Assessing vulnerability and adaptation to sea-level rise: Lifuka Island

Ha'apai, Tonga

B 1: Physical resources

1.1: Shoreline assessment

SPC Secretariat of the Pacific Community

Australian AID

Australian Government
Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education
AusAID

Assessing vulnerability and adaptation to sea-level rise: Lifuka Island, Ha'apai, Tonga

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Assessing vulnerability and adaptation to sea-level rise: Lifuka Island, Ha'apai, Tonga

As part of the Australian Government's International Climate Change Adaptation Initiative (ICCAI), the Pacific Adaptation Strategy Assistance Program (PASAP) aims to assist the development of evidence-based adaptation strategies to inform robust long-term national planning and decision-making in partner countries. The primary objective of PASAP is: 'to enhance the capacity of partner countries to assess key vulnerabilities and risks, formulate adaptation strategies and plans and mainstream adaptation into decision making' (PASAP, 2011). A major output of PASAP is: 'country-led vulnerability assessment and adaptive strategies informed by best practice methods and improved knowledge'.

The Lifuka project was developed in conjunction with the Government of Tonga Ministry for Lands, Survey, Natural Resources, Environment and Climate Change (MLSNRECC), PASAP and the Secretariat of the Pacific Community (SPC) to develop an evidenced-based strategy for adapting to sea-level rise in Lifuka Island.

Many technical reports were written for the project on Lifuka Island. They are listed below. They complement, and should be read in conjunction with, the final report : Rising oceans, changing lives.

A: Final report: Rising oceans, changing lives

B 1: Physical resources

1.1: Shoreline assessment

1.2: Groundwater resources assessment

1.3: Oceanographic assessment

1.4: Benthic habitat assessment

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- Andrick Lal, SPC–SOPAC
- Mike Davis, Bureau of Meteorology, Australia.

ABBREVIATIONS

AusAID	Australian Government Overseas Aid Program
AUSPOS	free online GPS data processing service provided by Geoscience Australia
BM	benchmark
DIICCSRTE	Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education (Australia)
GNSS	global navigation satellite system
GPS	Global Positioning System
LIFU	Lifuka, GPS Monument
LIFA	Lifuka, New Zealand Navy benchmark
MECC	Ministry of Environment and Climate Change (Tonga)
MLSNRECC	Ministry for Lands, Survey, Natural Resources, Environment and Climate Change (Tonga)
PASAP	Pacific Adaptation Strategy Assistance Program
RTK	real time kinematic
SOPAC	Applied Geoscience and Technology Division of the Secretariat of the Pacific Community (SPC)
SPC	Secretariat of the Pacific Community
TC	tropical cyclone
TON1	Benchmark Tongatapu

1. EXECUTIVE SUMMARY

Sea-level changes are a major contributor to coastal hazards in small island developing nations, especially in the low-lying islands of e South Pacific. Although various techniques and strategies in terms of development and adaptation are being suggested and/or recommended, the majority of island nations lack baseline data and the capacity to select appropriate approaches.

This is the situation in Lifuka Island in Tonga, which has become prone to storm and wave events following relative sea-level rise associated with coseismic subsidence.

This report gives details of the shoreline assessment completed by the Applied Geoscience and Technology Division of the Secretariat of the Pacific Community (SOPAC).

Topographical mapping of survey sites was completed with the use of real time kinematic Global Positioning System (RTK GPS), and permanent benchmarks were established in six communities of Lifuka. The benchmarks served as reference points from which profile lines were run to survey the status of the beach and understand its processes.

The main coastal features of Lifuka were mapped via 2758 geocoded photographs using a handheld GPS and digital camera. The photos taken over the survey period were compared, providing information on shoreline changes and, in particular, showing impacts on coastal structures such as sea walls.

Levelling runs were made and a tide staff was installed, from which the tide cycle was observed and the wave heights recorded. This enabled us to derive the mean sea level for the survey period, which was calculated to be 1.40 m below the LiDAR (AAM) benchmark.

Relevant government authorities in Tonga were involved in the survey work, which increased the capacity of their staff to assess coastal vulnerability.

Data from this survey now provide baseline information about Lifuka's shoreline and coastal processes. This can be used for coastal management and can also contribute to policy-making.

2. BACKGROUND

The Pacific Adaptation Strategy Assistance Program (PASAP) project, 'Assessing vulnerability and adaptation to sea-level rise: Lifuka Island, Ha'apai, Tonga', was developed in conjunction with the Secretariat of the Pacific Community (SPC), Tonga's Ministry of Environment and Climate Change (MECC) and Australia's Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education (DIICCSRTE).

The primary objective of PASAP is to: 'enhance the capacity of partner countries to assess key vulnerabilities and risks, formulate adaptation strategies and plans, and mainstream adaptation into decision making'. SPC and MECC were tasked to assess and provide 'evidence-based strategies for adaption to sea-level rise' in Lifuka.

Three principles guide the project:

- gathering robust evidence about coastal and environmental processes and social needs and values as these underpin the development of strategies for adaption to sea-level rise in Lifuka;
- ensuring community engagement and involvement; and
- building technical capacity among local people so that surveys can continue.

This report encompasses the following activities undertaken by the Ocean and Islands Programme of SOPAC:

- topographic mapping;
- beach profiling;
- shoreline photo mapping;
- Tropical Cyclone Cyril inundation survey; and
- temporary tide gauge installation.

The islands of Tonga lie west of the Tongan trench, which is an active subduction zone where the Pacific Plate is subducted beneath the Tongan and Indo-Australian plate. Uplift and subsidence of the Tonga Ridge is influenced by faulting. A series of transverse faults breaks the Tonga ridge into at least a dozen discrete forearc blocks (Dickinson et al. 1999; Dickinson 2001).

Lifuka is the largest island in the Ha'apai group and the main administrative centre. It has a population of 2967 (Tonga Census 2006) that lives in five main communities on the western leeward shore of the island (Figure 1). Lifuka has a sub-tropical climate and lies in a relatively dry zone. It has a marked seasonality, with a wet season from November to April and a dry season from May to October.

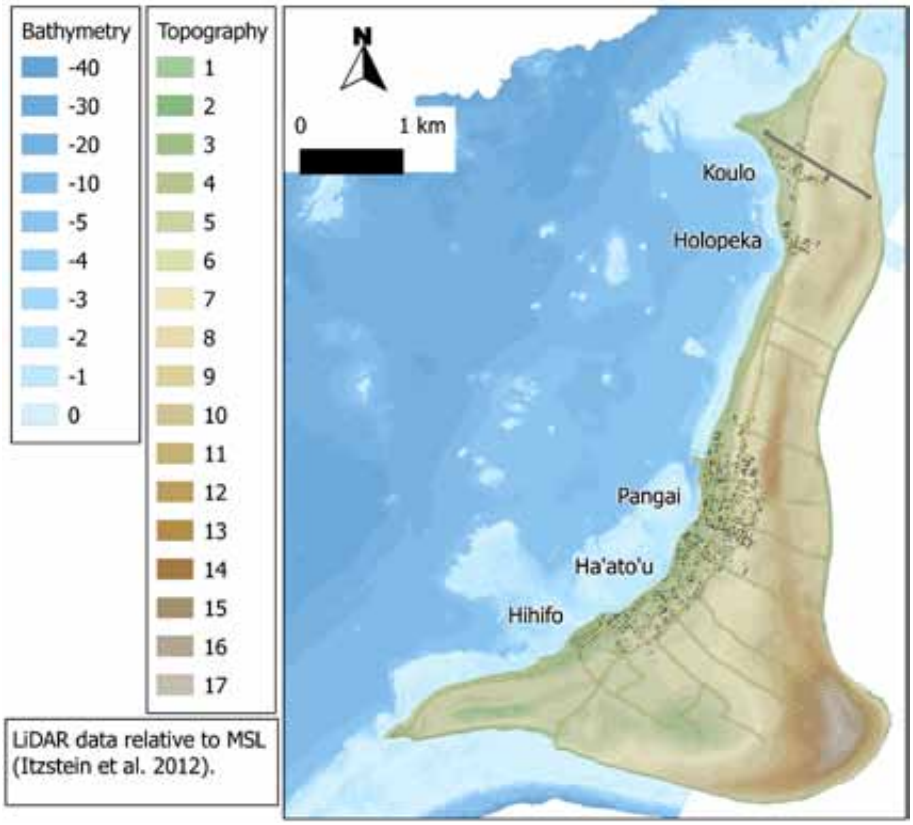

Figure 1: Coastal terrain model of Lifuka showing LiDAR bathymetry and topography collected under the PASAP project. The map also shows the location of major infrastructure such as houses, roads and the airport. Note that the majority of buildings are located on the low-lying western coastline.

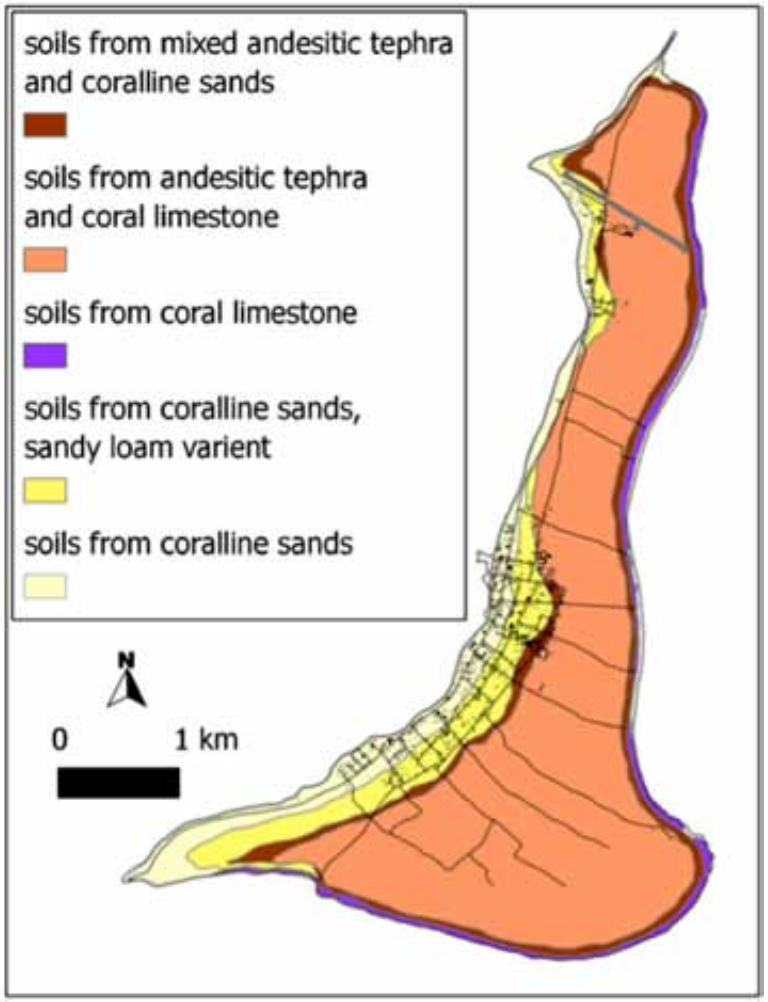

Figure 2: Soil map of Lifuka (redrawn from Wilson and Beecroft 1983) overlain with infrastructure (houses, roads, and airport). Note that the majority of buildings are situated on the sandy soils of the coastal plain.

Lifuka is a raised limestone island (maximum elevation of 17 m above mean sea level), and comprises a coastal plain of varying width (generally 200–500 m) along the western leeward shoreline (Figures 1 and 2). The island experienced relative sea level rise in the order of 23 cm due to tectonic subsidence associated with the May 2006 earthquake (Cummins et al. 2006).

3. METHODOLOGY

The shoreline assessment was accomplished by completing a GNSS survey to establish and define benchmarks. The benchmarks were used for repeated beach profiling. Shoreline mapping was conducted using a photo mapping technique.

3.1 Benchmark survey

3.1.1. Establishment of benchmarks

Six benchmarks were established in Lifuka. The first one, in the hospital compound, was established on a concrete slab next to an old water tank. Locations for the remaining benchmarks were chosen to give a homogeneous representation of the western coast, so a benchmark was installed in every community on the island. Several factors were considered when siting the benchmarks, such as disturbances by farm animals, vegetation cover and possible future infrastructure, such as road or building construction. Advice was also taken from the local town officers on the locations (Figure 3). The benchmarks were constructed with concrete mix and steel pins (see Figures 4, 5 and 6). Two pre-existing benchmarks were also located: the New Zealand Navy benchmark, Lifa, and the GPS monument, Lifu (Figures 7 and 8). The shoreward bollard on the northern edge of Pangai wharf was used as an additional benchmark (Figure 9).

Figure 3: Consultation with the governor's secretary and town officers on the placement of benchmarks, 12 September 2011

Figure 4: (Top left) Digging the spot where the benchmark was installed

Figure 5: (Top right) Inserting the steel pin and covering it with polythene bags to allow a firm hold with the concrete mix

Figure 6: (Bottom) Flattening the surface of the benchmark with a rod. Note that the concrete mix is levelled.

3.1.2. GNSS survey of benchmarks

The Lifa and Lifu benchmarks were used as the primary benchmarks during the GNSS survey. The Lifa station was observed with a Trimble R8 system (Figure 7), and the Lifu station was observed with a Trimble SPS852 system (Figure 8). Both stations were observed simultaneously for at least 24 hours. While the primary benchmark observations were being conducted, the secondary beach profiling benchmarks were observed with additional Trimble R8 units for at least one hour each. This provided survey grade horizontal positions at all locations, and the vertical heights were later adjusted to mean sea level as derived from the temporary tide gauge described below. Since the location of the LiDAR benchmark was not known at the time of the GNSS survey, the vertical correction was achieved later by transferring the height of the LiDAR benchmark to the height of the bollard benchmark using a levelling run (standard land survey technique) between the two benchmarks.

The Lifu benchmark GNSS data were submitted to AUSPOS (http://www.ga.gov.au/bin/gps.pl) for post-processing of coordinates and kept as the main primary horizontal reference point for subsequent processing of baselines, using the Trimble Business Centre version 2.60 (Figure 10). After transferring the height of the LiDAR benchmark to the bollard benchmark, the bollard was used as the primary vertical reference point for processing.

Figure 7: Image shows Trimble R8 set up at Lifa base.

Figure 8: Trimble SPS852 set up at the GPS monument, Lifu

Figure 9: Trimble R8 GNSS set up over the bolt at the bollard on the northern edge of Pangai wharf. The location of the bolt is indicated by the pen immediately to the right of the bollard. The old ramp and location of the LiDAR benchmark can be seen in the top left-hand corner of the photograph.

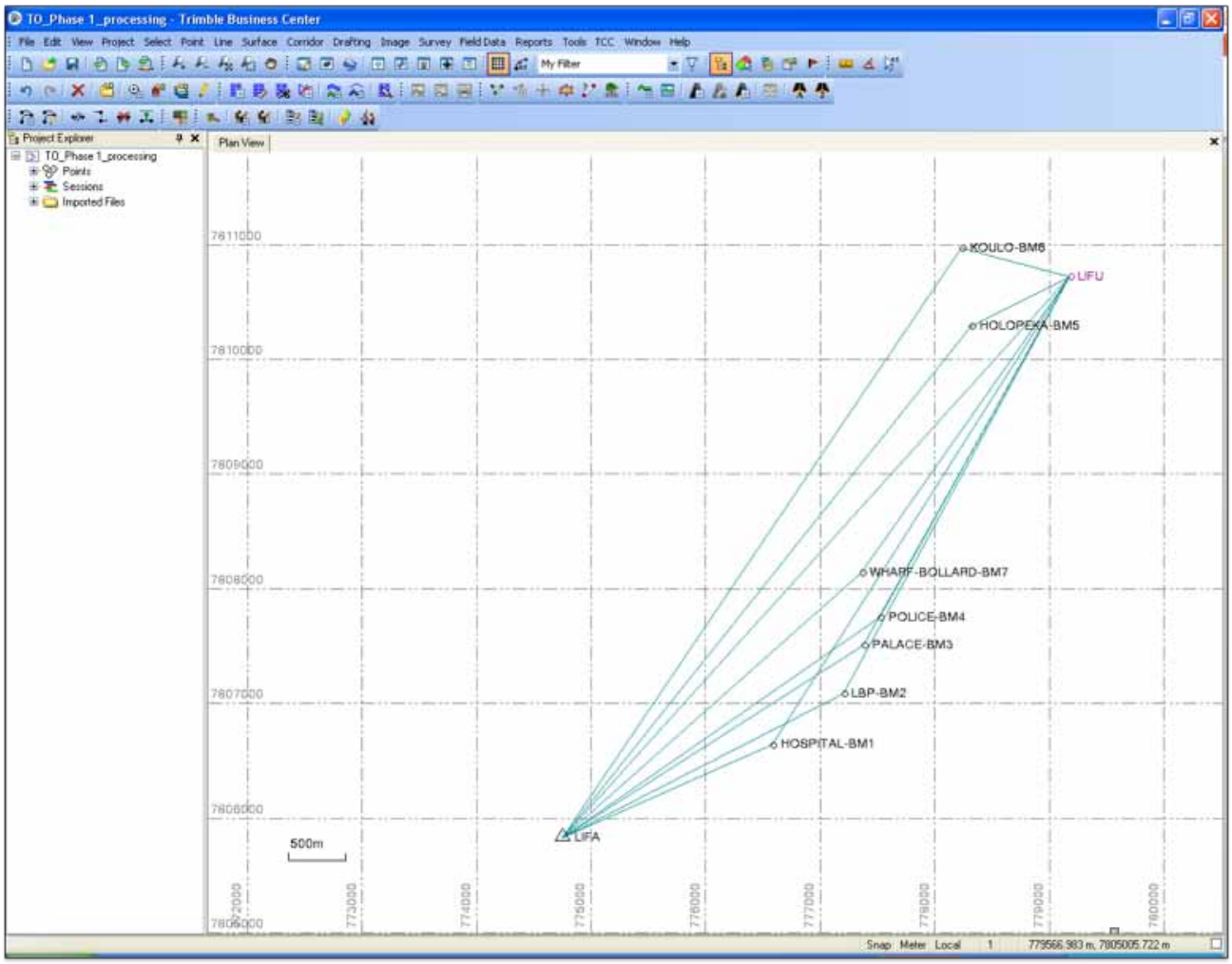

Figure 10: Screenshot of the Trimble Business Centre, showing the network of baselines using Lifu as the primary benchmark. Note that the bollard was later used as the primary height in adjusting the network.

3.2 Beach profiling

Five sets of beach profiles were completed during the project duration. Profile lines were run from the benchmark to the base of the beach. A Foif level and tech staff were used for profiling. Profile directions were adjusted by compass readings for consistency throughout the survey period. The following steps outline the beach profiling procedure (see Figures 11 to Figure 14):

- orientation of the profile line (approximately perpendicular to the shoreline);
- laying down of graduated tape from benchmark to base of beach;
- setting up of the Foif level on the profile line;
- placement of tech staff on the benchmark, and survey seward along the profile;
- elevations were usually recorded at 2 m intervals, as well as at distinct features, such as the edge of vegetation, the top of a scarp;
- GPS time was recorded for the height at water level.

Figure 11: Set-up of the tripod and FOIF level along the profile line

Figure 12: Features such as the edge of vegetation, height of a scarp were noted.

Figure 13: The profile line was measured right up to the base of the beach. Measurements were timed to be taken during low tide whenever possible.

Figure 14: Distances from structural features such as buildings and water tanks were measured to the beach to show changes in the width of beaches over the survey period.

A similar technique was used for inundation survey after TC Cyril, where the extent of water on land was measured and the locations marked as waypoints with a handheld Garmin GPS.

A worksheet was created in Microsoft Excel 2007 for calculations and graphing of beach profile data. Heights collected from profiles were adjusted to heights above mean sea level using benchmark heights derived from the GNSS survey relative to the tide gauge observations.

3.3 GPS shoreline photo mapping

For the shoreline photo mapping, a handheld Garmin Vista HCx GPS and an Olympus muTough digital camera were used to produce geocoded photographs of the coastal features in order to document the state of the shoreline. At the beginning of each day, the GPS was set to log position and time at five-second intervals, and a photo was taken of the display of the GPS showing the time of day. This effectively synchronised the respective internal clocks in the GPS and the camera for post-processing. The procedure then involved carrying the handheld GPS around the neck while taking photos along the shoreline, preferably during low tide.

Figure 15: A photo was taken of the handheld GPS displaying the time of day in local standard time at the start of each survey day. This enables geocoding of any subsequent photos by way of matching the GPS location and time with the time stamp embedded in the EXIF information of the JPG photo file.

At the end of the day, the track log from the GPS (.gpx file) was saved along with the digital photos downloaded from the camera. The open source software GPicSync v1.28 (http://code.google.com/p/gpicsync/) was then used to geocode the photos by tagging each photo with the appropriate geographic coordinates from the GPX file using time as the common reference. GPicSync also had the option of generating KML and KMZ files for use in Google Earth and other GIS software such as QGIS (www.qgis.org).

3.4 Temporary tide gauge installation

The objective of the tide gauge observations was to get the height of the tide staff in relation to the adjacent LiDAR benchmark and to derive the mean sea level for the benchmarks and beach profile surveys.

A tide staff was installed at the wharf in Pangai and observed for 24 hours at ten-minute intervals (Figures 16 and 17). Pressure observations were also made using a Nortek Aquadopp profiler at a nearby location (see the Oceanographic assessment companion report) for 42 days.

Level runs were done between the LiDAR benchmark to the top of the tide staff, as well as between the LiDAR and bollard benchmarks (Figures 18 and 19). The tide staff observations and pressure sensor data were sent to Glen Rowe, Senior Tidal Officer, New Zealand Hydrographic Authority, for analysis and computation of the Lifuka Vertical Datum 2012.

The height of the LiDAR benchmark was then transferred to the bollard at the wharf, which was then used as the primary vertical benchmark in order to transfer height relative to mean sea level to the other benchmarks using the Trimble Business Centre Software. All benchmarks were therefore referenced to the Lifuka Vertical Datum 2012.

Figure 16: Location of the temporary tide staff on the old northern ramp of Pangai Harbour. This was the same position used for the LiDAR tide gauge.

Figure 17: Placement of the tide staff at the ramp on the northern edge of the Pangai wharf

Figure 18: Levelling run, top of tide staff to LiDAR BM

Figure 19: Levelling run, LiDAR BM to top of tide staff

3.5 Equipment used

 *Trimble R8*	 *Trimble controller*
 *Leica Foif auto level*	 *Tech staff*
 *Olympus digital camera*	 *Garmin handheld GPS*

4 RESULTS

4.1 Locations of benchmarks on Lifuka

Figure 20 shows the location of the benchmarks that were surveyed during the project. Benchmarks one to six were used for the repeat beach profiling, whereas benchmarks Lifa and Lifu were used for horizontal control. The bollard benchmark was tied in to the LiDAR benchmark and the Lifuka Vertical Datum 2012 and therefore provided vertical control of the network.

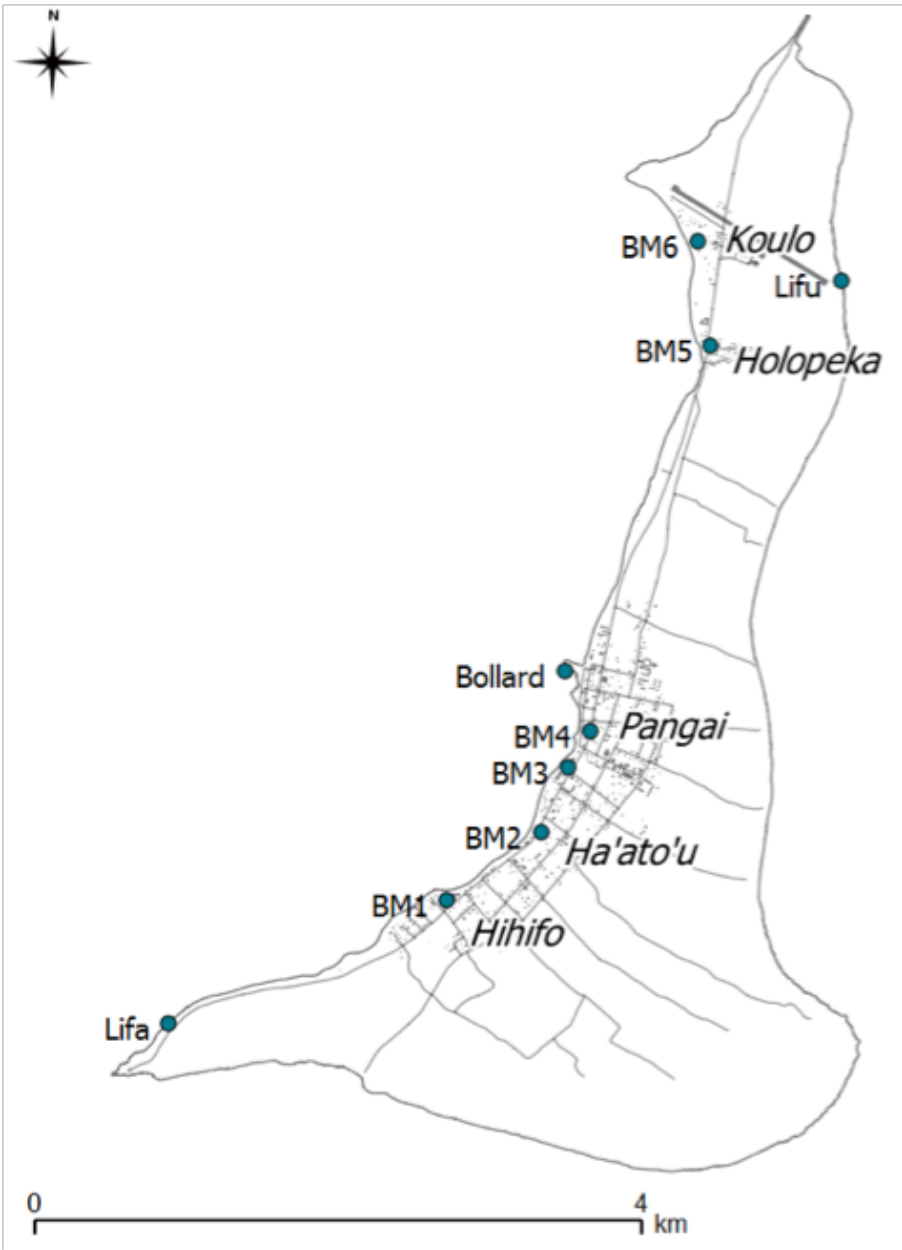

Figure 20: Map of Lifuka showing the locations of benchmarks. Note the two pre-existing benchmarks, Lifa and Lifu, which were used as 24-hour observation primary base stations.

4.2 Description of benchmarks

Location diagrams for each of the benchmarks used in the beach profiling surveys.

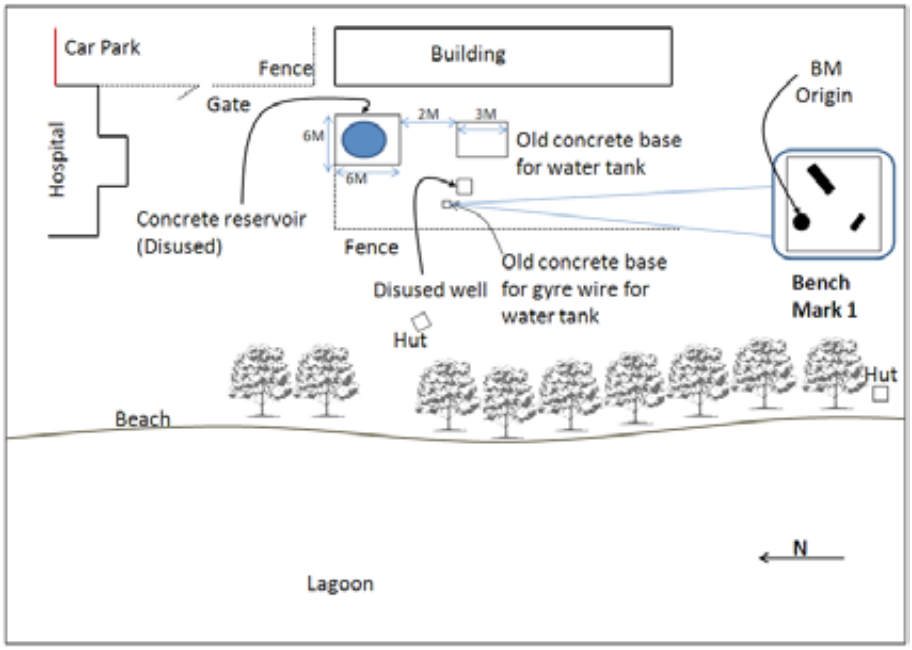

Figure 21: Location diagram for benchmark 1, at the hospital

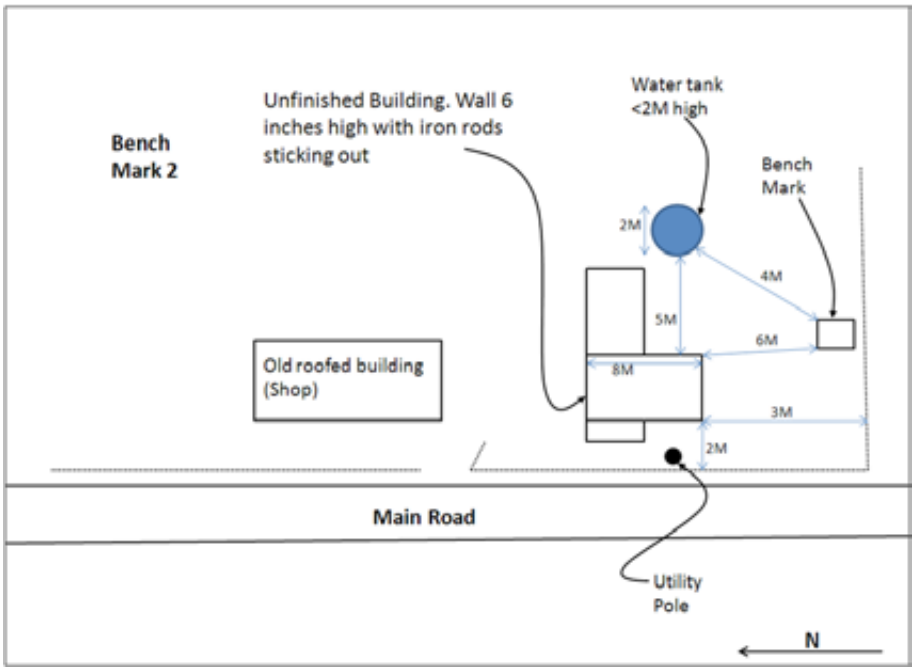

Figure 22: Location diagram for benchmark 2, in Ha'ato'u

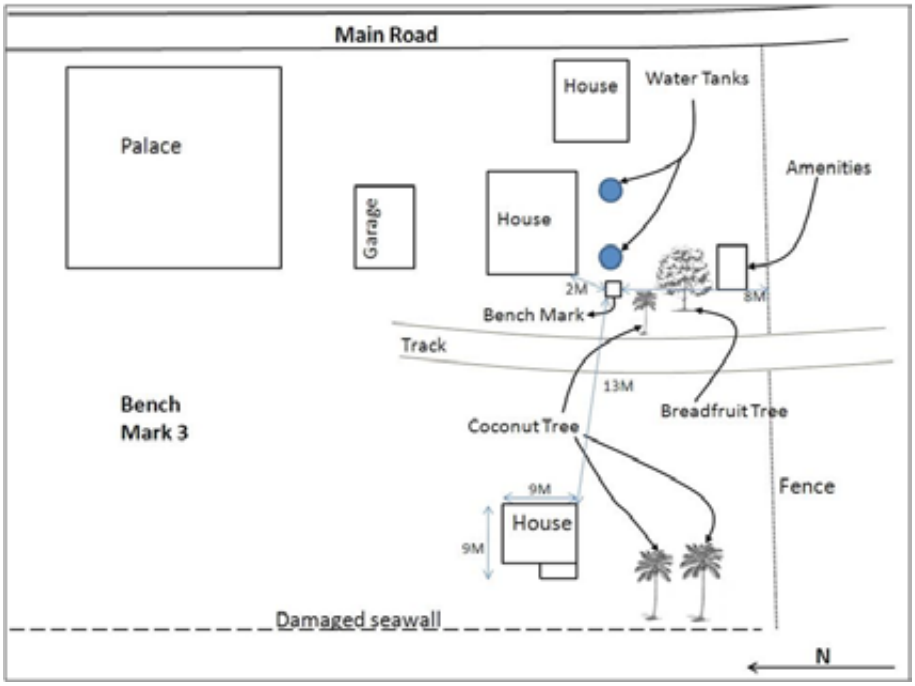

Figure 23: Location diagram for benchmark 3, within the grounds of the King's Palace

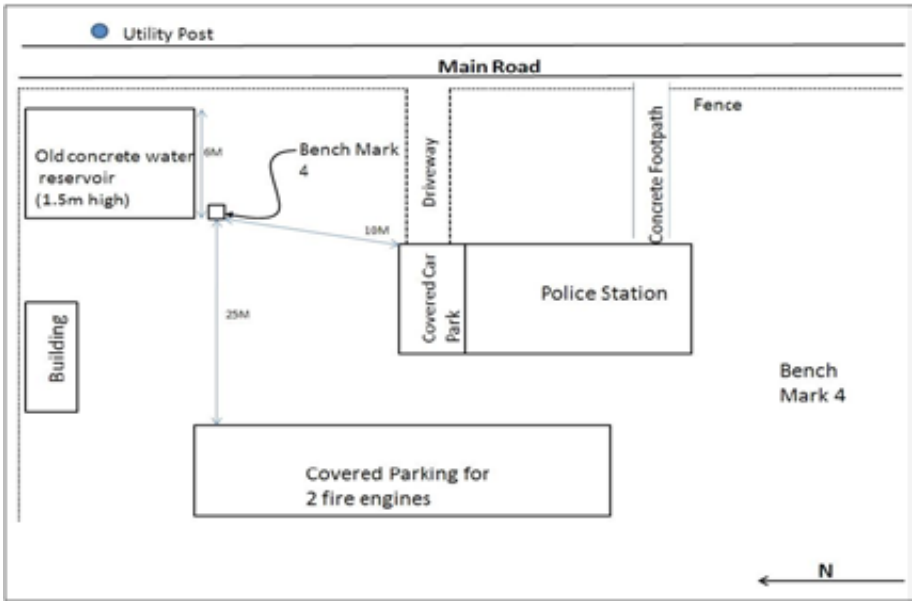

Figure 24: Location diagram for benchmark 4, within the police station compound, Pangai

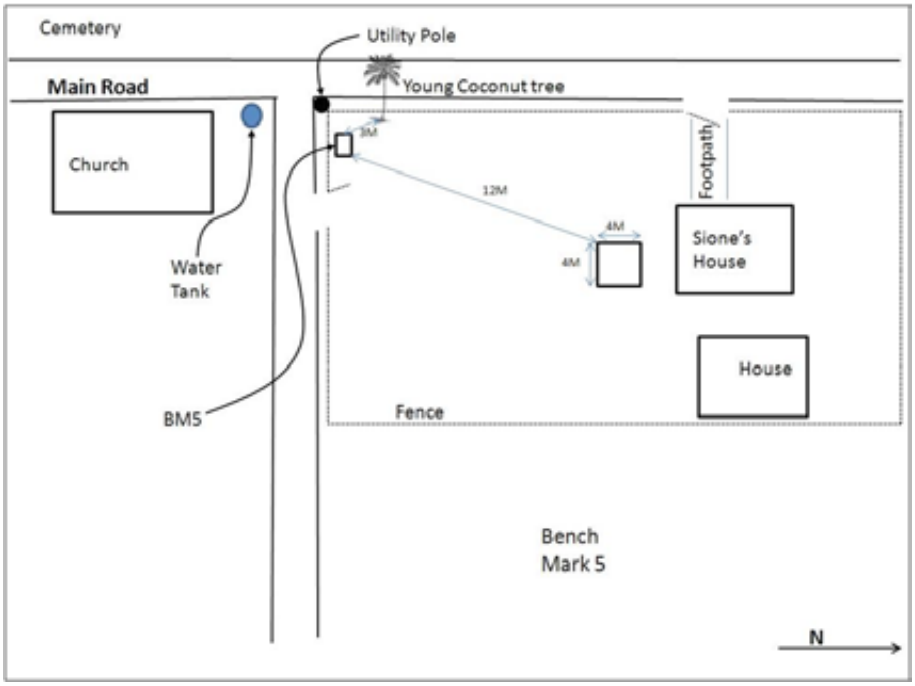

Figure 25: Location diagram for benchmark 5, in Holopeka

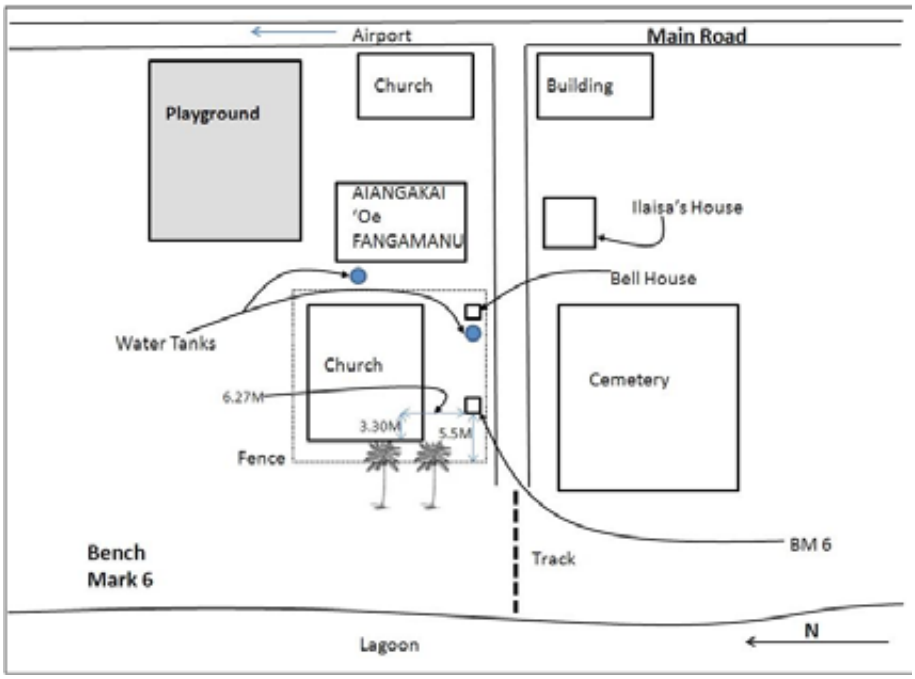

Figure 26: Location diagram for benchmark 6, in Koulo

4.3 Temporary tide gauge analysis

The levelling reduction form for the traverse between the temporary tide staff and the LiDAR benchmark is shown in Figure 27 and shown schematically in Figure 28.

LEVELLING REDUCTION FORM

Company:	SOPAC				Date.	18-Oct-12				Observer	Zulfikar		
Locality:	Lifuka				Time.	1600				Recorder	Simote		
BM'S:	LIDAR Benchmark to Tide Guage				Weather	Fine Sunny				Inst. No.	Leica NA720 Auto Level		
										Staff No.	MYZOX ALG-55EM-METRIC		
Staff Station	**Distance**		**Back Reading**	**Delta Height**	**Inter Reading**	**Forward Reading**	**Delta Height**	**Rise**	**Fall**	**Reduced Level**	**Remarks**		
1	0.000	**T**	1.043	0.031							Lidar Bench Mark to Tide staff		
	0.000	**M**	1.012							1.880			
	6.300	**B**	0.980	0.032									
2	6.500	**T**	1.146	0.034		1.135	0.035				Tide staff		
	0.000	**M**	1.112			1.100		0.000	0.088	1.792			
	6.500	**B**	1.081	0.031		1.070	0.030						
3	6.300	**T**		0.000		1.055	0.031				Lidar Bench Mark		
	0.000	**M**				1.024		0.088	0.000	1.880			
	0.000	**B**		0.000		0.992	0.032						
Check			Total Backs			Total Ons					Traverse length (K)	0.026	km
Totals	25.600		2.124			2.124		0.088	0.088		Total Length	0.0256	km
											Mean Height Difference		0.000
											Height of BM above CD		0.000
											Length of TP		2.000
											Height of BM on Tachstaff		0.000
											CD on or Off Pole + is off. Add this figure to readings to obtain true value from calculated CD.		-2.000
Reduced					Delta						Allow. M' close	1.920	mm
Checked					Height	0.000				0.000	Actual M'close	0.000	mm

Figure 27: Levelling run from the LiDAR benchmark to the tide staff and back to the LiDAR benchmark

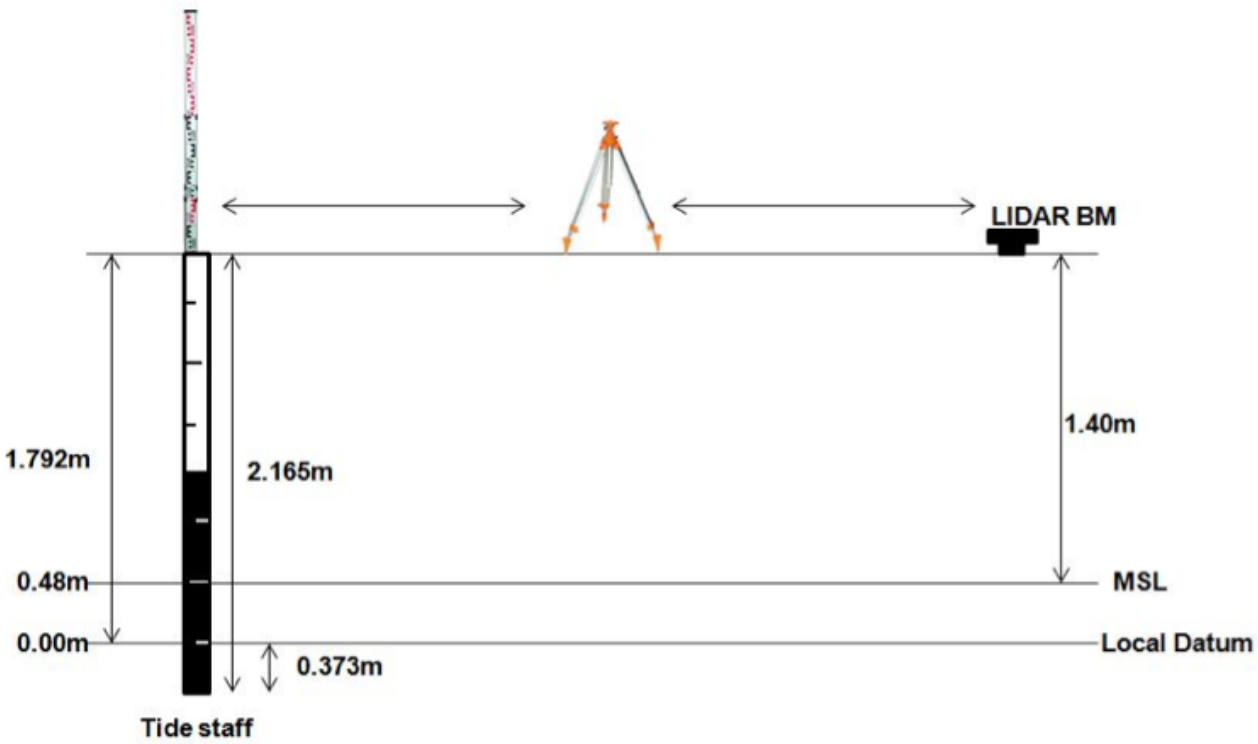

Figure 28: Schematic diagram of the tide staff in relation to the LiDAR benchmark. The mean sea level was derived to be 1.40 m below the LiDAR benchmark.

The final results of the tidal analysis are shown in the table below. The mean sea level was found to be 1.40 m below the brass pin referred to as the LiDAR benchmark, and is the definition of the Lifuka Vertical Datum 2012.

Table 1: Final results of the tidal analysis

Tidal term	Height (m)
Mean high water spring	0.71
Mean high water neap	0.37
Mean sea level	0.00
Mean low water neap	–0.39
Mean low water spring	–0.71

4.4 Trimble global positioning system (GNSS) survey

The results of the GNSS post-processing done in the Trimble Business Centre software are tabulated below. Geographic positions refer to WGS84, and coordinates given in Northings and Eastings are based on the Universal Transverse Mercator (UTM) Zone 1S, WGS84 system.

Table 2: Results of the GNSS post processing

Point ID	Latitude (Global)	Longitude (Global)	Ellipsoid height (Global)	Geoid height	Northing	Easting	Elevation	Corrected heights relative to Lifuka Vertical Datum 2012
LIFA	-19.82432	-174.37702	50.782	49.786	7805826	774755	0.995	0.515
LIFU	-19.77951	-174.33554	53.86	49.386	7810720	779181	4.474	3.994
BM1, Hospital	-19.81669	-174.35968	52.241	49.625	7806642	776585.3	2.616	2.136
BM2, Ha'ato'u	-19.81260	-174.35384	51.622	49.569	7807086	777205.1	2.053	1.573
BM3, Palace	-19.80874	-174.35220	52.286	49.552	7807510	777383.5	2.733	2.253
BM4, Police	-19.80652	-174.35089	51.583	49.539	7807754	777524.3	2.043	1.563
BM5, Holopeka	-19.78347	-174.34365	53.109	49.466	7810295	778323.5	3.643	3.163
BM6, Koulo	-19.77731	-174.34457	53.927	49.474	7810978	778237.5	4.453	3.973
Wharf bollard	-19.80302	-174.35250	52.086	49.554	7808145	777362.2	2.532	2.052

4.5 Beach profiling

An example of a beach profile record is given in Figure 30. Plots of the repeat profiles at each of the six profile locations are given in Figures 31 to 36.

SPC CPS
SECRETARIAT OF THE PACIFIC COMMUNITY
SECRÉTARIAT GÉNÉRAL DE LA COMMUNAUTÉ DU PACIFIQUE

Beach Profile Analysis

Location:	Lifuka, Tonga
Profile Orientation	330- NW
Known Height above OD:	2.136

Project:	PASAP
Surveyor:	Zulfikar
Staff Man	Simote
Bench Mark:	BM1 Hospital
Latitude:	-19.8126
Longitude:	-174.35968

Distance	Descriptio	Height (m) Phase 1	Height (m) Phase 2	Height (m) Phase 3	Height (m) Phase 4	Height (m) Phase 5	Corrected Height Reading 1(m)	Corrected Height Reading 2(m)	Corrected Height Reading 3(m)	Corrected Height Reading 4(m)	Corrected Height Reading 5(m)	Height variation: Phase 1 and Phase 2	Height variation: Phase 2 and Phase 3	Height variation: Phase 3 and Phase 4	Height variation: Phase 4 and Phase 5	Total Change
0	At the BM	1.030	1.335	1.640	1.930	1.540	3.166	3.471	3.776	4.066	3.676	0.305	0.305	0.290	-0.390	0.510
1	Grass		1.380				#N/A	2.091	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.000
2	Grass	1.550	1.445	1.750	2.040	1.650	1.616	2.026	2.026	2.026	2.026	0.410	0.000	0.000	0.000	0.410
3	Grass		1.468				#N/A	2.003	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.000
4	Grass	1.210	1.510	1.790	2.100	1.705	1.956	1.961	1.986	1.966	1.971	0.005	0.025	-0.020	0.005	0.015
5	Sand		1.480				#N/A	1.991	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.000
6	Sand	1.065	1.390	1.760	2.030	1.620	2.101	2.081	2.016	2.036	2.056	-0.020	-0.065	0.020	0.020	-0.045
7	Sand		1.368				#N/A	2.103	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.000
8	Sand	1.010	1.392	1.770	2.050	1.640	2.156	2.079	2.006	2.016	2.036	-0.077	-0.073	0.010	0.020	-0.120
9	Sand		1.410				#N/A	2.061	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.000
10	Sand	1.075	1.460	1.760	2.080	1.680	2.091	2.011	2.016	1.986	1.996	-0.080	0.005	-0.030	0.010	-0.095
11	Sand		1.455				#N/A	2.016	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.000
12	Grass	1.185	1.480	1.790	2.070	1.690	1.981	1.991	1.986	1.996	1.986	0.010	-0.005	0.010	-0.010	0.005
13	Grass		1.490				#N/A	1.981	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.000
14	Grass	1.165	1.540	1.740	2.040	1.680	2.001	1.931	2.036	2.026	1.996	-0.070	0.105	-0.010	-0.030	-0.005
15	Grass		1.570				#N/A	1.901	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.000
16	Grass	1.185	1.520	1.760	2.080	1.710	1.981	1.951	2.016	1.986	1.966	-0.030	0.065	-0.030	-0.020	-0.015
17	Grass		1.555				#N/A	1.916	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.000
18	Grass	1.250	1.525	1.740	2.085	1.720	1.916	1.946	2.036	1.981	1.956	0.030	0.090	-0.055	-0.025	0.040
19	Grass		1.478				#N/A	1.993	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.000
20	Grass	1.305	1.452	1.760	2.150	1.785	1.861	2.019	2.016	1.916	1.891	0.158	-0.003	-0.100	-0.025	0.030
21	Grass		1.520				#N/A	1.951	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.000
22	Grass	1.320	1.543	1.820	2.180	1.785	1.846	1.928	1.956	1.886	1.891	0.082	0.028	-0.070	0.005	0.045
23	Grass		1.610				#N/A	1.861	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.000
24	Soil	1.365	1.530	1.970	2.220	1.870	1.801	1.941	1.806	1.846	1.806	0.140	-0.135	0.040	-0.040	0.005
25	Soil		1.485				#N/A	1.986	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.000
26	Soil	1.420	1.612	2.02	2.850	1.870	1.746	1.859	1.756	1.216	1.806	0.113	-0.103	-0.540	0.590	0.060
27	Soil		1.575				#N/A	1.896	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.000
28	Soil	1.540	1.555	2.010	2.195	1.800	1.626	1.916	1.766	1.871	1.876	0.290	-0.150	0.105	0.005	0.250
29	Soil		1.600				#N/A	1.871	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.000
30	Reclaimed	1.515	1.630	2.030	2.190	1.700	1.651	1.841	1.746	1.876	1.976	0.190	-0.095	0.130	0.100	0.325
31	Reclaimed		1.605				#N/A	1.866	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.000
32	Reclaimed	1.515	1.590	2.030	2.100	1.595	1.651	1.881	1.746	1.966	2.081	0.230	-0.135	0.220	0.115	0.430
33	Reclaimed		1.570				#N/A	1.901	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.000
34	Reclaimed	1.565	1.635	1.890	1.945	1.500	1.601	1.836	1.886	2.121	2.176	0.235	0.050	0.235	0.055	0.575

Figure 30: Beach profile data were entered into an Excel spreadsheet and heights were corrected with corresponding heights of the benchmarks. Data collected for all phases were entered and variation from previous surveys was calculated. The figure is a screenshot of the Excel spreadsheet showing data for BM 1 at the hospital.

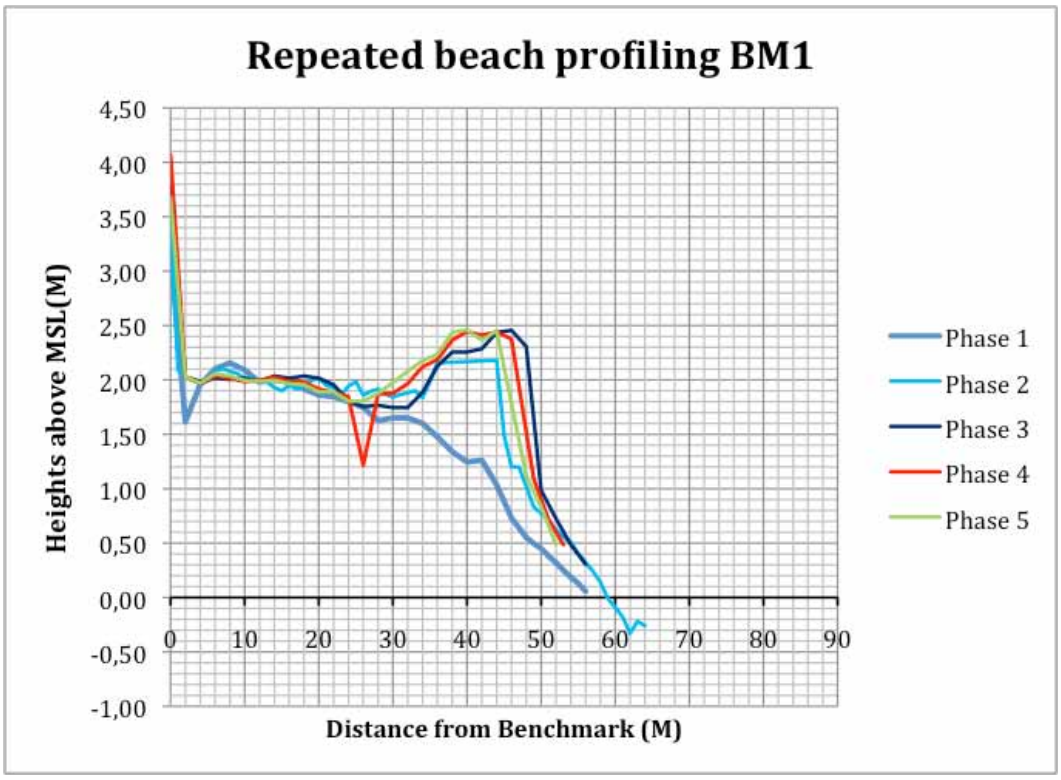

Figure 31: Beach profile plot for the five repeated surveys at benchmark 1

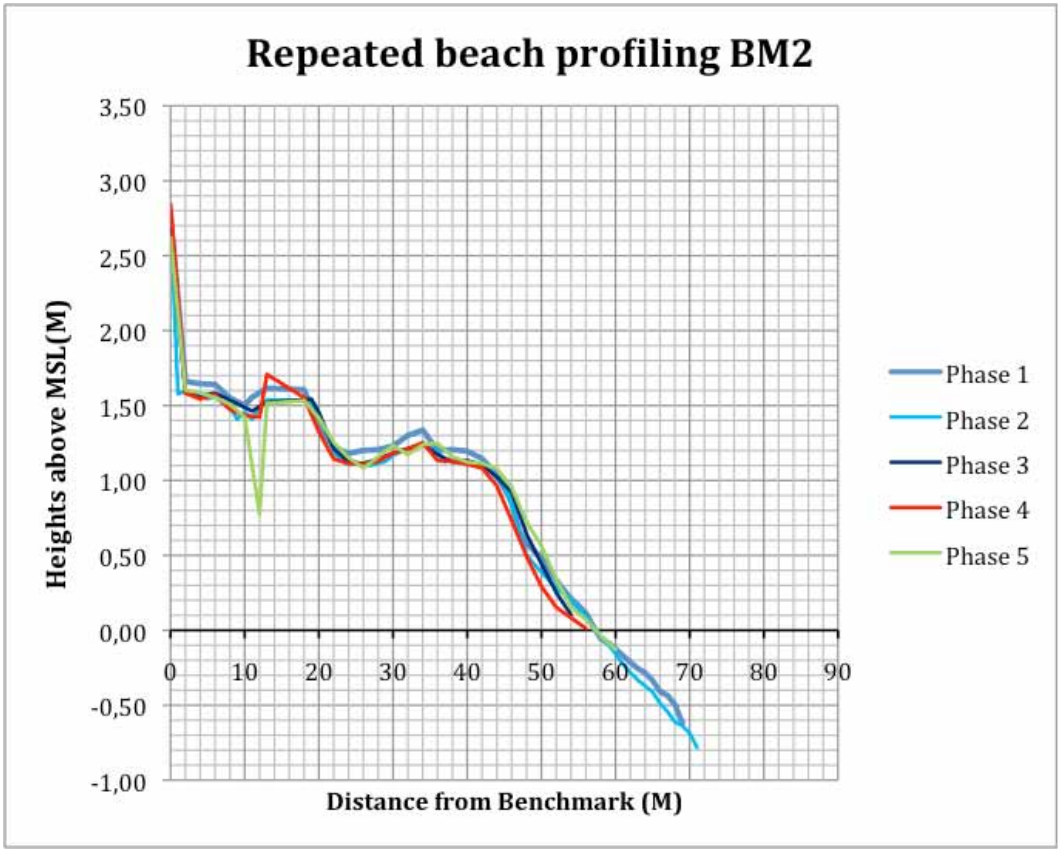

Figure 32: Beach profile plot for the five repeated surveys at benchmark 2

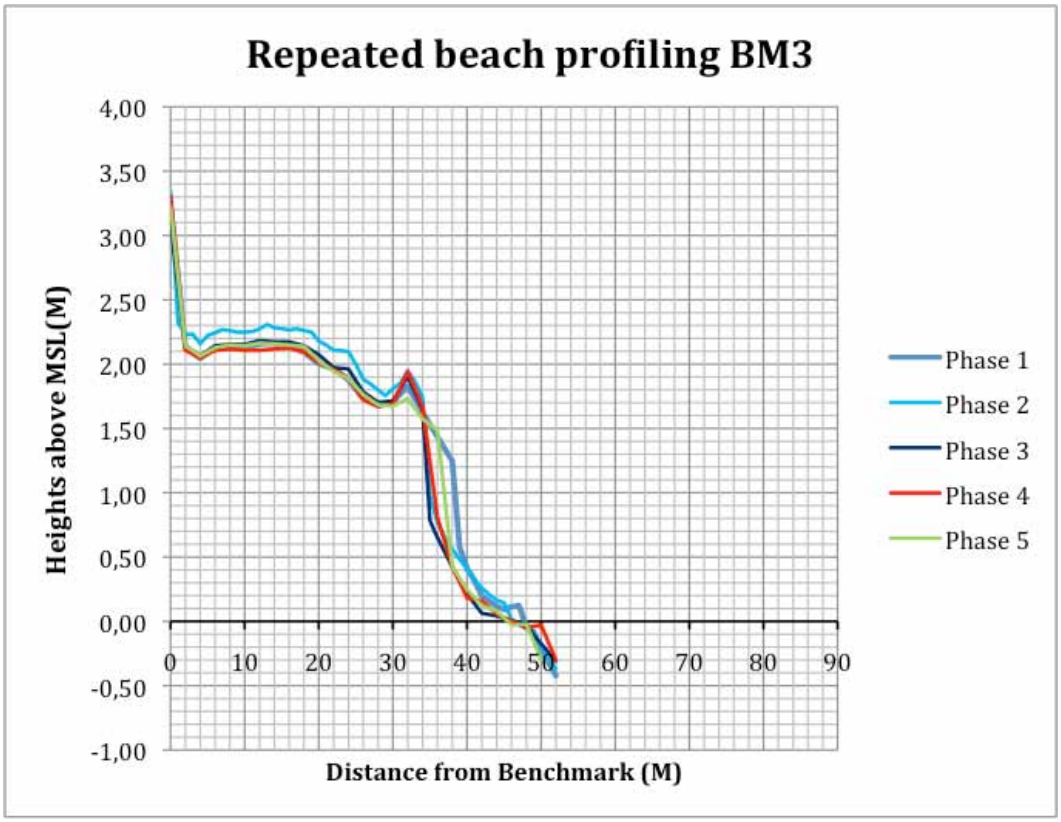

Figure 33: Beach profile plot for the five repeated surveys at benchmark 3

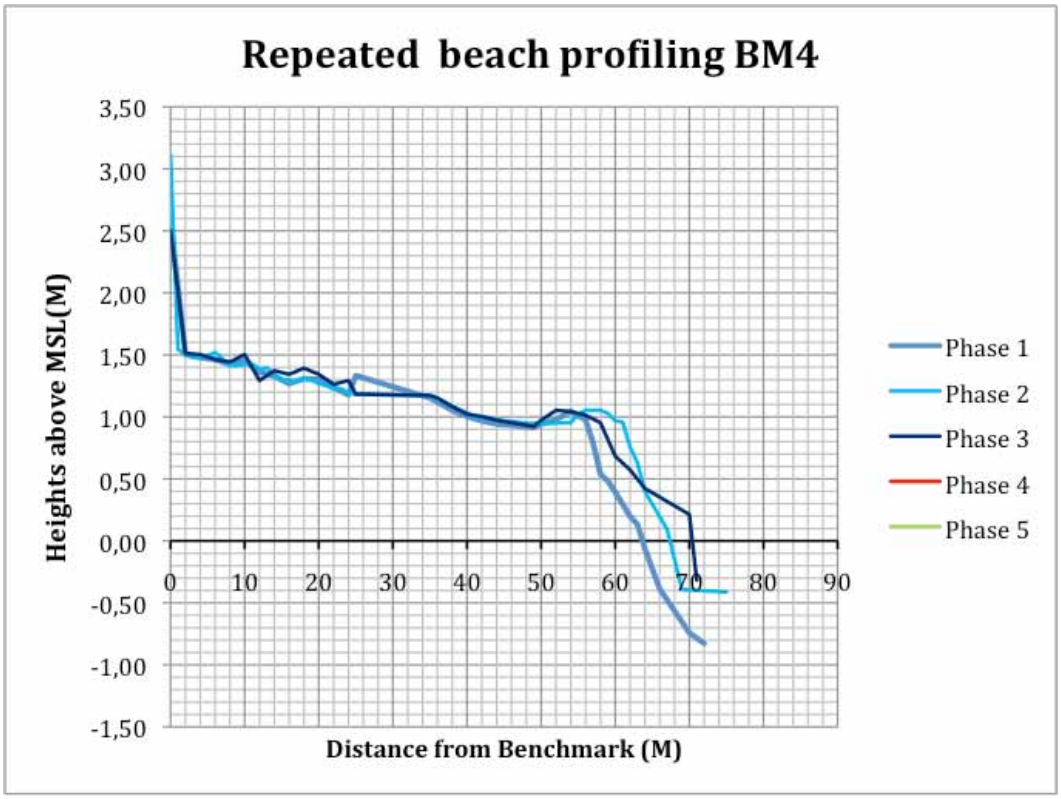

Figure 34: Beach profile plot for the five repeated surveys at benchmark 4

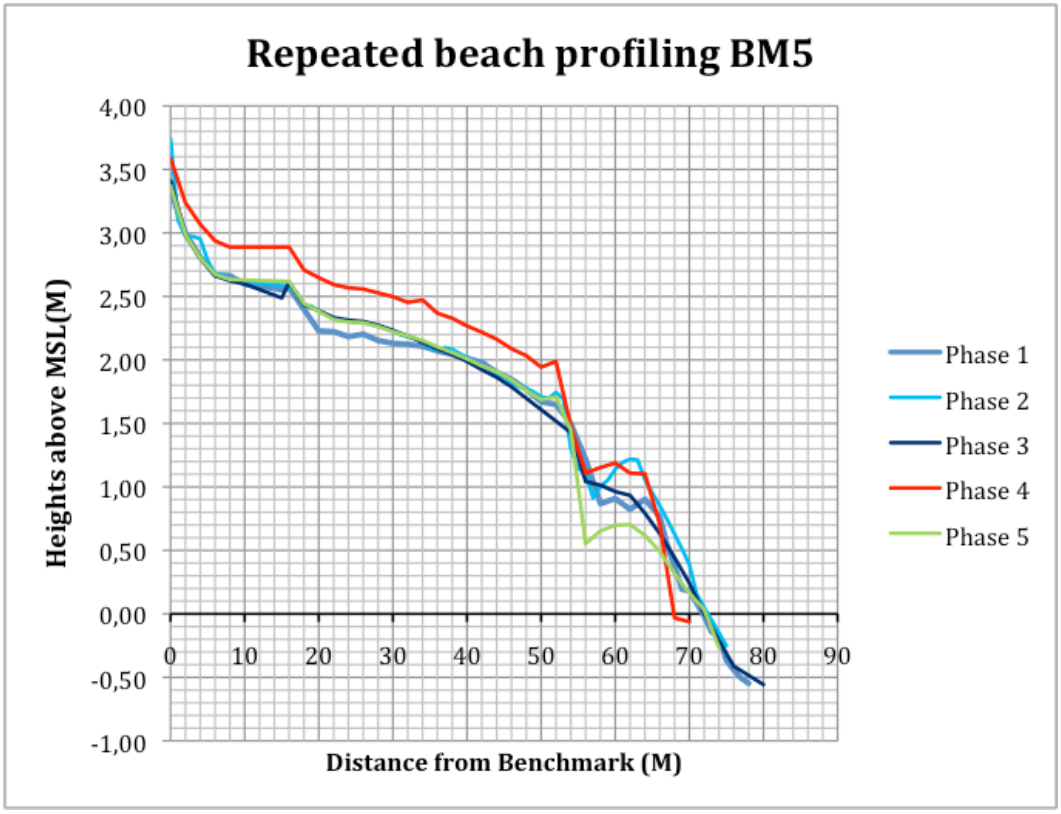

Figure 35: Beach profile plot for the five repeated surveys at benchmark 5

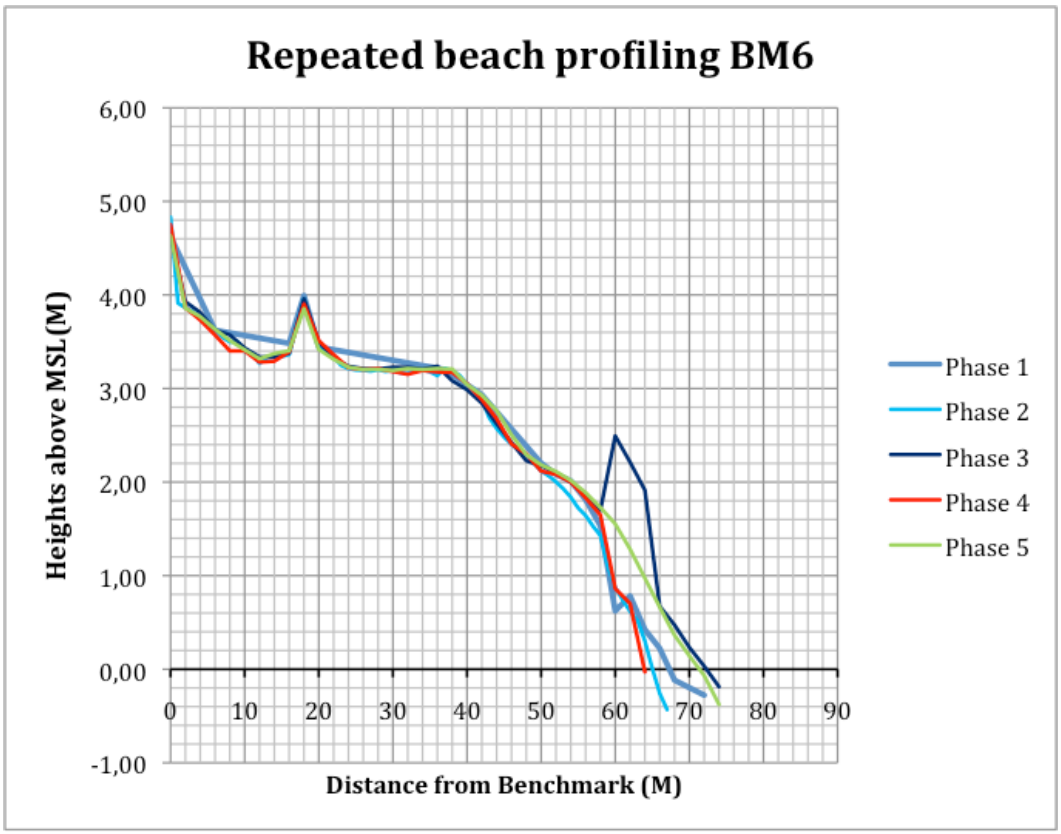

Figure 36: Beach profile plot for the five repeated surveys at benchmark 6

4.6 GPS photo mapping

A total of 2758 geocoded photos was produced, providing a detailed record of the state of the shoreline and adjacent coastal structures. The photos and accompanying KMZ files display in Google Earth as shown in Figure 37, and will also be available from SOPAC's Geonetwork server (see www.sopac.org).

Figure 37: GPS track and geocoded picture thumbnails of photos taken from 12–21 September 2011, displayed as an example from the KMZ file in Google Earth. Clicking on individual photos or groups of photos causes Google Earth to display larger size pop-outs (e.g. the picture DSCN0931 in the lower left-hand corner). Full-resolution photos can also be displayed. Geocoded photos were generated with GPicSync (see Methods section for details).

Figures 38 to 49 show some of the locations and structures prone to erosion and/or inundation observed over the survey period.

Figure 38: Causeway, north from Lifuka, after TC Cyril, February 2012. Sand piled up and seawater flooded parts of the causeway.

Figure 39: Erosional scarp undercutting the road surface next to the road in Holopeka. Photo was taken after TC Cyril in February 2012.

Figure 40: North side of Pangai wharf, in front of the fisheries building. Limestone boulders have been stacked up to protect erosion.

Figure 41: Crumbling sea wall in front of the government centre in Pangai. Parts have been temporarily repaired with concrete mix. Note the erosion scarp and exposed tree roots landward of the sea wall.

Figure 42: Public amenity in Pangai. The sea wall in front has been damaged. Limestone boulders and concrete slabs have been placed to protect against wave impacts.

Figure 43: Old jetty, looking southwards from Pangai wharf. The end of the jetty has broken off and pillars have been damaged. Note that the open construction of the jetty (piling) allows sediment to bypass this structure.

Figure 44: Sea wall in front of the Royal Palace. Slabs are falling apart and the southern down-drift shoreline is experiencing chronic erosion.

Figure 45: Southwest Hihifo. Boulders have been placed to protect homes from wave inundation. During spring tides or extreme events, waves reach the base of the houses.

Figure 46: Coral cemented together for wall protection. Wave overtopping is a regular occurrence in this area.

Figure 47: Sand–concrete mix put into bags and stacked up in front of the hospital. Photo shows the state of the protection two months after construction.

Figure 48: Concrete fence of the TCC building. Parts are deteriorating, with cracks appearing.

Figure 49: Waves at high tide reach the foundation of a house. The house is now vacated and used for bêche de mer processing.

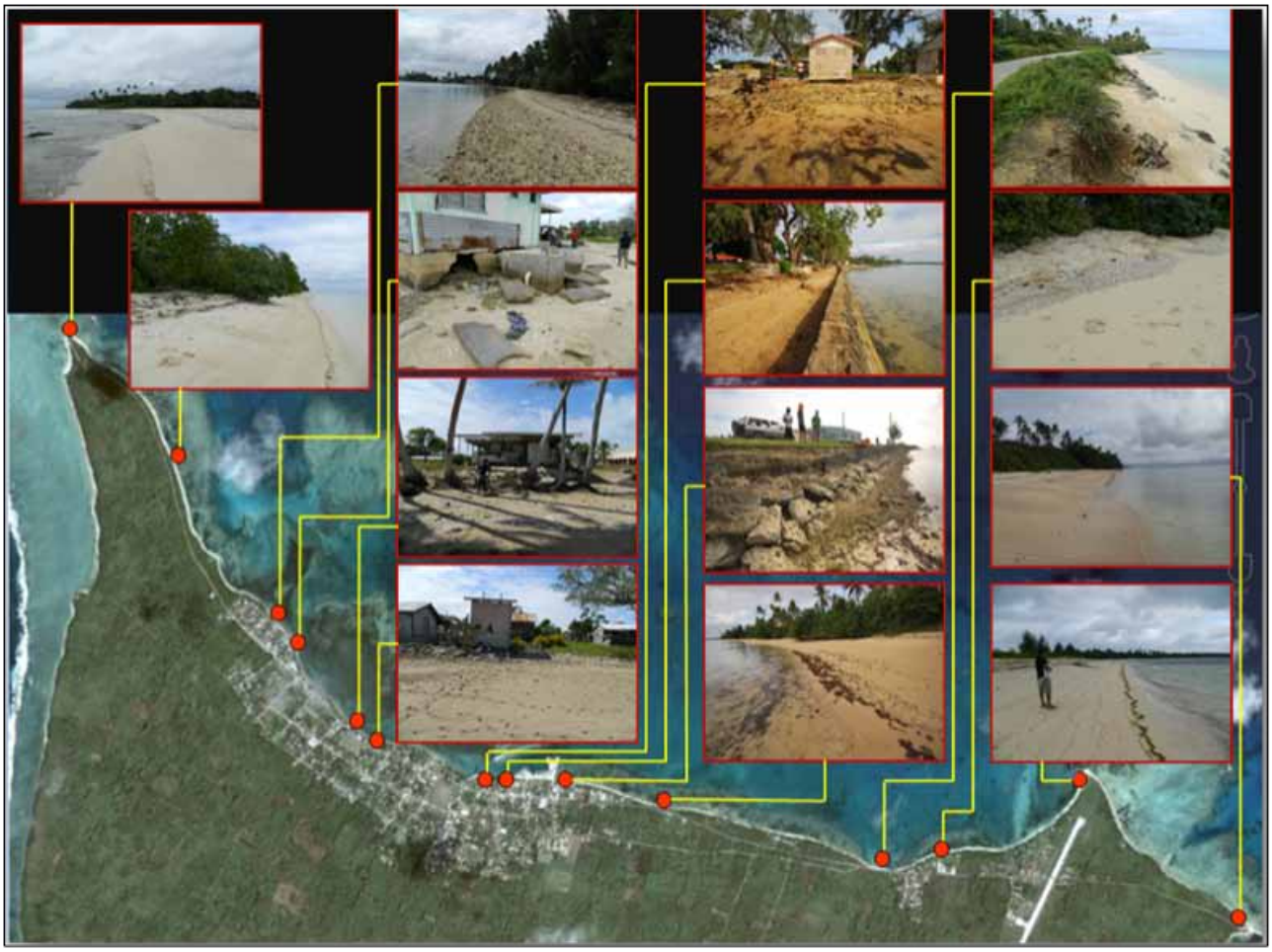

Figure 50: Image showing example photos taken during the shoreline survey, plotted on Google Earth.

4.7 Tropical Cyclone Cyril

Tropical Cyclone Cyril moved into Tongan waters from the northwest and was reported as a category two tropical cyclone, passing north of the Ha'apai group during the first week of February 2012 (Figure 51). Inundation and run-up measurements were made on 14 and 15 February 2012 at seven locations along the western shoreline of Lifuka (Figure 52). Standard land survey techniques were used to map the inundation, the distance from the base of the beach to the debris line, and run-up levels, being the height of the debris line above the base of the beach (Figure 53). The results of the survey are presented in Table 3.

Figure 51: Track of TC Cyril, which was active in the Fiji–Tonga region from 5–8 February 2012. (Source: www.wikipedia.org)

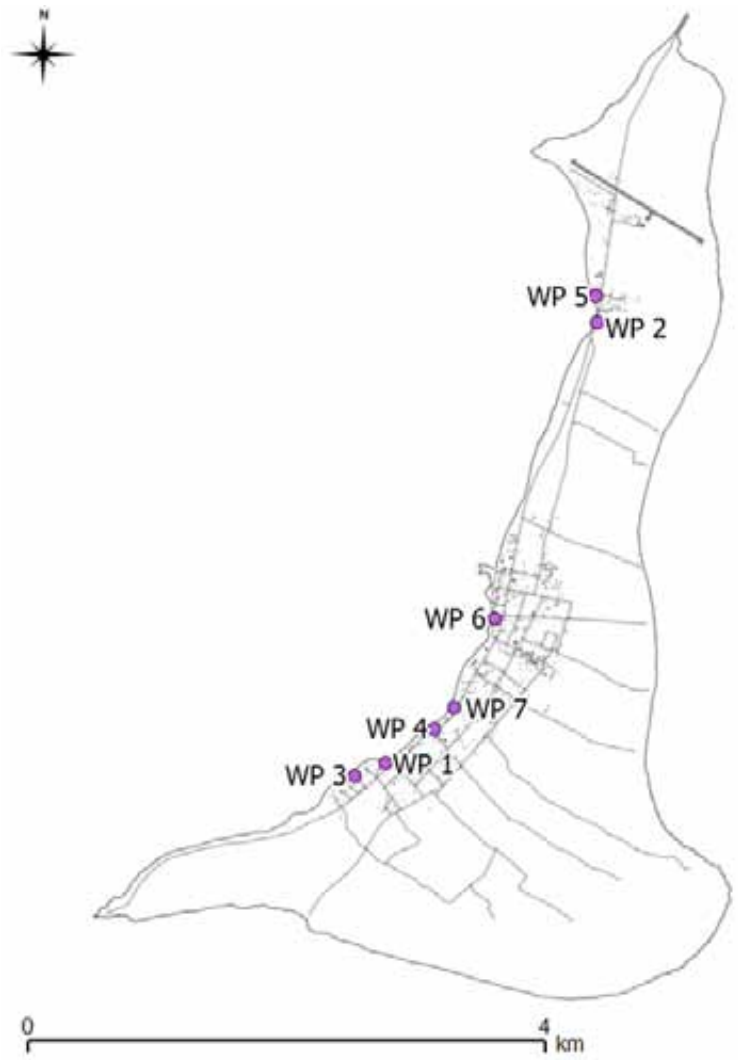

Figure 52: Map of Lifuka showing locations of waypoints where inundation and wave run-up levels were measured on 14 and 15 February 2012 following TC Cyril.

Figure 53: Example of debris line used as an indicator to establish inundation and run-up levels following TC Cyril.

Table 3: Post-TC Cyril ground truthing survey results

Location	Latitude	Longitude	Inundation extent	Wave run-up
Waypoint 001	–19.489820	–174.215540	31	2.737
Waypoint 002	–19.785390	–174.344350	13	2.834
Waypoint 003	–19.817560	–174.361470	32	0.998
Waypoint 004	–19.814080	–174.355500	22	1.797
Waypoint 005	–19.783470	–174.343650	18	3.135
Waypoint 006	–19.806520	–174.350890	19	1.9535
Waypoint 007	–19.812600	–174.353840	27	2.0395

5. DISCUSSION

From the beach profile analysis, it is apparent that the beaches or coasts in Lifuka vary in their geomorphology. This has been attributed to different wave characteristics in nearby areas, which are influenced by the adjacent nearshore morphology (e.g. whether fringing reef zones or lagoon).

For benchmark 1, at the hospital, most of the changes observed resulted from land reclamation and construction of a sandbag revetment. During the first phase of the survey, erosion and inundation were evident in the hospital compound, mainly in front of the ward section. During high tide, seawater was seen to be reaching the vegetation line, and the two water tanks nearest to the lagoon were undercut by erosion. This prompted action from the government and reclamation was initiated, with temporary protection using cement mix sandbags. With regard to beach morphology (Figure 31), minimal change was observed. Towards the end of the survey, an accumulation of sand was observed on the south corner of the beach, which is presumed to be a result of sand from sandbags being washed away.

Changes in beach morphology were observed for benchmark 2, at the old store in Ha'ato'u. Data from the survey show that the width of the beach decreased over the survey period (Figure 32). The decrease was observed after TC Cyril in February, 2012. Waves from the cyclone may have washed the sand away, probably southwards. As a result, waves now frequently reach the vegetation line during high tides. This also affects nearby homes.

The graph in Figure 32 shows that a slump was recorded 12 m from the benchmark during the fifth phase of the survey. This was a result of drainage work in the area.

Benchmark 3, located at the King's Palace, showed some changes to the morphology of the profile line. Noted was an increase in height as seen in Figure 33, resulting probably from soil and aggregates accumulating after TC Cyril. Minor erosion was observed on the scarp. A few palm trees were observed to have fallen over in that area as a result of the erosion.

Only three phases of survey were completed for benchmark 4 at the police station. The reference point was removed due to extension of the police building; therefore, surveys could not be repeated. From Figure 34, it can be noted that there were minimal changes to the morphology of the profile. Boulders and concrete slabs have been placed on the beach face and there is sea-wall protection, which shelters the beach and land from high-energy waves.

Benchmark 5, Holopeka, did not show much change in morphology. An increase in height during phase 4 (Figure 35) was a result of disturbance due to overgrown vegetation. With regard to erosion, beach size did not alter but the scarp next to the vegetation seemed to be increasing. This was evident after TC Cyril.

With regard to benchmark 6 (Figure 36), some changes were observed on the third phase of the survey. Large amounts of sand were piled up on the beach face, probably during TC Cyril. In later parts of the survey, the area seemed to normalising. Beach size remained consistent. Minor or minimal changes in the morphology were noted.

Changes to the shoreline and its state were difficult to record through visible or photographic observations, but the conditions of coastal structures over the survey period provided evidence of wave impacts. Some of these are shown in Figures 54 to 71.

Figure 54: Section of the main highway in Holopeka, September 2011

Figure 55: Part of the road eroded after TC Cyril, February 2012

Figure 56: Restoration of road, March 2012

Figure 57: Placement of concrete mix bags with boulders used as protection, June 2012

Figure 58: East side of the wharf in Pangai. Strong waves have washed over part of it, forming a deep hole, September 2011.

Figure 59: Damage caused by wave overtopping during TC Cyril. Materials are breaking from the wharf, February 2012.

Figure 60: Extent of erosion in front of benchmark 2, September 2011.

Figure 61: Note the increase in scarp height and fallen tree. October 2012.

Figure 62: Residential building in Hihifo, September 2011

Figure 63: Beach erosion has formed a scarp in front of the building and the high water level mark has moved inland, June 2012.

Figure 64: Beach in front of the hospital in Lifuka, September 2011

Figure 65: Reclamation of the area and use of concrete mix sandbags for protection, March 2012.

Figure 66: Sandbags are falling apart, March 2012.

Figure 67: Some of the fallen sandbags have been replaced and concrete mix has been used as a matrix to hold the bags, October 2012.

Figure 68: Southern tip of Lifuka, September 2011

Figure 69: Southern tip of Lifuka after TC Cyril, February 2012

Figure 70: Sand building up to its original state, June 2012

Figure 71: State of the southern end similar to Figure 68. Waves and current processes have moved the sand to its original state, October 2012.

6. CONCLUSION

In general, Lifuka has had limited data in terms of beach profiling and coastal assessment. This survey has provided a clear picture of the current state of Lifuka's coastal zones, including beaches and adjacent coastal structures. It ensures that data collected will now be the baseline for future work on shoreline and coastal assessment.

Six benchmarks were established along the communities in Lifuka, which now act as permanent reference points.

Changes in beach characteristics and geomorphology were assessed over the survey period.

Geocoded photos were produced detailing the state of the shoreline in Lifuka.

Levelling runs were completed and the mean sea level was derived through observation of two tide cycles, as well as recording tides for 35 days.

The probability of Lifuka being inundated and its coastal zones affected by high-energy waves was clearly evident after TC Cyril in February 2012.

Studies and surveys as such play an important role in providing strategies for adaptation, as well as contributing towards policies and advisories on disaster risk reduction.

7. REFERENCES

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