Water Research Laboratory

Coastal Adaptation Needs for Extreme Events and Climate Change, Avarua, Rarotonga, Cook Islands

Project Stage 2: Topographic and Bathymetric Survey Data Collection

WRL Technical Report 2013/12
November 2013

by
M J Blacka, D S Rayner and B Parkoti

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Water Research Laboratory
University of New South Wales
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Acronyms

AusAID	Australian Agency for International Development
BOM	Australian Bureau of Meteorology
CCCI	Climate Change Cook Islands
CGPS	Continuous Global Positioning System Station
CIG	Cook Islands Government
DCCEE	Department of Climate Change and Energy Efficiency
DEM	Digital Elevation Model
DRM	Disaster Risk Management
GA	Geoscience Australia
GIS	Geographical Information System
GLONASS	Globalnaya Navigatsionnaya Sputnikovaya Sistema
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
MSL	Mean Sea Level
NTC	National Tide Centre
OPM	Office of Prime Minister
PASAP	Pacific Adaptation Strategy Assistance Program
RTK	Real Time Kinetic
SPSLCMP	South Pacific Sea Level and Climate Monitoring Project
TGZ	Tide Gauge Zero
UNSW	University of New South Wales
UTM	Universal Transverse Mercator
WGS84	World Geodetic System
WRL	Water Research Laboratory

1. Introduction

This report outlines Stage 2 of the project *Coastal Adaptation Needs for Extreme Events and Climate Change, Avarua, Rarotonga, Cook Islands*. Stage 2 of the project involved a detailed topographic and lagoon bathymetric survey for the study area. An overview of the complete project including all five stages was provided in the Stage 1 project report (Blacka *et al.*, 2013).

This project was initiated by the Cook Islands Government, under the Pacific Adaptation Strategy Assistance Program (PASAP). The PASAP project is funded by AusAID through the Australian Government Department of Climate Change and Energy Efficiency (DCCEE) with contract administration undertaken by Climate Change Cook Islands (CCCI). The key objectives of the overall study were to:

1. Understand the risk posed by changes to sea level and wave behaviour on coastal infrastructure and community in the Avarua area, particularly during extreme events;

2. Identify needs and develop options for responses to the risks; and

3. Build local capacity to understand the science and manage the risk assessment and planning process.

The study is focussed on the Avarua to Nikao stretch of the northern coastline of Rarotonga (see Figure 1.1 for Cook Islands location and Figure 1.2 for the study area).

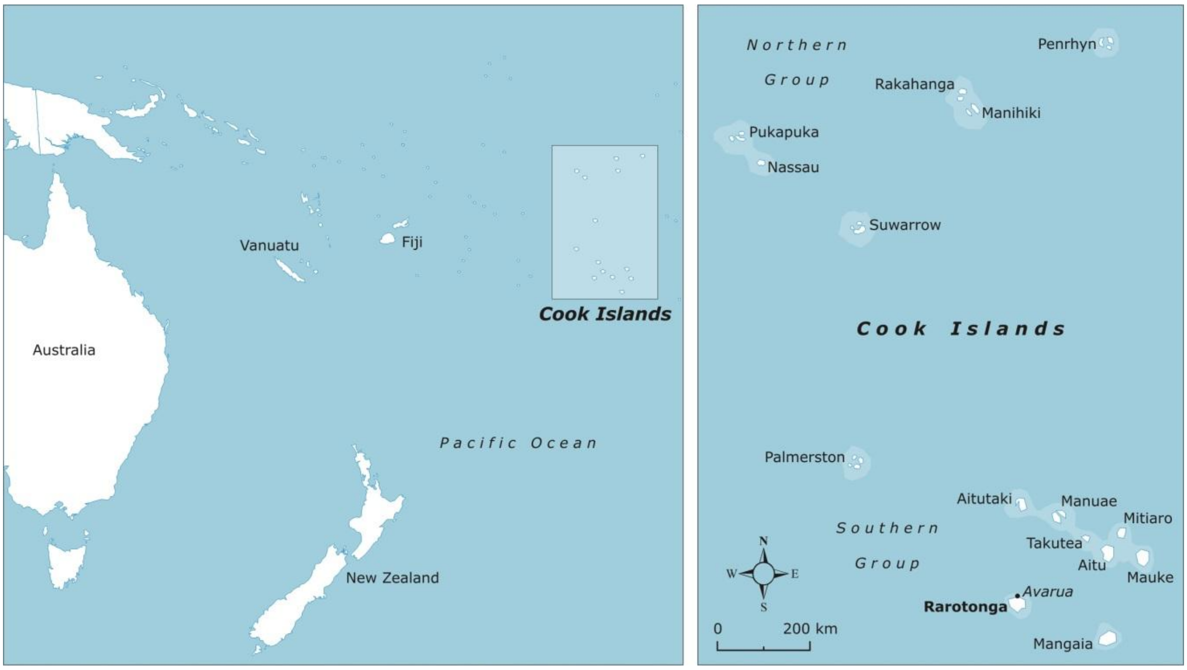

Figure 1.1: Location

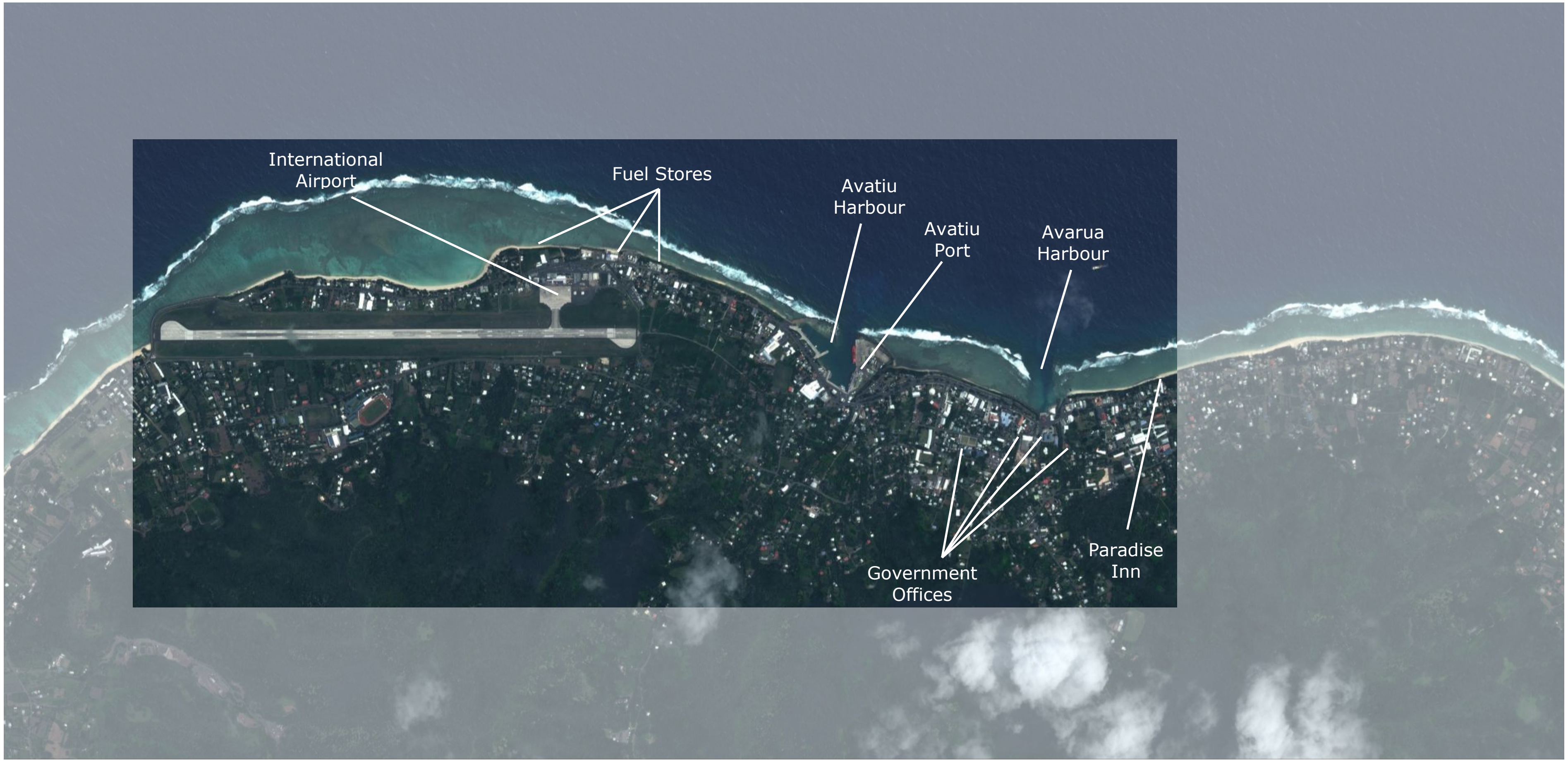

Figure 1.2: Study Area

The topographic and bathymetric survey undertaken in Stage 2 of the project and presented in this report, was completed to supplement existing geospatial data sets and allow the development of a digital elevation model (DEM) of the study area. A DEM is a 3D representation of the terrain surface that is created on a computer and used for various types of environmental modelling (among other things). In the case of this project the DEM required inclusion of the reef, lagoon and foreshore areas so that waves and storm surge could be modelled, and also required inclusion of the land areas so that coastal inundation could be modelled and the impacts mapped.

As discussed in the project Stage 1 report (Blacka *et al.*, 2013), prior to this survey there was very little available terrain data in several key areas that were important to enable adequate modelling of waves and storm surge. In particular there was:

- No bathymetry data for the surrounding lagoon; and
- No topography data for most land areas between mean sea level and 5 m MSL.

Based on these gaps in the existing geospatial terrain data, WRL completed a detailed RTK-GPS (Real Time Kinetic, Global Positioning System) survey of the areas where there was no or only sparse existing data. This was supported by a total station traverse of the Rarotonga International Airport undertaken by local surveyors Eagle Land Survey. WRL's RTK-GPS survey was undertaken during the seven day period 29/09/2012 to 5/10/2012.

As the study area is also the most densely developed section of Rarotonga, the topographic and bathymetric survey data set collected in the PASAP project is also invaluable for future scientific and technical assessments, environmental studies, as well as land use, infrastructure and Disaster Risk Management (DRM) planning by the Cook Islands Government. The survey data will significantly improve decision making with regards to Environmental Impact Assessments, and will also be fundamental to analysis of other future hazards such as tsunami.

2. Overview of RTK-GPS Survey Method

2.1 Survey Equipment

WRL's survey was undertaken using a Trimble differential GPS (DGPS) kit which included:

- 2 x R8 GNSS receivers (one operated as a base station and second operated as rover);
- 1 x TSC2 survey controller;
- 1 x HPB450 450 MHz radio (to transmit GPS corrections between base station and rover in real time);
- 1 x 12V battery to power radio;
- 1 x antenna to transmit radio signal;
- 1 x carbon survey staff; and
- 2 x survey tripods.

Figure 2.1 shows the R8 GNSS receiver and Figure 2.2 shows the base station setup. A custom mobile cart was also used for RTK-GPS topography roving which supported the rover receiver and allowed for continuous data collection (see Figure 2.3). Details of the Trimble R8 receivers can be found in Trimble (2009) and the TSC2 survey controller in Trimble (2011).

Figure 2.1: Trimble R8 GNSS Receiver (Trimble, 2009)

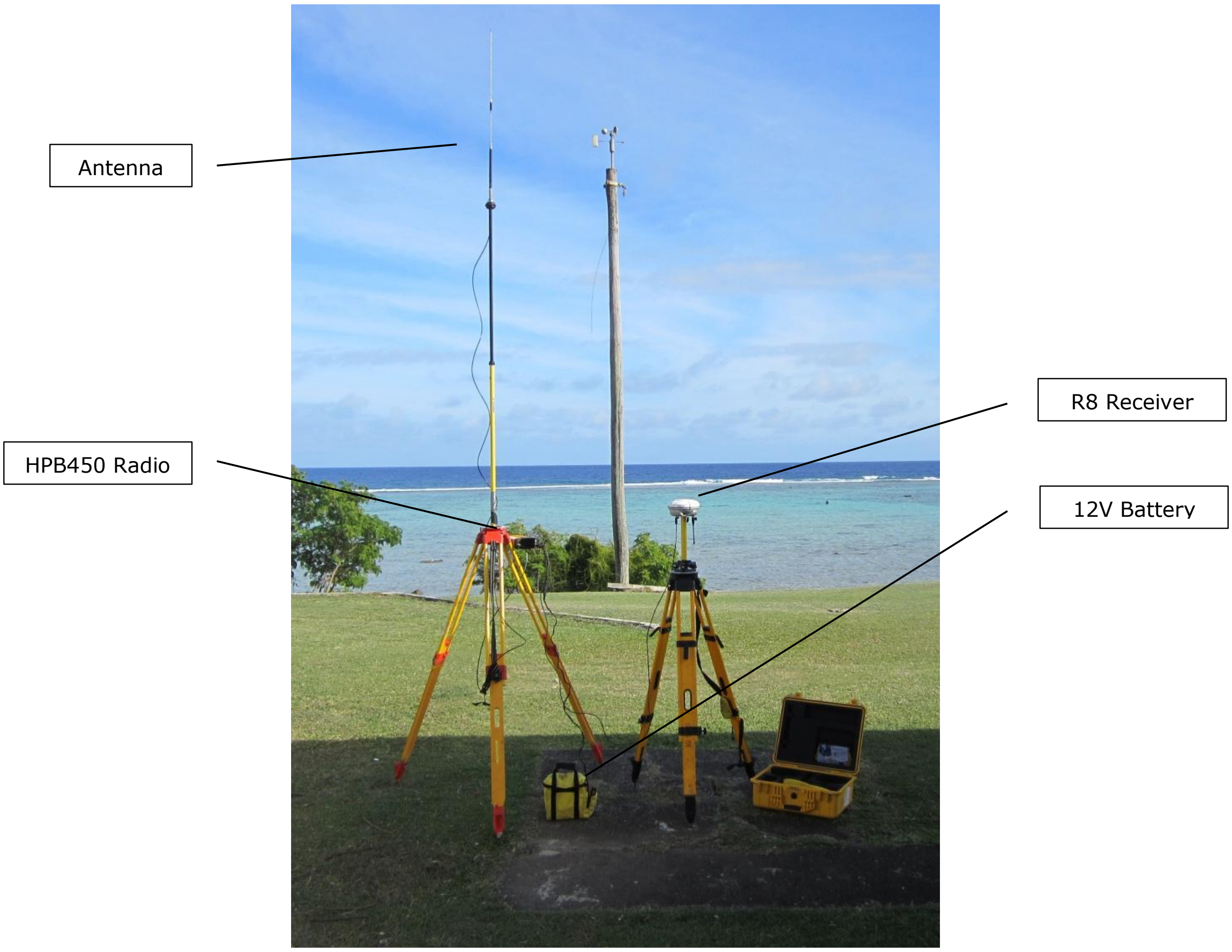

Figure 2.2: RTK-GPS Base Station Setup at Cook Islands Meteorological Office, Nikao

Figure 2.3: RTK-GPS Rover Receiver on Custom Mobile Cart, Avarua

2.2 Geodetic Datum

For consistency with existing geospatial data sets used within the Cook Islands, the survey was undertaken with horizontal coordinates specified in the WGS84 coordinate system and UTM zone 4 (south) projection. Two vertical elevation datums are used on Rarotonga, being TGZ (Tide Gauge Zero) and more commonly MSL (Mean Sea Level). It is understood that TGZ originates as the tide gauge zero for the original University of Hawaii gauge at Avarua, and that the MSL datum is adopted as 0.6139 m above TGZ (BOM, 2010). Presumably 0.6139 m TGZ was estimated to be the actual mean sea level on the Avarua tide gauge at some time. To maintain long term consistency of the vertical MSL datum (since actual mean sea level is varying with time), survey bench mark BM27 has since been adopted as 4.7407 m above the MSL datum (National Tide Facility, 2002). Bench mark BM24 is a deep driven bench mark and the vertical movements of this bench mark are regularly surveyed as a part of the differential levelling program (Yates and Lal, 2012).

2.3 Survey Control

In terms of ongoing land elevation and sea level measurement programs undertaken by Geoscience Australia (GA) and the National Tide Facility respectively, bench mark BM27 being 4.7407 m above the MSL datum is used as the vertical control. This has also been used as the vertical control for WRL's RTK-GPS survey for consistency.

A base survey was initially undertaken on Saturday 29/09/2012 and Sunday 30/09/2012 for five existing bench marks and one new bench mark. One hour of high-rate static GPS and GLONASS (Globalnaya Navigatsionnaya Sputnikovaya Sistema) data was collected on each bench mark and corrected against data from the Cook Islands Continuous GPS (CGPS) station located at the Rarotonga International Airport. Processing of survey baselines to get the corrected bench mark locations was completed using Trimble Business Centre version 2.40. The CGPS station is operated by Geoscience Australia as a part of the South Pacific Sea Level and Climate Monitoring Project (SPSLCMP), and has operated since 2001. Four of the six bench marks surveyed were a part of the differential levelling program undertaken regularly by GA, which traverses between the CGPS station and the SEAFRAME tide gauge at Avatiu Port. The vertical elevation of these bench marks relative to the MSL datum is precisely known from this levelling program. This allowed for accurate translation from the GPS measured elevations (which are relative to the WGS84 ellipsoid height) directly to elevations in the MSL datum.

Having completed the base survey, the bench marks were used to provide survey control for the RTK-GPS survey program. The base station GPS was set on one of the bench marks at all times (only three of the six bench marks were actually required). Table 2.1 shows the calculated coordinates of the six bench marks, while Figure 2.4 to Figure 2.9 shows the location and an image of each of the bench marks.

Table 2.1: Bench Marks Measured for Survey Control

Bench Mark	Description	Easting* (m, E)	Northing* (m, N)	Elevation (m MSL)
BM18	Brass plaque	418447.56	7654993.46	3.59
BM27	Deep driven stainless steel rod	418177.73	7655315.24	4.74
BM28	Deep driven stainless steel rod	417358.42	7655575.11	3.20
BM34	Deep driven stainless steel rod	417661.87	7655523.80	4.65
OCB1	Brass pin in concrete	419560.30	7654750.44	2.14
MET001	Copper pipe in concrete	415643.22	7655411.00	6.19

* WGS84, UTM Zone 4 South

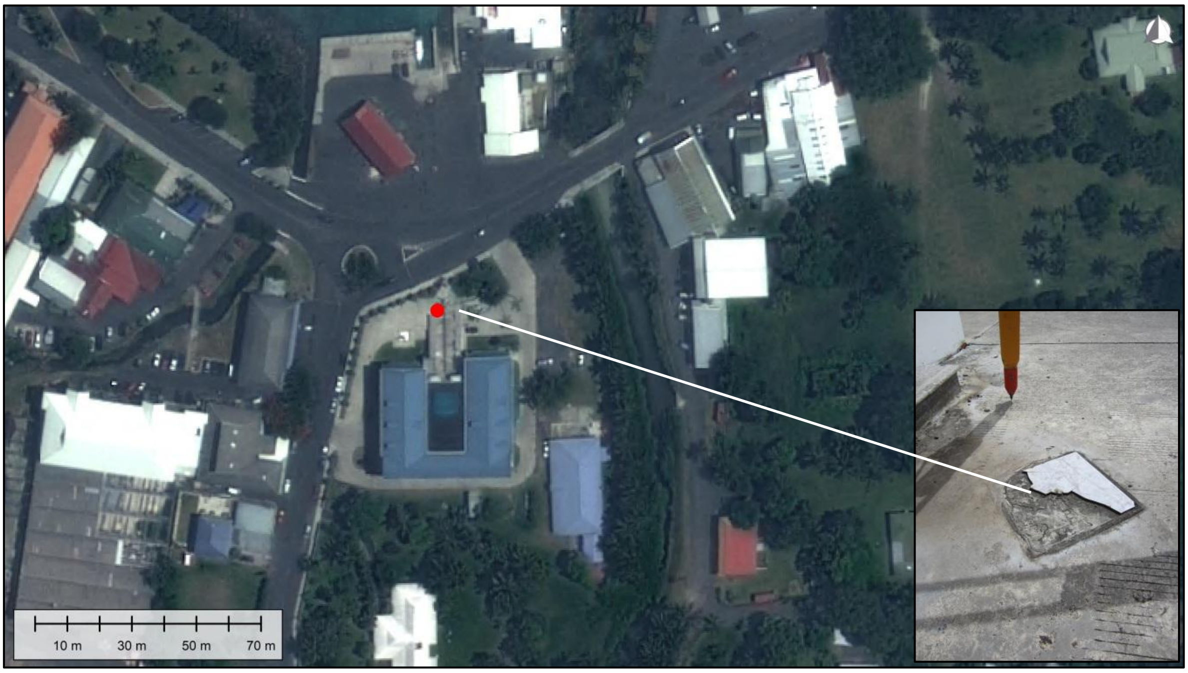

Figure 2.4: Location and Photo of Bench Mark OCB1 at the Court House, Avarua

Figure 2.5: Location and Photo of Bench Mark BM18 Near CITC Hardware, Avatiu

Figure 2.6: Location and Photo of Bench Mark BM27 Near Old Mobil/TOA Fuel Depot, Panama

Figure 2.7: Location and Photo of Bench Mark BM34 Near Cemetery, Panama

Figure 2.8: Location and Photo of Bench Mark BM28 Near Airport, Panama

Figure 2.9: Location and Photo of Bench Mark MET001 at the Meteorological Office, Nikao

2.4 RTK-GPS Survey Approach

Having collected static observations to establish a network of surveyed bench marks for use as ground control points, the topographic survey of the land areas and the lagoon bathymetric survey were able to be undertaken using an RTK-GPS method. The base station receiver was set up on one of the control bench marks at all times, with the HPB450 radio unit transmitting corrections in real time from the base station to the roving GNSS receiver. In general three types of survey data were collected:

- Survey points of general topographic terrain using mobile cart, recorded in continuous topo mode with either 3 second or 3 m observation frequency (see Figure 2.10);
- Walking survey points of specific items such as seawall/breakwater crest levels (see Figure 2.12) recorded in rapid point mode; and
- Wading survey points of lagoon bathymetry profiles (see Figure 2.11) recorded in rapid point mode.

Data was collected only with initialisation and a fixed solution, so the precision of the survey was generally better than 0.1 m (vertical and horizontal). In a small number of localised areas with heavier vegetation cover there were too few satellites visible to the GNSS roving receiver and so data could not be recorded with suitable precision. However, during most survey times both GNSS receivers could see approximately 14 satellites, which was many more than was needed to maintain the target precision.

Figure 2.10: Roving Survey of Land Topography using Mobile Cart

General topographic data points were collected in a method that was suitable to support the generation of a DEM. Survey coverage of terrain areas with relatively uniform gradient was maximised with more sparse spatial data collection, while significant features requiring definition in the DEM in order for it to be suitable for coastal modelling and mapping were captured with tighter spatial resolution.

Figure 2.11: Wading Survey of Lagoon Bathymetry

Bathymetric survey data in the lagoon was generally collected early in the mornings between 6:00 am and 10:00 am, as this period corresponded to the lowest tide levels on the days of WRL's survey. Waves breaking across the outer reef edge were also smallest during this period due to the absence of the Trade Winds. Bathymetry spot levels were collected at 5 m to 10 m spacing while wading seaward and landward across the lagoon, extending from the beach across the lagoon to as close to the reef edge as possible (which was limited by safety in the breaking waves and strong currents). In between the cross-shore wading profiles, data was also collected for the beach and crest of the back-beach bund, as well as along the outer reef edge.

To aid in the modelling of waves, wave runup, and overtopping during the later stages of the project, survey data was also collected for important coastal structures in the study area (Figure 2.12). These survey measurements typically included the structure crest and toe elevations where possible.

Figure 2.12: Surveying of Seawall and Breakwater Crest Levels

3. Survey Results

3.1 Lagoon Bathymetry Survey

Approximately 1600 survey data points were collected as a part of the lagoon and beach survey. In total, 40 cross-shore profiles across the lagoon were surveyed, which included:

- 12 profiles between the Paradise Inn and Avarua Harbour (Figure 3.1);
- 12 profiles between Avarua Harbour and Avatiu Port (Figure 3.2);
- 11 profiles between Avatiu Harbour and the TOA Petroleum depot (Figure 3.3); and
- 5 profiles between the TOA Petroleum depot and the COPED breakwater at the western end of the airport runway (Figure 3.4).

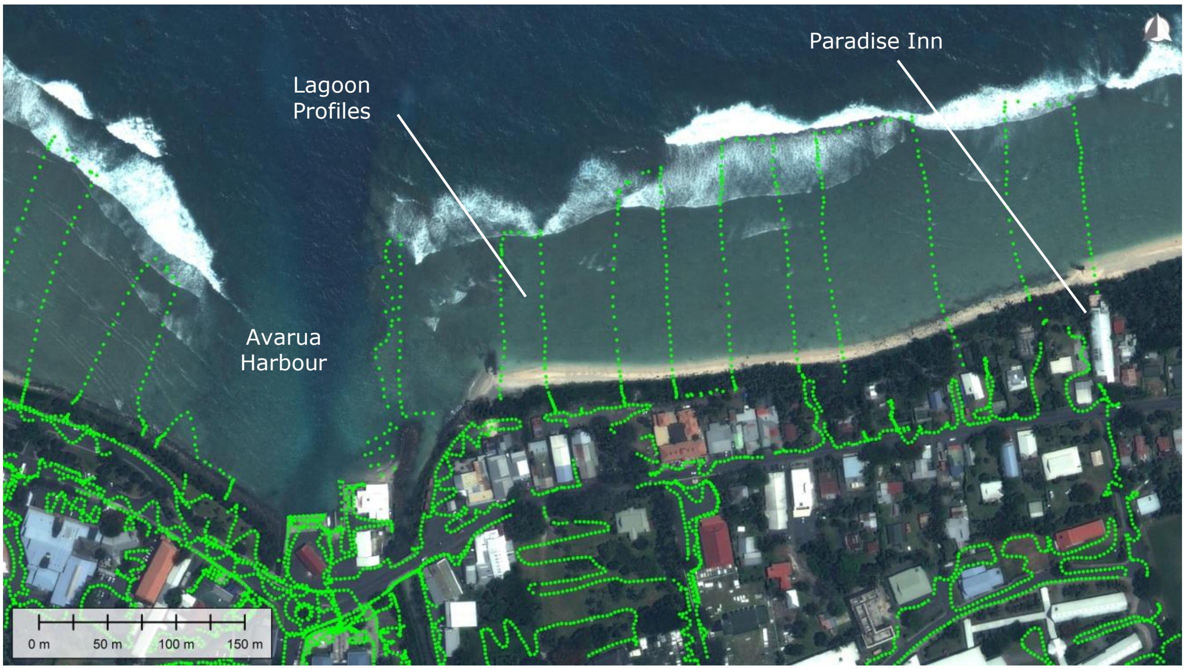

Figure 3.1: Lagoon Survey - Paradise Inn to Avarua Harbour

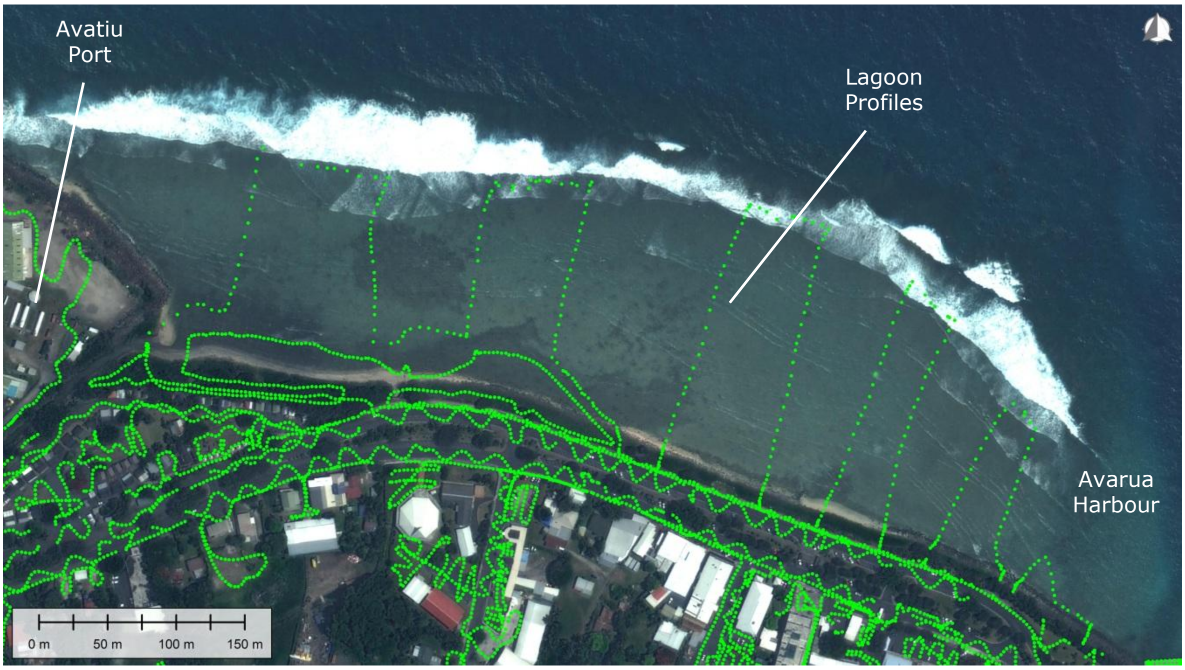

Figure 3.2: Lagoon Survey - Avarua Harbour to Avatiu Harbour

Figure 3.3: Lagoon Survey - Panama Area

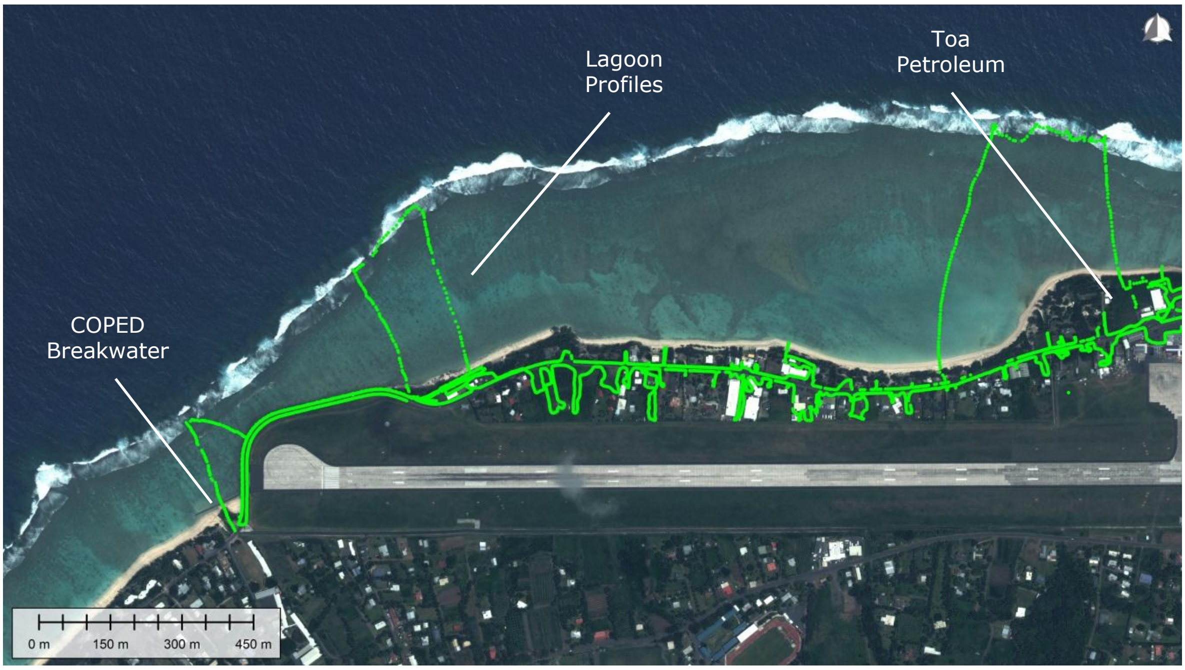

Figure 3.4: Lagoon Survey - Nikao Area

3.2 Topography Survey

The roving topography survey generally captured data over the complete area from the foreshore landward to the Ara Metua (inland road), and extended from the Paradise Inn to the western end of the airport runway (see Figure 3.5 for survey coverage). The areas that were omitted from the RTK-GPS survey included the Avatiu Swamp (GPS survey data had previously been collected in this area as a part of the CLIMAP project) and the airport (which was outside the study area at the time, but later included in the study and captured by total station survey undertaken by Eagle Land Survey).

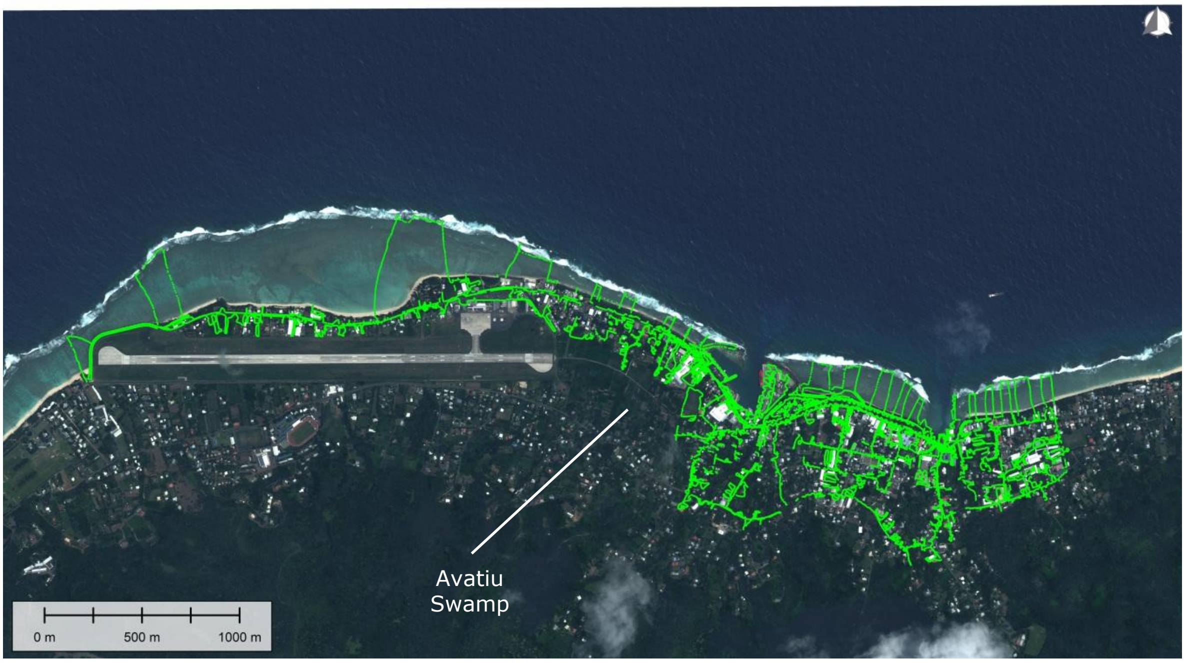

Figure 3.5: Complete Survey Data Coverage

3.3 Coastal Structure Survey

As discussed in Section 2.4, key parameters of coastal structures in the study area were also surveyed. The structures surveyed and data recorded included:

- COPED breakwater in the lagoon off the western end of the airport runway (crest and toe levels;
- Seawall along the coastal road edge around the end of the airport runway (crest and toe levels);
- Seawall in front of the meteorological office (crest and toe levels);
- Embankment and seawall on the lagoon side of the Pacific and Triad fuel depots (crest and toe levels);
- Avatiu western basin breakwater (crest levels only);
- Avatiu western basin wharf (wharf level);
- Avatiu Port wharf (wharf level); and
- Avarua wharf (wharf level).

4. Conclusions

Prior to the PASAP project there was very limited topography data available that was suitable for modelling or mapping wave and storm surge processes for most of the Avarua area. Five metre interval contour data existed, however, this was too coarse for undertaking analysis and mapping of coastal hazards which requires at least 0.5 m contour topography data. Most houses and infrastructure along the Avarua to Nikao stretch of coast are located in between the 0 m and 5 m contours. While reasonable bathymetry data sets exist in both the Avarua and Avatiu harbours, as well as outside of the reef, there was very limited bathymetry data for the fringing lagoon along the coast. Understanding the characteristics of the lagoon and reef are critical for assessing the future impacts of climate change and also the wave and storm surge processes during extreme cyclonic conditions.

Between 29/09/2012 and 5/10/2012 WRL staff in conjunction with the PASAP project counterpart engineer completed an RTK-GPS survey of the topography and lagoon bathymetry throughout the study area. The aim of the survey was to collect data where no other survey data existed, and to collect data suitable for use in coastal processes modelling and coastal hazard mapping. The complete survey collected in excess of 35,000 data points, which included 40 profiles across the lagoon and details of nine coastal structures. This data is provided with the project deliverables in digital format for incorporation into government GIS. The data is provided with 0.1 m precision to reflect the accuracy of the survey methods used.

When combined with the existing bathymetry and topography data sets for the north coast area of Rarotonga, it can be seen that most areas now have data coverage that is suitable for analysing and mapping coastal hazards (Figure 4.1). The DEM generated from the combined bathymetry and topography data sets is shown in Figure 4.2. This data set was crucial for completing the analysis in the remainder of the project. Furthermore, the data set will be particularly useful for future engineering and scientific assessments related to climate change, DRM, land use and development planning, and environmental impact assessments.

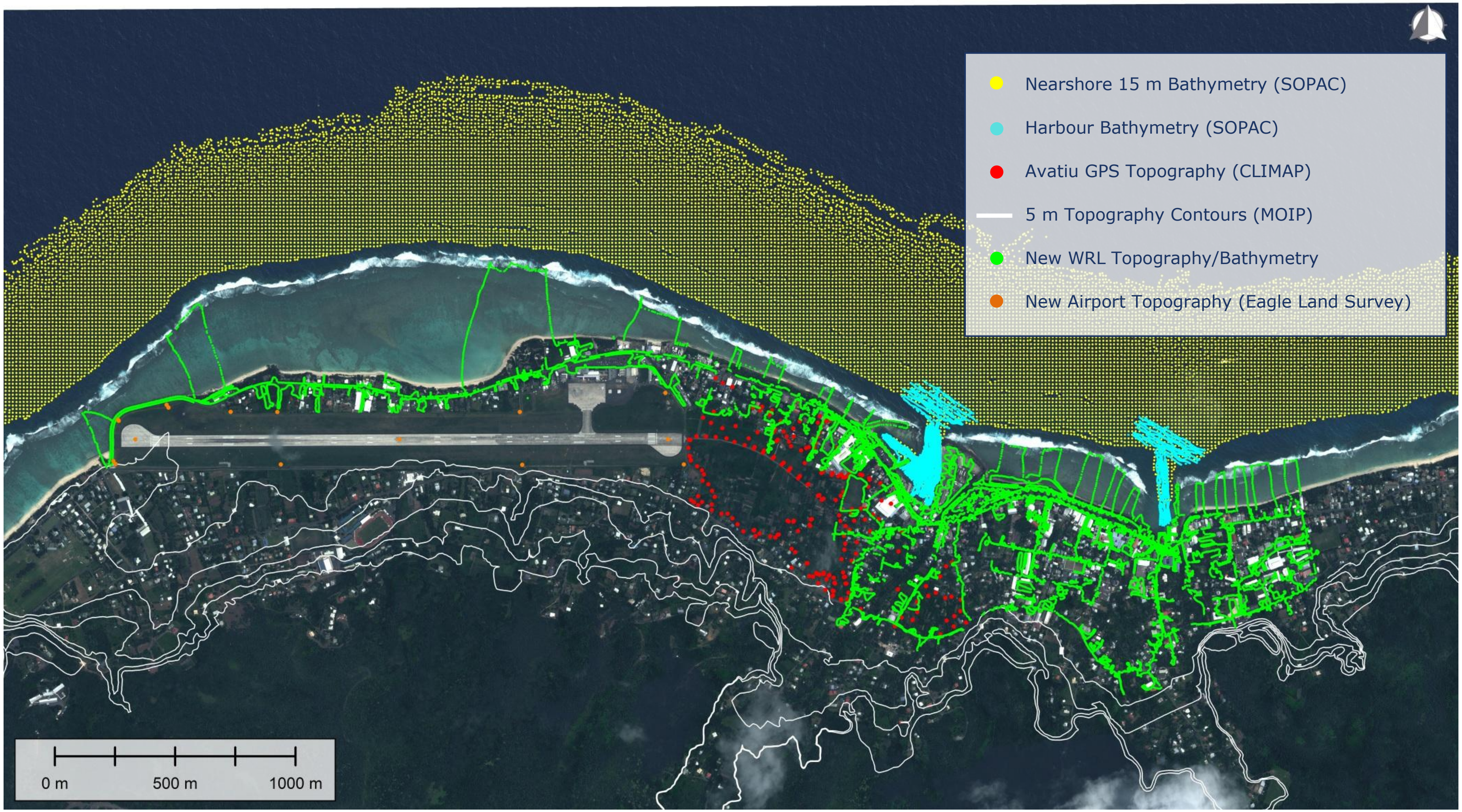

Figure 4.1: All Topography and Bathymetry Data for Avarua Area

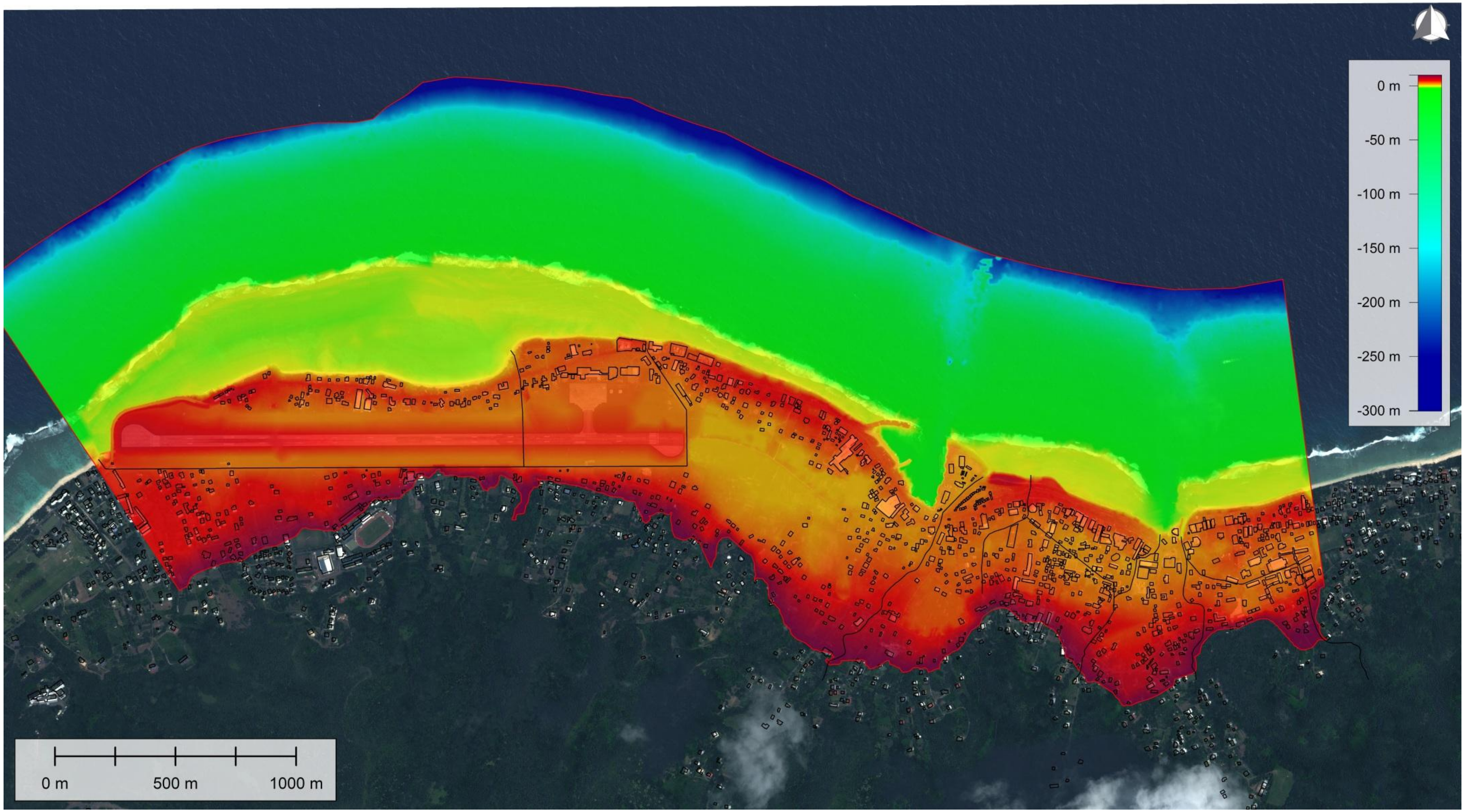

Figure 4.2: Digital Elevation Model of Study Area

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