Situation Report
Tonga

Impact assessment of past climate change adaptation actions

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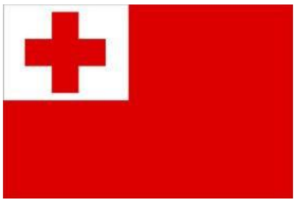

Impacts Assessment of Past Climate Change Adaptation Actions

Situation Report

Tonga

09.11.22

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1 Introduction

This report is structured in relation to the elements of climate change mitigation adaptation actions in Tonga which have elements in the GIS environment and within a relational database. Parallel to this status report there is a database documentation describing all tables and other elements (Access objects) of the database.

1.1 Visibility Impacts of Climate Change Adaptation Actions

Visibility is depending on the objects as well as on the sensor. Mangrove restoration for example is not visible during the first months after planting as the trees are too small to be visible within high reflecting water around them. When the mangroves start to grow and form a canopy the restoration area will be visible. Sensors like optical sensors, LiDAR or radar store different reflections or even direct radiation from the objects. These sensors can receive in different spatial and radiometric resolutions. Vegetation stress might not be visible but clearly shown in the near infrared of the spectrum.

1.2 Documentation Tools

The project requires to report change to see the impact of climate change adaptation and mitigation measures. In this case the time of observations have to be defined and documented as well as the geographical reference. The later is often neglected and change cannot be quantified.

1.2.1 The Common Reference in Tonga

GRID:	Tonga Map Grid
PROJECTION:	Transverse Mercator
SPHERIOD:	GRS80
UNIT OF MEASURE:	Metre
MERIDIAN OF ORIGIN:	177 degrees W of Greenwich
LATITUDE OF ORIGIN:	0 degrees (Equator)
SCALE FACTOR AT ORIGIN:	0.9996
FALSE COORDINATES:	1 500 000 m East
	5 000 000 m North
DATUM:	Tonga Geodetic Datum 2005

Figure 1.2.1-01: *Specifications of the 1:50,000 Topographic map of the Kingdom of Tonga*

The spatial common basis found so far is (A) the 1:50.000 Tonga Topographic Map, published by the Ministry of Lands, Survey, Natural Resources and Environment of the Kingdom of Tonga.

The map has clearly defined specifications printed on the map. The former map containing editing instructions was replaced by Tonga Lands Department with a clean version. Details of the map see Appendix A .- Cartographic Base 1:50,000

(B) There are also map sheets available on the internet at 1:25,000 scale which is detailed in Appendix B - Cartographic Base 1:25,000. The available map sheets do not have the appropriate resolution and should be replaced with properly scanned backdrops.

1.2.2 Common GIS Backdrop

The 1:50,000 scale map of the Tonga Lands Department provided a high resolution scan of the topographic and the projection information used in Tonga's GIS environment. The projection parameters are shown in figure 1.2.1-01. The scan was digitally cut out of the map content without legend, etc., geocoded and installed as a GIS backdrop.

All features digitised in a layer superimposed on this GIS backdrop automatically have the Tonga Map Grid (TMG) coordinates. When features are exported to KML format they are automatically recalculated to UTM WGS 84. The method was tested with features digitised on the GIS backdrop and then superimposed over Google Earth display and vice versa. At 1:50,000 scale it works well.

1.2.3 Database

All items visible in the GIS environment are stored in a relational database keeping all annotation information. Annotation information is quantitative or descriptive data specifying the object. For example for the revetment in Ahau (see chapter 3.3 and figure 3.3-02 and 3.3-03) the GIS calculates the lengths and the position coordinates. The condition and the time of the survey will be stored, for this example, in the “revetment table” of the database.

2 Overview Climate Change Adaptation Measures Tonga

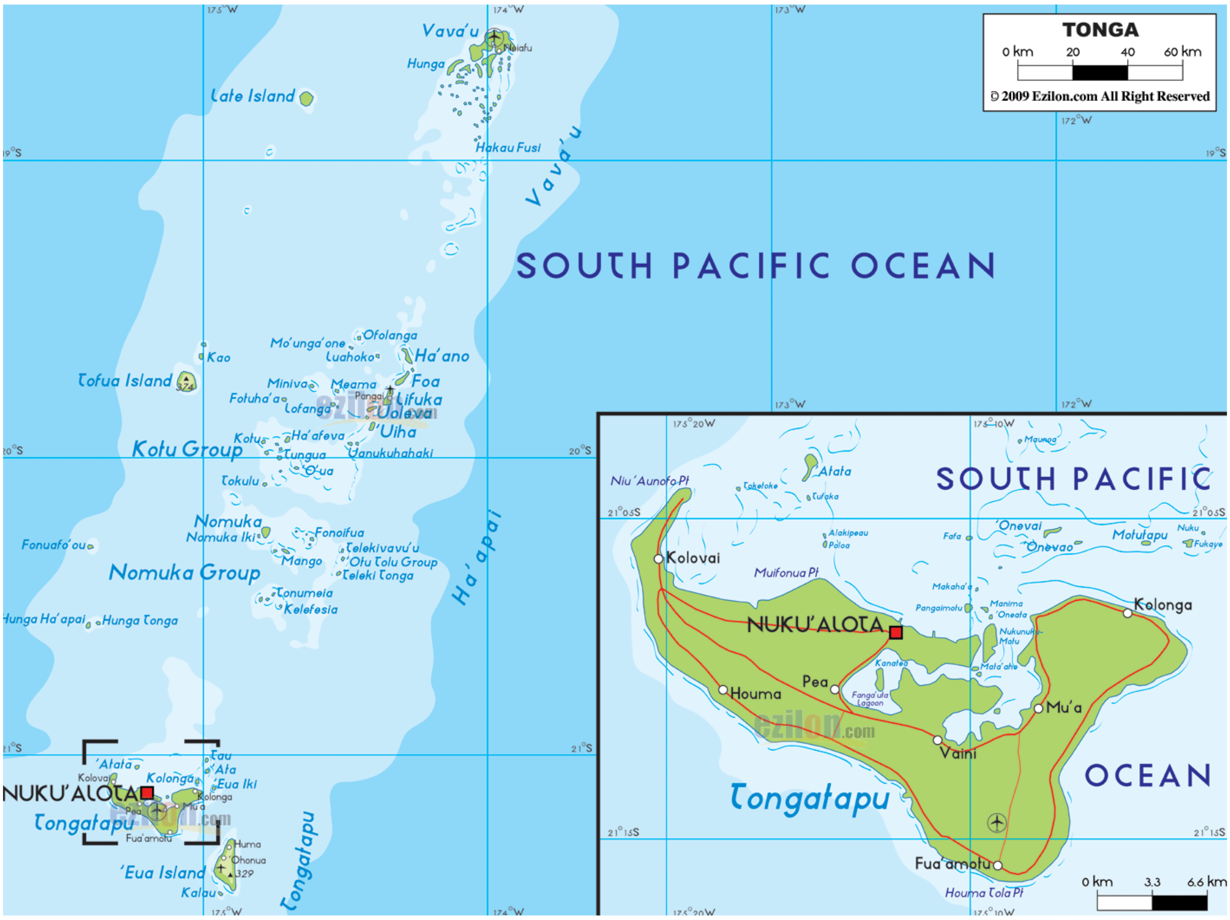


Figure 2-01: *Location of Tongatapu (internet display)*

There are several different climate change mitigation or adaptation measures in Tonga. (i) Revetments were established along the northern coast of Tongatapu and described in the corresponding chapter “Revetments”, (ii) groyens were created in Ahau, Nukuleka, Navutoka, Kolonga, Hahake District and Tukutonga. (iii) Breakwaters have been successfully implanted in the north east of Nukualofa and (iv) mangrove restoration took place in the north west of Nuku’alofa. (v) Finally the improvement of water supply including rainwater harvesting was invested and implemented.

3 Revetments

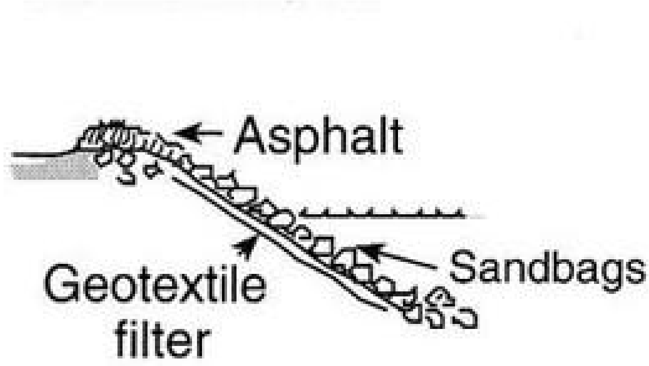


Figure 3.1-01 *Construction of a Revetment*

The project documents reported several revetments where the first one was completed in 2015 in Ahau and re-produced and completed in 2020. The others are in the north eastern part of Tongatapu.

3.1 Purpose of Lagoon Revetment

In coastal engineering revetments are sloping structures placed on banks or cliffs in such a way as to absorb the energy of incoming water. Coastal revetments are usually built to preserve the existing uses of the shoreline and to protect the slope, as defence against erosion[1]. Coastal revetments are supposed to also stop frequent inundation and stabilise the beach-line. The water between land and the revetment has less turbulence which induces more sediments which then enhances the condition for mangroves.

3.2 Visibility of Impact

If the revetments protect the area behind and results in increased sedimentation new mangroves should be visible. There is no increase of vegetation visible yet. The image recorded 2 years after the revet establishment does not show additional mangrove areas. However, there are many factors influencing (i) the visibility of mangroves in satellite image data and (ii) the successful mangrove planting such as drainage, micro relief, species, salinity, etc.

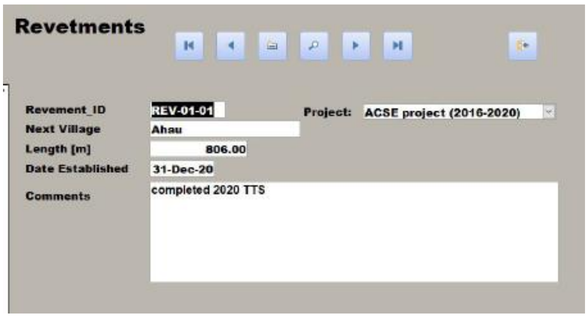
The GIS element “Revetment Ahau” can be exported to Google Earth and utilised in one or two years when the revetment might be difficult to see but it will allow to monitor the area behind.

Figure 3.3-01*: Location of the constructed revetments in Tongatapu. The location of the revetments REV-02 and REV-03 are unclear.*

3.3 Revetment Locations and Unique IDs

To link the information of a database with the corresponding map elements in GIS environment all revetments. For the time being a system is used where the first three digits indicate the type of climate mitigation element, which is “REV” for revetments. The next two digits “01” are showing a running number of the mitigation element.

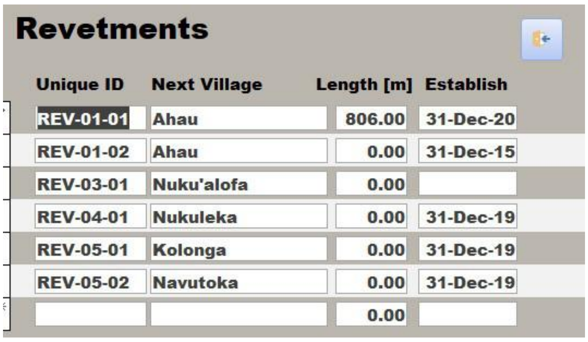
1 See https://en.wikipedia.org/wiki/Revetment



Revetments

Revement_ID	REV-01-01	Project:	ACSE project (2016-2020)
Next Village	Ahau		
Length [m]	806.00		
Date Established	31-Dec-20		
Comments	completed 2020 TTS		

***Figure 3.3-02**: Revetment table of the relational database behind a columnar form*



Revetments

Unique ID	Next Village	Length [m]	Establish
REV-01-01	Ahau	806.00	31-Dec-20
REV-01-02	Ahau	0.00	31-Dec-15
REV-03-01	Nuku'alofa	0.00	
REV-04-01	Nukuleka	0.00	31-Dec-19
REV-05-01	Kolonga	0.00	31-Dec-19
REV-05-02	Navutoka	0.00	31-Dec-19
		0.00	

***Figure 3.3-03**: Revetment table of the relational database behind a tabular displaying form*

So far all climate change adaptation action infrastructure elements in Tongatapu are within these areas shown.

3.4 Lagoon Revetment at Ahau (REV-01)

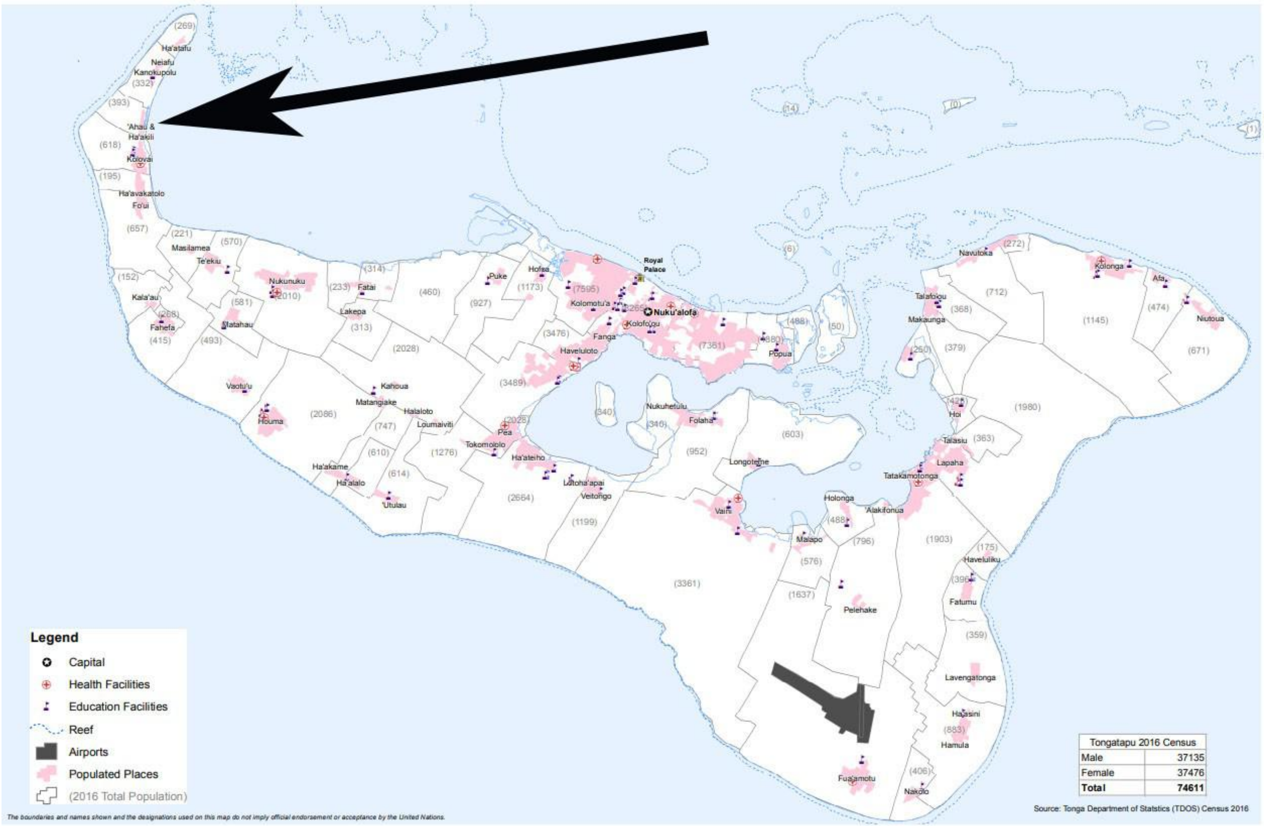


***Figure 3.4-01:** Location of Ahau on Tongatapu*

The Ahau revetment was listed in the "Tonga Trekking Sheet" as completed 2020.

Ahau is located 16 km east of Nukualofa. Mangrove utilisation caused erosion before 2000, visible on historical aerial photographs[2].

2 "Potential of IKONOS Image Data to visualise land degradation and coastal erosion" Pacific GIS&RS Newsletter 2001, Issue 1, Page 20 *http://www.picgisrs.org/wp-content/uploads/2018/05/0101.pdf*

Figure 3.4-02: *Satellite view of Ahau (Ha'akili) recorded in May 2021 shows that the revetment starts to be covered by plants*

Figure 3.4-03: *Satellite view of Ahau (Ha'akili) recorded in July 2019 shows clearly the revetment established.*

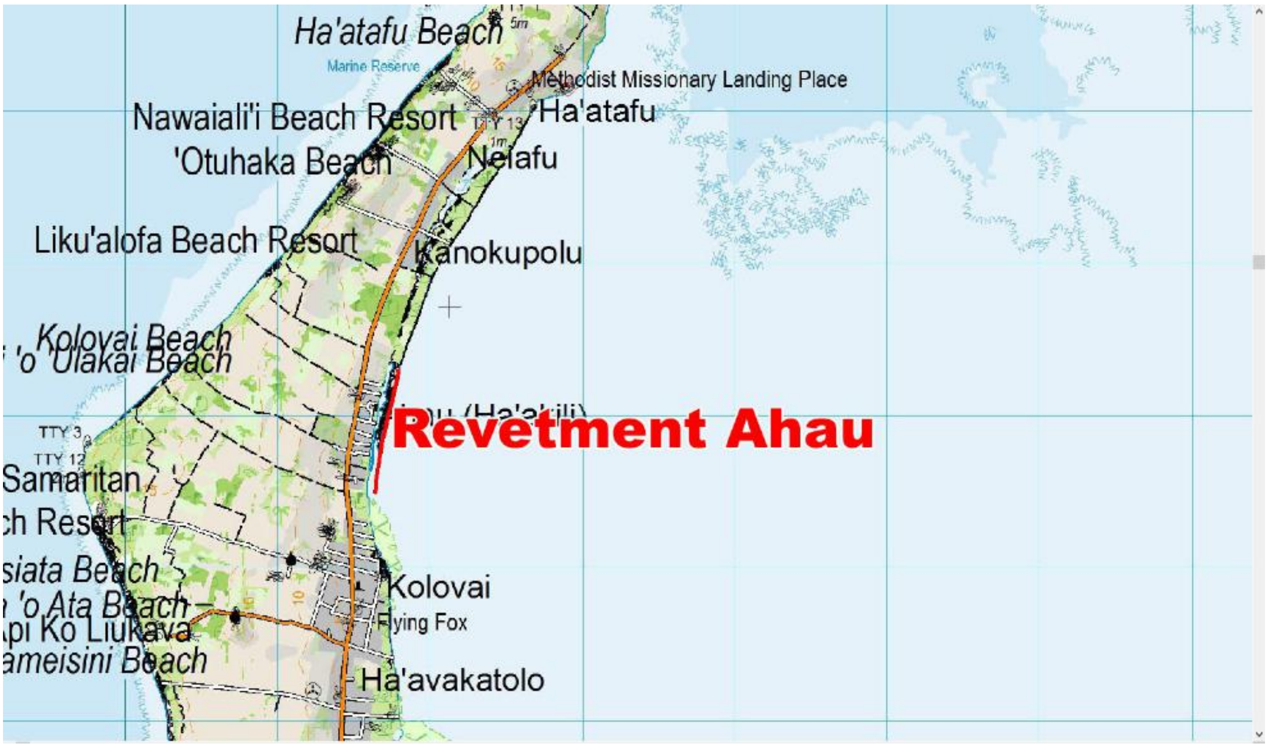


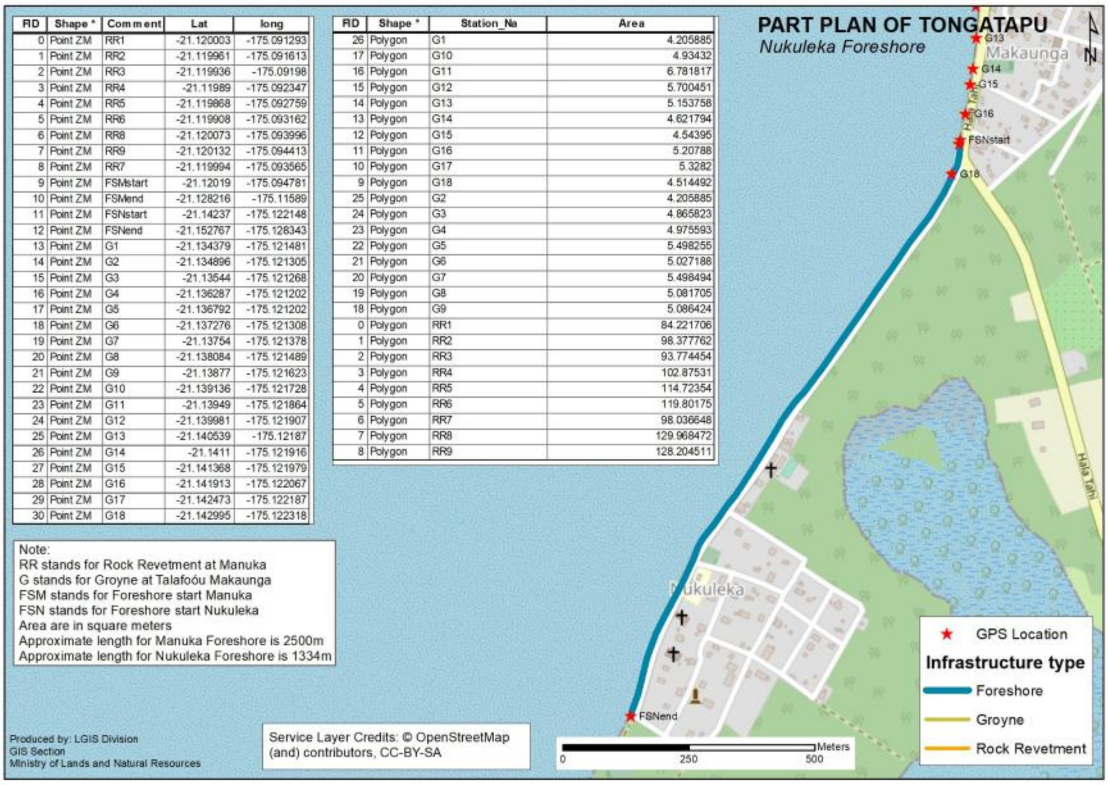
Figure 3.4-04: *After digitising the revetment of Ahau on Google Earth display the line element was imported to GIS. The GIS elements allow labels (Revetment Ahau) and the calculation of the length (806 metres).*

3.5 Revetment at Nukuleka (REV-05)

Figure 3.5-01: *Nukuleka recorded July 2021. A revetment is currently not visible with very high resolution image data.*

Figure 3.5-02: *Nukuleka recorded in June 2016*

Figure 3.5-03: *Nukuleka recorded in June 2009*



FID	Shape *	Comment	Lat	long
0	Point ZM	RR1	-21.120003	-175.091293
1	Point ZM	RR2	-21.119961	-175.091613
2	Point ZM	RR3	-21.119936	-175.09198
3	Point ZM	RR4	-21.11989	-175.092347
4	Point ZM	RR5	-21.119868	-175.092759
5	Point ZM	RR6	-21.119908	-175.093162
6	Point ZM	RR8	-21.120073	-175.093996
7	Point ZM	RR9	-21.120132	-175.094413
8	Point ZM	RR7	-21.119994	-175.093565
9	Point ZM	FSMstart	-21.12019	-175.094781
10	Point ZM	FSMend	-21.128216	-175.11589
11	Point ZM	FSNstart	-21.14237	-175.122148
12	Point ZM	FSNend	-21.152767	-175.128343
13	Point ZM	G1	-21.134379	-175.121481
14	Point ZM	G2	-21.134896	-175.121305
15	Point ZM	G3	-21.13544	-175.121268
16	Point ZM	G4	-21.136287	-175.121202
17	Point ZM	G5	-21.136792	-175.121202
18	Point ZM	G6	-21.137276	-175.121308
19	Point ZM	G7	-21.13754	-175.121378
20	Point ZM	G8	-21.138084	-175.121489
21	Point ZM	G9	-21.13877	-175.121623
22	Point ZM	G10	-21.139136	-175.121728
23	Point ZM	G11	-21.13949	-175.121864
24	Point ZM	G12	-21.139981	-175.121907
25	Point ZM	G13	-21.140539	-175.12187
26	Point ZM	G14	-21.1411	-175.121916
27	Point ZM	G15	-21.141368	-175.121979
28	Point ZM	G16	-21.141913	-175.122067
29	Point ZM	G17	-21.142473	-175.122187
30	Point ZM	G18	-21.142995	-175.122318

FID	Shape *	Station_Na	Area
26	Polygon	G1	4.205885
17	Polygon	G10	4.93432
16	Polygon	G11	6.781817
15	Polygon	G12	5.700451
14	Polygon	G13	5.153758
13	Polygon	G14	4.621794
12	Polygon	G15	4.54395
11	Polygon	G16	5.20788
10	Polygon	G17	5.3282
9	Polygon	G18	4.514492
25	Polygon	G2	4.205885
24	Polygon	G3	4.865823
23	Polygon	G4	4.975593
22	Polygon	G5	5.498255
21	Polygon	G6	5.027188
20	Polygon	G7	5.498494
19	Polygon	G8	5.081705
18	Polygon	G9	5.086424
0	Polygon	RR1	84.221706
1	Polygon	RR2	98.377762
2	Polygon	RR3	93.774454
3	Polygon	RR4	102.87531
4	Polygon	RR5	114.72354
5	Polygon	RR6	119.80175
6	Polygon	RR7	98.036648
7	Polygon	RR8	129.968472
8	Polygon	RR9	128.204511

Figure 3.5-04: *Nukuleka as screen dump of a map created by Lands Department Tonga.*

3.6 Revetment at Navutoka (REV-07)

Figure 3.6-01: *Navutoka recorded in July 2021.*

Figure 3.6-02: *Navutoka recorded in January 2018*

Figure 3.6-03: *Navutoka recorded in June 2009*

3.7 (REV-06) Revetment at Kolonga

Figure 3.7-01: *Kolonga recorded from space in July 2021*

Figure 3.7-02: *Kolonga recorded from space in June 2016*

Figure 3.7-03: *Kolonga recorded from space in September 2009*

For the coastline in front of the villages Kolonga, Navutoka and Nukuleka image data are available recorded in 2021. This is just two years after finishing the construction. There is the possibility that the revetments are already covered with vegetation as fast vegetation overgrow is also visible with the Ahau revetment see figure 3.4-05.

As a next step these three revetments should be surveyed with GNSS equipment suitable for 1:10,000 scale mapping[3]. This can be performed in half a day and will provide exact location in GIS

3 GNSS equipment for 1:10,000 scale mapping are (GPS) receivers allowing to receive satellite information from American, European and Russian satellites and enable differential correction with the

environment and the exact length of the revetment. Other information requirements would be (i) the exact date of construction completion as it might be a relevant time difference if the revetment is built in the beginning or by end of the year; (ii) a detailed description or better photos as the type of material influences the sun reflection and subsequently the visibility in space borne image data.

The following images created from GIS displays show the location of rock revetments.

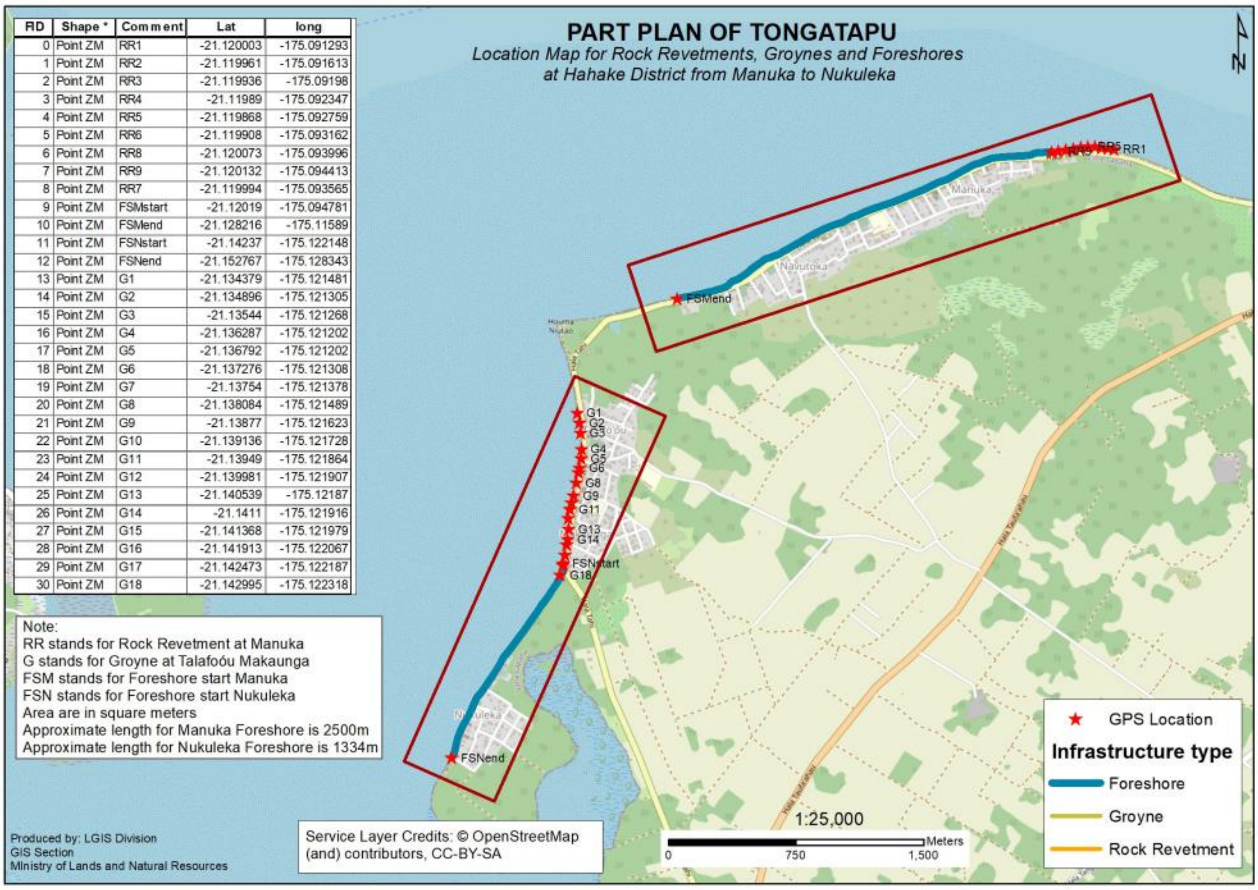


Figure 3.7-04: *Screen dump of a GIS display showing the location of rock revetments at Manuka (upper left of the figure).*

base station of the Tonga Lands Department.

3.8 (REV-02) Rock Revetments Hahake District

It was stated that rock revetments in parts of the coast of Hahake district were built with a mix of coastal planting of mangroves and salt tolerant plants for the sand groynes, complimented these engineering structures to safeguard at risk communities from imminent flooding, storms, and sea level rise.

The elements were not visible yet.

3.9 Revetments in Tukutonga (REV-04)

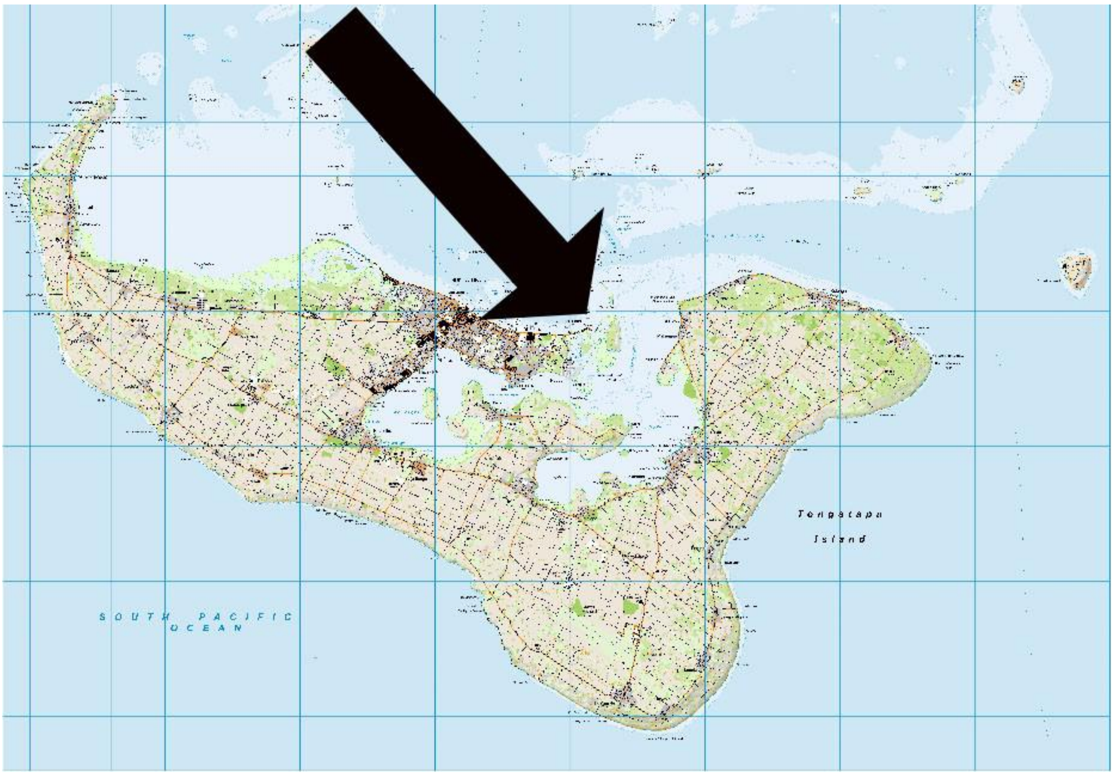


Figure 3.9-01 *Tukutonga location on 1:50,000 topographic map*

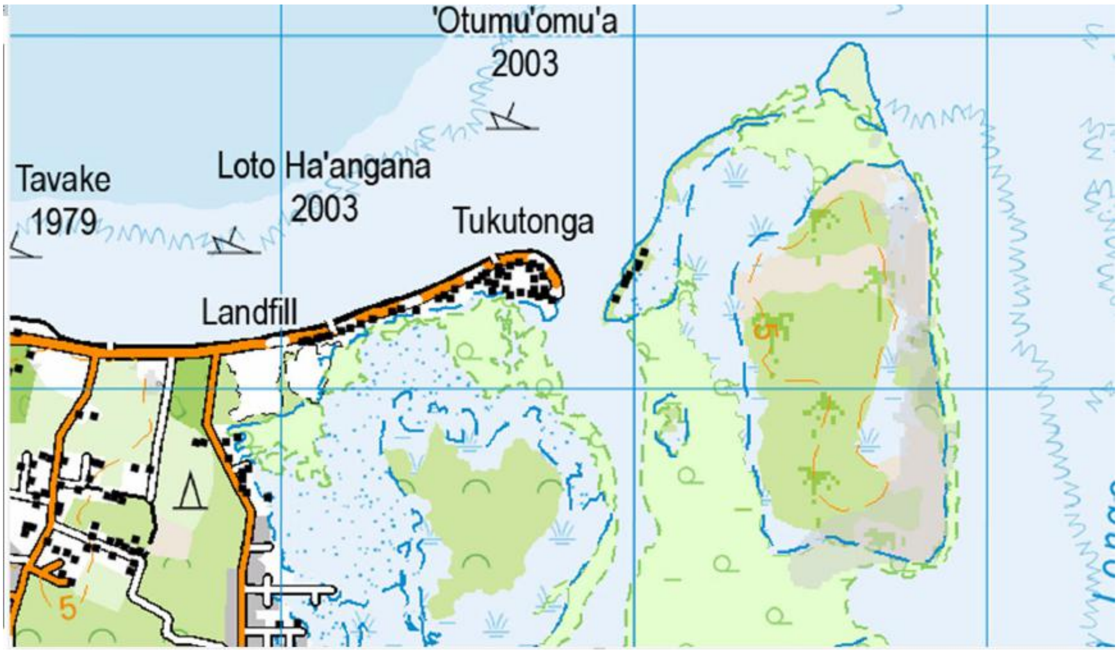


***Figure 3.9-02** Tukutonga location on 1:50,000 topographic zoom in*

***Figure 3.9-03** Tukutonga revetments satellite image data 22 July 2021*

Figure 3.9-04 *Tukutonga revetments satellite image data 21 April 2020*

Figure 3.9-05 *Tukutonga revetments satellite image data 01 December 2018*

Figure 3.9-06 *Tukutonga revetments satellite image data 02 June 2016*

Figure 3.9-07 *Tukutonga revetments satellite image data 18 July 2014*

Figure 3.9-08 *Tukutonga revetments satellite image data 05 September 2005*

Figure 3.9-09: *Possible revetment digitised on Google Earth display*

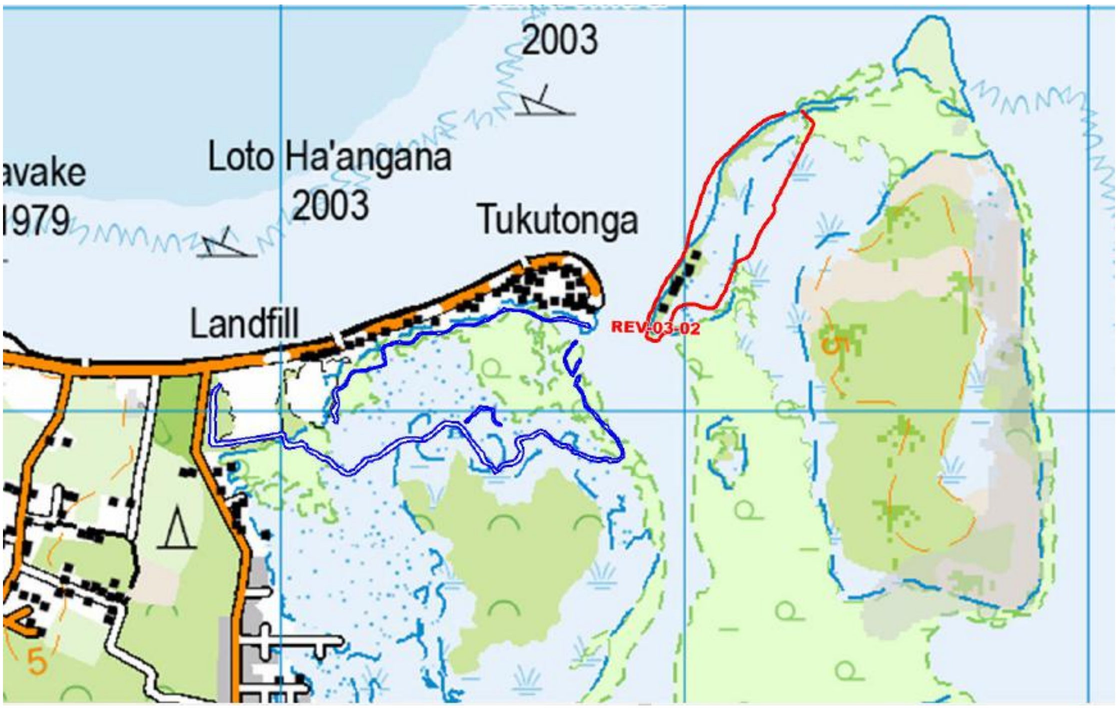


Figure 3.9-10: *Possible revetment and channels in GIS environment. Channels blue, revetment red*

The appearance in the satellite image indicates a revetment. This has to be verified through field work see figure 3.9-11. For the time being this revetment of 1,480.3 metre is in GIS and database. It has to be discussed if channels are elements of the past climate change adaptation action infrastructure. They definitely need maintenance and management. They were digitised from the Google Earth display visible through the blue colour.

Figure 3.9-11: *UAV borne image data of revetments and channels. Image of Lands Department Tonga*

4 Groynes

Groynes have been planned at several locations in Tonga.

4.1 History, Function and Visibility of Groynes

One of the worlds largest wadden sea[4] is the North Sea in front of Germany and the Netherlands. Groynes are used for nearly 200 years to protect the shoreline and at the same time to win land from the sea.

A groyne, built perpendicular to the shore, is a rigid hydraulic structure built from an ocean shore[5] that interrupts water flow and limits the movement of sediment. It is usually made out of wood, concrete, or stone. Groynes can create beaches, prevent beach erosion caused by longshore drift where this is the dominant process and facilitate beach accumulation[6], see figure 4.1-01.

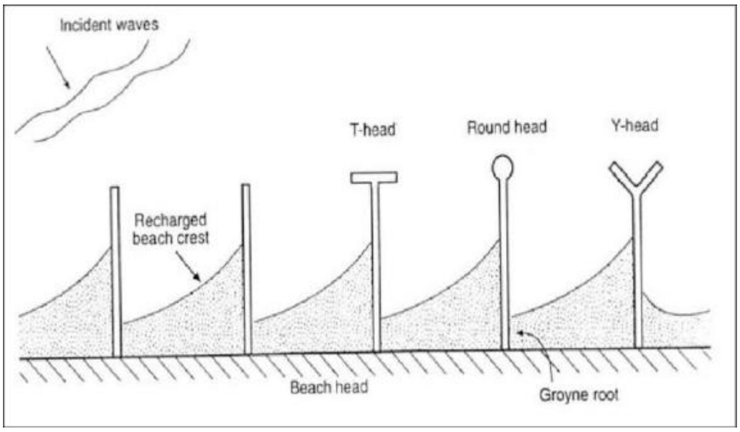


Figure 4.1-01:

***Figure 4.1-02:** Beach groynes in Portugal*

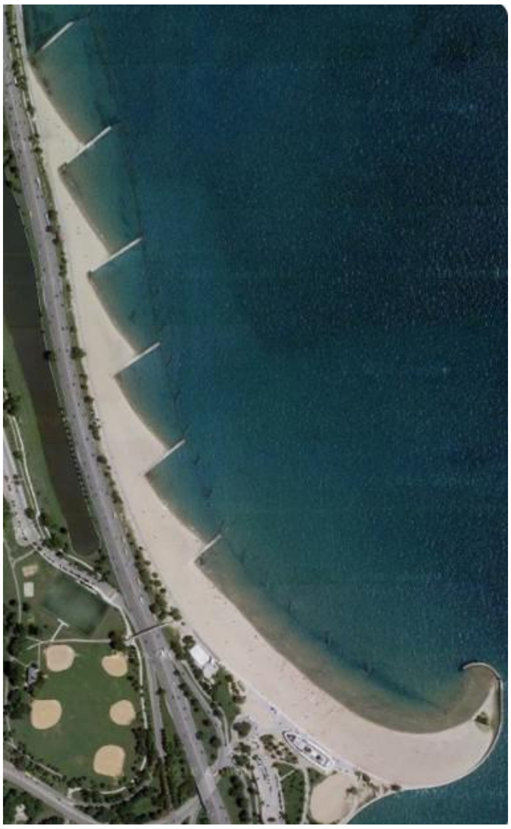


***Figure 4.1-03:** Satellite image of groynes with accumulated sand.*

The accumulated sand has a typical pattern and is visible with VHR[7] space borne image data even if the groynes itself might be not visible.

4 Wadden sea or mud flat sea
5 There are also river groynes to deepen the middle of the river by speeding central the river flow
6 Wikipedia
7 VHR = **v**ery **h**igh **r**esolution image data are image data less than 1 m spatial resolution.

4.2 Monitoring of Groynes and Impact of Groynes

At the shore of the North Sea in Netherlands and Germany coastal protection and land reclamation has a long history as mentioned before. Land reclamation is a work for generations. One essential factor is the maintenance of groynes. Not only waves and storms weaken the mostly wooden poles also biotic factors require observation and maintenance[8] and saltwater can corrode all non wooden materials.

A proper maintenance requires that all groynes are registered and observed as separate objects. This is best performed through a database. Currently it seems that this is not the case and the project database could be a start.

4.3 Permeable Groynes at Talafoou and Makaunga Villages

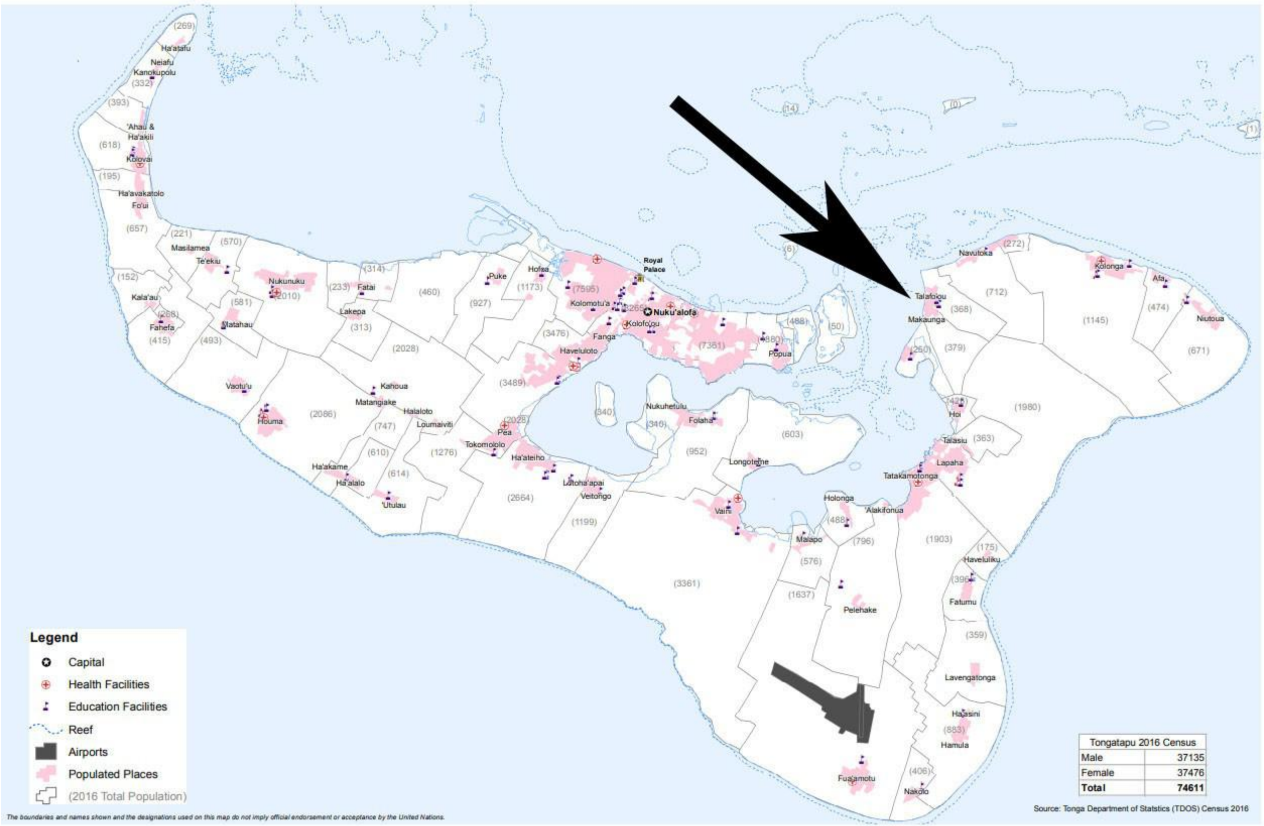


Figure 4.3-01: *Location of Talafoou and Makaunga Village on Tongatapu Island.*

The project document states that 20 permeable groynes were established at Talafoou and Makaunga villages.

8 For example a naval shipworm (Teredo navalis) can destroy complete groynes

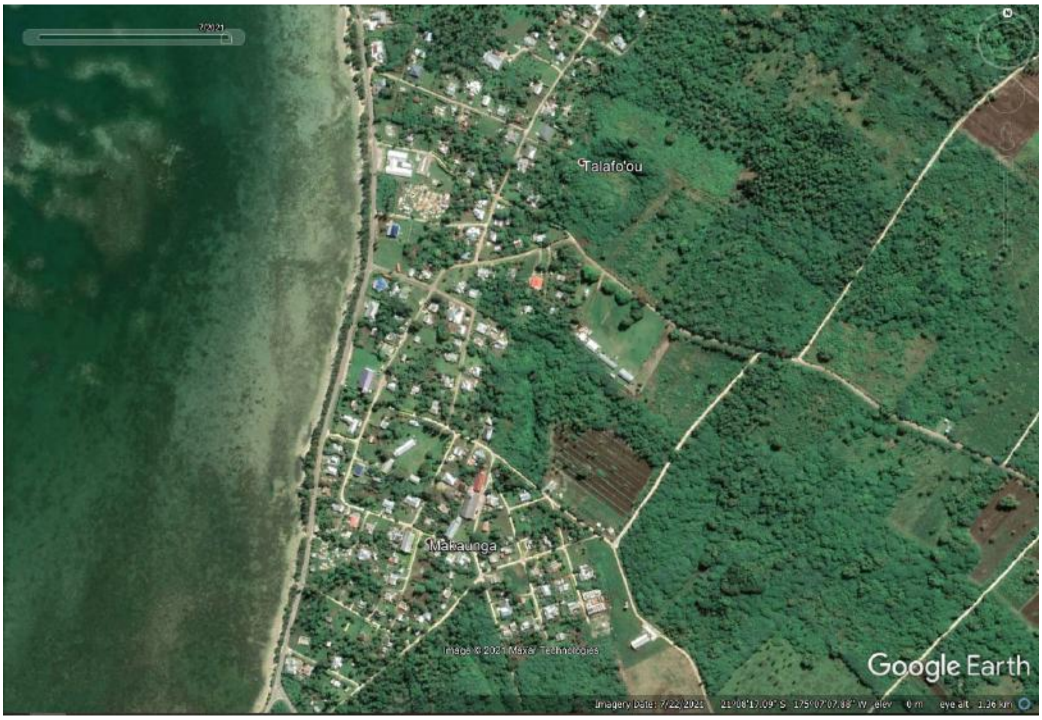


Figure 4.3-03: *Beach of Talafoou and Makaunga village 22/07/21*

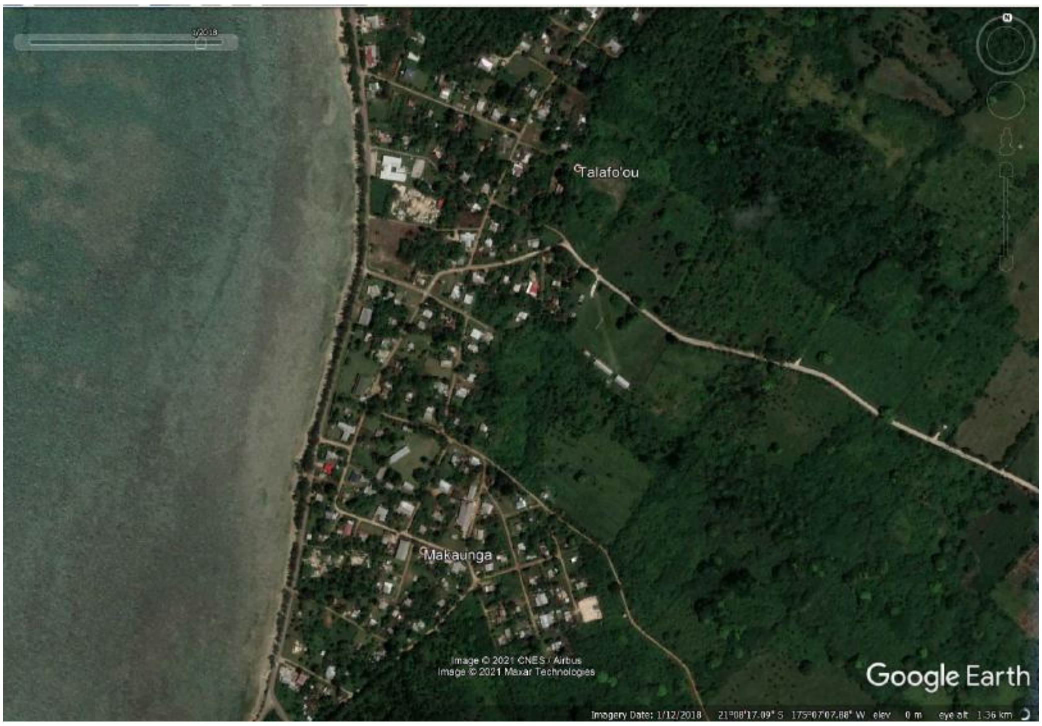


Figure 4.3-04: *Beach of Talafoou and Makaunga village 12/01/18*

Figure 4.3-05: *Beach of Talafoou and Makaunga village 19/05/16*

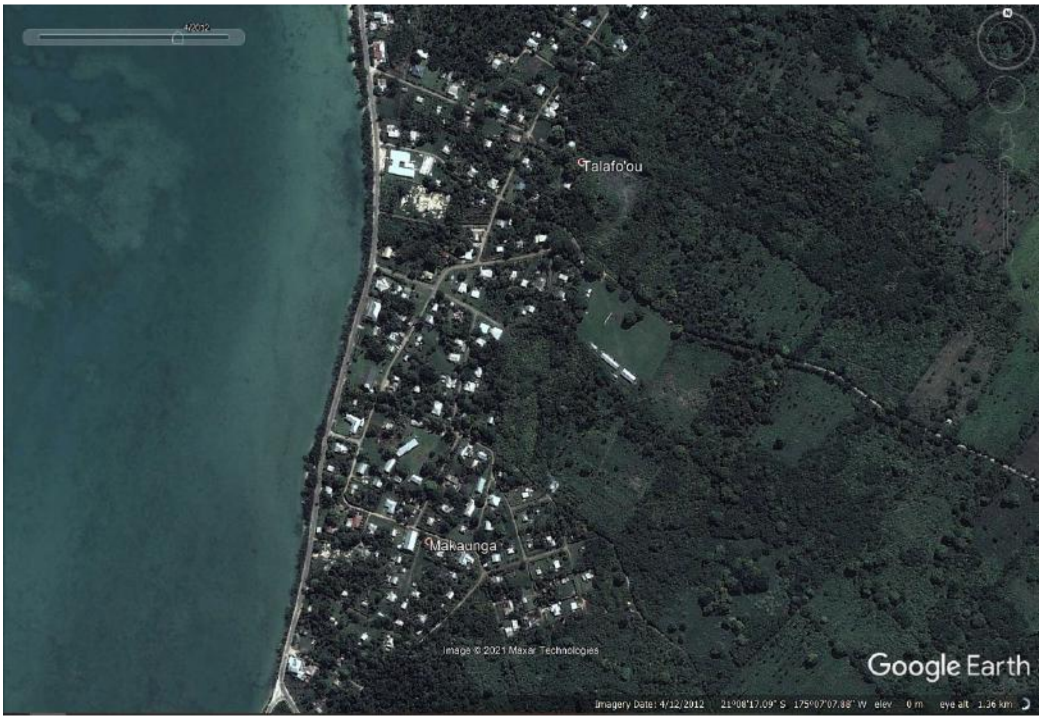


Figure 4.3-06: *Beach of Talafoou and Makaunga village 12/04/12*

An impact of the beach permeable groynes at Talafoou and Makaunga Village is not visible in the VHR image data of Google Earth. The display of image data captured from the same area in 2012, 2016, 2018 and 2021 does not document coastal change.

4.3.1 Mapping with Very Resolution Satellite Image Data

The Mapping

Figure 4.3.1-01: *Satellite image data of 15 cm spatial resolution allow the identification of the groynes established during the last years.*

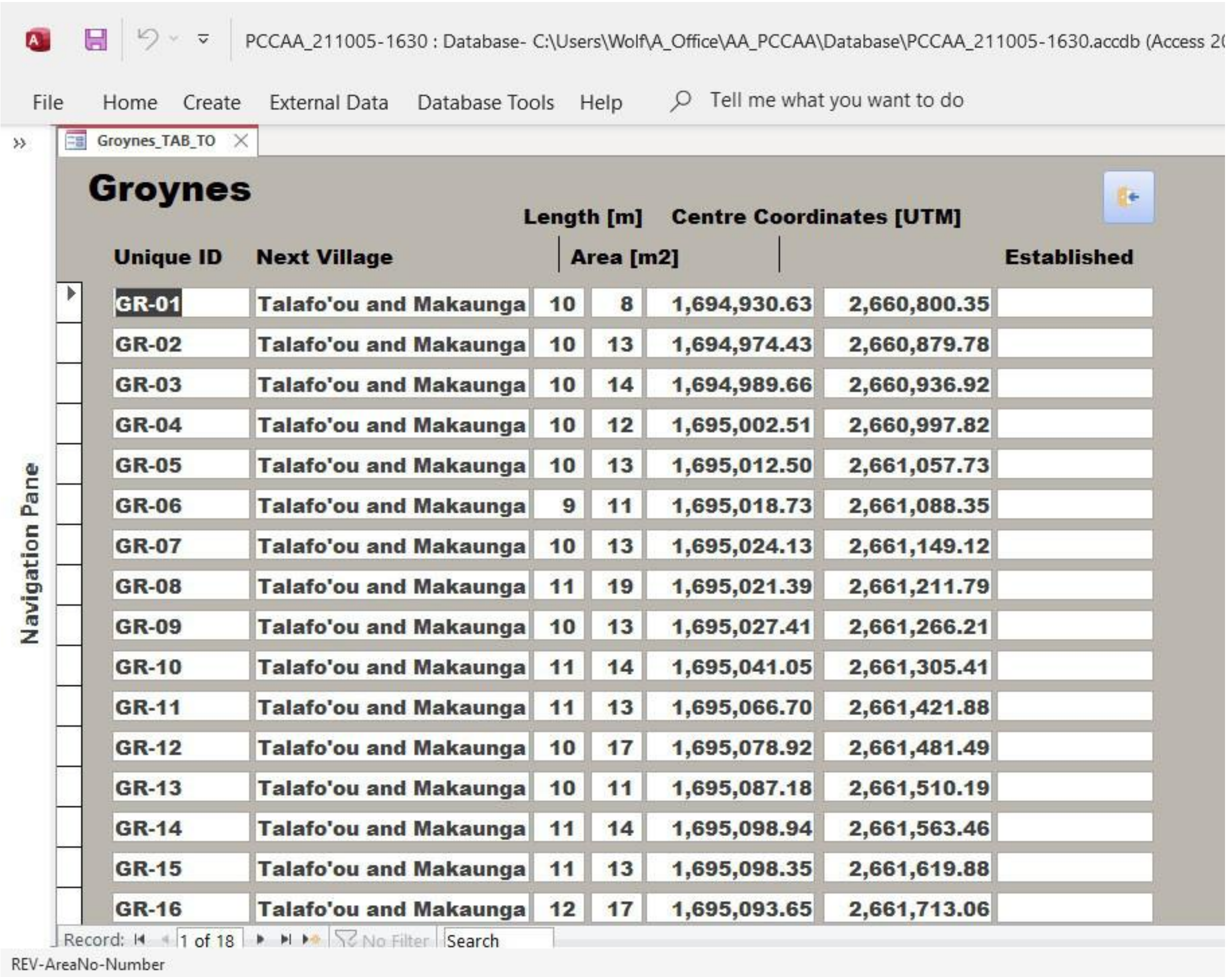
Figure 4.3.1-02: *A GIS based estimation of length and area is possible.*

Figure 4.3.1-03: *Display of groyne of image subset 02. Every groyne has a unique ID. The corresponding GIS layers allow a zoom in, see figures 4.3.1-01*

The groynes were mapped, the length, the area and the UTM coordinates of the centroid were calculated in the database keeping all climate change adaptation infrastructure elements.

The database does not keep information showing a real quality assessment as this is difficult with the remote sensing data currently in use. Here a link to the terrestrial assessment will also allow to store ranking of functionality. However, the length and area over time provides a rough indicator of maintenance requirement.

Figure 4.3.1-04: *Display of groyne of image subset 03*


PCCAA_211005-1630 : Database- C:\Users\Wolf\A_Office\AA_PCCAA\Database\PCCAA_211005-1630.accdb (Access 2(

File Home Create External Data Database Tools Help Tell me what you want to do

Groynes_TAB_TO

Navigation Pane

Groynes

Unique ID	Next Village	Length [m]	Area [m2]	Centre Coordinates [UTM]		Established
GR-01	Talafo'ou and Makaunga	10	8	1,694,930.63	2,660,800.35	
GR-02	Talafo'ou and Makaunga	10	13	1,694,974.43	2,660,879.78	
GR-03	Talafo'ou and Makaunga	10	14	1,694,989.66	2,660,936.92	
GR-04	Talafo'ou and Makaunga	10	12	1,695,002.51	2,660,997.82	
GR-05	Talafo'ou and Makaunga	10	13	1,695,012.50	2,661,057.73	
GR-06	Talafo'ou and Makaunga	9	11	1,695,018.73	2,661,088.35	
GR-07	Talafo'ou and Makaunga	10	13	1,695,024.13	2,661,149.12	
GR-08	Talafo'ou and Makaunga	11	19	1,695,021.39	2,661,211.79	
GR-09	Talafo'ou and Makaunga	10	13	1,695,027.41	2,661,266.21	
GR-10	Talafo'ou and Makaunga	11	14	1,695,041.05	2,661,305.41	
GR-11	Talafo'ou and Makaunga	11	13	1,695,066.70	2,661,421.88	
GR-12	Talafo'ou and Makaunga	10	17	1,695,078.92	2,661,481.49	
GR-13	Talafo'ou and Makaunga	10	11	1,695,087.18	2,661,510.19	
GR-14	Talafo'ou and Makaunga	11	14	1,695,098.94	2,661,563.46	
GR-15	Talafo'ou and Makaunga	11	13	1,695,098.35	2,661,619.88	
GR-16	Talafo'ou and Makaunga	12	17	1,695,093.65	2,661,713.06	

Record: 1 of 18 No Filter Search

REV-AreaNo-Number

Figure 4.3.1-05: *Database display of information stored for groynes in Tonga.*

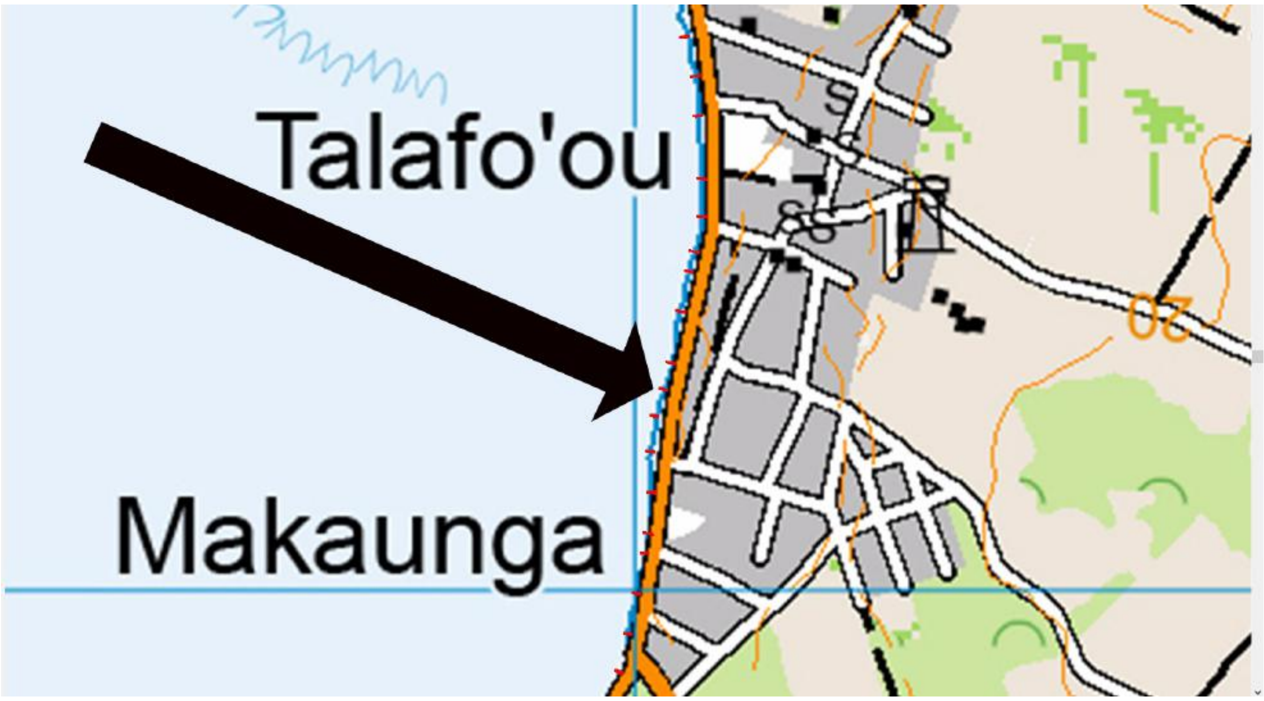


Figure 4.3.1-06: *Display GNSS survey of groynes carried out by Tonga Lands Department (red)*

5 Breakwaters

Breakwaters are structures constructed near the coasts as part of coastal management or to protect an anchorage from the effects of both weather and longshore drift. Breakwaters are structures constructed water-ward of, and usually parallel to, the shoreline. Seawalls are vertical structures, constructed parallel to the ocean shoreline on land[9].

A detached breakwater is defined as a hard shore-parallel structure protecting a section of the shoreline by forming a shield to the waves (blocking of incident wave energy). The crest may be positioned above the still water level (emerged) or below the still water level (submerged) and has a width of the order of the local water depth[10].

5.1 Visibility of Breakwaters

“Normal” breakwaters protecting anchorage are clearly visible with VHR space borne images. To be stable they must have a width which allows interpretation even with image data for 1:50,000 scale level such as Sentinel.

Figure 5.1-01: *Breakwater at Suva Point during high tide*

Detached breakwaters might be submerged and during this time the visibility is very limited.

Figure 5.1-03: *Detached breakwater (internet)*

Figure 5.1-02: *Breakwater at Suva Point from space recorded with VHR image data in January 2020 (Google Earth)*

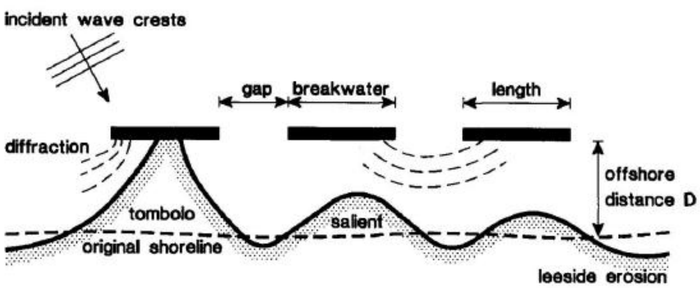


Figure 5.1-04: *Detached breakwater beach accumulation (copied from Leo C. van Rijn)*

The impact of detached breakwaters must be visible as the coastline will change by accumulating sand on the part of the beach facing the breakwater, see figure 5.1-03 and 5.1-04.

9 Wikipedia
10 DETACHED BREAKWATERS by Leo C. van Rijn; www.leovanrijn-sediment.com

5.2 Maintenance of Breakwaters and Database Handling

Literature[11] states: “Disadvantages of detached breakwaters are the relatively high construction and maintenance costs. Maintenance of detached breakwaters generally is relatively high, because of settlement of the structures due to impact loads and scour and the necessity of floating equipment for repair.” Like groynes the high maintenance results in monitoring every single element of a detached or other breakwater.

So far breakwaters are handled in summary. There is a need to monitor every construction separately. This is performed in the GIS environment were the polygons created on Google Earth display where imported as KML file into the GIS layer breakwaters.

Figure 5.2-01: *All e.g. Manuka breakwaters visible in the image data where digitised and imported to GIS as single map element in the layer “breakwaters”. There is also table breakwaters in the relational database where every breakwater has an own record.*

Breakwaters

Unique ID	Next Village	Length [m]	Establish
BW-03-01	Seisia	0.0	
BW-05-01	Manuka	0.0	
BW-05-02	Manuka	0.0	
BW-05-03	Manuka	0.0	
BW-05-04	Manuka	0.0	
BW-05-05	Manuka	0.0	
BW-05-06	Manuka	0.0	
BW-05-07	Manuka	0.0	
BW-05-08	Manuka	0.0	
BW-05-09	Manuka	0.0	

Figure 4.2-02: *All all records of the table breakwaters displayed by an Access form*

The table so far only contains the unique ID, length and date of construction. Later monitoring data will be added and the impact of the construction.

The impact would be the amount of sand accumulated at the shoreline which is a quantitative value.

11 DETACHED BREAKWATERS by Leo C. van Rijn; www.leovanrijn-sediment.com

5.3 Detached Breakwaters East of Manuka

"Detached breakwaters were established east of Manuka in total 10 breakwaters" is stated in the documents.

Nine of these 10 detached breakwaters were visible in the image data and showed visible impact on the coastline through beach accumulation.

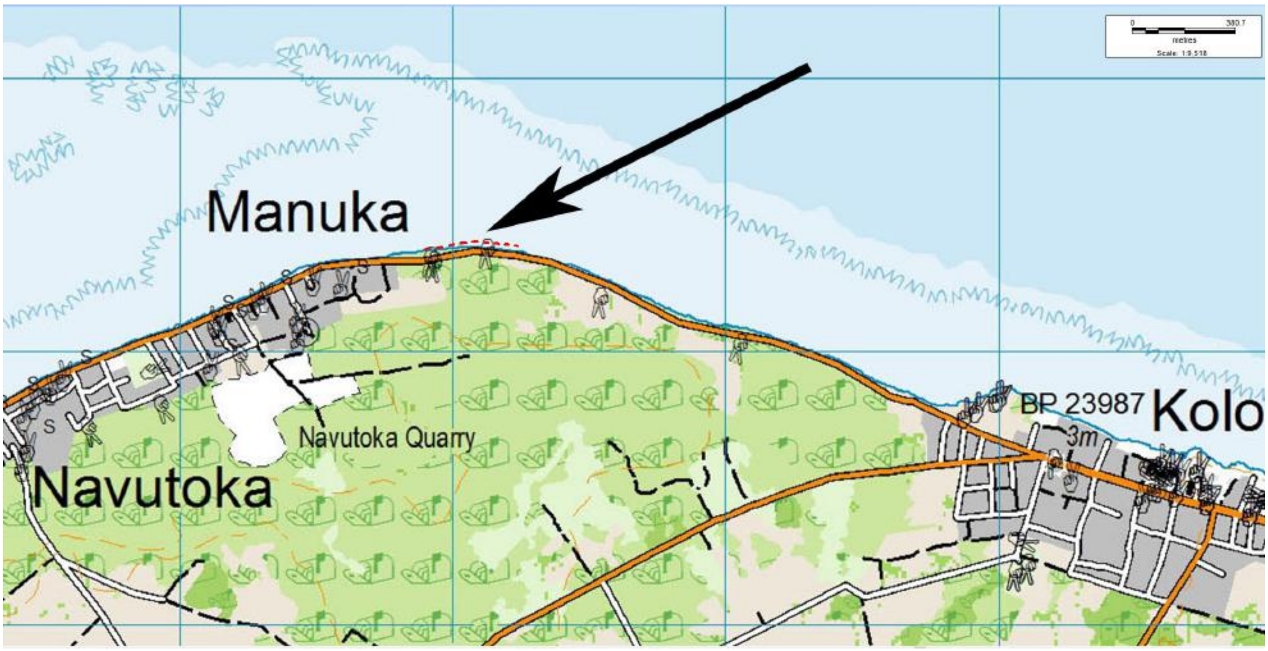


Figure 4.3-01: *Location of Manuka breakwaters between Navutoka and Kolonga on Tonga's topographic map.*

Figure 4.3-02: *Location of breakwater polygons on space borne image data recorded on 18 July 2014. The detached breakwaters were not constructed yet*

Figure 4.3-03: *Location of breakwater polygons on space borne image data recorded on 02 June 2016. The breakwaters were constructed and started to change the shoreline.*

Figure 4.3-04: *Location of breakwater polygons on space borne image data recorded on 14 May 2021. Vegetation is visible on the accumulated sand.*

5.3.1 Detailed Mapping of Manuka Breakwaters with VHR Satellite Image Data

The project purchased very high resolution (VHR) satellite image data of WorldView 2 satellite with 50 cm resolution. The image data was rectified to UTM WGS 84 Zone 1 South.

Figure 5.3.1-01: *The breakwaters were digitised again as the image had a better geo accuracy compared to Google Earth copies. The coastline was digitised and the coastal road as reference.*

In the GIS environment for every breakwater the outline was digitised and the area calculated. The length was calculated which has its limits die to 50 cm resolution, however, is an indicator when monitored over time. In addition the UTM X and Y of the centroid was calculated.

Area, length and centroid was stored in the database.

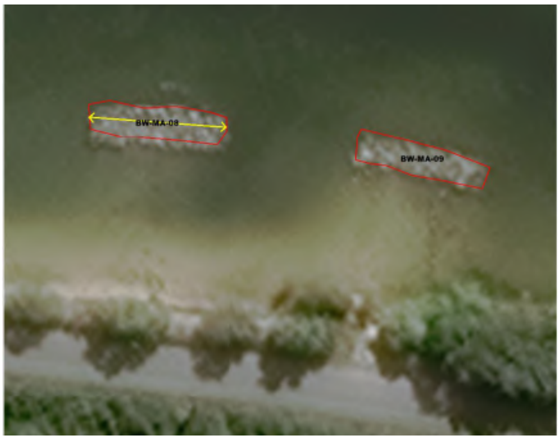
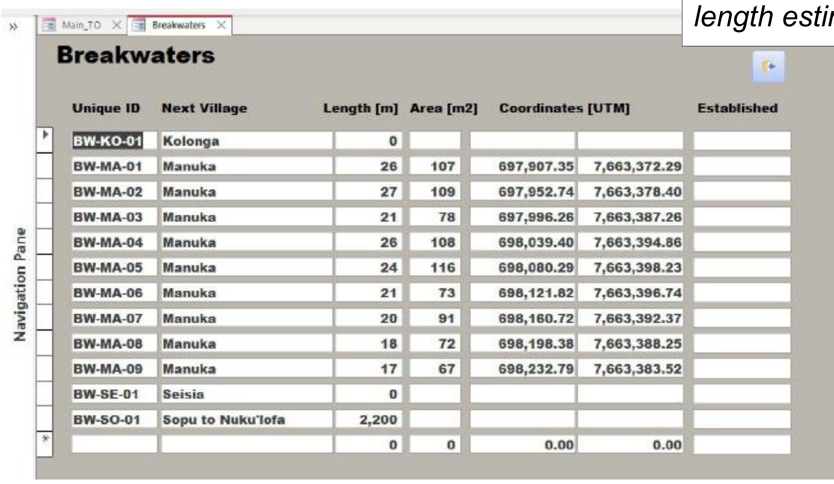


Figure 5.3.1-02: *The image shows the length estimation in GIS environment.*



Breakwaters

Unique ID	Next Village	Length [m]	Area [m2]	Coordinates [UTM]		Established
BW-KO-01	Kolonga	0				
BW-MA-01	Manuka	26	107	697,907.35	7,663,372.29	
BW-MA-02	Manuka	27	109	697,952.74	7,663,378.40	
BW-MA-03	Manuka	21	78	697,996.26	7,663,387.26	
BW-MA-04	Manuka	26	108	698,039.40	7,663,394.86	
BW-MA-05	Manuka	24	116	698,080.29	7,663,398.23	
BW-MA-06	Manuka	21	73	698,121.82	7,663,396.74	
BW-MA-07	Manuka	20	91	698,160.72	7,663,392.37	
BW-MA-08	Manuka	18	72	698,198.38	7,663,388.25	
BW-MA-09	Manuka	17	67	698,232.79	7,663,383.52	
BW-SE-01	Seisia	0				
BW-SO-01	Sopu to Nuku'lofa	2,200				
		0	0	0.00	0.00	

Figure 5.3.1-03: *Improved breakwater database display*

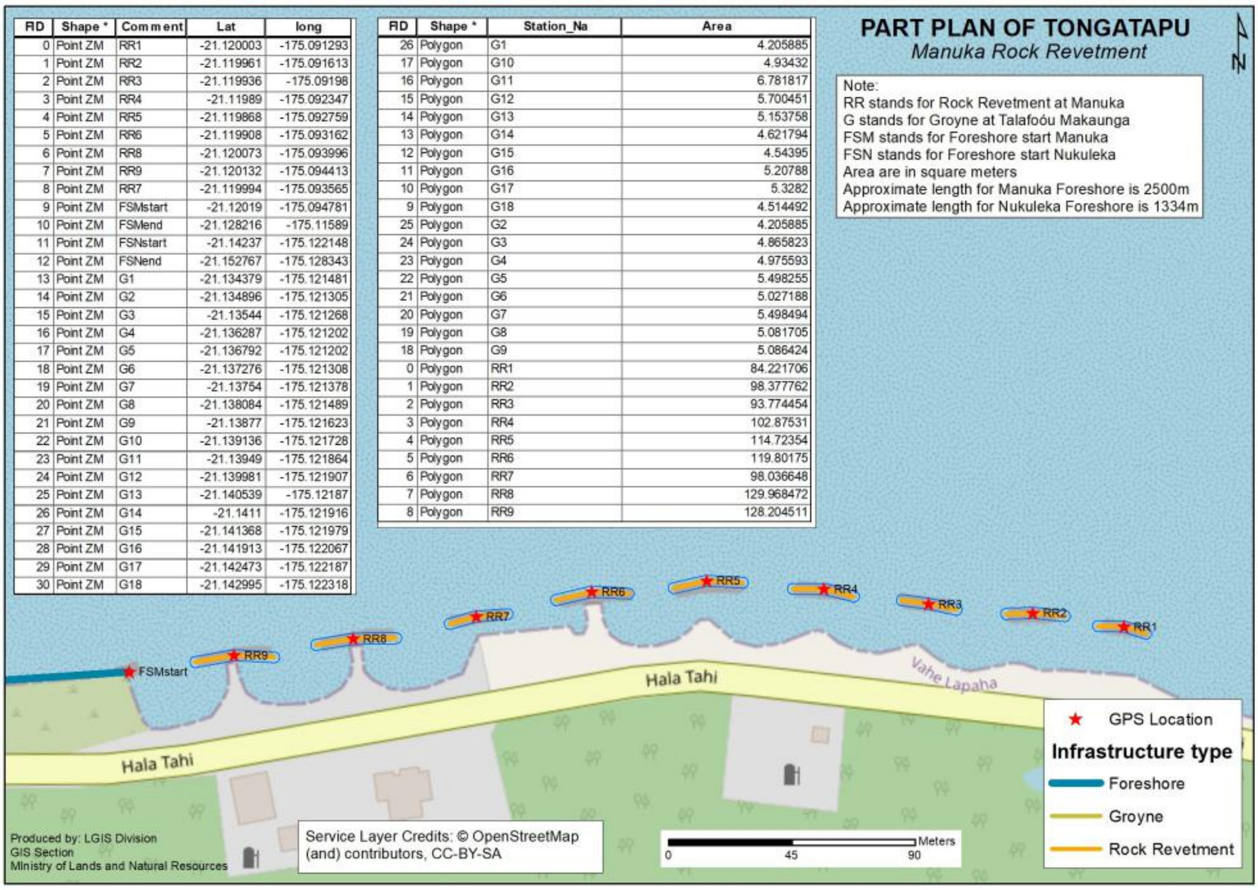


Figure 5.3.1-04: *The breakwaters are here called Rock Revetments visible on a GIS display of the Tonga Lands Department. They are stored as polygons and the central position as GPS point.*

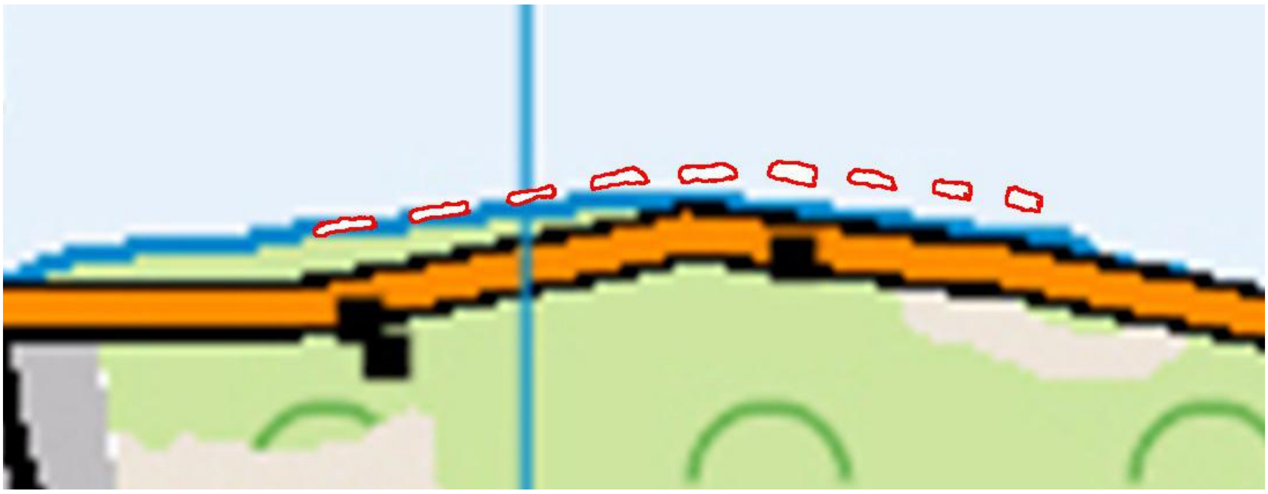


Figure 5.3.1-05: *The breakwaters visible as polygon extracted out of a GNSS survey of the Tonga Lands Department.*

5.4 Quantitative Change of Beach Area through Breakwaters

The established breakwaters in Manuka definitely changed the beach. The beach line was mapped with data from 2014 before the breakwater establishment and then mapping with data recorded

Figure 5.4-01: *Change of beach after breakwater establishment. Yellow = original beach in 2014, blue = beach area 2016 and red = beach area 2021.*

2016 and 2021[12]. As a common base line the road was used to establish an area between road and beach line.

Year	AREA [m2]	%
2014	4420	100
2016	4773	108
2021	5601	127

Table 5.4-01: *Area comparison of beach development*

As the southern line of the area the beach road was used as it is a fixed line without change in the observation period from 2014 to 2021.

The beach definitely grew within the seven years of development. The area figures and percentage only provide a rough indication as the area between road and beach line influences the total area, if the road is further away from the beach line the area change is less. However, it is the only stable line.

5.4.1 Method of Quantitative Beach Change Detection

The change detection requires three elements: (i) satellite image data before and after the breakwater establishment, (ii) geometric correction of the image data, (iii) mapping for the different years and (iv) changing the beach line to an area (v) overlay plus area calculation.

Satellite Image Data

The satellite image data was copied from Google Earth and saved as TIF files. This was performed for the years 2014 (before the breakwater establishment) 2016 (after the breakwater establishment) and 2021 up-to-date situation.

12 Detailed description in chapter "Method of Quantitative Beach Change Detection"

Geometric Correction of Image Data

The project purchased WorldView 2 image data with 50 cm spatial resolution as mentioned before. This image data was rectified to UTM projection WGS84 Zone 1 South by company MAXAR.

This enabled to identify Ground Control Point or Reference Image Points, which are points visible in all image data sets.

Figure 5.4-02: *Image reference points distributed over the image. Important is to have points at the outer area of the image such as point 08 and point 10.*

For the points GIS software calculates the X and Y values in reference to the image backdrop, which is in this case the WorldView 2 image. Here the coordinates of the image data had a shift of 1,000,000 to the west and 5,000,000 to the north. All GIS calculations was changed towards the image data.

Figure 5.4-03: *Exact position of an image reference point.*

For every reference image point an image was produced showing the exact location of the point, see figure 5.4-03 showing point 10.

When georeferencing the image data during the GIS import three image reference points are necessary. However, to have an idea of the accuracy a minimum of five points were used. The deviation did not exceed 2 pixels, which is an indicator that Google Earth image layers are accurate in flat areas. The GIS software performs a linear transformation and after the rectification all image reference points have to fit on the correct position.

Mapping the Beach Line

The beach line was first mapped from the georeferenced image data 2014, 2016 and 2021. Important is that the interpreter does not perform three independent delineations. As a first step the largest beach extent was mapped. Then, this beach line was ***adjusted*** to the 2016 situation where areas without change stayed untouched. If there are three totally independent mappings an interpretation error is automatically created.

From Line to Area

To ensure that all calculation utilises the same base line the north road boundary was digitised and joined the polylines 2014, 2016 and 2021 to corresponding areas 2014, 2016 and 2021. These joined polylines were converted the polygons. If the road would be digitised three times an error would be created even with very accurate delineation.

Overlay plus Area Calculation

The area calculation is a semi automatic process in the GIS environment. Three different GIS tables are created and exported to the Access based relational database where the area chance can be calculated which results in table 5.4-01.

The overlay visualises the area change where the corresponding beach areas are differently colour coded and overlaid which results in figure 5.4-01.

5.5 Breakwater Kolonga

The breakwater Kolonga is mentioned in the Tonga Trekking Sheet. However, it is not visible in space borne image data yet.

5.6 Detached Breakwater Sopu to Nuku'lofa

The eCoast Report lists 2.2 km of detached breakwaters from Sopu to Nuku'lofa. This is not identified yet.

5.7 Detached Breakwater near Seisia

The coast report lists a detached breakwater. The breakwater could not be located yet.

6 Mangrove Restoration

The restoration of mangrove forest is currently an issue world wide financially supported to fight against the loss of this important ecosystem. On the other hand there is a high rate of failure in mangrove planting. Dick Watling recently released a discussion paper analysing this issue[13].

6.1 Types of Mangroves and Restoration Techniques

Mangroves are trees adapted to temporary cover of salt water and to temporary cut of air from the root system. There are different mangrove types allowing different time spans of flooding, different salinity and other factors.

13 Dick Watling "A Review Of Mangrove Planting"

The micro relief is apparently a more important factor than the planting itself as it determines drainage, fresh water supply and the time mangroves are not flooded. The partly can be monitored with remote sensing data.

Normally mangroves grow where there have been mangroves before as the mangroves naturally select places of optimal conditions. A part of the restoration technique is to select these places[14]. Here analysing historical image data such as historical aerial photographs can be a substantial support.

6.2 Mangrove Monitoring

Mangrove monitoring is often performed by the tabular data "number of trees planted". However, especially mangrove planting can have a big rate of failure. The indicator must be the survival rate which is visible after a few years indicated by the mangrove cover.

The mangrove cover is visible with VHR space borne image data at 1:10,000 scale level. However, it has to be a mangrove cover. Recently planted areas reflect significantly more water than mangrove leaves and are difficult to detect with space borne image data (see figure 6.13-02). The mangrove crown cover survival rate a few years after planting compared with the part of the area where the trees died back is the quantitative success of mangrove restoration. This requires a GNSS survey at 1:10,000 scale level after the planting to create the spatial reference.

6.3 Mangrove Restoration Area Kovolai

Mangrove restoration in Kovolai of 0.9 hectares is mentioned in (CPS 20/140) Report 2. Changes in satellite image data are not visible yet. The mangrove restoration site is included in the database without an area figure.

6.4 Mangrove Restoration Area Foui

Mangrove restoration in Foui of 1.1 hectares is mentioned in (CPS 20/140) Report 2. Changes in satellite image data are not visible yet. The mangrove restoration site is included in the database without an area figure.

6.5 Mangrove Restoration Area Pea to Veitongo

Mangrove restoration of 4 hectares from Pea to Veitongo is mentioned in (CPS 20/140) Report 2. The mangrove restoration site is included in the database without an area figure.

6.6 Mangrove Restoration Area Nukuhetulu

Mangrove restoration of 1.2 hectares at Nukuhetulu is mentioned in (CPS 20/140) Report 2. The mangrove restoration site is included in the database without an area figure.

6.7 Mangrove Restoration Area Vaini to Longoteme

Mangrove restoration of 4.2 hectares from Vaini to Longoteme is mentioned in (CPS 20/140) Report 2. The mangrove restoration site is included in the database without an area figure.

14 The US Forest Service has detailed guidelines for terrestrial mangrove monitoring

6.8 Mangrove Restoration Area Mua and Alaki

Mangrove restoration of 5 hectares at Mua and Alaki is mentioned in (CPS 20/140) Report 2. The mangrove restoration site is included in the database without an area figure.

6.9 Mangrove Restoration Area at Hoi

Mangrove restoration of 1.4 hectares at Hoi is mentioned in (CPS 20/140) Report 2. The mangrove restoration site is included in the database without an area figure.

6.10 Mangrove Restoration Area Ahau

The EU GIZ Adapting to climate change and sustainable energy, ACSE project (2016-2020) focused on reinforcing revetment along west coastline of Tongatapu to reduce inundation with restoration of mangroves in Ahau and Kolovai villages. This is mentioned in the project document. The mangrove restoration site is included in the database without an area figure.

6.11 Mangrove Restoration Area Hahake District

The ADB Climate Resilience Sector, CRSP project (2014-2019) focused on rock revetment with mangrove restoration along villages in Hahake district. The mangrove restoration site is included in the database without an area figure.

6.12 Mangrove Restoration Area Masilamea

Mangrove restoration of 76 hectares from Masilamea to Matafonua is mentioned in (CPS 20/140) Report 2. The mangrove restoration site is included in the database without an area figure.

6.13 Mangrove Restoration Area Nukunuku

Mangrove restoration of 58 hectares from Nukunuku to Sai'atoutai is mentioned in (CPS 20/140) Report 2. The mangrove restoration site is included in the database without an area figure.

Figure 6.13-01: *Location of the main mangrove restoration areas*

Figure 6.13-02: *Mangroves directly after planting. Water dominates the reflection*

76 and 58 hectares are a reasonable amount and a change in the mangrove cover should be visible. The comparison of image data from 2021, 2018, 2014 and 2009 does not reflect a change. It is possible that the mangrove restoration

did not take place yet or that the mangroves are still too low and the water around them dominates the reflection, see figure 6.13-02[15]. To be visible on satellite image data mangroves must have a crown closure.

Figure 6.13-03: *Location of the main mangrove restoration areas Masilamea (76 hectares) and the area between Nukunuku and Sia'afoutai (58 hectares)*

Figure 6.13-04: *Main mangrove restoration areas Masilamea (76 hectares) and the area between Nukunuku and Sia'afoutai satellite image data 26 June 2021*

15 Source of image: https://www.ctc-n.org/products/reforested-mangroves

Figure 6.13-05: *Main mangrove restoration areas Masilamea (76 hectares) and the area between Nukunuku and Sia'afoutai satellite image data 01 November 2018*

Figure 6.13-06: *Main mangrove restoration areas Masilamea (76 hectares) and the area between Nukunuku and Sia'afoutai satellite image data 18 July 2014*

6.14 Mangrove Restoration Area Nukuleka

Mangrove restoration of 2.5 hectares at Nukuleka is mentioned in (CPS 20/140) Report 2. The mangrove restoration site is included in the database without an area figure.

Figure 6.13-07: *Main mangrove restoration areas Masilamea (76 hectares) and the area between Nukunuku and Sia'afoutai satellite image data 10 July 2009*

7 Improvement of Water Supply

The project document mentions: "The Pacific Adaptation to Climate Change, PACC project (2009-2013) focused on priority sector water resources with intent to improve community water supply and water management practices at Hihifo district."

It is difficult to identify water tanks with space borne image data. Here a terrestrial survey with GNSS equipment is necessary to identify the location and condition of the water tank. "Condition" covers the capacity, status defect or working and the connection to the catchment. The catchment in form of roof area can be roughly estimated with satellite image data.

Currently the water tanks are not included in the database yet.

7.1 Estimating Rainwater Harvest Potential

The project purchased very high resolution image data with 15 cm spatila resolution for the complete area of Hihifo, see figure 7.1-01. This data was mosaicked to one seamless GIS backdrop layer and then cut into image tiles covering one village each, see example Kolovai figure 7.1.1-01.

The image data as one only dataset for Hihifo requires too much memory to allow a fast roof digitising.

With 15 cm spatial resolution the area can be calculated in sufficient accuracy to link the roofs to available tanks and number of persons in a household.

Figure 7.1-01: *Image coverage Hihifo*

7.1.1 Purpose of Rainwater Harvest

Tonga has a tropical rainforest climate. The average amount of annual precipitation is: 1721.0 mm. On average, February is the wettest month with 210.0 mm of precipitation and November is the driest month with 23.0 mm of precipitation[16].

Kolovai has rainwater harvesting facilities established. It is possible to estimate and monitor the potential of rainwater harvest of this village and ensure assistance in time before a potential drought effects life in Kolovai and other villages. Dry periods might have a bigger time window and might be more frequent in future due to climate change.

There is sufficient rainfall to supply required drinking water through rainwater harvest.

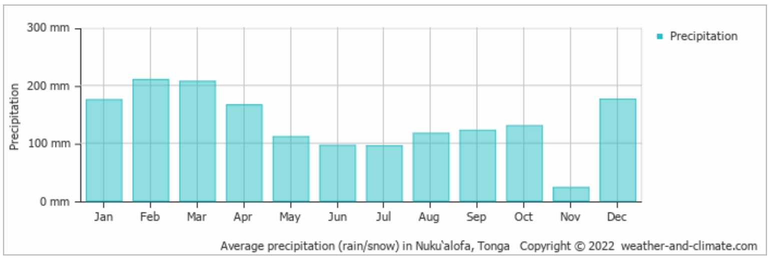


Figure 7.1.1-01: *Rainfall in Nukualofa*

There is also sufficient roof area of more than 36,157 m^2 which theoretically could capture 22,226,200 litre per year (36,157 x 1721)[17]. A person uses in average 150 litre per day[18]. Detailed figures show 283 litre per day for Fiji and 165 litre per day for PNG[19]. With an assumption that Tonga is with 200 litre per person and day in the middle, the figure of yearly consumption per person would sum to ~ 73,000 litre per year. 305 persons could be supplied with rainwater from the existing roofs. This can be detailed to households if the number of household members can be linked to the rainwater harvest figures. However, this is a theoretical figure under the assumption that all roof areas are capturing the water!

This roughly estimated figures of the roof areas, where theoretically water can be captured, have to detailed where following parameters have to be surveyed:

1. ***Actual capture area:*** The current mapping with very high resolution satellite image data only estimates the potential capture area. For many roof rainwater harvest facilities do not exist. These roofs cannot be counted as actual capture areas. In many cases water is collected only from parts of the roof and not the complete roof.
2. ***Storage capacity*** is the next factor. The water tanks have to be large enough that they capture all water during intense rainfall. The tank capacity has to be adjusted to the capture area.
3. ***Functionality of rainwater harvesting facilities*** is another contributing factor. Gutters and downpipes have to be in working condition.

Only the potential capture area can be delineated with space-born image data. The collection of all other parameters requires field survey.

16 https://weather-and-climate.com/average-monthly-precipitation-Rainfall,nuku-alofa,Tonga
17 1 mm per square metre = 1 litre
18 https://www.ccwater.org.uk/households/using-water-wisely/averagewateruse/
19 Worldometer: https://www.worldometers.info/water/

7.1.2 Roof Mapping Kolovai

Figure 7.1.2-01: *Digitised roofs of Kolovai. The image tile covers the complete village. So far 231 roofs were digitised.*

The digitising was performed manually. It is also possible to apply an object based classifier which would map all houses automatically. The visual mapping also can be improved by mapping with higher zoom in rate which would improve the accuracy. Furthermore the mapping could separate different catchment areas for all roofs which will be explained in a chapter below.

The current image data also allows to map all tanks not standing under a tree crown as shown in figure 7.1.2-02.

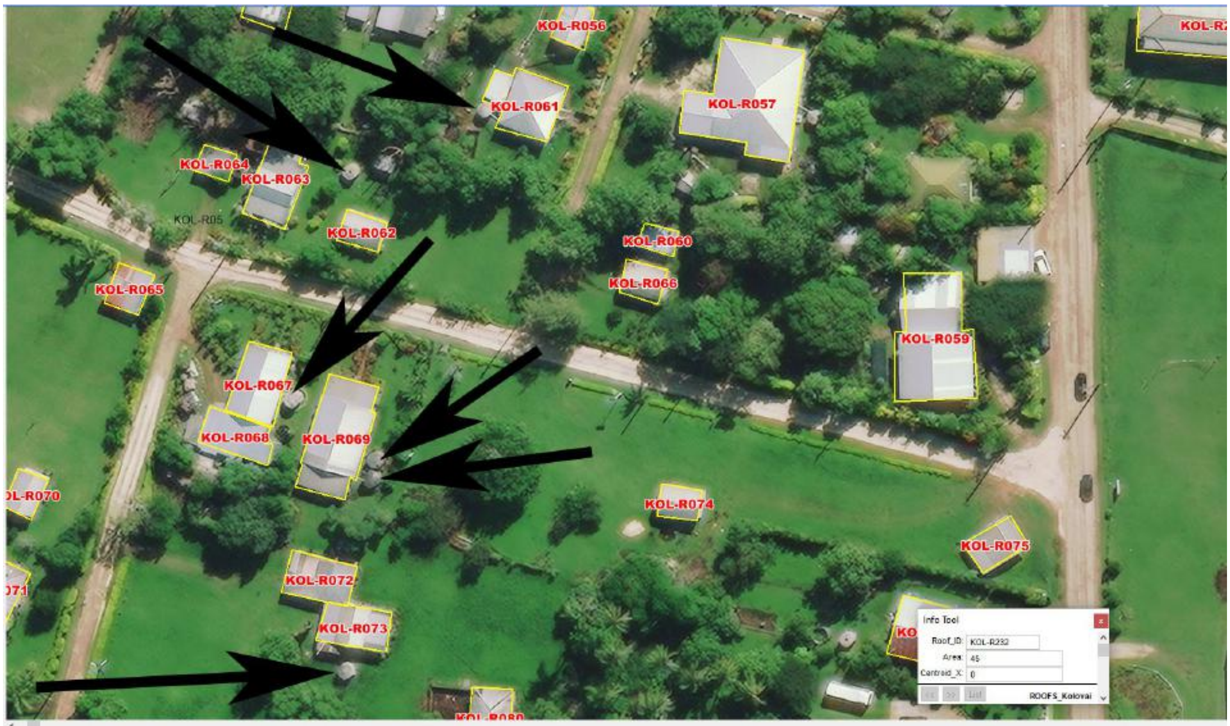
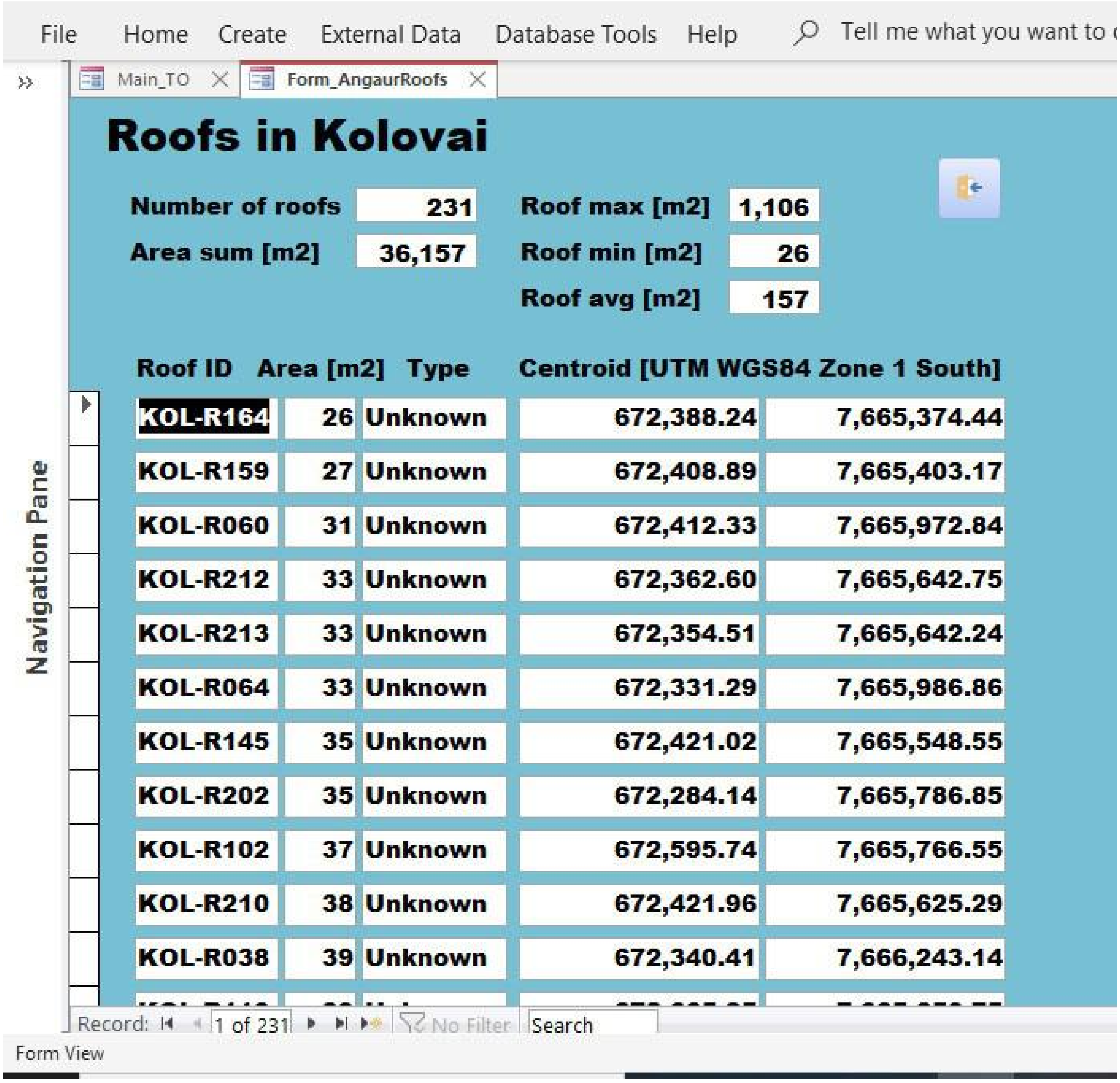


Figure 7.1.2-02: *Digitised roofs of Kolovai. Every roof polygon has a unique ID. Many of the tanks connected to the roofs are visible (see arrow heads).*

7.1.3 Analysis of Potential Rainwater Harvest Kolovai

The roof area in m^2 was calculated with GIS software and exported to the Access based database. The display is shown in figure 7.1.3-01.



File Home Create External Data Database Tools Help Tell me what you want to

Main_TO Form_AngaurRoofs

Navigation Pane

Roofs in Kolovai

Number of roofs	231	Roof max [m2]	1,106
Area sum [m2]	36,157	Roof min [m2]	26
		Roof avg [m2]	157

Roof ID	Area [m2]	Type	Centroid [UTM WGS84 Zone 1 South]	
KOL-R164	26	Unknown	672,388.24	7,665,374.44
KOL-R159	27	Unknown	672,408.89	7,665,403.17
KOL-R060	31	Unknown	672,412.33	7,665,972.84
KOL-R212	33	Unknown	672,362.60	7,665,642.75
KOL-R213	33	Unknown	672,354.51	7,665,642.24
KOL-R064	33	Unknown	672,331.29	7,665,986.86
KOL-R145	35	Unknown	672,421.02	7,665,548.55
KOL-R202	35	Unknown	672,284.14	7,665,786.85
KOL-R102	37	Unknown	672,595.74	7,665,766.55
KOL-R210	38	Unknown	672,421.96	7,665,625.29
KOL-R038	39	Unknown	672,340.41	7,666,243.14

Record: 1 of 231 No Filter Search

Form View

***Figure 7.1.3-01:** Database display of table Roofs Kolovai*

8 Input for Visibility of Climate Change Adaption Actions

The current attempt to provide visibility for the impact of climate change adaptation action is based on creating displays with VHR Google Earth image data where the infrastructure items and the impact can be seen. However, there are limitations as (i) Google Earth display is geometrically not very correct, (ii) the display is limited to the visible bands and (iii) the Google Earth might not allow to see the elements e.g. submerged groyes.

The documentation approach has two steps (i) documentation infrastructure elements spatially (GIS) and descriptive if possible quantitative (database). For the spatial documentation a scale of 1:10,000 is required and the base map has a scale of 1:50,000. GNSS survey filled the gap and allowed mapping with appropriate accuracy. Possibly other remote sensing sources could be made available in addition. For the annotation part most infrastructure elements were visited in the field and the condition is most probably described. Where ever possible the infrastructure elements should be measured or classified to get quantitative data. This is apparently performed with the new GNSS survey. Step (ii) would be the description and quantification of impact as soon as an impact is visible, like for the breakwaters in Manuka.

8.1 Documentation of Revetments

It was possible to map the revetment near Ahau and it was possible to measure the element from Google Earth display. The revetments in Nuku'alofa, Nukuleka, Kolongo and Nautoka are not visible on Google Earth display. A GNSS survey was carried out and the elements are mapped and available as GIS elements (see figure 3.7-04).

8.2 Documentation of Groynes

There are 17 groynes included in the database near Talafo'ou and Makaunga. This was done due to the statement that 17 out of 20 were established. However, these groynes are not visible in Google Earth display. They were visited and mapped with GNSS equipment. The elements are available as GIS polygons and imported to GIS visible in figure 4.3.1-06. That they only appear as little red points is related to a display on a 1:50,000 scale map instead of 1:10,000. However the elements are available.

8.3 Documentation of Breakwaters

From 10 detached breakwaters east of Manuka 9 are visible in satellite image data. There is also the impact visible in the form of sand enlarging the beach. Other breakwaters could not be located yet. GNSS survey will be sometimes difficult, possibly drone images can be made available. However, the last GNSS survey mapped the elements as polygon visible in figure 5.3.1-05.

8.4 Documentation of Mangrove Restoration Areas

Most of the mangrove areas are too small to be visible in Google earth display. A GNSS survey is essential, which is a standard for all forest restoration areas. Historical image data was asked from SPC resources which will help the monitoring as mangroves normally only grow where they have been before. Again the data of the first completion of planted area is needed

8.5 Documentation of Rainwater Harvest and Sewage Facilities

As stated in the corresponding chapter the capture of water tanks need a field survey.

8.6 Documentation of Seawalls

Seawalls will not be visible with image data, also here a GNSS survey is necessary and date each seawall was completed.

9 Appendix A - Cartographic Base 1:50,000 Scale

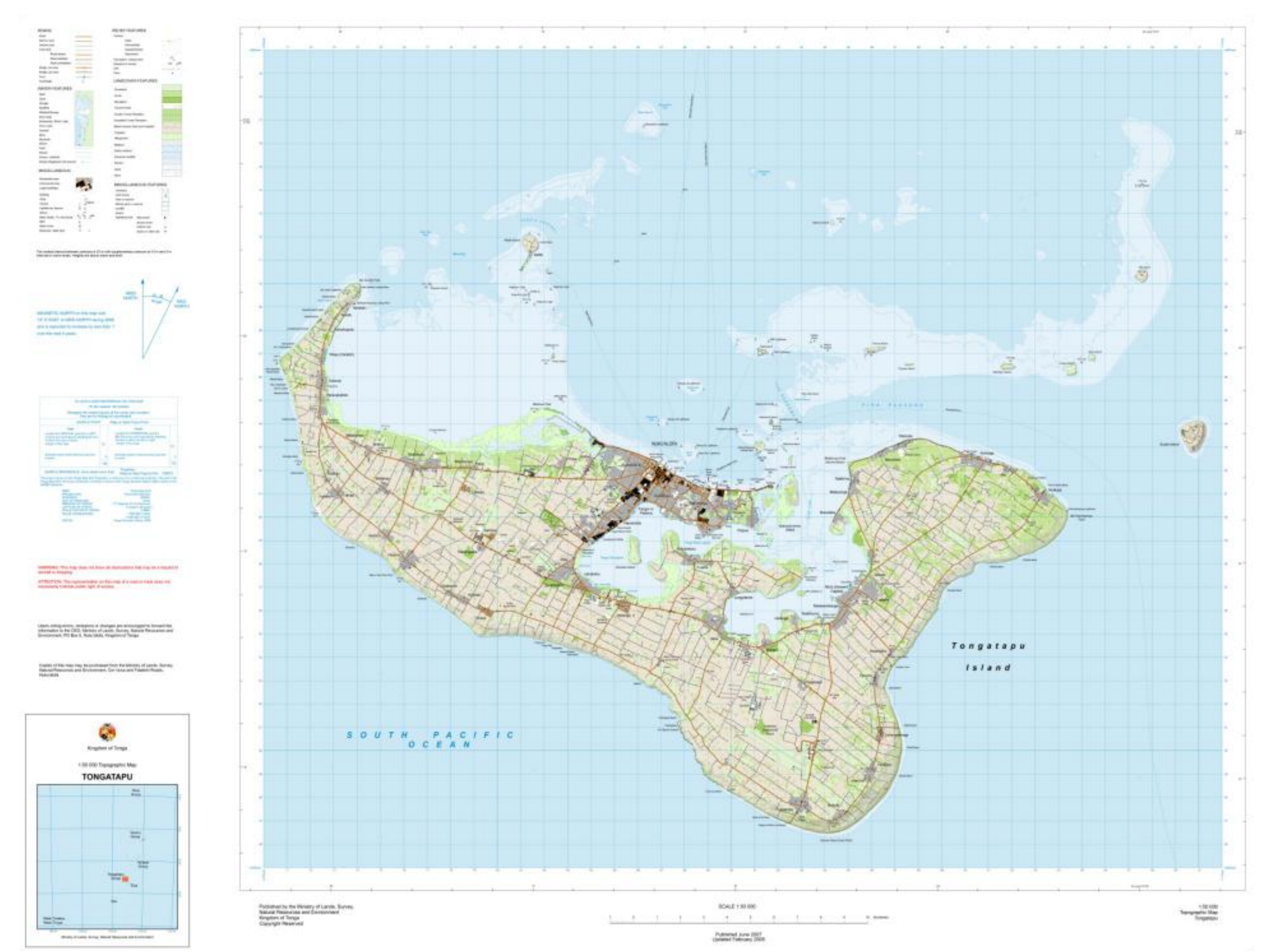


Figure 09-01: *The available map of Tongatapu at 1:50,000 scale.*

The Tongatapu map in full size as image file in JPEG format. The available grid was used to geometrically rectify the map image to Tonga Map Grid and in this way the image can be used as GIS backdrop, see figure 10-02. However, 1:50,000 is not the appropriate scale for mapping climate change adaptation elements, the scale should be 1:10,000.

The map was published in June 2007 and updated in February 2008. The first map delivered as a JPEG file had editing instructions on it and had only limited use as GIS backdrop. This version received from Tonga Lands Department now is clear and usable as a GIS backdrop.

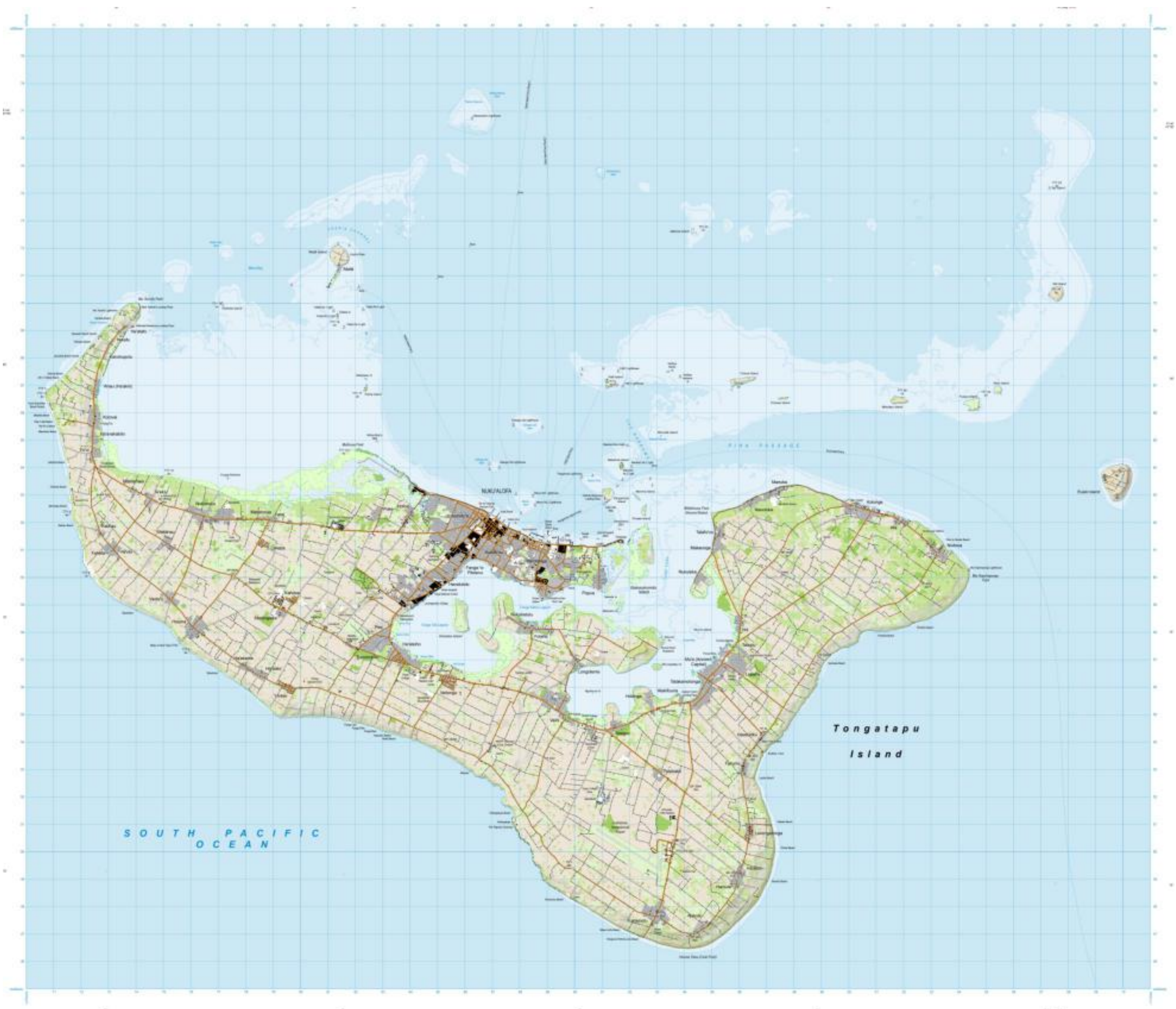


Figure 09-02: *The rectified sub-image usable as GIS backdrop.*

10 Appendix B - Cartographic Base 1:25,000 Scale

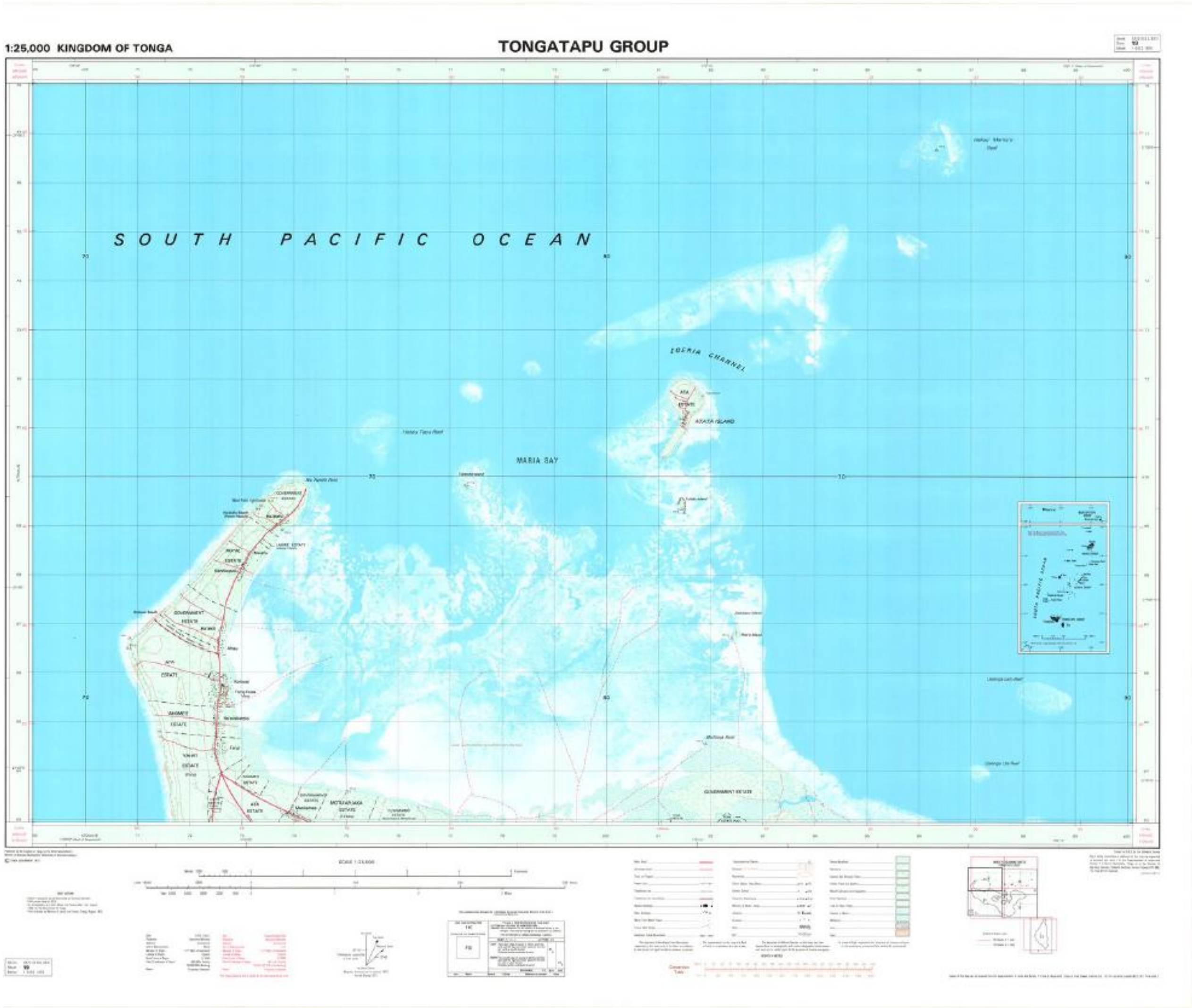


Figure 10-01: *Map sheet 19 of the 1:25,000 map series of Tonga.*

Four map sheets covering Tongatapu were downloaded from the internet. However, the poor resolution does not even allow to identify the year of publishing.

For a GIS backdrop the image files are not usable as the scanning resolution is far too low.

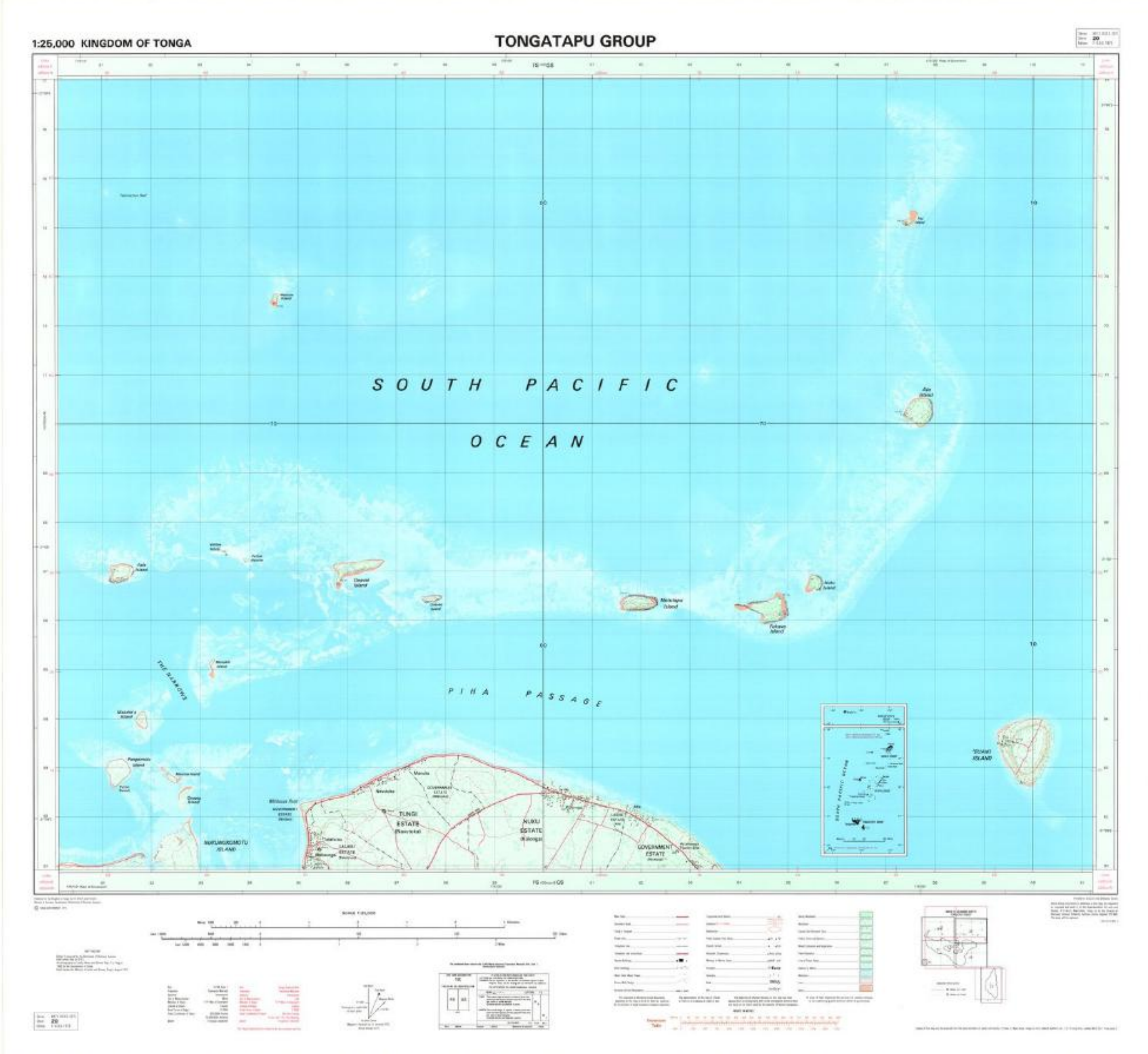


Figure 10-02: *Map sheet 20 of the 1:25,000 map series of Tonga.*

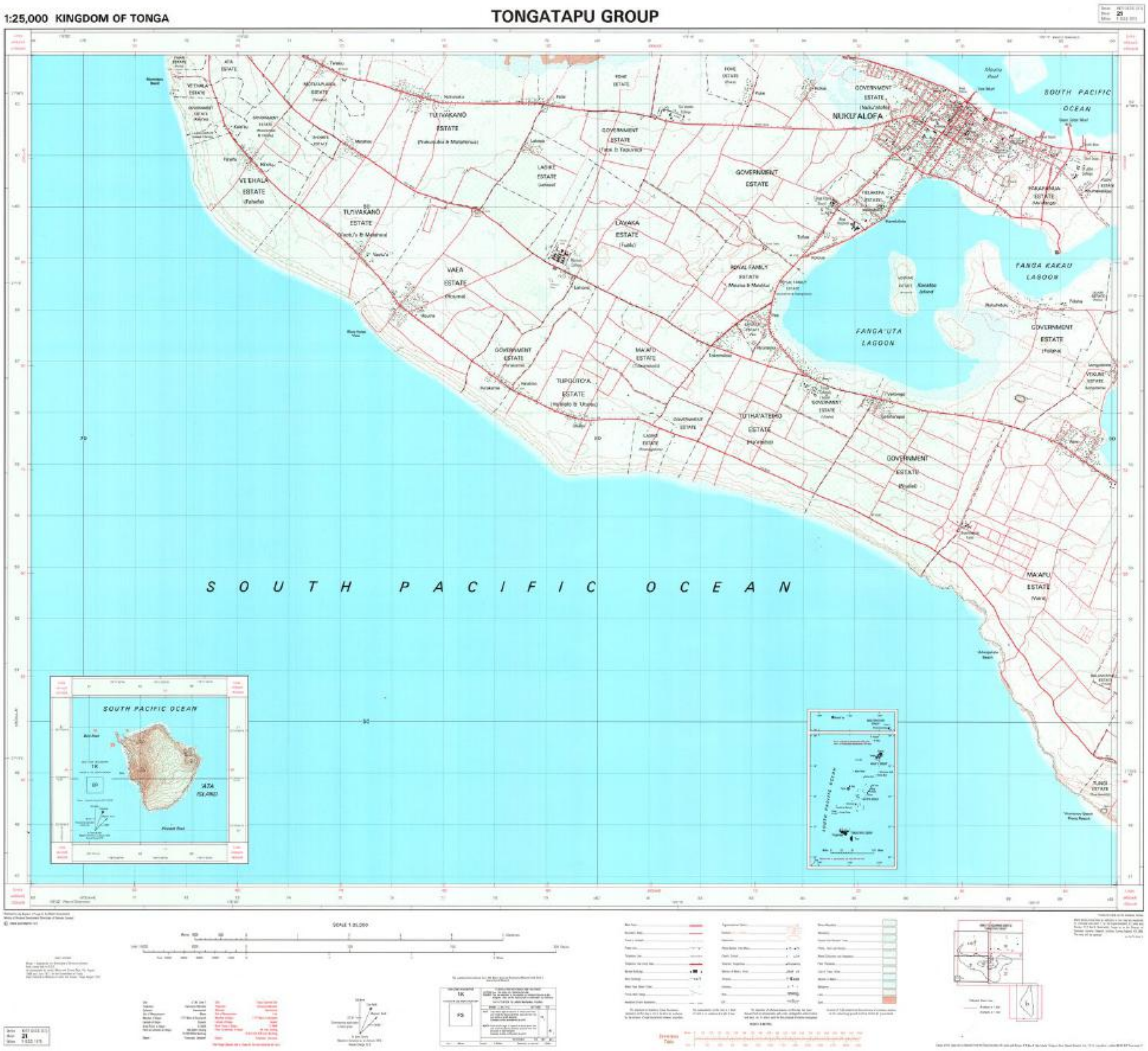


Figure 10-03: *Map sheet 21 of the 1:25,000 map series of Tonga.*

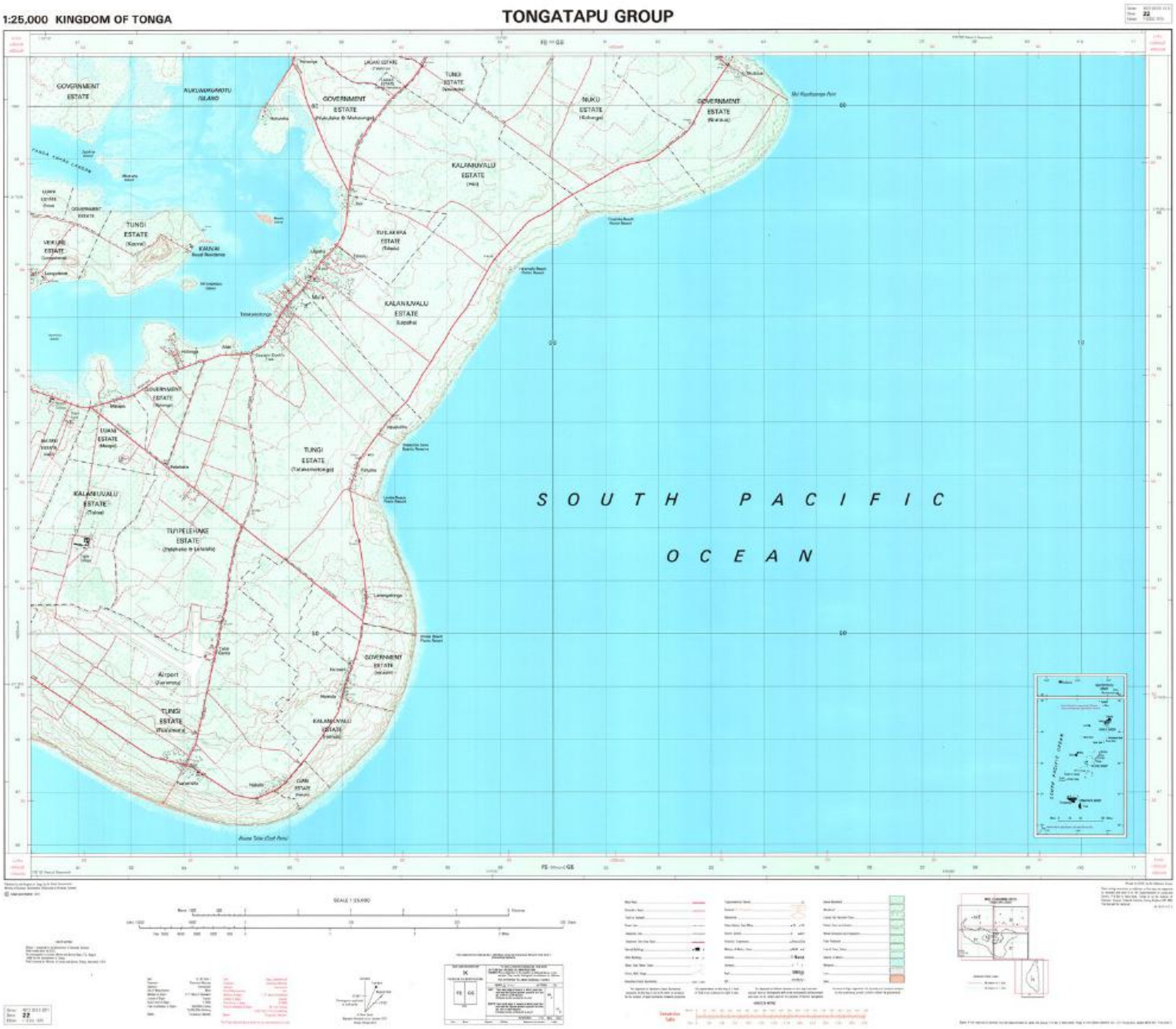


Figure 10-04: *Map sheet 22 of the 1:25,000 map series of Tonga.*