Waves and Coasts in the Pacific

Maui Bay (Fiji), Bathymetric and Topographic Data Collection

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WACOP

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Executive summary

Understanding the costal morphology and topography in the Pacific region is critical for coastal management and to the implementation of climate change adaptation. However, little is known about reef beach morphology on the reef coast of Pacific islands. The Changing Waves and Coast in the Pacific (WACOP) project is collecting baseline information and using the latest research tools to assess the wave climate and its variability to improve the understanding of reef hydrodynamics and morphology as well as predict how these will change with the climate. The project aim is to better understand coastal erosion and inundation and to assess the potential for wave energy harvesting.

The data presented in this document is the result of an intensive survey of topography and morphology of Maui Bay. The data shows how the beach perched on a mid-holocene beachrock is highly stable and document the detailed topography of the reef flat fronting Maui Bay on the Coral Coast. The processing of the data has created a high resolution topography/bathymetry model of Maui Bay suitable for high resolution numerical modelling.

The data presented here is the baseline of a more in-depth analysis of the hydrodynamics of Maui Bay (Bosserelle et al. 2015) and is likely to support further findings on reef hydrodynamics.

1 Background

The Pacific island countries (PICs) are vulnerable to climate change, and have a high dependence on imported fossil fuels. Both of these problems can be attributed to the smallness and geographic isolation of PICs. In terms of climate change, a specific disadvantage that arises from the smallness of the islands is a greater coastline to land-area ratio. The majority of urban areas are located in dynamic coastal zones, and, with a total population of 10 million, these tend to be densely populated with a relatively high concentration of infrastructure. The shorelines of PICs are therefore vulnerable areas with the greatest risk of displacement and loss of livelihood assets through erosion and inundation.

These coastal hazards are projected to become more frequent and intense with climate change. However, current coastal vulnerability and adaptation assessments still focus mainly on sea-level rise, with less attention paid to other important coastal change drivers such as ocean surface waves. Waves wear away land and remove beach sediments, and are also a cause of coastal flooding and habitat destruction during extreme events. Wave research is very limited in the PICs, particularly given their dependence on the coast. The limiting factor in assessing the effects of climate change on coastal areas is therefore insufficient information on the variability and trends of ocean waves as a driver of shoreline changes at relevant island and community scales.

PICs lag behind in research on wave climate variability and trends. Only a few short-term (years) *in-situ* wave observations exist, and there have only been a limited number of studies that analyse historical wave climate data in terms of coastal impacts and wave power availability. PICs do not currently conduct research as to how wave climate, wave power, and shorelines may evolve under emissions scenarios. The poor understanding on how damaging waves, eroding shorelines and wave power have changed in the recent past, and may change in the future under climate change is a major knowledge gap which will be addressed by the WACOP project.

1.1 Aims of the WACOP project

The project addressed these knowledge gaps in two ways. Firstly, in terms of ocean waves, the project used computer models to downscale public domain data on the historical (decadal) wave variability and trends to relevant regional and local scales, and estimate how wave climate will change in the future under projected climate change scenarios. Secondly, in terms of coastal erosion and inundation, field visits were conducted and data collected at specific local sites to calibrate and validate models (at scales of 10s of metres) that can predict shoreline behaviour under climate change and thereby assist with adaptation and disaster risk reduction. This latter part presents a specific problem as available models have been developed for the open sandy coasts found on continental shorelines. The majority of PIC coasts however, are fringed by coral reefs, and adapting existing predictive models to reef environments will involve relevant and original research through this project.

1.2 This report

The field investigations presented in this report were aimed at gathering baseline information on the bathymetry, morphology and topography of the fringing reef and the beach fronting the shoreline in Maui Bay, on the Coral Coast of Fiji. This information is critical to better understand the role of waves in coastal hazards (erosion and inundation) in the Pacific. The Maui Bay site is one of 2 sites selected as the Project field sites. A similar report has been produced for the ocean side of Fatato Island on the atoll of Funafuti, in Tuvalu (Figure 1).

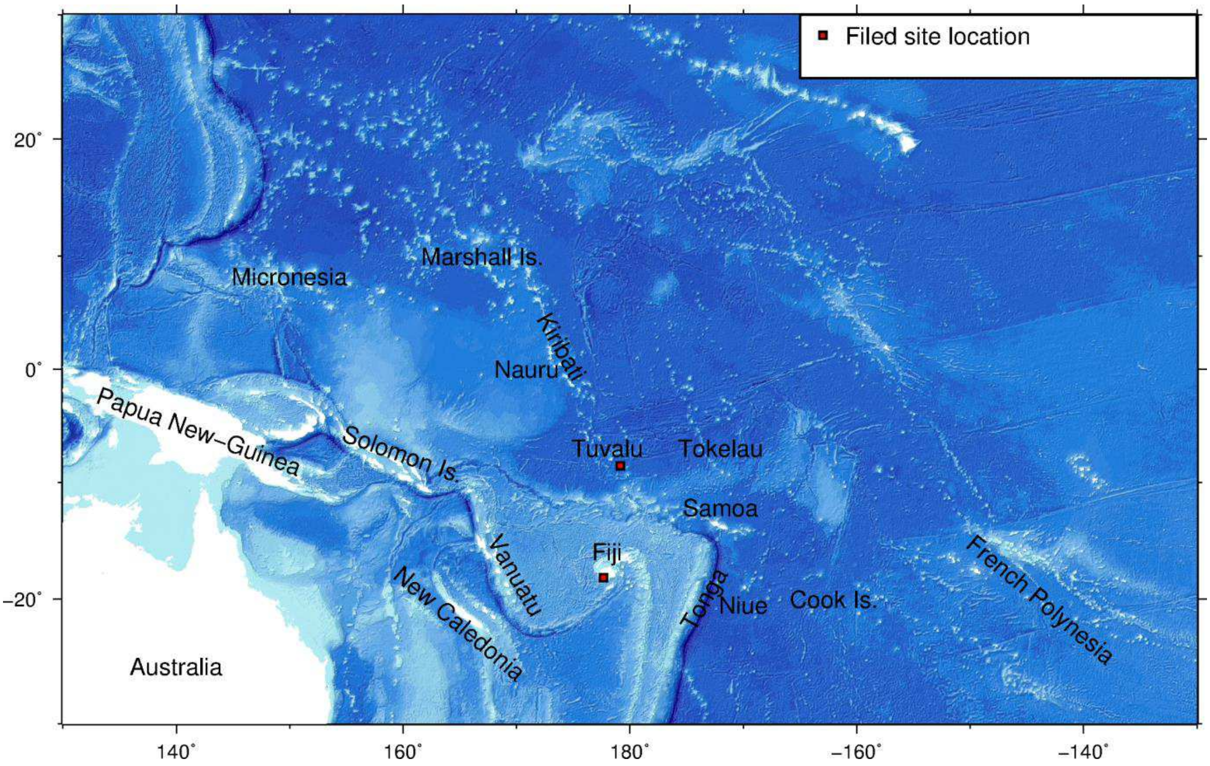

Figure 1.1 WACOP field sites in the Pacific

2 Site Overview

The Coral Coast is an area south of Viti Levu with a fringing reef system 400 – 800m wide and interrupted by narrow passage. Maui Bay is the name of a development area located on the Coral Coast of Viti Levu in Fiji between the village of Tagaqe to the West and Votua-o-lailai to the East. The field site (Figure 2) corresponds to a 1,600m long shoreline from the Maui Bay jetty in the East to the Tagaqe passage in the West.

2.1 Morphology

Maui Bay field site is fronted by a fringing reef 650m wide. The reef is bounded by a narrow passage (40m wide) to the east and a relatively wide passage (150m) to the west. The lagoon area of the fringing reef is relatively shallow (less than 1.5m deep) and is bounded east and west by a shallow algal ridge effectively forming a closed basin covering an area of 1.4km^2.

The interior of the Lagoon is covered with an alternation between coral patches reaching close to mean sea level in elevation and sandy patch. Seagrass is present in the area but not extensively. The coral patches tend to be more common towards the reef crest and less towards the shore.

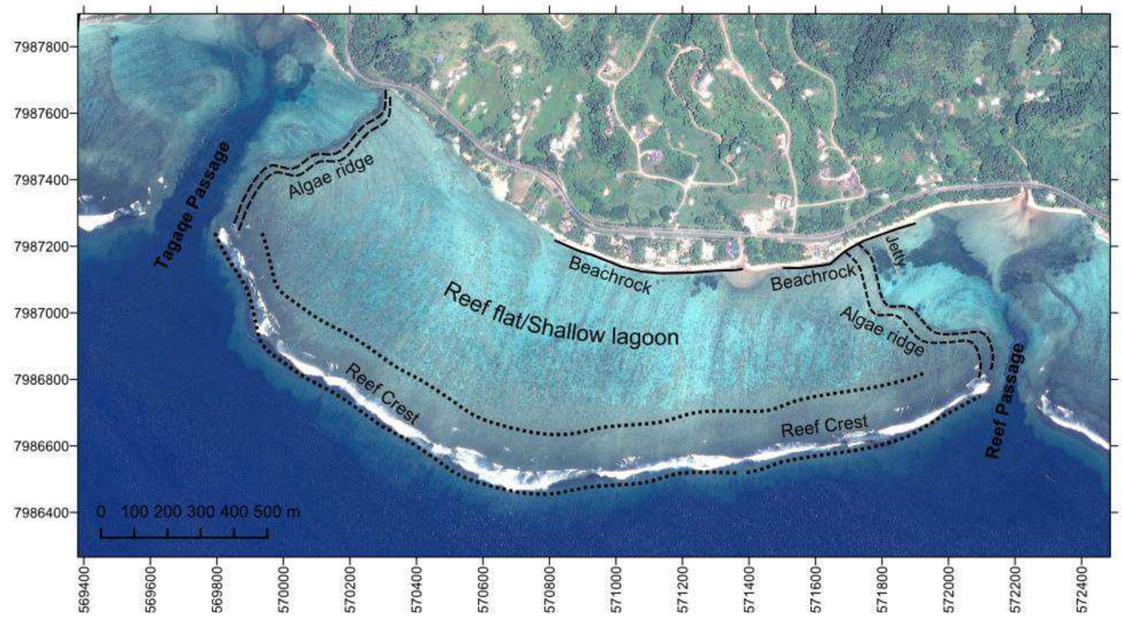

Figure 2.1. Location of beachrock and algae ridge in Maui Bay.

3 Topography/Bathymetry

A detailed investigation of the bathymetry and topography was undertaken to collect suitable data for coastal inundation modelling.

3.1 Benchmarks

Benchmarks are essential to create reference points that will allow combining and comparing all the geographical information collected for Maui Bay. Benchmarks were placed on the beachrock at 10 locations in Maui Bay. The baseline benchmark was referenced using a static GPS survey relative to an existing benchmark near Tagaqe and a new benchmark installed on the Maui Bay Jetty.

Benchmark 4 was surveyed using a classic static survey of 6 hours using the Tagaqe benchmark and Maui Bay jetty benchmark as the core station. Other benchmarks were surveyed using a single station RTK survey technique using benchmark 4 as the reference station. The elevations were collected in reference to the geoid. The elevations were later corrected to Mean Sea Level (MSL) using water level collected at the shore of benchmark 4 (Table 3.1).

Table 3.1 Location of benchmarks in Maui Bay

Benchmark Name	Easting (m)	Northing (m)	Elevation (above MSL)	Method
BM1	570834.15	7987222.11	1.342	RTK
BM2	570933.53	7987180.08	1.197	RTK
BM3	571050.08	7987145.24	1.353	RTK
BM4	571150.20	7987125	1.126	Static GNSS
BM5	571254.61	7987131.42	1.337	RTK
BM6	571919.58	7987137.41	1.370	RTK
BM7	571431.66	7987121.77	0.257	RTK - Disappeared
BM8	571533.24	7987139.97	0.797	RTK
BM9	571646.95	7987160.07	1.050	RTK – elevation using dumpy level
BM10	571725.613	7987211.67	1.111	RTK – elevation using dumpy level
BMW	571839.99	7987146.054	3.210	Static GNSS

3.2 RTK GPS survey

RTK GPS survey was undertaken on two separate surveys in Maui Bay. For each survey, the RTK station was established on Benchmark 4 which was derived from a static GPS survey.

The first survey occurred in February 2013 at the same time as the benchmarks were defined. The survey consisted of an alongshore survey of the beach from benchmark 1 all the way to the Jetty; a cross shore survey in front of benchmark 4 all the way to the reef crest and a reef crest survey extending as far as the benchmarks (Figure 3.1). This survey was completed using the Trimble R8 system.

The second survey was in December 2013 to measure the more detailed elevation of the beachrock, the top of the beach and the reef crest and algal ridge. The survey covered from the jetty to the algae ridge on the Tagaqe passage. This survey was completed using a Trimble R10 system.

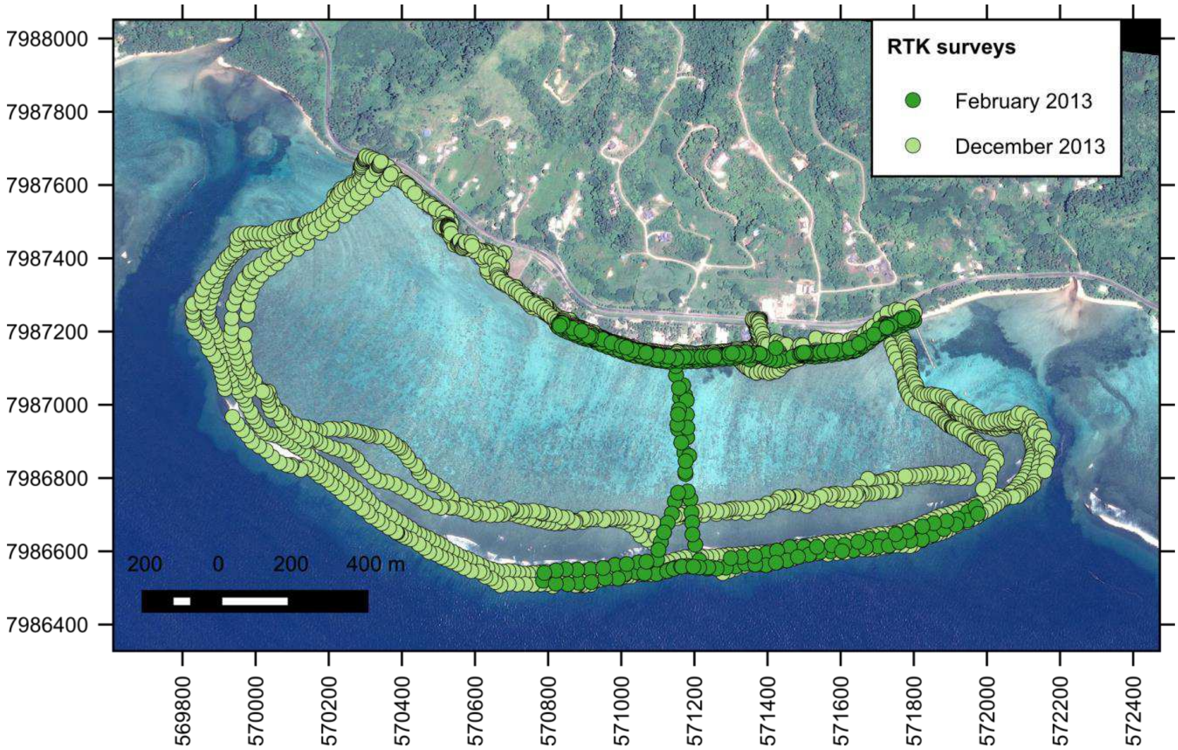

Figure 3.1. RTK surveys of Maui Bay

The relative mean error for the December 2013 RTK survey is 0.06m in the horizontal and 0.02m in the vertical.

3.3 Beach Profiles

Beach profiles were collected along each benchmark on several occasions between 2013 and 2014. Each profile was reference with the elevation of each benchmark to reduce the elevation to the reference datum. Comparison between surveys revealed changes no greater than the estimated survey error (0.05m). Hence the data collected was simply added to the RTK data.

3.4 Bathymetry survey

Although RTK data was collected on the reef flat and on the reef crest, this wasn't sufficient to cover significant portion of the reef slope or the reef flat. A single beam bathymetry survey was used to collect bathymetry information across a wider area of Maui Bay.

3.4.1 Lagoon / reef flat

For the Lagoon/reef flat survey, a small, low draft boat was used with a single beam system tied to the side of the boat and a GNSS antenna extension, 2.0m above the water line (Figure 3.2). The survey was completed in the last week of January 2014 with spring tides and calm winds.

CTD measurements were completed at the beginning and end of the survey to calculate water density to correct the beam data. Water levels were collected every 3 minutes at the front of benchmark 4 which was the start and end point of each survey cruise.

3.4.2 Outside slope

The reef slope survey was completed in February 2014 with calm swell and calm wind condition which allowed the boat to come as close as possible from the reef crest without risk. The set up was virtually identical to the Lagoon/Reef flat survey except using a much larger boat to cover a larger distance.

CTD measurements were completed at the beginning and end of the survey to calculate water density to correct the beam data. Water levels were collected every 3 minutes at the end of the Jetty which was the start and end point of the cruise. Figure 3.4 show the final coverage from the bathymetry survey.

Figure 3.2 Boat setup for the lagoon/reef flat bathymetry survey

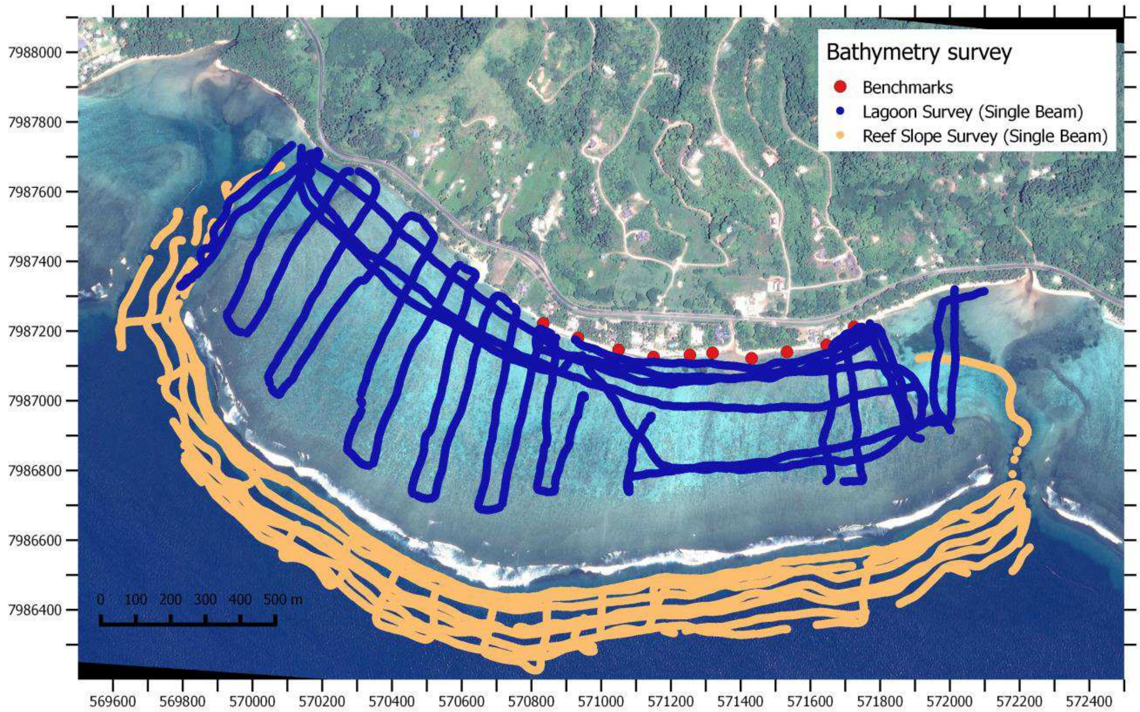

Figure 3.3 Bathymetry data coverage the reef flat and reef slope surveys.

3.5 Photogrammetry

RTK surveys allow the collection of critical data on major morphological feature but the coverage was still too coarse to capture the small scale variation of the topography of the top of the beach and the beach rock. To add more information to the dataset, an Unmanned Aerial Vehicle (UAV) was used to collect detailed photography of the shoreline and use photogrammetry method to derive the detailed topographic features of the coast.

3.5.1 Ortho mosaic

Using all the pictures collected across 3 UAV flights, a mosaic was created using Structure From Motion (SFM) algorithm. The mosaic was then georectified using the location of 7 benchmarks especially marked on the ground during the survey (Figure 3.4).

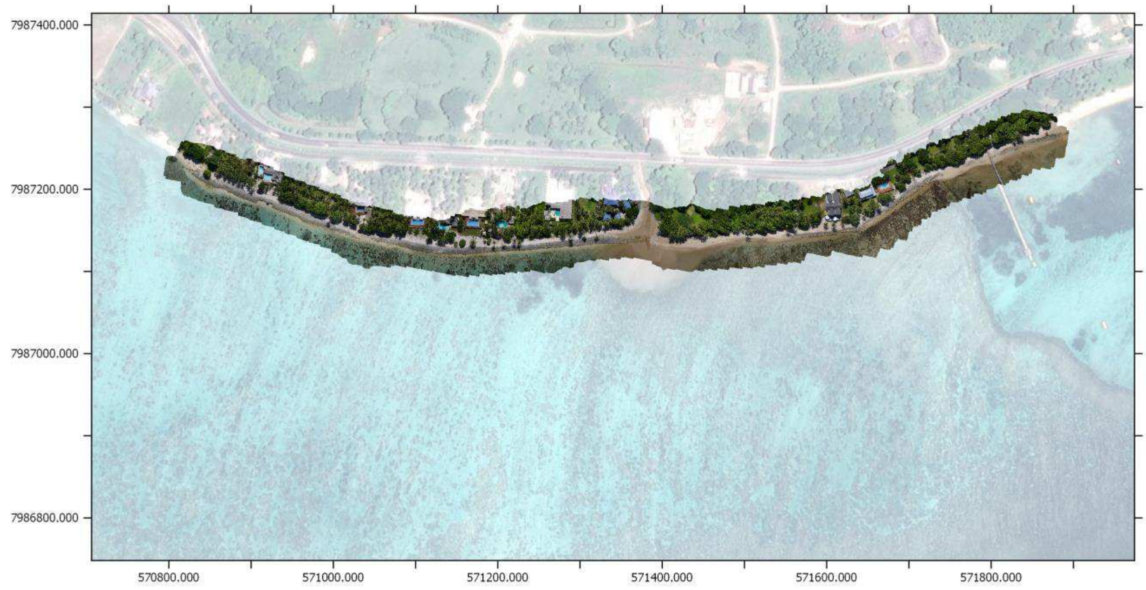

Figure 3.4 Georeferenced Orthophoto mosaic obtained from the UAV survey

3.5.2 Validation

The UAV data was processed to obtain a terrain model for the area using 7 benchmarks. To verify further the validity of the survey, the elevation of the UAV points were compared to the elevation of RTK points that were located no further than 0.1m from the UAV points (Figure 3.5). The additional validity shows that the RTK data and UAV data are very similar. The UAV data does not show any bias and most of the difference can be attributed to sharp variation in topography and morphological changes.

3.5.3 Digital Elevation model

Although the digital elevations calculated from photogrammetry have been validated, the digital model (Figure 3.6) had to be processed further to extract elevation relative to the ground level and remove elevation related to trees and bushes. This would allow the data from the UAV survey to be blended safely with RTK survey and bathymetry survey data.

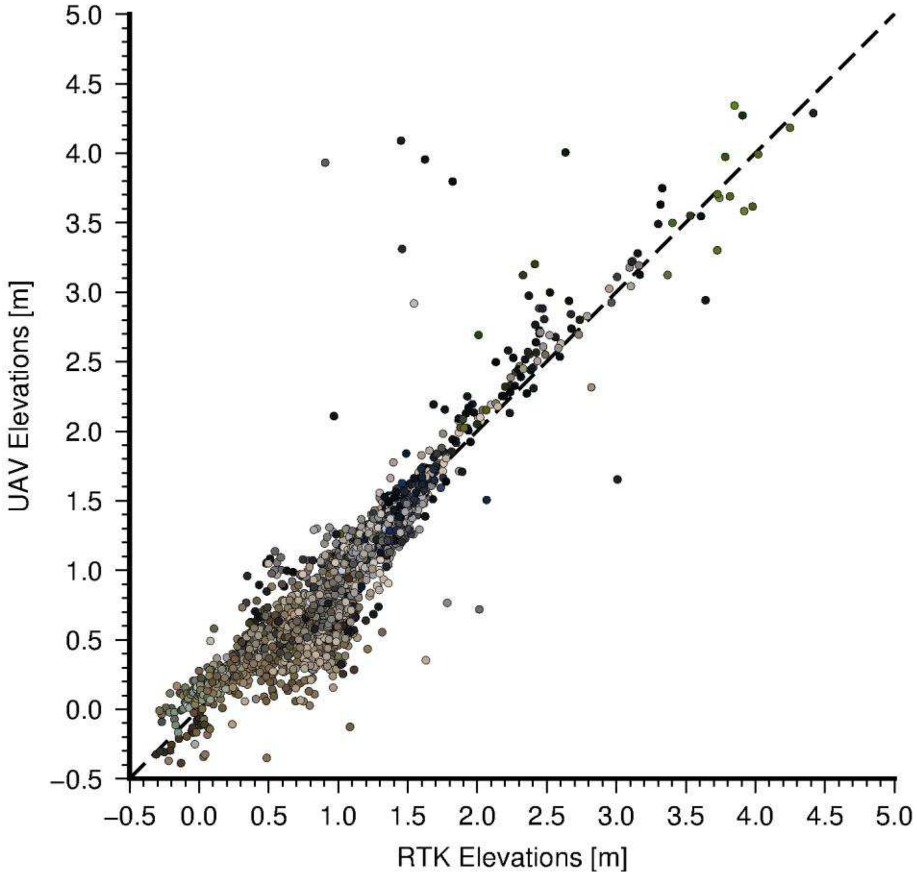

Figure 3.5 Comparison of elevation recorded using the RTK GNSS and the UAV data.

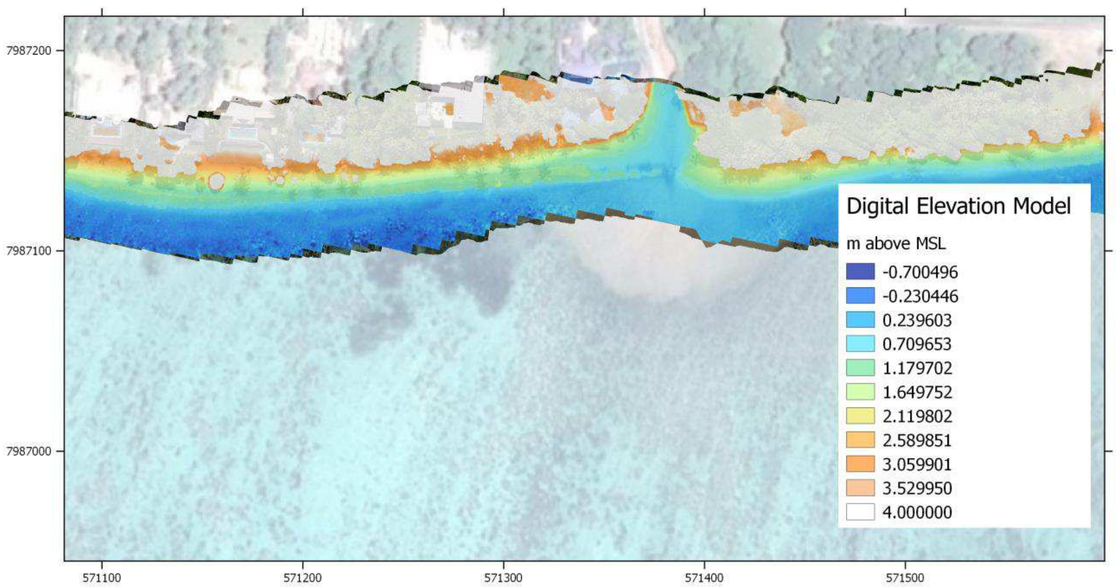

Figure 3.6 Digital elevation model calculated from the UAV survey.

3.6 Satellite derived bathymetry

The bathymetry of the lagoon/reef flat is highly variable and the single beam survey was not sufficient to capture all the bathymetry features. Most of the bathymetry features are however, clearly visible from satellite imagery. The colours displayed on the satellite image (Figure 2.1) are effectively hues of blues depending on the depth and type of seafloor. A linear relation was calculated between the cyan colour component of the satellite image (Figure 2.1) and the single beam data collected (Figure 3.7). The scatter on the relation can be explained by the error in the single beam Easting and Northing data.

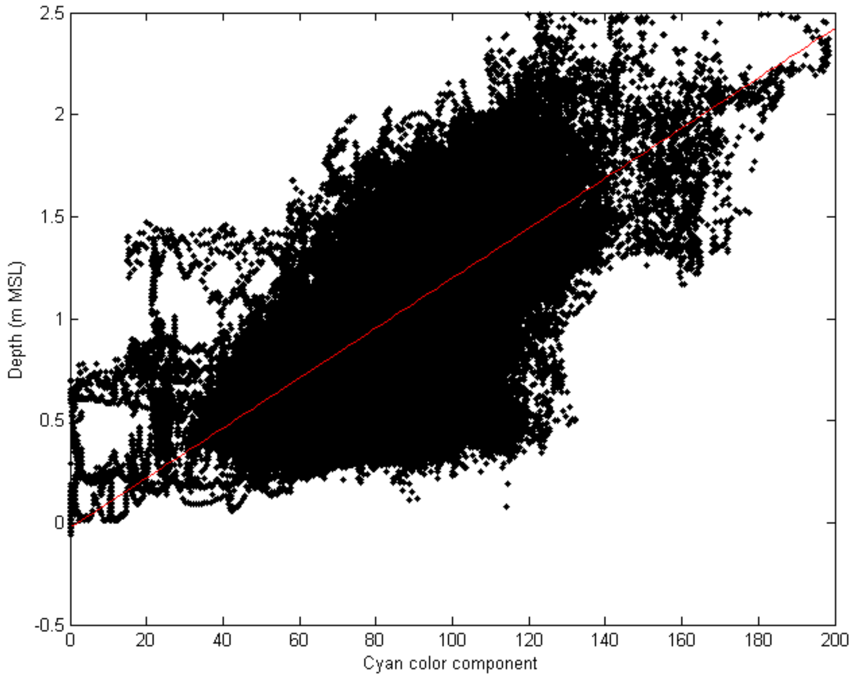

Figure 3.7 Linear relationships between the lagoon single beam data and the Cyan colour component of the satellite imagery in figure 2.1.

Although the relationship found may be introducing some errors, taking account of all the bathymetric features outweighs the cost of these errors on the model. Still, the derived bathymetry is only meant to be applied in shallow water where the bathy coverage is limited. The derived bathymetry was therefore cropped to an area with low depth and no RTK coverage (Figure 3.8).

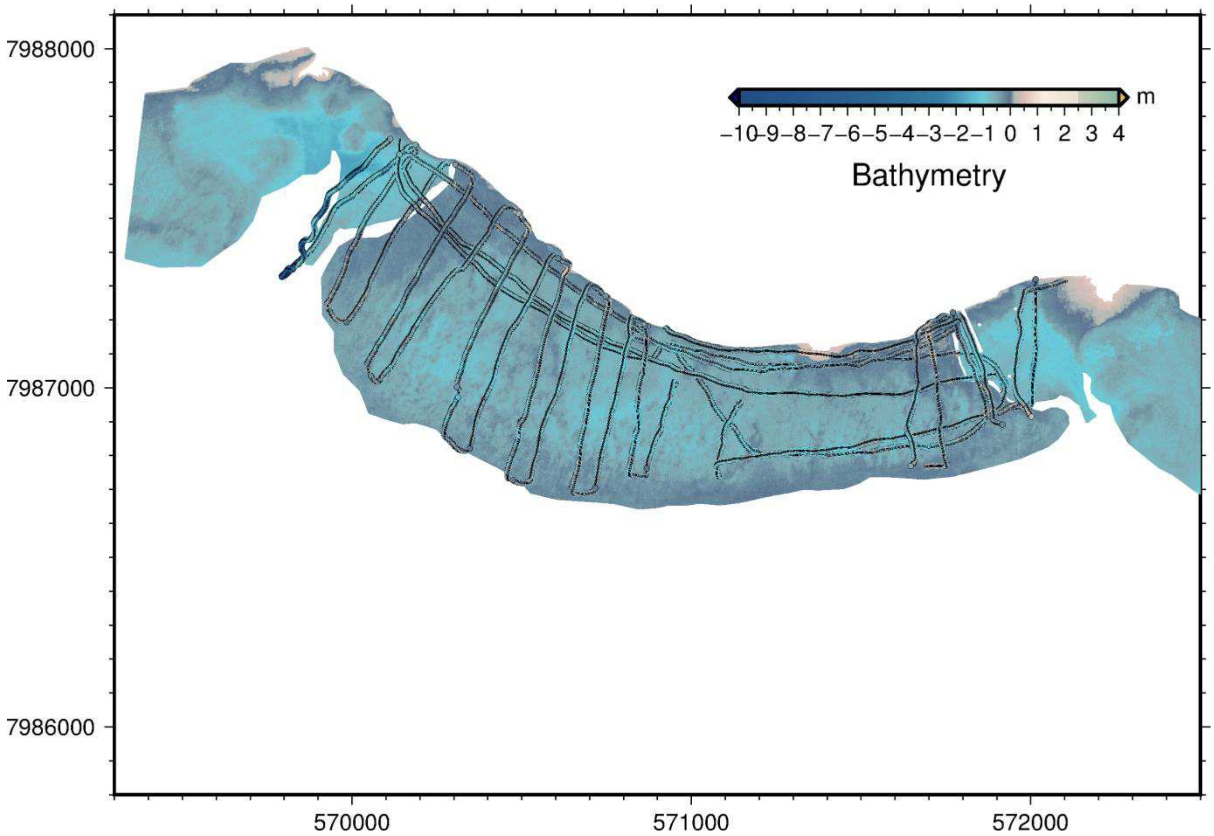

Figure 3.8 Satellite derived bathymetry (shadings) and lagoon bathymetry survey (colored circles)

3.7 Combined datasets

All the topographic and bathymetric data collected was shifted to Mean Sea Level datum as calculated from the water level data from the shore instrument. The datasets were all combined using a hierarchical approach where points were only added if they were not overlapping (within 5m) with data of higher priorities as follow:

1. RTK survey
2. Reef slope single beam survey
3. UAV survey
4. 2012 Multibeam bathymetry survey (From previous project)
5. Digitised morphology
6. Satellite derived bathymetry

The combined points (Figure 3.9) still showed significant gaps in the data, these gaps were interpolated to a 5m grid using a continuous curvature spline with a tension factor of 0.6 (Smith and Wessel, 1990) (Figure 3.10). This datasets was used as the basis for generating bathymetric grid for numerical simulations.

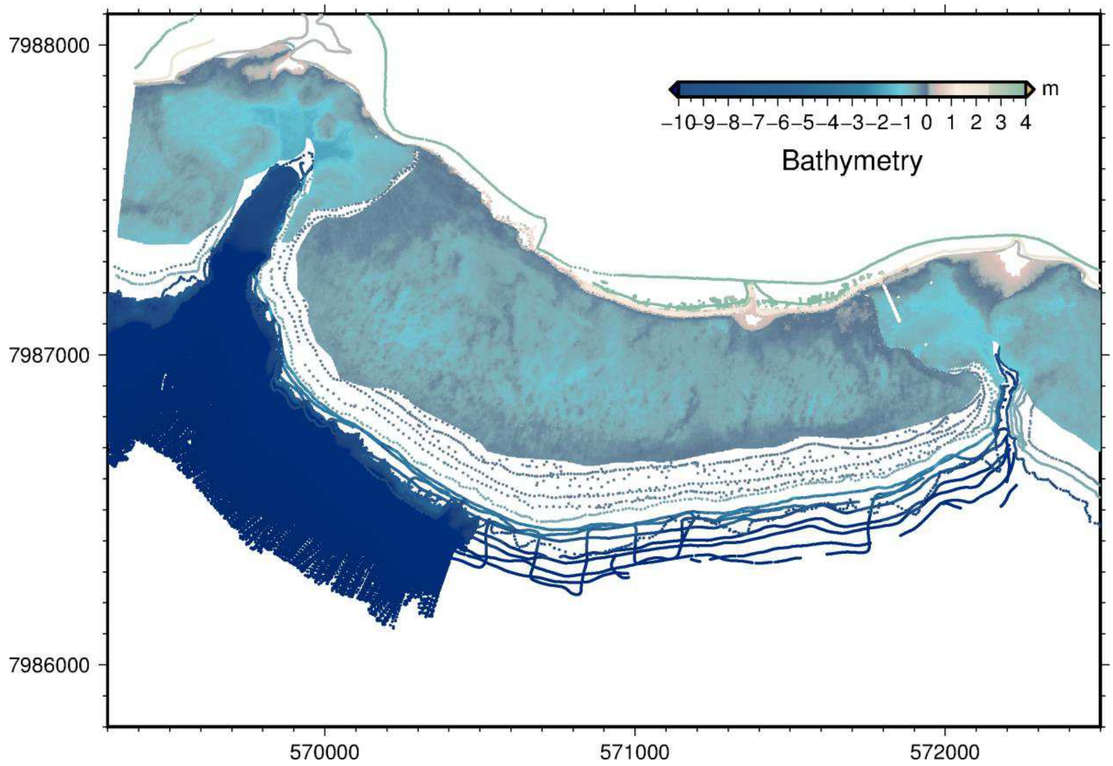

Figure 3.9 Combined topography, bathymetry surveys and digitised morphological features

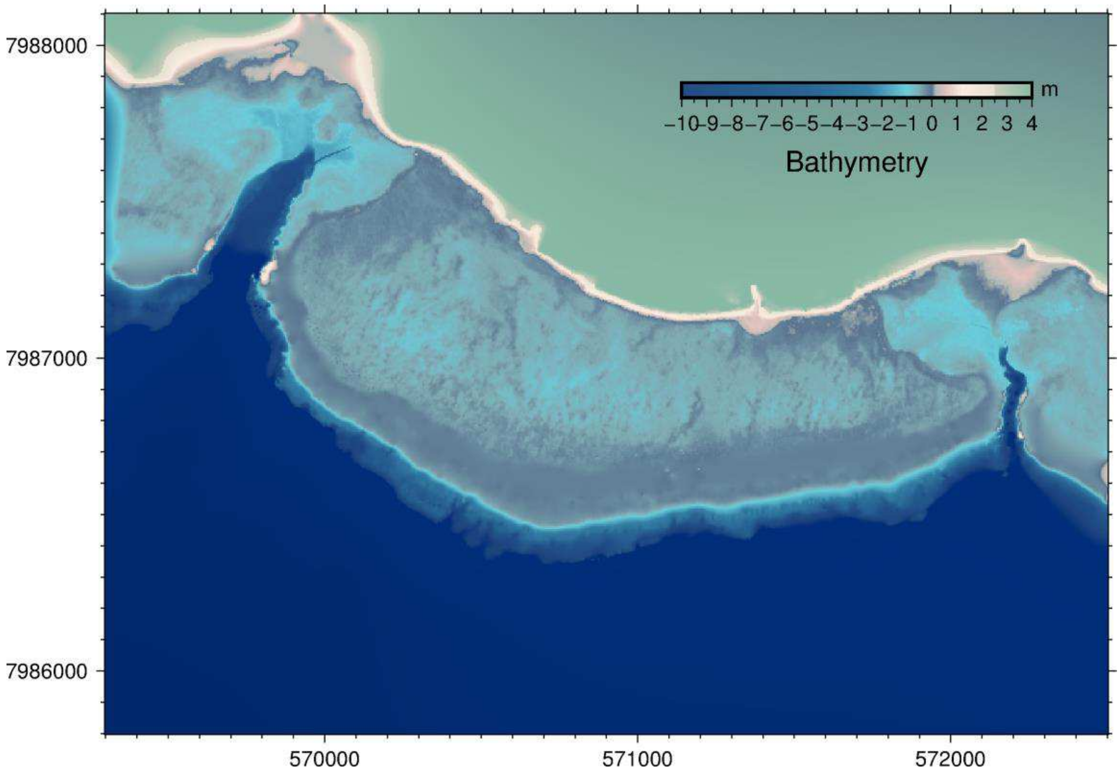

Figure 3.10 Interpolated bathymetry at 5m resolution for Maui Bay.

4 Sediment samples

Sediment samples were collected along crossshore transects fronting benchmark 2 and 4 (Figure 4.1). The sample aimed at identifying the variability in size and composition of sediment in the lagoon/reef flat of Maui Bay.

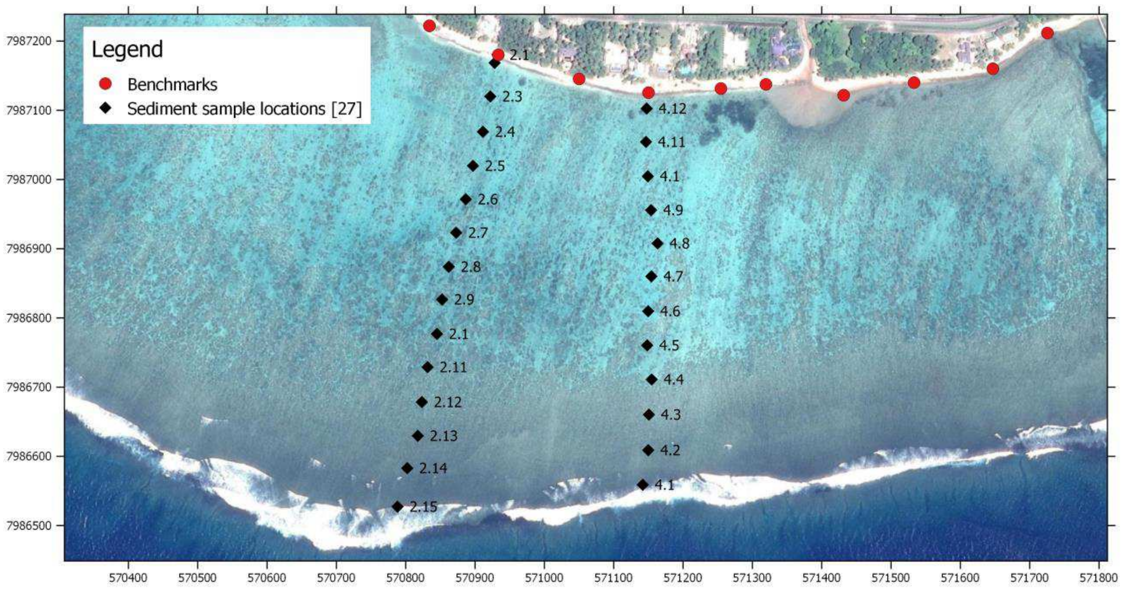

Figure 4.1 Sediment sample locations

4.1 Grain size

Sediment size was measured by dry sieving samples with 9 increasingly finer meshes. The weight of sediment collected in each sieves was measured and by diving by the total sample weight. The cumulative weight percentages of each sample are given in table 4.1 and 4.2. The median grain size (D50) ranged between 1 and 2mm (very coarse sand).

Table 4.1 Cumulative weight percent for different grain size along transect fronting benchmark 2

Phi (size in µm)	2.1	2.2	2.3	2.5	2.6	2.7	2.8	2.10	2.11	2.12	2.13
-4 (16000)	4.49	0	2.55	1.32		6.72	15.8	3.4	12.07	2.95	14.65
-3 (8000)	6.36	5.87	4.42	5.05	3.85	20.15	41.01	9.41	25.16	16.44	20.94
-2 (4000)	15.66	7.08	5.69	8.05	14.38	40.3	47.4	11.97	30.63	20.14	39.36
-1 (2000)	46.33	16.47	35.56	31.7	32.2	67.17	65.93	36.21	49.89	39.82	71.98
0 (1000)	64.59	32.25	55.98	57.02	56.02	80.13	81.35	64.12	77.06	77.45	92.1
1 (500)	79.06	56.45	75.25	81.93	79.65	92.31	93.92	88.82	96.7	94.73	98.75
2 (250)	95.33	84.78	93.74	94.42	95.99	98.37	98.47	98.29	99.54	99.68	99.82
3 (125)	99.76	98.6	99.28	96.08	99.5	99.58	97.43	99.92	99.91	99.91	99.98
4 (62.5)	99.79	99.95	99.63	96.17	99.87	99.88	99.77	99.96	99.98	99.92	99.997

5 (pan)	99.94	100	99.63	96.17	100	99.99	99.77	99.99	100	99.92	100

Table 4.2 Cumulative weight percent for different grain size along transect fronting benchmark 4

Phi (size in µm)	4.1	4.3	4.4	4.5	4.6	4.7	4.8	4.9
-4 (16000)			13.48			5.48		3.28
-3 (8000)	9.76	19.99	24.22	47.59	2.03	10.44	8.5	6.26
-2 (4000)	25.53	28.95	28.31	58.12	8.26	13.84	10.89	9.97
-1 (2000)	80.64	59.34	43.86	75.11	17.17	36.69	28.23	26.78
0 (1000)	89.25	82.51	68.54	89.15	50.84	59.79	55.61	48.58
1 (500)	96.51	95.40	91.52	97.01	74.03	83.88	83.65	77.22
2 (250)	99.76	98.12	98.33	99.14	88.69	96.49	97.52	96.07
3 (125)	99.96	98.42	99.62	99.66	98.21	99.19	99.67	99.27
4 (62.5)	99.99	98.47	99.9	99.74	99.95	99.62	99.91	100
5 (pan)	99.995	98.53	99.99	99.9	100	99.93	100	100

4.2 Composition

Using microscopes, the origin of some fragments of sediment could be identified using criteria such as colour and shape. A summary of the sediment composition is given in Table 4.3 – Table 4.6.

Coral fragment dominate the sediment composition in most grain sizes. Molluscs and Halimeda appear to be more dominant near the reef crest whereas foraminifer’s abundance seems relatively uniform.

Table 4.3 Sediment composition of sample 2.3

	>2mm	1mm	500µm	250µm	125 µm
Molluscs	8%	23%	8%	6%	-
Foraminifera	7%	26%	54%	17%	-
Coral Fragment	62%	24%	16%	27%	-
Halimeda sp.	8%	8%	2%	0%	-
Red algae	6%	6%	2%	20%	-
Unknown	9%	13%	18%	30%	-
Total	100%	100%	100%	100%	-

Table 4.4 Sediment composition of sample 2.11

	>2mm	1mm	500µm	250µm	125 µm
Molluscs	12%	13%	18%	14%	30%
Foraminifera	3%	10%	4%	10%	15%
Coral Fragment	78%	60%	48%	62%	34%
Halimeda sp.	1%	1%	0%	3%	4%
Red algae	4%	8%	4%	5%	8%
Unknown	2%	8%	26%	6%	9%
Total	100%	100%	100%	100%	100%

Table 4.4 Sediment composition of sample 4.5

	>2mm	1mm	500µm	250µm	125 µm
Molluscs	22%	16%	23%	16%	10%
Foraminifera	7%	10%	25%	20%	12%
Coral Fragment	42%	39%	24%	22%	21%
Halimeda sp.	16%	8%	2%	5%	5%
Red algae	8%	0%	0%	10%	3%
Unknown	5%	27%	26%	27%	49%
Total	100%	100%	100%	100%	100%

Table 4.4 Sediment composition of sample 4.8

	>2mm	1mm	500µm	250µm	125 µm
Molluscs	20%	20%	22%	15%	--
Foraminifera	3%	11%	27%	12%	--
Coral Fragment	31%	26%	21%	21%	--
Halimeda sp.	14%	15%	13%	10%	--
Red algae	6%	10%	11%	13%	
Unknown	16%	18%	6%	29%	--
Total	100%	100%	100%	100%	--

5 Carbon dating

The beach rock formation fronting the shore in Maui Bay shows well preserved Giant Clam shells (*Tridacna sp.*). Two well preserved specimens were collected in May 2015 from within the top section of the beachrock for carbon dating. The preparation of the sample, dating and calibration was then completed at the Institute for Geology and Mineralogy of the University of Cologne following methods of Rethemeyer et al. (2013), Reimer et al. (2014) and Ramsey (2013). Results (Table 5.1) show a calibrated age of 2988—3380 BP.

Table 5.1 Calibrated age of samples

Sample location	Sample size (µg)	F14C (error)	Age (yr BP)	δ13C (‰)	Calibrated age (yr BP)
BM3	1000	0.68152 (0.00345)	3080 (+/-41)	2.6	3380 – 3179
BM4	994	0.69161 (0.00355)	2962 (+/-41)	2.0	3318 – 2988

6 Habitat Map

Habitat map was created by comparing in-situ observation and photograph of the type of habitat (Figure 6.1) and the colour and textures of satellite imagery. The correlation between colour and texture are then used to predict the type of habitat over the whole lagoon/reef flat (Figure 6.2).

Figure 6.1 Sample photograph used to identify the typ of habitat: Here live coral.

The predicted habitat map can then be used to assign roughness parameter for wave dissipation or current friction and create map of the amount of sediment available for resuspension.

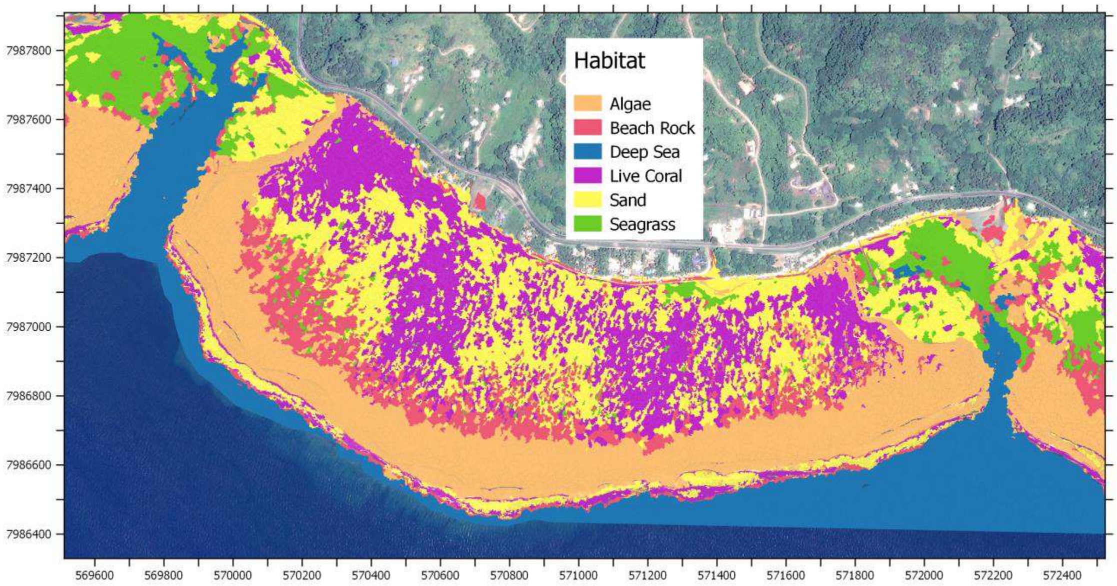

Figure 6.2 Predicted Habitat map for Maui Bay

7 Historical shorelines

Historical images were georeferenced against the latest 2014 imagery (Table 7.1), the resulting error ranged between 3 –9m . The toe of the beach (where visible) was used as a proxy for shoreline (Boak and Turner, 2005) (Figure 7.1). The shorelines positions for each of the years were located within 4m from each other, suggesting that there has been no significant changes in the shoreline position since 1967.

Table 7.1 Summary of imagery georeferenced for shoreline analysis

Imagery date	Type (Source)	Resolution (m)	Georeferencing error (m)
1967	Aerial-BW (Fiji Lands Dep.)	3.2	8.7
1978	Aerial-BW (Fiji Lands Dep.)	0.48	3.0
1986	Aerial-BW (Fiji Lands Dep.)	0.6	7.1
2010	Satellite-Colour (WorldView)	0.36	4.7
2013	Satellite-Colour (WorldView2)	0.51	3.5
2014	Satellite-Colour (CNES/Astrium)	0.76	Ref
2014	UAV survey orthophoto mosaic	0.05	?

A more accurate shoreline (Toe of beach) can be digitized from the orthophoto mosaic collected with the UAV survey. The toe of the beach rock can be clearly identified from the UAV survey. Toe of Beachrock likely corresponds to Holocene beach extent (Figure 7.2).

Figure 7.1 Shoreline position between 1967 and 2013. Background image is from 2014.

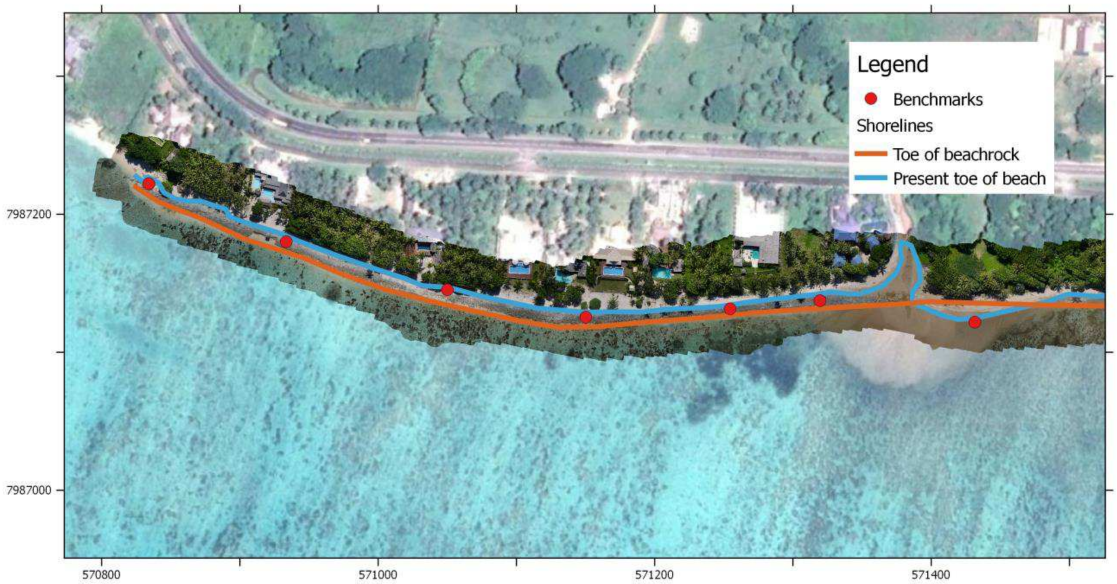

Figure 7.2 Toe of Beach and present day shoreline (2014) based on high resolution orthophoto.

8 Discussion

The beach in Maui Bay can be described as a perched beach lying atop an intertidal beachrock platform (Gallop et al. 2011). For most of the shoreline, the toe of the beach is located above the highest astronomical tide (1.0m) (Bosserelle et al. 2016) (Figure 8.1). Hence the beach face is only activated by a combination of tide and wave setup/infragravity waves.

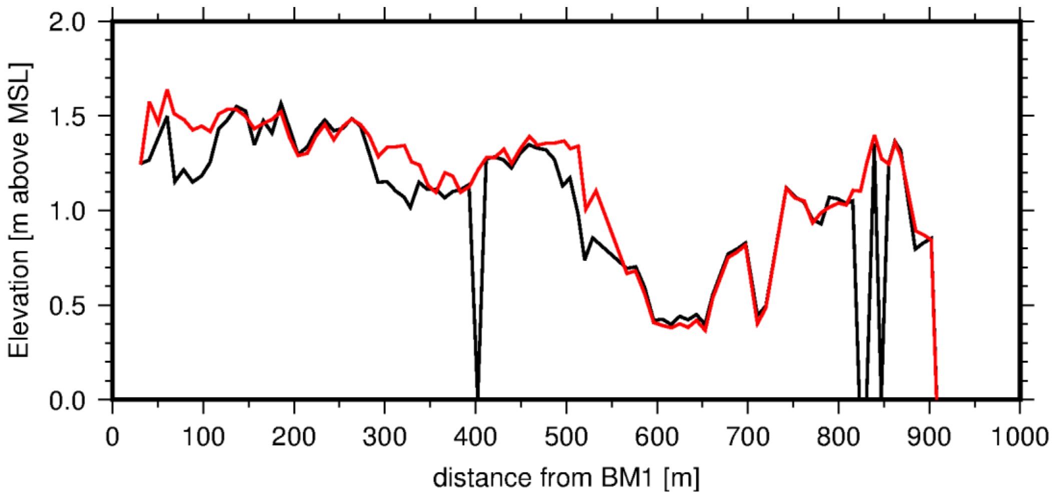

Figure 8.1 Elevation of the toe of the beach (black) and maximum elevation of the beach rock (red)

Carbon dating of the beachrock formation supporting the beach has been dated at approximately 3000yr BP. This age correspond roughly to the mid-holocene emergence of 1.4-2.2m in Fiji (Dickinson 2001). It is therefore likely that the beach in Maui Bay is a relic of a wider beach system that extended at least to the edge of the beachrock. Prior to the construction of the development, no significant changes in the beach could be identified, suggesting that the beach is relatively stable. The beachrock may be a significant barrier for sediment supply to the beach. The beach may therefore be starved and slowly retreating. However the rates of erosion were too small to be measured.

9 Conclusion

The detailed analysis of the reef and beach topography in Maui Bay has provided insight in the geomorphology of the Coral Coast. The extensive topography work has allowed for the creation of a high resolution bathymetry grid suitable for numerical modelling.

10 Data download and Citation

The processed data presented in this report may be downloaded on the PacGeo web portal

Maui Bay Benchmarks

http://www.pacgeo.org/layers/geonode%3Afiji_mauibay_2016_benchmarks

Maui Bay RTK data

http://www.pacgeo.org/layers/geonode%3Afiji_mauibay_2016_rtk_msl

Maui Bay Toe of beach

http://www.pacgeo.org/layers/geonode%3Afiji_mauibay_2016_toe_of_beach_67_14

Maui Bay sediment sample

http://www.pacgeo.org/layers/geonode%3Afiji_mauibay_2016_sediment_sample

Maui Bay Habitat Map

http://www.pacgeo.org/layers/geonode%3Afiji_mauibay_2016_habitat_map

Maui Bay Single beam offshore data

http://www.pacgeo.org/layers/geonode%3Afiji_mauibay_2016_bathy_singlebeam_offshore_msl

Maui Bay Single beam bathymetry

http://www.pacgeo.org/layers/geonode%3Afiji_mauibay_2016_lagoonreefflat_msl_singlebeam_bathymetry

The raw data can be freely obtained upon request to the authors.

When using the data for publication, please cite this report:

Bosserelle C., Pohler S., Lal D., Reddy S., Movono M., Begg Z., Kumar S., Krüger J. Maui Bay (Fiji), bathymetric and topographic data collection, WACOP project, SPC technical report SPC00037, 2016

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