more compared to households without persons with disabilities at 18.8%. In terms of education, the majority of those who never attended school was due to their illness or disability. In the field of employment, there is a slight increase in persons with disability working in agriculture, livestock and fisheries, plants and machine operators than those without disability. A higher number of people without disability are working as clerical and retail occupations than persons with disability.

Overall, persons with disabilities have a lot of difficulties accessing all the activities such as employment, education, household decision making, etc as well as all forms of transport (land, sea, air and private) compared to those without disabilities.

10.3 Social Assessment

A social assessment was undertaken as part of a feasibility study for the coastal protection along the north coast of Tongatapu, Tonga for the Global Climate Change Alliance Plus (GCCA+) Scaling Up Pacific Adaptation (SUPA) project. The assessment comprises of the following:

- Inception Meeting
- Public Presentation and Community Meetings
- Community Survey Questionnaires

There was a total of five (5) public presentation and stakeholder consultation meetings held regarding the coastal protection feasibility study that was undertaken within Northern Tongatapu.

Due to the restrictions put in place by the Tongan Government as a result of CoVID 19, the attendance to these meetings were limited. Therefore, those who attended the meeting were more likely to be representatives of their communities rather than a variety of concerned/interested community members.

An initial Inception meeting was held to inform relevant stakeholders, including government officials, civil society and the community regarding the Feasibility Study and the activities that would be occurring. The Inception meeting was held on 10th September 2020 at 10am at the Baha'I Church Hall in Nuku'alofa, Tonga (Annex A above).

The public consultation meetings and survey questionnaires were conducted as a critical part of the Feasibility Study Investigation, so as to further introduce the project to the stakeholders and communities. It was to gauge the current situation, as well as the concerns, of the members of the communities and relevant stakeholders towards the need for coastal protection within the Northern Tongatapu communities, for consideration and inclusion into the Feasibility Report.

10.3.1 Public Consultation Meeting

The public consultation meetings were held within the following five (5) areas:

a. ***Nukunuku Constituency*** - this included the communities of Nukunuku, Fatai, Sai'atoutai, Puke, Matafonua, Te'ekiuu, and Masilamea
b. ***Vaini Constituency*** - this included the communities of Vaini, Pea, Ha'ateiho, Veitongo, Nualei, Folaha, Nukuhetulu, Malapo, and Holonga
c. ***Lapaha Constituency*** - this included the communities of Tatakamotonga, Lapaha, Talasiu, Hoi, Makaunga, Nukuleka, Talafo'ou, Navutoka, Manuka, Kolonga, Afa, and Niutoua
d. ***Kolovai Constituency*** - this included the communities Fo'ui, Kolovai, Ha'avakatolo, 'ahau, Kanokupolu, and Ha'atafu
e. ***Nuku'alofa Constituency*** - this included the communities of Kolofo'ou, Kolomotu'a and Ma'ufanga

See Figure 10.10 for a map of these constituency areas and meeting locations.

Figure 10.10. Community Consultation Meeting Locations and Constituencies Areas

The purpose of the public consultation meetings was:

- To provide background information on the GCCA+ SUPA project to the stakeholders and local communities, and specifically the Tongan component of this project

- To gather information, in particular, the potential social impacts, concerns, challenges and issues that the communities were facing
- To create a working partnership with the communities which will be crucial for the development of the overall assessment

During the various community presentations, several issues and challenges were raised by stakeholders and community members with regard to the proposed activities. A summary of these challenges can be found in Section 10.3.1.1 and Section 10.3.1.2.

The meeting minutes for the community presentations are included as Annex I of this report

10.3.1.1 Key Issues/Concerns Raised at the Public Consultation Meeting

During the Inception Meeting for the GCCA+ and SUPA Project the following concerns and issues were raised:

It was queried as to whether the project is in line with the government's long-term development goals. This was responded to by explaining that this project was in line with the Tonga Strategic Development Framework, Climate Change Policy and Joint National Action Plan 2. The concern about the sustainability of the project was also raised as other promising projects had been left or not completed, and therefore was disappointing to the surrounding communities. It was explained to the attendees that some projects were to be partnerships between the Tongan government and the donor agency. As part of that partnership, the Tongan government is to maintain and monitor once the initial project is completed. Other projects are with the understanding that another donor agency will continue the next stage of the project.

The adequacy of budget for this project came into question, to which it was responded that the first key result area was intended to cover the whole of Tongatapu, but that the small hard and soft option projects will start with the area from Sopu to Ha'atafu. After that, another proposal for a bigger project will be created that will cover the whole northern coast of Tongatapu.

The representatives noted that the communities were facing issues of rising sea levels, inundation, erosion, and overtopping. Issues with the sedi-tunnel groynes were raised, including the extended time it was taking to see any results from this project. This particular issue was addressed by explaining that it takes time for sand to deposit as there was only currently one source that provided sand for that area. Although the sedi-tunnel groynes have widened stretches of the beach, additional groynes and renourishment are required for the area.

10.3.1.2 Key Concerns/Challenges Raised at the Public Consultation Meetings

The following is a list of key challenges and issues raised during the public presentation and consultation meetings. The list below does not appear in any order of priority or importance; however, it is arranged by each Public Consultation Meeting.

10.3.1.2.1 Nukunuku Constituency Challenges

During the community consultation with those located within the Nukunuku Constituency they stated that the main challenges that they faced were due to flooding; i.e., both coastal flooding and flooding due to heavy rainfall. They found that even average rainfall caused problems with flooding, such as the roads being under water. Due to the different elevations located at the seaward side of their community, the heavy rain and overtopping that occurs causes large volumes of water to be trapped, and that the salt water from the sea is negatively impacting their crops.

Further discussion with the community members found that there was a major concern regarding the destruction of the mangroves. Unbeknownst to the community at the time, as the mangroves diminished there were repercussions for their community.

Finally, the community brought up the issue of drownings that were occurring due to the flooding issue. People with little or no swimming capabilities have gotten caught in sudden situations of flooding and when the person tries to cross channels, the current is too strong for them. It has been relayed to them by people who have almost died, that a major issue is finding a safe place to enter in these channels where the currents were not too strong.

10.3.1.2.2 Vaini Constituency Challenges

During the community consultation with those located within the Vaini Constituency, it was noted that the main issue in the areas of Pea and Ha'ateiho was flooding which occurred when winds blew from the North East direction and was only made more problematic by strong winds and heavy rainfall. The Vai Langilangi which is located in the north-eastern part of Vaini have had to deal with constant, daily flooding mainly caused by overtopping. This has led to land being lost and washed away.

One community member discussed the correlation between the removal of the mangroves with the constant flooding that their community now faces. Concerns were raised about the continuous reclamation of land in Havelu, Fanga and Pahu where it was stated that land reclamation was worsening the situation that the community is experiencing.

It was noted that the planting of timber plants and other coastal vegetation had helped reduce the flooding issue in one area.

10.3.1.2.3 Lapaha Constituency Challenges

During the community consultation with those located within the Lapaha Constituency, the major challenges that they as a community faced were noted to be the extreme weather events such as cyclones, flooding, and inundation. Storm surges during Tropical Cyclone Harold highlighted these particular issues. Road damages appeared to be a major outcome of the flooding and inundation.

Residents located along Tatakamotonga and Lapaha faced issues of coastal flooding and inundation. Residents from this area felt that the main cause of the flooding and inundation stemmed from the removal of mangroves within the last 30 years, as before the increased mangrove removal they did not face these same issues.

Another issue that was raised was the roaming pigs. While roaming pigs are illegal due to their foraging of the sand flats that consequently damage the natural ecology—especially the calceric seaweeds that generate sand for the beach—it is still an issue. However, it was also noted that the government has endorsed a law that requires pig owners to keep their livestock in enclosures.

Finally, unauthorized sand mining was discussed as another factor contributing to the issue of coastal flooding and inundation.

10.3.1.2.4 Kolovai Constituency Challenges

During the community consultation with those located within the Lapaha Constituency, it was noted that nearly 2 acres of mangroves were "dying"—caused by both the clearing of mangroves, as well as no new seedlings propagating.

It was noted that there was a newly constructed seawall within the area of Kolovai; however, some felt during storm surges the water was still entering their properties.

It was also reported that there were some issues with the current protections that had been put in place. In Kolovai a portion of the existing seawall had collapsed and needed attention, and the culverts that were installed were no longer functioning. Ha'atafu noted similar issues.

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10.3.1.2.5 Nuku'alofa Constituency Challenges

During the community consultation with those located within the Nuku'alofa Constituency, it was noted that the major challenges that the communities were faced with were flooding, erosion, and inundation, with Siesia, Popua, and Sopu being the most affected.

Within the community of Siesia, the Ministry of Infrastructure had begun building a wall using mud from their shore. However, only 50% has been completed with 50% remaining to be constructed. The community felt that the use of a mud wall seemed to be working.

Within northern Popua, overtopping of the seawall is a constant issue while on the southern side, water during high tide enters and is made worse during strong winds and storm surges. This issue is exacerbated by the lower elevation of the residents in comparison to the roads, causing water to be trapped within the properties.

The community of Sopu found that the existing seawall was progressively declining which allowed overtopping to occur on a regular basis. This decline was aggravated due to the removal of trees along the seawall which in turn weakened the integrity of the seawall allowing water to penetrate through the seawall. Sea levels have risen along the landward side of Hofoa and Puke until there are only a few meters of land remaining.

Areas including Kolofo'ou Kolomotu'a, Havelu, Fanga and Tofoa experience problems of flooding during heavy rainfall.

10.3.1.3 Community Consultation Recommendations

Throughout the five (5) community consultations, various recommendations and requests were presented by the communities to help assist with the issues that they are facing. Below is a list of these recommendations:

- Identify areas of different elevation that causes water to be trapped and install culverts to drain this water
- Install signs within villages that outline the nature of the coastline to protect against potential drownings during flooding situations
- Plant more trees and coastal vegetation to help negate issues of flooding
- Plant Feta'anu, Milo, Feta'u, Fotulona, Seta'u, Fao, and other mangrove trees to protect their shores
- Relocation to higher elevation including providing services and assistance for services such as water and electricity
- Assistance for the clean-up of polluted water springs

- Use gravel to fill in properties and raise the foundations
- Construction of a seawall

10.3.2 Socio-Economic & Social-Cultural Survey

Due to the restrictions in place because of the CoVID 19 global pandemic, it was not possible to do household community surveys throughout the Northern Tongatapu area. As such, surveys were distributed to the attendees of the community consultation meetings.

10.3.2.1 Community Survey Methodology

The survey questionnaires were designed to capture the general demographic details of the people surveyed, as well as obtain an overview of the concerns and issues related to coastal protection activities and its surrounds. This includes the usage of services in each area – particularly telecommunications, solar panels, generators and boats, their travel, health status, as well as gathering the community's thoughts and concerns regarding the coastal zone hazards, disaster response and community improvements. A copy of the survey questionnaire is attached in Section 12.10 below.

Due to travel restrictions the technical members of PLANIT Pacific were unable travel to Tonga to administer the household questionnaires. The original intention was for these technical members to visit the relevant communities and individual households throughout Northern Tongatapu and administer the household surveys in each of the communities.

Considering this, as well as the local restrictions of meeting numbers and available resources, the questionnaires were distributed through PLANIT Pacific's in-country partner during the five (5) community consultation meetings. The attendees of the meetings then became the respondents for the questionnaires. During each individual meeting, the survey questionnaires were distributed to the individuals, similar to a focus group session. The focus group was led by the meeting facilitator who provided an explanation of the various questions for the participants to answer.

10.3.2.1.1 Demographic Details

Of the 76 participants surveyed, 24% were from the Nukunuku Constituency, 22% from the Vaini Constituency, 14% from the Lapaha Constituency, 28% from the Kolovai Constituency and 12% were from the Nuku'alofa Constituency. 54% were male and 46% were female.

In terms of age, 9% were between the ages of 0-20 years, 18% were between 21-35 years, 16% were between 36-45 years, 37% were between 46-59 years, and 20% were 60 years or older, as seen in Table 10.6.

While this does not follow the national statistics on the population age, this is to be expected as there were limitations on who was allowed to attend these meetings. Those attending were representatives of their community and as such over 50% of the respondents were between the ages of 36 and 59.

Table 10.6. Age of Respondents

Age	Number of Respondents	Percentage
0-20	7	9%
21-35	14	18%
36-45	12	16%
46-59	28	37%
60+	15	20%

The majority of households (37%) surveyed had 4-6 people living in the household, whilst 33% of the respondents had 7-9 people residing within their household and approximately 13% had 1-3 people living within their household. A further 17% seemed to be living in an extended family situation with 10+ people residing within their household. In terms of gender, half of the respondents (50%) had 1-3 males living in the household. The next highest range was 4-6 males (34%), and finally 7-9 males (9%). Six (6) respondents stated that they did not have any males living within their household. The female population within the households of the respondents was similar to that of the male population with 55% of the respondents having 1-3 females, 36% had 4-6 females, 8% had 7-9 females, and 1% had more than ten (10) females. Only one respondent noted that there were no females living within the household.

Table 10.7. Total Household Population

HOUSEHOLD POPULATION	Survey Number	Percentage
1-3	10	13%
4-6	28	37%
7-9	25	33%
10+	13	17%

Table 10.8. Total Male Population within Household

MALE HOUSEHOLD POPULATION	Survey Number	Percentage
0	6	8%
1-3	38	50%
4-6	25	33%
7-9	7	9%
10+	0	0%

Table 10.9 Total Female Population Household within Household

FEMALE HOUSEHOLD POPULATION	Survey Number	Percentage
0	1	1%
1-3	42	55%
4-6	26	34%
7-9	6	8%
10+	1	1%

Of those surveyed, 18% of the respondents did not have any persons attending any form of school, from pre-school to University. Of those that did have household members in school, 12% had at least one member in pre-school, 46% had a member in primary school, 53% had a member in secondary school, 15% has a member within technical school, and only 5% had a member in university. Refer to Table 10.10 for a more in-depth account of the number of household members attending the different levels of school.

Table 10.10. Total Number of Household Members that Attend School

#	Pre-School	%	Primary School	%	Secondary School	%	Technical School	%	University	%
0	67	88%	41	54%	36	47%	65	86%	72	95%
1	7	9%	13	17%	15	20%	8	11%	4	5%
2	2	3%	7	9%	20	26%	2	3%	-	-
3	-	-	7	9%	3	4%	1	1%	-	-
4	-	-	4	5%	2	3%	-	-	-	-
5	-	-	1	1%	-	-	-	-	-	-
6	-	-	0	0%	-	-	-	-	-	-
7	-	-	1	1%	-	-	-	-	-	-
8	-	-	2	3%	-	-	-	-	-	-

10.3.2.1.2 Employment & Income

This section outlines the employment/unemployment information for the respondents and their household. The various employment categories that were given as options included Employed Full time, Employed Part Time and Unemployed (whether they were skilled or unskilled). As per the Tongan 2016 Census, the various employment/unemployment categories were also delineated by those within and those who were not within the "labour force." Those who were looking for work were considered within the "labour force" even if they were not currently employed. However, those who were both unemployed as well as not looking for work were not considered to be part of the labour force. This included, but was not limited to, people who had retired, people with severe disabilities that did not allow them to work and children too young to work. For the information gathered through the questionnaires, the focus was regarding those employed verses unemployed, full time vs part time and skilled vs unskilled. Further information pertaining as to why those who were not employed was not within the questionnaires' purview. Refer to Section 10.2.9 for Employment Information for Tonga, in general.

10.3.2.1.3 Employment of Survey Respondents

The majority of the survey respondents (58%) were not employed, leaving 46% as employed. Regarding their primary employment of those who were employed, it is to be noted that there is a significant number of District and Town Officers present, causing the occupations to be skewed for those who are within leadership positions within their communities. This is due to the fact that the meetings were restricted in numbers due to CoVID 19 and therefore, in many cases, the town and district officers were there as representatives speaking on behalf of their communities.

Only one respondent indicated having a secondary form of employment, which they noted as "Truck Rental."

Table 10.11. Primary Employment of Respondents

Primary Employment	TOTAL	Percentage
Administrator	1	1%
Boat Crew	1	1%
Civil Servant	1	1%
District Officer	3	4%
Event Planner	1	1%
Farmer	1	1%
Joiner	1	1%
Office Worker	1	1%
Teacher	1	1%
Town Officer	20	26%
Weaving	1	1%
Not Employed	44	58%

10.3.2.1.4 Employment for Household

In terms of the entire household, only 25% of the respondent's entire household were without any form of employment. The forms of employment for those within the household – excluding the respondents – included:

- Bank Officer
- Carpenter
- Civil Servant
- Cleaner
- Finance
- Fisherman
- Mechanic
- Nurse
- Office Worker
- Overseas Worker
- Seasonal Worker
- Soldier
- Teacher
- Tractor Operator

68% had at least one person within their household with full time employment,11% had at least one person within their household with part time employment and 7% had at least one person within their household with casual employment.

Some households indicating having multiple categories of employment: with 7% indicating that they had at least one person employed full time as well as 1 person with part time employment. 4% had at least one person employed full time as well as 1 person with causal employment. No households had any persons employed with part and casual employment within the same household at the same time.

In terms of unemployment, 7% of the respondents indicated that they had only one (1) skilled worker within their household that was still unemployed. In comparison, 65% had unemployed, unskilled workers within their household. As seen below in Table 10.13, 41% of these household had 1-3 persons, 21% had 4-6 persons and 3% had 7-9 persons living within the household as unemployed, unskilled workers.

Table 10.12. Unemployed, Skilled Workers within the Household

Unemployed Skilled Workers in Household	Total	Percentage
0	71	93%
1	5	7%

Table 10.13. Unemployed, Unskilled Workers within the Household

UNEMPLOYED UNSKILLED WORKERS IN HOUSEHOLD	**Total**	**Percentage**
0	27	36%
1-3	31	41%
4-6	16	21%
7-9	2	3%

10.3.2.1.5 Source of Income

Besides the salaries from the primary employment of those within the household, other sources of income for the households included the following:

- Bus Rental
- Boat Owner
- Construction/Joinery
- Farming/Produce/Flower Seedlings
- Fishing/Seafood Collection
- Food Items—BBQ/Baking
- Flea Market/Handicraft
- Landscaper
- Livestock
- Remittance from Overseas
- Tailor
- Weaving and Tapa

Many of these other sources of income are from activities in which the household uses their labour and their surrounding resources to produce a livelihood, such as handicrafts, selling of fish and seafood, and farming.

Very few respondents provided information regarding the total income that they, or the households, received. However, of the 4 respondents that did provide this information, it was a wide income range in which they stated: $400 bi-weekly, $500 monthly, $5,000 monthly, and $89,000 annually.

It is to note that while there were obvious limitations and restrictions in the survey process and number of respondents, with this difference in income levels it is clear that there was a variety in our sample population.

10.3.2.2 Land Use and Services

10.3.2.2.1 Land Tenureship

Within the survey questionnaire, respondents were given three options in terms of their current land tenure: tax allotment, town allotment and leasehold. 95% indicated their land tenureship as town allotment and 72% indicated tax allotment. Of the 76 participants, 54 selected that they had both town and tax allotment as their land tenureship. It is reasonable to assume this occurred due to the similar nature of these two land tenureships. Town allotment is distinguished as "a life interest held by a single Tongan male and used for residential purposes. Passed down from father to son. Normally located on a hereditary estate, but may be located on Crown Land[2], while tax allotment is considered to be the "same as town allotments but used for agriculture." Therefore, the confusion between the two types is understandable.

Only two (2) respondents indicated that they had leasehold as their land tenureship.

10.3.2.2.2 Access to Services

The participants were questioned about their access to various services, including water, health and food. See Table 10.14 for a description of their water sources. This list finds that most respondents use a combination of tap water and rainwater for their water needs. Many households used a secondary source for drinking water such as purchasing water or rainwater catchment possibly via tank. This is mainly due to the fact that communal water facilities, including the taps and local springs are not considered appropriate for consumption. Issues with local springs were brought up within multiple community consultations due to the pollution/contamination of those springs through salt water and/or mud intrusion. As for water within the taps it is considered that due to the hardness of the ground water that other water sources are used in supplementation of this ground water. As seen within Table 10.14,the "conjunctive use of ground water and rainwater resources is a preoccupation throughout the islands due to the omni presence of saline intrusion into groundwater resources"[3].

2 *Disaster Law Housing, Land, and Property Mapping Project* (Vol. 15, Rep. No. A0138367049v15 120641715). (n.d.). Allens.

3 *Tonga Water Supply System Description Nuku'alofa/Lomaiviti* (Rep.). (n.d.). Retrieved http://www.globalislands.net/userfiles/tonga_8.pdf

Table 10.14. Household Water Sources

Water Sources	TOTAL	Percentage
Community Water & Purchased drinks	5	6.58%
Community Water & water tank	6	7.89%
Tap Water & Purchased Drinks	1	1.32%
Tap Water & Rainwater for drinking	63	82.89%
Borrow Water from Neighbours	1	1.32%

Health services are available within Tonga and used by all of the surveyed participants. The respondents included using a variety of hospitals, local clinics or health care centres when they or a family member was sick. As the Kingdom of Tonga has a national health care system, which includes government pharmacies, it is not surprising that all the respondents have made use of this system.

For food consumption, it was broken down into two main categories: meat consumption and vegetable/root crops. Most respondents indicated buying meat for their consumption (78%). However, some used fishing and seafood collection as mean of subsistence. Fishing methods included nets, traps and diving for various sea life. Those who described the fish and seafood collected included mullet, crabs, both high and low tide fishes, seashells, ama and ta mehingo.

In terms of agricultural subsistence farming, the main crops being planted for consumption were taro and cassava. Other produce included banana, sweet potatoes/yams and watermelon. Moreover, over 50% of the respondents indicated that they planted different crops and vegetables, but did not provide a description of what those items were.

10.3.2.2.3 Infrastructure

The number of mobile phones within a singular household ranged from 1 to 16 phones, with most homes having between 1-4 mobile phones (68%). Only 1 household within each category had 9 phones, 10 phones or 16 phones.

The vast majority of households surveyed did not use solar power and did not have a generator. Due to the fact that the Kingdom of Tonga is a collection of islands in which these particular items would have to be imported rather than produced locally, the cost of these items would most likely deter families from purchasing them.

While many NGO's or other initiatives throughout the country might provide or subsidize these items, for the average Tongan family these alternative sources of power are not practical as most appear to be connected to the central power grid. Tonga Power Limited (TPL) ensures that "close to 95% of the population has access to electricity with 89% of all households having grid electricity access. All urban centres in the country have access to energy, as well as all rural areas on the main islands of Tonga."[4]

As for boats, 8% of those surveyed stated that they had a boat. While the respondents did not describe what the boats were used for, it is most likely that these boats were mainly used for fishing and various seafood collection as well as travelling from shoreline to shoreline or outer islands. All household who indicated having a boat disclosed that they had one boat, except for one household that had two boats.

When queried about other services or infrastructure that they had within their homes one respondent stated that they had net(s), and another stated that they had a car.

Table 10.15. Household Usage of Services

Service	Yes	Percentage	No	Percentage
Mobile	76	100.00%	0	0.00%
Solar	4	5%	72	95%
Generators	1	1%	75	99%
Boat	6	8%	70	92%

Travel

In respect to travel, the majority (71%) of the respondent indicated traveling outside of their village/community to get to work which was located in "town" and that they travelled to work 5-6 days a week. Travel for education was a reason for travel for a significant portion of the households surveyed (55%) with most households traveling 5-6 days. In regard to selling produce, only three households indicated travel for that reason, with one clarifying that it was only once a fortnight. Approximately, 71% also indicated traveling for medical visits mainly to

4 *Tonga Power and Electricity Additional Information* (Rep.). (n.d.). Tonga Power Limited.

the hospital, noting the occurrence primarily to be “often”. Finally, over 70% of the households surveyed travelled to visit relatives or family members within different villages from their own.

Every respondent indicated traveling outside of their community for at least one of the previously discussed reasons.

10.3.2.3 Social Issues

10.3.2.3.1 People with Disabilities

The information provided by the respondents in regard to those living with disabilities within their household was extremely limited. Six of the respondents indicated that they had a person with a form of physical disability living in their household. Four respondents specified it only as a form of physical disability, one respondent noted the disability as being deaf, and one respondent noted the disability as amnesia/memory loss.

All six of the respondents indicated that their household member with the disability did not receive assistance in the form of wheelchairs, hearing aids, visual aids, educational assistance or ramps both in home or in public.

10.3.2.3.2 Gender Equality

Concerning gender roles within the household and community refer to Table 10.16 which outlines these roles.

Table 10.16. Gender Roles within the Household and Community

Gender	Household Role	Community Role
Male	Farming	Farming
	Work	Community Police
	Carpenter	Fishing
	Fishing	Church Leader
	Decision Maker	Carpenter
	Seasonal Worker	Leader
		Decision Maker
Female	Housekeeping	Handicrafts/Weaving/Tapa Making
	Office Work	Community Clean up
	Low Tide Fishing	Women Community Groups/Community Work

	Tailor	Farming
	Handicrafts/Weaving	Fishing
	Farming	Tailor
		Housing Keeping

The answers of the respondents lean towards more traditional gender roles within the family and communities, with women responsible for housework and clean up, handicrafts and community groups while men have roles as leaders, police, decision makers and providers either as a breadwinner and/or physical labourers (farming/fishing).

All of the respondents had various women's groups and committees within their communities – some with multiple women's committees – noting the roles of these committees to be:

- Community Clean up
- Domestic Fowl
- Handicrafts/Tapa/Weaving
- Planting Fruits & Vegetables/Gardening
- Selling of Baked Goods/Paper Mulberry
- Social, Economic & Environment
- Tailor

There is a marked similarity between the answers provided for the women's committees and the women's roles within the community with overlapping answers including: handicrafts/tapa/weaving, gardening, community clean up and tailor.

Only three (3) respondents did not indicate having a youth group/s within their community. Of those who did have such groups, they noted the activities included:

- Community Police
- Community Clean up
- Community Sports (Volleyball, Soccer)
- Assisting with Women's Projects
- Cluster Farming

10.3.2.3.3 Health Status

The majority of respondents (79%) did not indicate any form of disease and/or illness suffered by themselves or their family member. Of the remaining 21% respondents, the following are the health issues pertaining to their household:

- Pneumonia
- Injuries
- Diarrhoea
- Diabetes
- High Blood pressure
- ALS
- Fever
- Memory Loss
- Heart Disease

Diabetes was the most popular illness that they faced, with high blood pressure next. Both of these illnesses are related to non-communicable diseases which continue to be a growing issue within Tonga and the Pacific.

10.3.2.4 Perception of the Area

Due to the various CoVID-19 restrictions and limitations, which have previously been addressed and directly affected the methodology of this report, many respondents did not provide as in-depth of information regarding their perceptions as normally gathered during the questionnaire process. This is unfortunate as this information is deemed vital to understanding how the community is being impacted, recognizing the issues that they are facing, and therefore being able to address these issues and provide a response to them through various mitigation measures and recommendations.

Nevertheless, find below in the following sections the information that was provided by the respondents regarding their views on the existing socio-economic value of the area, coastal hazards and community benefits.

10.3.2.4.1 Socio Economic Value

Three areas were raised regarding the important features on the coastal zone that were seen as significant to their community and needed to be protected. All three areas of concerns were noted within the area fronting the foreshore (above the high-water mark).

The first issue was regarding cultural/religious areas. The respondents noted that there had previously been four fishing areas, but that they no longer fished there.

The second issue pertained to the natural areas, such as mangroves, that were used for medicinal and construction purposes.

Finally, the respondents noted areas of concern in terms of their food sources, specifically mentioning the following fish/seafood: oo, tanutanu, koputu, ihe, unomoa, paka, feke, lomu, teepupulu, 'elili, takaniko, and mehingo, as well as food items such as carrots, tomatoes, cucumber, lettuce, cabbage, and onions.

The respondents did not indicate any concerns for water sources, access to the beach, or any particular built structure that might be in jeopardy.

10.3.2.4.2 Coastal Zone Hazards

80% of the respondents stated that they frequently visited the coastal zone and made use of coastal amenities, while the other 20% of respondents visited occasional.

All respondents indicated having seen or experienced major changes to the beach front and/or within coastal watersheds. These changes included erosion/loss of land, loss/changes to engineered structures or roads, and loss of vegetation.

Further information on the coastal zone hazards faced by these communities are discussed Annex .

10.3.2.4.3 Disaster Response

No information was provided regarding the survey questions pertaining to disaster response, including information on early warning systems, disaster management procedures, location and the time it takes to get to the evacuation centre, and possible things that the respondents might give up in order to address the issue of overtopping.

10.3.2.4.4 Community Benefits

All of the respondents felt the need for improvements within the coastal zone fronting their community. These improvements included beach restoration, rock baskets, sea walls, reclamation, and planting of coastal vegetation.

It is to note that some of these same improvements have already been implemented, and as such the survey participants have been able to see the value and benefit of these particular improvements.

One respondent also commented, noting the need to educate students and all levels of the community on coastal protection and better practices.

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10.4 Social Impacts & Mitigation Measures

This section of the report addresses the social impacts that the current coastal zone situation has on the immediate and surrounding environment and communities. This section reviews those impacts and proposes recommendation and some mitigation measures to curtail the negative impacts.

10.4.1 Social Impacts

It is considered that the social impacts identified during the community consultations and survey questionnaires included:

- Concerns based on rising sea levels that have increased inundation, flooding, and overtopping, as well as land reclamation by the sea;
- Concerns that flooding is causing road closures and damaging the road integrity;
- Concerns regarding the impacts to crops and their livelihoods due to flooding and overtopping;
- Concerns regarding deaths due to drowning caused by flooding for those with limited swimming abilities and a lack of knowledge of safe areas to cross channels during these times of flooding;
- Concerns surrounding the previous and continuous removal of mangroves, and other illegal activities including sand mining, that has a direct correlation to increased flooding issues;
- Concerns regarding lack of maintenance of previous coastal protections projects.

10.4.2 Recommendation and Mitigation Measures

The following are recommendations to help mitigate some of these impacts for those living along the coastal zones:

- Dedicated community liaison for disaster management to assist the communities by relaying information to them, as well as during natural disasters such as tropical cyclones or tsunamis providing current, up-to-date evacuation information and status;
- Increased monitoring of illegal activities, including sand mining, mangrove clearing, and pig roaming, including providing clear procedures on who and how to report these activities when observed;
- Working with local school and community groups to organize the replanting of mangrove and other coastal vegetation;

- Provide awareness trainings and programmes to communities to educate the communities on the coastal processes and the impacts of various activities, such as the removal of mangroves, sand mining, etc.;
- Installation of a monitoring programme to evaluate the effectiveness of the coastal measures and changes that are put in place;
- Installation and maintenance of culverts;
- Potential relocation for those communities who have no other effective coastal protection measure options.

10.5 Limitations

This Socio-Economic Characteristics Report was prepared for eCoast as part of the Coastal Protection Feasibility Study along the north coast of Tongatapu and is based on PLANIT's understanding of the scope of works to be carried out for this project and the information provided to us by eCoast at the time of reporting. The findings presented in this report should not be applied to another site or area in Tonga or the Pacific without consulting eCoast or PLANIT Pacific.

PLANIT Pacific has prepared this report exclusively for eCoast for specific application for the overall feasibility assessment of the northern coast comprising of geomorphological, biophysical, engineering and social characteristics.

PLANIT Pacific accepts no responsibility or liability for the use of this information for any other purposes. Furthermore, due to the travel restriction caused by the CoVid-19 global pandemic, the results of this social-economic characteristics study was primarily done by way of a desktop review of the 2016 Census data in comparison to the 2011 Census data, as well as, the 2018 Labour Force Survey and the 2018 Disability Survey, the results of household community surveys which were undertaken by government partners to assessment community priority issues and their needs based on past community consultations, as well as, recent consultation meetings that have recently been conducted with the communities living along the northern coast line.

PLANIT Pacific acknowledges that due to the above travel limitations, impacts beyond those identified in this report may occur or need to be further captured, and therefore, suggests that in order to mitigate and manage these effects, regular monitoring of various potential impacts and on-going community and stakeholder consultations should be undertaken beyond the scope of this study.

11 Annex I: Coastal Hazards

11.1 Introduction

This section provides a description of the coastal hazards (e.g., over-topping, coastal inundation, erosion, etc.), along the northern coast, much of which has been derived from the information gained from the community consultation (i.e., meetings and questionnaires).

11.2 Coastal Unit 1: Ha'atafu to Foui

The coastline from Ha'atafu to Foui has been the subject of several previous climate change resilience projects over more than a decade, with a range of measures implemented along the coast during this period (detailed in Section 5, Annex C).

Over-topping at the Ha'atafu end of revetment where these is an existing dwelling occurred during TC Harold, and some parts are also reported to be failing along this revetment, which was last maintained in 2015 (Figure 11.1).

Figure 11.1. Overtopping of the revetment at Ha'atafu during TC Harold and repairs are required along its length.

At A’hau, where a green buffer zone has been developed over the past 6 years, it was reported that there are still issues with opening of the southern the entrance to flush the area. One local representative requested that it be closed down, however, the removal of mangrove from this area in the past led to inundation hazards (similar to many other areas of the northern Tongatapu coast).

At Kovolai, it is reported that water sometimes comes around the back of the seawalls, and also came through gaps in the walls in TC Harold causing inundation of properties. Requests were made to close the gaps towards the end of the wall, and to provide entrance to the sea for access.

Figure 11.2. Locations of the A’hau green buffer zone (top) and Kovolai seawall (bottom)

11.3 Coastal Unit 2: Foui to Sopu

The villages in this coastal unit all report issues with inundation during heavy rain and high tides, with many roads going under-water, which is made worse with spring tides and onshore winds. It is low-lying with variable land heights, with some higher land nearer the sea than those further inland, and so it cannot drain following inundation (Figure 11.3). Some of the drainage area (shown in the bottom image of Figure 11.3) is currently being used for planting mangroves. Village representatives reported a preference for more mangrove planting for climate change resilience.

Figure 11.3. All of the villages in this coastal unit are low-lying with variable land heights, some higher nearer the sea than those further inland, and so they cannot drain well once flooded. The area shown in the bottom image is currently being used to be for planting mangroves.

These villages also reported a water-safety/drowning hazard. The sand flats are open for fishing for all, and people walk out on the flats to forage. In the past year, 6 people across a range of age groups have drowned during the seacucumber harvesting season. When the weather changes quickly (wind and waves) people are trapped on the sand flats and get swept out of channels on the north of the lagoon by strong currents running off the flats and out to sea. Requests were made for signage warning people to increase safety, as well as safer access to the sand flats.

Sopu is very vulnerable to over -topping and inundation, with saltwater coming around from the west and nearly meeting the other side. Water gets trapped during King tides and heavy rainfall. (Figure 11.4). In the past 20 years a lot of trees have died as a consequence of flooding, including mangroves and other coastal vegetation.

Figure 11.4. Sopu is very vulnerable to over -topping and inundation, with saltwater coming around from the west and nearly meeting the other side. In the past 20 years lot of trees have died as a consequence, including mangroves and other coastal vegetation.

11.4 Coastal Unit 3: Sopu to the Nuku'alofa shore of the lagoon

The village representatives reported that the seawall/revetment along the Nuku'alofa seafront is mostly working, although there are some failures. There are still rocks and coral on the side of the roads that was thrown up by TC Harold, mostly from Sopu to Popua except where wharfs are (Figure 11.5). Most houses were flooded during TC Harold along the road, which occurred at the same time as a King tide (+TC Harold onshore winds + storm surge due to extremely low barometric pressure = very high coastal water levels).

Figure 11.5. The seawall/revetment along the Nuku'alofa seafront is mostly 'working', although there are some failures.

At Siesia, they have built mud/sand walls/bunds around the coast and properties (Figure 11.6). TC Harold threw lots of rocks and coral into properties, which built up and raised the properties. This is an example of coral island's keeping up with SLR (e.g., Kench *et al*., 2015; Mead *et al*., 2017). 50% of the seawall has been done, and the village requested help to complete it.

In Popua village at the eastern end of Nuku'alofa, the roads are higher than properties, so they flood due to heavy rain and extreme storm surge (Figure 11.6). Options put forward by the village representatives included raising the land and houses, and putting in culverts to drain water from the properties.

On the shores of the lagoon, inundation occurs because the land is very low similar to Pea and the rest of the northern lagoon coast (Figure 11.6). Reclamation is still being undertaken along this coast, mostly without permission and it is not being policed. This is leading to flooding issues due to the lack of drainage planning. Some claim that the land reclaimed from one area pushes water to other areas, however, this cannot happen in a water body with an open coast boundary, the water levels in the lagoon are driven by tides and metocean conditions, and so is more likely associated with SLR.

Figure 11.6. At Siesia (top right), they have built mud walls around the coast and properties. TC Harold deposited a lot of rocks and coral into properties, which built up and raised the ground levels. In Popua village (middle right), the roads are higher than properties, so they flood due to heavy rain and extreme water levels. On the shores of the lagoon, there are inundation problems since the land is very low (similar to Pea and the rest of the northern lagoon coast)

Figure 11.7. Lots of reclamation still occurring mostly without permission and it is not being policed. This is leading to flooding issues due to the lack of drainage planning.

11.5 Coastal Unit 4: Nuku'alofa to Nukuleka

Pea to Veitongo is one of the most susceptible areas to inundation (Figure 11.8). Village representatives claim it to be lowest part of lagoon, and are concerned that reclamations lead to additional flooding. These days, the high tide comes in and floods across the road, especially during northerly winds. Similar flooding occurs to the east, although this land is not as low-lying.

Figure 11.8. Pea to Veitongo is one of the worst/lowest areas for inundation.

Nukuhetulu and Folaha are losing farmland due to inundation, which is likely being compounded by SLR (Figure 11.9). Local farmers grow cassava, taro, yams, and sweet potatoes, and have also planted pine trees, and are planning more pine tree planting in the near future.

Figure 11.9. Nukuhetulu and Folaha are losing farmland due to inundation, likely being compounded by SLR.

At Vaini, the road north to Longoteme was 20 m inland a few decades ago, but has been lost to the sea due to removed mangroves (Figure 11.10). The villages would like to replant with mangroves. At high tide and with onshore winds, sea water floods and crosses the road into these areas, the village representatives indicated that they thought that seawalls are the best solution.

Figure 11.10. At Vaini (left), the road north to Longoteme was 20 m inland a few decades ago, but has been lost to the sea due to removed mangroves. At Malapo (centre), water comes in either side and causes flooding, especially during high tide and northerly winds.

At Malapo, water comes in either side of the village and causes flooding of some properties, especially during high tide and northerly winds (Figure 11.10).

From Alaki to Hoi, inundation occurs along some of the coastal properties (Figure 11.11). Erosion has occurred, and people have lost property along the waterfront (Figure 11.11 middle). The land in this area becomes higher moving inland, although inundation occurs along the waterfront properties at Hoi and Mua.

Figure 11.11. From Alaki to Hoi, inundation occurs along the coastal properties. Erosion has occurred, and people have lost property along the water front (middle).

11.6 Coastal Unit 5: Nukuleka to Niutoua

Like Sopu, water comes around both sides of the village at Nukuleka, which has become worst in recent years and is coming up either side of the road at the top of the channel through the mangroves (Figure 11.12). At Talafo'ou and Makaunga, there is some concern that the trial groynes are not working as well as they should. However, sand supply is very limited, and more groynes to fill in the 120 m and 60 m spaces and more sand from the borrow area will result in this stretch of the coast being >10 m wider, as it is where the groyne spacing is 30 m (Mead, 2020).

Figure 11.12. Like Sopu, water comes around both sides at Nukuleka (bottom), which has become worst in recent years and is coming up either side of the road at the top of the channel through the mangroves.

The low road between the detached breakwaters at Manuka and Kolonga regularly experiences over-topping and inundation, which was severe during TC Harold (Figure 11.13). The coast from Kolonga to Niutoua becomes increasingly elevated and is a mix of uplifted coral and limestone, meaning that there are no inundation and erosion hazards present.

Figure 11.13. The low road between the detached breakwaters at Manuka and Kolonga regularly experiences over-topping and inundation, which was severe during TC Harold.

The information presented in this Section, in combination with the community's priority issues and the information compiled on the bio-physical nature of the northern Tongatapu coastline will be use for the development of the next phase of this project:

c) Overall conceptual design and costing for the entire length of coastline from Niutoua to Ha'atafu including the Fanga'uta Lagoon for the 2030 and 2050 planning horizons, and;
d) Specific conceptual design and costing for the minimum 10 small-scale hard and soft engineering measures for the northwest coastal stretch from Sopu to Ha'atafu to be considered for implementation during the period mid-2021 to end 2022.

12 Annex J: Community Meetings Report

12.1 Introduction

Consultation with the community is an important part of the strategic planning effort of the Global Climate Change Alliance Plus (GCCA+) Scaling Up Pacific Adaptation (SUPA) project in Tonga. On the 10th September, the Project conducted its Inception meeting (Section 3 above) and was attended by selected Government officials, civil society groups, NGOs and representatives from the coastal communities along northern Tongatapu. The objective was to inform these stakeholders about the project and its activities and, the project's plan to conduct five (5) meetings with the northern Tongatapu coastal communities.

This report summarises information on the five community meetings and the challenges and feedback provided by the community members in attendance. The intention was to gather more information to be incorporated with data collected in the desktop review of the existing information/data on the biophysical nature of the northern coast of Tongatapu. The information/data collected for the assessment of the Northern Tongatapu areas will be used to develop an overall conceptual design and costing for the coastal protection measures of the entire length of the coastline from Niutoua to Ha'atafu including the Fanga'uta Lagoon for the 2030 and 2050 planning horizons.

The project team will later communicate the action plans to be undertaken to the participants and the community as a whole; Report 2 – Conceptual Design and Preliminary Costing for the Recommended Large and Small Scale Measures and Approaches to Coastal Protection.

12.2 Objective

The purpose of the meetings was to inform the community about the project and to gather more information/data particularly the challenges/issues that the community are facing. In addition, the project sought a working partnership with the community to share some of the experiences and traditional knowledge they have as it will be crucial for the development of the overall assessment of the northern coast of Tongatapu.

12.3 Methodology

Each meeting begun with a prayer and followed by the Welcoming Speech – both delivered by either the District Officer or Town Officer.

This was followed by a group photo prior to the introduction of participants.

A PowerPoint presentation was then delivered by the Project Coordinator, Manu Manuofetoa. The content of the presentation is summarized below;

A. Background information of the GCCA+ SUPA Project – a regional project funded by the European Union and implemented by SPC, SPREP and USP in partnership with 10 countries in the Pacific

B. **i. Tonga's Project:** *"Scaling up of coastal protection in northern Tongatapu in response to climate change".*

ii. Overall Objective: *"Holistic approach to coastal protection in northern Tongatapu adopted by the Government of Tonga"*.

Specific Objective: *"Communities on the northern parts of Tongatapu are better equipped to undertake small-scale coastal protection measures (both hard and soft engineering measures").*

C. Four (4) Key Result Areas (KRAs) of the project:

- Conduct an assessment, feasibility, and conceptual design study for coastal protection along the entire north coast of Tongatapu (Niutoua to Ha'atafu) and share findings with stakeholders in Tonga and with development partners
- Implement small-scale coastal protection and ecosystem-based measures in northwest Tongatapu (Sopu to Ha'atafu)
- Enhance awareness about the impact of climate change and natural disasters in Tonga
- Coordination of project activities

D. eCoast Consultant: eCoast has been engaged directly by SPC and is currently undertaking desktop review of the existing data on the biological nature of northern Tongatapu (project sites) to undertake overall assessment of the northern coast of Tongatapu

E. Coastal Issues – Man-made & Climate change related Issues in Tonga

i. Man-Made issues

- Clearing of the coasts for development need such as construction of new infrastructure, farming, cutting of mangroves and other coastal vegetation for firewood and other usage, sand mining etc.

ii. Climate change related Issues

- Extreme Events
- Sea Level Rise (SLR)
- Flooding
- Inundation etc.

F. Potential solutions

G. Q&A

12.44. Challenges

After the presentation, participants were asked to share the challenges that they are currently facing which is summarized below.

12.5 Meeting No.1: Nukunuku Constituency (Nukunuku, Fatai, Sia'atoutai, Puke, Matafonua, Te'ekiuu and Masilamea) Coastal Unit 2: Foui to Sopu

Flooding and Inundation are major concerns for the people of Masilamea, Te'ekiu, Nukunuku, Fatai, Matafonua and Sia'atoutai. Flooding in this community is two-fold. 1. Coastal flooding during king's tides and storm surges and 2. Flooding due to heavy rainfall. Because these communities are among the lowest in the country they are easily flooded. The roads are always under water when there is average rainfall and even during high tide. To make things worse, there are areas in the seaward side that are higher than the other. When heavy rain and overtopping occurs only small amount of water goes back to the sea through these low areas while large volumes are trapped in areas with higher elevation to the seaward sides. With inundation, some farm lands have been claimed by sea. Crops are also affected by the spill over saltwater from the sea. Upon discussion of the issue, participants suggested that it would be helpful to identify the areas that are high and low and maybe install culverts to drain out the water.

Destruction of mangroves was a major concern for the participants who said that mangrove forests in their community were very thick. Community members have destroyed bulk of these mangroves forest without knowing the repercussions of their action. Now they realise the mistake they made and have all pledged to restore those mangroves provided the project will assist them.

A separate interesting issue reported during the meeting regarding how most people died along these coastal villages – both people from the district and those from the other districts. The problem according to the participants is that the entire coastline is dry when it is low tide; however, when its high tide the water level goes higher than expected in certain parts of the coast and is always associated with strong current that either leads all the way to the deep water or the shore. So many people with no swimming skills have lost their life when they cross these channels and are taken into the deep sea by the current. Even those with swimming skills have often died especially when they want to swim against the current. The same problem happened to some that washed ashore. They died because they were lost. They couldn't find the exact place safe to enter, thus roamed around the entire coast causing fatigue due to thirst and hunger and ended up losing their lives. Participants put forward the idea of installing signs on each village with notes that explain the nature of the coastline.

12.6 Meeting No.2: Vaini Constituency (Vaini, Pea, Ha'ateiho, Veitongo, Nualei, Folaha, Nukuhetulu, Malapo and Holonga) Coastal Unit 4: Nuku'alofa to Nukuleka

Flooding is the main issue in Pea and Ha'ateiho especially the north eastern sides to the Fangauta lagoon. Flooding occurs when wind blew from north east direction. The problem is worsened during strong wind and heavy rainfall. Flooding and inundation starts from the Alonga Centre in Pea all the way to the north eastern side of Ha'ateiho to Veitongo.

North eastern part of Vaini known as Vai Langilangi towards Folaha and Nukuhetulu experience overtopping almost on daily basis and caused flooding. Consequently a lot of lands have been claimed by the sea.

A number of fresh water springs in Vaini are polluted and are buried under the mud that requires dredging and total clean up.

An elderly woman shared that in the past 30-50 years there was mangrove forest along the shore and there was hardly any flooding and overtopping. However, those mangrove forest have rapidly disappeared and now they experience constant flooding.

About 64 acres of land in the North eastern side of Nukuhetulu and Folaha particularly along Ngutungutu Road have been claimed by the sea. These are farmlands that are now under water. Another 5 lots of lands and 15 individual properties in Folaha faces constant flooding and the problem is worsened during strong wind particularly when it blows from the north east.

Concern raised about the continuous reclamation of lands in Havelu, Fanga and Pahu where participants claimed that these land reclamation worsen the situation they are experiencing.

Folaha youth representatives shared their observation that part of the Folaha Government Primary School area are under water from the sea. However, there is no flooding on the other side of the school because the school planted timber plants (pine) and other coastal vegetation. The youth requested if the project could support them to plant more trees along their shores.

12.7 Meeting No.3: Lapaha Constituency (Tatakamotonga, Lapaha, Talasiu, Hoi, Makaunga, Nukuleka, Makaunga, Talafo'ou, Navutoka, Manuka, Kolonga, Afa and Niutoua) Coastal Unit 5.

Major challenges for these coastal communities are associated with extreme weather events, particularly cyclone. The impacts of cyclones are almost always the same, although slightly differs depending on the route of the cyclone. For instance, there were only few damages to residents starting from Kolonga to Niutoua since the wind blew from the west compare to Nukuleka, Talafo'ou and Makaunga as they were facing wind direction of TC Harold.

Flooding and inundation also affects these communities. Again this was evident during the storm surges caused by TC Harold. Some portions of the roads were damaged especially the side of the road between Manuka and Kolonga.

Some residents along Tatakamotonga and Lapaha are facing coastal flooding and inundation. Reports from these residents showed that there were no such issue in the past 30 years as there were mangrove forest along their areas but have been destroyed for various reasons, thus, allow water to come straight to their properties. Residents requested if the project could provide specific coastal plants such as 'Feta'anu, Milo, Feta'u, Fotulona' and mangrove that used to protect their shores before so that they could replant them.

Relocation to higher ground (part of the solutions for the problem of sea level rise and climate change) was supported by the participants. However, they shared that it would work with some form of assistance to encourage people to move to higher ground. For instance, if water and electricity are available in the landward sides of these communities (which are a bit higher compare to the seaward sides) people will move and build there.

Representatives from Navutoka put forward the idea to include their views in the designing of the projects planned to implement in their areas and was reminded that was the whole purpose why the meeting was conducted to collect their views and ideas.

There was still issues with roaming pigs, but participants were reminded that roaming pigs is illegal as the government had endorsed law that requires every pig owner to put their livestock on a pig pen.

Unauthorized sand mining is still a problem which also contributed the issue of coastal flooding and inundation.

12.8 Meeting 4. Kolovai Constituency (Fo'ui, Kolovai, Ha'avakatolo, 'ahau, Kanokupolu and Ha'atafu) Coastal Unit 1.

The mangrove forest in Fo'ui is dying out - nearly two acres. This has allowed sea water to enter new properties further inland bring it close to the village by about 500 meters.

Ha'avakatolo requested if the project could assist with the clean-up of its polluted water spring (located at the seaward side) as it was previously used by community as source of fresh water for bathing.

Whist some people of Kolovai acknowledged their newly constructed seawall some claim that water still entering some properties during storm surges.

There was no major issue for 'Ahau apart from internal indifferences within their representatives.

For Kolovai, some portion of the existing seawall have had collapsed and requires immediate assistance. Also the culverts installed by the Pacific Adaptation to Climate Change (PACC) project have become dysfunctional and is longer serve the purpose as to why they were installed.

The same issue reported from Ha'atafu. Water entered the southern end to Kanokupolu during TC Harold. This is the lowest part of Ha'atafu and its representative recommended if the existing foreshore be reinforced and to be accompanied by planting of coastal trees such as Seta'u, Fotulona and Fao.

12.9 Meeting 5. Nuku’alofa Constituencies (Kolofo’ou, Kolomotu’a and Ma’ufanga) Coastal Unit 2.

Major issues affecting these areas include flooding, erosion and inundation. The most affected communities are Siesia, Popua and Sopu. Siesia is entangled by water. Residents can walk to Popua during low tided and when it is high tide they use small boats. Representative from Siesia reported that the Ministry of Infrastructure (MOI) last year dug up the mud from the shore and built their wall of mud and when storm surges took place during TC Harold small rocks and debris were thrown over and filled up the entire community. In their opinion, the idea of using the mud for their protection appears to be working. However, they reported that only 50% of the community was completed by MOI and the remaining 50% is yet to be covered.

As for Popua people has to fight the problem in two fronts. On the northern side, there is regular overtopping coming through the seawall. On the southern side to the lagoon, enters constantly during high tide and worst during strong wind and storm surges. To make things worse, most properties are lower than the road so water is trapped in those properties. This is why most properties are filled with water even during dry season. Meanwhile, participants shared the views that people in Popua and neighbouring villages should use gravel to fill their properties first and raise up the foundation of their houses. Some also suggested the installation of culvert while a few supported the idea of relocation to higher ground.

For Sopu it was reported that the existing seawall is getting lower each year allowing overtopping to occur on regular basis. In addition to this, people cut down trees on top of the seawall which weakened the structure of the seawall allowing the water to penetrate through the seawall. On the north western side of Sopu, water comes around at the corner to the western side and claimed the land from the landward side to Hofoa and Puke and there are only few meters of land remains before it reaches back to the sea at the northern side. Because of the water coming around western end of Sopu it also claims few household in Hofoa. Participants discussed and agreed that it is highly likely that the only solution for this problem is to construct a seawall all the way from Sopu to Kanokupolu or ‘Ahau.

Other areas like Kolofo’ou, Kolomotu’a, Havelu, Fanga and Tofoa experience the same problem of flooding during heavy rainfall.

12.10 Household Survey Questionnaire

Coastal Protection for North Coast Tongatapu Questionnaire

Pacific Community
Communauté du Pacifique
eCoast eTakutai
PLANIT Pacific Limited

Community interview form

1. Respondent details

Name of Village/Community	
Name of respondent	
Gender	
Age	

2. Family and household

a. How many people live in your house?	_______ Male _________ Female
b. How many work?	________ Full Time ________ Part time ________ Casual
c. Of those employed, how many are male and how many are female?	________ Male _____________ Female
d. How many unemployed?	________ (skilled/unskilled but no work available)
e. How many go to school?	_______ Pre-school _______ Primary _______ Secondary _______ Technical School _______ University

3. Land tenue

a. What is your current land tenure?

______ tax allotment ____ town allotment ______ leasehold

b. Total area of land leased? __________

4. Employment, income and education

a. What is your main paid job?		
b. Besides your main job do you have any other jobs?	**Yes**	**No**
c. If yes, please specify what skill or trade?		
d. Do others in your household have any other job skills or trade? If yes, what is it?		
e. Source of household income	**Description**	**Total income**
f. What is the main source of household income?		
g. Other sources of household income		

5. Persons with Disability/Challenges (Physical/Emotional)

a. Is there any person(s) living in your household with any form of disability (ie. Physically or emotionally challenged?	Yes	No

b. If yes, please specify what type of disability/challenge?	
c. Do they receive any assistance?	**Wheelchair** **Hearing aid** **Visual aids** **Educational assistance** **Ramps in the home** **Ramps in the public areas (beaches, parks in the community)** **Other** ______________________________

6. Gender-based Equality

a. Please specify the male and female role in your household (ie. Decision maker, main bread winner, fishing, house cleaning, cooking, looking after children, collecting aquatic products on the shoreline, etc:

Male:

____

Female:

____

b. Please specify the male/female role in your community (ie. Church leader, community leader, women's community group, disaster management and organising:

Male:

____

Female:

____

c. Are any women run committees within your community? If yes, what is the name of the committee and what roles does this committee play in your community:

____

____

d. Are there any youth groups within your community? If yes, what is the name of the youth groups and what roles do these youth groups play in your community:

____

____

7. Access to services

Where do you…

a. Take your sick family to see a Doctor and for medication?	
b. Go to wash your clothes?	
c. Get water from?	
d. Gather food (fishing, growing vegetables, etc).	
i. (for fishing, what are the main fish you catch?)	
ii. (for food, what are the main vegetables you grow?)	
e. Other activities	

8. Household services and infrastructure

a. What services or infrastructure do you have in your house?

	Yes/No	How many?	
i. Mobile			
ii. Solar panels			
iii. Generators			
iv. Boat			
v. Other			

9. Travel

1. Do you or your family member travel outside of your village/community for…

	Yes/No	Where?	How often?
i. Work			
ii. Education			
iii. Selling produce			
iv. Visiting relatives or friends			
v. Visiting doctor			
vi. Other reasons			

10. Health status

a. What kind of disease and/or other illness has been suffered by your family members in the last three months?

Malaria		Injuries	
Pneumonia		Diarrhoea	
Malnutrition		Other diseases	

If other, please specify

11. Existing socio-economic values

a. What do you value/what is important about the coastal setting and what do you not like/value? Are there any important features on the coastal zone that is significant to your village/community that needs to be protected?

Value	Description/ location	
	Fronting the foreshore (above the HWM)	**Coastal Zone**
i. Cultural/Religious areas (ie. Burial grounds, special foreshore areas for traditional		

ceremonies, fishing rituals etc)		
ii. Natural areas (ie. Mangrove areas used for traditional medicinal purposes, building materials (timber, sand), etc.)		
iii. Water sources **(ie. Desalination pipes, fishing ponds, etc)**		
iv. Food sources (fishing, growing vegetables).		
(for fishing, what are the main fish you catch?)		
(for food, what are the main vegetables you grow?)		
v. Other areas or features of importance: • Beach access (where?) • Built structures (where?) • Walking along the beach		

12. Coastal Zone Hazard

a. What interest do you have in the coastal zone?

Tick (if Relevant)

I live and/or own a property in (or near) the coastal zone	

I own a business in (or near) the coastal zone	
I frequently visit the coastal zone and make use of coastal amenities	
I occasionally visit the coastal zone and make use of coastal amenities	

b. Have you seen/experienced changes to the beachfront and/or within coastal watersheds.

No, these areas appear the same to be as they did when I first saw them	
Yes, I've seen minor changes in these areas	
Yes, I've seen major changes in these areas	
I don't know, I haven't been here long enough	

c. Have there been any major coastal events in your local community that has caused some concern for you and your family: If yes, please state the event and date/period?

____

____

d. What changes have you noticed?

	Yes/No	Where?	How often?
Erosion/loss of sand			
Sand accretion			
Loss of vegetation			
New vegetations			
Loss/changes to engineered structures or road			
Other reasons			

e. What happens during extreme storm event?

	Yes/No	How Often?	Can you recall dates/list them	To what extent?	
Does over-topping occur on your property or where nearby				(e.g. Spray into the property; Large volumes of discharge across the road and into your property, etc)	
Does your property flood during storm events?					

f. Disaster Response

a. Are there any early warning systems in your local community? **Ie. Sirens, weather reports, community leader warnings etc. Please specify.**	
b. Are there any disaster management procedures that you are aware of in your community? If yes, please specify.	
c. Is there an evacuation centre near you? If yes, please specify the name & location and	**Name & location of Evacuation Centre: ___________________** **Distance of Evacuation Centre to your house: _____________**

how long it takes to get to the evacuation centre from your house?	

g. What would you be happy to give up in order to address the increasing occurrence of over topping due to sea level rise?

Some views of the coast due to heightened protection structures	
Access to the coast to accommodate a wider buffer zone	
Other	

Community benefits

What community improvements do you most want to see within the coastal zone fronting your village/community?

	(Top 1-5)	Reasons
Sea walls via concrete		

Sea walls via gabion baskets (rocks filled in baskets)		
Beach restoration		
Rock groynes to protect sand movement along the beach		
Reclamation		
Replanting of Mangroves		
Planting of coastal vegetation		
Security of water sources ie. Rain water tanks		
Others		

13. Other comments

Do you have any other comments about the feasibility study for coastal protection and what you think should also be considered as part of this project?
