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Department of Infrastructure, Transport, Regional Development, Communications and the Arts

GOVERNMENT OF WESTERN AUSTRALIA

Cocos (Keeling) Islands Coastal Vulnerability Study

Assessment Report (Volume I)

The Department of Planning, Lands and Heritage acknowledges the traditional owners and custodians of this land. We pay our respect to Elders past and present, their descendants who are with us today, and those who will follow in their footsteps.

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Executive Summary

Royal HaskoningDHV (RHDHV) and their sub-consultants, Bluecoast Consulting Engineers (Bluecoast), have prepared this report on behalf of the Department of Planning, Lands and Heritage (DPLH). DPLH, in collaboration with the Commonwealth Government of Australia and the Shire of Cocos (Keeling) Islands (the Shire), has commenced the process of completing a Coastal Hazard Risk Management and Adaptation Plan (CHRMAP) for the Cocos (Keeling) Islands. As the first stage of this process, this report presents a Coastal Vulnerability Assessment (CVA).

The objective of the CVA is to identify coastal hazard risks and assess the vulnerability of built and natural assets to erosion and inundations hazard. The work to meet this objective was guided by the Western Australian Planning Commission's State Planning Policy No. 2.6 – State Coastal Planning Policy (SPP 2.6).

To ensure the objectives of the study were met, RHDHV undertook the following as part of this phase of the study:

- Literature review and review of existing data to summarise the current state of knowledge on coastal processes in the study area;
- Collection and analysis of targeted coastal monitoring datasets for the study area;
- Development and calibration of numerical modelling tools and the application of these tools in understanding the coastal processes and hazards in the study area;
- Development of a working conceptual coastal processes model that identifies sediment sources, sinks, pathways and vulnerable areas for focus in subsequent stages of the study;
- Coastal hazard assessments including the definition of appropriate coastal erosion and inundation allowances based on application of SPP2.6 and the application of the knowledge gained from the above tasks; and
- A coastal vulnerability assessment, based on the CHRMAP Guidelines (WAPC, 2019), for each asset that was identified as being at risk from erosion and inundation over three planning periods (2018, 2068 and 2118) .

Current State of Knowledge

There have been several key coastal/atoll processes and related studies over the past 50 years that are relevant to this study. The literature reviewed as part of the CVA process documented herein has highlighted the overall lack of long term and consistent, metocean and hydrographic data collected in vicinity of the Cocos (Keeling) Islands. While there are several useful findings in the previous literature, targeted monitoring-based studies are required to improve the knowledge of coastal processes, shoreline movement and sediment transport processes. This will in turn lead to improved decision making around coastal zone management.

Coastal and Metocean Monitoring Data

Metocean data, including the measurement of waves, currents and water level variation, has been collected at key locations and water depths around Cocos (Keeling) Islands. Eight (8) oceanographic monitoring sites were deployed and good quality metocean data has been recorded from early July 2018 to late December 2019. During the metocean monitoring period, beach transects were captured at regular intervals (up to 50m) tangential to the shore and vegetation lines at selected areas and a trial drone survey was undertaken at the West Island settlement during the initial site visit. The metocean data captured provides valuable insight into the coastal processes that operate at the Cocos (Keeling) Islands and when combined with the coastal survey data is a valuable tool to inform subsequent coastal management at the Cocos (Keeling) Islands.

Numerical Modelling

A series of numerical models were established and calibrated using the metocean data collected at the Cocos (Keeling) Islands.:

- A coupled 2-dimensional hydrodynamic (D-Flow) and spectral wave (D-Wave) model was developed to transform offshore waves to the nearshore and simulate atoll wide hydrodynamics and sediment transport.
- Tropical cyclone spectral wave model (D-Wave) was used to simulate cyclonic waves in Cocos (Keeling) Islands's nearshore.
- A high-resolution, non-linear nearshore wave model (Xbeach) used to estimate inshore wave heights and wave setup at the fringing reef coastline. This model was also used to simulate storm erosion at a series of coastal profiles.
- SBEACH profile model was used to simulate storm erosion at the lagoon-facing beaches.

The numerical modelling completed for this study focused on the present day (or existing) conditions within the study area as well as future sea level rise conditions. The results of the numerical modelling were used to inform the understanding of coastal processes and hazards within the study area.

Conceptual Coastal Processes Model

Based on review of available data and literature, site observations, numerical modelling and understanding of coastal processes, a conceptual model of sediment transport processes in the study area has been developed. The conceptual model identifies sediment sources, sinks, pathways and vulnerable areas for focus in subsequent stages of the study. The key points are summarised as:

- The planform shape of the atoll and its islands are in part governed by the shape of the seamount. The atoll's island are wave-built accumulations of carbonate sediment derived from the physical breakdown as well as biological breakdown. Other factors that affect the planform shape and elevation of the sand islands are the interaction with oceanic swells, hydrodynamics and the rate and grading of sediment supply for island building.

- Atolls are inherently resilient structures. The fringing reef that surrounds the Cocos (Keeling) Islands atoll are of paramount importance in understanding the morphological response of the sand and gravel islands themselves. The sediments produced across the fringing reef, both sand-sized and larger, are transported onshore by wave action. This onshore movement of sediment sustains the atoll islands. The living reefs also act as natural breakwaters in dissipating wave energy with wave breaking on the reef crest. Wave driven currents, water level set-up, wave dissipation and infragravity waves occur on the reef flats - controlling the height of the beach ridges. The reef crests are living structures and can grow vertically with sea level rise.
- Almost all oceanward beaches are interpreted as having a base of coral shingle, rubble and/or coral boulders, acting as an underlying ridge of less erodible material that greatly reduces the vulnerability to erosion and shoreline recession. Oceanward beaches are steep and backed by a ridge built by wave run-up and overwash. During storm conditions the beach ridges can be overwashed due to wave set-up of the reef tops and swash reaching well above high tide levels on exposed beaches. However, some shorelines exhibits windblown dunes, which is unlike many other coral atolls, indicating a healthy sediment supply at the Cocos (Keeling) Islands.
- Wave processes also play an important role in the redistribution of sediments along the West Island and Home Island shorelines. Longshore sediment transport is the process of sand or other sediments moving in an alongshore direction. For example, the elongated shape of West Island is explained by this alongshore redistribution by waves.
- The oceanward shorelines of West Island and Home Island are generally stable but some areas are receding particularly those fronting the West Island settlement. Progressive introduction of coastal structures and associated downdrift sediment starvation at this stretch has created a domino effect with each structure moving the erosion issue further downdrift.
- On Home Island there are isolated areas like the northern end of Home Island (Pulu Gangsa), which serves as the community cemetery, which have suffered significant erosion on its northern and western (i.e. lagoon sides) beach since the reclamation of Pulu Gangsa. Conversely on the ocean-facing side, our analysis shows the beach that was formed by the reclamation has continued to accrete as it is now the termination of this alongshore pathway. General, however, Home Island has a relatively stable shoreline. The lower elevations of Home Island make it more susceptible to coastal inundation.

- Generally, lagoonward shoreline change is location-specific being a function of the lagoon hydrodynamics, swell penetration and sediment sources and availability.
- A key impact of sea-level rise and other climate change stress factors on atolls is that living fringing reefs may become less effective at mediating the ocean wave energy before it reaches the islands shores. Recent research is suggesting that atoll shorelines / beach barrier systems may have greater potential resilience than previously thought. The implications of this research are that the Cocos (Keeling) Islands likely have a degree natural resilience and have some capacity to adjust to higher sea levels. Key to the natural capacity for resilience is uninterrupted sediment supply. However, as climate change threatens sediment productivity (reef decline) as well as transport patterns (changes in the incidence and frequency of storms) any measured capacity for past resilience, cannot be assumed far into the future.

Coastal Hazard Mapping

Through the above tasks an understanding of coastal processes in the study area has been gained. This understanding has been used to define appropriate allowances for coastal hazards and mapped in accordance with SPP2.6. This included:

- Adopting the following planning periods 2018, 2068 and 2118.
- Erosion hazard allowances (S1, S2 and S3) have been defined following SPP2.6 and have been applied to West Island and Home Island. Erosion hazard lines have been defined for two scenarios: with and without coastal protection structures.
- Suitable coastal inundation levels have been defined and mapped. This includes identification of low-lying areas that may be potentially impacted by wave-driven water level variations such as wave setup and wave runup.

The resulting hazard maps are provided in the **Maps** section at the end of this report. A key limitation to this mapping is the application of the S3 allowance for erosion due to sea level rise. While the application follows SPP2.6, the approach overly conservative and does not provide useful information for planning of island atolls.

Coastal Vulnerability Assessment

Based on the coastal hazard mapping completed in line with SPP2.6, a vulnerability assessment was completed in based on the CHRMAP Guidelines (WAPC, 2019). The vulnerability assessment provides useful classification for each asset that was identified as being at risk from erosion and inundation for the 2018 planning periods. For the erosion hazard, the issues related to the definition of the S3 allowance limit the usefulness of the 2068 and 2118 erosion hazard to assess the future vulnerability of built and natural assets.

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1 Introduction

1.1 General

The Western Australian Department of Planning, Lands and Heritage (DPLH), in collaboration with the Commonwealth Government of Australia and the Shire of Cocos (Keeling) Islands (the Shire), is undertaking a Coastal Vulnerability Assessment (CVA) for the Cocos (Keeling) Islands.

The objective of the CVA is to identify coastal hazard risks and assess the vulnerability of built and natural assets to erosion and inundations hazard to properly inform future Coastal Hazard Risk Management and Adaption Planning (CHRMAP) as detailed in the Western Australian Planning Commission's State Planning Policy No. 2.6 – State Coastal Planning Policy (SPP 2.6; WAPC, 2013). The CVA delivers the major components of Stages 1 to 3 of the CHRMAP process (see **Figure 1**). Subsequent CHRMAP stages will be undertaken separately but informed by the CVA outcomes. The CHRMAP aims to properly plan for adaptive land use and development on the Cocos (Keeling) Islands considering a changing coastal environment. By informing Stages 4 to 7 of the CHRMAP, the CVA ultimately seeks to inform sound coastal management at the Cocos (Keeling) Islands.

The CVA is written with the intention of addressing the relevant objectives of SPP 2.6:

1. Ensure that development and the location of coastal facilities takes into account coastal processes, landform stability, coastal hazards, climate change and biophysical criteria.
2. Ensure the identification of appropriate areas for the sustainable use of the coast for housing, tourism, recreation, ocean access, maritime industry, commercial and other activities.
3. Provide for public coastal foreshore reserves and access to them on the coast.
4. Protect, conserve and enhance coastal zone values, particularly in areas of landscape, biodiversity and ecosystem integrity, indigenous and cultural significance.

1.2 Study approach

The methodology for the project has been developed in accordance with the Coastal Hazard Risk Management Adaptation Plan Guidelines (WAPC, 2014). The scope of works is broken down into the following ten key tasks:

Task 1: Project Plan

Task 2: Data Gathering and Desktop Review

Task 3: Project Execution Plan

Task 4: Site Visit

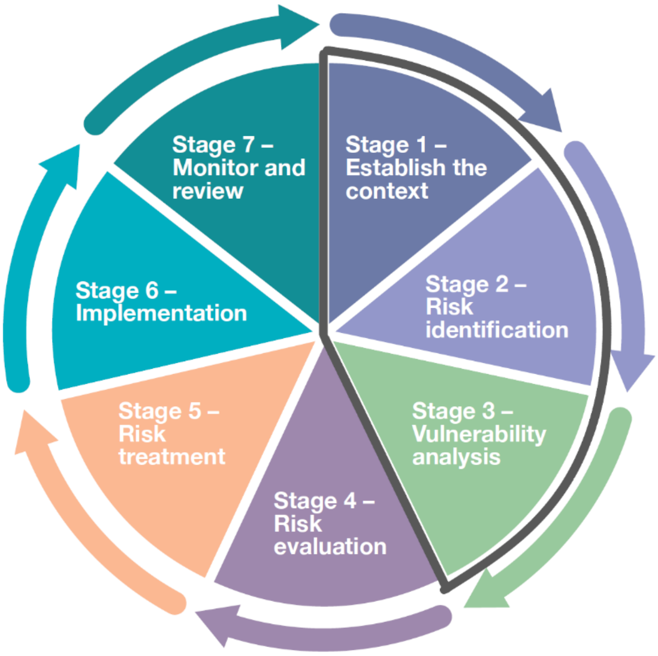


Figure 1: Preparation and implementation stages in the CHRMAP process (source: WAPC, 2019), this study forms the major component of Stage 1 to Stage 3 as outlined in grey.

Task 5: Metocean Data Collection

Task 6: Survey Data Applications

Task 7: Coastal Inundation Assessment

Task 8: Shoreline Stability Assessment

Task 9: Vulnerability Assessment

Task 10: Coastal Vulnerability Assessment (CVA) Report

DPLH engaged Royal HaskoningDHV (RHDHV) to complete the scope of the CVA. RHDHV has engaged the services of Bluecoast Consulting Engineers (Bluecoast) to assist in preparing Tasks 7 to 10.

1.3 Report structure

This report is the final report in a series that covers the scope of works for the CVA. As required by the project brief it presents a concise summary of the technical investigations completed. It is set out as:

- **Section 2** provides background information including the key findings of the first four tasks listed above.
- The metocean and shoreline data collected as part of the CVA project is presented in **Section**

3 along with a summary of the islands metocean conditions covering wave climate, water level variations and wind regime.

- An overview of the numerical modelling systems employed to assist with the technical assessment is set out in **Section 4**
- **Section 5** outlines the results of the coastal inundation assessment.
- Similarly, **Section 6** outlines the results of the shoreline stability assessment.
- **Section 7**provides the assessment of coastal vulnerability to key assets at the Cocos (Keeling) Islands.

For ease of cross referencing and map viewing, this final CVA document is presented as a report (**Volume I**) and maps of the hazards (**Volume II**), describing and showing what areas may be impacted by erosion or inundation.

1.4 Study area

Due to its remote Indian Ocean location as well as its low-lying geography, vulnerability to coastal hazard and the potential impacts of climate change is perhaps the most critical issue affecting the future sustainability of human settlement on the Cocos (Keeling) Islands.

The Cocos (Keeling) Islands are a remote territory of Australia located in the Indian Ocean around 2,750 kilometres northwest of Perth. **Figure 2** shows a map of all the islands including the main South Keeling Islands. The Southern Cocos Islands (centred around 12°09'S, 96°52'E) are composed of a coral atoll capping a volcanic seamount (Woodroffe et al., 1994). The atoll consists of a reef rim, broken by two major entrances, one to the northwest which incorporates the Western Channel and one to the north which incorporates the Port Refuge channel (**Figure 3**). On the reef rim is a series of 26 reef islands that partially enclose a main central lagoon. The coral sand islands have an area of 14.2 square kilometres with 26 kilometres of coastline and a highest elevation of 5 metres. The lagoon has an area of 102 square kilometres, consisting of a shallow southern region (with a mean depth of 3 metres) and a deeper northern section (water depth of up to 10 - 20 metres) connected to the two major entrances.

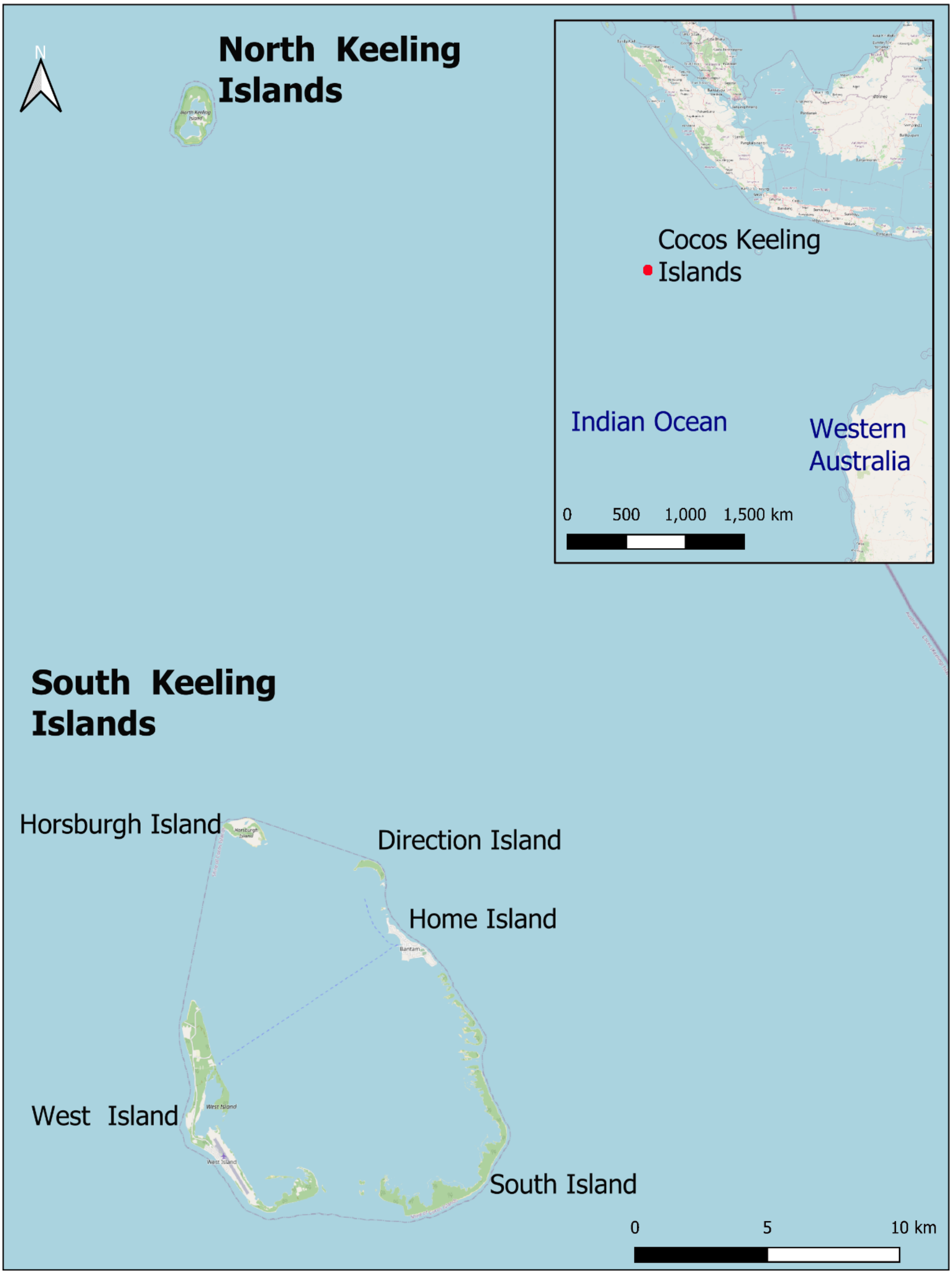


Figure 2: Location of Cocos (Keeling) Islands.

The South Keeling Islands are the focus of this study and typically referred to herein as the Cocos (Keeling) Islands (see **Figure 3**). According to the 2016 Australian Census, the Cocos (Keeling) Islands have a population of about 510 people with a settlement of around 410 living on Home Island and the remaining 100 living on West Island. The islands are densely vegetated by coconut palms (*Cocos nucifera*).

The focus of this CVA is Home Island and West Island. Consideration has been given to the other islands in the southern atoll in the discussion.

North Keeling Island is the other coral atoll that forms part of the island group. It is a single uninhabited island located 27 kilometres to the north of Horsburgh Island. It is a proclaimed National Park with a land area of 1.1 square kilometres.

1.5 Study objectives

The key objectives of the study are to:

1. Collate, analyse, and summarise relevant historic metocean data, survey data, and any other necessary data critical for appropriate model validation and effective data analysis.
2. Create and conduct a data collection program at the Cocos (Keeling) Islands that gathers and analyses metocean and survey data.
3. Identify, assess, and model relevant coastal processes and hazards at the Cocos (Keeling) Islands using the outcomes of (1) and (2) for ambient conditions and over various scenarios.
4. Identify, assess, and map areas subject to inundation and/or erosion by coastal processes described in (3) over various scenarios.
5. Identify, assess, and map the exposure, sensitivity, and adaptive capacity of key built, natural and community assets to coastal hazards using the outcomes of (3) and (4).

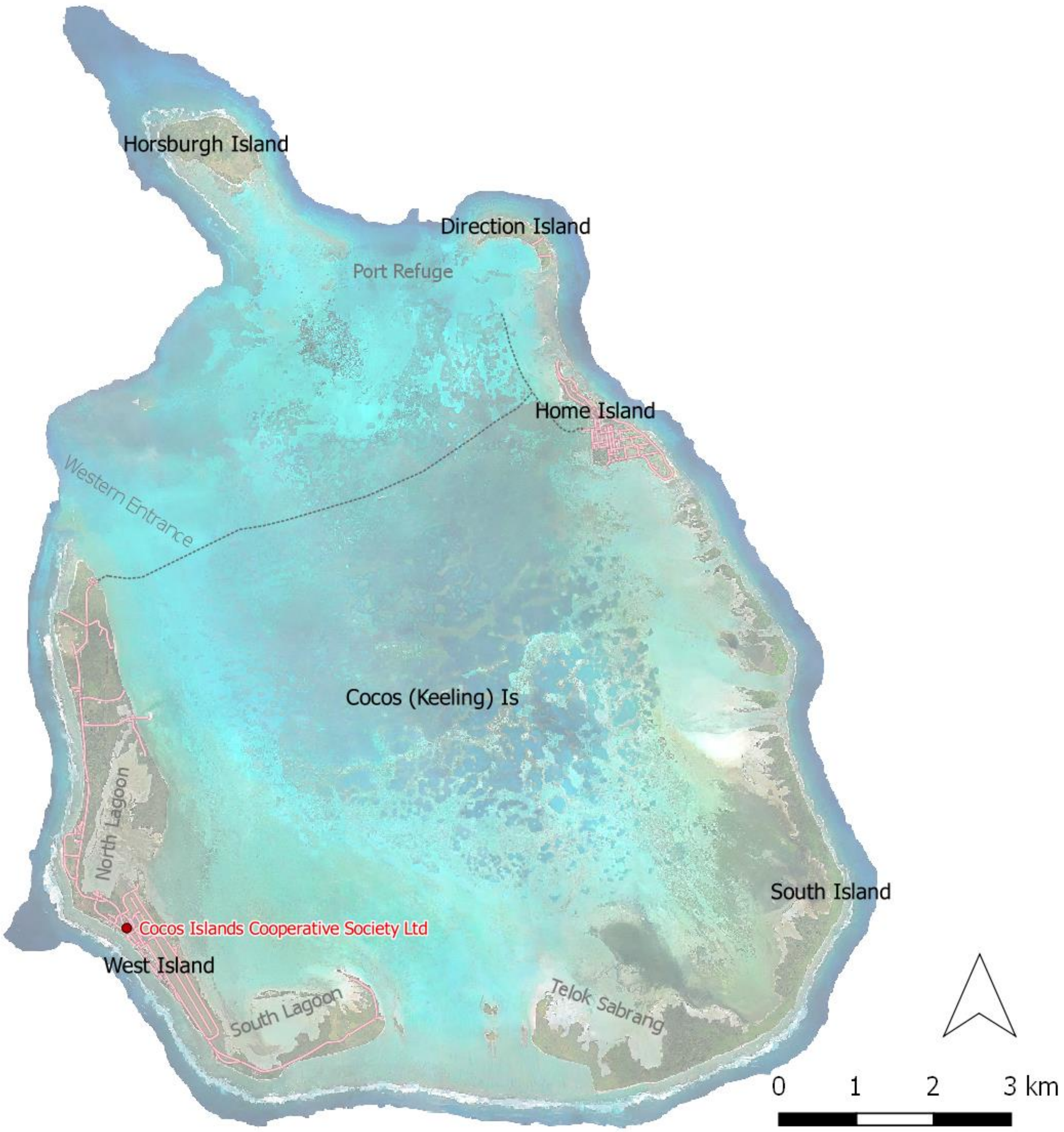


Figure 3: Cocos (Keeling) Islands location map.

2 Background information

2.1 Climate

The climate of the Cocos (Keeling) Islands is tropical, with a hotter period from December to March, during which the maximum temperature is around 30°C and a relatively cool period from June to October, during which the maximum temperature drops to around 28°C (BoM, 2018). The warmest months are February and March. The relative humidity is always high, but is tempered by the trade winds, which blow throughout the year, with a greater intensity in the coolest months (July and August), and a lower intensity in the warmest months (February and March). The region experiences tropical cyclones and the islands are subject to storm surge under extreme conditions.

The Cocos (Keeling) Islands experience on average just under 2,000 millimetres of rainfall per year; there is no dry season, even though typically the rains are more abundant from January to July, with averages around 200 millimetres per month, with a maximum in March and April (BoM, 2018). The drier months are typically September to November, when rainfall is less than approximately 100 millimetres per month. However, during some years the rains do not follow the typical pattern.

2.2 Geology and geomorphology

Seismic and radiometric-dated core sample data taken from within the southern lagoon (Searle, 1994) supports the antecedent model of reef development on a subsiding core. This model, first theorised by Charles Darwin on his visit to the islands in 1836 describes an evolutionary sequence where vertical reef growth from volcanic island fringing reefs is driven by the gradual subsidence of the volcanic island core, as demonstrated in **Figure 4**. The fringing reefs become barrier reefs and finally coral atolls as the volcanic core slowly recedes.

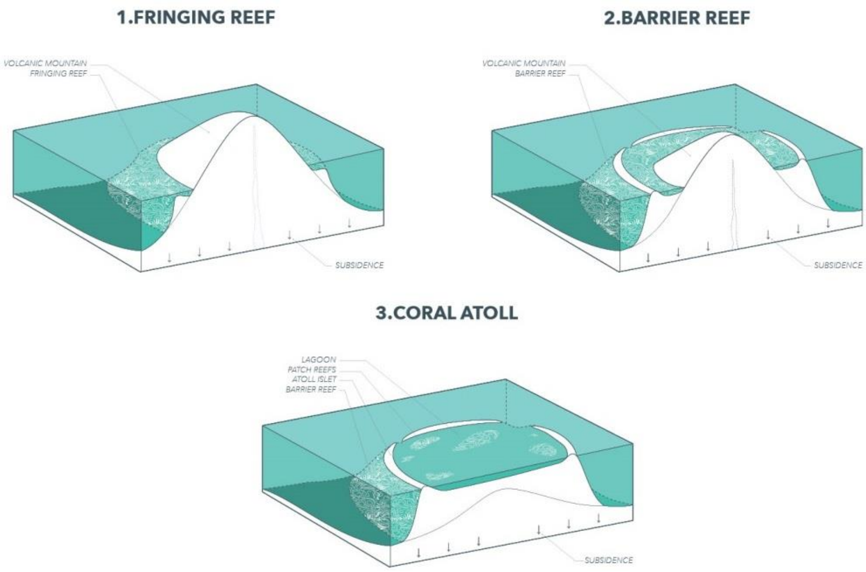


Figure 4: Coral atoll formation (The Plan Journal, 2018)

The last interglacial atoll surface, both island and lagoon had a very similar morphology to the present atoll and lies 8 to 28 metres below sea level. It is overlain by 8 to 18 metres of Holocene reef deposits. Searle's study estimated the subsidence of the Cocos (Keeling) Islands atoll during the late quaternary of 0.02 millimetres per year.

The Cocos (Keeling) Islands sit atop an ancient volcanic seamount which rises from the surrounding seafloor which is at depths of approximately 5,000 metres. This seamount is part of an undersea range known as the Vening Meinesz Seamounts, which also include Christmas Island.

Fringing coral reef surrounds all but the two deeper entrances between the northern top of West Island and Direction Island. The coast geomorphology around the reef rim is typically fore reef, reef crest, flat reef top then land. The fringing reef also features a series of shallow channels between the reef islands which connect the ocean with the lagoon. Such shallow cross-reef channels are referred to as "Hoa", a Polynesian word (Danielson, 1954). The term has been adopted here as it accurately describes these geomorphic features. The term distinguishes these shallow channels from the two main entrances (Western Entrance and Port Refuge) that are much deeper and associated with a break in the reef rim (Kench, 1994 and Kench and Maclean, 2004).

The lagoon is shallowest in the southeast, deepening toward the two main entrances in the northwest.

2.3 Literature review

A substantial body of literature in the form of consultant and government technical and management reports as well as scientific papers exist for the Cocos (Keeling) Islands. All the available literature addressing coastal processes, coastal protection works and coastal management within the Cocos (Keeling) Islands was consulted. This included the management of risks to public safety and built assets, as well as risks from climate change. A summary of key documents, where it is relevant to the study area and the scope of the CVA, is presented in the following Sections. The quality and reliability of the data and information was also assessed. Historical context to contemporary issues was provided where possible.

2.3.1 Investigations for the Proposed Freight and Passenger Facilities at Rumah Baru (Cocos Islands) (DA Lord & Associates, 1999)

This report was one of several studies undertaken as part of the Rumah Baru Freight and Passenger Facility, located on the lagoon side of West Island. This particular study is most relevant as it presents the findings of studies into coastal processes at Rumah Baru and was used by GHD to inform the design of the marine facility. It presents an appraisal of the wind, wave and currents at Rumah Baru and the effects of sediment transport and shoreline change. It provides some useful observations of this area prior to the construction of the Rumah Baru marine facility.

The report notes a lagoonal current, located 100 to 200 metres offshore from the shoreline, flowing in a predominantly northerly direction parallel to the shore with occasional reversals in direction around high tide. The northerly current was determined to be primarily a function of the predominant south-easterly wind direction. Counteracting this wind-driven flow is a nearshore current induced by swell penetrating the lagoon from Port Refuge and Western Entrance and generating a southward littoral drift. Significantly more swell energy can penetrate the lagoon and reach Rumah Baru at high tide, therefore the rate of sediment transport is a function of tidal state as much as wave height.

Given the low wave energy environment and the potential for sand movement both northwards with wind waves and southwards with swell made it difficult to predict the net sand longshore transport direction and rates at this site. In recognition of this, GHD arranged the construction of two temporary groynes at Rumah Baru to quantify longshore transport. The temporary groynes were constructed in July 1999 and were 32 metres in length and located 20 metres either side of the boat ramp. Soon after construction of the groynes, a substantial amount of sand was observed to have built up against the northern side of the northern groyne. **Figure 5** shows the cumulative change in the beach volume profiles over the period, the greatest change on the northern side of the northern groyne with a net increase in subaerial beach profile volume of 0.86 m^3/m, which predominately occurred over a 3-day period around 18 August 1999. While this would indicate a southerly littoral drift, the temporary groynes failed in August before any conclusive results could be obtained from the groyne monitoring programme. It is not known if the temporary groynes were reconstructed or not.

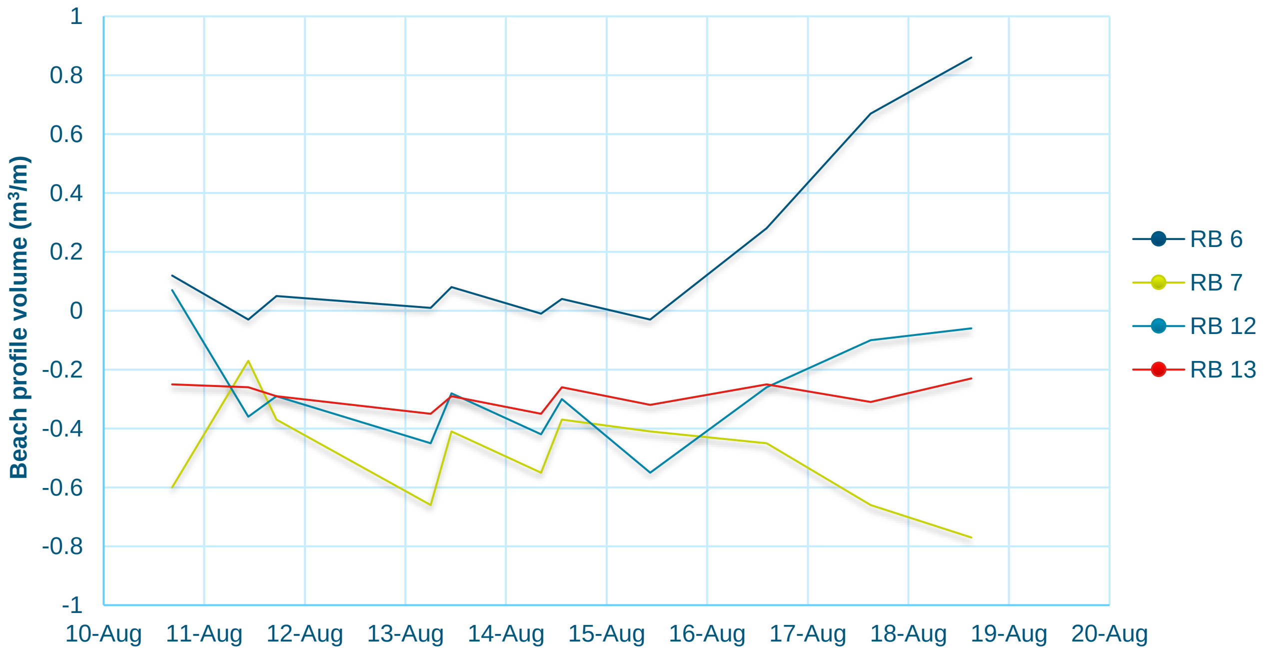


Figure 5: Cumulative change in beach profile volume at Rumah Baru foreshore during 1999 temporary groyne trial.

Note: RB 6 is 1 m to the north and RB 7 is 1 m to the south of the northern groyne. RB12 is 1 m north and RB13 is 1 m south of the southern groyne.

Beach width data collected between 1996 and 1999 showed that the beach to the north of Rumah

Baru has narrowed by approximately 2 to 3 metres while the beach to the south widened by a similar amount. However, the report does note that observations by residents suggest that the shoreline has been stable over the longer term. It was assumed that this shoreline stability is a result of the low-energy environment, the dense vegetation onshore and the extensive seagrass beds offshore which act to dissipate wave energy.

2.3.2 CKI Coastal Management Plan (GHD, 2000)

A coastal management plan was developed by GHD in 2000 for the then Department of Transport and Regional Services. The plan was developed to inform guidelines for future development on the island with the aim of ensuring sustainable development in the long term. Predicted erosion extents for various sections of West Island were presented considering known coastal processes at the time.

Sea level rise estimates in 2000 to 2030 had a best estimate of 18 centimetres and to 2070 the best estimate was 44 centimetres. A 20-centimetre allowance for sea level rise was adopted by GHD for design water levels. Development setback allowance for sea level rise was recommended by GHD to be 5 metres for areas of high relief and 10 metres for lagoon shorelines.

Areas to be protected by coastal engineering structures if trends of erosion continued were identified on West Island. Locations identified included: near the northern end at the Shell Fuel Farm, Trannies Beach, a section of Sydney Highway 500 metres south of the Rumah Baru turn off, in front of the Medical Centre and in front of houses on Qantas Close.

GHD recommended that building construction should be restricted within 20 metres of the 3.0 metres above Mean Sea Level (MSL) contour for both future residential and other uses.

An assessment of available materials for use in construction was undertaken including assessment of extraction limits. Sand, coral shingle and coralline silts resources were identified with recommendations on extracting sediments from sink areas and a preference to avoid removal of sediment from sources above sea level.

2.3.3 Cocos (Keeling) Islands Coastal Engineering Investigations (DoT, 2010)

On behalf of the then federal Attorney-General's Department, the Western Australian Department of Transport (DoT) conducted a coastal engineering investigation in 2010 that consisted of a site visit along with analysis of the available metocean data. The report includes:

- Plots of monthly sea levels measured at the Bureau of Meteorology (BoM) tide gauge from 1992 to 2010 showing a long-term increasing trend and seasonal variation with water levels.
- BoM wind roses for 1952 to 2010 showing the dominate south-easterly and easterly trade winds.
- Sediment sample collection and analysis showing smaller grain sizes at lagoon beaches than

at the ocean beaches.

The report indicates a distinct lack of data for other important variables, noting:

- No known wave data at the Cocos (Keeling) Islands with a high priority recommendation that directional wave data be collected before major coastal infrastructure can be appropriately planned. Wave data collection in both deep and shallow water is recommended.
- A lack of beach and hydrographic survey with a high priority recommendation that regular beach surveys be collected around Home Island and West Island.
- Three aerial images are listed, 1987, 2003 and 2006 along with a high priority recommendation that aerial photography be collected every five to ten years.

Based on site observations and aerial photography vulnerable sections of coast were described as:

- Home Island is most susceptible to coastal inundation during high water level events. This is because of the low land levels on which the settlement and infrastructure has been developed. Coastal erosion was not considered to be as significant a hazard as development is generally well set back from the ocean (east) coast and the lagoon side beaches have a low-wave energy wave climate with lower variability in the shoreline position.
- West Island on the other hand is more susceptible to coastal erosion as well as coastal inundation. Development on the ocean (western) coast is rarely appropriately set-back from the shoreline. Six locations were at risk from erosion and/or inundation hazards including: Twiss memorial, the culverts adjacent to the southern end of the runway, Airforce Road adjacent to the southern runway, Settlement (William Keeling Crescent and southern houses), Quarantine station and sections of Sydney Highway. Geotextile sand container seawalls were recommended as mitigation options along with monitoring and relocation of some assets.
- Wave setup was inferred as being higher at the Cocos (Keeling) Islands' ocean facing beaches when compared to a normal sandy beach owing to the fringing reef platforms and deep-water drop-off. This was confirmed anecdotally using historical photographs of an overtopping event in May 2007.

Condition inspections of local protection structures were conducted, and management recommendations were presented.

2.3.4 Climate change risk assessment for the Australian Indian Ocean Territories – Cocos (Keeling) Islands and Christmas Island (Maunsell-Aecom, 2009)

Maunsell-Aecom (2009) conducted a risk assessment for the Indian Ocean Territories (IOT) of Christmas Island and the CKI. The report addresses climate change observations and predictions as well as coastal hazards including sea level rise, inundation, extreme weathers and cyclones.

The observed climate trends for CKI include:

- an increase in annual and seasonal air temperature by 0.7°C for CKI since 1974;
- an increase in sea surface temperature by 0.5°C, with a stronger warming trend during the winter season; and
- sea level rise of 4 millimetres per year based on the tide gauge station data, since 1992. The 4 millimetres per year estimate was revised down from an earlier estimate of 9 millimetres per year.

Future climate change predictions included an average sea level rise of 14 centimetres by 2030 and 40 centimetres by 2070. An increase in the number of intense tropical cyclones and storm events by 2030, and a decrease by 2070.

The report concludes that the Cocos (Keeling) Islands are especially vulnerable to inundation, and extremely vulnerable to potential impacts of climate change and sea level rise due to the low-lying nature of the atoll. Any rise in the mean water level due to sea level rise will exacerbate inundation, storm surge and erosion and threaten infrastructure, settlements and facilities. The importance of wave setup to contribute to storm tide on the ocean facing coastlines exposed to dominant wave directions was acknowledged. Detailed coastal hazard mapping for Home Island and West Island recommended.

In addition to the vulnerabilities to climate change, sea level rise and coastal erosion, the report also highlights the vulnerability of the Cocos (Keeling) Islands' coral reefs, water resources, economic development and tourism. Adaptation measures proposed include; strategic protection of key assets and the settlement by seawalls, erosion control and revegetation plan, and development of a relocation and resettlement strategy for the Cocos (Keeling) Islands.

This report was updated in 2010 (Aecom, 2010). The above discussion has been verified against the updated report.

2.3.5 CKI Sand Management Strategy Numerical Modelling Report (GHD, 2017b)

Patrick Ports commissioned GHD to provide an update to the 2000 CKI Coastal Management Plan. This was to inform sand management practices on the Cocos (Keeling) Islands, identify suitable sand sources and extraction limits and provide an updated investigation into sand movements within the atoll.

To address these matters GHD undertook numerical sediment transport modelling, site investigations and site-specific surveys.

GHD's sediment transport modelling consisted of a coupled wave and hydrodynamic model for typical summer and winter conditions (GHD, 2017a). The sediment transport modelling was based on limited available metocean, sediment and seafloor characterisation but was used to identify sources and sinks of sediment. Importantly, the wave and hydrodynamic models were not calibrated nor was the sediment transport model validated. The approach did not consider cross shore or longshore sediment transport, wave set-up or infragravity waves that are known to effect reef top sand island atolls like the Cocos (Keeling) Islands. As such, it considered sediment movements on the lagoon floor only and in isolation.

The sediment transport modelling study results, discussions with relevant stakeholders and ground truthing of the modelling results through survey and observations were used to determine the locations of sand accretion within the atoll. Each source was accessed for suitability for sand extraction. Consideration was given to whether extracting sand from the areas identified would cause downstream deficit, the practicality of extracting the sand and the approximate volumes available.

The recommended locations for sand extraction are Rumah Baru and north to Bob's Folley on West Island and Turtle Beach on Home Island (limited). Other identified areas of sand accretion were not considered suitable by GHD due to the limited available volume or potential environmental or coastal process impacts.

GHD's 2017 report acknowledged the need for additional coastal monitoring data (shoreline mapping, regular survey and aerial photos) to be undertaken in conjunction with collection of metocean data (wind, water levels and waves conditions).

2.3.6 Cocos (Keeling) Islands Site Investigations Summary – October 2017 (DoT, 2017)

Staff from DoT and DPLH conducted a site visit as part of the scoping for this CVA. The scoping report includes the rational for siting of the metocean monitoring locations (CK01, CK02, CK03 and CK04) that were adopted for this study. A useful summary of on-island logistics, operational strategies and resources is provided. The report includes an engineering assessment of twelve coastal protections inspected on the Cocos (Keeling) Islands with the details included in the review provided in the Task 4 – Site Visit Report. A total of 17 sediment samples were collected with the resulting particle size analysis data reported.

2.3.7 Summary

The literature review as part of the CVA process documented herein has highlighted the overall lack of long term and consistent, metocean and hydrographic data collected in vicinity of the Cocos (Keeling) Islands. While there are several useful findings in the previous literature, targeted monitoring-based studies are required to improve the knowledge of coastal processes, shoreline movement and sediment transport processes. This will in turn lead to improved decision making around coastal zone management.

2.4 Existing data used

This CVA study follows a data driven or evidenced based approach. It uses a combination of existing data made available for use in the study (see **Table 1**) and targeted data collected during and for the CVA (see **Section 3**).

Table 1: Overview of existing data used in this study.

Data type	Source	Application	Year
Wave	CAWCR hindcast model extraction point: [-12.4°, 96.8°] NOAA hindcast model extraction point	Model boundary conditions Extreme value analysis (non-cyclonic)	January 1979 to November 2019
Winds	Bureau of Meteorology (BoM) anemometer (airport)	Model calibration	2006 to 2019
Water levels	BoM tide gauge (Home Island jetty)	Extreme value analysis Model calibration	1992 to 2019
Bathymetry and topography	Topographic Digital Elevation Model LiDAR (1m resolution)	Model setup	2011
	Bathymetric LiDAR (~25m resolution)	Model setup	2012
	RTK beach transects (Task 5)	Model setup	July & October 2018 February & July 2019
	GEBCO offshore bathymetry	Model setup	2014

2.5 Site visit findings

Between the 30 June 2018 and 12 July 2018 coastal and metocean engineers from RHDHV's project team visited the Cocos (Keeling) Islands.

Field observations and photographs are documented for each location and are described in the following sub-sections. These notes consider the shoreline and, where relevant, the coastal infrastructure and recreational uses of each area. Along the natural shoreline, areas affected by erosion or otherwise potentially vulnerable have been noted. To supplement the information already provided in DoT (2017), coastal protection structures were examined, and any relevant observations noted. Several informal conversations were conducted with residents. However, these were confined to residents of West Island. It is recommended that formal engagement is undertaken including Home Island residents in subsequent CHRMAP Stages.

In follow up site visits associated with the metocean data collection task (Task 5 of the CVA scope of works) additional observations around key locations and informal conversations with stakeholders and residents was undertaken.

To date, project team has visited Home Island, West Island, Direction Island and South Island as well as several areas in the lagoon and a few of the smaller atoll islands. However, for the purpose of this CVA report, observations have only been documented for the inhabited Home Island and West Island.

The Cocos (Keeling) Islands CVA Technical Note – Site Visit Report (RHDHV, 2019) provides additional details including discussion of the specific coastal observations and conditions of each coastal structure. This covers the locations shown **Figure 6**. General observations from the site visit(s) are:

- The shoreline around the Cocos (Keeling) Islands can be divided into oceanward shores that occur around the perimeter of the atoll and face the open ocean, and lagoonward shores that flank the lagoon.
- The geomorphology including the substrata is critical to understanding coastal vulnerability. Natural shorelines on the Cocos (Keeling) Islands are composed of sandy beaches or in many cases of coral shingle/boulder beaches. Observations suggest that almost all sandy beaches are characterised with a base of coral shingle[1] or coral boulder[2]. Morphological differences also occur between windward (facing the prevailing wind) and leeward (away from the wind) margins of the atoll.
- The oceanward fringing shoreline is characterised by varying distances to the reef edge. Perched beaches with medium grained sand interspersed with coral shingle, and boulders. Oceanward beaches are generally steep and backed by a ridge built by ocean wave run-up. Typically, there are no established dunes. However, evidence of a few windblown dunes was observed in some locations. In areas where the reef edge is closer to the shoreline, predominantly coral boulders exist on the beach (e.g. The Shack, West Island).

- Two elongated islands (West Island and South Island) occupy the southern corners of the horseshoe shaped southern lagoon. The remaining islands are small crescent-shaped islands on the conglomerate platform, separated by shallow inter-island passages (or shallow channels).
- On West Island, strong northward wave-driven alongshore currents across the reef flats were observed along most of the west coast.
- On Home Island, currents in the channels located to the north and south of the island were observed flowing in a lagoonward direction.
- Circulation of the shallow southern lagoon is predominantly driven by wind and wave processes while tidal currents appear to be limited.

[1] Coral shingle is pebble or cobble sized (diameter from 4 to 256 millimetres) coralline material. In this report the term shingle beach (or shingle ridge) is used to describe a beach that is armoured with shingles. These terms are synonymous with the terms gravel beach (or gravel ridge).
[2] Coral boulders are rocks comprised of coralline material that are larger than cobbles (>256 millimetres in diameter).

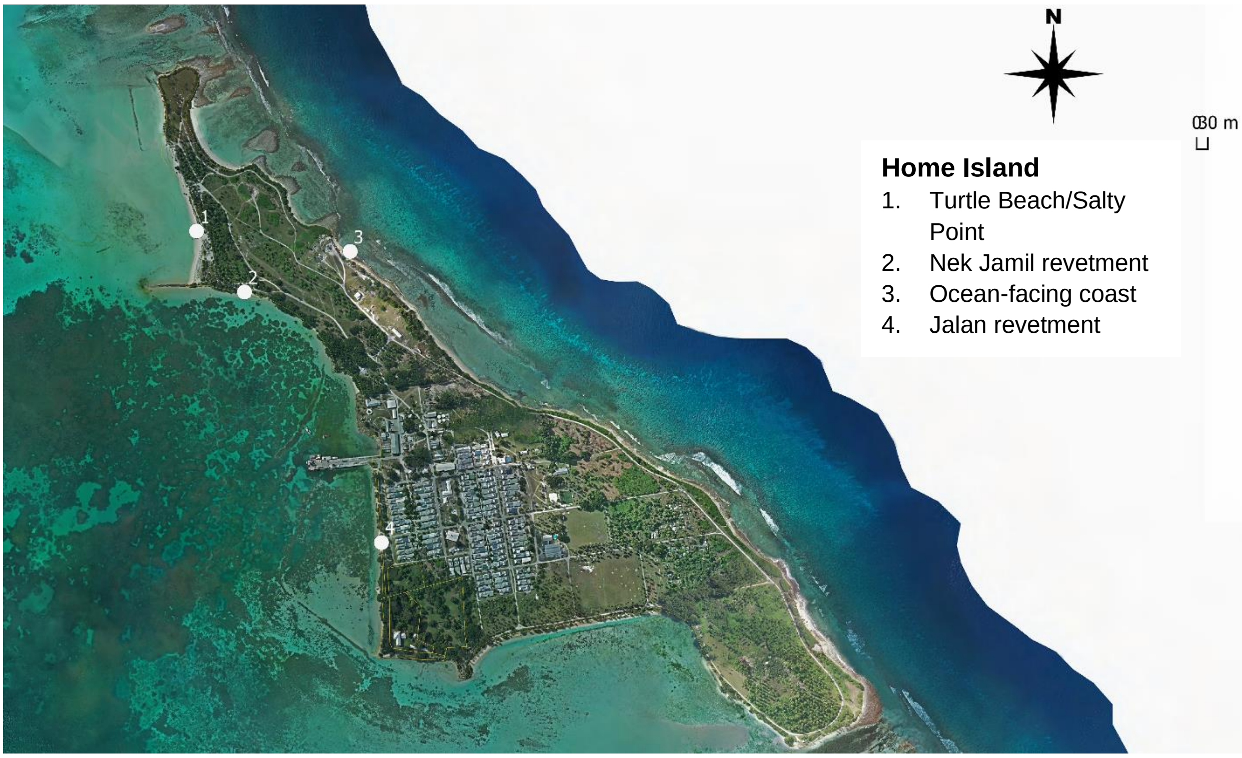
2.6 Gap analysis

A summary of identified data gaps based on the existing data and from observations during the site visits is provided in Table 2.

Table 2: Summary of identified data gaps.

Data type	Description	Purpose	Addressed in CVA?
Metocean	Wave measurements on ocean side, reef tops and within the Cocos (Keeling) Islands lagoon	Understanding of coastal processes and verification of numerical models to inform vulnerability	Yes
	Concurrent current measurements on ocean side, reef tops and within the Cocos (Keeling) Islands lagoon		Yes
	Concurrent water level measurements on ocean side, reef tops and within the Cocos (Keeling) Islands lagoon		Yes
	Spatial measurements of currents around the lagoon and on the reef rim under typical conditions		No
Survey	Frequent temporal vegetation line analysis / beach transect data for the coastlines of the Cocos (Keeling) Islands	Assess seasonal variation and create long-term dataset on island morphology	No
	High resolution and repeated bathymetric and topographic survey (e.g. LiDAR) of enough quality and temporal coverage	Determine a medium to long term sediment budget to inform coastal management	No
	Substrata at key locations around the Cocos (Keeling) Islands, particularly the mapping of coral boulder ridges	Some information is available from Woodroffe's Atoll Research Bulletin, but more detail would benefit the	No

	which were observed to underlay sandy beaches at several locations	understanding of the islands' true vulnerability to coastal erosion	
	Sediment data (incl. profiling) at key locations around the Cocos (Keeling) Islands	Understand sources, transport processes and deposition of sand to verify conceptual understanding of coastal processes	No
Other	The interaction between ground water and ocean water levels including the possibility of saline intrusion into the freshwater aquifers	Understand risk to freshwater supply	No



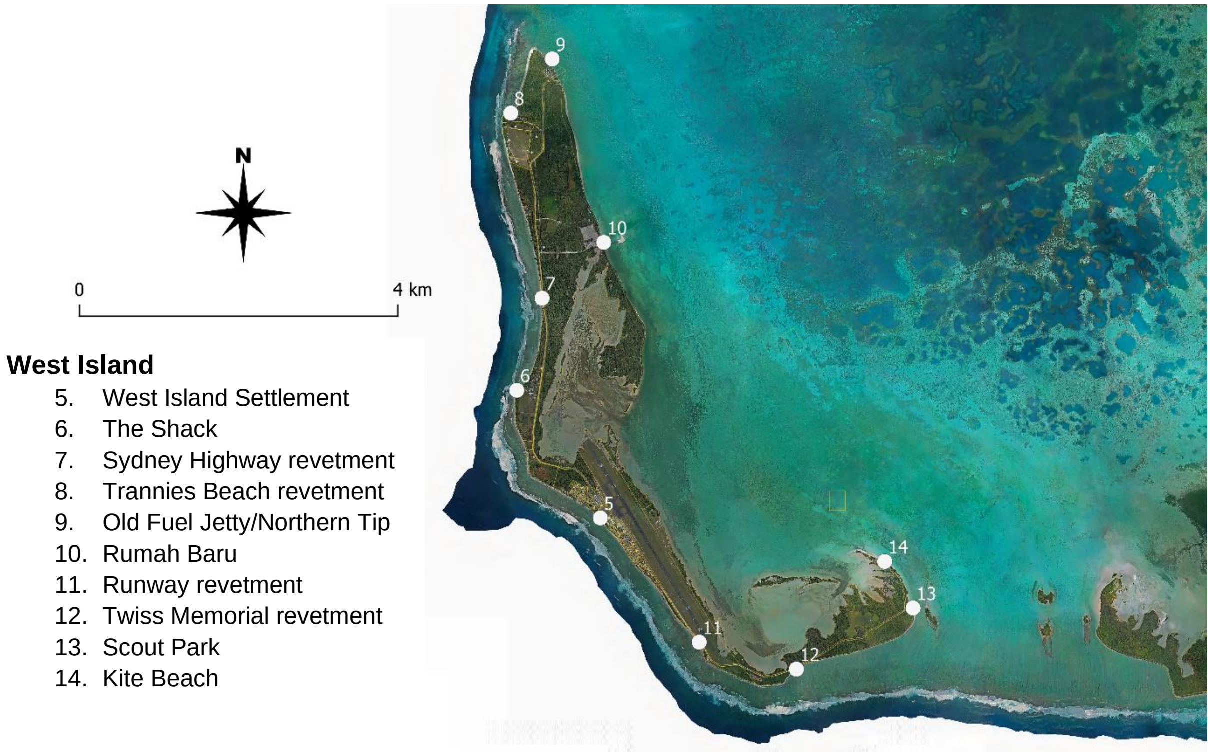


Figure 6: Location inspected as part of the site visits of the study area

3 Data collection

3.1 Metocean data

3.1.1 Metocean deployments

Metocean data, included the measurement of waves, currents and water level variation, has been collected at key locations and water depths around CKI. RHDHV's Metocean Data Collection Report sets out a comprehensive presentation of the planning, field work and results of this monitoring campaign (RHDHV, 2020a). A concise summary is provided herein.

Eight (8) oceanographic monitoring sites were deployed during the July 2018 site visit. To capture seasonal variations, the monitoring sites were intended to be in-place for a period of at least 12-month period. The eight monitoring sites are shown on **Figure 7** with details of the instruments used provided in **Table 3.** A brief description of each of the sites is provided below.

CK01a – The primary objective of this site is to characterise the wave climate affecting the ocean side of West Island. This site measures incoming south to south-westerly Indian/Southern Ocean swells largely unaffected by CKI's bottom contours. CK01a is located just to the north and offshore of the unprotected section of shoreline fronting the Cocos Beach Motel. This is one of the most vulnerable areas of the West Island settlement. By design, the site is directly offshore of the reef top monitoring sites (CK01b and CK01c) which are located on a relatively straight section of reef. Due to prevailing weather patterns, waves at Cocos (Keeling) Islands rarely approach from the north-west to north. However, under such conditions the CK01a site would be expected to measure waves that have undergone refraction across the broader reef area to the north of this location.

A Nortek AWAC 1MHz instrument was deployed very close to the steep drop-off in the reef. The instrument was located as close to the steep drop-off as possible to maximise the water depth.

The CK01a position was selected to balance the need to capture the wave climate affecting West Island along with maximising the value of the reef top monitoring and shoreline change measurements, as well as safety of personnel and equipment during deployment and servicing exercises.

CK01b and CK01c – The primary objective of these sites is to measure waves and water level variation (including wave set-up) on the reef top. This is important for understanding coastal erosion and wave overwash on unprotected shorelines, wave overtopping on protected shorelines and for the calibration of wave and hydrodynamic models in the lee of these natural fringing reefs. The shoreline on the northern side West Island settlement was selected for this purpose. The site has been selected based on its relatively uniform coastline orientation and reef bathymetry, its proximity to key areas of interest as well as the lack of coastal structures. In addition, this is area is exposed to large swell waves and is therefore a characteristic study site.

RBR high frequency pressure transducers were deployed at CK01b and CK01c. CK01a to CK01c are in a straight line to get an unhindered representation of the offshore waves prior to their transformation across the reef flat. In this way, wave groups can also be considered.

CK02 – The primary objective of this site is to measure the incident wave climate affecting Home Island. Located on the ocean (east) site of Home Island this site primarily measures the persistent south to south-easterly waves (seas and swells) generated by the trade winds. The instrument at CK02 is located on the reef rim in an area where the bottom is predominately hard coral. The reef rim in this area has a mild slope toward a steep drop-over which is located further to the east. Waves measured at this site are expected to have undergone some refraction and shoaling. Two locations, in relatively proximity, were adopted as:

> CK02a: For the first two deployments, between 3 July 2019 and 5 February 2019, a Nortek AWAC 1MHz (or Nortek Signature during second deployment) instrument was positioned in a small depression with a water depth of 8.6 metres relative to MSL. CK02a is located offshore of a shallow reef channel referred to as 'Hoa 3' (Kench, 1994 and Kench et. al., 2004). The location of CK02a was chosen to also provide some insight into the hydrodynamics nearby the entrance of this shallow reef passage. These shallow reef channels are significant as the lagoon-ward flow of water and sediment affects circulation and sediment supply to the lagoon side of Home Island.

CK02b: For the subsequent two deployments, between 6 February 2019 and 18 October 2019, the Nortek Signature 1000 instrument was deployed 720 metres to the north west of CK02a. This location was closer to the reef rim's drop off in a water depth of 13.2 metres relative to MSL.

CK03 – The primary objective of this site is to measure tidal and non-tidal currents in the Western Channel area, one of two major entrances to the lagoon. A secondary objective is to measure the wave climate within the channel. The wave climate at the CK03 location was expected to be predominately composed of heavily refracted south to south-west swell as well as intermittent periods of westerly and north-westerly waves.

The Nortek AWAC/Signature at CK03 is within the main flow channel where the bottom is predominately sand/coral rubble interspersed with the coral heads. The instrument is positioned in water depth of around 9 metres.

CK04 – The primary objective of this site is to measure tidal and non-tidal currents at the southern end of the CKI lagoon. This will help characterise the circulation patterns within the lagoon. CK04 is located on the lagoon side of the shallow but wide reef passage at the southern end of CKI. While the instrument has been configured to measure waves during the first deployment, as limited wave energy was measured, subsequent deployments measured currents only.

Due to the very shallow depths encountered at this site, for the second deployment onwards the instrument was upgraded to a Nortek Aquadopp 2MHz. The Aquadopp 2MHz has a small blanking distance and finer vertical resolution.

H3 and H8 – The primary objective of these sites is to measure tidal and non-tidal currents within two of the 15 shallow cross-reef channels that separate the coral sand islands between Direction Island and West Island. Previous investigations (Kench et al, 1994 and 2004) have highlighted the importance of these channels on lagoon circulation, as well as sediment fluxes, around the atoll.

A description of the instruments used is provided below:

- All Nortek devices were Acoustic Doppler Current Profiler (ADCP) type instruments, capable of measuring waves, current, water depth and water temperature.
- The RBR pressure transducers are instruments capable of measuring water depth at a very high frequency from which non-directional waves, tide and other water level variations such as wave setup can be determined.
- The Marotte is a tilt drag current metre which logs the tilt of a buoyant housing in the water, which is then processed to determine water current velocity in a usable measuring range of 0.05 m/s – 1.20 m/s within an accuracy of ±0.05 m/s.

For all instruments, measured data was logged internally and downloaded during routine service visits to the islands by members of the project team. During servicing at each of the monitoring sites the instruments were recovered, data downloaded, equipment serviced and redeployed. The equipment was deployed in shallow depths (less than 20m relative to mean sea level (MSL)) around the CKI and firmly secured to the seabed using ballasting or by fixing with bolts. No surface markers or buoys were used.

The metocean monitoring sites were specifically selected for spatial coverage and to account for key areas of interest. Following recommendations in DoT's 2017 report, the main four monitoring sites (CK01a, CK02, CK03 and CK04) were included in the initial monitoring plan. Two additional reef top monitoring sites (CK01b and CK01c) were also included as part of the monitoring plan following recommendations by RHDHV. The primary objective of these additional sites is to measure waves and water level variation (including wave set-up) on the reef top. This is important for understanding coastal erosion and wave overwash on unprotected shorelines, wave overtopping on protected shorelines and for the calibration of wave and hydrodynamic models in the lee of these natural fringing reefs. During the July 2018 site visit, the project team also elected to deploy two additional current monitoring sites (H3 and H8) each located in shallow reef channels near Home Island and West Island, respectively. This was decided upon in order to measure tidal and non-tidal currents within two of the 15 shallow cross-reef channels that separate the coral sand islands between Direction Island and West Island.

Table 3: As-deployed co-ordinates of metocean monitoring equipment.

Site ID	Measurements	Monitoring Equipment	Depth (to MSL)	Location [Latitude; Longitude]
CK01a	Waves, currents and water levels	Nortek AWAC mounted on a ballasted seabed frame	-18.6m	12°11.401'S; 96°49.364'E
CK01b	Waves and water levels	RBR pressure transducer mounted on a steel frame that has been fixed to the reef	-0.9m	12°11.243'S; 96°49.475'E
CK01c	Waves and water levels	RBR pressure transducer mounted on a steel frame that has been fixed to the reef	-0.9m	12°11.189'S; 96°49.510'E
CK02[3]	Waves, currents and water levels	Nortek AWAC/Signature mounted on a ballasted seabed frame	CK02a: -8.6m CK02b: -13.2m	12°7.345'S; 96°54.523'E 12°6.999'S; 96°54.313'E
CK03	Waves, currents and water levels	Nortek AWAC/Signature mounted on ballasted seabed frame	-8.3m	12°7.324'S; 96°49.506'E
CK04	Currents and water levels (and waves)	Nortek Aquadopp mounted on grid and concrete weights	-0.75m	12°11.373'S; 96°52.450'E

[3] Following request by DoT, the monitoring instrument at CK02 was relocated during the third deployment in February 2019 from a location near the southern end of Home Island (8.6m depth, CK02a) to a location 720m to the north-west (13.2m depth, CK02b). The monitoring results suggest minimal differences in the wave climate at these two locations. The relocation of the monitoring instrument resulted in an extension of the 12-months monitoring campaign to ensure measurements were undertaken during the more energetic winter months at both sites.

H3	Currents	Marotte current meter mounted on a concrete weight	-0.5m	12°7.424'S; 96°54.272'E
H8	Currents	Marotte current meter mounted on a concrete weight	-0.6m	12°12.012'S; 96°51.875'E

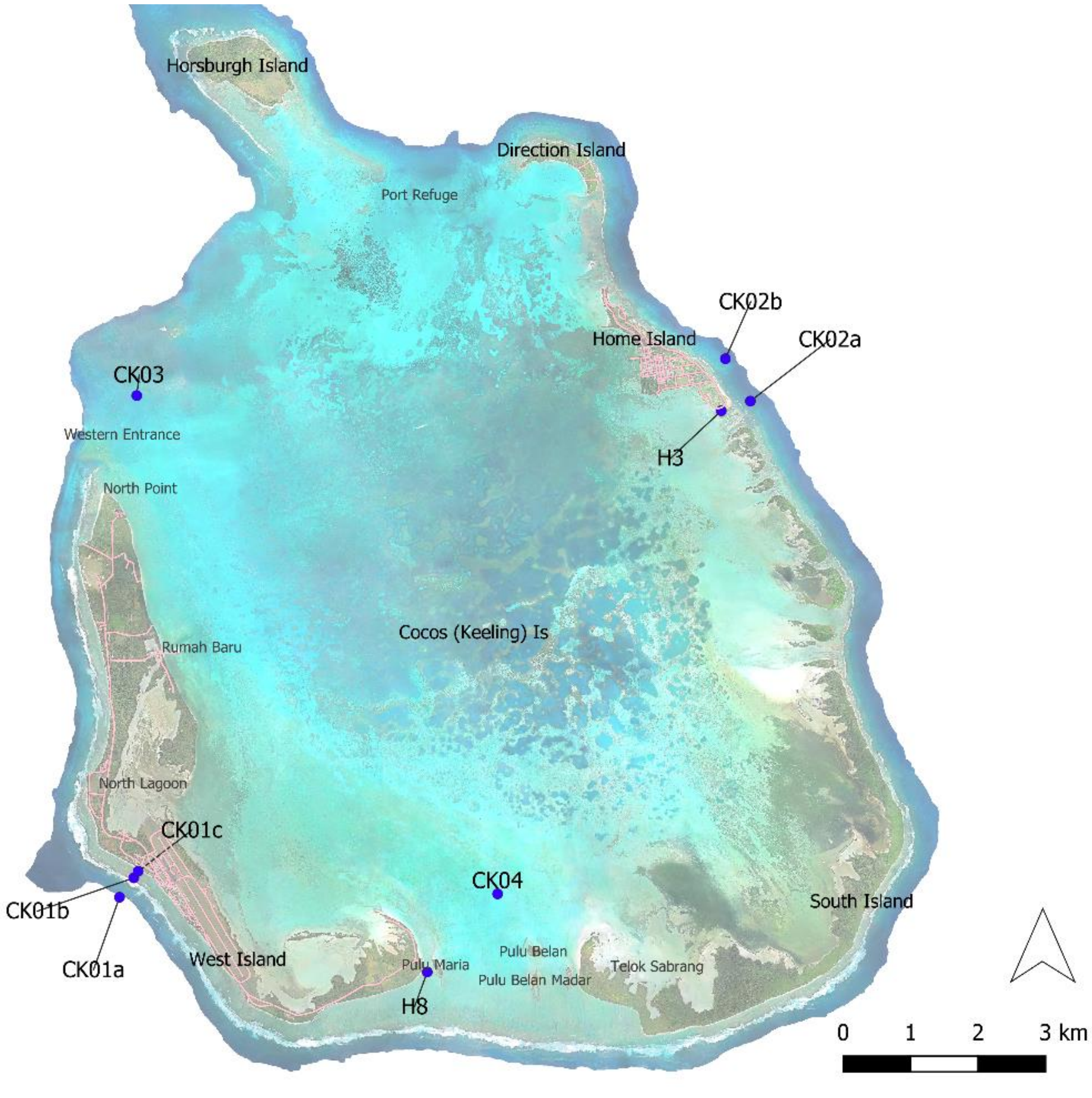


Figure 7: Location of oceanographic monitoring sites (blue dots) on Cocos (Keeling) Islands during the CVA monitoring period.

3.1.2 Metocean data processing and coverage

There were two stages under which raw data from the metocean instruments was processed into quality assured (QA) data. Firstly, the instrument manufacturer's software was used to process the raw measurements and to produce measurements for the various parameters. Further post-processing of outputs from the instrument manufacture software was then undertaken using an in-house metocean data analysis toolbox to ensure spurious data that hadn't previously been detected was removed. All raw and processed data was saved according to strict data management protocols including back-up copies saved on cloud storage, and a copy of the datafiles were supplied to the client on a hard drive. Complete data capture was generally observed across all instruments with three main exceptions. Firstly, notable downtime was observed for the instrument frame at CK01a, which was damaged by an extreme swell event not long after the initial deployment. Corrective actions implemented during the first service visit included the addition of extra moorings at this site as well as at CK02. Secondly, the shallow water depth at site CK04 limited the ability of the specified instrument to collect current velocity data during lower water levels. A more suitable instrument was placed at this site during the first service visit. Finally, in July 2019, the instrument at CK03 incurred a fault related to the internal memory card which resulted in largely reduced data capture. The monitoring period was extended at CK03 to capture the required data following a failure of the instrument's recorder during reporting period three.

3.1.3 Analysis of metocean data

Statistics relating to measured waves and current during the data collection period are provided in **Table 4** and **Table 5**, respectively. For the wave data, a summary of the long-term average wave climate statistics based on the NOAA WWIII wave hindcast are also included to help depict the regional wave climate. However, it is noted that due to varying location and exposure, the statistics for the four main monitoring sites are not directly comparable to the outputs from NOAA WWIII.

Time series plots of the wave, current, water level and water temperature measured at the four ADCP type instrument sites (CK01a, CK02, CK03 and CK04) covering the entire monitoring period were generated. Additionally, wave rose plots were generated for total energy, sea and swell conditions. Finally, time-averaged and directional wave energy spectrum plots of two-dimensional wave spectra were created. An example of these analysis outputs has been provided for the CK02 site in **Figure 8** to **Figure 12. Figure 13** provides current roses for a range of sites around CKI. Additional presentation of the measured data is provided in RHDHV 2020a.

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Table 4: Long-term average (LTA) statistics for NOAA WWIII hindcast wave data at model extraction location [-12.5°, 96.5°], 1979 – 2018 along with statistics from the monitoring period.

Parameter	Statistic	NOAA WWIII long term-averages			CK01a (416 days excluding a 70-day gap)	CK02 (472 days)	CK03 (335 days excluding a 189-day gap)	CK04 (95 days)
		Annual (38+ years)	Dry season (J,J,A,S,O,N)	Wet season (D,J,J,M,A,M)				
Significant wave height, H_s (m)	Average	2.75	3.01	2.49	1.65	1.28	0.71	0.14
	20th percentile	2.08	2.44	2.03	1.25	0.88	0.52	0.10
	90th percentile	3.82	3.89	3.23	2.36	1.92	1.03	0.18
	Maximum	6.53	6.38	5.59	5.11	3.66	3.40	0.29
Peak wave period, T_p (s)	Average	13.1	13.5	12.7	12.8	7.2	12.3	1.6
	Percentage of time sea (T_p < 8s)	4%	2%	6%	3%	74%	13%	100%
	Percentage of time swell (T_p > 8s)	96%	98%	94%	97%	26%	87%	0%
Weighted peak wave direction (°N)	Average	202	202	202	213	81	277	83.9

Table 5: Summary of current speed statistics at six sites over their entire monitored period.

Parameter	Statistic	Profile Depth	CK01a	CK02	CK03	CK04	H3 (0.4m above bed)	H8 (0.4m above bed)
Current speed (m/s)	Mean	Average	0.08	0.09	0.13	0.25	0.47	0.38
		Bottom	0.06	0.06	0.12	0.25		
		Surface	0.12	0.13	0.15	0.25		
	20th percentile	Average	0.03	0.04	0.06	0.14	0.26	0.29
		Bottom	0.03	0.03	0.06	0.13		
		Surface	0.06	0.06	0.07	0.13		
	90th percentile	Average	0.16	0.18	0.24	0.42	0.72	0.54
		Bottom	0.11	0.12	0.21	0.41		
		Surface	0.22	0.24	0.27	0.41		
	Maximum	Average	0.56	0.61	0.54	0.96	1.20*	1.20*
		Bottom	0.44	0.35	0.49	0.95		
		Surface	0.85	0.82	0.57	0.87		
Net direction (°N)	Net direction	Average	302	324	310	324	267	351
		Bottom	265	340	311	323		
		Surface	294	288	309	330		

* 1.20m is the maximum measurable speed with the tilt drag current metres deployed at H3 and H8

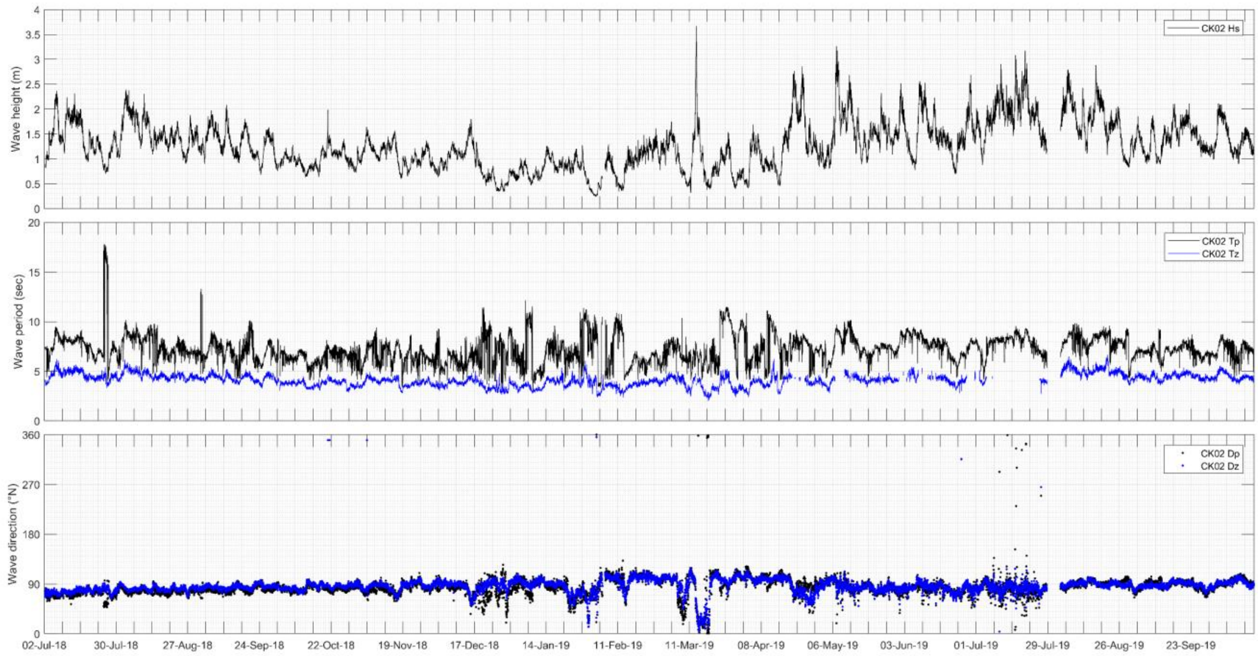


Figure 8: Time series plot of significant wave height, peak and mean wave period, peak and mean wave direction at CK02.

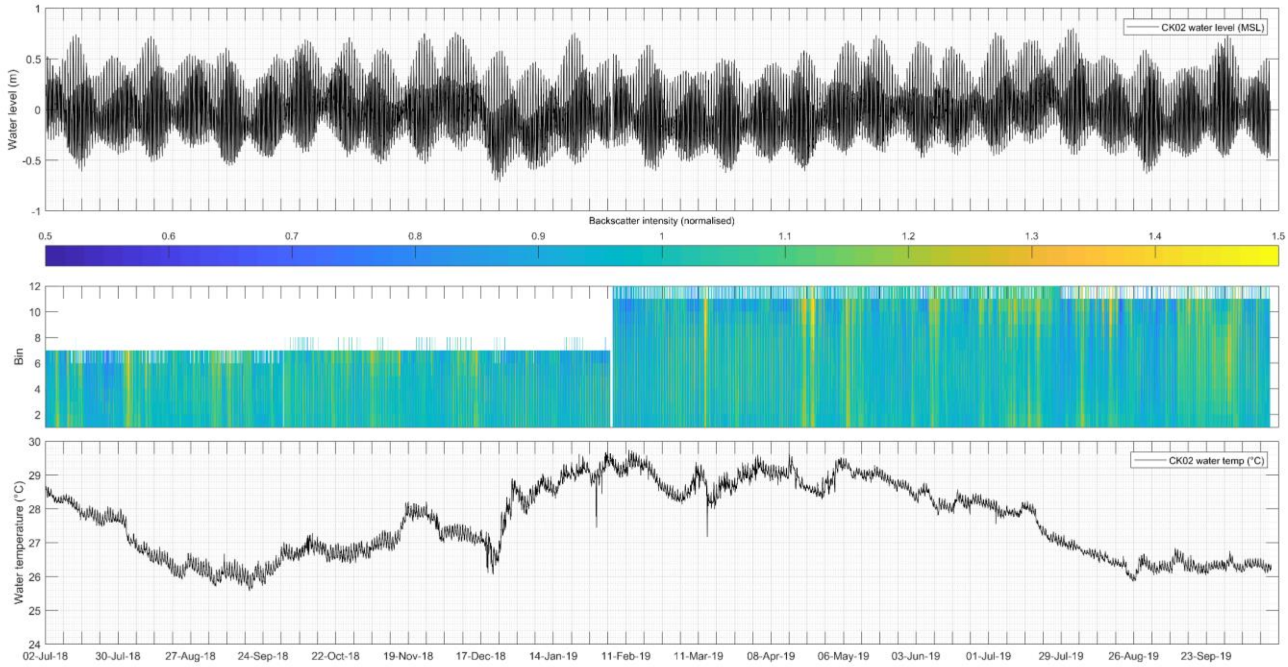


Figure 9: Time series plot of water level, backscatter intensity in bins throughout the water column and water temperature at CK02.

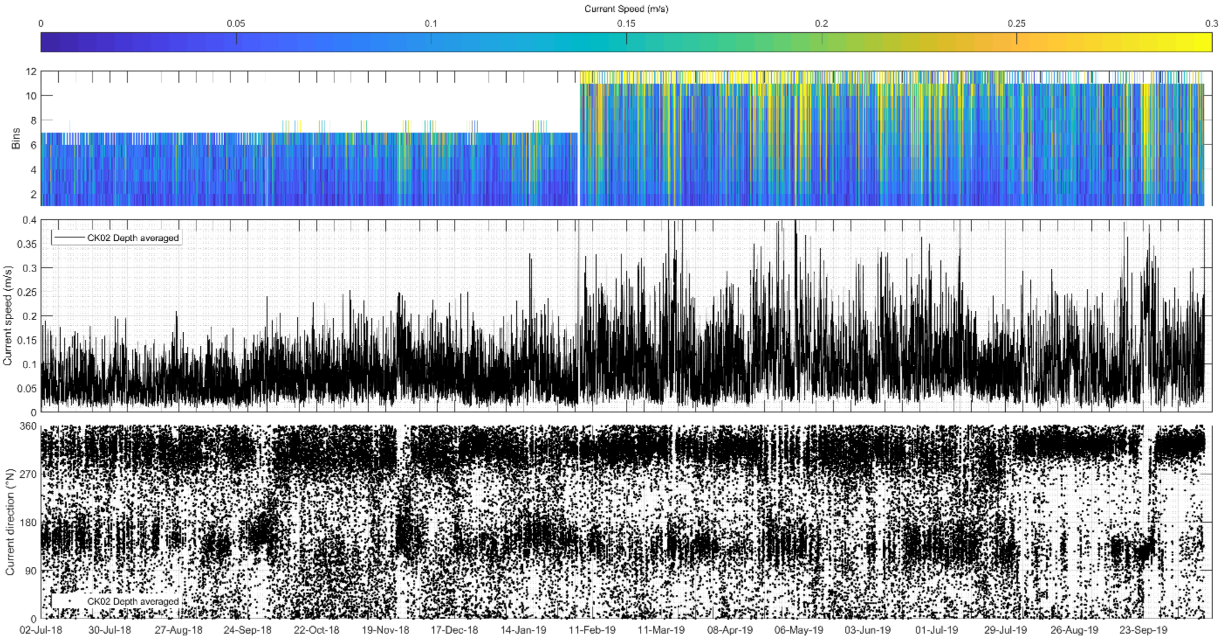


Figure 10: Time series plot of current speeds in bins throughout the water column, depth averaged current speed and depth averaged current direction at CK02.

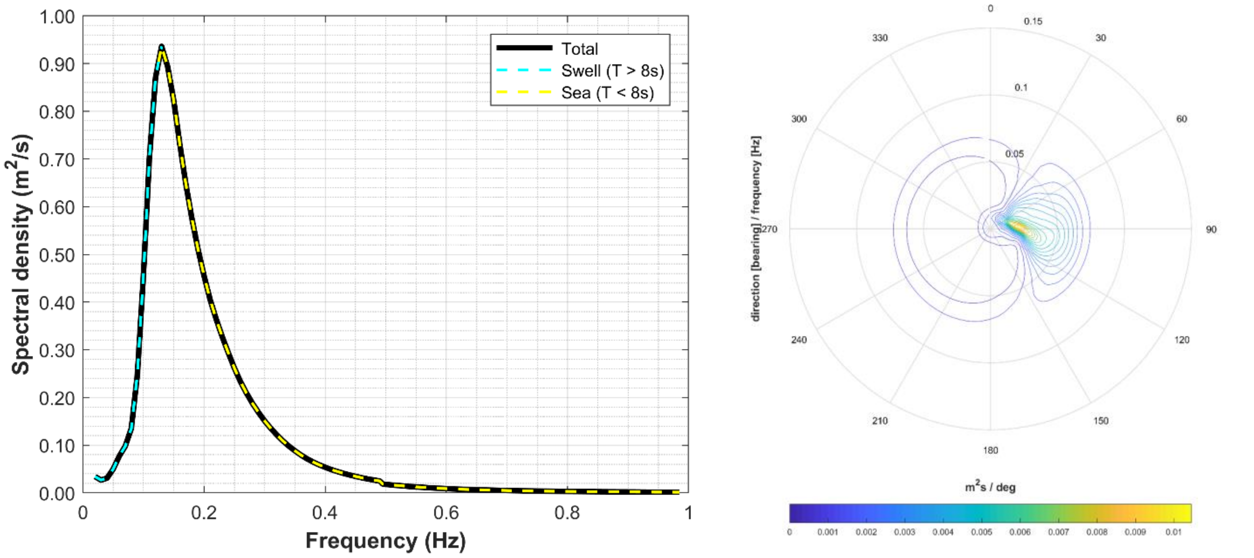


Figure 11: Time averaged wave energy spectrum plot (left) and time averaged directional wave energy spectrum plot (right) for CK02 for the monitored period.

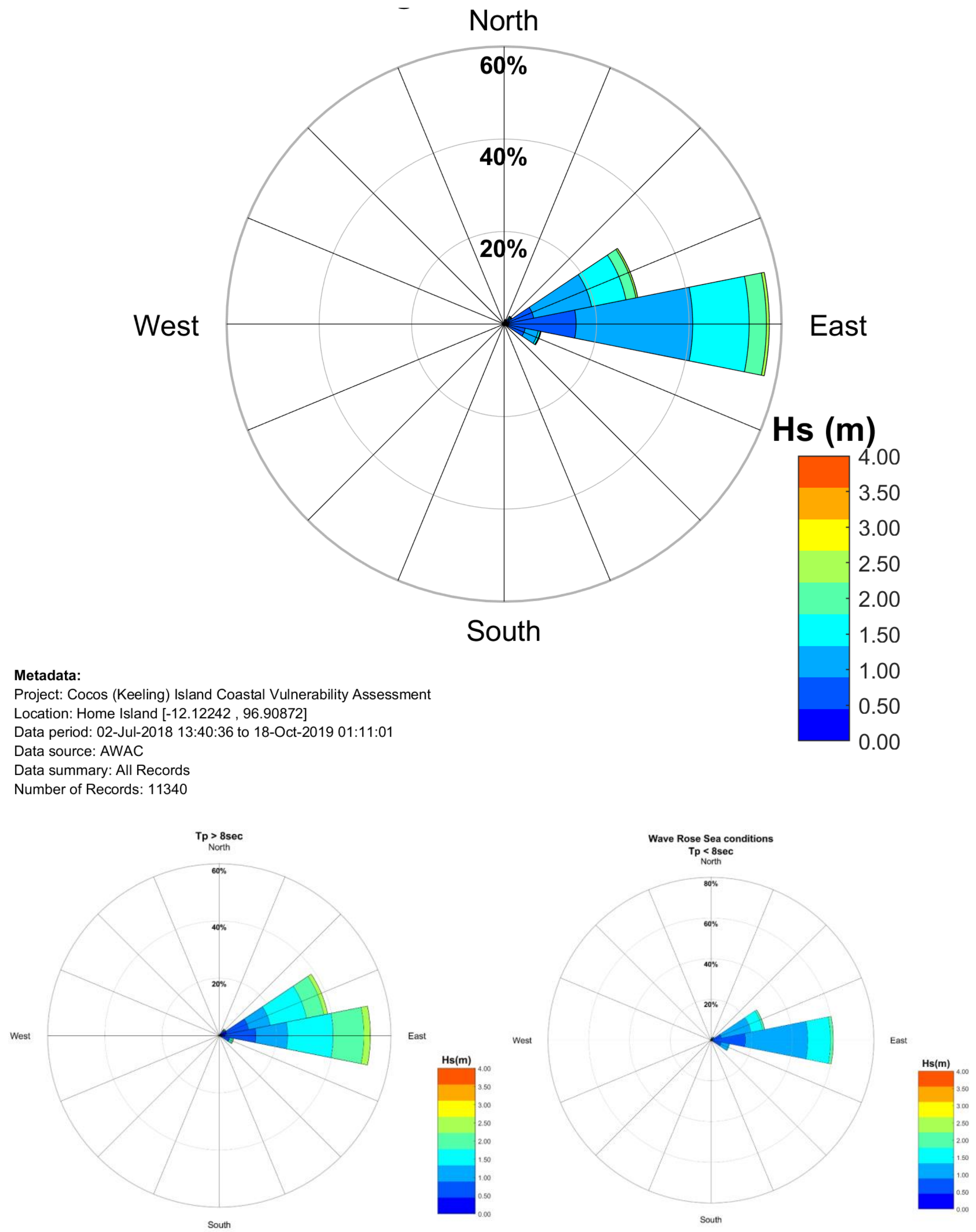


Figure 12: Total wave energy, swell and sea roses at CK02 for entire reporting period

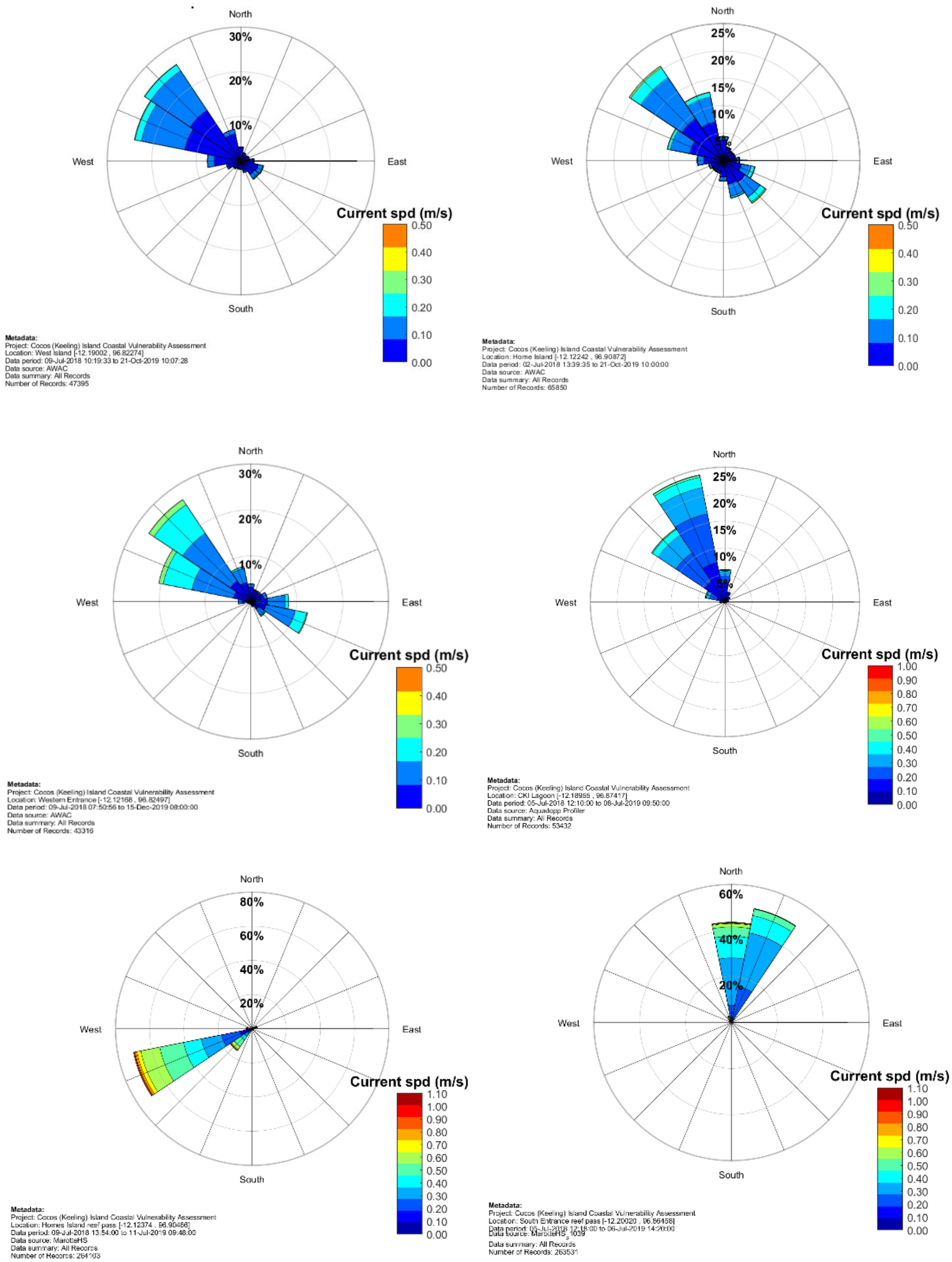


Figure 13: Rose plots showing current speed at six in situ sites.

3.1.4 Summary of metocean monitoring

A summary of the main findings of the metocean data collection campaign is as follows:

- Good quality metocean data has been recorded at the Cocos (Keeling) Islands during the monitoring period (early July to late December 2019). At CK01a, both raw and quality assured data ceased due to storm wave damage near the peak of the event on the 24 July 2018 at 8:20pm. Corrective actions implemented during the first service visit included the addition of extra moorings at this site as well as at CK02. At CK04 the shallow water depth at this location limited the ability of the specified instrument to collect current velocity data during lower water levels. A more suitable instrument was placed at this site during the first service visit. The monitoring period was extended at CK03 to capture the required data following a failure of the instrument's recorder during reporting period three.

- The data captured provides valuable insight into the coastal processes that operate at the Cocos (Keeling) Islands and when combined with the coastal survey data (see **Section 4**) is an invaluable tool to inform the CVA and subsequent coastal management at the Cocos (Keeling) Islands.

- The data collected is suitable for the purpose of model calibration and validation.

- **CK01a -** Wave measurements show a unidirectional long period swell wave climate with high energy. Current speeds were relatively high (up to 0.35 m/s – depth averaged) given the location and water depth. Surface speeds were faster than seabed speeds. While there was some influence from astronomical tides, currents measured at this location were mostly in an alongshore/offshore (west north-west) direction. A significant Indian Ocean swell event on 23 to 24 July 2018 was captured up until close to the peak of the event at this site. For more information on this event refer to RHDHV's 2018 Post-event report (RHDHV, 2018a).

- **CK02 -** Wave measurements show a combined sea and wind (i.e. short period) swell wave climate of moderate energy. This site is on the windward side of the Cocos (Keeling) Islands and exposed to the waves generated by the trade winds over local fetches to the east and south-east. Based on the observed east north-east directions refraction of the incoming waves has occurred and this is representative of the waves that would affect Home Island. The currents measured at this site were tidally affected and follow an alongshore/reef direction. There is a bias for higher speeds to the north-west which may be because of the trade winds. As described in **Section 3.1.1**, the monitoring instrument at CK02 was deployed at two locations (relocated during the third deployment in February 2019), however the data shows that there were minimal differences in the wave climate at these two locations.

- **CK03 -** Wave measurements were composed primarily of heavily refracted swell waves of moderate to low energy. A mildly bi-modal wave climate was observed with a lower energy and shorter period wind wave component observed coming from the east to south-east.

These wind waves are generated by the persistent trade winds blowing over the lagoon. Currents are tidally dominated. However, a strong ebb tide bias was observed (i.e. ebb tide current speed asymmetry). The cause of the asymmetry was be investigated further in subsequent tasks.

- **CK04** – Currents measured show lagoon-ward flow during the entire record with speeds correlated to offshore swell waves. While not the prime purpose of this monitoring site, the wave climate measured in the first deployment was composed of small energy wind waves (periods less than 3 seconds) generated within the lagoon. Waves in the swell range frequencies, or lower, were also recorded but at a very small height.
- Both **H3** and **H8** also recorded unidirectional lagoon-ward flow. At H3 the speed of the current appears to be influenced by both tide and offshore wave conditions and may also be influenced by the trade winds. H8 shows similar observations but shows less variability.
- Reef top measurements show the importance of the effect of the fringing reef in controlling both wave heights and water levels along the ocean exposed shoreline of CKI.

3.2 Coastal survey data

Beaches change in response to a range of environmental factors such as; wave, water level and seasonal conditions. Regular beach surveys enable these changes to be quantified. Prior to this study there was very little beach transect data available for the Cocos (Keeling) Islands. GHD (2017a) reported on some beach transect data but quality assured spatial data was not available.

During the metocean monitoring campaign, beach transects were captured at regular intervals (up to 50m) tangential to the shore and vegetation lines at selected areas. Complementary to the beach transects, drone surveys were completed during the service visits in key areas on Home Island and West Island. A trial drone survey was undertaken at the West Island settlement during the initial site visit. An error analysis for this trial survey was completed to determine the relative difference between the RTK-GPS transects and drone survey.

3.2.1 Beach transect data

Real-time Kinematic (RTK) positioning is a survey method using GPS. Beach transects were completed using RTK survey equipment during all service visits. Additional beach transects can also be extracted from the historical DEM and bathymetric data to provide past beach profile data at each of the selected locations from the field campaign.

During the July 2018 site visit a Navcom SF-3050 GNSS receiver with a live satellite GNSS correction service (StarFire) was used to determine ground levels. Due to the remoteness of the Cocos (Keeling) Islands and the lack of a 3G/4G mobile phone network the more conventional and superior cellular GNSS correction services are not available. The StarFire GNSS correction service is significantly slower compared to cellular correction signals and is only capable of reducing vertical GNSS error down to ±10-15cm.

To improve the RTK survey accuracy and survey efficiency new GNSS equipment was used in all subsequent service visits. A Trimble R8 Model 2 base station and rover system was sourced to allow the installation of an accurate GNSS base station from existing Landgate survey marks on the Cocos (Keeling) Islands. This survey system does not require a live GNSS correction service and can achieve accuracies of up to ±2-3cm (vertical and horizontal). For the October 2018 survey the RTK-GPS was setup to record raw ellipsoidal heights without a datum conversion. The data was converted into UTM 47S and AHD in post-processing. The AHD datum is calculated using the AUSGeoid2020 online tool and a 7-parameter similarity method (ICSM.gov.au).

3.2.2 Drone survey data

Two sets of drone surveys were conducted. An initial trial drone survey was conducted in July 2018 using a DJI Mavic Pro drone. In October 2018, a second set of surveys was carried out across four key locations using a DJI Phantom 4 Pro, which has a higher resolution camera and more powerful rotors. Prior to carrying out drone surveys, a detailed risk assessment as prepared in order to receive authorisation to fly the sub-2kg drone in an 'excluded category' survey flight at the Cocos (Keeling) Islands.

For each survey, the flight path followed a predefined, shore-perpendicular grid and a final perimeter around the entire survey area for optimal 3D data capture. The drone height during image capture was up to 80m resulting in an image resolution of ~2cm/pixel. The outputs from the processing of drone data included a 3D point cloud prepared using Autodesk Recap Photo and a digital surface model (DSM) generated using WebODM georeferencing software. Examples of these outputs are presented in **Figure 14** and **Figure 15**, respectively.

To accurately georeference the captured drone imagery several surveyed ground control points (GCPs) within each of the surveyed areas were established. Sensitivity test suggested that a minimum of ten GCPs strategically placed throughout the survey area were required, and these were installed for each survey area using A3 sized 'cross-hair' targets. The accurate location and elevation of each GCP was determined using the RTK-GPS system.

Royal HaskoningDHV

Figure 14: 3D Point cloud of the West Island settlement derived from the July 2018 drone survey using Autodesk Recap Photo.

Royal HaskoningDHV

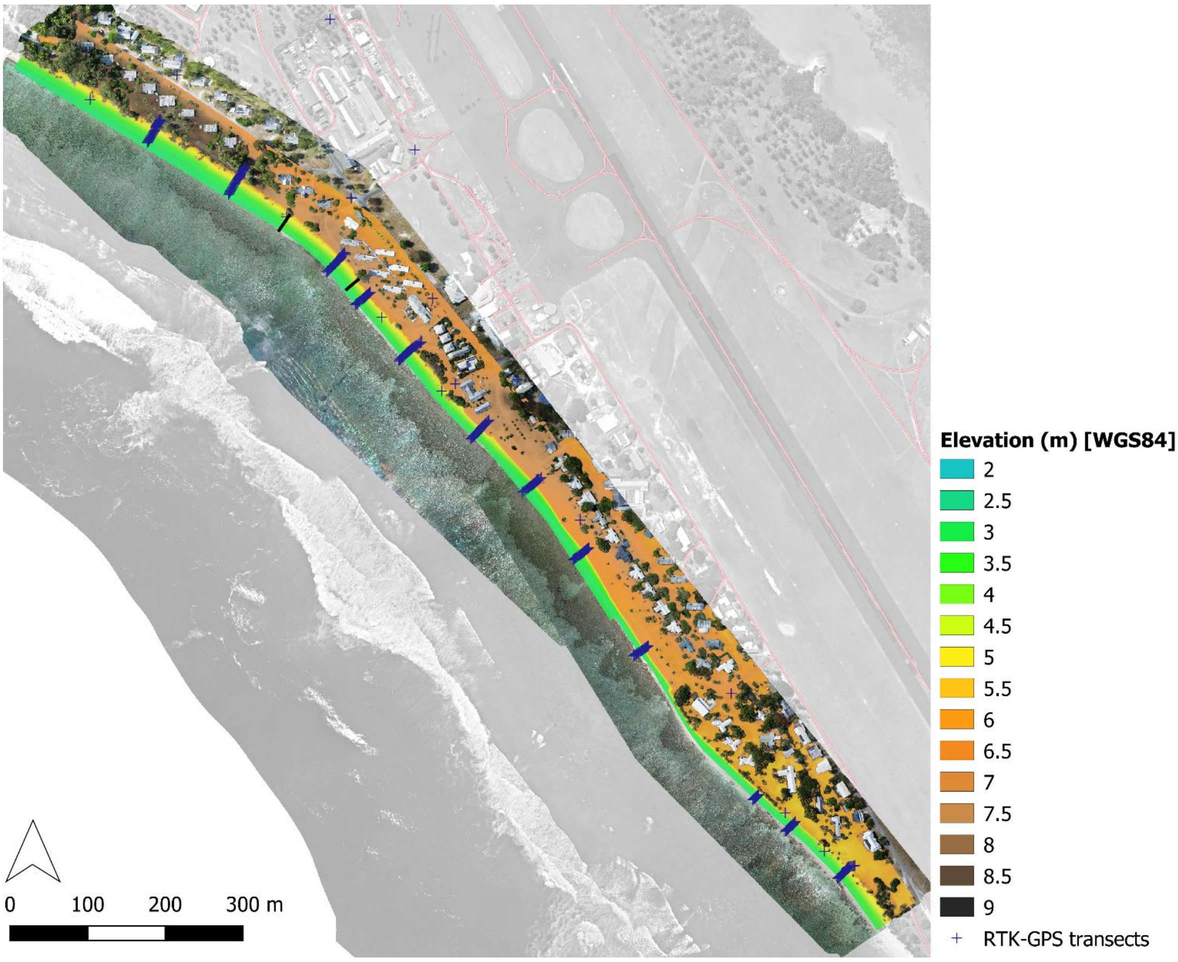


Figure 15: Example of a drone survey derived DSM and aerial imagery for the West Island settlement in October 2018. The RTK-GPS beach transect locations are also shown.

3.2.3 Comparison of beach transect and drone survey data

To determine the applicability and accuracy of the drone survey approach a selection of beach transects extracted from the drone-derived DSM were compared to the concurrent RTK-GPS beach transects for the July 2018 and October 2018 West Island settlement survey. This also allowed the effects of the upgraded drone and RTK-GPS equipment to be investigated.

The comparison shows that the differences in the measured elevations between the two survey techniques are very small. The most noticeable differences were in areas of vegetation (RTK-GPS measures ground elevations while the drone measures surface elevations), unconsolidated ground (e.g. rubble with large voids) and at the water line where wave run-up occurs. Furthermore, elevation differences due to RTK-GPS error were evident predominantly in the July 2018 surveys where the Navcom GNSS (StarFire correction) receiver was used which has a limit of ±15cm accuracy. During the October 2018 work elevation differences between the two survey techniques in most areas were minimal (around ±3cm). The improved accuracy was largely due to the improved RTK system (Trimble R8 base and rover).

A statistical comparison is shown in **Figure 16** and **Table 6**. The absolute differences between drone and RTK-GPS derived elevations are considerably smaller for the October 2018 survey. The mean absolute difference in October 2018 was 0.11m (median is 0.04m) for all survey samples (beach transects and GCPs) and 0.03m (median is 0.02m) for the GCPs only. It is noted that the GCPs were strategically placed in areas clear of vegetation while some of the beach transect samples are taken under foliage and palm trees. As discussed above, the latter resulted in considerable elevation differences between the two survey techniques as the RTK-GPS measures ground elevations and the drone measures surface elevation (i.e. including vegetation). These differences are represented in the stated 0.11m mean absolute difference for this survey comparison, hence a more accurate description of the survey error is the median (i.e. 0.04m) or the mean absolute difference of the GCP samples (i.e. 0.03m).

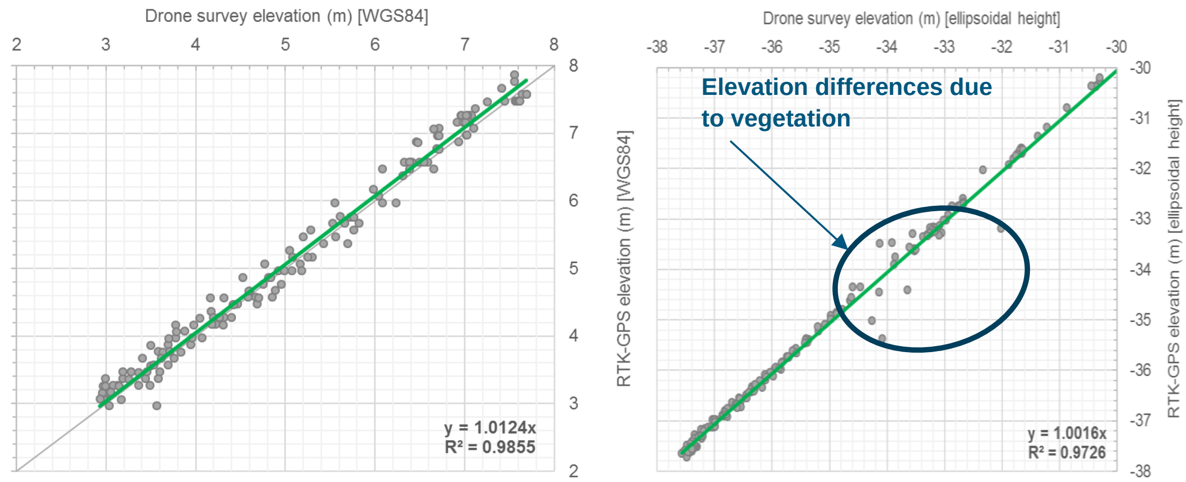


Figure 16: Comparison of drone and RTK-GPS elevations for the Left: July 2018 and Right: October 2018m surveys at the West Island settlement.

Table 6: Statistical analysis results for drone and RTK-GPS comparison of measured elevations.

Parameter	July 2018		October 2018	
	Transects (152 samples)	GCPs only (13 samples)	Transects (192 samples)	GCPs only (10 samples)
Mean (m)	0.16	0.07	0.11	0.03
Median (m)	0.13	0.07	0.04	0.02
Standard Deviation (m)	0.18	0.06	0.36	0.02
Root-Mean-Square Error (m)	0.16	0.09	0.34	0.04
% of samples ≤0.15m difference	55		88	
% of samples ≤0.30m difference	90		95	

3.2.4 Verification of 2011 LiDAR DEM

In 2011, Geoscience Australia (GA) commissioned a LiDAR survey of the Cocos (Keeling) Islands and Christmas Island. GA provided this data to RHDHV which included both a digital surface model (DSM) and a digital elevation model (DEM) that have been quality controlled using 462 accurate survey points on the Cocos (Keeling) Islands. The contractor's report (AAM, 2011) states a horizontal accuracy of 0.3m and a vertical accuracy of 0.15m which is believed to be suitable for the CVA. Additionally, an extensive LiDAR survey was undertaken by the Australian Department of Defence (DoD) in 2012 for all islands of CKI. RHDHV has combined the two datasets, i.e. 2011 GA topography and 2012 DoD bathymetry, to produce a complete DEM of the Cocos (Keeling) Islands atoll, as shown in **Figure 17**. This data formed the basis from which the numerical modelling components of the CVA were undertaken.

To further validate this elevation model, a comparison of the 2011 LiDAR topography and the measured RTK-GPS ground control points from the October 2018 survey as well as Landgate Standard Survey Marks (SSM) on West Island and Home Island was undertaken. A direct comparison of the elevations of these data sets is presented in **Table 7** and **Figure 18**. It is evident that for all terrestrial validation points (i.e. points on 'fixed' land) the 2011 LiDAR data compares well with the RTK-GPS and Landgate SSM elevations with average differences of 0.12m and 0.17m, respectively. This aligns with the stated accuracy of the 2011 LiDAR data in AAM, 2011. Larger differences are evident in areas where changes in elevations are expected in the 7-year period between the 2011 and 2018 data sets including natural changes in coastal areas and changes due to development (e.g. Rumah Baru and Kite Beach).

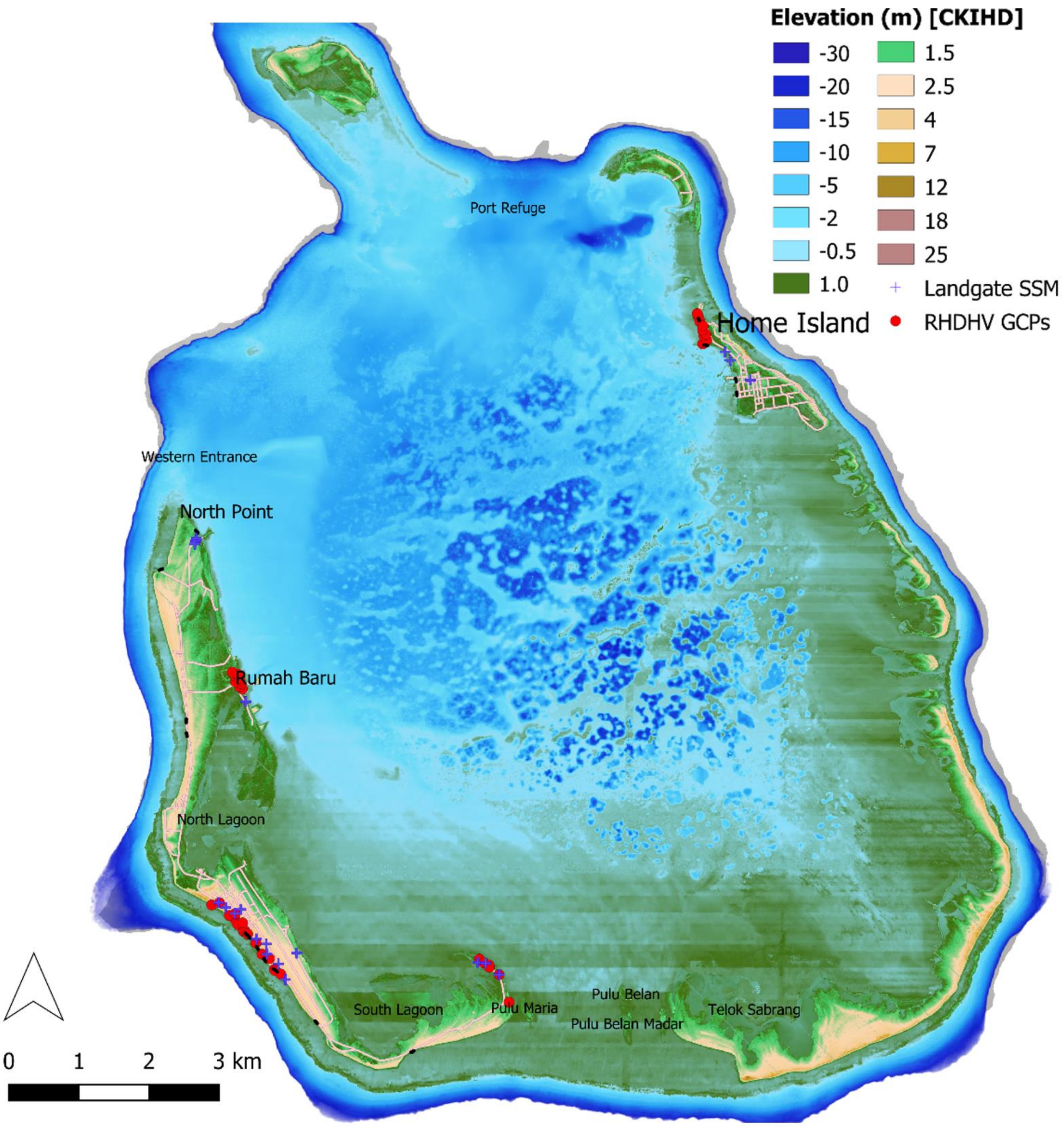


Figure 17: Digital elevation model of Cocos (Keeling) Islands derived from the 2011 LiDAR data (topography) and 2012 LiDAR bathymetry. The red and blue markers show the locations of the validation points.

Table 7: Statistical analysis results for elevations difference comparing the 2011 LiDAR DEM with RTK-GPS and Landgate Standard Survey Marks (SSM).

Parameter	Comparison with RTK-GPS		Comparison with Landgate SSM
	All samples	Terrestrial only	
Mean (m)	0.38	0.12	0.17
Median (m)	0.19	0.09	0.14
Standard Deviation (m)	0.56	0.14	0.22

Root-Mean-Square Error (m)	0.55	0.18	0.24
% of samples ≤0.15m difference	44	74	52
% of samples ≤0.30m difference	63	95	95

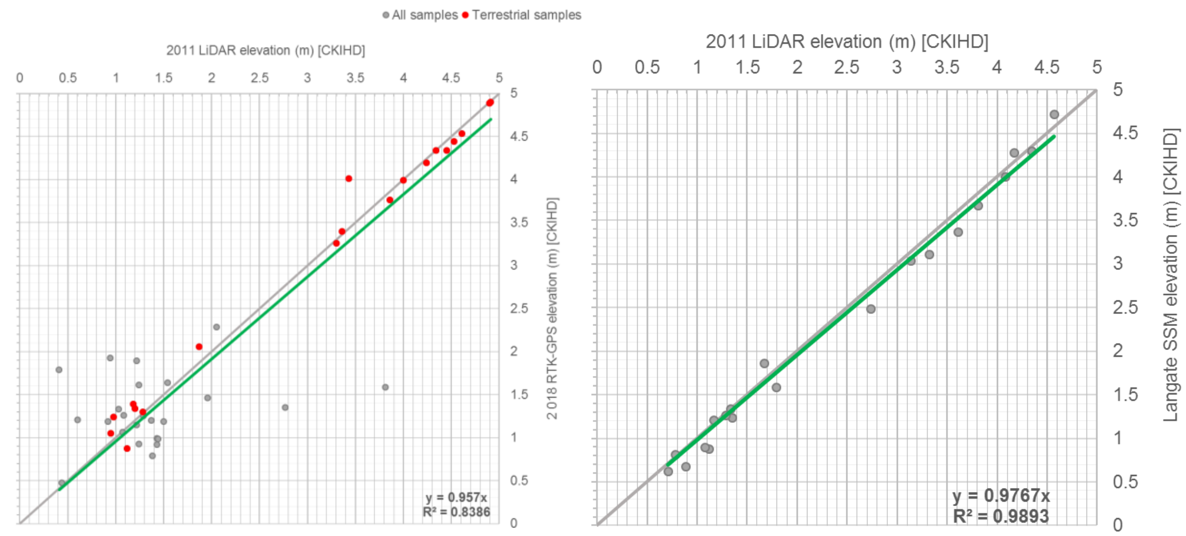


Figure 18: Comparison of 2011 LiDAR DEM with Left: RTK-GPS elevations from October 2018 survey, and Right: Landgate Standard Survey Marks (SSM) elevations on West Island and Home Island.

3.3 Coastal asset database

An inventory of coastal assets, both natural and man-made, on Home Island and West Island has been created. The assets on the Cocos (Keeling) Islands have been identified through:

- Site survey using GPS during the site visits conducted on-island
- Shire of Cocos (Keeling) Islands cadastre
- Aerial photography
- OpenStreetMap data (www.openstreetmap.org)

The coastal asset inventory has been developed in the form of a GIS database. Relevant asset attributes; asset group, size and extents, site photo, condition (where available), private/public usage, owner (where available) and zoning (where available) has been stored in the database. An overview of the key assets on West Island and Home Island is provided in

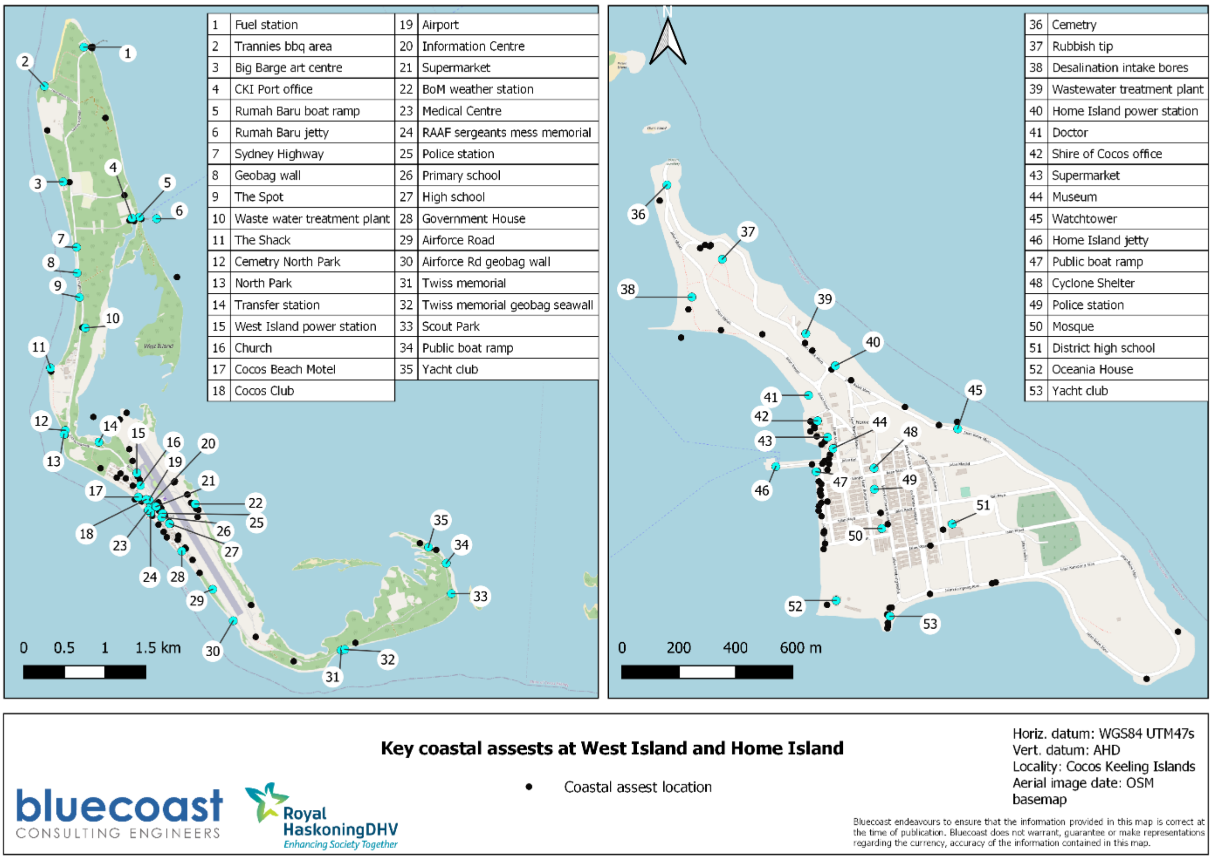


Figure 19. Further description of the coastal asset database and grouping of assets is provided in **Section 7.3** and **Appendix E**.

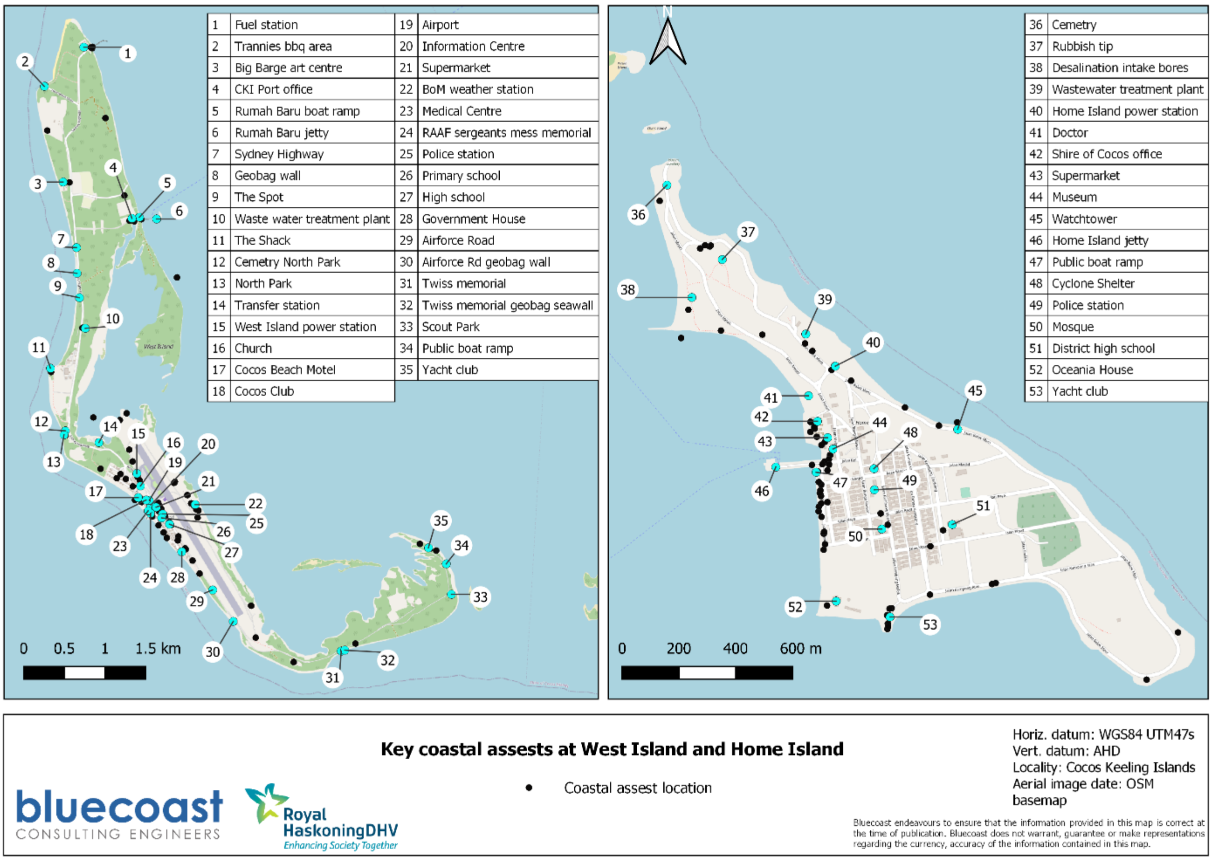


Figure 19: Overview of key assets on West Island and Home Island.

4 Numerical modelling

A series of numerical models were established and calibrated using the metocean data collected at the Cocos (Keeling) Islands (Task 5 of the CVA scope of works), see monitoring sites in **Figure 7.** A detailed description of the model setup and calibration for the numerical modelling systems are presented in **Appendix A**.

4.1 Model description

The numerical models that have been used are:

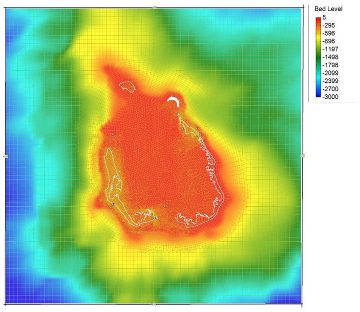
- Delft3D Flexible Mesh (FM) suite for hydrodynamic (D-Flow) and spectral wave (D-Wave) modelling. A coupled D-Wave/ D-Flow model was developed to transform offshore waves to the nearshore and simulate atoll wide hydrodynamics and sediment transport.
- Tropical cyclone spectral wave model (D-Wave) to simulate wind wave growth in the eastern Indian Ocean and transformation to CKI's nearshore using the Holland (2010) parametric wind field model.
- A high-resolution, non-linear nearshore wave model using Xbeach (Roelvink et al. 2009) was required to estimate inshore wave heights and wave setup at the fringing reef coastline. This model was also used to simulate storm erosion at a series of coastal profiles. Xbeach has been widely used for similar applications at fringing coral reef environments around the world.
- SBEACH profile model to simulate storm erosion at the lagoon-facing beaches. SBEACH has been used extensively for this purpose in Western Australia and has been validated on several sandy coastlines (Rogers et al, 2005).

4.2 Model development

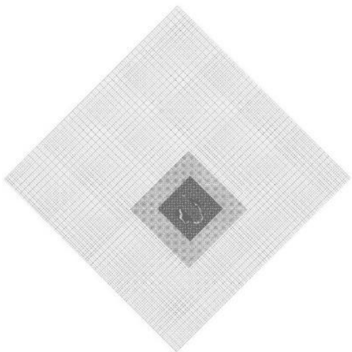
An overview of the adopted numerical modelling tools, extents and resolution is provided in **Table 8**.

A range of bathymetry and topography datasets were available for the model development. The 2011 LiDAR and RTK survey data were adopted for land areas, while the 2012 marine LiDAR data was used for nearshore bathymetry in areas down to 25m water depth. In deeper areas, bathymetric data was derived from the General Bathymetric Chart of the Oceans (GEBCO, 2014). All elevation data has been corrected to Australian Height Datum (AHD).

Table 8: Overview of modelling tools and extents used in the CVA.

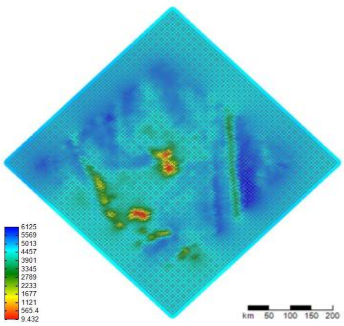
<table>
<tr><th>Model</th><th>Extent</th><th>Grid resolution</th><th>Objective</th></tr>
<tr><td>Deflt3D FM</td><td>
Atoll model</td><td>Offshore 1km

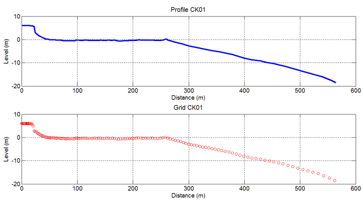
Nearshore 10m

Land 5m</td><td>Tidal, wind and wave driven flows, overland inundation as well as sediment transport patterns</td></tr>
<tr><td rowspan="2">Delft3D Wave (SWAN)</td><td>
Regional model</td><td>Regional domain 1km

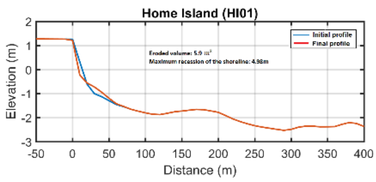
Transitional domain 300m

Nearshore domain 100m

West Island and Home Island domain 40m</td><td>Transformation of offshore waves to nearshore</td></tr>
<tr><td>
Ocean model</td><td>Offshore 7km

Nearshore 300m</td><td>Simulate wind wave growth from tropical cyclones and transform to nearshore</td></tr>
<tr><td>Xbeach</td><td>
Nearshore profile model</td><td>Offshore 10m

Reef crest 5m

Shoreline 0.2m</td><td>Simulation of non-linear reef-top waves and water levels as well as storm erosion</td></tr>
<tr><td>SBEACH</td><td></td><td>Nearshore 10m</td><td>Simulation of storm erosion at lagoon facing beaches</td></tr>
</table>

4.3 Model validation

Where possible the numerical models used herein where calibrated and validated to measured data at multiple locations at the Cocos (Keeling) Islands. A summary of the validation results is provided in the following sections while further detail is provided in **Appendix A** (wave and hydrodynamic models) and **Appendix D** (morphology models).

4.3.1 Delft3D FM/ Wave

The validation of the atoll wide models showed that a reasonable representation of the key wave and hydrodynamic processes observed at the Cocos (Keeling) Islands and are relevant for the CVA was achieved for all modelling tools. A series of timeseries comparisons of measured and modelled water level, currents and wave conditions are presented in Figure 20 to Figure 23.

At the outer atoll monitoring sites (CK01a and CK02) wave driven currents are the dominant component and are temporally highly variable due the complex nearshore wave processes. The model does not fully resolve the complex nearshore wave driven hydrodynamics that occur at the reef edge (e.g. drainage of trapped reef top water levels). In addition, large-scale ocean currents have not been included in this assessment. Nevertheless, the order of magnitude of current speeds and the mean current directions agree well with the measured data at all sites which was deemed most important to represent the flow circulation around the atoll. Hence, for the application of the coupled spectral wave and hydrodynamic model in this study the discrepancies are considered acceptable and reef top wave processes are further investigated using the nearshore wave model, Xbeach.

The comparison of the measured and modelled wave conditions shows that the model is capable of accurately reproducing the observations during both, low and high energetic wave conditions. Some deviations are evident in the modelled wave periods which is inherent to the offshore boundary conditions derived from the CAWCR wave hindcast and the mixed swell and sea spectrum, however, for the purpose of this study this is considered acceptable.

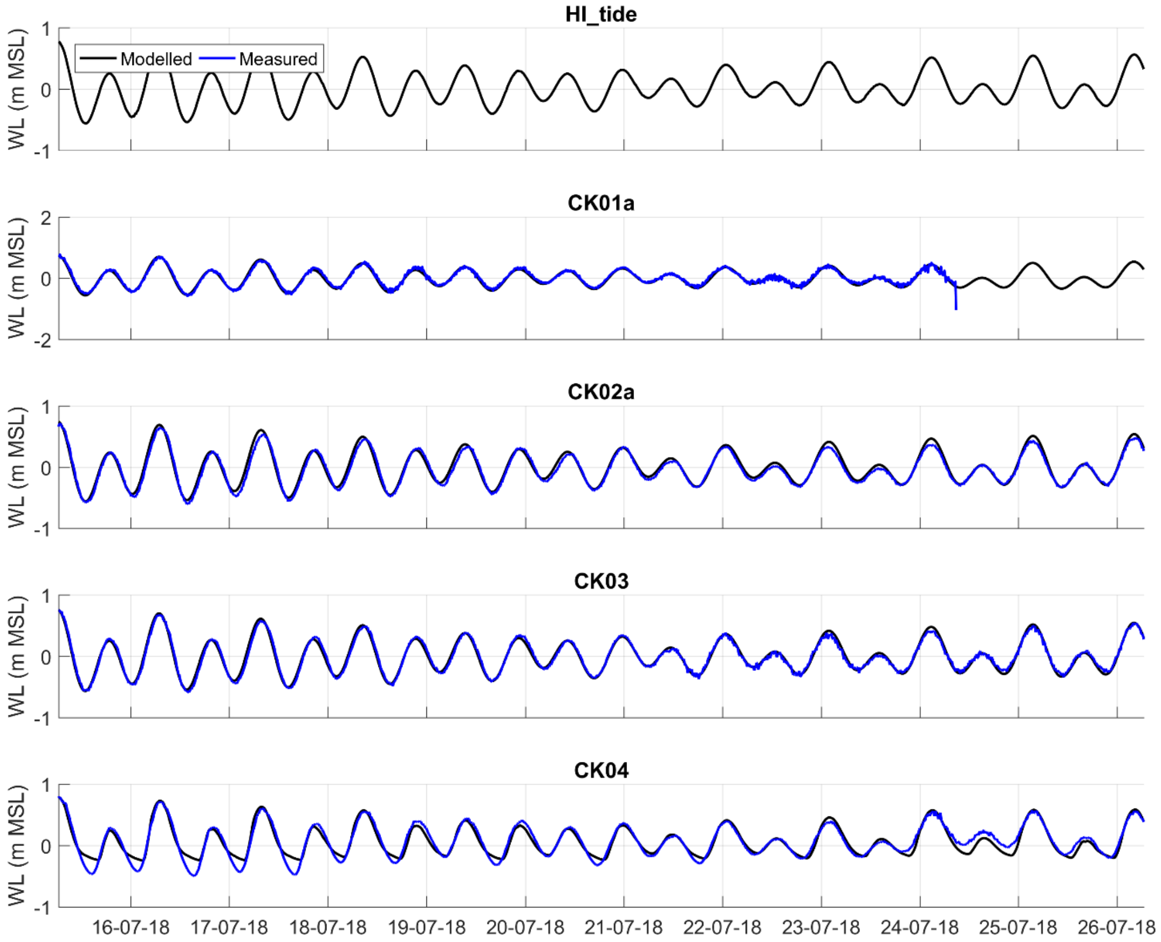


Figure 20: Comparison of measured and modelled water levels at the two offshore sites (CK01 and CK02) as well as lagoon sites (CK03 and CK04) during a 10-day period in July 2018.

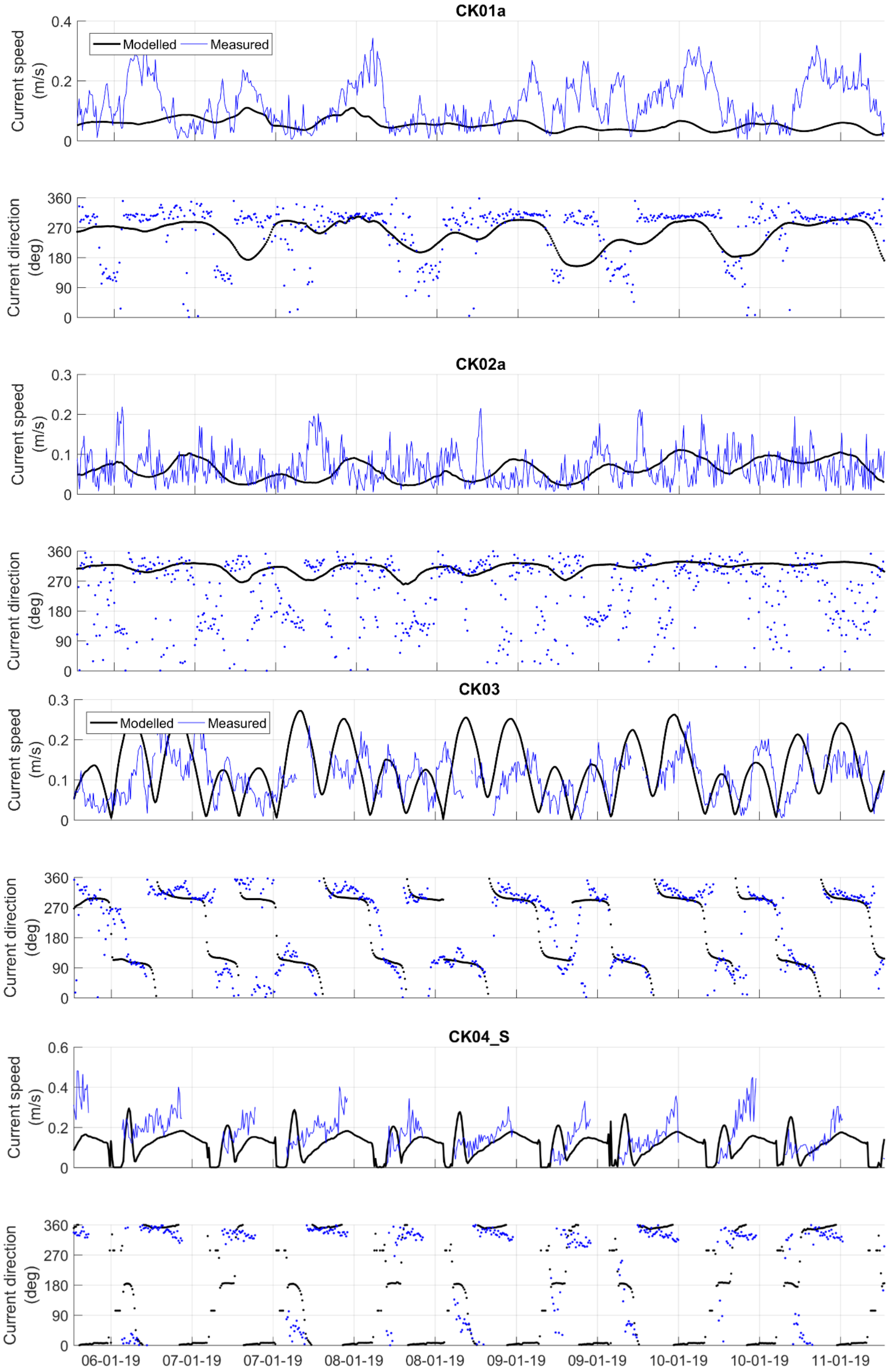


Figure 21: Comparison of measured and modelled currents at the two offshore sites (CK01 and CK02) as well as lagoon sites (CK03 and CK04) during a one-week period in January 2019.

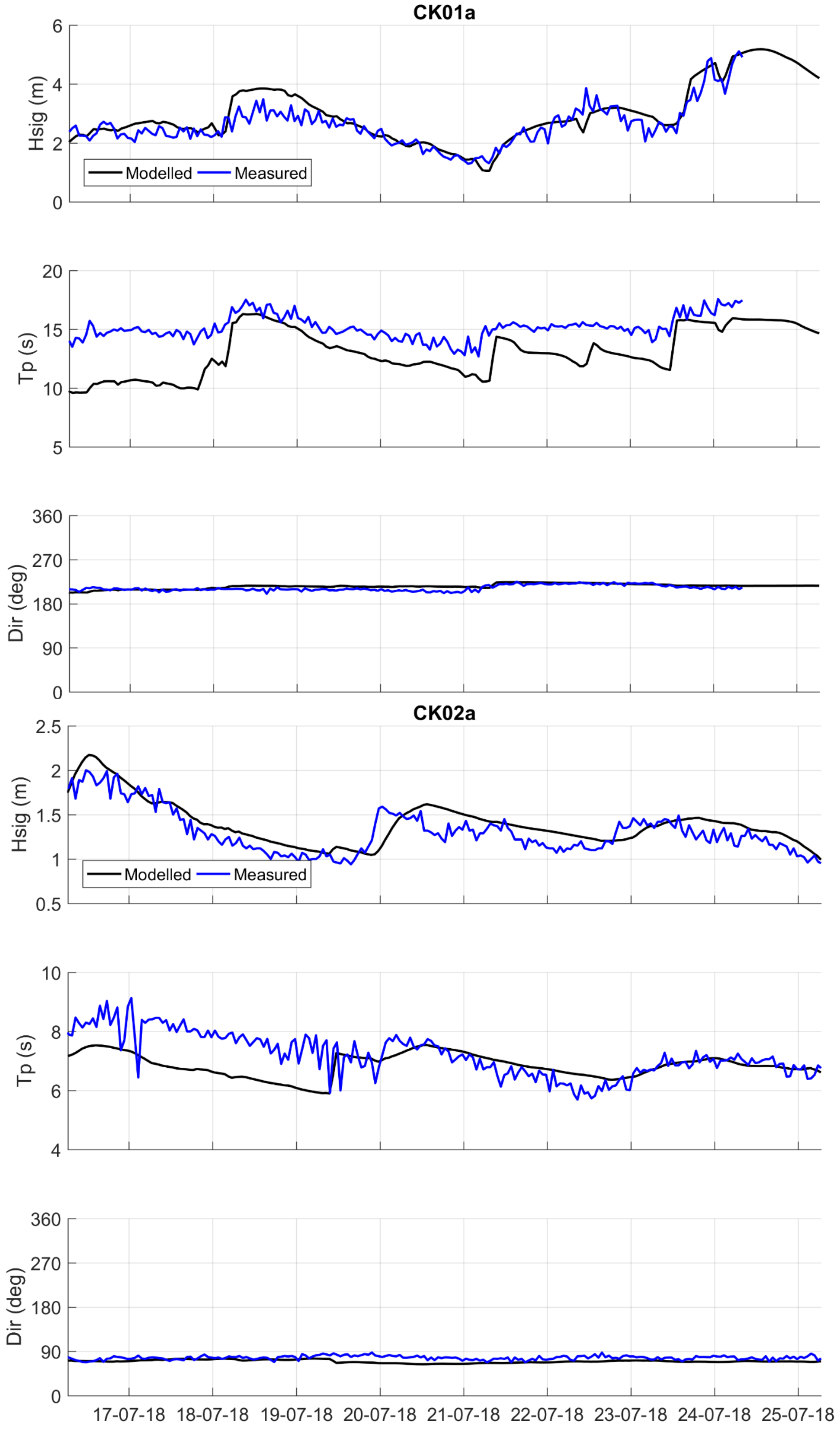


Figure 22: Timeseries comparison of measured and modelled wave conditions at the two offshore sites (CK01a and CK02a) during the July 2018 swell event.

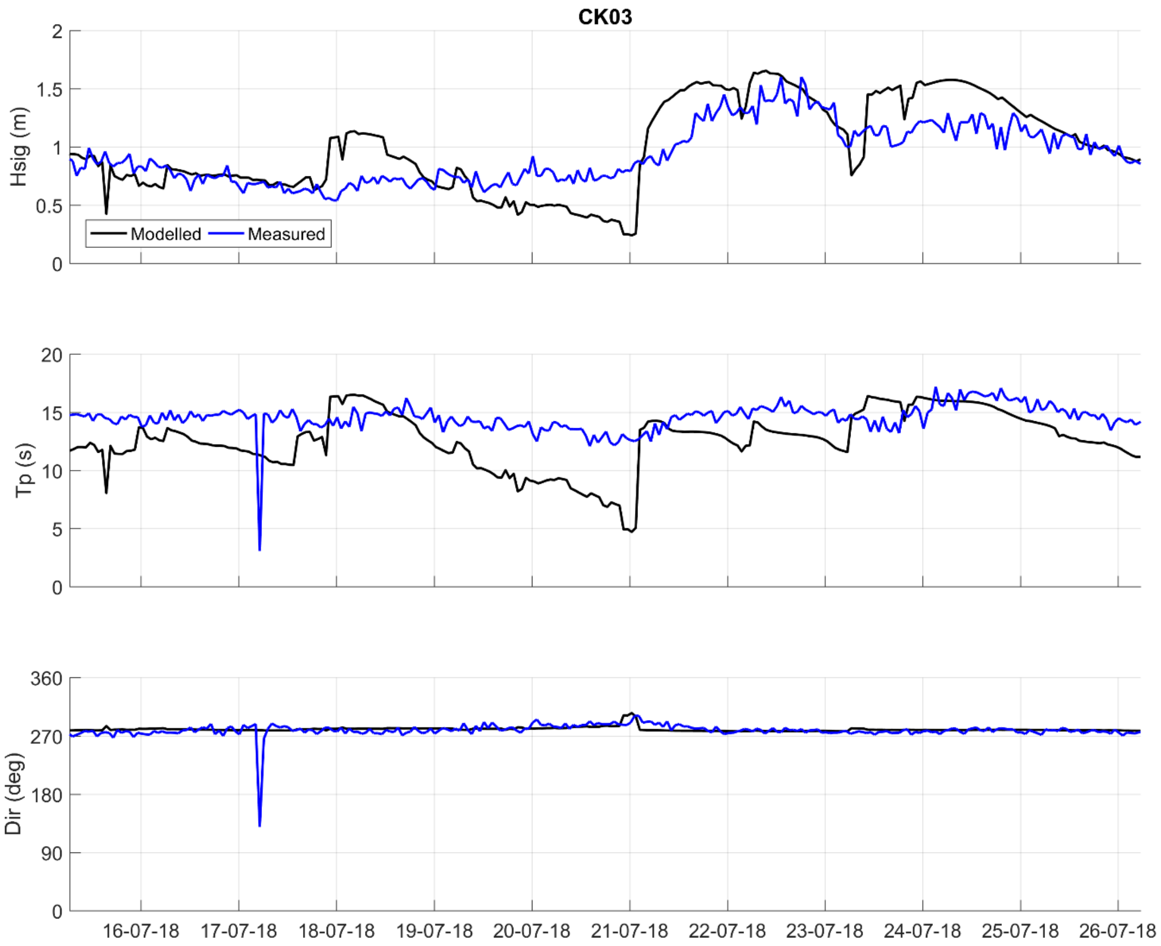


Figure 23: Timeseries comparison of measured and modelled wave conditions at the Western Entrance site (CK03) during the July 2018 swell event.

4.3.2 Tropical cyclone model

The Holland (2010) wind field and estimated peak wind speed and direction were validated using data recorded wind data during the passage of TC Savannah in March 2018. The parametric wind field and a comparison of the modelled and measured wind speed are shown in Figure 24. A reasonable agreement was achieved between and the measured and modelled wind speeds and directions. As a result, the tropical wind model is considered sufficiently accurate of peak cyclonic conditions.

A comparison of the modelled and measured wave heights during the passage of TC Savannah is shown in Figure 25. The comparison suggests that the wave conditions simulated using the parametric wind fields (Holland, 2010) to force the Delft3D Wave model for this event are in close agreement with the measured data. While some differences in the shape of the modelled wave heights are evident, the peak wave heights and directions are well reproduced. It is noted that the measured wave conditions present a mixed wave climate of the tropical cyclone generated waves as well as underlying sea and well waves. The latter are not included in the tropical cyclone simulations as only the extreme waves are of interest in the assessment and modelled therein.

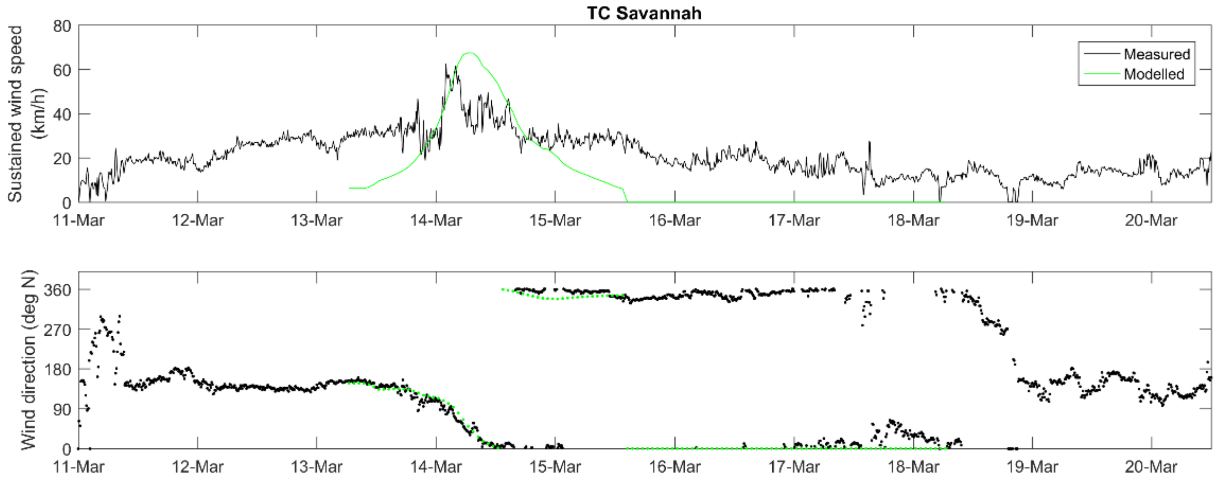


Figure 24: Comparison of measured wind data at CKI and estimated wind speeds using the Holland (2010) model for TC Savannah.

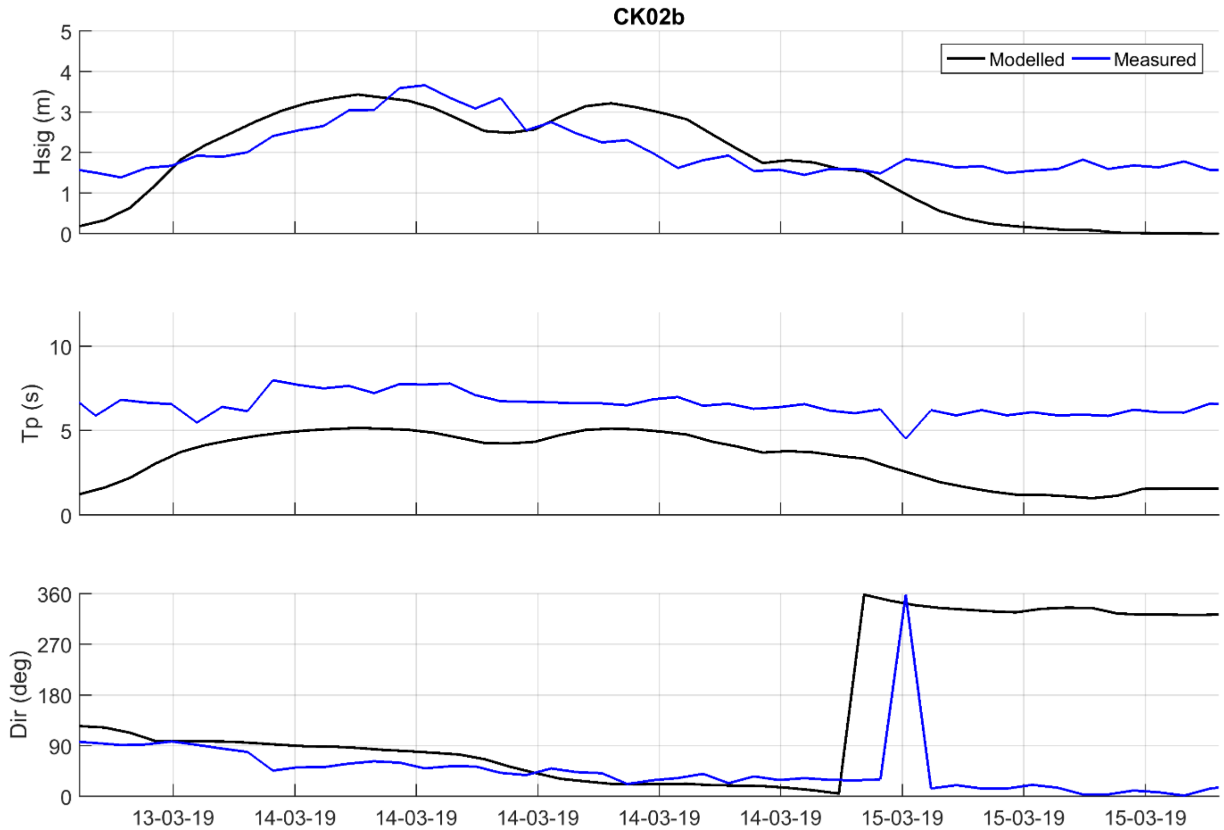


Figure 25: Timeseries comparison of measured and modelled (using the Holland, 2010 wind field) wave conditions at the Home Island monitoring site (CK02b) during the passage of TC Savannah.

4.3.3 Xbeach

The calibration of the Xbeach model to observed hydrodynamics and wave conditions was undertaken using the water level and wave data collected at the reef top monitoring sites at CK01. A timeseries comparison of the modelled and observed wave and water levels during the July 2018 swell event is presented in Figure 26. Good agreement with the observed wave conditions (i.e. +/-10cm) was demonstrated. Modelled peak significant wave heights were slightly overestimated and hence, peak water levels were slightly underestimated (less wave breaking induced setup). However, the 1D profile model is considered adequate for the purpose of this study with consideration of its simplification of the complex reef wave processes (cross-shore and alongshore). In addition, a comparison of the measured and modelled 1% wave setup during the calibration event is provided in Figure 27. It is evident that the model is capable in reproducing the extreme wave setup levels.

For the morphological response, a coastal profile located at one of the worst erosion spots observed along the West Island settlement and nearby the CK01 wave and water level measurements was selected. At this site, survey data for the beach and dune areas was available that describes pre-event and post-event conditions for the July 2018 swell event (RHDHV, 2018a).

Predicted storm erosion with the Xbeach profile model was acceptable when compared against RTK profile measurements undertaken during the CVA monitoring campaign. Figure 28 shows that the erosion of the upper part of the profile (above 2.5m AHD) is well represented in the model. Lower down on the profile (between 0.5m and 2.5m AHD) Xbeach tends to overpredict the observed storm erosion as well as the storm deposition on the reef flats (below +0.5m and seaward of chainages <520m). The differences were assumed to be explained by a combination of factors, including:

- Coral rubble and other larger grained material that is more resistant to erosion is not represented in the model but is likely to exist.
- Beach recovery of the lower profile following the July storm event prior to post-event survey.
- The model does not account for alongshore sand transport.

Given that erosion of the upper beach profile (dune) was well represented by the model, the model validation was deemed acceptable for the purpose of this investigation (i.e., determine the S1 storm erosion allowance).

No erosion impact was observed at the RTK transect locations at the ocean-facing coast on Home Island during the monitoring campaign. As the model was to be calibrated to predict storm erosion, the Home Island RTK data was not suitable. This may have been due to post-storm recovery or due to a stable coastal profile at the measurement locations during the July 2018 swell event and the passage of TC Savannah in March 2019. Given the suitability of the available data at West Island for storm-erosion calibration, the model parameters were considered appropriate and applied for both West and Home Islands.

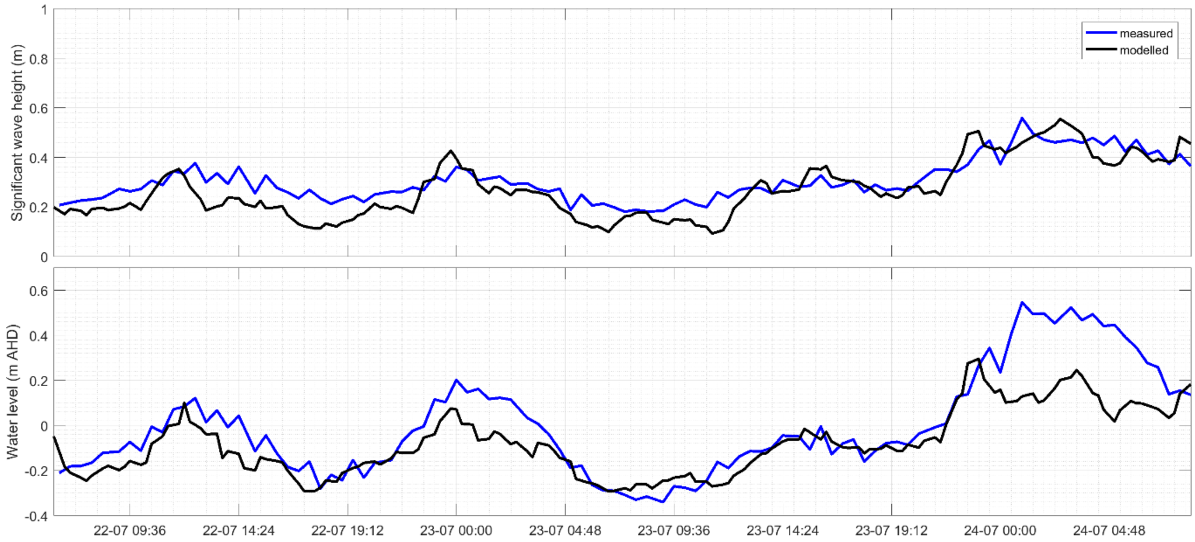


Figure 26: Comparison between measured significant wave height and nearshore (mean) water level and Xbeach model output during the July 2018 swell event at the West Island Settlement (CK01c) site.

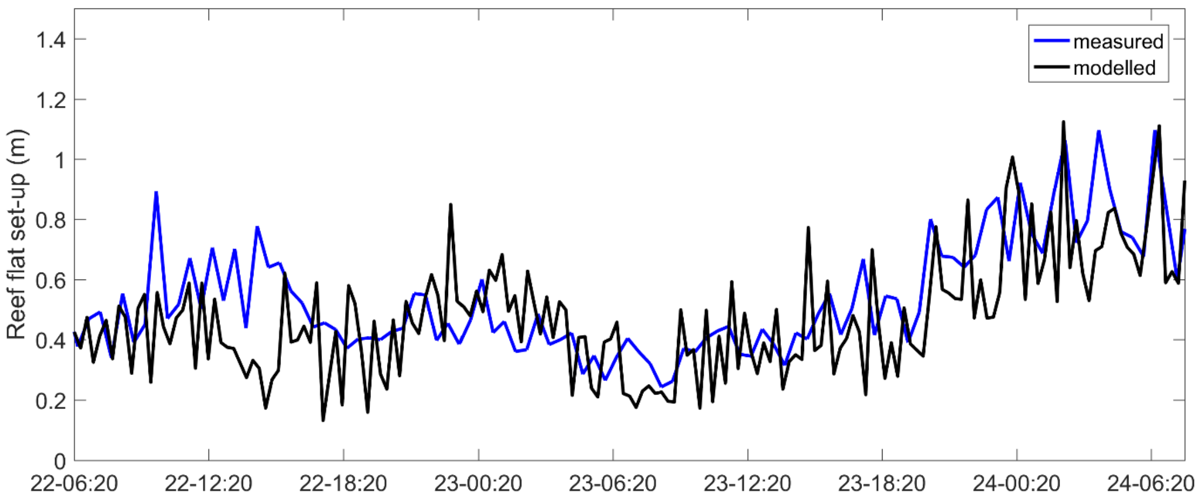


Figure 27: Comparison between measured and modelled reef top wave setup during the July 2018 swell event at the West Island Settlement (CK01c) site.

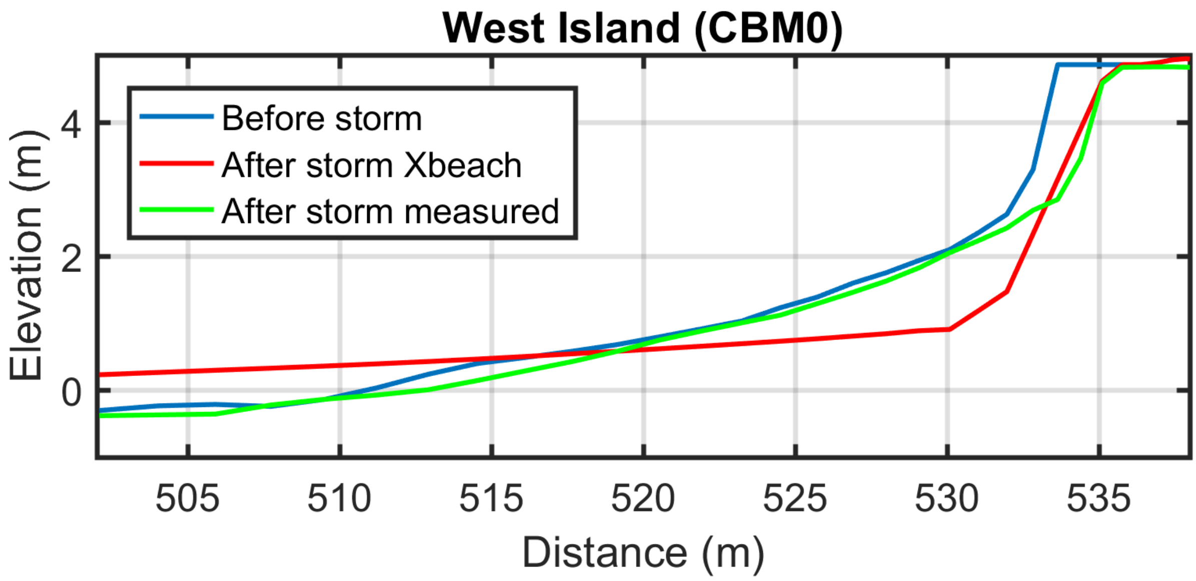


Figure 28: Comparison between measured coastal profile and the output of the XBeach model in front of the Cocos Beach Motel (transect CBM0).

4.3.4 SBEACH

No validation data of storm erosion at the lagoon-facing beaches was available for calibration of the SBEACH model. Model parameters were selected based on experience in using this model at similar environments elsewhere.

4.4 Modelling limitations

There are some key limitations that require consideration for interpretation of results presented, these include:

- The 2012 marine LiDAR bathymetry data contains errors that required smoothing of the data, this was particularly important for the shallow southern lagoon areas where flows are highly variable due to small changes in bathymetry. Model calibration to measured current speeds and directions proved difficult in this area. However, the net flows were found to be accurately represented by the hydrodynamic model.

- Morphological changes along the Cocos (Keeling) Islands coast have occurred between the LiDAR data capture dates in 2011 and 2012 to the present-day bathymetry and topography which control the wave and hydrodynamic processes measured during the CVA monitoring campaign. These differences are reflected in the numerical modelling simulations.

- Wave-driven currents are the dominant driver of nearshore currents and sediment transport at the ocean facing coastline and are temporally highly variable due the complex wave processes at the fringing coral reef. The coupled spectral wave and hydrodynamic model (Delft3D FM/Wave) does not fully resolve the complex nearshore wave-driven hydrodynamics that occur at the reef edge (e.g. drainage of trapped reef top water levels). The inherent limitations of the modelling software made it difficult to calibrate the model to the observed currents at the outer atoll locations, shown in Section 4.3.1. Tidal currents and overall current circulation were accurately simulated by the model and wave-driven hydrodynamics were further assessed for several coastal profiles at the Cocos (Keeling) Islands using the Xbeach model. To overcome this limitation, an atoll-wide, computational expensive, non-linear wave modelling software (e.g., 2D Xbeach) would be required which is outside of the scope of this assessment.

The above limitations of the hydrodynamic modelling were considered in the application of this model for the CVA. Importantly, where uncertainty in the model performance was identified, the adopted allowances for the coastal inundation (S4) and erosion hazard (S3) assessment were determined using alternative investigations, including:

- Extreme wave-driven water levels at the ocean-facing shorelines and associated storm erosion were determined using the Xbeach model to overcome limitations of the Delft3D FM/Wave model.
- Extreme peak steady water levels were determined from measured sea level data at the Home Island tide gauge and do not rely on modelling.

Further limitations of the numerical modelling investigations are discussed, where relevant, in **Appendix A and Appendix D**.

4.5 General modelling results

Waves and currents during ambient and high-energy metocean conditions were simulated to provide an overview of the spatial distribution of the hydrodynamics and wave processes around the southern atoll and within the central lagoon. A selection of simulation results is presented in the following Sections.

4.5.1 Ambient conditions

Maps of current speeds and direction during peak ebb and peak flood flows during a period with low-energy wave conditions on 5th January 2019 are provided in **Figure 29** and **Figure 30** (zoomed in). A flow discharge timeseries for the main lagoon entrances is shown in **Figure 31.**

The results show that Western Entrance is flood dominated while Port Refuge (between Direction Island and Horsburgh Island) is ebb dominated, i.e. there is a bias of tidal flow entering the lagoon through Western Entrance and existing through Port Refuge. The flow at the shallow entrances at the southern end of the central lagoon is predominantly unidirectional flowing into the lagoon.

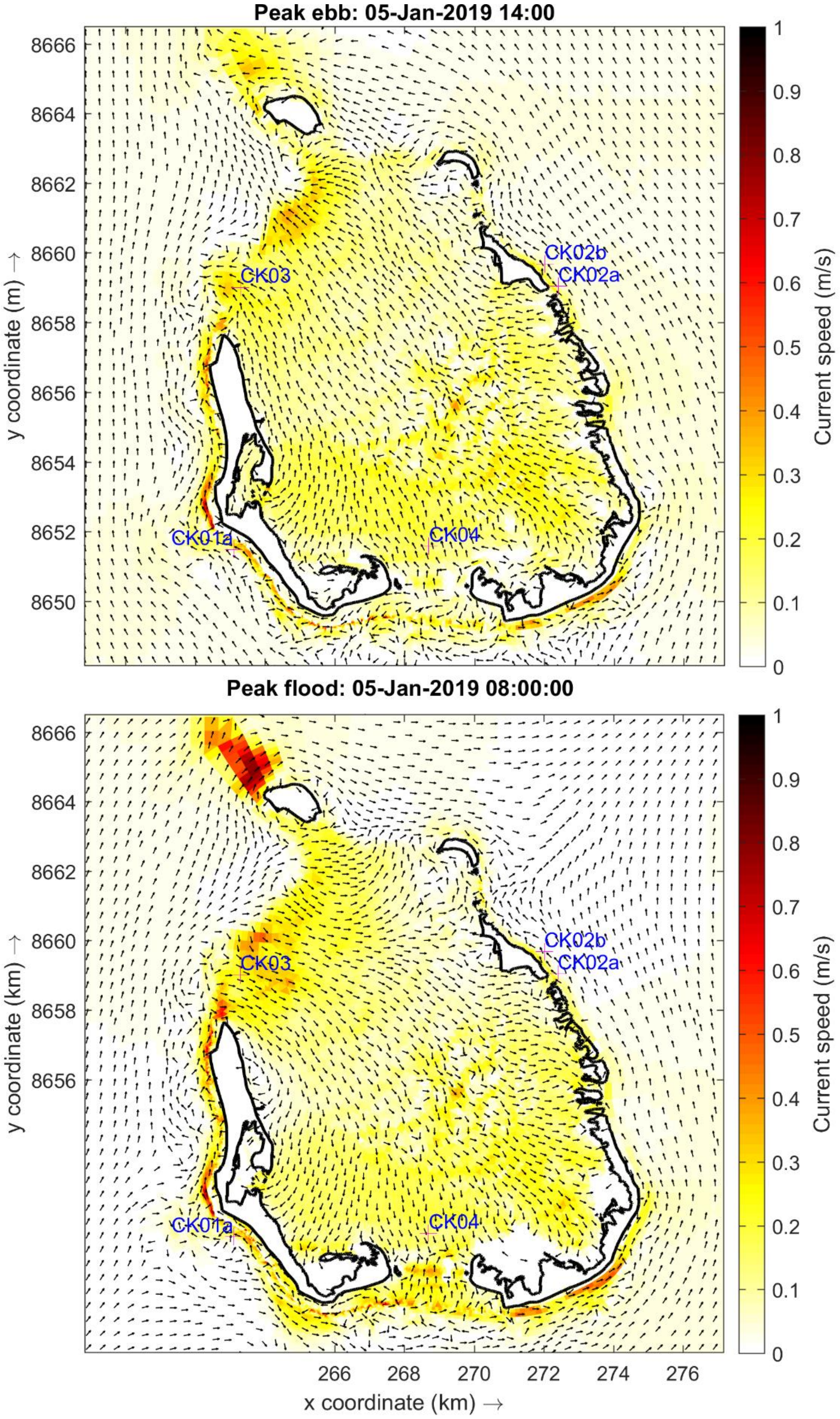


Figure 29: Atoll wide maps of simulated (top) peak ebb and (bottom) peak flood currents during low-energy wave conditions on 5th January 2019.

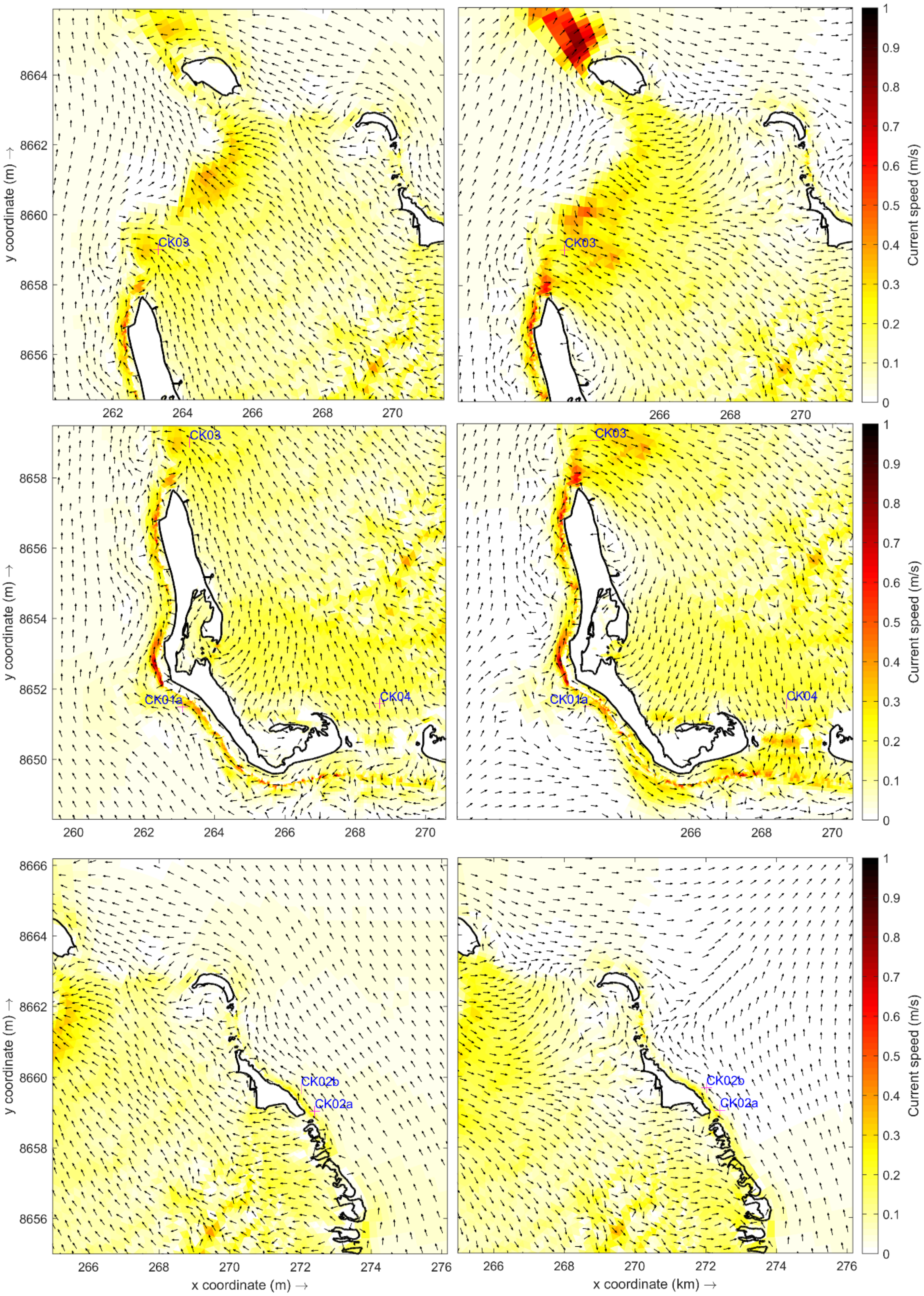


Figure 30: Zoomed-in maps of simulated (left) peak ebb and (right) peak flood currents during low-energy wave conditions on 5th January 2019.

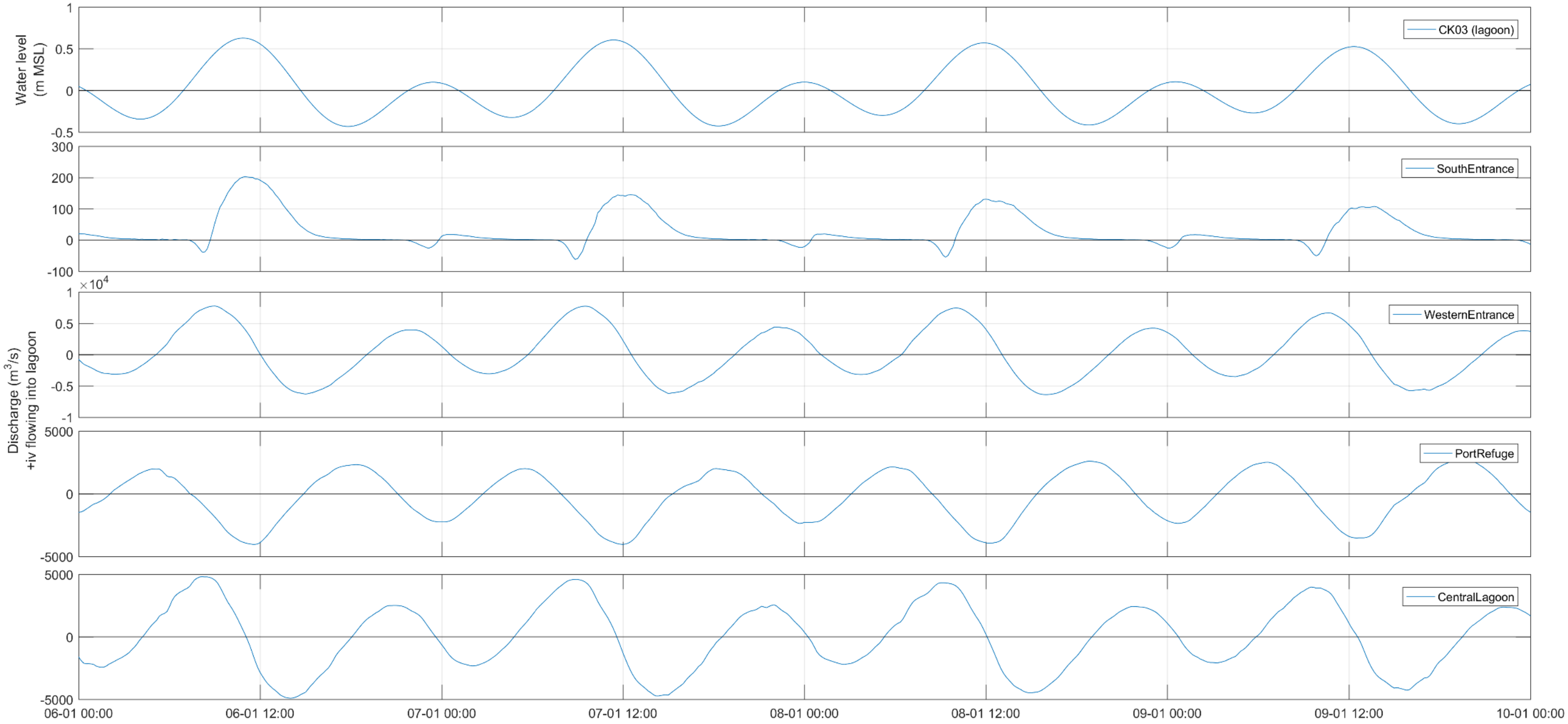


Figure 31: Timeseries of flow discharge through the main lagoon entrances during low-energy offshore wave conditions: a positive discharge indicates flow into the central lagoon while a negative discharge indicates flow out of the lagoon.

4.5.2 Seasonal mean currents

To assess the net-circulation of currents around the atoll the mean currents over a one-month period in June 2018 (winter) and January 2019 (summer) were calculated. Spatial mean current maps and net sediment transport patterns over the winter month simulation are presented in **Figure 32** and **Figure 33**, respectively. The mean currents and net sediment transport maps for the summer month simulation are presented in **Figure 34** and **Figure 35**.

While net current magnitudes and resulting net sediment transport potential are relatively higher in winter, the overall current circulation was found to be very similar for the two seasons. It is noted that given the abovementioned limitations of the coupled spectral wave and hydrodynamic model, the sediment transport results are to be interpreted in a qualitative manner. The areas of erosion and accretion assume that sand is available to be mobilised. Furthermore, the results are representative of the seabed morphology at the time of the 2012 survey data.

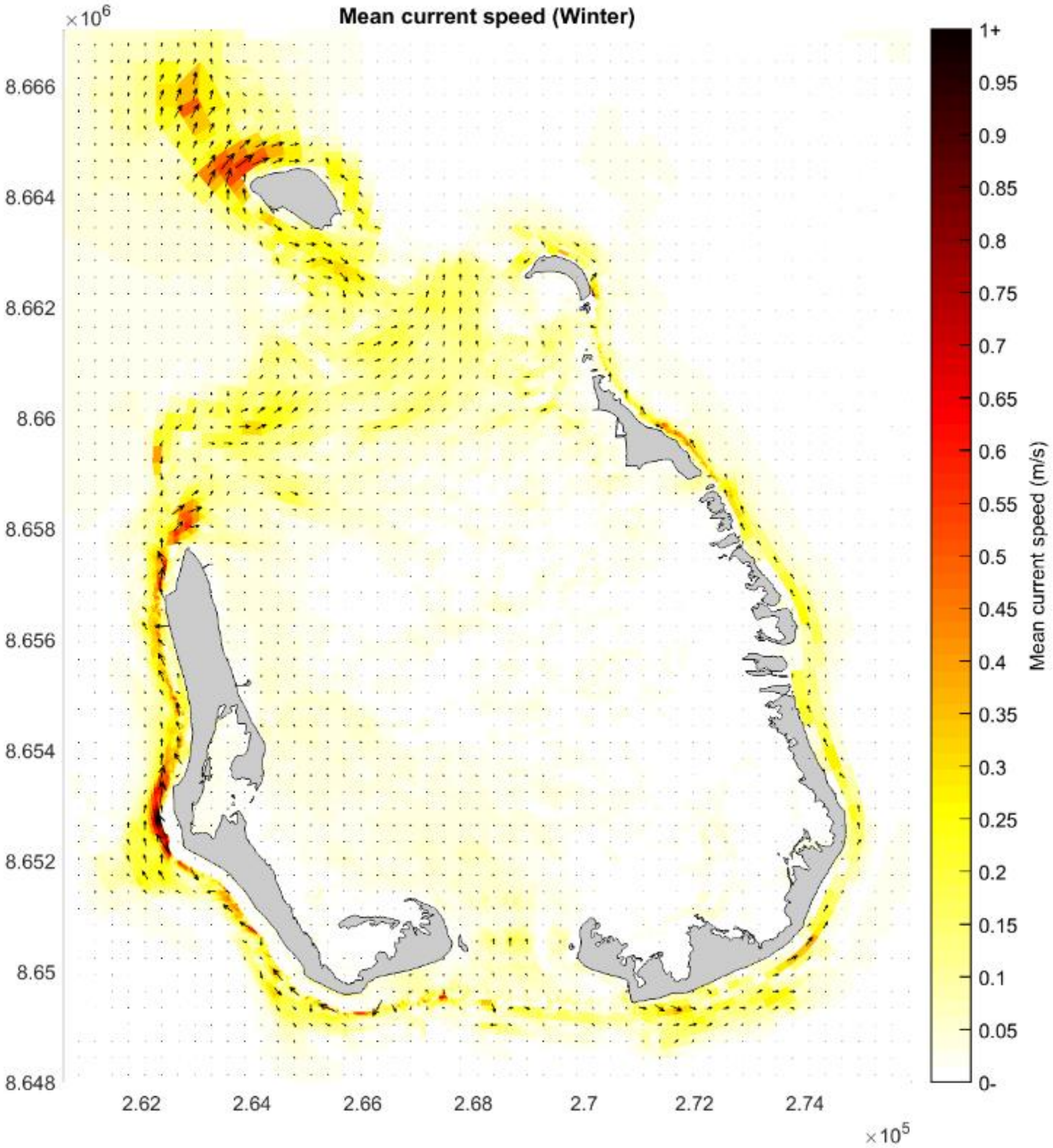


Figure 32: Simulated mean currents over a one-month period in June 2018.

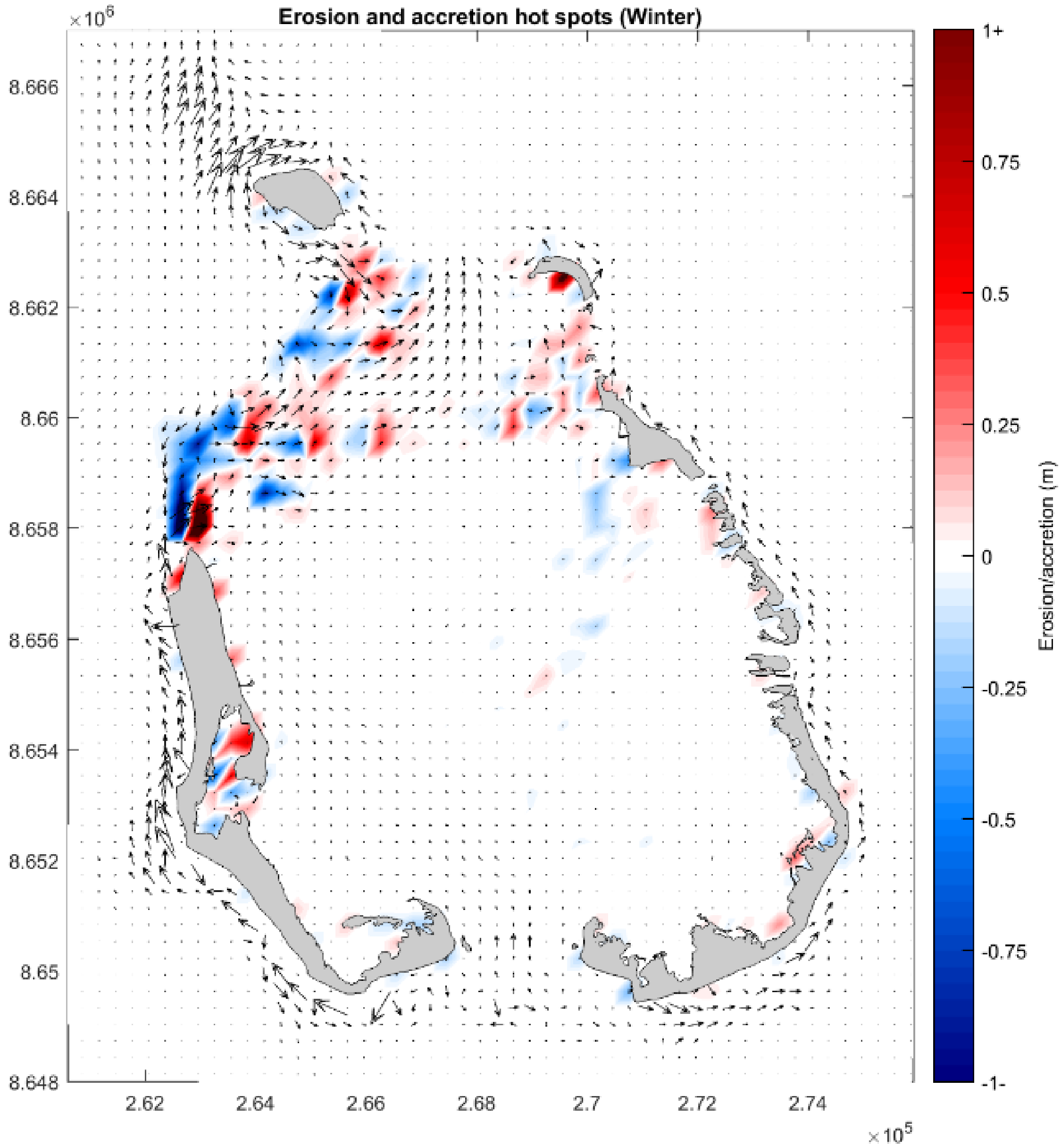


Figure 33: Simulated net sediment transport pathways and erosion (blue)/ accretion (red) hotspots over a one-month period in June 2018.

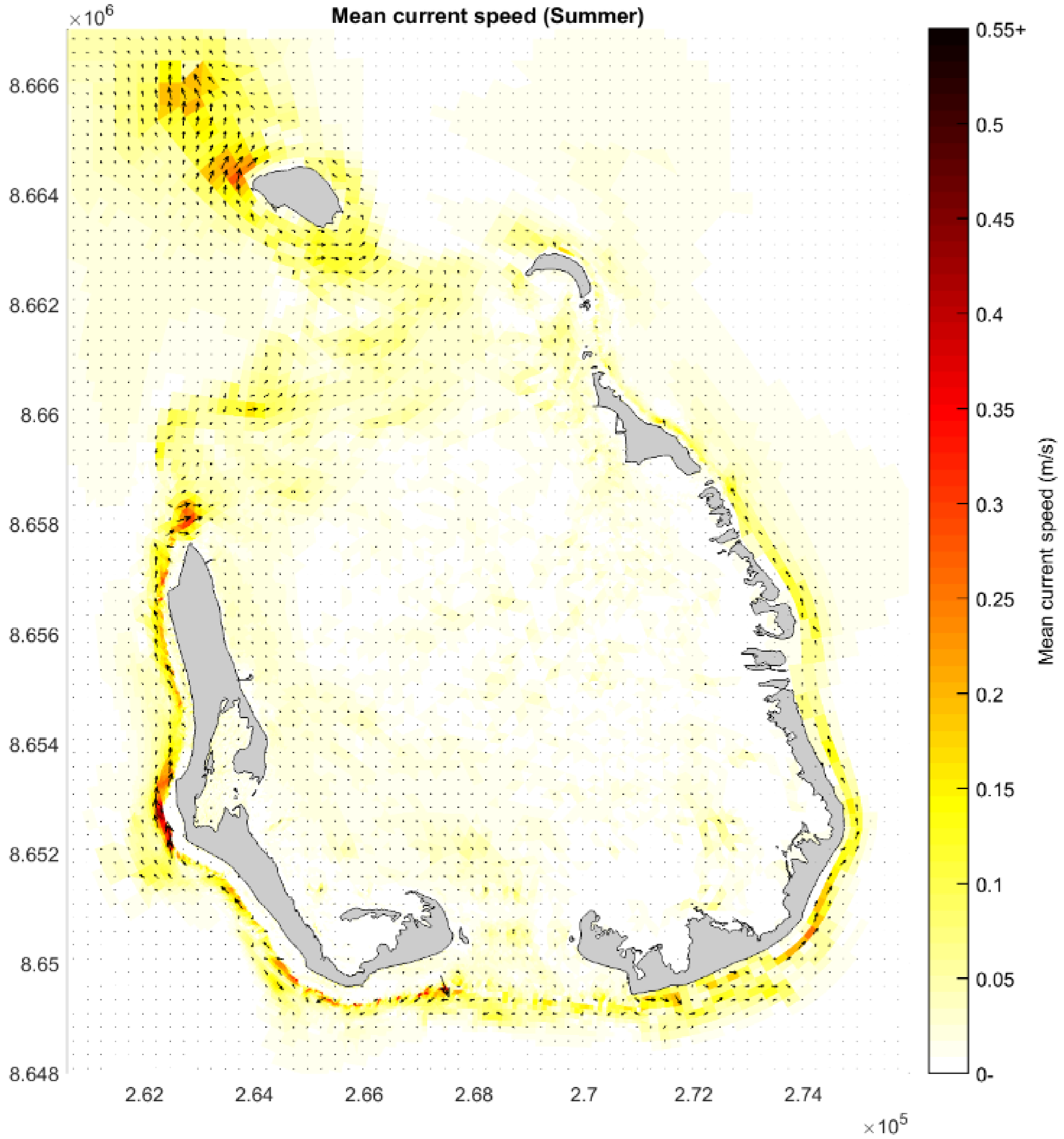


Figure 34: Simulated mean currents over a one-month period in January 2019.

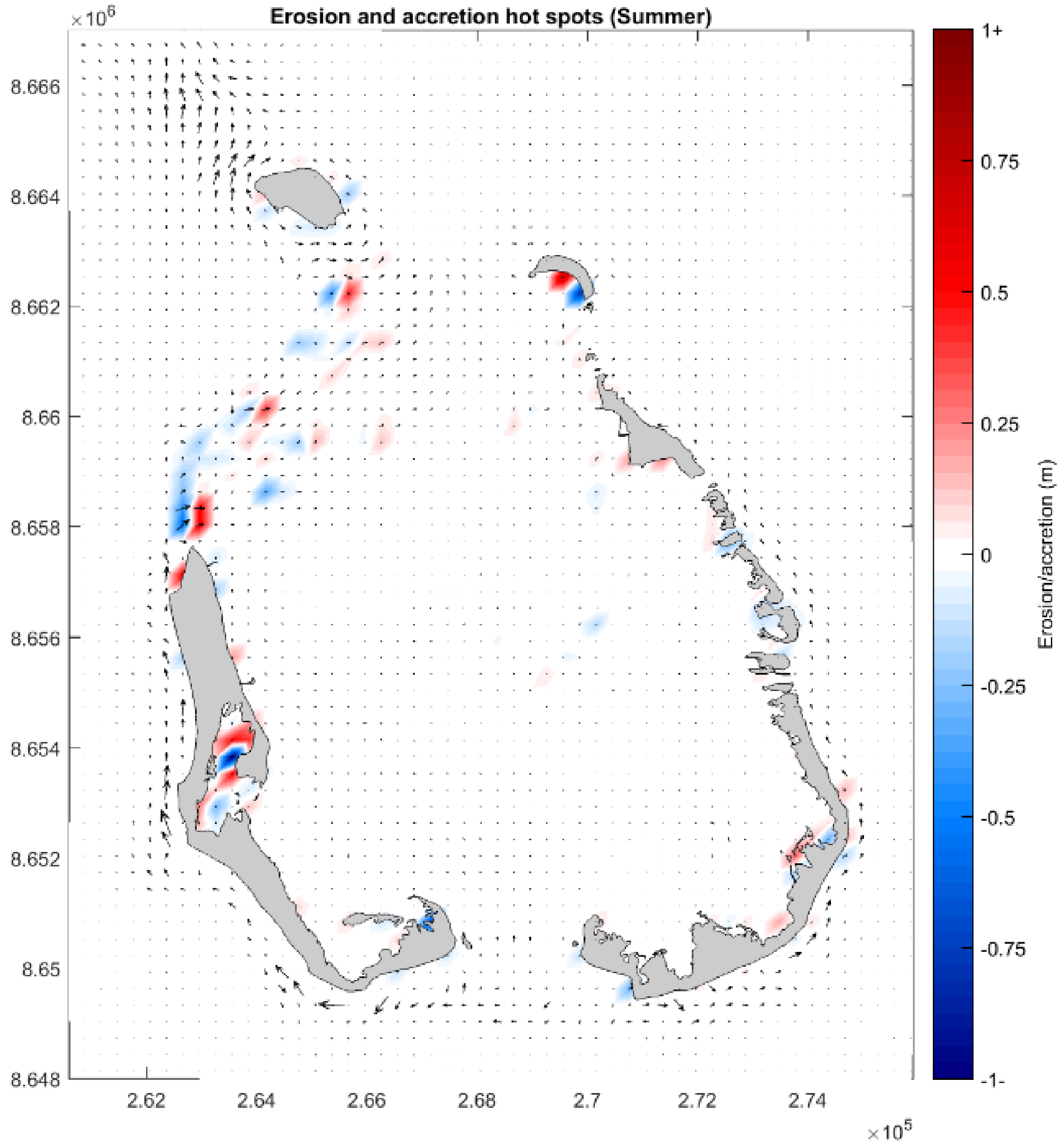


Figure 35: Simulated net sediment transport pathways and erosion/accretion hotspots over a one-month period in January 2019.

4.5.3 Swell event (24 July 2018)

A spatial map of wave heights around the southern atoll during the peak of the swell event that occurred around 24th July 2018 is provided in **Figure 36**. A map of current speed and direction during the peak of the event is shown in **Figure 37**.

The simulation results show that during this swell event the western ocean-facing coastline experienced large wave heights breaking along the fringing reef while the eastern coastline was very sheltered. Some wave ingress through the western entrance into the central lagoon is indicated by the simulation with some swell waves propagating across to the lagoon-facing beaches of Home Island. A strong northward current along the fringing reef at West Island is simulated due to the south-westerly swell direction. High current speeds (>0.6m/s) through the Western Entrance channel flowing into the central lagoon and largely exiting through Port Refuge in the north east, are indicated by the simulation.

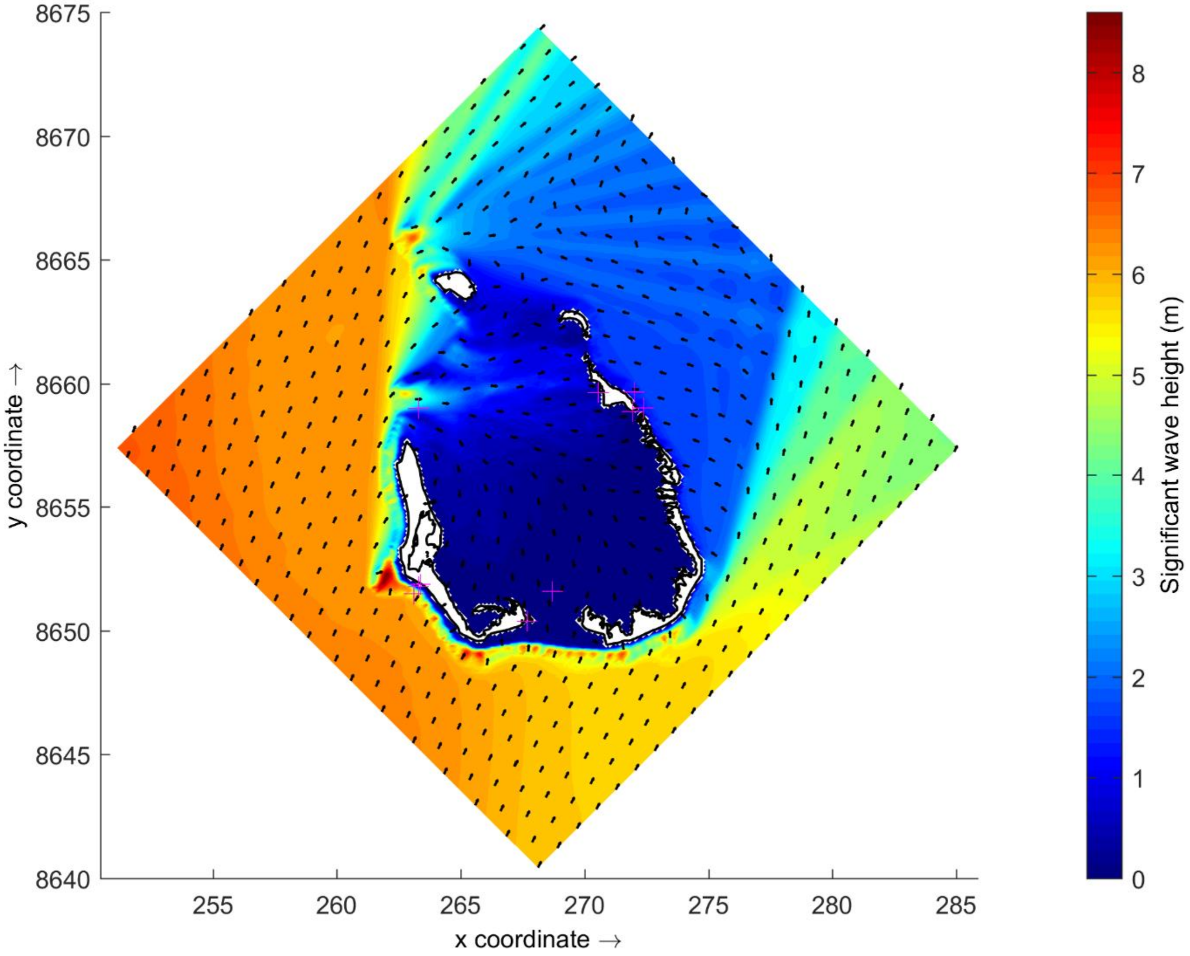


Figure 36: Spatial wave height distribution around the southern atoll during the peak of the large swell event on 24th July 2018.

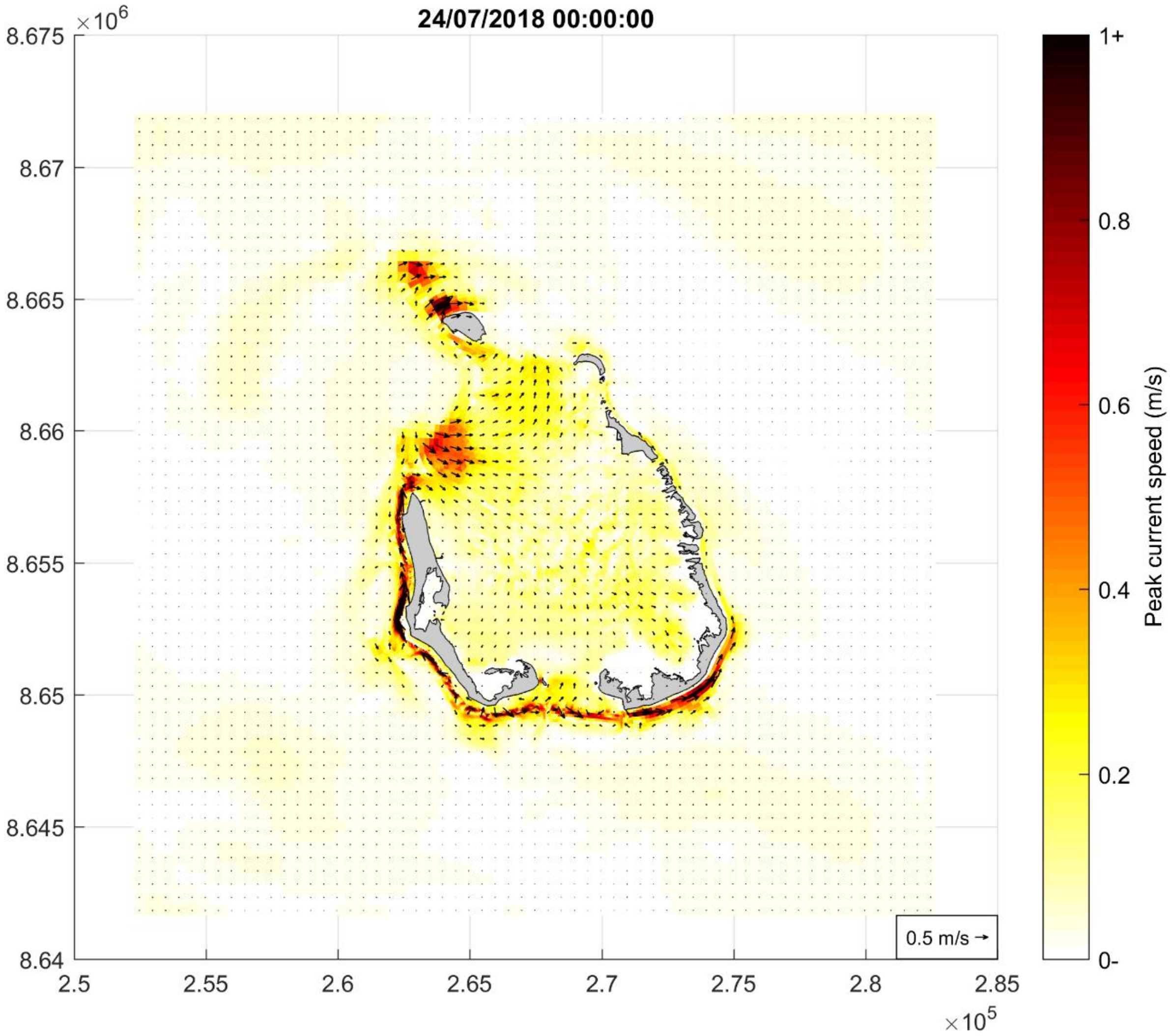


Figure 37: Map of simulated currents speed and directions during peak flood conditions around the peak of the large swell event on 24th of July 2018.

5 Coastal inundation assessment

With respect to inundation, SPP 2.6 requires that development consider the potential effects of an event with an Annual Encounter Probability (AEP) of 0.2% per year. This is equivalent to an inundation event with an Average Recurrence Interval (ARI) of 500 years. This is referred to as the S4 Allowance for coastal inundation. Refer to **Section 6.7** for further details regarding coastal erosion allowances.

The coastal inundation assessment is required to quantify the coastal inundation levels, extent and duration for the present day 500-year ARI event as per SPP 2.6 requirements. The S4 allowance is defined by the maximum extent of the inundation predicted for the present day 500-year ARI[4] event. At the Cocos (Keeling) Islands, such extreme events are expected to be associated to the passage of nearby tropical cyclones. The total allowance for coastal inundation is the S4 inundation extent plus the predicted extent of sea level rise (SLR) values for 2018, 2068, 2118. More frequent coastal inundation events were assessed for tropical cyclones and as a result of elevated still water levels in combination with large swell events (e.g. as observed during the July 2018 swell event).

The Cocos (Keeling) Islands is a coral atoll with the ocean-facing shoreline fringed by reef and a sheltered central lagoon with sandy and gently sloping shorelines. Therefore, coastal inundation at the ocean-facing shorelines is dominated by wave-driven water levels (i.e. wave setup and wave run-up resulting in overwash/ overtopping) whereas inundation on the lagoon side is mainly controlled by still water levels (i.e. tide and storm surge). The key sea level processes contributing to the coastal inundation risk at the Cocos (Keeling) Islands are schematically shown in **Figure 38**. Freshwater flooding is not included in this coastal vulnerability assessment for the Cocos (Keeling) Islands.

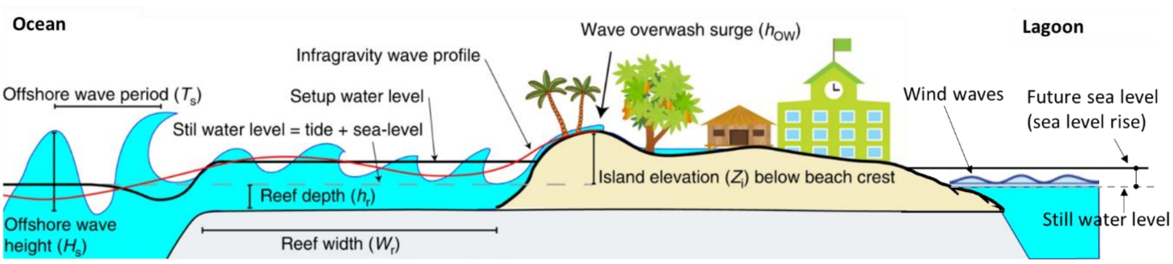


Figure 38: Schematic of sea level processes at the Cocos (Keeling) Islands (modified from Beetham and Kench, 2018).

4 The terms return interval or ARI are used here to describe an event that is expected to be exceed once during the average return interval. The theoretical return interval is the inverse of the probability that the event will be exceeded in any one year (or more accurately the inverse of the expected number of occurrences in a year). For example, a 10-year ARI event has a 0.1 or 10% chance of being exceeded in any one year and a 50-year ARI event has a 0.02 or 2% chance of being exceeded in any one year.

This does not mean that a 100-year ARI event will happen regularly every 100 years, or only once in 100 years. In any given 100-year period, a 100-year event may occur once, twice, more, or not at all, and each outcome has a probability that can be calculated.

An overview of the numerical modelling process for the inundation assessment is shown in **Figure 39.**

The approach adopted to quantifying the coastal inundation hazard for the southern atoll with a focus on the two key study sites, Home Island and West Island, is outlined below:

- Extreme value analyses of key water level drivers to inform modelling scenarios and determine peak steady water levels.
- Wave and hydrodynamic modelling using the models described in **Section 4**, including:
    - Tropical cyclone wave modelling and transformation of extreme offshore wave conditions to estimate extreme nearshore waves.
    - Xbeach (1D profile) modelling to estimate inshore wave heights and wave setup at the fringing reef coastline. This was required to overcome limitations of the Delft3D FM/ Wave models in this environment (see Section 4.4) and informed the allowances for wave-driven water levels and wave overwash/ overtopping calculations required for the coastal inundation assessment.
    - Combined simulation of extreme offshore wave conditions and extreme water level using the coupled wave and hydrodynamic model to predict coastal inundation and resulting overland flows.
- Overtopping volumes calculated using the EurOtop (2018) formulae. These pre-calculated overtopping volumes were implemented into the numerical modelling system to allow simulation of inundation of the area in the lee of coastal structures.
- Wave overwash areas were identified considering the nearshore wave-driven water levels and coastal barrier elevations.

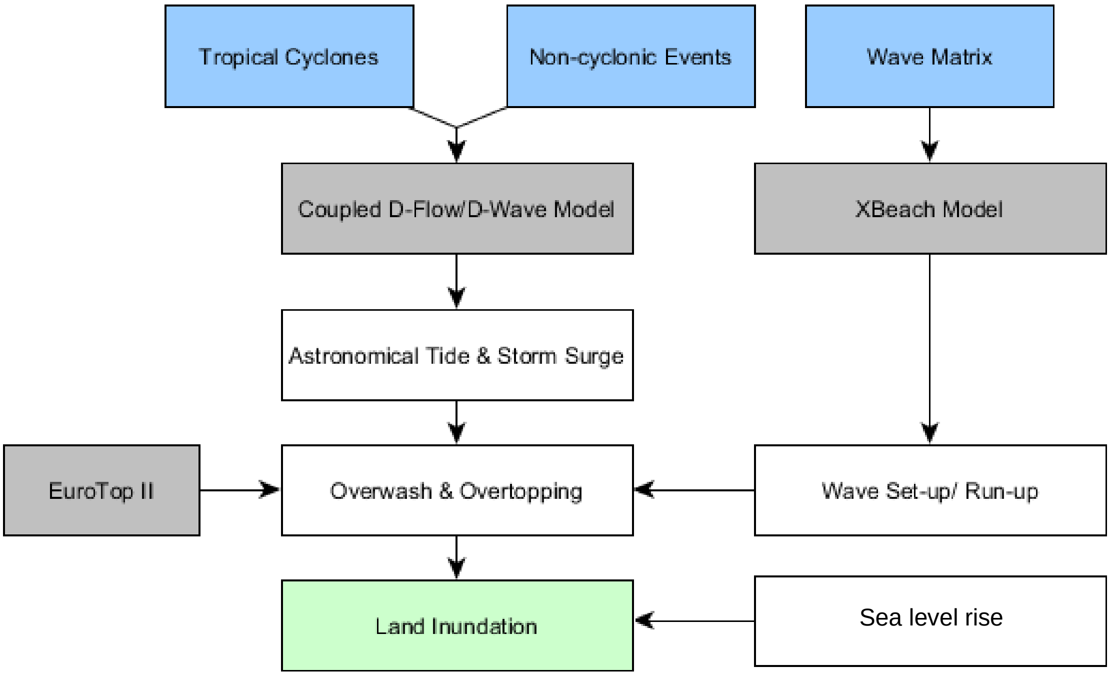


Figure 39: Overview of numerical modelling approach for the inundation assessment.

5.1 Extreme value analysis

5.1.1 Sea levels

Still water levels

An extreme value analysis was undertaken for the 27-year tide gauge record at the Home Island jetty (see **Table 9**). A peak over threshold method was applied for the determination of independent extreme surge events (i.e. minimum 7 days apart), shown in **Figure 42**. In agreement with previous studies (e.g. SEA, 2001) and further discussion in RHDHV (2018a), joint occurrence analysis of the tide gauge data and offshore wave heights shows no significant correlation between the two parameters at this lagoon location (see **Figure 40**).

Table 9: Extreme value analysis results for the Home Island tide gauge data (27-year record).

ARI (years)	Total sea level (m AHD)			Non-tidal residual (m)		
	Estimate	Lower CL*	Upper CL*	Estimate	Lower CL*	Upper CL*
1	0.98	0.97	1.00	0.23	0.23	0.24
10	1.09	1.06	1.11	0.31	0.28	0.34
25	1.12	1.09	1.15	0.33	0.29	0.38
50	1.14	1.12	1.17	0.35	0.30	0.40
100	1.16	1.13	1.19	0.37	0.31	0.43
500**	1.21	1.17	1.25	0.40	0.32	0.49

*CL – 98% confidence levels

**500-year ARI estimate is only presented as a guidance for the inundation risk assessment as events with such low occurrence cannot be predicted from the relatively short data record available for this analysis.

As previously identified in RHDHV (2018a) and SEA (2001), surges that occur as a result of tropical cyclones are predominantly due to the inverse barometer effect (i.e. drop in sea level pressure) with very little contribution of wind-driven sea level setup. This is due to the atoll morphology and surrounding deep water. The drop in sea level pressure and corresponding surge is most pronounced in the eye (i.e. central part) of the tropical cyclone whereas peak wind speeds and associated extreme wave heights are generated some distance away from the eye and down-wind (see **Figure 41**). This implies that the most extreme tropical cyclone generated surges at the Cocos (Keeling) Islands and extreme tropical cyclone generated wave heights do not coincide, as observed in the tide gauge record. Therefore, the two processes of extreme still water levels and wave heights are investigated independently for the coastal inundation assessment.

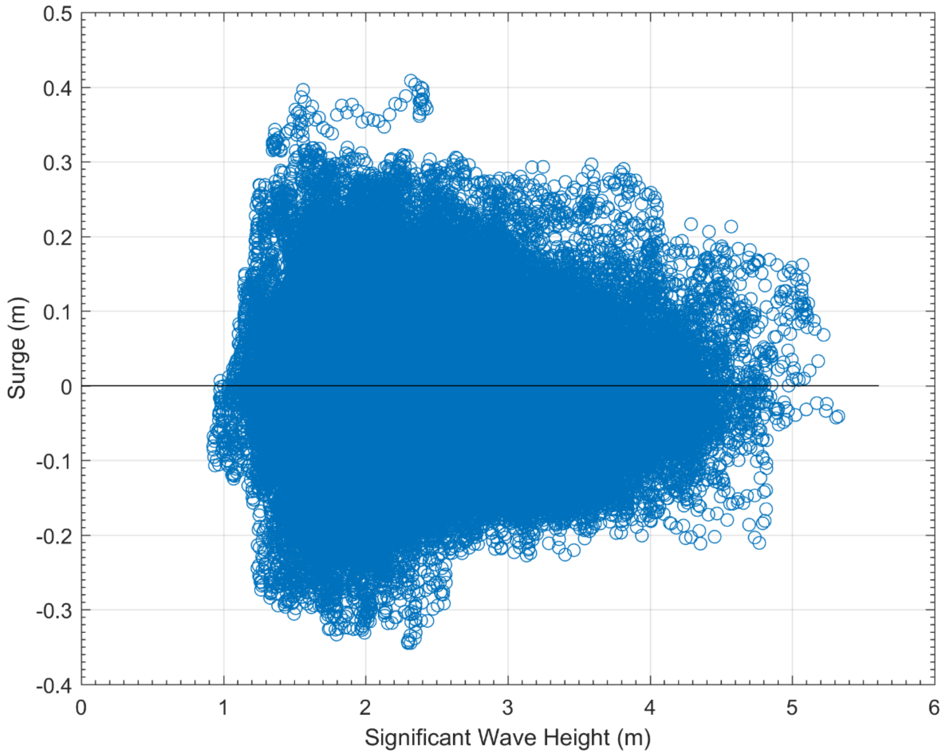


Figure 40: Joint occurrence of non-tidal residuals (or surge) measured at the Home Island tide gauge (27-year record) and offshore significant wave heights (CAWCR).

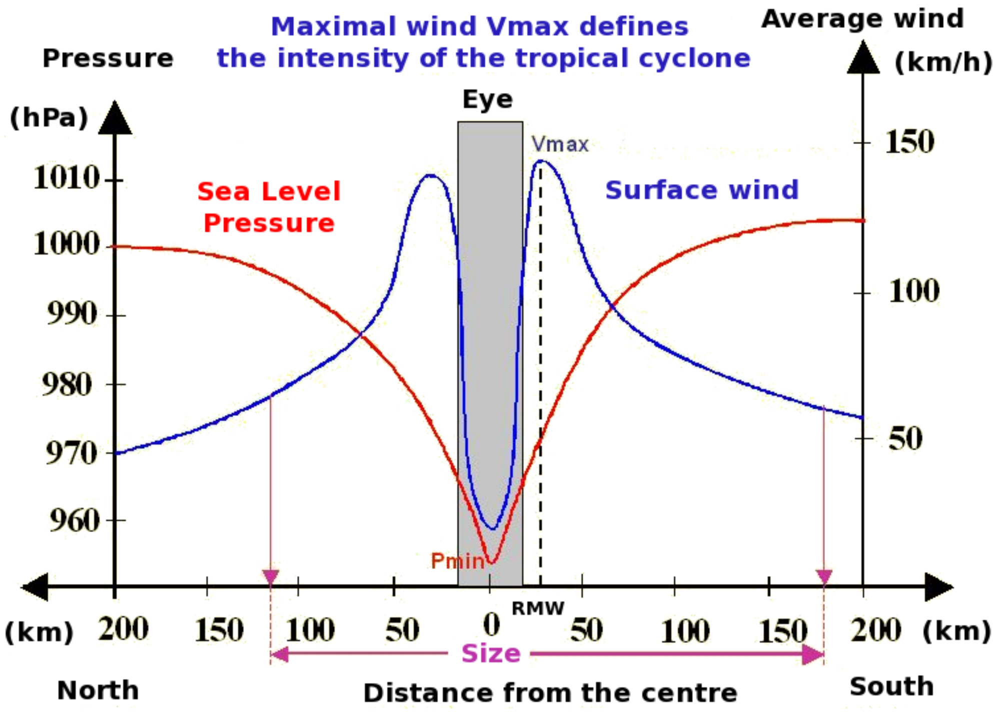


Figure 41: Typical southern hemisphere tropical cyclone structure showing radial distribution of sea level pressure and surface winds (source: Meteo.fr).

To understand the influence of long-term sea level variations on extreme events, **Figure 42** also shows the concurrent climatic conditions as described by the Southern Oscillation Index (SOI) and the Indian Ocean Dipole (IOD) as well as the occurrence of tropical cyclones within 1,000km of the Cocos (Keeling) Islands. The analysis showed that the highest water levels and surges at the Cocos (Keeling) Islands predominantly coincide with month-long increases in mean sea level. Extreme surge levels measured at the Home Island tide gauge are in the order of 0.2m to 0.4m. Some occurrences coincide with passages of tropical cyclones (e.g. on 1st January 1998, TC Selwyn) but fall within the range observed for non-cyclonic surges.

The detailed storm surge modelling undertaken by SEA (2001) predicted a 500-year ARI water level at the Home Island jetty of 0.99m above MSL and 1.18m at Rumah Baru on West Island. These values are slightly lower than the extrapolated tide gauge EVA results presented herein, i.e. 1.21m above AHD (approximately MSL) at the Home Island jetty. Given the uncertainty in either of the investigations, the more conservative estimate calculated herein has been adopted for the coastal inundation assessment.

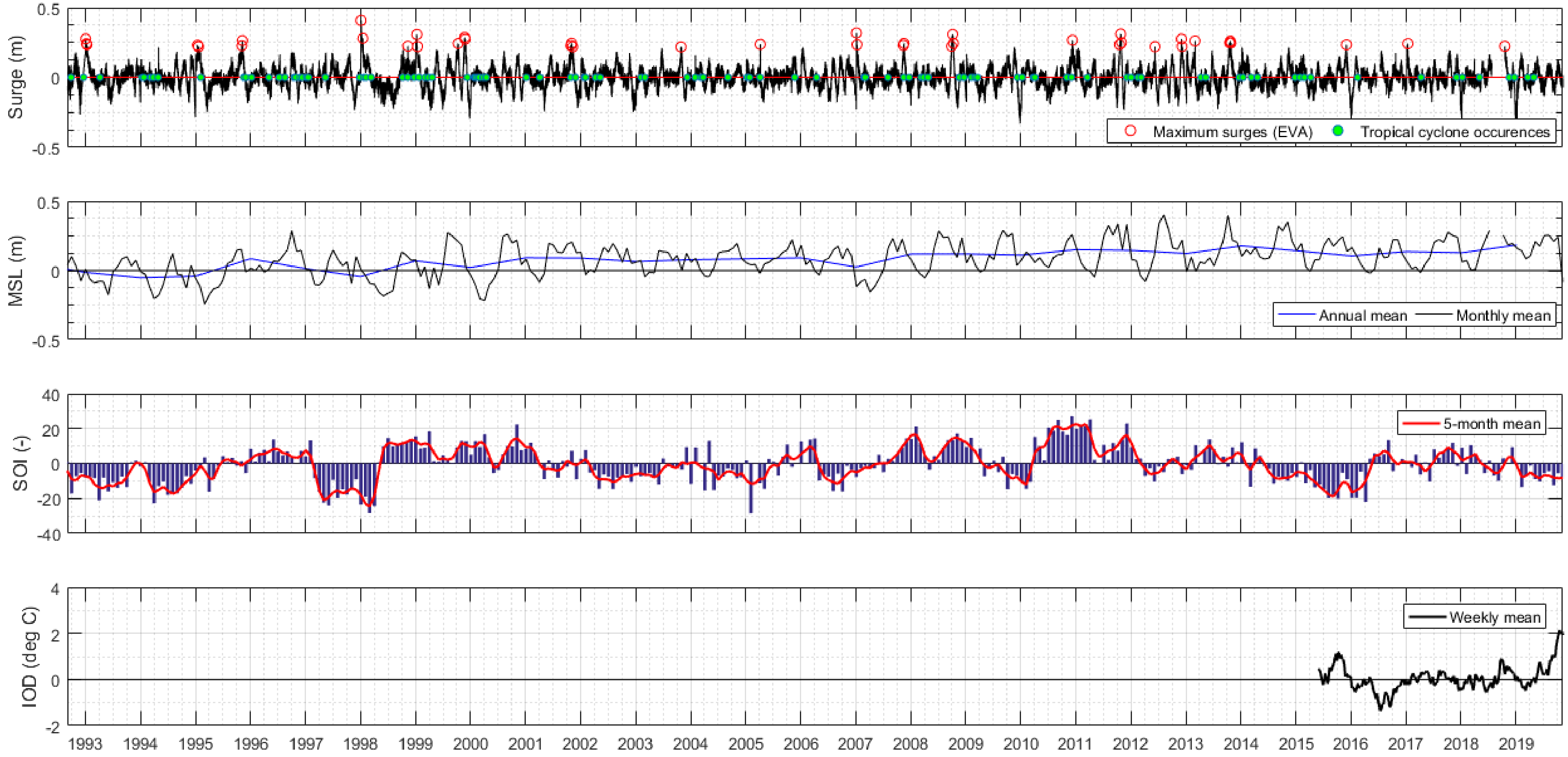


Figure 42: Overview of non-tidal residuals (or surge) and extreme events in the Home Island tide gauge data (top panel), mean sea levels (2nd panel), and concurrent climatic conditions as described by the Southern Oscillation Index (SOI, source BoM) and the Indian Ocean Dipole (IOD, source BoM - post 2015).

Wave-driven sea levels

Wave setup in the lee of the fringing coral reef crest around the southern atoll has been identified as being the single largest component of non-tidal sea levels along the ocean exposed CKI shoreline in SEA (2001). A schematic of the nearshore wave and sea level processes at these fringing reefs was shown in **Figure 38**.

Nearshore waves and water level were measured on top of the shallow reef flat in front of the West Island settlement during the Cocos (Keeling) Islands CVA monitoring campaign (see **Section 3**). A detailed analysis of the water levels was undertaken to estimate wave-driven setup induced by swell wave groups breaking at the reef crest (see **Appendix A**). A statistical summary of measured reef-top water levels and wave heights are presented in **Table 10**. Wave-driven setup reached up to 1.1m above MSL during the 12-month measurement period. While most of the wave energy dissipates during breaking at the reef crest (~70%), some swell and short-period waves are transmitted to shore where run-up and overwash of the beach ridge or overtopping of coastal structures occurs. Transmitted waves reached up to ~0.9m significant wave height during the monitoring period and strongly depend on reef top water levels (i.e. freeboard over reef crest). It was found that higher wave setup levels occurred during lower water levels but higher wave transmission of short period waves on the reef flat occurred during higher water levels. No direct measurements of wave run-up were undertaken as part of this study.

To determine the wave-driven sea levels during the more extreme wave scenarios for the coastal inundation assessment, non-linear Xbeach wave modelling was undertaken as presented in **Section 5.3.2**.

Table 10: Statistical summary of measured reef-top water level and wave heights at West Island (CK01c).

Statistic	Reef-top 1% water level* (m above MSL)	Reef-top waves	
		Significant wave height (m)	Peak period (s)
20%ile	0.12	0.13	5.3
50%ile	0.20	0.23	7.0
90%ile	0.35	0.40	12.6
99%ile	0.63	0.59	23.4
99.9%ile	0.89	0.74	43.7
Max	1.10	0.87	76.9

5.1.2 Swell and sea waves

Swell waves from the south-westerly direction mainly impact the southern and western exposed coastlines of the southern atoll (e.g. West Island Settlement). The eastern exposed coastlines (e.g. Home Island) are protected from these swell waves but are exposed to the east to south-east sea (as shown in **Section 3.1**). Analysis of the monitoring data confirmed that the sea wave climate varies with exposure to the trade winds (see **Appendix A**). Therefore, extreme wave heights for the eastern and western exposed coastlines have been considered independently. Lagoon wind waves have not been included in the inundation assessment as their relative importance in beach run-up/ overwash and overtopping of coastal structures is less significant for the inundation levels.

An EVA was undertaken for the swell wave and sea component at the offshore extraction point of the CAWCR wave hindcast data. A timeseries of the swell wave and sea component is provided in **Figure 43** which shows the independent events (i.e. minimum 5 days apart) selected for inclusion in the EVA. The EVA results are presented in **Figure 44** and **Figure 45**. This global wave hindcast data does not accurately reproduce tropical cyclone induced waves due to its relatively coarse spatial and temporal resolution. Tropical cyclone generated wave heights are therefore considered separately in **Section 5.1.3**.

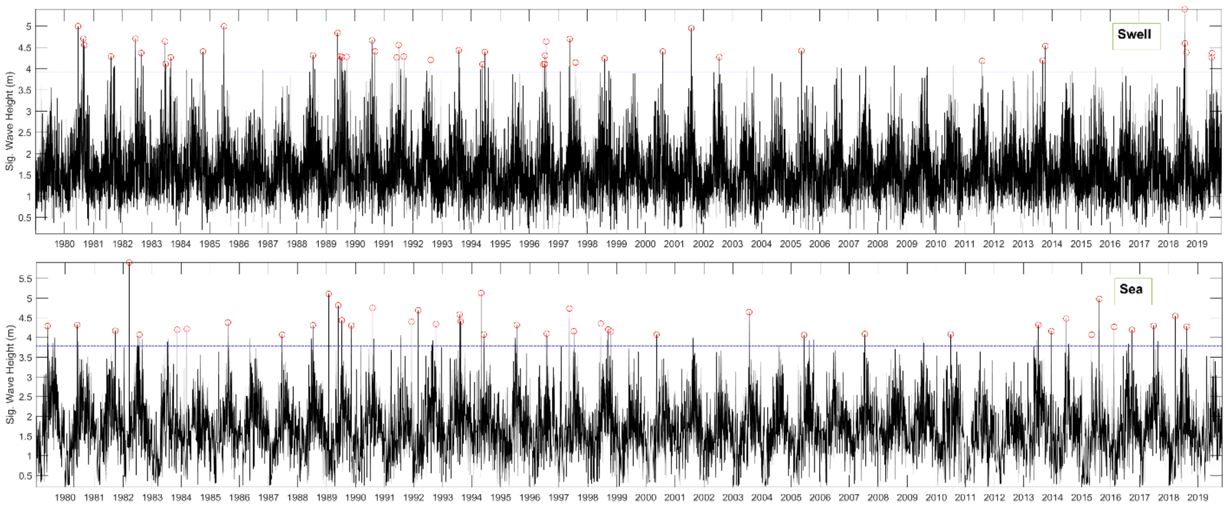


Figure 43: Time-series of offshore swell wave heights (top) and sea wave heights (bottom) between 1979 and 2019 (source CAWCR). The largest wave heights included in the extreme value analysis are circled in red.

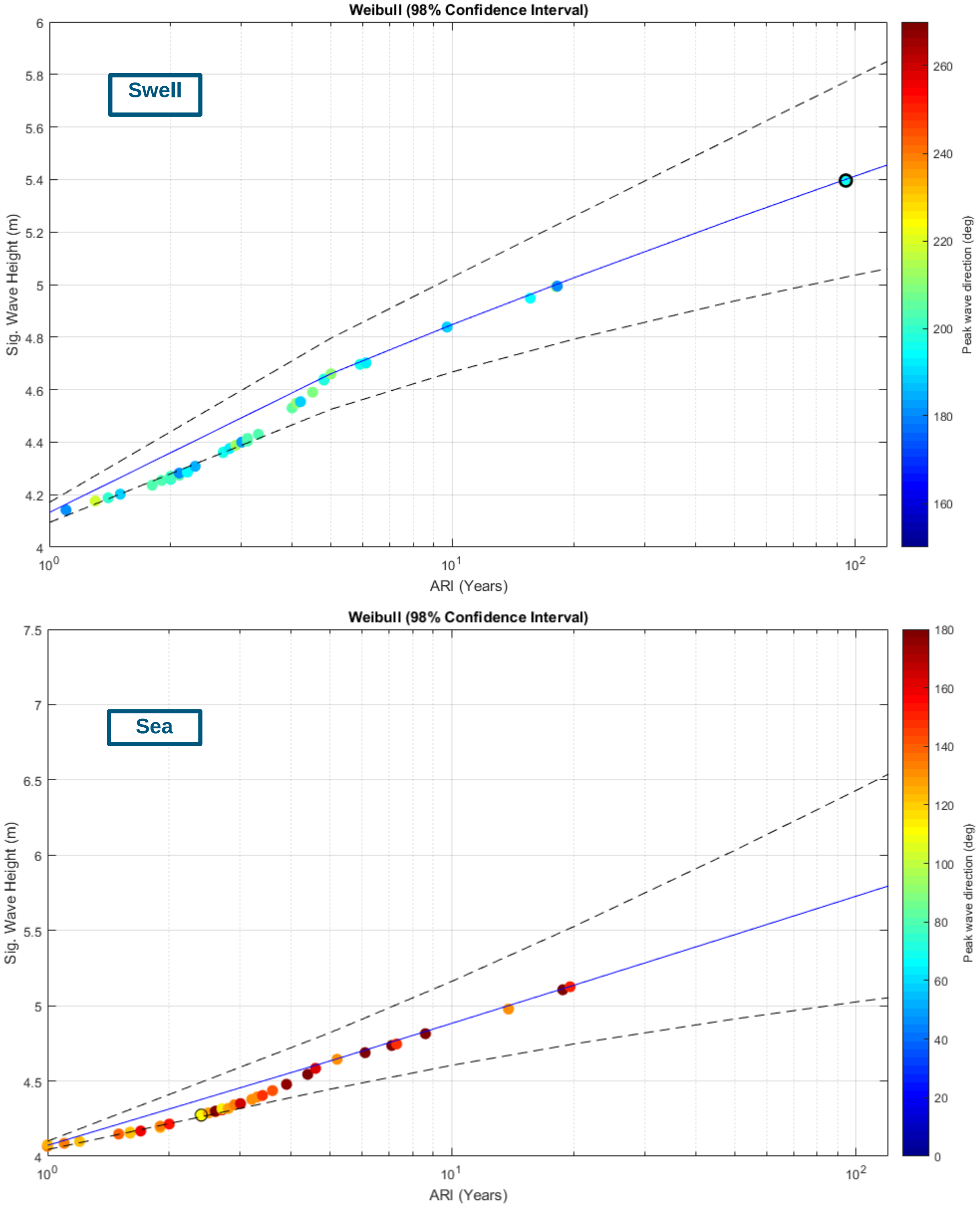


Figure 44: Average recurrence interval (ARI) offshore swell wave heights (top) and sea wave heights (bottom) for CKI (note: tropical cyclones not accurately included). The coloured dots show the analysis events (Figure 43) and associated wave directions. The black circled dot (top panel) represents the July 2018 swell event.

5.1.3 Tropical cyclone waves

A review of historic tropical cyclones that tracked nearby the Cocos (Keeling) Islands is presented in **Appendix A**. The spatial and temporal resolution of global wave hindcasts do not provide accurate representation of tropical cyclones and associated wave conditions. Furthermore, observed wave and wind records are often too short and sparse to quantify ARIs of extreme tropical cyclone conditions. Therefore, it is required to assess cyclonic extreme waves at the Cocos (Keeling) Islands in more detail by undertaking high-resolution wave modelling using a large set of synthetic tropical cyclone wind fields.

Based on the characteristics of historic tropical cyclones experienced in the eastern Indian Ocean a set of synthetic cyclones was produced using Geoscience Australia's Tropical Cyclone Risk Model (TCRM). This toolbox has been widely used for similar applications and uses stochastic models to generate plausible, synthetic tropical cyclones. For the Cocos (Keeling) Islands, 1,000 years of synthetic tropical cyclones were produced to estimate ARI wind speeds. The tracks of the synthetic cyclone that passed within 300km of the Cocos (Keeling) Islands are presented in **Figure 45**. Spatial and time-varying wind fields were produced from the synthetic tracks using a validated parametric wind model described in Holland et al. (2010). A detailed validation of the wind field model and associated wave modelling against measured wind and wave data was undertaken for the passage of TC Savannah in March 2018 and is presented in **Appendix A**. Synoptic winds were not included in the synthetic wind fields as the largest wave heights are expected as a direct result of the maximum wind speeds close to the centre of the tropical cyclone structure.

An extreme value analysis of measured winds at the Cocos (Keeling) Islands Airport (14-year record) and modelled winds at the Cocos (Keeling) Islands derived from the 1,000-year synthetic tropical cyclone record is presented in **Figure 46**. Due to the different exposure of the eastern coastline of CKI compared to the western coastline, a separate EVA was undertaken for tropical cyclone winds with wind directions at the Cocos (Keeling) Islands from 0 to 180 degrees to north and 181 to 360 degrees to north, see **Table 11**.

Table 11: Extreme value analyses results for modelled wind speeds at the Cocos (Keeling) Islands derived from the 1,000-year synthetic tropical cyclone record.

ARI (years)	Wind speed (m/s) Directions: 0 to 180 °TN			Wind speed (m/s) Directions: 181 to 360 °TN		
	Value	Lower CL*	Upper CL*	Value	Lower CL*	Upper CL*
10	20.7	20.0	21.5	20.5	19.5	21.5
25	30.0	28.4	31.6	29.4	27.6	31.1
50	35.2	33.0	37.4	34.5	32.2	36.8
100	39.8	36.7	42.9	39.0	36.4	41.8
500	49.3	43.4	55.2	48.7	44.7	52.7

*CL – 98% confidence levels

To simulate the extreme wave heights at two nearshore sites off Home Island and West Island (i.e. CK01a and CK02b, see **Section 3.1.1**) a subset of fifteen synthetic cyclone tracks was used to force the validated spectral wave model (see **Appendix A**). The synthetic tracks were selected to represent the 10, 25, 50, 100 and 500-year ARI wind speeds for Home Island and West Island, respectively. The worst-case track in consideration of the wind direction and fetch to the respective site was selected for each ARI scenario. Where more than one worst-case track was identified for an ARI scenario, multiple synthetic tracks were simulated in the spectral wave model for this scenario.

The simulated synthetic tropical cyclone tracks for the eastern and western shorelines of the Cocos (Keeling) Islands are presented in **Figure 47**. Time-series of wind conditions and sea level pressure for the selected 500-year ARI tropical cyclone tracks for both sites are provided in **Figure 48** and **Figure 49**.

A summary of the adopted synthetic tropical cyclone tracks and simulated maximum wave heights is provided in **Table 12.**

Table 12: Summary of adopted synthetic tropical cyclone modelling results.

ARI (years)	Maximum wind speed (m/s)	Peak direction (deg N)	Minimum sea level pressure (hPa)	Maximum significant wave height (m)
Eastern coastlines				
500	45.8	71	960	6.9
100	42.5	73	976	6.8
50	32.8	101	993	6.4
25	28.0	68	987	5.9
10	19.7	66	998	5.5
Western coastlines				
500	53.1	266	957	6.5
100	45.3	264	962	6.1
50	36.1	211	993	3.8
25	31.8	243	992	3.8
10	27.5	286	995	3.8

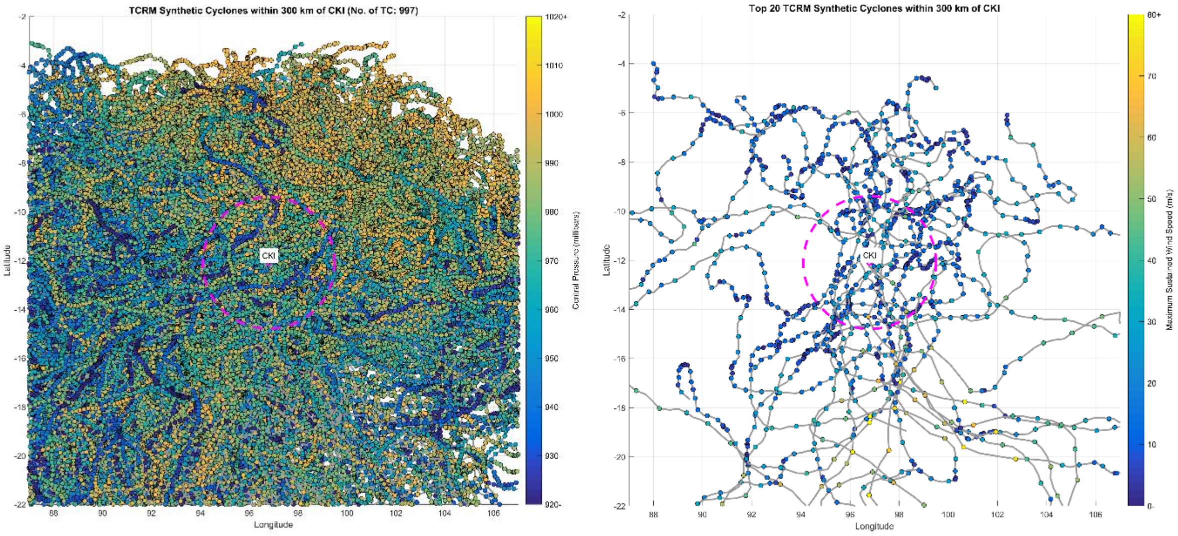


Figure 45: Tracks of (left) all synthetic cyclones and central pressures and (right) top 20 synthetic cyclones and maximum wind speeds within 300km of CKI.

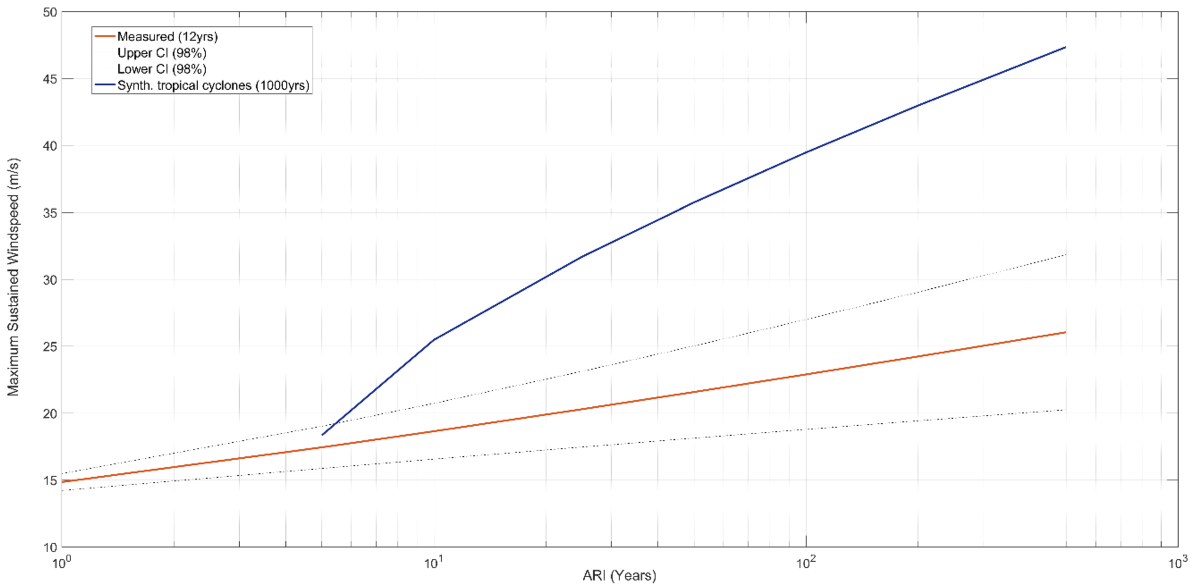


Figure 46: Results from the EVA for measured wind speeds at CKI and the 1,000-year synthetic tropical cyclone record (all directions) at the Cocos (Keeling) Islands.

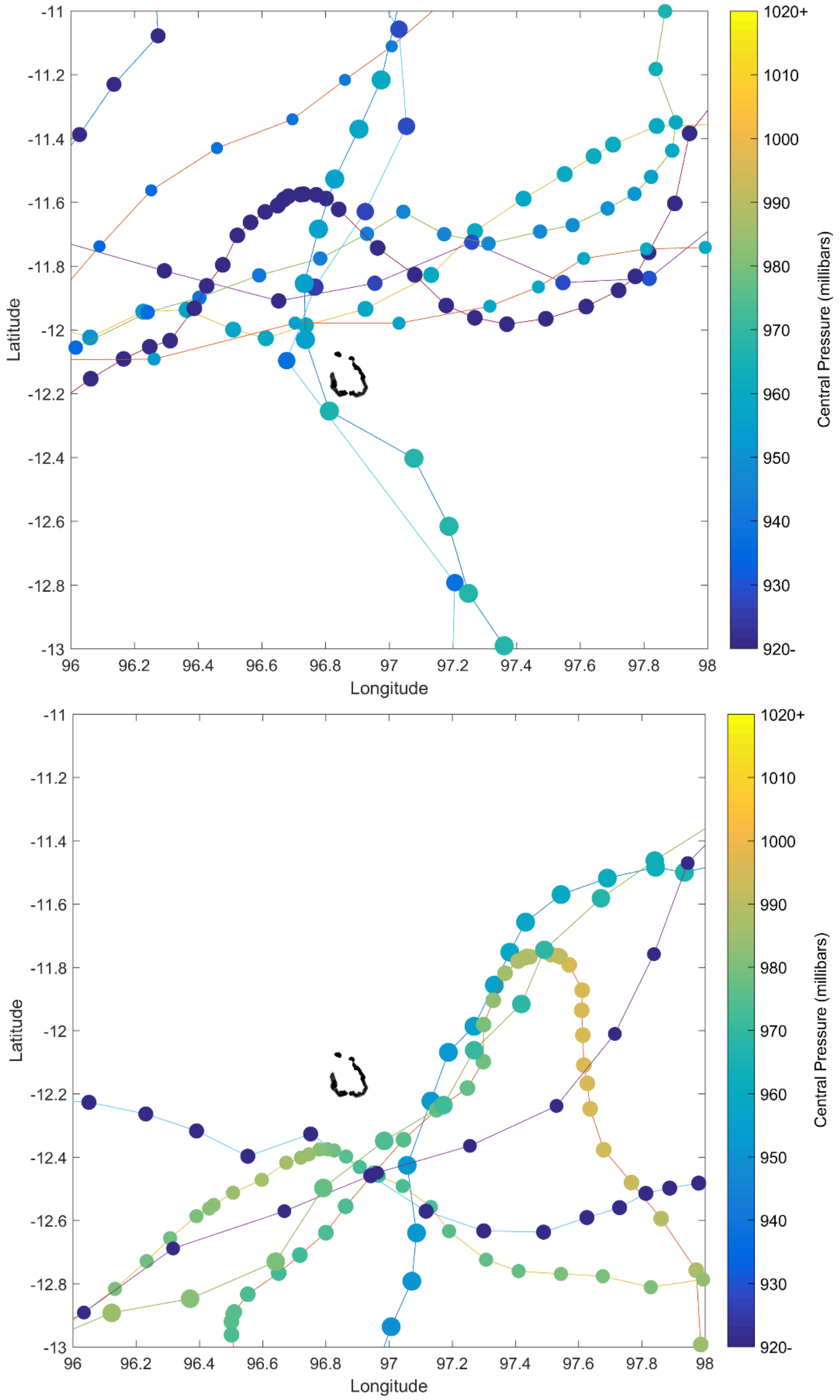


Figure 47: Simulated synthetic tropical cyclone worst-case tracks for offshore extreme waves for (top) eastern and (bottom) western shorelines.

***Note:** the general tropical cyclone movement is from east to west and the wind field is rotating clockwise.

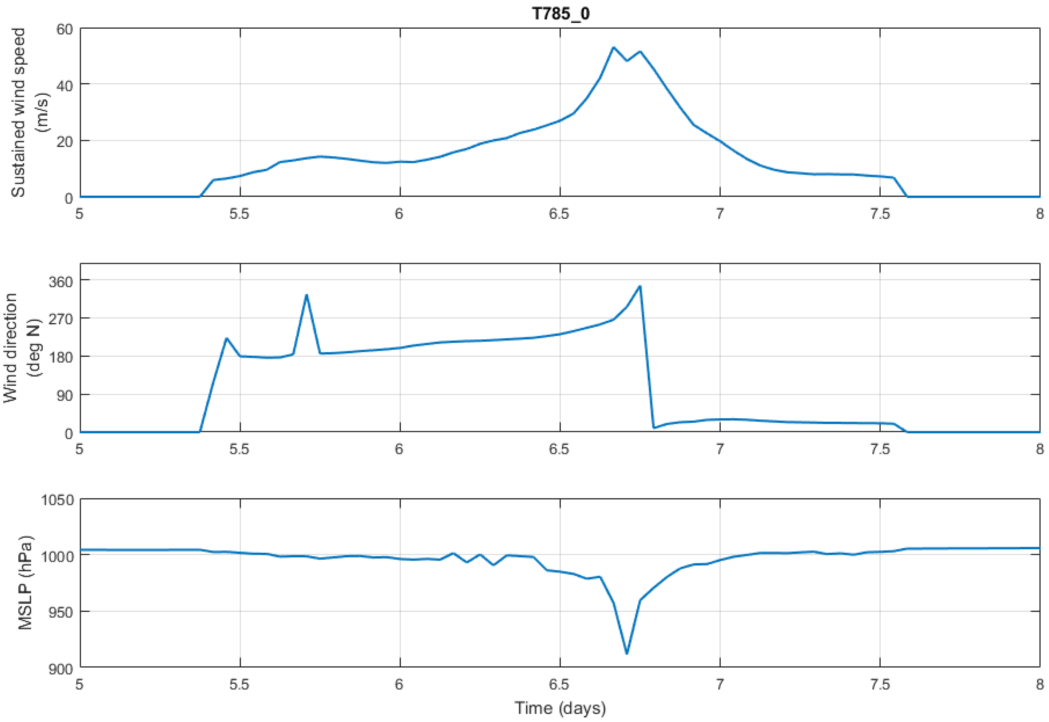


Figure 48: Wind conditions and sea level pressure for 500-year ARI synthetic tropical cyclone for western coastline (e.g. West Island).

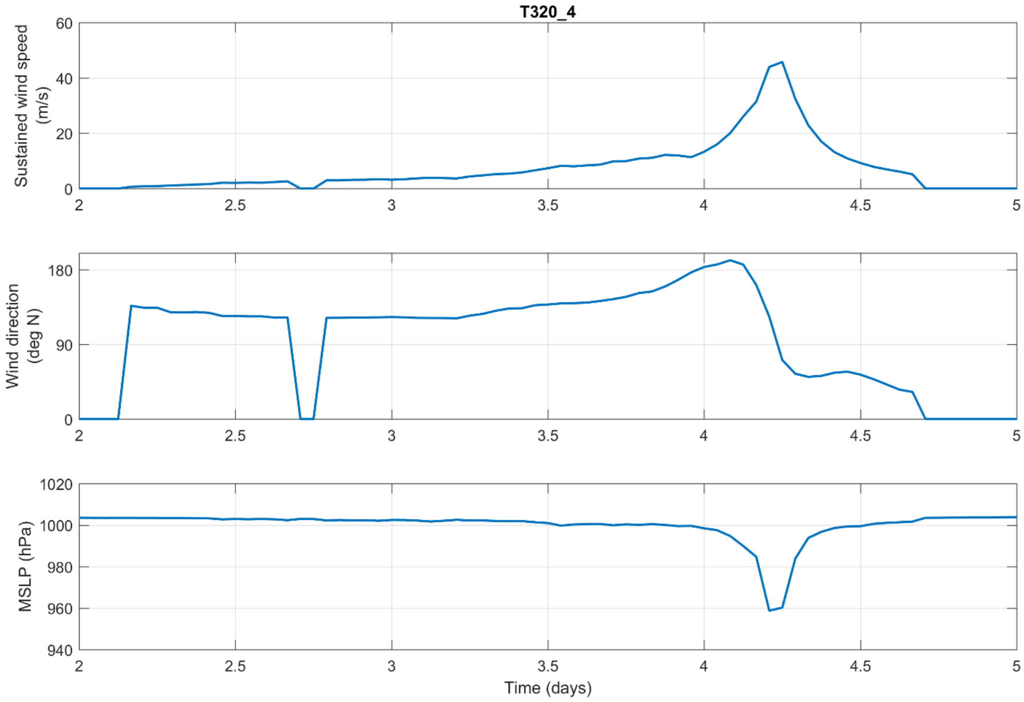


Figure 49: Wind conditions and sea level pressure for 500-year ARI synthetic tropical cyclone for eastern coastline (e.g. Home Island).

5.2 Model scenarios

A set of model input scenarios for each of the numerical modelling investigations was selected to determine the boundary conditions at the shoreline for the 500-year ARI inundation risk. The following model scenarios for the various modelling tools were adopted and results are provided in **Section 5.3**:

- **Outer atoll waves:** ARI of extreme wave heights at the reef edge around the southern atoll from two sources of extreme wave heights using the spectral wave model: (i) extreme swell and sea wave transformation from offshore global wave hindcast data (CAWCR) and (ii) tropical cyclone generated wave heights for selected synthetic extreme events.
- **Reef top waves:** ARI of extreme wave heights and water levels on the inshore reef flat using the high-resolution nearshore wave model (Xbeach). A series of extreme wave conditions were transformed from the reef edge to the inshore reef flat near the shoreline at three representative locations on Home Island and West Island.
- **Overtopping:** Wave overtopping volumes at seawall/ revetment locations were calculated using inshore wave conditions derived from the Xbeach modelling for a series of water levels.

Using the high-resolution, coupled hydrodynamic model, overland flows and inundation depths were then simulated at Home Island and West Island for the adopted sea level and overtopping allowances derived from the above modelling scenarios. The coastal inundation modelling results are presented in **Section 5.4**.

5.3 Simulation results

5.3.1 Outer atoll waves

Design wave heights for areas seaward of the reef crest on the oceanside of the West Island Settlement (CK01a) and Home Island (CK02b) have been estimated using the spectral wave model. Offshore design wave heights have been derived from the extreme value analysis of the offshore CAWCR 40-year wave hindcast (see **Section 5.1.2**) and transformed inshore or from the synthetic tropical cyclone modelling (see **Section 5.1.3**), whichever is the higher.

The resulting nearshore design wave heights are provided in **Table 13.**

Table 13: Estimated design wave heights for ocean side of West Island and Home Island.

ARI (years)	Significant wave height (m)	
	Western shorelines (20m water depth)	Eastern shorelines (20m water depth)
1	3.8	4.4
10	4.4	5.5*
25	4.8	5.9*
50	4.9	6.4*
100	6.1*	6.8*
500	6.5*	6.9*

*wave height derived from synthetic tropical cyclone modelling

5.3.2 Reef top waves

In order to determine wave heights inshore of the reef crest (i.e. waves transmitted over the reef flats) and associated wave setup and runup levels the Xbeach model was used to simulate a range of extreme wave conditions derived from the spectral wave model (see **Section 5.3.1**). The simulations were run using the calibrated Xbeach model (see **Appendix A**) for a one-hour duration and mean high water spring (MHWS) water level (i.e. 0.47m above AHD). A sensitivity analysis for various water levels has been undertaken for the West Island settlement site (CK01) and it was found that while higher inshore wave heights are observed for higher water level scenarios, wave setup was considerably reduced. This is also shown in **Table 14** for the sea level rise scenarios of the 500-year ARI event where wave setup is reduced for the future scenarios. Adopting the MHWS water level is considered conservative as it results in relatively high wave transmission (i.e. higher reef top wave heights) but also results in high wave setup due to regular wave breaking.

An overview of the wave transformation results is provided in **Figure 50. Table 14** and

Table 15 provide summaries for West Island and Home Island, respectively. The inshore wave heights were used to inform the overwash and overtopping calculations described in the following Sections.

As expected, the results show that the freeboard over the reef crest and reef flat plays a significant role on the transmitted inshore wave heights and resulting water levels. Maximum significant wave heights at the inshore locations ranged between 0.9 to 1.6m at MHWS. Additional simulations for the 500-year ARI wave heights were undertaken for the MHWS + 0.4m (year 2068) and MHWS + 0.9m (year 2118) sea level rise scenarios which resulted in inshore significant wave heights of up to 1.62m.

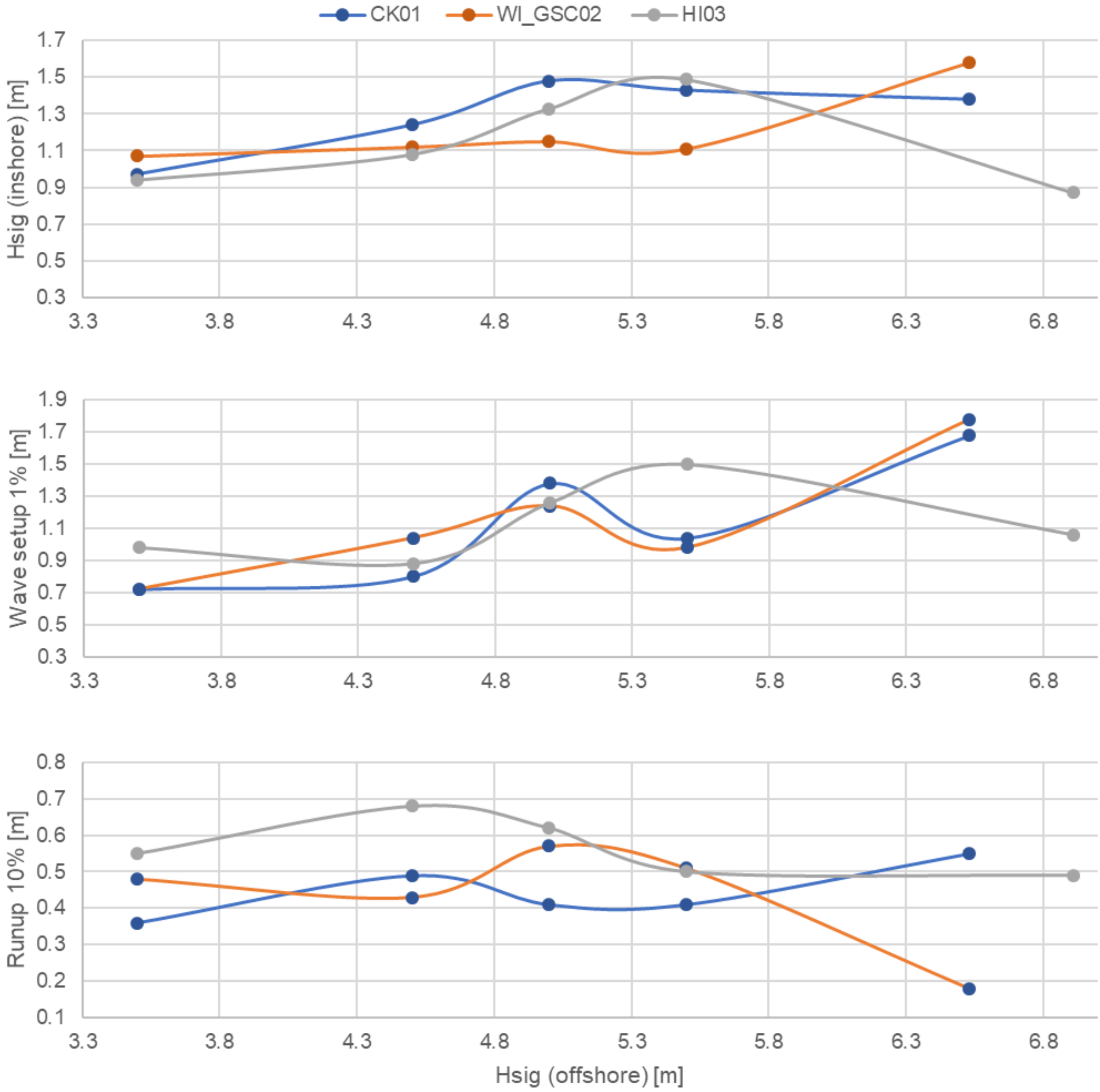


Figure 50: Wave transformation results for the three selected reef profiles derived from the Xbeach nearshore wave model (water level = MHWS).

Table 14: Summary of transformed inshore significant wave heights (H_{sig}), wave setup and runup for the two West Island Xbeach transect locations (still water level = MHWS).

Offshore H_{sig} (m)	West Island Settlement (site CK01c – 0.5m water depth)			North-west West Island (site WI_GSC02 – 0.5m water depth)		
	H_{sig} (m)	Wave setup 1% (m)	Wave Runup 10% (m)	H_{sig} (m)	Wave setup 1% (m)	Wave Runup 10% (m)
3.5	0.97	0.72	0.36	1.07	0.72	0.55
4.5	1.24	0.80	0.49	1.12	1.04	0.68
5.0	1.48	1.38	0.41	1.15	1.24	0.62
5.5	1.43	1.04	0.41	1.11	0.98	0.50
6.53 (500-year ARI)	1.38	1.68	0.55	1.58	1.78	0.49
6.53 (0.4m SLR)	1.46	1.50	0.66	1.30	-*	-*
6.53 (0.9m SLR)	1.62	1.34	0.54	1.49	-*	-*

*Significant overtopping occurred during this run which affected wave setup and runup results

Table 15: Summary of transformed inshore significant wave heights (H_{sig}) and 1% wave setup for the three Home Island Xbeach transect locations (still water level = MHWS).

Offshore H_{sig} (m)	East Home Island (site HI03 – 0.5m water depth)		
	H_{sig} (m)	Wave setup 1% (m)	Wave Runup 10% (m)
3.5	0.94	0.98	0.55
4.5	1.08	0.88	0.68
5.0	1.33	1.26	0.62
5.5	1.49	1.5	0.5
6.91 (500-year ARI)	0.87	1.06	0.49
6.91 (0.4m SLR)	0.87	0.94	-*
6.91 (0.9m SLR)	1.18	1.08	-*

*Significant overtopping occurred during this run which affected wave setup and runup results

5.3.3 Overtopping

In addition to the overwash of coastal barriers, overtopping of coastal structures plays a key role for coastal inundation by wave-driven processes on the Cocos (Keeling) Islands. Again, this process is not resolved in the spectral wave modelling and hydrodynamic modelling in this study. Therefore, overtopping at ocean-facing coastal structure locations at West Island was considered using additional tools.

Overtopping volumes were calculated using the empirical EurOtop formulae described in EurOtop (2018). The overtopping estimates were calculated using input from the reef top wave modelling and structure dimensions from the RTK surveys. An example for the William Keeling Drive overtopping estimates for the various extreme event scenarios is provided in **Figure 52**. Further detail and calibration results are provided in **Appendix A**.

The estimated overtopping discharge volumes were added to the hydrodynamic model to include an additional coastal process that can cause inundation but is otherwise unresolved in the coupled spectral wave and hydrodynamic modelling. Overtopping volumes were estimated for a 12-hour tidal curve representing a 500-year ARI still water level event (see, **Figure 51**). An allowance for wave-driven setup has been conservatively added to the 500-year still water level as a constant increase in water level over the simulation period (see adopted allowances in **Section 5.4.1**).

The calculated overtopping discharges have then been applied on the landward side of existing coastal protection structures on West Island as lateral inflow sources (i.e. litres/second/metre of structure crest) in the coupled spectral wave and hydrodynamic model.

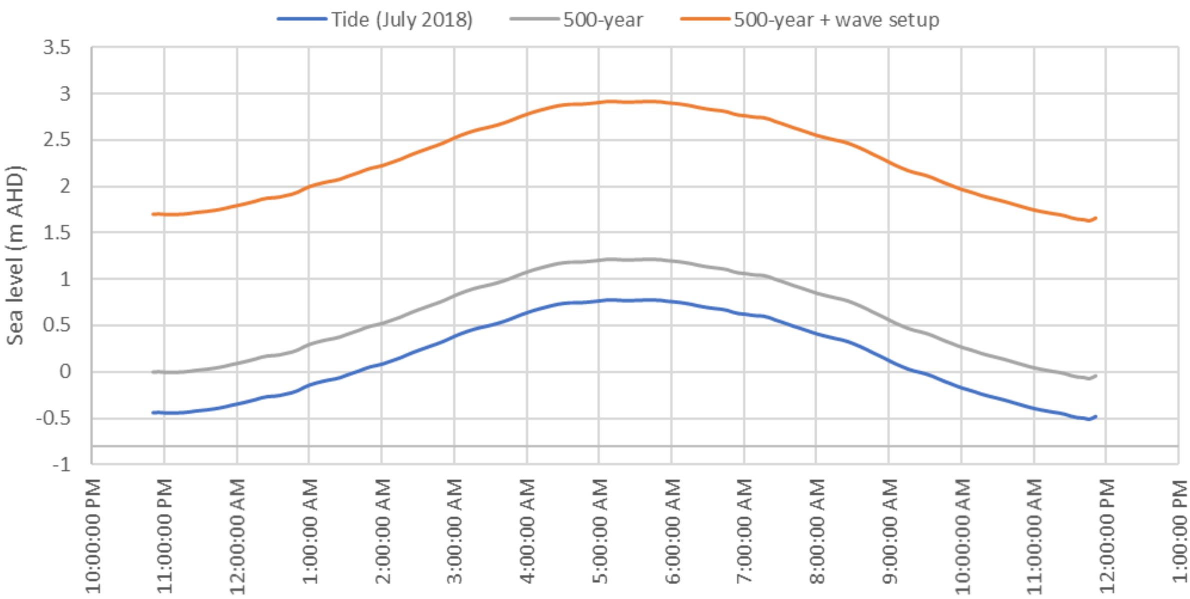


Figure 51: Still water level and wave setup allowance used to determine overtopping volumes at the ocean-facing coast at West Island.

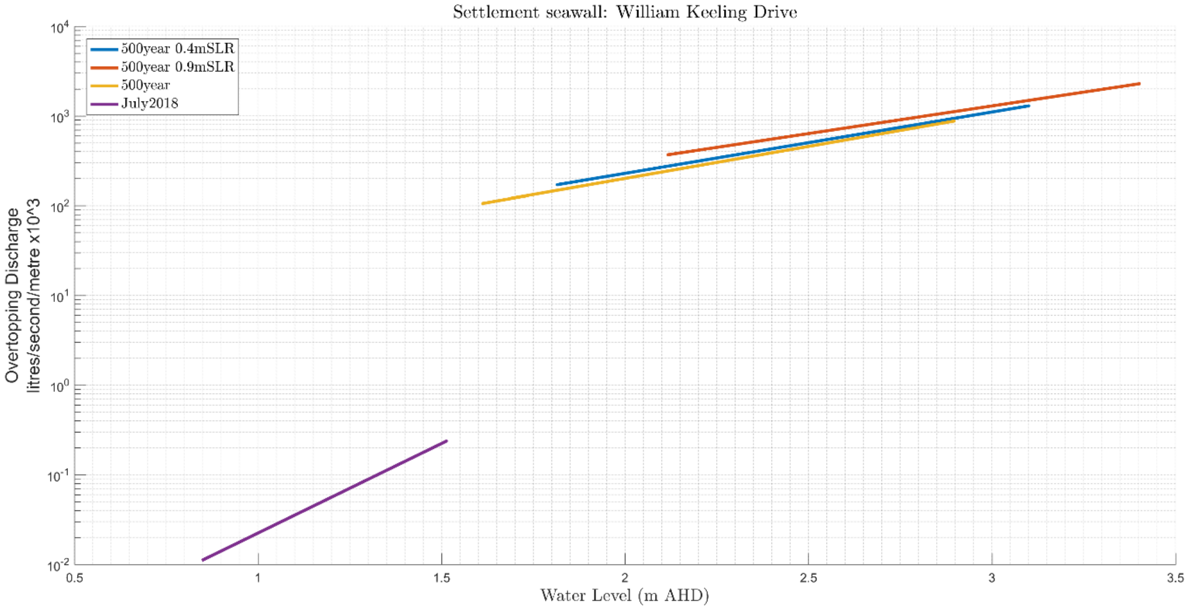


Figure 52: Example of estimated wave overtopping discharge volumes at the William Keeling Drive geotextile sand container revetment for a range of wave and water level scenarios.

5.4 Coastal inundation mapping

5.4.1 Adopted sea level allowances

As per the SPP 2.6 Guidelines, the S4 allowance for the current risk of inundation should be the maximum extent of storm inundation, defined as the peak steady water level plus wave-driven water level. These have been defined as:

- Peak steady water level, i.e. tide, storm surge and sea level rise.
- Wave-driven water level, i.e. wave setup and wave runup.

The coastal inundation assessment is to be completed with reference to an event with a 0.2% chance of exceedance per year, otherwise referred to as the 500-year ARI event. In order to define the peak steady water level and wave-driven water levels for a 500-year ARI storm within the study area, a hybrid approach using empirical and numerical modelling have been used, as described in **Section 5.3**. The adopted allowances for the ocean exposed, both west-facing (e.g. West Island) and east-facing coasts (e.g. South Island and Home Island), as well as lagoon facing coastlines for each of the planning timeframes are summarised in **Table 16**.

A high uncertainty remains for the future planning horizons and the ability of the fringing coral reef to vertically grow as sea levels are rising. In this study it has been assumed the coral reef crest and platforms are static. Studies around the globe have indicated that healthy corals can grow at a similar rate as sea level rise (e.g. Storlazzi et. al, 2018) and that vertical reef accretion in response to SLR may prevent any significant increase in shoreline wave energy and mitigate wave-driven flooding volume by 72% based on a study on a coral atoll in Tuvalu (Beetham et al., 2017). This could significantly reduce the wave-driven allowances for the future sea level rise scenarios applied herein and therefore reduce predicted overwash and overtopping volumes.

Table 16: 500-year ARI sea level allowances for each of the planning timeframes and western ocean facing, eastern ocean facing and lagoon facing coastlines.

Component	**Planning Horizon**								
	2018			2068			2118		
Shoreline location	Western	Eastern	Lagoon	Western	Eastern	Lagoon	Western	Eastern	Lagoon
500-year ARI peak water level (no wave setup) (m AHD)	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Allowance for sea level rise (m)	0	0	0	0.4	0.4	0.4	0.9	0.9	0.9
Peak steady water level at the shoreline (m AHD)	1.2	1.2	1.2	1.6	1.6	1.6	2.1	2.1	2.1
Allowance for nearshore wave setup (m)	1.7	1.0	0.0*	1.5	1.0	0.0*	1.3	1.0	0.0*
Allowance for wave runup (m)	0.6	0.5	0.0	0.6	0.5	0.0	0.6	0.5	0.0
Peak steady water level + wave-driven water level (m AHD)	3.5	2.7	1.2	3.7	3.1	1.6	4.0	3.6	2.1

*wind/wave setup allowance within the central lagoon areas is included in the peak water level

5.4.2 Limitations

There are some key limitations that require consideration for the inundation assessment presented herein, including:

- Wave overwash of the coastal barrier is a key process contributing to inundation of low-lying areas of the Cocos (Keeling) Islands but given the limitations of the coupled spectral wave and hydrodynamic model described in Section 4.3.1 and Section 4.4, this process is not accurately represented in the simulations. Hence, overwash driven inundation extents and depth could not be derived. Indicative areas of overwash areas have been provided for consideration.

- No allowance for sea water infiltration into the ground or morphology change was included in the modelling which may affect the predicted inundation extents and depths.

5.4.3 Overwash areas

Wave-driven overwash is an important coastal process on the Cocos (Keeling) Islands and coral atolls (Storlazzi et al, 2015). This process influences sediment transport and island building but can also lead to coastal inundation. However, to numerically simulate overwash (or overtopping) processes at the beach ridges along the ocean-facing coast, a minimum two-dimensional, phase-resolving nearshore wave and hydrodynamic model for the entire southern atoll would be required. This task does not form part of the scope of this study and hence, overwash must be considered using other techniques.

Given the estimated wave setup and runup levels on the ocean-facing shoreline, overwash would only be expected to result in frequent inundation of low-lying areas. For example where there is a beach ridge (see orange areas in **Figure 53**). Where there is a wind-blown dune (see red areas in **Figure 53**, for example at West Island settlement and much of South Island) the coastal barrier is higher and no overwash would be expected.

The adopted 500-year ARI inshore wave setup and runup levels result in a total wave-driven sea level of 2.3m on top of the 500-year ARI still water level of 1.2m AHD on the western ocean facing coastline (i.e. total sea level of 3.5m AHD). At the eastern ocean facing coastline, the wave-driven component is 1.5m on top of the 500-year ARI still water level of 1.2m AHD (i.e. total sea level of 2.7m AHD). These have been adopted for the entire southern atoll to assess where wave-driven overwash would occur. The sections of the ocean-facing coastline where overwash would occur because the beach ridge or dune elevation is lower than the combined 500-year ARI still water and wave-driven sea level are shown in **Figure 53** to **Figure 55** for the 2018, 2068 and 2118 planning periods including 0.4m and 0.9m sea level rise, respectively.

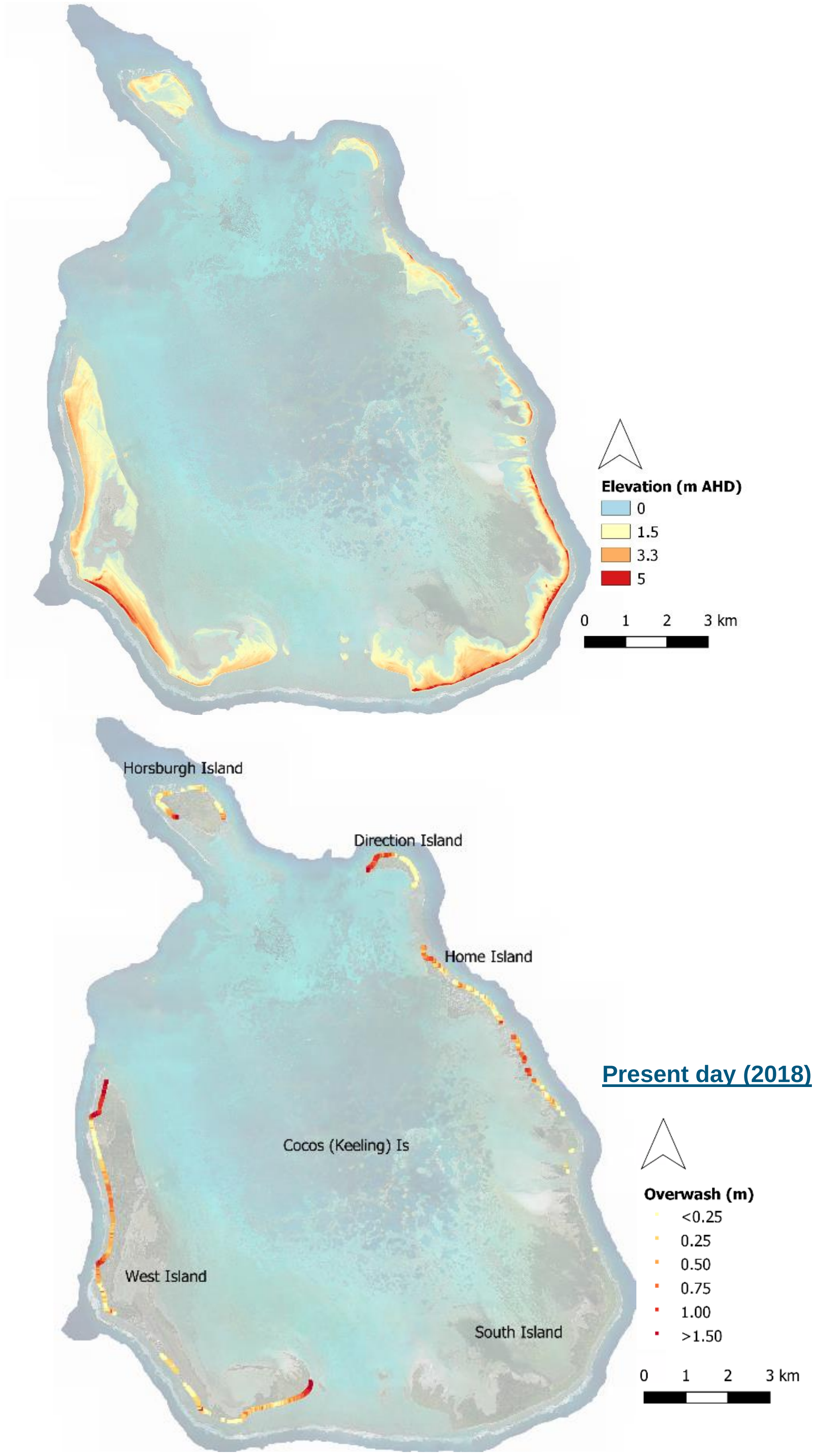


Figure 53: (top) Elevation map of the southern atoll islands in 2018 (bottom) areas where overwash would occur during a 500-year ARI combined still water and wave-driven sea level for the 2018 planning period and associated overwash level above coastal barrier elevation level.

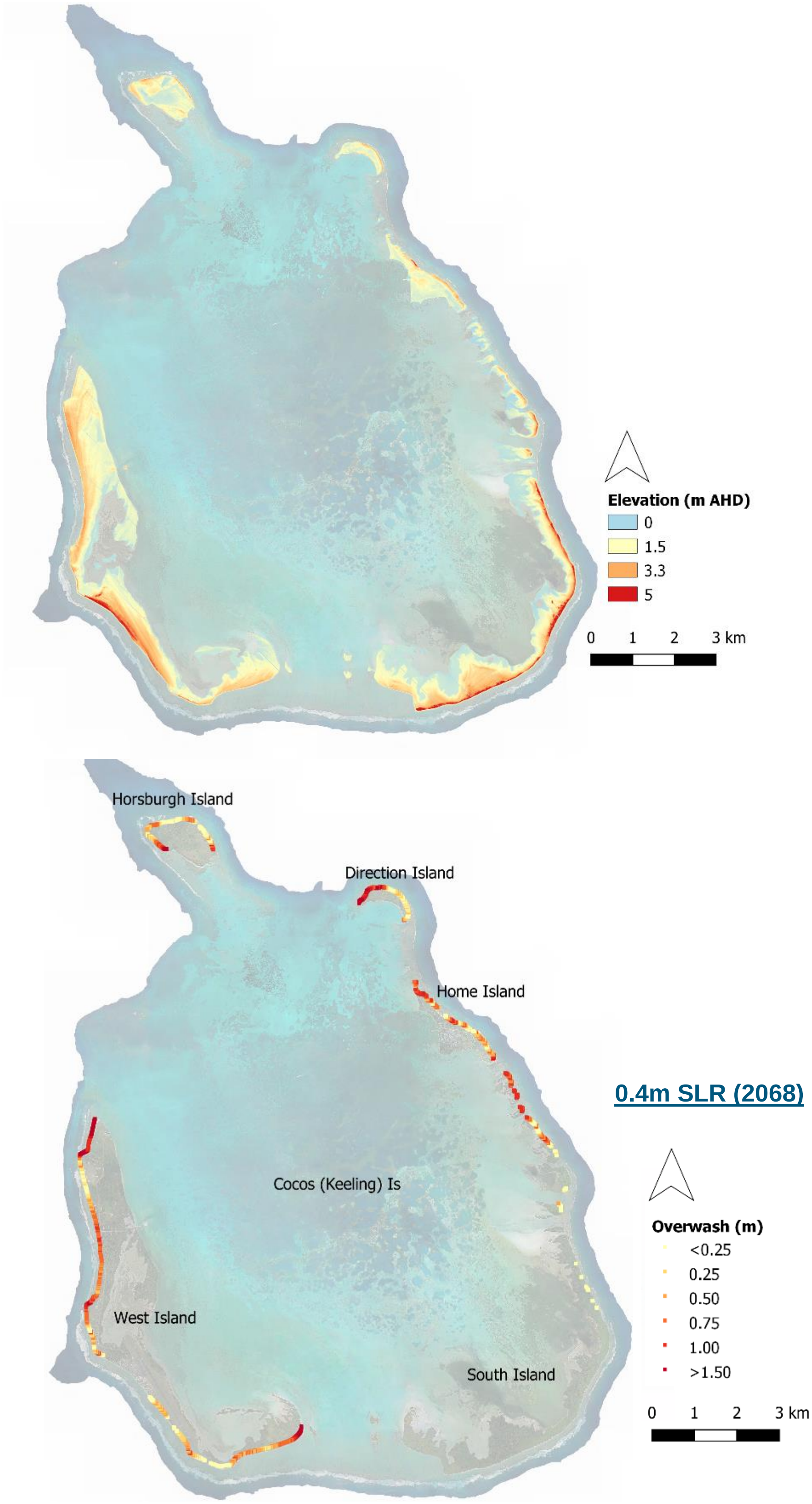


Figure 54: (top) Elevation map of the southern atoll islands in 2018 (bottom) areas where overwash would occur during a 500-year ARI combined still water and wave-driven sea level for the 2068 planning period and associated overwash level above coastal barrier elevation level.

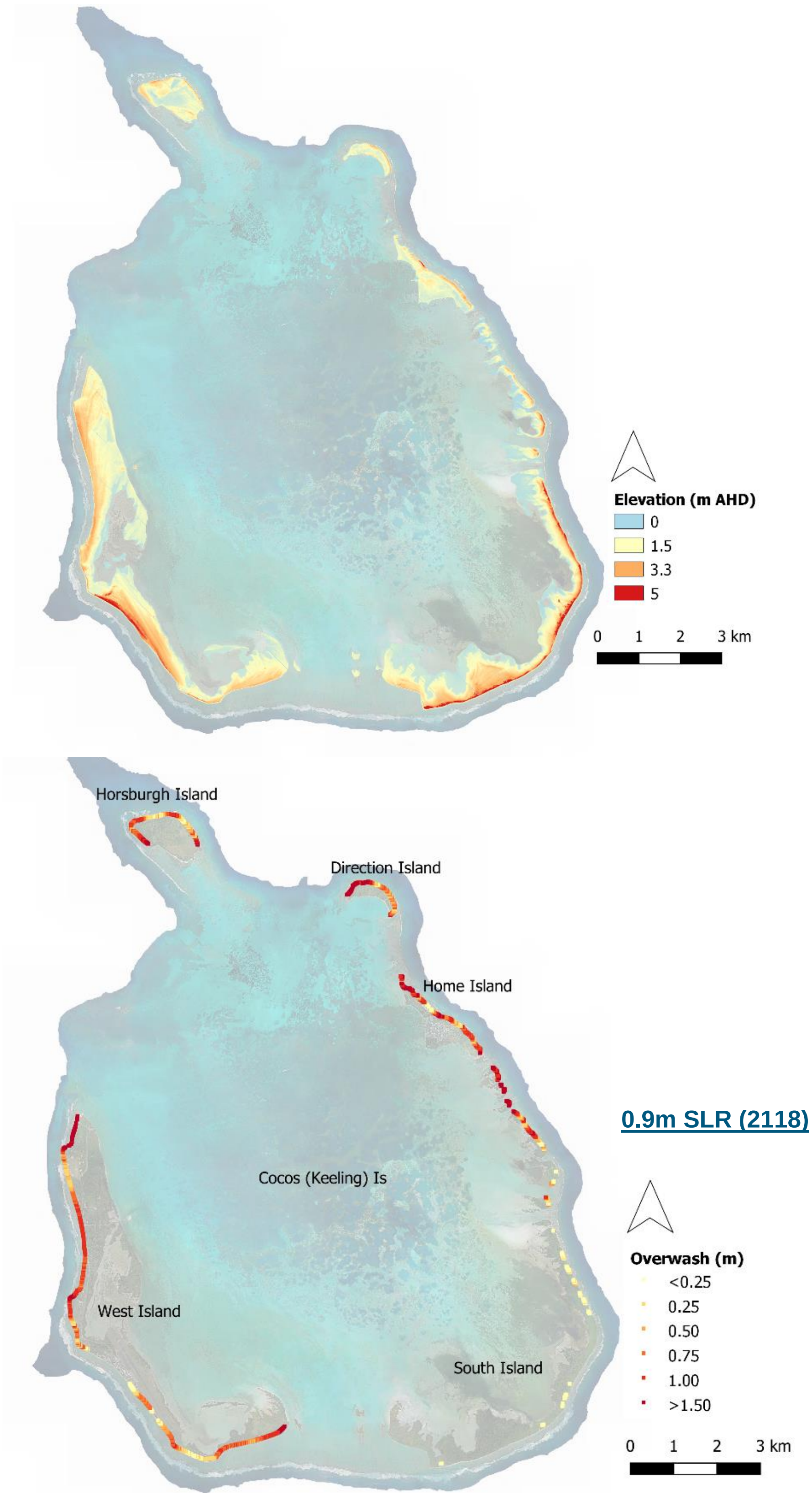


Figure 55: (top) Elevation map of the southern atoll islands in 2018 (bottom) areas where overwash would occur during a 500-year ARI combined still water and wave-driven sea level for the 2118 planning period and associated overwash level above coastal barrier elevation level.

5.4.4 Still water inundation

Still water inundation maps for the 2018, 2068 and 2118 planning periods are presented in **Appendix B**. This provides the maximum inundation extent and depth, duration and maximum flow speeds over the 13-hour simulation period for peak steady water levels only, i.e. the 500-year ARI tide and surge water level. No wave-driven sea level allowances are included in the still water level inundation maps.

5.4.5 Wave-driven inundation

Wave-driven inundation maps for the 2018, 2068 and 2118 planning periods are presented in **Figure A1** to **Figure A6** in **Volume II** of this report. These present the maximum inundation extent and depth over the 13-hour simulation period for peak steady water levels (i.e., still water levels) plus an allowance for wave-driven water levels, including overtopping of coastal structures.

While the coupled spectral wave and hydrodynamic model were forced with a 500-year still water level and a 500-year wave event concurrently, due to the limitation of the spectral wave model the process of overwash of the coastal barrier is not accurately represented. To overcome this limitation, the areas where overwash is expected (see **Figure 53**) to occur because of the coastal barrier elevation is lower than the combined wave setup and runup estimates from the Xbeach modelling are graphically shown on the maps in **Volume II**. However, these do not showcase the overwash volumes and associated inundation depths, flow magnitudes or inundation duration. A comparison of the simulated sea levels at the shoreline (i.e. where wave setup and runup occurs) from the coupled spectral wave and hydrodynamic model and the Xbeach results, indicated that the coupled model underestimates this by over 1m.

Consideration of the model limitation should therefore be made when interpreting the maps presented.

Additional inundation maps showing the inundation depth, duration and maximum flow speeds are provided in **Appendix B**.

6 Shoreline stability assessment

6.1 Preamble

An assessment of the shoreline stability considering the sediment transport characteristics and geomorphological responses at the Cocos (Keeling) Islands is required. Shoreline stability has been quantified following the requirements of SPP 2.6 including existing conditions and long-term climate change projections.

The two main inhabited islands of West Island and Home Island form the study area for the shoreline stability assessment. The approach adopted to quantifying shoreline stability in the study area is outlined as:

- Available data related to the stability of the islands' shorelines was analysed, this included aerial photography, vegetation lines and drone surveys;
- Storm erosion modelling using:
    - XBeach - for ocean-facing shorelines
    - SBeach - for lagoon-facing beaches;
- Conceptual coastal processes model that incorporates the knowledge gained from the above tasks as well as broader knowledge of atoll environments and two-dimensional sediment transport modelling;
- Mapping of the appropriate coastal processes allowance (CPA) distance due to erosion hazard as per SPP 2.6.

6.2 Study area and management units

The study area has been broken into nine management units. The management units define sections of the coastline which share similar characteristics and provides a framework for monitoring and management as part of the CHRMAP. The definition of management unit has been based on geological features, exposure, assets and other factors. The management units are listed with a description of their characteristics in Table 17 and are illustrated in **Figure 56** and **Figure 57** for West Island and Home Island, respectively. Typical photos of each unit are also provided in **Figure 58**.

Table 17: Management unit characteristics.

Management Unit	Characteristics
MU1 West Island Settlement	Section of shoreline fronting the ocean side of the main settlement on West Island. Having undergone significant human modifications, much of the shoreline is protected by formal coastal protection structures. North of the protected shoreline the beach is receding and prone to erosion.
MU2 West Island, ocean-facing (north)	This section of the coastline is less prone to erosion but is receding with an increase in the rate of recession to the north. This coastline is largely undeveloped but contains several popular recreational areas including the Shack and Trannies Beach. Sydney Highway, the islands only northern road runs close to the shoreline at places.
MU3 West Island, lagoon-facing	The northern lagoon shoreline of West Island is dynamic whereas the central and southern sections are stable. Part from the section along the airfield and the Old Fuel Jetty, it is also largely undeveloped. It contains two smaller lagoons South Lagoon and North Lagoon as well as some straighter sections of shoreline.
MU4 West Island, Rumah Baru	Rumah Baru is located on the eastern (lagoon) shores of West Island. This port facility was constructed in 2011 and provides the ferry terminal for the service to Home Island and Direction Island. As well as being a highly developed, the shoreline itself has different behaviour to adjacent lagoon shores with a salient feature inshore of the island terminal and erosion downdrift (to south).
MU5 Scout Park/Kite Beach	This section of shoreline has been accreting (growing) over recent years. It also has little exposure to storm waves and is not susceptible to storm erosion. It is an important recreational area for tourists as this is where lagoon tours depart from and visiting kite boarders can often be found.
MU6 West Island, ocean-facing (south)	This shoreline has been relatively stable historically but has the greatest exposure to storm waves and erosion. It contains the narrowest section of the island that is low-lying and suspectable to overwash, inundation and possible breach. The main southern road Air Force Drive connects the rest of West Island to Scout Park and Kite Beach.
MU7 Home Island Settlement	This section fronts the lagoon facing shoreline around the Home Island settlement. **MU7a** comprises of the formal protection (revetment) along the Jalan Pantai Road that extends south from the harbour jetty and main ferry terminal to West Island and Direction Island. **MU7b** includes the southern coastline of Home Island which is a low lying natural (unprotected) sandy shoreline but typically stable and exposed to a low wave climate with low storm erosion potential. As such coastal inundation is the greater hazard at this location.
MU8 Home Island, ocean-facing	This section of shoreline has been accreting (growing) or stable in recent years. This section of shoreline also has the greatest exposure to storm events, particularly tropical cyclones, and it is susceptible to storm erosion. However, it can rebuild and naturally repair. In the short-term it is expected to be stable with a good natural buffer to shoreward assets.
MU9 Home Island, lagoon-facing	This section of shoreline is the sandy lagoon facing Turtle or Sandy Beach. This is an important recreational beach. It is also differentiated because of its importance for coastal management (i.e. current practice of sand extraction) as it has several shoreward assets.

Royal HaskoningDHV

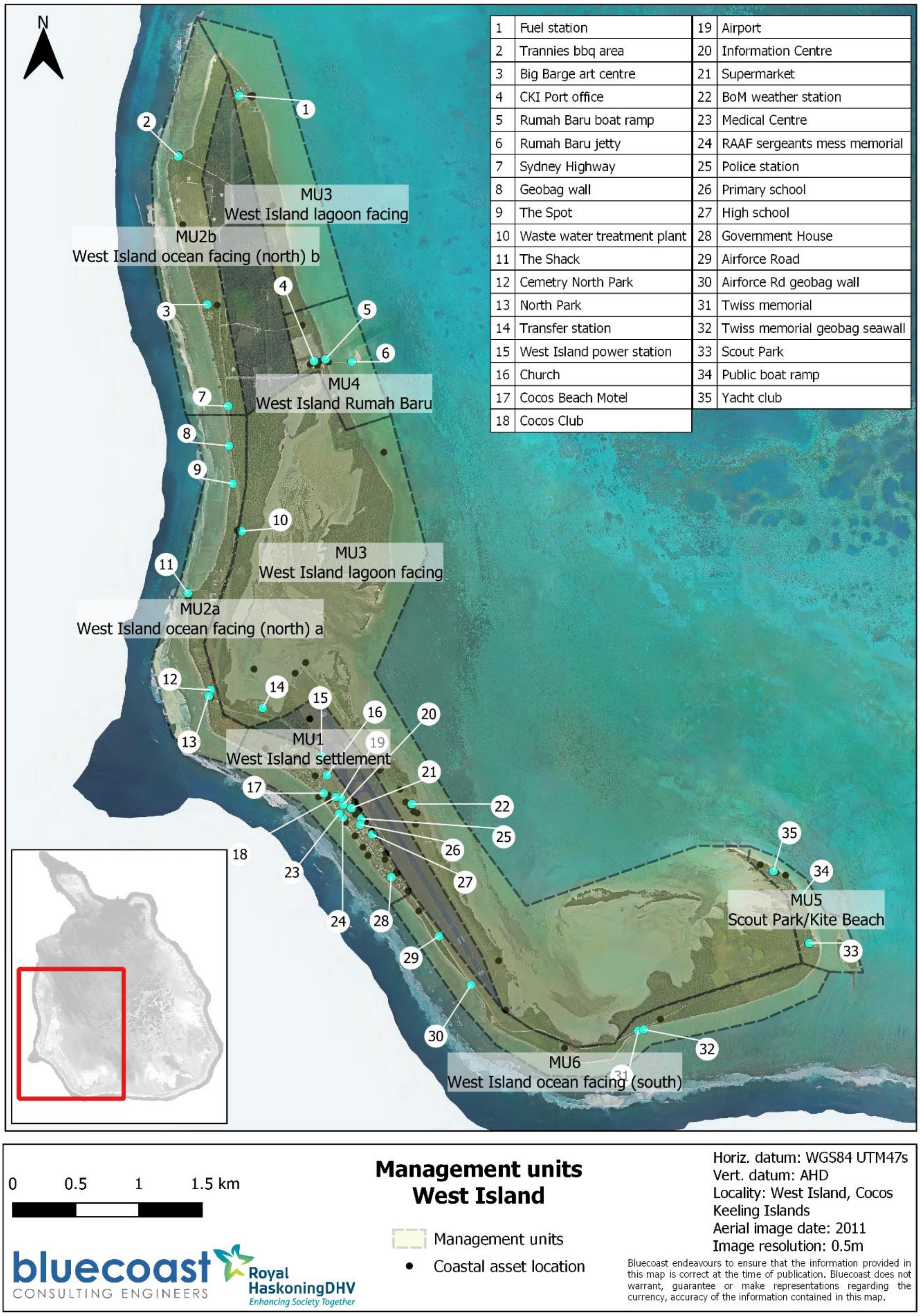


Figure 56: West Island management units.

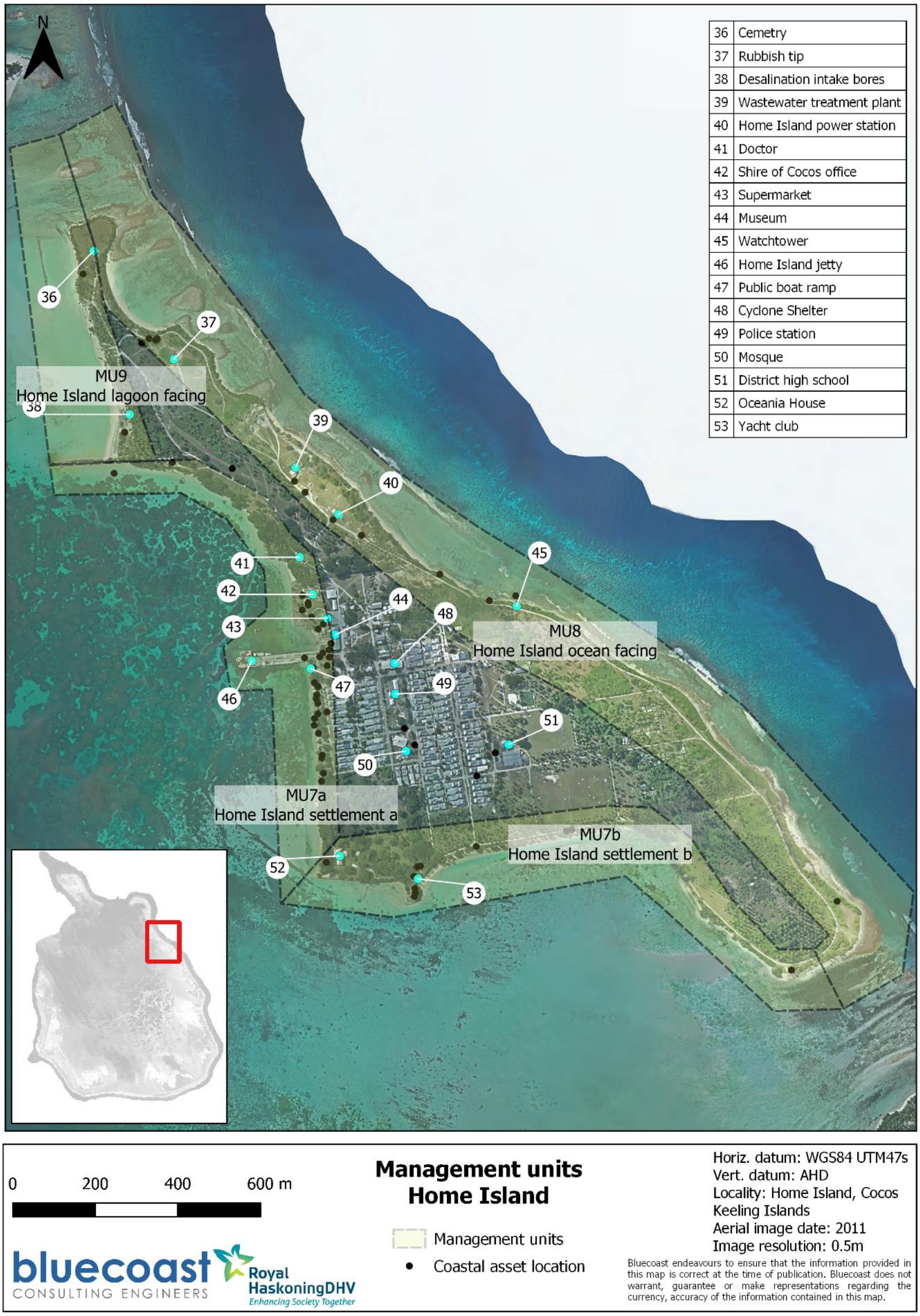


Figure 57: Home Island management units.

MU1: West Island Settlement

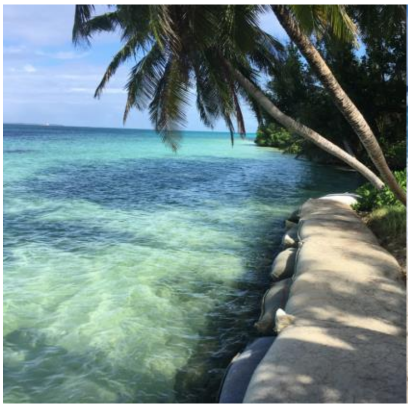
MU2: West Island, ocean-facing (north)

MU3: West Island, lagoon-facing

MU4: West Island, Rumah Baru

MU5: Scout Park/Kite Beach

MU6: West Island, ocean-facing (south)



MU7: Home Island Settlement

MU8: Home Island, ocean-facing

MU9: Home Island, lagoon-facing

Figure 58: Typical photos of for each management unit.

6.3 Shoreline structures, seabed and sediment information

6.3.1 Coastal protection structures

Known coastal structures are documented in the Field Investigation Summary (DoT, 2017) and in a similar report by DoT in 2010. **Table 18** presents a list of the Cocos (Keeling) Islands coastal structures including; the location, structure type, date of construction and condition. As illustrated in the timeline provided in **Figure 59**, six (6) coastal structures were constructed between 2010 and 2013, with a further four (4) introduced between 2015 and 2017.

Table 18: List of CKI coastal structures (source: DoT, 2017 and DoT, 2010).

Structure name	Structure type	Length (m)	Date installed	Condition
Fuel farm revetment	GSC revetment: 5-6 bags high	143	2012	Fair
Trannies revetment	GSC revetment: 3-4 bags high	56	2012	Fair
Sydney HWY revetment	GSC revetment: 6-7 bags high	300	2015	Good
Hospital revetment	GSC revetment: 12 bags high	46	2013	Fair
William Keeling revetment	GSC revetment: 12 bags high with concrete at terminus	411	2017	Good
Settlement concrete seawall	Concrete planks inserted between steel bearing pile sections (at 5m spacing)	60	1975	Poor
Runway revetment	GSC revetment: 7-8 bags high	80	2012 (?)	Fair
Twiss revetment	GSC revetment: 3-4 bags high	65	2017	Good
North lagoon revetment	GSC revetment: 2-3 bags high	28	2013	Good
Nek Jamil revetment	GSC revetment: 3-4 bags high	77	2017	Good
Jalan Pantai revetment	GSC revetment: 4-5 bags high	346	2013	Good

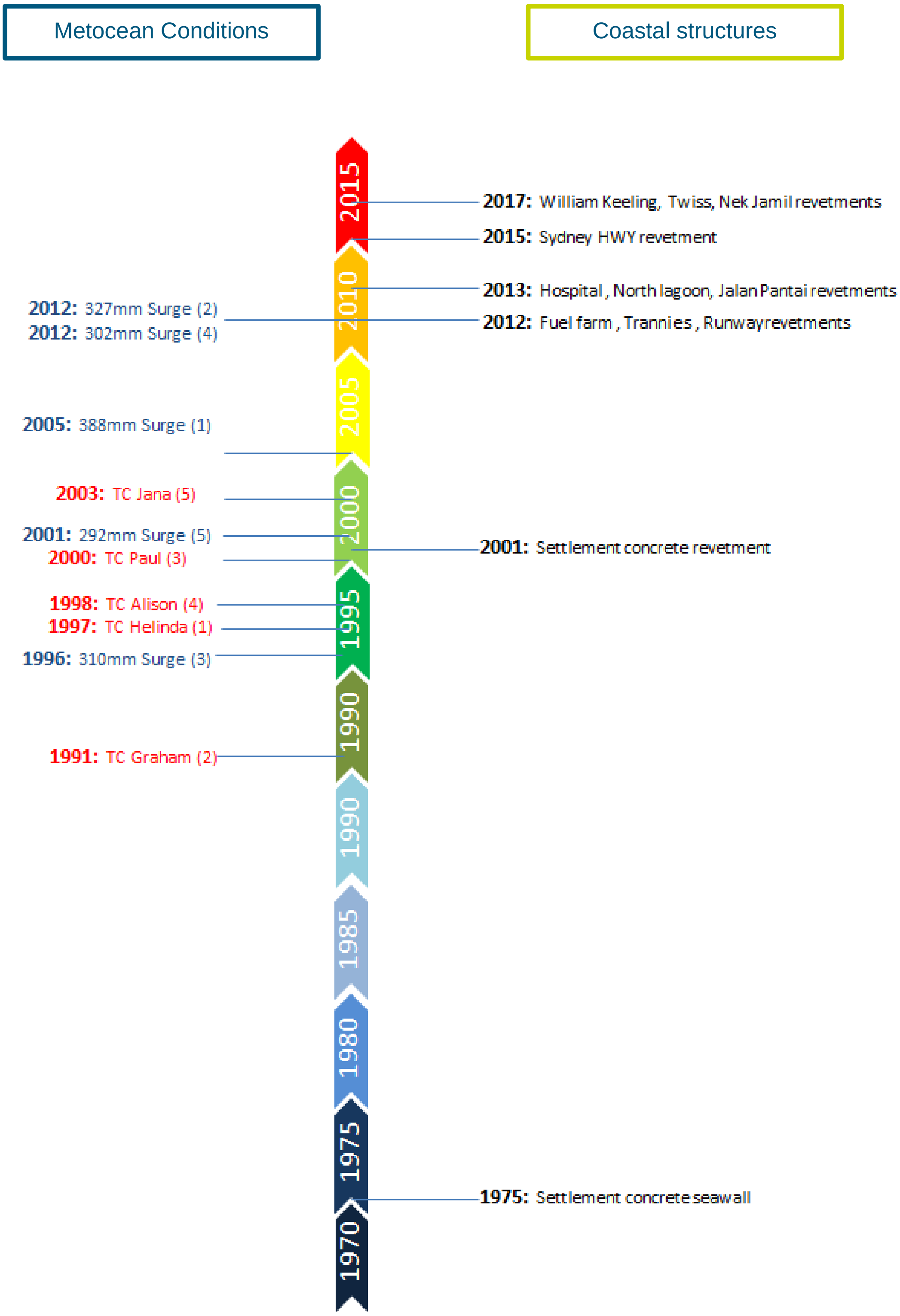


Figure 59 Timeline of CKI coastal structures and metocean conditions.

6.3.2 Seafloor mapping

Seabed features maps are useful in understanding area of active coastal change (i.e. sand movements), defining the bed friction and material type susceptibility to erosion. GHD (2017b) provides seafloor information based on processed satellite imagery data received from EOMAP. The composition and classification of seafloor is shown in **Figure 60**.

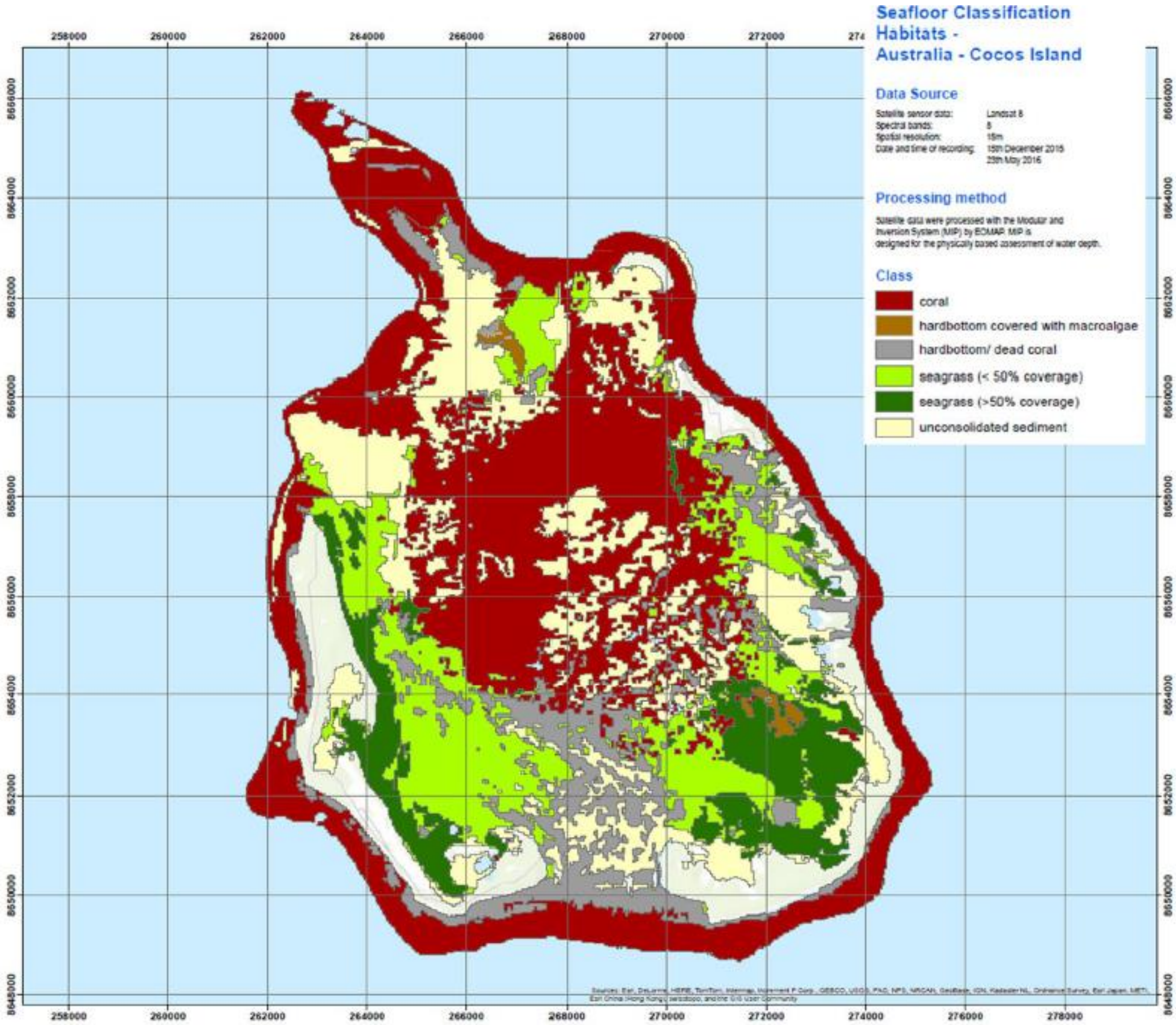


Figure 60: Seafloor mapping (source: EOMAP 2016 as seen in GHD, 2017).

6.3.3 Sediment data

Sediment data can provide important information about morphology and is also required for sediment transport modelling. Sediment data has been collected and analysed in several previous investigations at the Cocos (Keeling) Islands, the most significant of which are:

- DoT (2017) collected 17 sediment samples at the locations shown in **Figure 61**. Samples were collected from a variety of depths and include ocean and lagoon side sample locations. These samples were analysed using laser particle size analysis with the results presented in **Table 19** (samples with the 'SS' pre-fix). **Figure 61** also providing the grain sizes (D_{10}, D_{50} and D_{90}) showing the spatial variability of the observed grain sizes.
- In 2010, DoT collected and analysed four (4) samples, one from a Home Island beach and the other three from West Island beaches. While the exact locations of these samples were not presented, approximate location and grain sizes can be seen in **Table 19** (samples with the 'Cocos' pre-fix).
- A few other investigations (e.g. GHD, 2014) have included sediment data at the Cocos (Keeling) Islands with reported grain sizes in the ranges observed in the DoT 2017 and DoT 2010 observations.

As seen in **Figure 62**, sediment grain sizes across the Cocos (Keeling) Islands vary markedly from finer grained sand (D_{50} of 0.21mm) to coarse sand (D_{50} of 0.74mm). Coarser material was typically encountered on the ocean side beaches, particularly at the exposed southern end of West Island as well as the less exposed northern end of West Island. Sand samples from ocean beaches also contained intact shell material (DoT, 2010). The coarse nature of the sand found on the ocean beaches indicates the higher wave energy that these beaches are exposed to. The ocean beaches on Home Island were seen to contain generally finer material than the ocean beaches of West Island. Some of the beaches along the ocean side of West Island and Home Island consist of coral gravel and coral boulders with very little sand sized sediment. Sediment samples taken from the ocean side of West Island suggest that ocean beaches are also dominated by biogenic sediments.

The median grain size (D_{50}) observed in lagoon samples were considerably finer than that found on the ocean beaches which typically ranged from 0.25 to 0.40mm (medium grained sand). These observations suggest that ocean side deposits are newer and originate from the reef, whereas the lagoon sediments have been broken down as they were transported from the ocean beaches into the lagoon. The lagoon beaches on CKI are characterised by narrow white calcareous sandy beaches with a relatively flat beach face. They are sheltered beaches containing finer grained sand that has deposited in accordance with the low energy wave conditions of the lagoon.

At the deeper offshore sites (SS01, SS02, SS03 and SS16), the sand was medium grained but the grain sizes varied depending on the locations.

From the collation of the Cocos (Keeling) Islands sediment samples it appears that there are a few important 'gradients' in grain size that reflect the nature of the sediment supplied to the islands; from breakdown of the fringing coral reefs and shells as well as the coastal processes that redistribute sediments around the islands.

Table 19: Summary of the Cocos (Keeling) Islands sediment data – arranged from fine to coarse.

Sample ID	Location	Depositional Environment	Depth (m)	Sediment Sizes (mm)		
				D10	D50	D90
SS01	Offshore	Ocean side nearshore	-7.3	0.12	0.21	0.35
Cocos2	Home Island	Lagoon beach (northern beach)		0.16	0.22	0.27
SS16	Offshore	Protected shoal	-6	0.15	0.25	0.45
SS12*	Home Island	Lagoon (stockpile)	2.2	0.15	0.28	0.70
SS11	Home Island	Lagoon beach	1.2	0.17	0.32	0.62
SS13*	Home Island	Land sample	2.7	0.06	0.33	0.93
SS03	Offshore	Western Entrance Channel	-5.4	0.20	0.40	0.83
SS05	West Island	Lagoon beach	0.6	0.27	0.43	0.66
SS09	West Island	Ocean beach	1.4	0.18	0.43	0.90
Cocos1	West Island	Lagoon (Cocos Yacht Club)		0.24	0.46	0.74
Cocos3	West Island	Ocean beach (near R.B.)		0.22	0.48	0.89
SS08	West Island	Ocean beach	1.6	0.28	0.50	0.85
SS02	Offshore	Ocean side nearshore	-10.3	0.29	0.50	0.86
SS15	Home Island	Lagoon beach (south facing)	0.7	0.28	0.54	0.97
SS04	West Island	Ocean beach	2	0.33	0.57	0.94
SS14	Home Island	Ocean beach	3.3	0.37	0.57	0.89
Cocos4	West Island	Ocean beach (North Park)		0.43	0.59	0.89
SS06	West Island	Ocean beach	2.4	0.35	0.59	1.00
SS07	West Island	Ocean beach	1.1	0.32	0.61	1.11
SS10	West Island	Ocean beach	1.7	0.40	0.72	1.26
SS17	West Island	Lagoon hoa deposition	1.8	0.38	0.74	1.32

**Taken from sand sourced for geotextile sand container construction source*

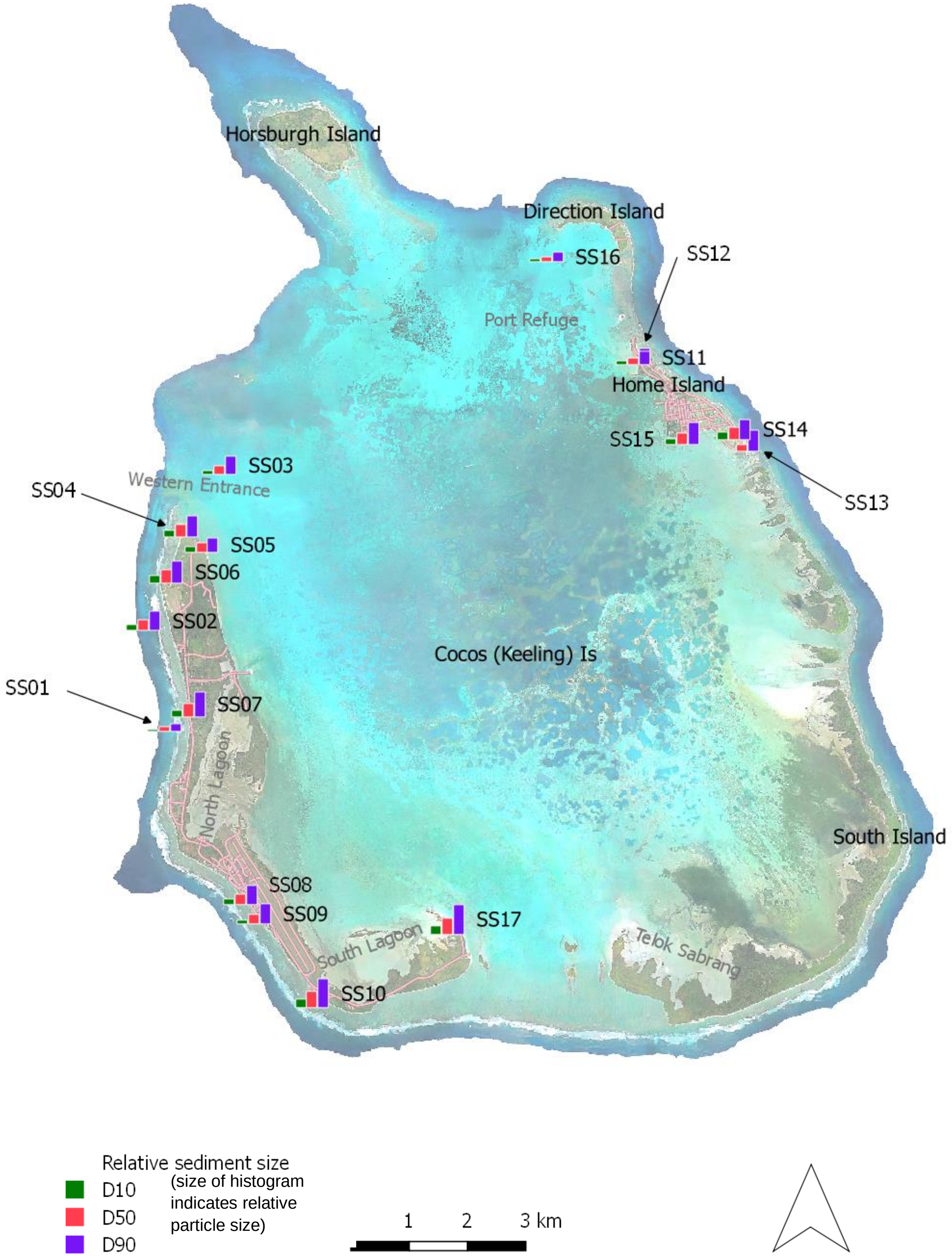


Figure 61: Map of DoT 2017 sediment grain sizes (source: DoT, 2017).

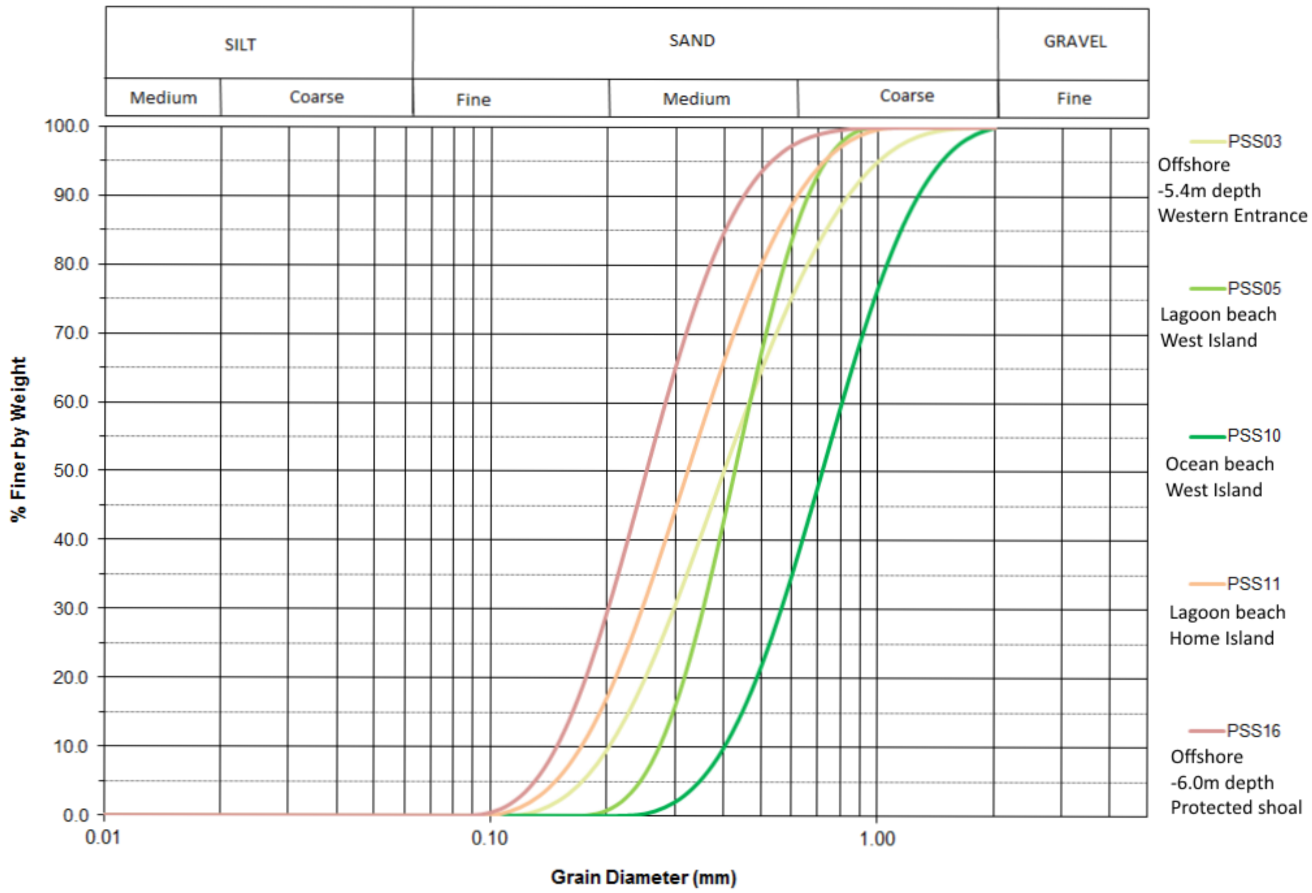


Figure 62: Example particle size distribution from the DoT sediment samples (source: DoT, 2017).

6.4 Historical shoreline change

Aerial photography and vegetation line position information spanning a 32-year period, from 1987 to 2019, was available for West Island and Home Island. The vegetation lines were used as an indicator of shoreline position defined as the alignment of the upper part of the beach and/or the vegetation. The vegetation line of each aerial photography was manually digitised by using a Geographic Information System tool. Close inspection and comparison of these images and vegetation lines reveals the long-term changes to beach planform within the study area. The accuracy of the position of these vegetation lines is believed to be in the order of plus/minus five metres, depending on the resolution of the aerial photographs and the rectification process.

These vegetation lines were analysed across the available dataset at selected locations on both West and Home Island. These locations were specially chosen as providing representative coverage of key areas as well as the location of coastal structures across both Islands. In some cases, these representative locations were split into sectors in order to accurately capture varying spatial trends. A complete overview of the analysis process can be found in **Appendix C**, but a summary of the key results is presented below in **Table 20**.

The results show that most of the ocean-facing beaches on West Island are experiencing recession (e.g. West Island Settlement, The Shack). Whilst numerous coastal protection structures exist at these locations, it is believed that these structures may be limiting the net longshore sediment transport resulting in downdrift deficits and subsequent erosion observed in some areas. Lagoon-facing vegetation lines have been more stable in areas where there was no interaction with coastal structures that alter the sediment drift.

The Home Island coast was observed to be less erosive, which may be the result of the lack of coastal structures modifying coastal processes. The vegetation lines along the ocean-facing coastline were observed to be stable, with the embayed Pulu Gangsa Beach observed to be accretionary over the analysis period. The two lagoon-facing analysis locations comprised revetments, and accretion was observed south of these structures in both cases.

Table 20: Summary of the vegetation line position analysis across all management units for both Islands.

West Island	Sector	Vegetation line status	Rate (m/year)
MU1 West Island Settlement *(ocean-facing)*	MU1-North	Recession	-0.30
	MU1-Middle	Recession	-0.16
	MU1-South	Recession	-0.02
MU2a The Shack *(ocean-facing)*	-	Recession	-2.63
MU2b Trannies beach *(ocean-facing)*	MU2b-North	Recession	-0.65
	MU2b-South	Recession / accretion	-0.65 / 1.219
MU3 Old Fuel Jetty *(lagoon-facing)*	MU3-North	Recession	-3.28
	MU3-South	Recession	-2.8
MU3 Lagoon-facing coast *(lagoon facing)*	-	Stable	-
MU4 Rumah Baru *(lagoon-facing)*	-	Stable	-
Home Island	**Sector**	**Vegetation line status**	**Rate (m/year)**
MU7 Jalan revetment *(lagoon-facing)*	MU7-North	Stable	-
	MU7-South	Accretion	0.59
MU8 Pulu Gangsa *(ocean-facing)*	-	Accretion	0.6
MU8 Ocean-facing coast *(ocean-facing)*	-	Stable	-

MU9 Turtle Beach *(lagoon-facing)*	MU9-North	Recession	-0.86
	MU9-Middle	Accretion	0.22
	MU9-South	Accretion	1.02

6.5 Storm erosion modelling

SPP 2.6 outlines that the S1 allowance (see **Section 6.7.1**) should provide an adequate buffer to accommodate the potential erosion caused by a storm with an annual encounter probability (AEP) of 1%. This is equivalent to a 100-year average recurrence interval (ARI) storm. For the Cocos (Keeling) Islands the erosion extents for a 100-year ARI storm have been assessed using XBeach for ocean-facing beaches and SBEACH for lagoon-facing beaches. A series of shoreline profiles were established across the study area and subjected to design water levels and wave heights representative of a 100-year ARI storm. The input beach profiles for the model were taken from the latest beach profile surveys (July 2018 and July 2019) undertaken as part of the CVA. The selected profiles used in the analysis are shown below in **Figure 63.**

Wind-driven current have not been specifically accounted for in the modelling and calculation of the S1 allowance. This is considered an acceptable and pragmatic approach given wave action and wave-driven currents are the key driver for shoreline change around Cocos (Keeling) Islands.

Note that this section provides a high-level summary of the approach and results of the modelling. A complete overview of the process can be found in **Appendix D**.

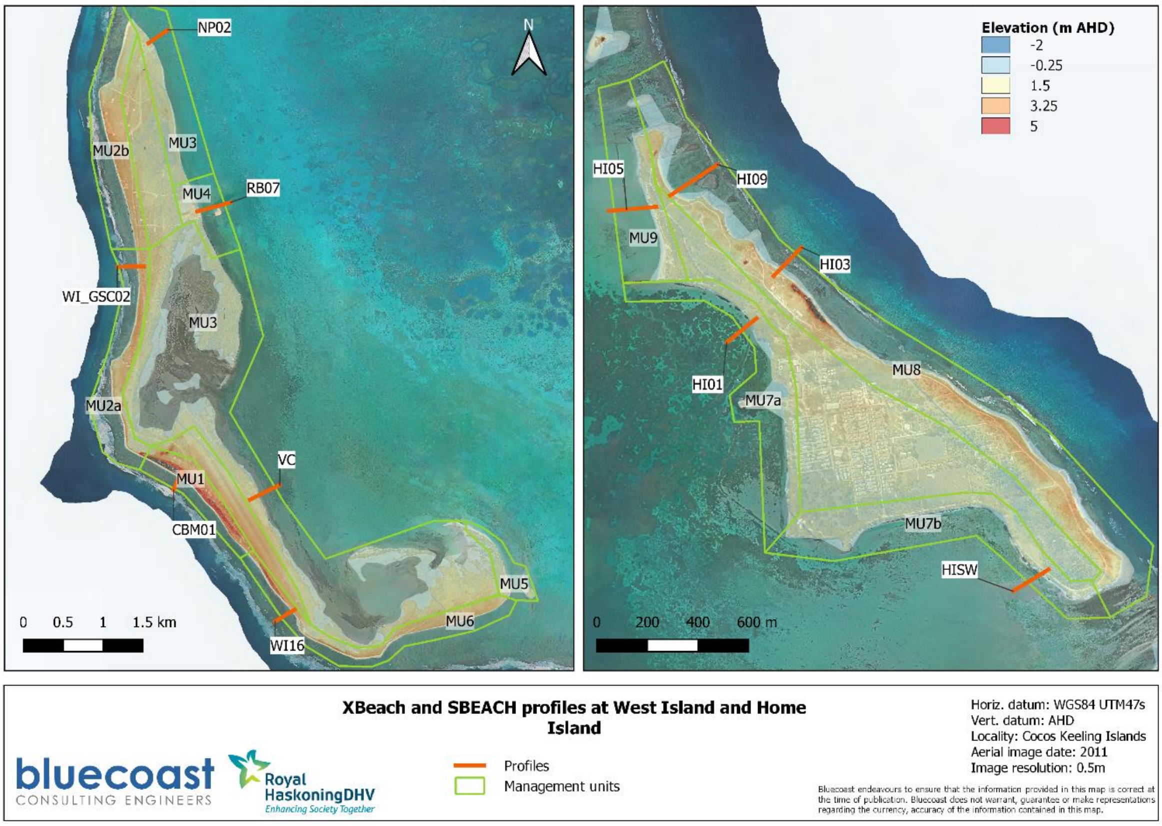


Figure 63: Selected ocean-facing and lagoon-facing profiles.

6.5.1 XBeach erosion model (ocean-facing shorelines)

The XBeach model was used to analyse the erosion extent for ocean-facing beaches. The XBeach model is a process-based model that is commonly used to determine nearshore morphological changes. It covers a wide set of cross-shore processes (i.e. return flow, wave asymmetry, wave rollers and long waves). The morphodynamic processes include bed load and suspended sediment transport, dune face avalanching, bed update and breaching. Because of the inclusion of long waves (or infragravity waves) XBeach is specifically suitable to model morphological changes of the nearshore area, beaches, dunes and backbarrier during storms.

Prior to being applied to the XBeach model wax calibrated for CKI open coastline conditions use observed wave, hydrodynamic and morphological conditions at the reef top monitoring sites at CK01 of West Island. The was described above in **Section 4.3.3** and in **Appendix D**. The profiles CBM01, WI16, HI09 and HI03 were selected as they are representative of each of the ocean-facing profiles (see Figure 63) across both Islands. CBM01 and WI16 profiles are erosion hot spots backed by residential lots and the airstrip, respectively. HI09 and HI03 are located at the only two beach areas on Home Island.

The key objective of the modelling was to determine the storm erosion allowance and maximum erosion allowances for shoreline movement. These values have been calculated on the basis of the modelling results and are presented in **Table 21**.

Table 21: Eroded sand volume, maximum allowance of the shoreline (level 0m) and the dune (level ~1m) for each profile and respective management unit.

Modelled profile	Management unit	Allowance distance (m)		Eroded volume (m^3/m)
		At 0m AHD shoreline	At ~1.5m AHD dune	
CBM0	MU1	24.1	-5.9	15.6
WI_GSC02	MU2	0.0	-0.5	3.36
WI16	MU6	15.3	-7.0	17.0
HI03	MU8	30.7	-7.1	24.0
HI09	MU8	19.9	-12.0	30.6

6.5.2 SBEACH erosion model (lagoon-facing shorelines)

Storm erosion along the lagoon-facing shoreline was investigated using the SBEACH numerical model. SBEACH is commonly used to assess the impact to the beach profile resulting from a severe storm event on sandy coastlines. SBEACH simulates the erosion and deposition of sand as large waves and elevated water levels reshape the shoreline. SBEACH model was not used to model ocean-facing profiles due to the complexity of the coast with the presence of coral reefs.

Consequential loss of beach area following large storm events is investigated to provide a measure of the beach area at risk from short term storm events (S1). SBEACH has been used extensively for this purpose in Western Australia and has been validated on several sandy coastlines, like those on the Cocos (Keeling) Islands lagoon (Rogers et al, 2005 and RHDHV, 2017). This validation has shown that SBEACH can provide useful and relevant predictions of the storm induced erosion, provided the inputs are correctly applied. The main inputs include a time series of storm wave heights, wave period and water level, as well as pre-storm beach profile and median sediment grain size.

As in the case of the XBeach results, the eroded sand volume as well as the maximum erosion allowance of the shoreline movement have been calculated on the basis of the SBEACH outputs for lagoon-facing shorelines and presented in **Table 22.**

Table 22: Eroded sand volume, maximum recession of the shoreline (level 0m) and the dune for each profile and respective management unit.

Profile	Management Unit	Allowance distance (m)		Eroded volume (m^3/m)
		Shoreline (0m AHD)	Dune (~1.5m AHD)	
HI05	MU9	-1.4	-0.5	12.6
HISW	MU7	-0.4	-0.1	0. 6
HI01	MU7	-5.0	-1.3	5.9
NP02	MU3	-1.5	-1.2	2.6
VC	MU3	0.0	0.0	2.4
RB07	MU4	-3.7	-2.0	7.1

6.6 Conceptual coastal processes model

Based on review of available data and literature, site observations, numerical modelling and understanding of coastal processes, a conceptual model of sediment transport processes in the study area has been developed. The conceptual model identifies sediment sources, sinks, pathways and vulnerable areas to assist the understanding coastal change both in the past and future.

Figure 64 and **Figure 65** provides a graphical overview of the conceptual coastal processes model, while the additional discussion below provides detail on the following elements:

- atoll geological setting including the island morphology
- climate and oceanographic setting of the atolls (i.e. wind, waves and sea level)
- atoll cross-shore processes including reef derived sediment production and onshore (one-way) movement of sediment leading to accumulation of sediment on the islands and within the lagoon
- longshore transport and plan form shape of the Cocos atoll islands
- morphodynamic response to sea level rise

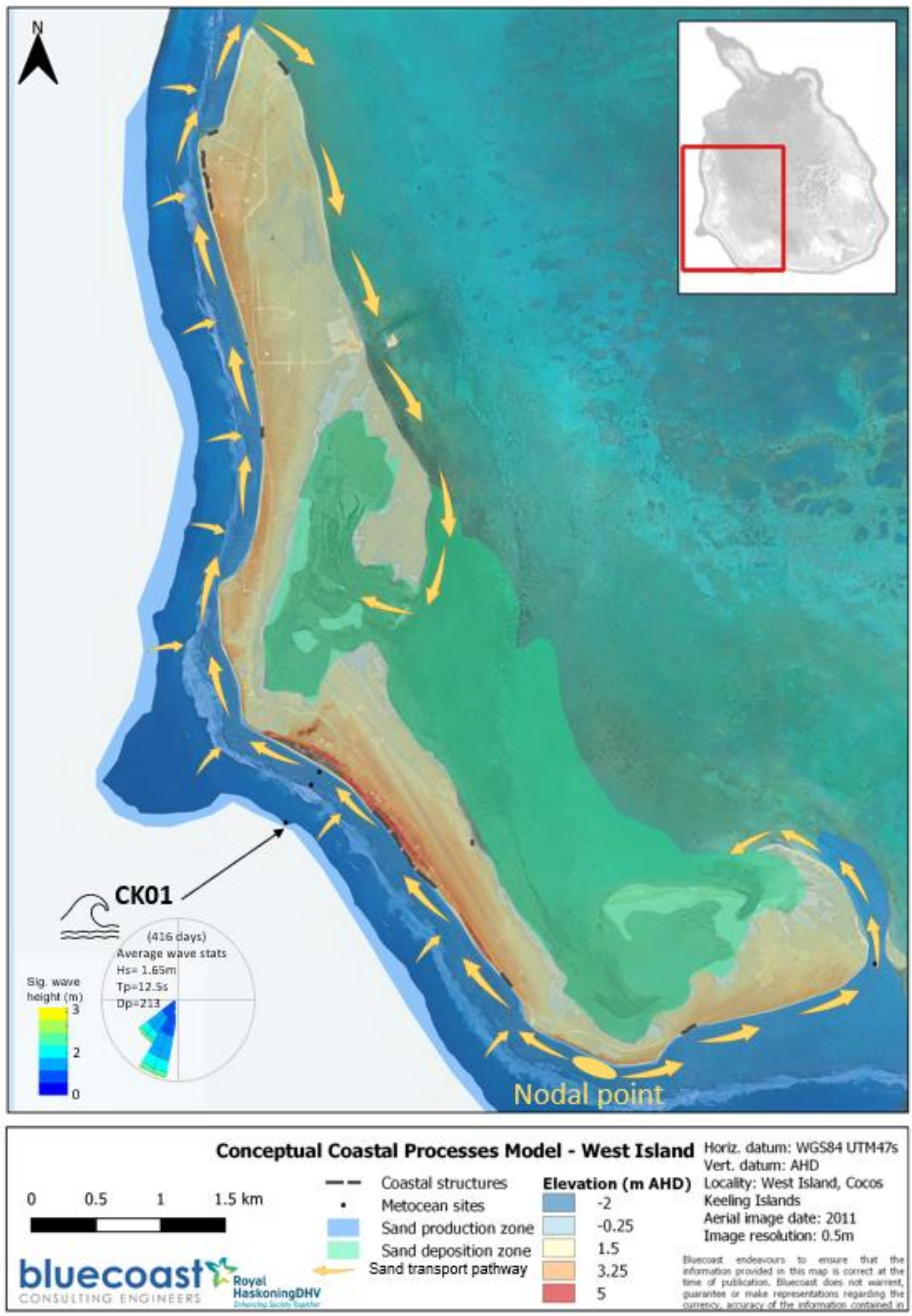


Figure 64: Conceptual coastal processes model for West Island.

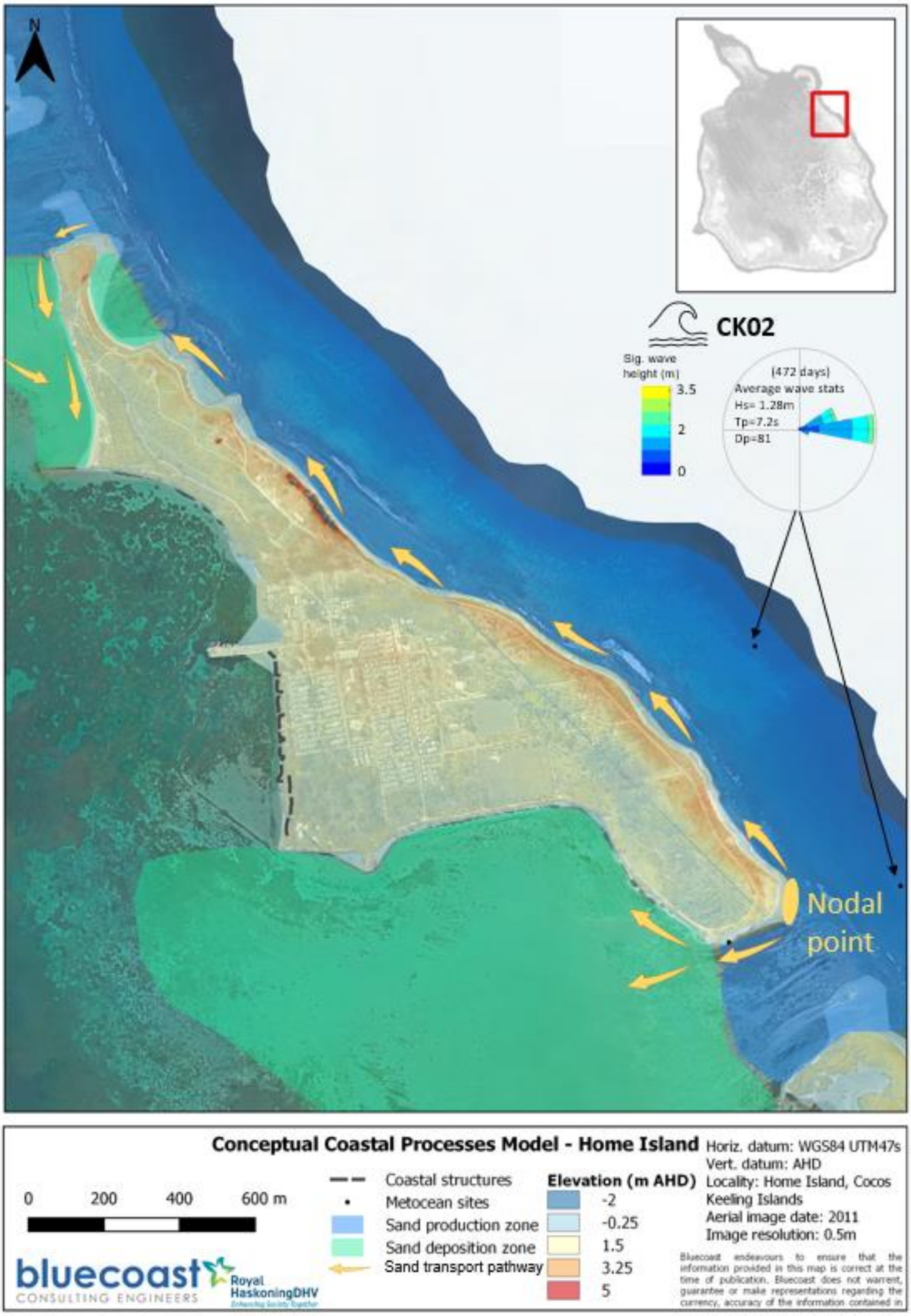


Figure 65: Conceptual coastal processes model for Home Island.

6.6.1 Atoll setting and island morphology

Atoll structure is best understood as a response to gradual subsidence as proposed by Charles Darwin in his theory of coral reef formation (Darwin, 1842). Darwin's theory of prolonged subsidence of volcanic island core together with the upward growth of the reef-constructing corals, was published following his 1836 visit to Cocos Islands aboard the *Beagle*.

The Cocos (Keeling) Islands sits atop an ancient volcanic seamount which rises from the surrounding seafloor with depths of 5,000 metres (**Figure 66**). The atoll consists of a fringing reef rim, broken by two major entrances, the Western Channel situated between West and Horsburgh Islands and the Port Refuge channel between Horsburgh and Direction Islands. The central lagoon has an area of 102 square kilometres, consisting of a shallow southern region (with a mean depth of 1 metre) and a deeper northern region (water depth of up to 20 metres) connected to the two major entrances.

The planform shape of the atoll is governed by the shape of a horizontal slice through the seamount. For example, some key features evident in **Figure 66** include:

- Horsburgh Island lies on a saddle that runs off to the north towards North Keeling Island and on either side of that saddle is two deeper areas associated with breaks in the reef (Western Channel and the Port refuge channel);
- Horseshoe shape of the 24 islands around the southern lagoon formed on the unbroken reef rim
- There are several spines around that influence the shape of the bathymetry and sand islands. Two spines run up the western side of the seamount influence the plan form shape of West Islands. The main spine creates a large wave focusing and breaking area off the area referred to as North Park area.

On the reef rim is a series of 26 reef islands with a combined area of 14.2 square kilometres with 26 kilometres of coastline and a highest elevation of 9 metres above sea-level. However, the average elevation is 1.5 metres. Two elongated islands (West Island and South Island) occupy the southern corners of the horseshoe shaped southern lagoon. The remaining islands are small crescent-shaped islands on the conglomerate platform, separated by shallow inter-island passages (or shallow channels) that connect the ocean with the lagoon.

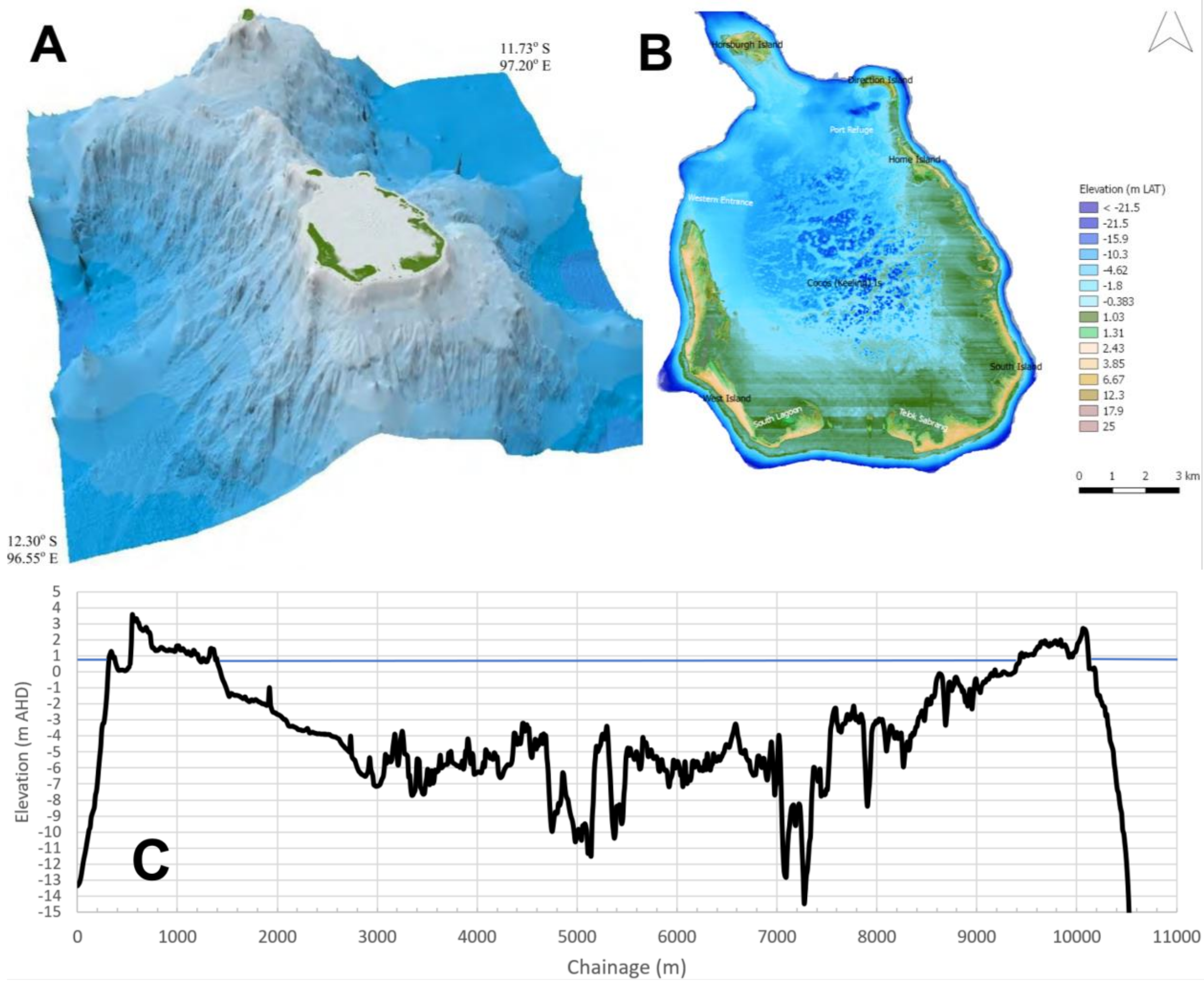


*Figure 66: **A:** 3-dimensional model of the Cocos (Keeling) Islands atoll (source: Geoscience Australia, 2011). **B:** Elevation map of the Cocos (Keeling) Islands. **C:** An east-west profiles of the Cocos (Keeling) Islands (data source: 2011 AAM Marine LiDAR).*

The islands on the Cocos (Keeling) Islands atoll are wave-built accumulations of carbonate sediment derived from the physical breakdown as well as breakdown by calcium carbonate–secreting organisms and Foraminifera that dwell on the adjacent coral reef systems (Perry et al, 2011). The location, planform configuration, size, and elevation of islands reflect both the interaction of oceanic swell with reef structures and the availability and grade of sediment for island building.

The Cocos (Keeling) Islands shorelines can be divided into oceanward shores that occur around the perimeter of the atoll and face the open ocean, and lagoonward shores that flank the lagoon. Beaches of medium to coarse grained and biologically derived (calcareous) sand (see **Section 6.3.3**) interspersed with coral shingle, and boulders are deposited directly on the reef surface and interact with reef platform processes.

Oceanward beaches are steep and backed by a ridge built by wave run-up and overwash. Typically, there are no established dunes. However, unlike many other coral atolls the Cocos

(Keeling) Islands exhibits windblown dunes in some locations (see **Figure 67**). In areas where the reef edge is closer to the shoreline, predominantly coral boulders exist on the beach (e.g. The Shack, West Island). Surveyed cross sections across West Island show several characteristic features of island morphology (**Figure 68**).

RHDHV's observations on-site suggest that almost all oceanward sandy beaches have a base of coral shingle, rubble and/or coral boulders. That is the sandy beaches is believed to be underlaid by a ridge of coral rubble and boulders. More ground investigations are required to confirm the extent and elevations of these deposits. However, their presence is significant as an underlying ridge of less erodible material will greatly reduce the vulnerability to erosion and shoreline recession. Morphically the presence can be explained by physical breakdown of the reef by the high energy swell environment (i.e. large boulder size sediments being broken off the reef during large waves). This larger material is then transported across the reef flats to the sandy beach. Where subsequent wave action would tend to 'shake down' any large material to the typical beach scour level (i.e. the beach level after large storm erosion).

The observations that suggest the wide-spread presence of this coral boulder ridges comes from several shallow beach excavation during RHDHV's site visits, the presence of coral boulders when eroded profiles were observed (e.g. see **Appendix C**) and aerial observations. An example is provided in **Figure 69**, in which the sandy beach in photo B is known to be underlaid by the coral boulder beach that is exposed at The Shack. The Shack is one of the areas of West Island where the reef edge is closest to the shoreline, hence having a higher energy wave climate and permanent exposure of the coral boulder beach.

On West Island, the oceanward shoreline is characterised by varying distances to the reef edge (235 to 960 metres). The position of the sandy islands is controlled by the shape and position of the protective reef they are surrounded by. On West Island, the oceanward shoreline is characterised by varying distances to the reef edge (235 to 960 metres). On Home Island oceanward shoreline is closer to the reef edge (90 to 150 metres), reflecting the lower energy wave climate.

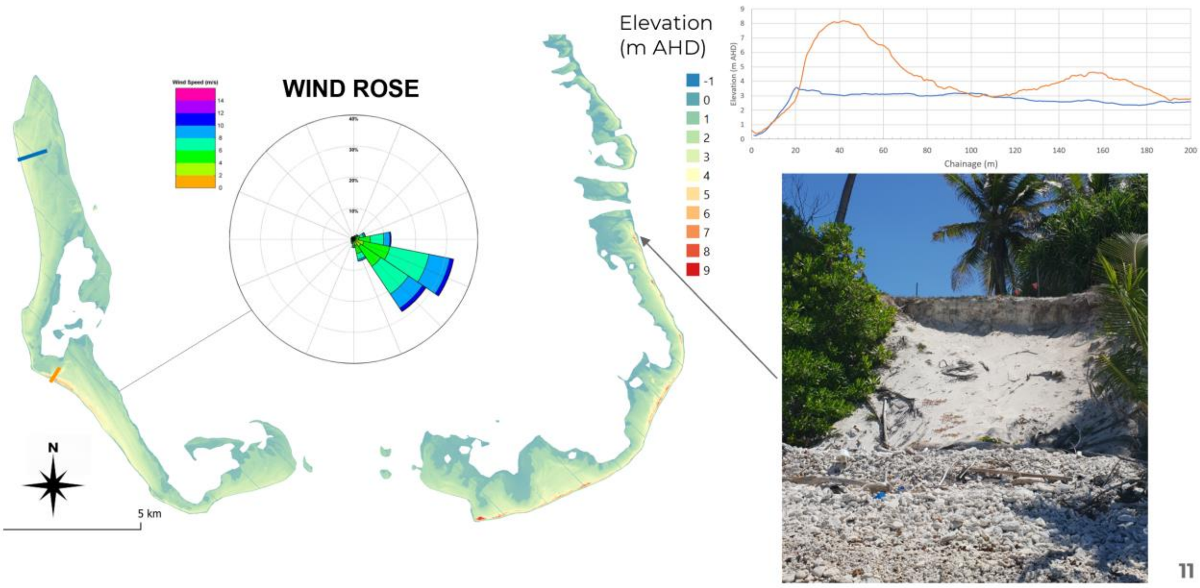


Figure 67: Dunes (orange and red > 5m AHD) on Cocos (Keeling) Islands atoll.

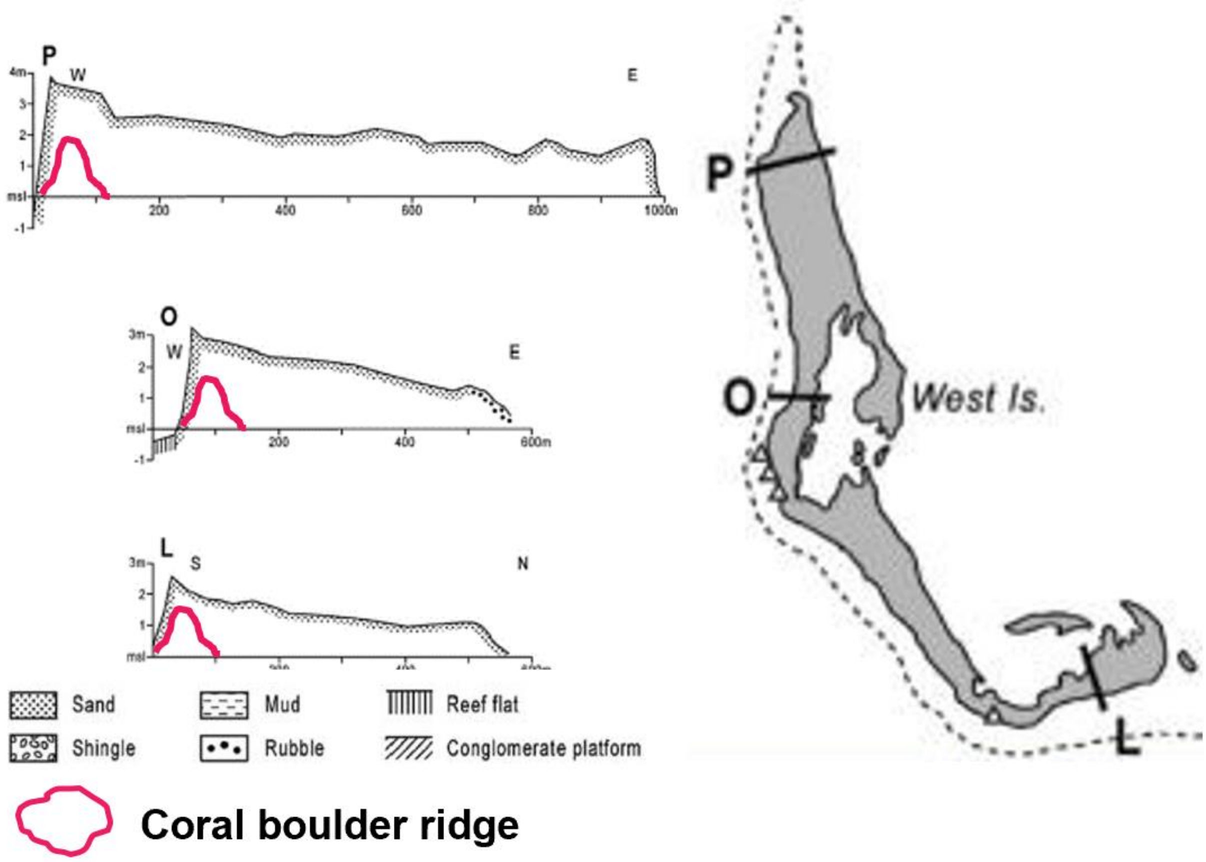


Figure 68: Selected profiles across West Island (annotated from original source in Woodroffe et. al., 1994)

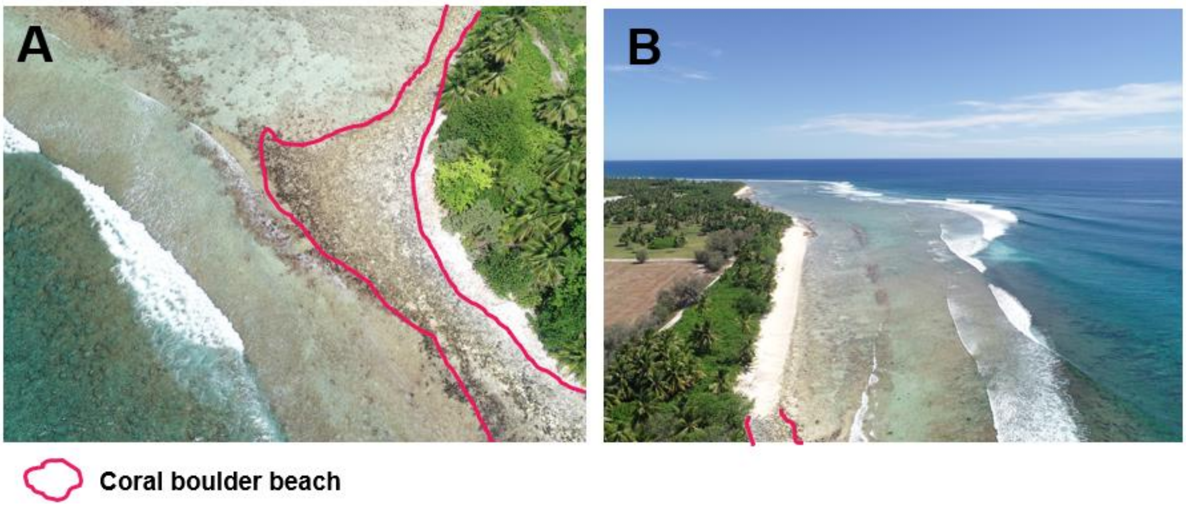


Figure 69: Example drone images of coral boulder beach (A) transitioning to sandy beach underlaid by coral boulder beach (B) from the shoreline nearby The Shack, West Island.

6.6.2 Wind, wave and sea-level climate

The climate and oceanographic setting of the Cocos (Keeling) Islands is summarised in Figure 70 and **Figure 71**. Points of note include:

- Micro tidal with mean neap and spring tides of 0.5 and 0.7 metres, respectively, with a maximum range of 1.2 metres. A 7mm/yr rise in sea level is recorded at the tide gauge.
- The Indian Ocean basin is saturated with swell from the deep south latitudes. These arrive at the Cocos (Keeling) Islands from a south-westerly direction and form the primary contribution to the wave climate. They typically have peak periods in the range 10 to 18 seconds. The south-westerly swells occur year-round but are most active in the winter months when storms occur regularly in the Southern Indian Ocean. The direction of these swells is relatively consistent being south to south-westerly direction. Occasionally, westerly swells can occur. As such, Indian Ocean swells primarily effect West Island and South Island and occasionally the lagoonward facing shorelines of Direction Island and Home Island.
- Trade winds, dominated by easterly and south easterly trade winds are sustained for 85 per cent of the year (Figure 71). The strongest mean daily winds occur from June to October following a monsoonal pattern; with lighter, variable conditions occurring from November to March. November to March also sees occasional tropical cyclone event with extreme wind speeds can occur.
- The persistent south-easterly trade winds produce south-easterly sea and swell waves typically in the range 6 to 10 seconds. The trade winds and resulting waves are most prevalent over the May and October months. Ocean generated sea waves predominately effect Home Island, the eastern side of South Island and the other eastern atoll islands.

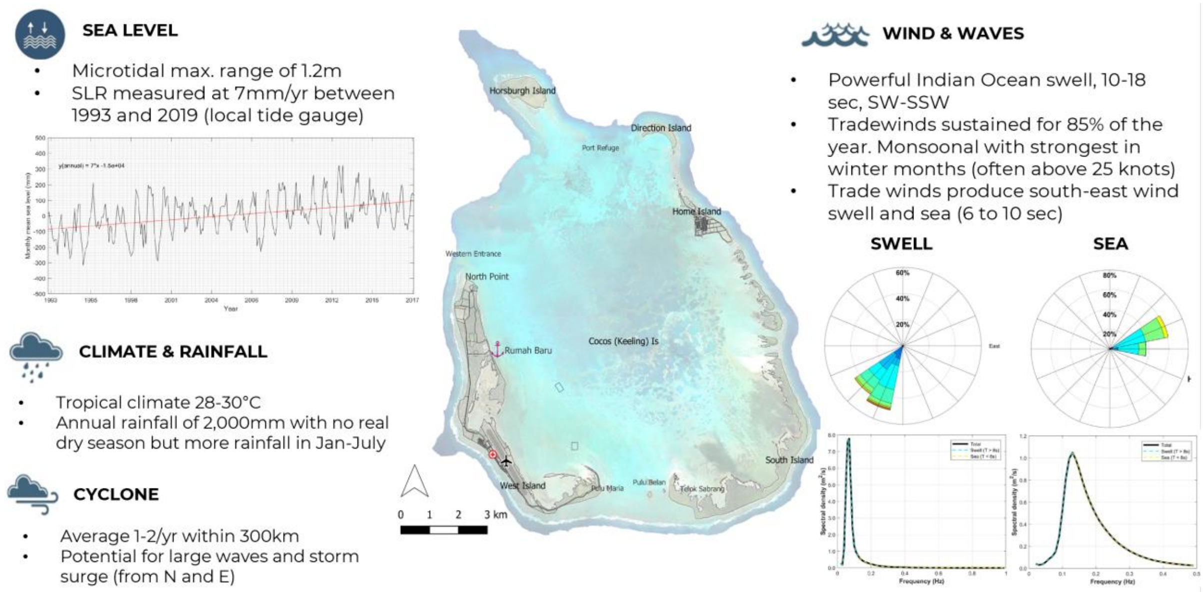


Figure 70: Summary of climate and oceanographic setting of Cocos islands (data source: BoM and this study).

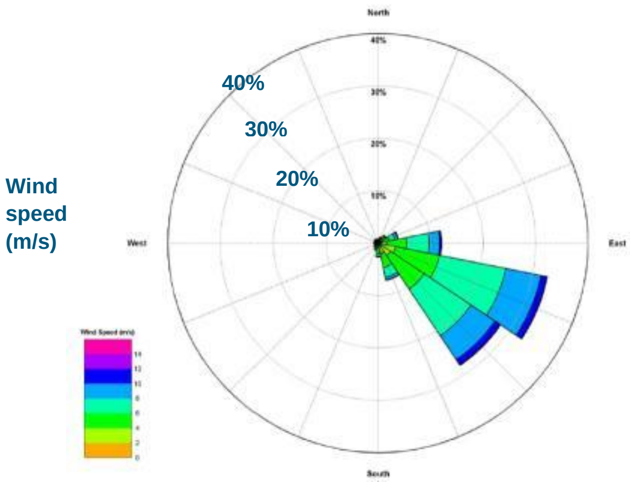


Figure 71: Wind rose of Cocos Airport data (2006 - 2018) provided by the BoM.

6.6.3 Atoll cross-shore processes

The fringing reef that surrounds the Cocos (Keeling) Islands atoll are of paramount importance in understanding the morphological response of the sand and gravel islands themselves. Atolls are inherently resilient structures (Masselink et al, 2020) (i.e. their existence relies on their ability to naturally adapt to changes in ocean conditions including the sea level rise). Therefore, understanding this inherent resilience is critical to understanding the coastal vulnerability of the Cocos (Keeling) Islands. The key processes of importance in the atoll cross-shore profile are displayed in **Figure 72**. Working from the ocean to lagoon these are described below.

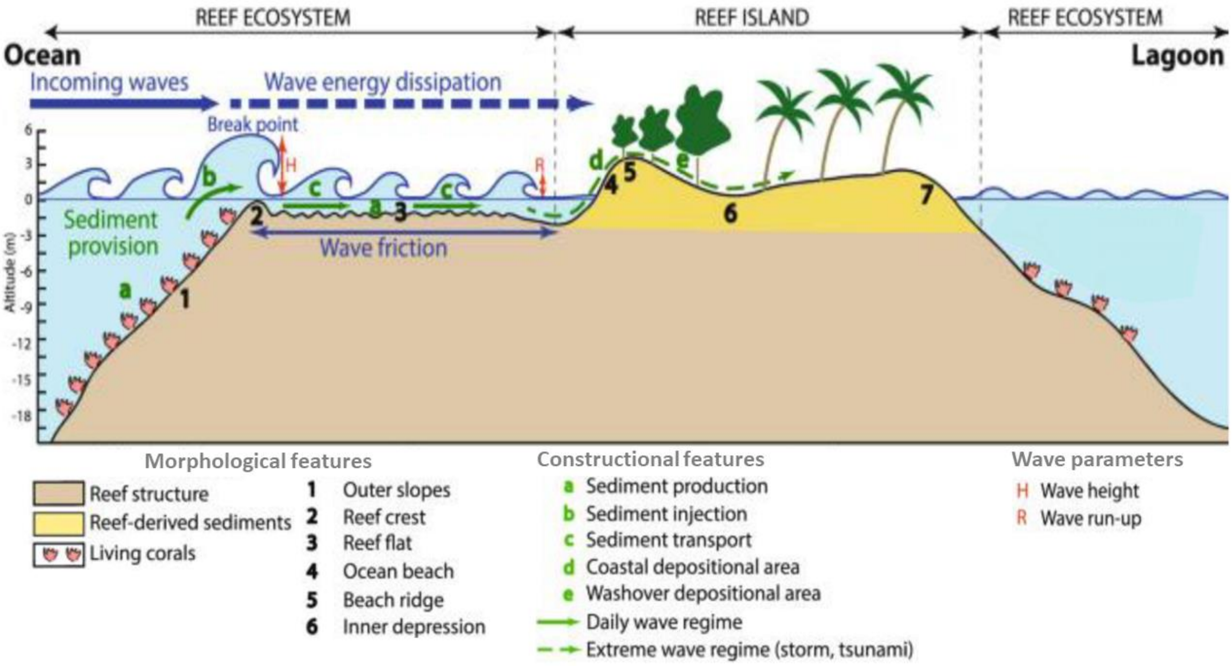


Figure 72: Conceptual model for atoll cross shore processes (adapted from Duvat et al, 2019).

Sediment production

Sediment production in atoll environments like the Cocos (Keeling) Islands is controlled by two important mechanisms(Perry et. al., 2011) . The first is physical breakdown of the reef structure, that is wave abrasion breaking up reef branches or other reef structures. Physical breakdown by waves tends to produce larger sized material including coral rubble and boulders. While it takes a long time for this larger size material to breakdown to sand-sized sediments the gravel, cobble and boulder sized material itself is important for island building. The production rate of material by mechanical abrasion by waves is influenced by reef health and wave energy, particularly long period swells which tends to have an abrasive effect of the reef. Given the Cocos (Keeling) Islands, and particularly West Island is saturated in long period swell, this mechanical breakdown is an important source of material to support island building and maintenance.

The second sediment production mechanism is biological. This mechanism is predominately grazing mainly by parrot fish but also urchins. By feeding on the reef these animals break down the reef framework and produce significant quantities of sand-sized sediments. Therefore, the population and spatial distribution of grazers that bio-erode the reef is a key factor in the production rate of sand-sized material. The abundance of reef grazers is a function of reef health. A naturally healthy reef system will tend to support a healthy population of reef graziers, maintaining an overall more resilient system. Foraminifera (single-celled protists with shells) may also play an important role in biological sediment production at Cocos (Keeling) Islands, as it does at some other atolls (Bluecoast, 2020). However, determining the abundance of foraminifera in Cocos (Keeling) Islands sediment composition requires further assessment.

Carbonate sediment production regimes contribute to island building and maintenance (Perry et. al., 2011). Maintaining the supply rate of sediments, from either physical or biological breakdown, relies on a healthy coral reef system.

Onshore sediment transport

The sediments produced across the fringing reef, both sand-sized and larger, are transported onshore by wave action (Masselink et al, 2020 and Duvat et al, 2019). This onshore movement of sediment sustains the atoll islands. The potential transport rate is far greater than the actual transport which is limited to the rate of sediment production.

At the shore, wave run-up occasionally over washes during periods of high wave activity depositing sand and coral to contributed to accretion of the islands. Such island adjustment is driven by wave overtopping processes transferring sediment from the beachface to the island surface. This island building and maintenance mechanism is important for natural adaption and resilience.

Beach ridges on the Cocos (Keeling) Islands ocean facing beaches reach heights of 2 - 4 m, which is the limit to which wave processes can build up the beach ridge.

As mentioned above some of the Cocos (Keeling) Islands oceanward shoreline have dunes that are not overtopped or overwashed.

Living breakwaters

The living reefs act as natural breakwaters in dissipating wave energy with wave breaking on the reef crest. Wave driven currents, water level set-up, wave dissipation and infragravity waves occur on the reef flats. The water levels on the reef control the height of the beach ridges. Interestingly it is the water level that also controls the height of reef crest – reefs are living structures and can grow vertically upwards with sea level rise (McLean and Kench, 2015, Kench et. al, 2015 and Duvat et. al., 2019).

The Cocos (Keeling) Islands are characterised by oceanward beach ridges built by waves of up to three metres above Mean Sea Level (MSL) (Woodroffe, 1994). The relationship of the land elevation to that of the highest water level is of particularly significance. Water levels at the oceanward shoreline are also subject to wave set-up and wave runup across the reef platforms, meaning that swash reaches well above high tide levels on the more exposed beaches.

As part of a 12-month oceanographic monitoring program spanning eight atoll-wide sites (see **Figure 73**) a series of wave and water level sites were established along a line perpendicular to a West Island settlement shoreline that suffers chronic erosion. These sites are: CK01a – offshore of reef crest in 20 metre water depth, CK01b – just shoreward of reef platform and CK01c on reef platform at inshore location. Time-series plots of observed conditions and a water surface elevation plot at CK01c for a selected high wave energy condition is provided in **Figure 73**.

The observed inshore wave and water levels conditions from data collected in this project highlight the importance of understanding fringing reef processes and their influence on both erosion and inundation. In addition to broken swell waves that propagated over the reef, infragravity waves with periods of between around 30s to 1000s are clearly present and underline the high instantaneous water levels near the shoreline. Based on reef top observation as well as observation of nearby shoreline change, when reef top water levels reach these levels and the beach ridge is not over washed erosion occurs.

6.6.4 Longshore sediment transport

Wave processes play an important role in the redistribution of sediments along the West Island and Home Island shorelines. Longshore sediment transport is the process of sand or other sediments moving in an alongshore direction and is driven by wave arriving oblique to the shoreline orientation. The role of longshore sediment transport is discussed below for West Island and Home Island.

West Island

West Island is the largest of the Cocos (Keeling) Islands. It has an elongated shape with predominately sandy shoreline. Development is concentrated around the airport and West Island Settlement in the southern part of the island. Approximately, 90 residential lots as well as commercial and industrial assets are located between the airport and the coastline.

Driven by the incoming south-west swell, the longshore sediment pathways are shown in **Figure 64** and described as:

- a nodal point at southern most top of West Island with divergent longshore sediment transport direction
- longshore transport is northward along western coast and eastward along southern coast and both oceanside pathways continue along the respective lagoonward shorelines before terminating in deposition zones in the southern lagoon as indicated on **Figure 64**.

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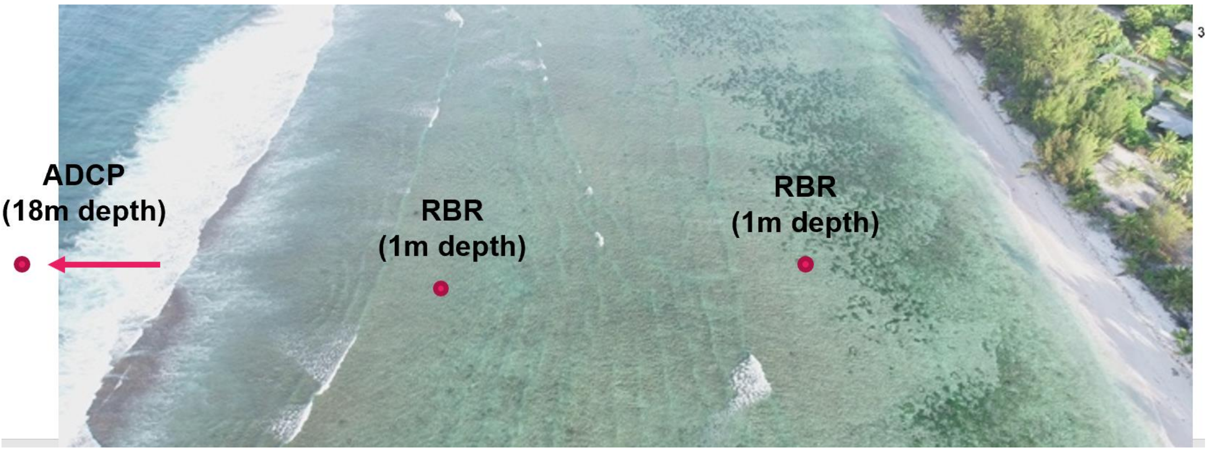

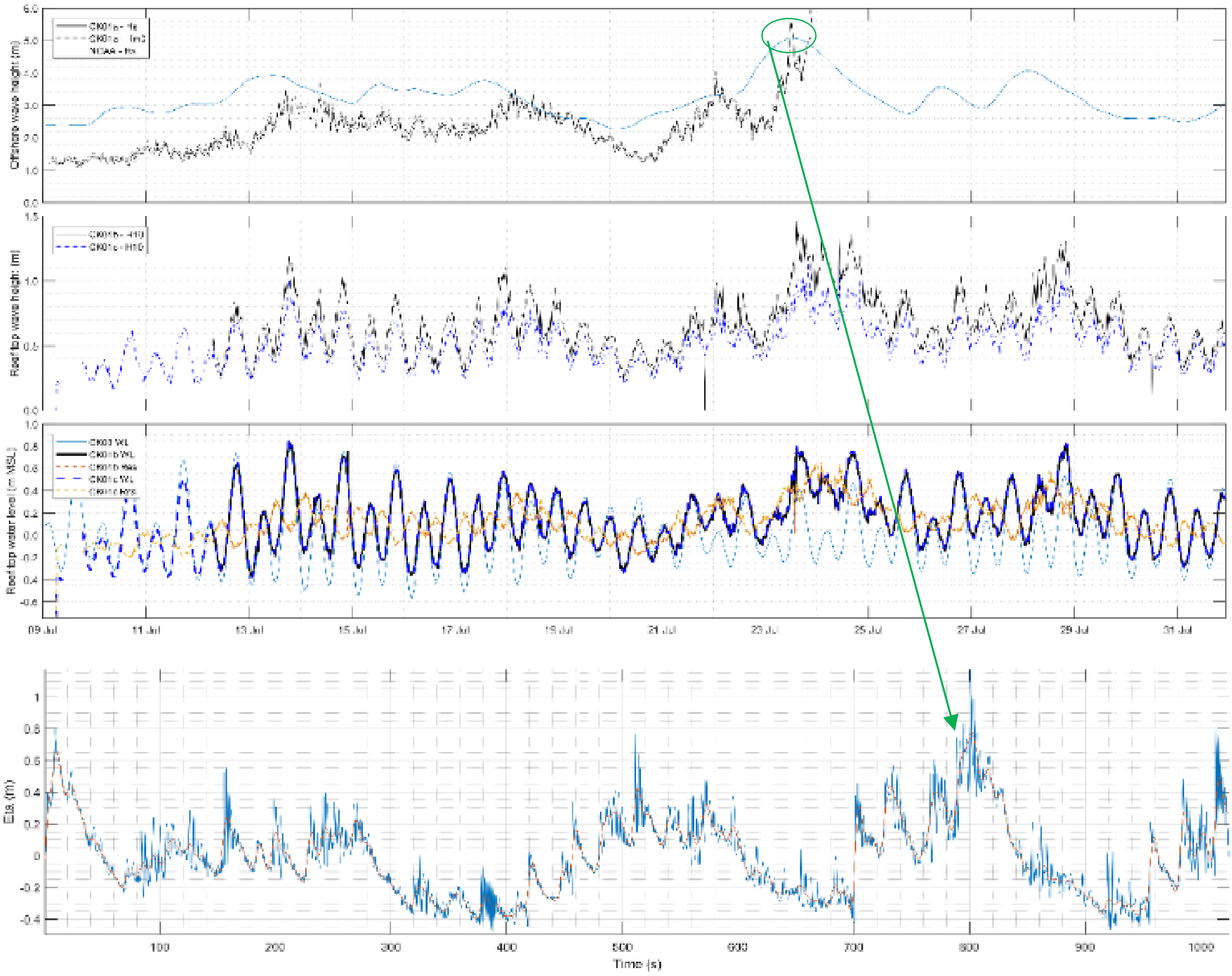

Figure 73: 23-day time series of offshore significant wave height at CK01a (top), reef top wave heights (2nd from top) and reef top still water levels (3rd from top) at CK01b and Ck01c. The bottom plot shows water surface elevation at CK01c for a selected 17-minute period near the event peak.

Evidence for these pathways comes from various sources. Long-term accretion on the extremities of West Island is a result of longshore sand transport across the reef platforms and sandy shores. South westerly swells drive northern sediment transport along much of the western shoreline, while along the southern shoreline the longshore transport is to the east terminating at sand spits that extend into the lagoon. Radiocarbon dating of coral shingle provides evidence that confirms the gradual accretion and build out of the island by these sand spit and ridges (**Figure 74**) (Woodroffe et. al, 1994). At the northern tip of West Island sand slugs periodically observed in aerial photography are evidence of the lagoonward sediment transport. The slug transport behaviour around West Island northern tip results in a very dynamic shoreline and which is evidenced by the recent loss of the bus shelter (RHDHV, 2019c).

The elongated shape of West Island is therefore explained by this longshore movement of sediment. The remaining plan form shape of the island can be explained by the shape of volcano and reef crest lines along with a few headland controls formed by deposits of coral boulders and conglomerate outcrops (e.g. The Shack), as described in **Section 6.6.1** above.

Lagoonward beach ridges are less prominent and shoreline change is location-specific being a function of the lagoon hydrodynamics, swell penetration and sediment sources and availability. The northern lagoon shoreline of West Island has a net southward alongshore drift driven by swells that have penetrated through the Western Entrance and to a lesser extent Port Refuge (**Figure 64**). The southward flow of sediment terminates at the sand spit that protrudes into Telok Jembu, the larger of the two lagoonlet areas of West Island's eastern side. This direction of sediment transport opposes the circulation current and lagoon wind-waves from the south-east trade winds as determined by numerical modelling and oceanographic monitoring.

Figure 74: Aerial photograph showing the south eastern tip of West Island (source: Woodroffe et. al, 1994). Radiocarbon dates on coral shingle indicate the progressive buildout of the spits.

The oceanward shorelines of West Island are generally stable (see Section 6.4) but some areas are receding particularly those fronting the West Island settlement. Over the past decades a series of coastal structures have been introduced to the West Island settlement shoreline to protect the landward infrastructure (**Figure 75**). These have been built in a progress downdrift direction, starting with an old vertical seawall (date unknown) which was later replaced with a 224-metre-long sloping Seabee seawall constructed in 2000 -2001 to protect Government House (Jones and Semen, 2003). This was followed by two geotextile sand container (GSC) revetments constructed between 2014 and 2017 with a total length of 461 metres. Further downdrift of the GCS revetments an older groyne field with four short groynes have been partially re-exposed by chronic erosion.

The unprotected sections of this shoreline suffer from chronic erosion. Given the northward direction of both sediment transport and progressive introduction of coastal structures, downdrift sediment starvation has created a domino effect with each structure moving the erosion issue further downdrift. The area currently suffering the worst erosion is located to the north of the last GSC seawalls. This area is characterised by a permanent erosion scarp, mature trees that have fallen, or are in the process of falling, onto the beach and erosion debris is evident (**Figure 75**).

The erosion and shoreline recession are threatening high value tourism infrastructure, including the Cocos Beach Motel, Tropica restaurant and Cocos Castaway hotel.

Figure 75:Recent erosion along unprotected West Island settlement shoreline (left) and on right is photographs of the series of coastal protection structures introduced to protect the West Island settlement (a) older vertical seawall (b) Seabee seawall (c) GSC revetment and (d) older groynes.

Home Island

Home Island is located on the eastern side of the Cocos (Keeling) Islands. Driven by the incoming east and south-east sea waves and wind swells less than 10s (Figure 70), the longshore sediment pathways are shown in **Figure 65** and described as:

- a nodal point at the south eastern tip of Home Island with divergent longshore sediment transport direction
- longshore transport is northward along east coast and eastward along southern coast
- the oceanside pathways continues along Home Island shoreline terminating at the beach that joins Pulu Gangsa to the main part of Home Island
- the southern lagoonward pathway terminate in deposition zones in the lagoon as indicated on **Figure 65**.

At the northern end of the beach is an area known as Pulu Gangsa, which serves as the community cemetery. This area was once a separate island (Bunce, 1988). In the late 1940s it was artificially joined onto the northern end of Home Island. This was achieved by placing coral boulders and concrete-filled drums across the shallow causeway that originally separated the islands. Sand, mostly from longshore sediment transport, slowly infilled and the two islands gradually merged into one (Bunce, 1988). Since the reclamation Pulu Gangsa has suffered significant erosion on its northern and western (i.e. lagoon sides). For example, a former seawall, 175-metres in length, used to serve to protect the former western lagoon shoreline position. The remnants of the failed seawall are still visible in the lagoon some 70 to 80 metres from the present-day shoreline. Conversely on the ocean-facing side, our analysis shows the beach that was formed by the reclamation has continued to accrete (see **Section 6.4** and **Appendix C**) as it is now the termination of this alongshore pathway.

6.6.5 Lagoon circulation and deposition in the southern lagoon

Unidirectional transport of sediment occurs in shallow passages that connect the fringing reef and the lagoon causing a slow infill of the lagoon (Kench, 1994 and Kench and McLean, 2004). As part of the 12-month oceanographic and shoreline monitoring program (see **Section 3**) tilt-drag current meters were deployed in two of the shallow (less than 1.5m) passages around the Cocos (Keeling) Islands. Both recorded unidirectional lagoon-ward flow, including the one located off the south eastern tip of West Island (**Figure 76**) with the speeds correlated to ocean wave height and period as well as tidal height (i.e. higher lagoonward flow when incident waves are larger and the tide is higher). This wave-driven current provides the mechanism to explain the on-going accumulation of sand inside the southern lagoon. Historical accounts indicate that in the early days of settlement (1826) access to South Island was relatively easy. It later became necessary to dredge boating channels, which have subsequently infilled. Now the island is only accessible to shallow-draught vessels at high tide (Bruce, 1998).

The infilling of the southern lagoon with reef-derived sediments is further supported by the wave and flow modelling completed herein (see **Section 4**). Key wave height and mean current results are shown in **Figure 77**. These show the driving processes (waves) that lead to the one-directional inflow as well as the mean tidal and wave driven circulation in the lagoon that favours deposition within the southern lagoon.

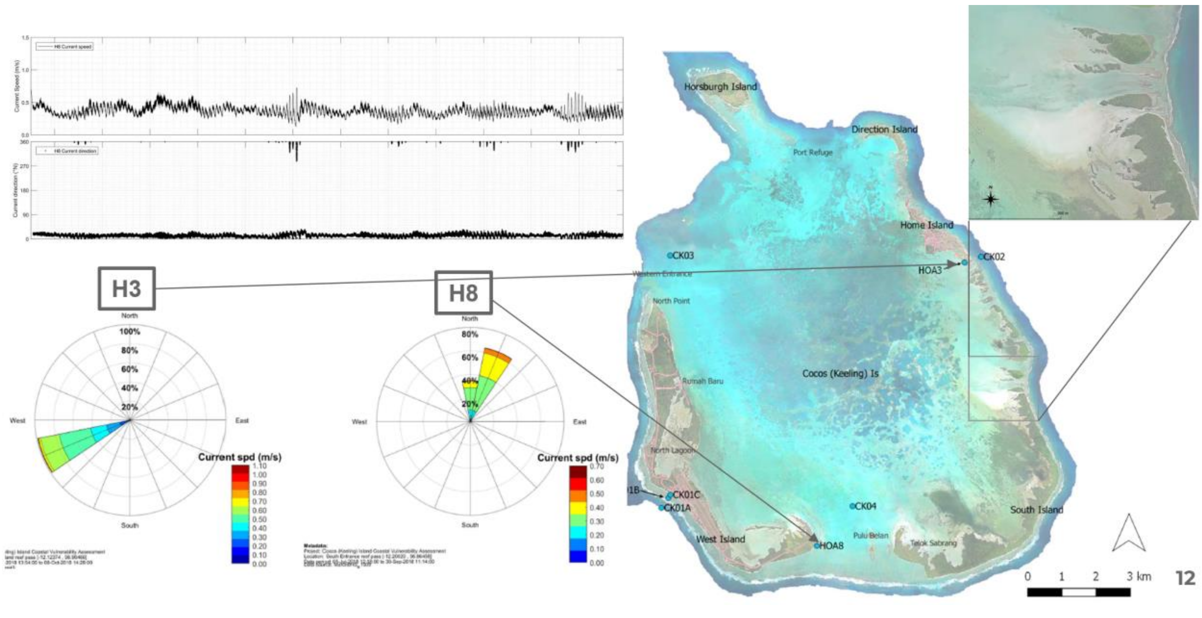

Figure 76: East-west current (U) vs north-south current (V) at a monitoring site located in the shallow passage just off the shore from West Islands south eastern tip.

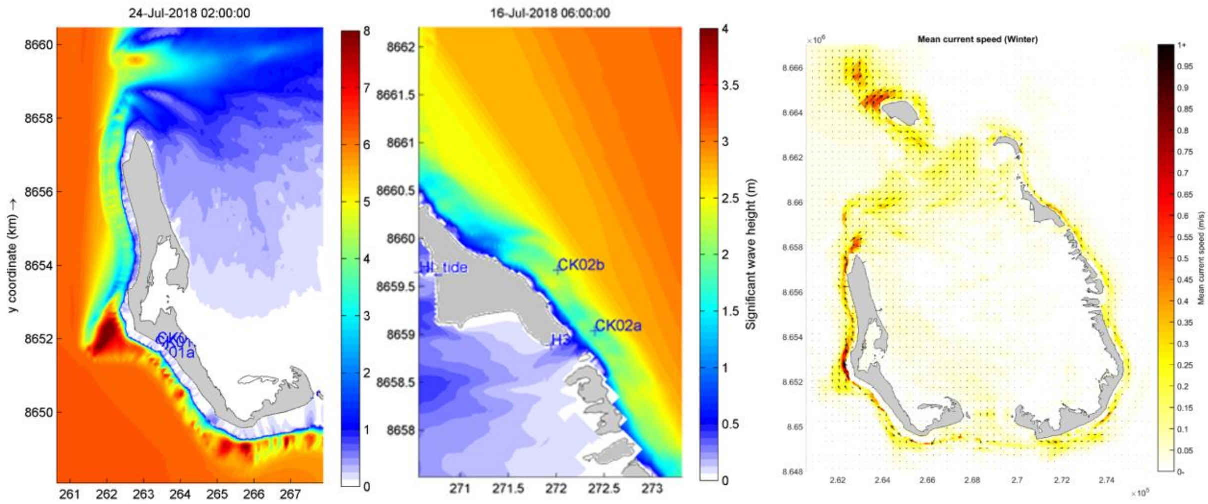

Figure 77: Wave modelling results showing wave height maps during (left) high-energy swell conditions at West Island and (middle) high-energy sea conditions at Home Island. Mean seasonal current patters are shown on the right.

The longshore transport pathways and wave-driven lagoonward currents are important processes that are in a state of dynamic equilibrium balance on Cocos. When these natural processes are altered by human modification changes occur as the system moves toward finding a new equilibrium. This is evident in the history of Prison Island, which is located just north of Home Island. As depicted in Figure 78 Prison Island was once larger. In 1827 it was home to a large two storey house and a forest of palms Bunce (1988). However, after the reclamation and joining of Home Island and Pulu Gangsa, Prison Island has eroded. Today it is a small sand island with little remaining vegetation.

The northward longshore sand movement pathway along Home Island's oceanward shoreline (**Figure 65**) supplied sediment to the area to the north of Home Island, including Prison Island. The joining of Pulu Gansa and Home Island likely resulted in a blocking of this pathway, thus reducing the sand supply that maintained Prison Island. Prison Island continues to supply sand to the lagoon, with an idealised sand pathway depicted in Figure 78.

Turtle Beach on Home Island's western, lagoonward shores is also connected to the sand apron that characterises the area north of Home Island. Protected from the trade winds, the site is home to a picturesque lagoon facing beach, popular for beach going and fishing. Turtle Beach can be characterised as a sandy low energy beach with a gentle slope and shallow/intertidal sand flats and shoals. The sand on this beach is finer grained sand and well sorted (see Section 6.3.3). The back beach is vegetated with few pine trees, palms and other vegetation. Seawater desalination equipment is in the area in the lee of this beach.

The northern end of the beach is also used for sand stockpiling. The Shire use earth moving equipment to win sand from the intertidal sand flats at low tide (pers. coms Ian Evans, Works Manager, Shire of Cocos (Keeling) Islands). This sand is stored in stockpiles at the back of the beach and used for projects such as the Home Island paving project which was completed on the 6th July 2018 after taking two years. The stockpile is also used to fill GSC for coastal protection works.

Figure 78: History of Prison Island and the joining of Home Island and Pulu Gangsa.

6.6.6 Response to sea level rise

Recent numerical modelling studies show that reef islands composed of gravel material are morphodynamically resilient landforms that evolve under sea level rise by accreting to maintain positive freeboard while retreating lagoonward (Masselink, Beetham and Kench, 2020). Such island adjustment is driven by wave overtopping processes transferring sediment from the beachface to the island surface (see **Section 6.6.3**).

Physical modelling and numerical modelling (XBeach) was used to demonstrate that a Tuvaluan atoll island crest (i.e., highest point) accreted vertically by 0.6m during a 0.5m increase in sea level while retreating lagoonward by 25m (**Figure 79**). The physical mechanism for this adjustment is wave overtopping, where run-up exceeds the crest of the island, driven by sea level rise increasing wave height and water level at the shoreline. Wave overtopping effectively transfers sediment from the nearshore and beachface to the island crest and surface and is the primary mechanism for vertical island accretion. The net result is a morphodynamic rollover response.

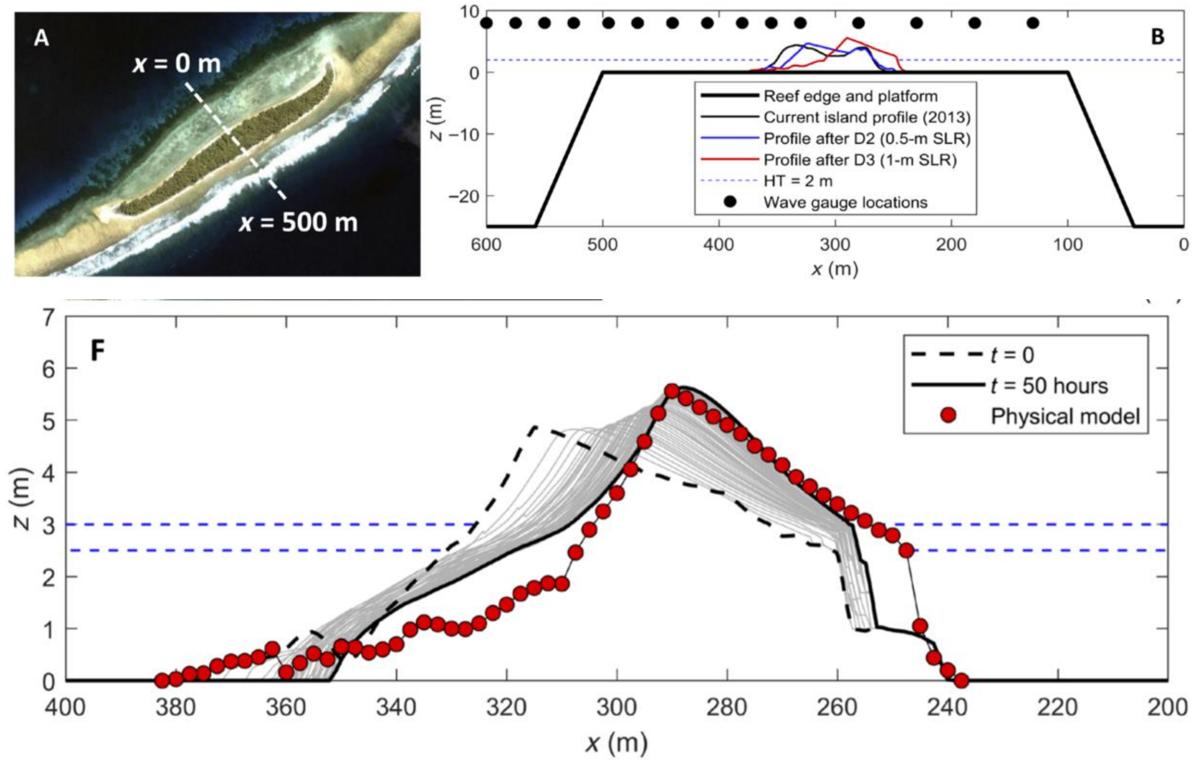

*Figure 79: Reef island response to sea level rise. **A** Aerial photograph of Fatato, Funafuti atoll, Tuvalu; white dashed line indicates central profile line. **B** Experimental setup in the physical and numerical model. **F** Measured and modelled reef island morphology after 50 hours with sea level raised from 2.5 m to 3 m above the reef platform. Source: Masselink, Beetham and Kench, 2020.*

As an example, recent research by Masselink et al (2020) describes the net effect of sea level rise on the cross-shore profile of atoll islands like Cocos (Keeling) Islands (see **Figure 79**). The results present an island-building model whereby island topography can increase in height (adjust vertically) and migrate landward via the rollover process. It follows that storms can be important phenomenon that can either increase or decrease natural resilience to sea-level rise, depending on intensity and frequency. Masselink et al (2020) results found that islands exposed to periodic low to moderate volume overtopping will build vertically at nearly the same rate as sea-level rise. In contrast, episodic high-volume overtopping can flatten islands and increase hazard exposure.

This likely morphological response to sea level rise indicates that such natural adaptation of reef islands may provide an alternative future trajectory that can potentially support near-term habitability on some islands, albeit with additional management challenges. The vertical build-up of island elevation by low to moderate volume overwash processes can also offset the increase in future flood risk due to sea level rise.

While the natural resilience of reef island morphodynamics to sea level rise are encouraging, communities are still likely to be confronted with ongoing and escalating rates of island physical change that will stress populations and require careful consideration of the full spectrum of adaptation strategies. Other climate change factors will also influence resilience. Ocean water temperature is expected to increase the intensity of tropical storms, resulting in enhanced coastal flooding (IPCC, 2019). Water temperature and ocean acidification will have substantial adverse effects on the health of coral reef systems that may modify carbonate sediment production regimes that contribute to island building and maintenance (IPCC, 2019). In addition, island habitability is not only a function of island freeboard it also depends on the island planform area, which, without sediment input from the reef structure, may reduce as a result of rollover. Enhanced coastal flooding due to sea level rise is expected to lead to increased contamination of the freshwater aquifer.

Physical responses are likely to vary between islands, reflecting differences in antecedent condition (e.g., sedimentary fabric and abundance, island size, and presence/absence of conglomerate platform) and environmental boundary conditions (storm wave climate and rate of sea level rise). Such differences in morphodynamic behaviour present the opportunity to develop nuanced adaptation solutions in different island settings, rather than adopt a one-solution approach that ultimately results in island abandonment and relocation. Islands with artificial shoreline defences compromise the ability of shorelines to undergo natural adjustment to changes in the process regime and lock communities into hard structural solutions and a maladaptive dependency.

It is important to note that these more complex dynamic island responses were not considered in this coastal vulnerability assessment for future planning periods (i.e. 2068 and 2118). As per the requirements of the project brief, SPP 2.6 has been adopted. The application of SPP2.6 for erosion hazard mapping is explained in the following section.

6.7 Erosion hazard mapping

The following sections present an overview of the methodology and outcomes from the coastal hazard assessment. The resulting hazard maps are presented in **Volume II**.

6.7.1 State Coastal Planning Policy

SPP 2.6 was released in July 2013 to provide guidance for land use and development within the coastal zone, including managing development and land use change, establishment of coastal foreshore reserves, and to protect, conserve and enhance coastal values. (Western Australian Planning Commission, 2013). Schedule One of SPP 2.6 provides direction for calculating the appropriate Coastal Processes Allowance (CPA) for development on the Western Australian coast. The CVA report will inform decision making for a range of agencies and an essential element of the CVA is to address the objectives of SPP 2.6. While the objectives of SPP 2.6 are important overarching goals, SPP 2.6 also acknowledges the variation of coastal environments in the state, and the range of development and use contexts that can be present, and requires the policy to be applied to each case under consideration on its merits using the best available information and a precautionary approach. SPP 2.6 also states that where the effects of CPAs would ordinarily preclude development, but where the application of the policy in this regard is not realistic nor feasible, coastal hazard risk management and adaptation planning (CHRMAP) should be undertaken to reduce the risk from coastal hazards over the 100-year planning timeframe, to an acceptable level. The Cocos (Keeling) Islands are a special case that will require a CHRMAP approach as set out in SPP 2.6 cl. 5.5in addition to typical CPA calculations from SPP 2.6 (which were primarily developed for mainland areas).

The intention of the CPA is to provide a buffer zone between the shoreline and development in which coastline changes in the short term (severe storms), the medium term (shoreline movement) and the longer term (sea level rise and fluctuation of natural processes) can occur. The calculation of the CPA distance is based on the combined result of the following factors:

1. S1 allowance - distance for absorbing acute erosion (extreme storm sequence)
2. S2 allowance - distance to allow for historic trends (chronic erosion or accretion)
3. S3 allowance - distance to allow for sea level change

These CPAs will be included in this CVA. However, it should be noted that the additional understanding of coastal processes and hazard provided in the conceptual coastal processes model (**Section 6.6**) provide an extra layer of information for the agencies, particularly the Shire to develop a realistic adaptation pathway as part of CHRMAP.

The coastal erosion hazards assessment has been completed for a 100-year Average Recurrence Interval (ARI) event in accordance with SPP 2.6 requirements. As required by the project brief planning horizons of 2018 (current), 2028, 2065 and 2120 have been considered to assess the changes to coastal vulnerability over time.

With respect to inundation, SPP 2.6 requires that developments consider the potential effects of an event with an Annual Encounter Probability (AEP) of 0.2% per year. This has been addressed as part of the CVA's coastal inundation assessment.

6.7.2 Coastal protection structures

SPP 2.6 requires coastal protection structures to be considered within CHRMAP. This is particularly relevant for the formal (or engineered) coastal protection structures that protect part of the West Island (structure ID's: CLIW04, CLIW05 and CLIW06) and Home Island (CLIH03) settlements.

Following previous experience in Western Australian coastal management, two sets of coastal erosion hazard lines have been prepared for areas protected by formal engineered coastal protection works. The hazard lines are prepared for both with and without the structures in place for each of the planning periods. For later stages of the CHRMAP process it is important to understand the maximum extent of potential impacts for both scenarios. In preparing the erosion hazard lines, the following is assumed for each scenario:

- for the with coastal protection structures scenario the relevant structures have been assumed to be able to withstand erosion from a 100-year ARI event. Therefore, the erosion extents are limited to the seawall crests. This limited extent of erosion assumes the ongoing maintenance and upgrade of the protection structures to continue to offer effective protection against the 100-year ARI event. While this is not guaranteed, it is one possible option for the Shire to consider in the future.
- for the without coastal protection structures scenario it has been assumed that the current shoreline sits at the location of the coastal protection structures and are erodible. Scenarios have been hypothesized to determine the erosion CPA assuming there is no significant change in the hydrodynamics of the system following the removal of the structures.

The smaller and less formal coastal protection structures that exist around CKI are treated as being erodible given their expected failure during extreme erosion events.

6.7.3 S1 storm erosion allowance

The S1 allowances for each of the planning timeframes are presented in **Table 23** and **Table 24** for West Island and Home Island, respectively. These have been determined by the erosion modelling (XBeach and SBEACH) presented in (**Section 6.5 and Appendix D).** It should be noted that the same allowance has been allocated to all planning timeframes as SPP 2.6 specifies that the design storm should have an AEP of 1%, therefore the storm severity is the same, regardless of the timeframe being considered.

As discussed above, the formal coastal protection works along West Island and Home Island settlement were assumed to be designed and constructed to withstand a 100-year ARI design event. The Shire are currently monitoring and maintaining these structures. For the case of with coastal protection structure it has been assumed this would continue in the future. Any changes to these structures would necessitate a review of these hazard lines. This compartment currently has no available shoreward beach available to be eroded and as such the S1 Allowance for this location will be at the same location as the Horizontal Shoreline Datum (HSD).

For the scenario without coastal protection structures, it has been assumed the shoreline is composed out of unconsolidated sand and is subject to storm erosion.

Table 23: S1 erosion allowance for West Island by management unit.

Planning period	S1 allowance (m)							
	MU1 – Settlement		MU2-A Ocean facing (north)	MU2-B Ocean facing (north)	MU3 Lagoo n facing	MU4 Rumah Baru	MU5 Scout Park/Kite Beach	MU6 Ocean facing (south)
	With protection structure	Without protection structure						
Present Day (2018)	0	5.9	0.5	0.5	1.5	2	0	7
2028	0	5.9	0.5	0.5	1.5	2	0	7
2068	0	5.9	0.5	0.5	1.5	2	0	7
2118	0	5.9	0.5	0.5	1.5	2	0	7

Table 24: S1 erosion allowance for Home Island by management unit.

Planning period	S1 allowance (m)			
	MU7 – Settlement		MU8 – Ocean facing	MU9 – Lagoon facing
	South side	North side		
Present Day (2018)	0.1	1.3	12	0.5
2028	0.1	1.3	12	0.5
2068	0.1	1.3	12	0.5
2118	0.1	1.3	12	0.5

6.7.4 S2 allowance for historical shoreline change

The S2 allowance accounts for the long-term trends in historical vegetation line position that may occur within the planning timeframes. To estimate the S2 allowance, long term historical shoreline movement trends were examined, and likely future shoreline movements predicted.

The analysis of historical shoreline change is presented in **Section 6.4** and **Appendix C**. Based on the results of that assessment the S2 allowances adopted for each of the planning timeframes are presented in **Table 25** and **Table 26**. Negative allowances are taken as reductions in CPA distances.

Table 25: S2 allowance for historical shoreline change on West Island by management unit.

Planning period	S2 allowance (m)							
	MU1 (with hard structures) [Adopted rate = 0.0m/yr.]	MU1 (without hard structures) [Adopted rate = -0.3m/yr.]	MU2-A [Adopted rate = 0.0m/yr.]	MU2-B [Adopted rate = -0.3m/yr.]	MU3 [Adopted rate = 0.0m/yr.]	MU4 [Adopted rate = 0.0m/yr.]	MU5 [Adopted rate = 0.4m/yr.*]	MU6 [Adopted rate = 0.0m/yr.]
Present Day (2018)	0	0	0	0	0	0	0	0
2028	0	-4	0	-3	0	0	2*	0
2068	0	-10	0	-15	0	0	10*	0
2118	0	-16	0	-30	0	0	40*	0

*****positive allowances are representative of accreting shorelines

Table 26: S2 allowance for historical shoreline change on Home Island by management unit.

Planning period	S2 allowance (m)			
	MU7-Settlement [Adopted rate = 0.0m/yr.]		MU8 Oceanward (north) [Adopted rate = 0.0m/yr.]	MU9 [Adopted rate = 0.0m/yr.]
	South side	North side		
Present Day (2018)	0		0	0
2028	0		0	0
2068	0		0	0
2118	0		0	0

6.7.5 S3 allowance for erosion due to sea level change

In 2010 the magnitude of sea level rise (SLR) recommended for CPA planning in Western Australia was updated in SPP 2.6 for planning periods up to 100 years. For this CVA, the project brief used the sea level rise estimates from DoT (2010) to recommend a vertical sea level rise of 0.4m be adopted for the 50-year planning timeframe (i.e. 2068) and 0.9m rise being appropriate for the 100-year planning timeframe (2118) (DLH, 2018).

The recommended allowances for sea level rise for planning periods sooner than 2118 have been determined based on the above benchmarks. The sea level rise allowances for each of the planning timeframes are presented in **Table 27**. It is noted that all values of sea level rise are provided relative to 2018 levels. That is, it is assumed that appropriate discounting was made in the project brief for the sea level rise that occurred between the 2010 baseline used by DoT and the 2018 baseline used in this study.

Table 27: Adopted sea level rise values relative to 2018 baseline.

Planning period	Sea level rise (m) (relative to 2018)
Present Day (2018)	0.00
2028	0.08
2068	0.40
2118	0.90

SPP 2.6 recommends that a form of the Bruun rule (Bruun, 1962) be used for calculation of a CPA distance based on the vertical SLR component. Moreover, SPP 2.6 states that the allowances for erosion on coasts with fringing reefs should generally be determined using the methods specified for sandy coasts. For sandy coasts, SPP 2.6 specifies a multiplication factor of 100 be applied under the Bruun rule. For example, a 100-year planning timeframe a vertical SLR of 0.9m results in a horizontal CPA distance (S3) of 90m. For the 50-year planning timeframe a CPA distance (S3) of 40m is applicable. There are presently no features (i.e. obstacles to longshore sediment transport) in the study area that warrant consideration to increase the allowance for S3. Sea level rise will impact the entire study area.

The S3 allowances adopted for each of the planning timeframes are presented in **Table 28** and **Table 29** for West Island and Home Island, respectively.

Table 28: West Island S3 erosion allowance (m) for shoreline recession due to sea level rise.

Planning period	S3 allowance (m)							
	MU1 – Settlement		MU2-A Ocean facing (north)	MU2-B Ocean facing (north)	MU3 Lagoon facing	MU4 Rumah Baru	MU5 Scout Park/Kite Beach	MU6 Ocean facing (south)
	With protection structure	Without protection structure						
Present Day (2018)	0	0	0	0	0	0	0	0
2028	0	8	8	8	8	8	8	8
2068	0	40	40	40	40	40	40	40
2118	0	90	90	90	90	90	90	90

Table 29: Home Island S3 erosion allowance (m) for shoreline recession due to sea level rise.

Planning period	S3 allowance (m)			
	MU7 – Settlement		MU8 – Ocean facing	MU9 – Lagoon facing
	South side	North side		
Present Day (2018)	0	0	0	0
2028	8	8	8	8
2068	40	40	40	40
2118	90	90	90	90

6.7.6 Coastal hazard mapping

The CPAs as determined in the preceding sections are presented in **Table 30** and **Table 31** for West Island and Home Island, respectively. As required by SPP 2.6 a 0.2 m/yr allowance for uncertainty has been included to the total CPA. The total allowances are the sum of the S1, S2, S3 and 0.2 m/yr uncertainty components. The CPA is measured from the HSD.

Map 7 and **Map 8** in **Volume II** presents the resulting coastal erosion hazard maps showing all required planning periods for the study area for both West Island and Home Island.

Table 30: West Island summary of erosion allowances (m), S1, S2 and S3 and uncertainty for study area.

Planning period	Allowances	Unprotected sandy coast allowances (measured landward from HSD)						
		MU1	MU2A	MU2B	MU3	MU4	MU5	MU6
Present day (2018)	S1	6	1	1	2	2	0	7
	S2	0	0	0	0	0	0	0
	S3	0	0	0	0	0	0	0
	Uncertainly [Rate =0.2m/yr.]	0	0	0	0	0	0	0
	Total allowance	**6**	**1**	**1**	**2**	**2**	**0**	**7**
2028	S1	6	1	1	2	2	0	7
	S2	3	0	3	0	0	-2	0
	S3	8	8	8	8	8	8	8
	Uncertainly [Rate =0.2m/yr.]	2	2	2	2	2	2	2
	Total allowance	**19**	**11**	**14**	**12**	**12**	**8**	**17**
2068	S1	6	1	1	2	2	0	7
	S2	15	0	15	0	0	-10	0
	S3	40	40	40	40	40	40	40
	Uncertainly [Rate =0.2m/yr.]	10	10	10	10	10	10	10
	Total allowance	**71**	**51**	**66**	**52**	**52**	**40**	**57**
2118	S1	6	1	1	2	2	0	7
	S2	30	0	30	0	0	-20	0
	S3	90	90	90	90	90	90	90
	Uncertainly [Rate =0.2m/yr.]	20	20	20	20	20	20	20
	Total allowance	**146**	**111**	**141**	**112**	**112**	**91**	**117**

Table 31: Home Island summary of erosion allowances (m), S1, S2 and S3 and uncertainty for study area.

Planning period	Allowances	Unprotected sandy coast setback allowances (measured landward from HSD)			
		MU7		MU8	MU9
		South side	North side		
Present day (2018)	S1	0.1	1.3	12	0.5
	S2	0	0	0	0
	S3	0	0	0	0
	Uncertainly [Rate =0.2m/yr.]	0	0	0	0
	Total allowance	**0**	**1**	**12**	**1**
2028	S1	0.1	1.3	12	0.5
	S2	0	0	0	0
	S3	8	8	8	8
	Uncertainly [Rate =0.2m/yr.]	2	2	2	2
	Total allowance	**10**	**11**	**22**	**11**
2068	S1	0.1	1.3	12	0.5
	S2	0	0	0	0
	S3	40	40	40	40
	Uncertainly [Rate =0.2m/yr.]	10	10	10	10
	Total allowance	**50**	**51**	**62**	**51**
2118	S1	0.1	1.3	12	0.5
	S2	0	0	0	0
	S3	90	90	90	90
	Uncertainly [Rate =0.2m/yr.]	20	20	20	20
	Total allowance	**110**	**111**	**122**	**111**

7 Vulnerability assessment

7.1 Overview of approach

A vulnerability assessment has been completed for each of the assets on CKI that was identified as being at risk from erosion and inundation over three planning periods (2018, 2068 and 2118). The vulnerability assessment identifies how the effects of coastal hazards are likely to impact on assets on the Cocos (Keeling) Islands. It defines the degree to which an asset is susceptible to, and able or unable to cope with, the adverse effects of coastal hazards. The result is a vulnerability rating for each asset within the study area, described over time and for each hazard.

The CVA process follows a risk assessment approach (see **Figure 80**) adopted from SPP 2,6 and based on the risk management and vulnerability assessment processes identified in *Australian Standard: Risk management - Guidelines* (2018), *Australian Standard: Climate change adaptation for settlement and infrastructure - A risk based approach* (2013), *Climate Change Impacts and Risk Management: A Guide for Business and Government* (2007), *Australian Standard Environmental risk management - Principles and Processes* (2006), and *Climate Change Risk and Vulnerability: Promoting an efficient adaptation response in Australia, Report to the Australian Greenhouse Office* (2005). The risk can be defined as; ongoing coastal processes at CKI will lead to assets either being destroyed, or their functionality compromised such that the value those assets provide to the community is permanently lost or reduced.

The identification of inundation and erosion hazards has been presented in **Section 5 and 6**, respectively. The vulnerability assessment based on the presented hazards is described in the following Sections.

It is normal to have an inherent diversity of community and stakeholder views and it is important to communicate, consult and involve key stakeholders and the wider community to provide, share and obtain information. Therefore, it is important to note that it was beyond the scope of this CVA to formally engage with stakeholders or formally consult with the community. As per the project brief the linkage to the community and key stakeholders was one of the functions of the project steering group. It is suggested that provision of a risk workshop, or alternative stakeholder consultation, should be considered prior to the implementation of any management actions which rely on the results of this vulnerability assessment.

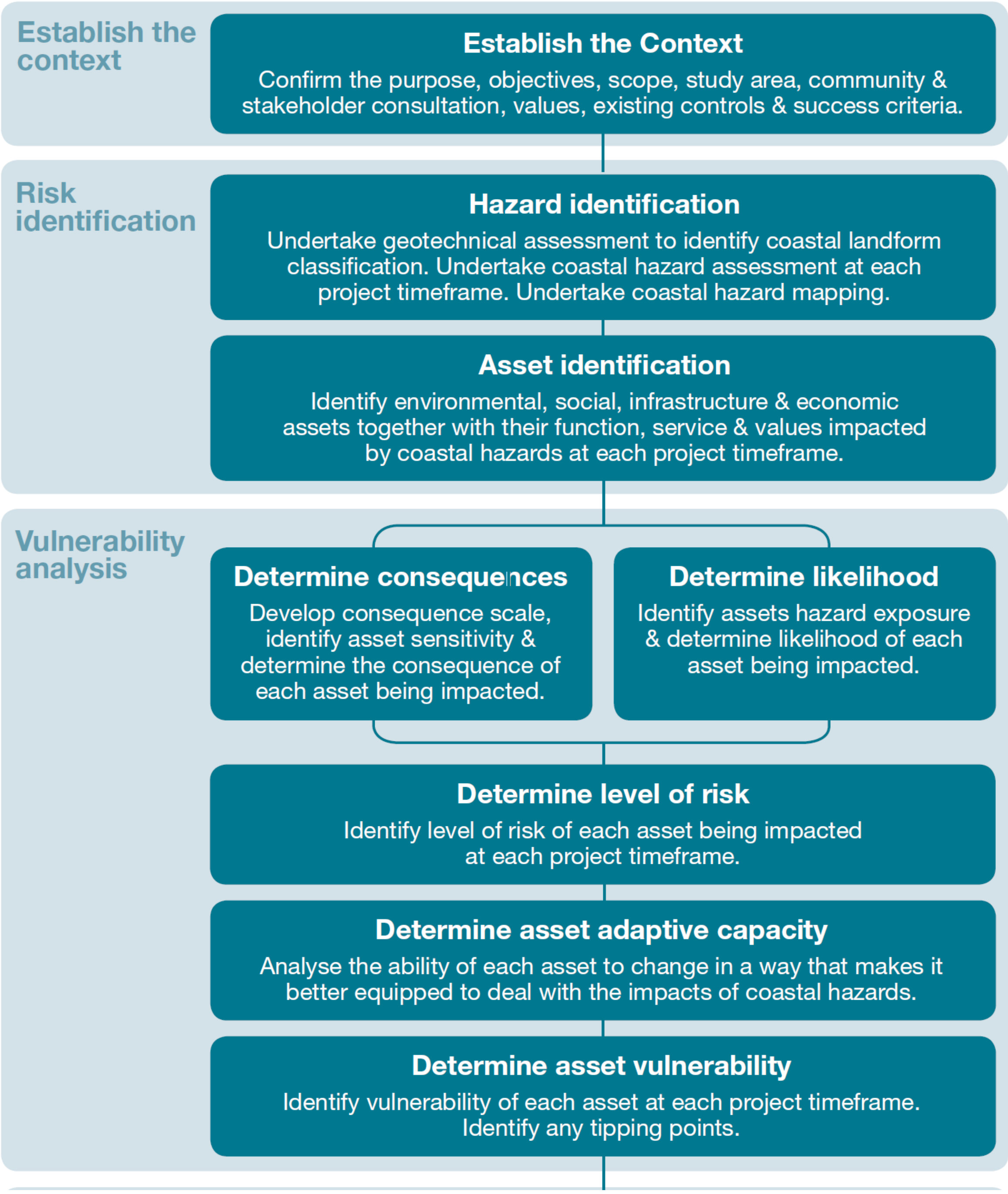

Figure 80: Risk management process flowchart adapted to coastal planning (WAPC, 2019).

7.2 Existing planning framework

The CHRMAP process is a requirement of SPP 2.6 to support decision makers in addressing risks associated with coastal erosion and inundation. This CVA is consistent with the requirements of SPP 2.6 and associated guidelines.

A review of existing planning controls was undertaken to identify and summarise the key legislation, policies and guidelines that need to be considered as part of the process. The following legislation and planning controls were identified:

- WA State Planning Policy 2.6 State Coastal Planning Policy: as described above.
- Shire of Cocos (Keeling) Islands Local Planning Scheme No. 1 (Gazetted July 2007). The Scheme divides the local government district into zones to identify areas for uses and the types of development allowed in different zones. There are controls included for special control areas. The Scheme Text also sets out the requirements for planning approval, enforcement of the Scheme provisions and non-conforming uses. A nominal width of the 'Foreshore and Nature Conservation' reserve is defined, and the Shire has regard to the Coastal Management Plan (GHD, 2017) when considering development and land use on or adjacent to the coastal foreshore.
- WA State Planning Policy 3-1 Residential Design Codes (2018) under the Planning and Development Act (2005). Unless otherwise provided for in the Scheme the development of land for any of the residential purposes dealt with by the Residential Design Codes shall conform to the provisions of those Codes.
- Environment Protection and Biodiversity Conservation Act 1999 (Commonwealth)

7.3 Asset grouping

Following identification, assets have been classified by grouping where values or risk management requirements are shared. In the absence of community and stakeholder views in the function, service and values of asset groups, the characterisation has been based on CHRMAP Guidelines (WAPC, 2019). In doing so the assets were grouped into the following categories:

- Environment;
- Social; and
- Economic assets.

Each of these asset groups has unique sensitivity and adaptive capacities that are considered in the CVA. An overview of the adopted asset groups is provided in **Table 32**. Maps showing the spatial distribution of the assets by group are provided in **Figure 81** and **Figure 82** for Home Island and West Island, respectively. **Table 33** provides the number of assets in the inventory from both Home Island and West Island including a breakdown by asset group. The asset inventory, in the form of a GIS database, include photos of individual assets and has been delivered to DPLH as part of this project.

An environmental asset that has been included in the database is the fringing reef system that surrounds the atoll, including Home Island and West Island. This is considered appropriate as although the fringing reefs are not directly impacted by coastal erosion or inundation, the importance of a healthy fringing reef system to the resilience of CKI to these hazards cannot be understated. As well as provide the only source of new sediments they also provide a barrier to ocean waves that protects the shorelines of the sand islands. The reefs also play a key role in controlling water levels along ocean facing coastlines.

Table 32: Description of asset groups and functions/values.

Assets	Functions/services and values
Environment	
Foreshore reserves and beaches	Coastal access, recreation and conservation. Tourist drawcard. Habitat for flora and fauna (conservation value for rare and threatened species). Supports biodiversity and ecosystem integrity. Important geo-morphological features of locality. Buffer to other 'higher value' assets. CKI is an island community with a strong connection to the ocean. Erosion and permanent loss of land to due to the actions of the sea can leave the community feeling vulnerable. The role of the beach, beach ridges and dunes (where present), as well as the fringing reef, in providing a buffer to protect land and property is well recognised. Beach amenity itself is generally rated highly by the community, for instance due to the perceived scenic, recreation or environmental value. It is not understood if this is the case at CKI, however, there is a large portion of the community for which tourism is a critical source of livelihoods. Beaches, particularly Kite Beach, Trannies Beach, Turtle Beach, Direction Island beaches are important for the island's visitors.
Social	
Foreshore amenity (picnic facilities, BBQ, toilets)	Ongoing access and recreation. There are several options for foreshore amenity facilities spread across both West Island and Home Island, each with vary exposure based on the location on the islands. This means that if anyone facility is damaged or lost due to erosion or inundation, residents and visitors will still be able to use a different area/facility that was not impacted by the preceding event(s).
Residential development	Provides housing for resident population and future population. For the public, other community assets may rate more highly. However, given the remote location of CKI, replacing residential building is difficult. For the individual owner, this asset is of very high importance.
Hospital, school, cyclone shelter, club house, cemetery, mosque/church	Provides essential and cultural services, local employment. Such facilities are socially vital, while the building is typically highly financially costly to build and fit out, making relocation of the physical asset difficult. An example is the West Island Medical Centre which is semi-

Assets	Functions/services and values
	protected by geobag seawall but located in an erosion hotspot.
Economic	
Roads	Provides transport services and evacuation routes. Roads are the key conduits for traffic flow within the island community. Damage or loss that blocks or impedes these routes would indeed cause major disruption to the community.
Jetties, boat ramps, marina	Provides recreation facilities and transport services. Provides local employment. Contributes to local economy. As a group of islands, jetties, boat ramps and ferry terminals are key services for CKI community members, compared with other transport infrastructure.
Pump station, wastewater disposal, waste disposal, desalination plant, power generator, fuel depot	Provides essential services. Pump station, wastewater disposal, waste disposal, desalination plant, power generator and fuel depots all provide a vital service to social health and functioning on the islands.
Commercial/ industrial/ commonwealth development and infrastructure	Provides employment and contributes to economy. CKI has a large government sector, which in addition to the tourism sector provides the most employment. While local government is concentrated at Home Island, most commonwealth and state government agencies are concentrated on West Island.

Table 33: Number of assets by group for Home Island and West Island in the Coastal Asset Database.

Asset group	Home Island	West Island	Total
Environmental	28	42	**70**
Social	149	120	**296**
Economic	74	106	**180**
Total	**251**	**268**	**519**

Figure 81: Map of Home Island assets by group.

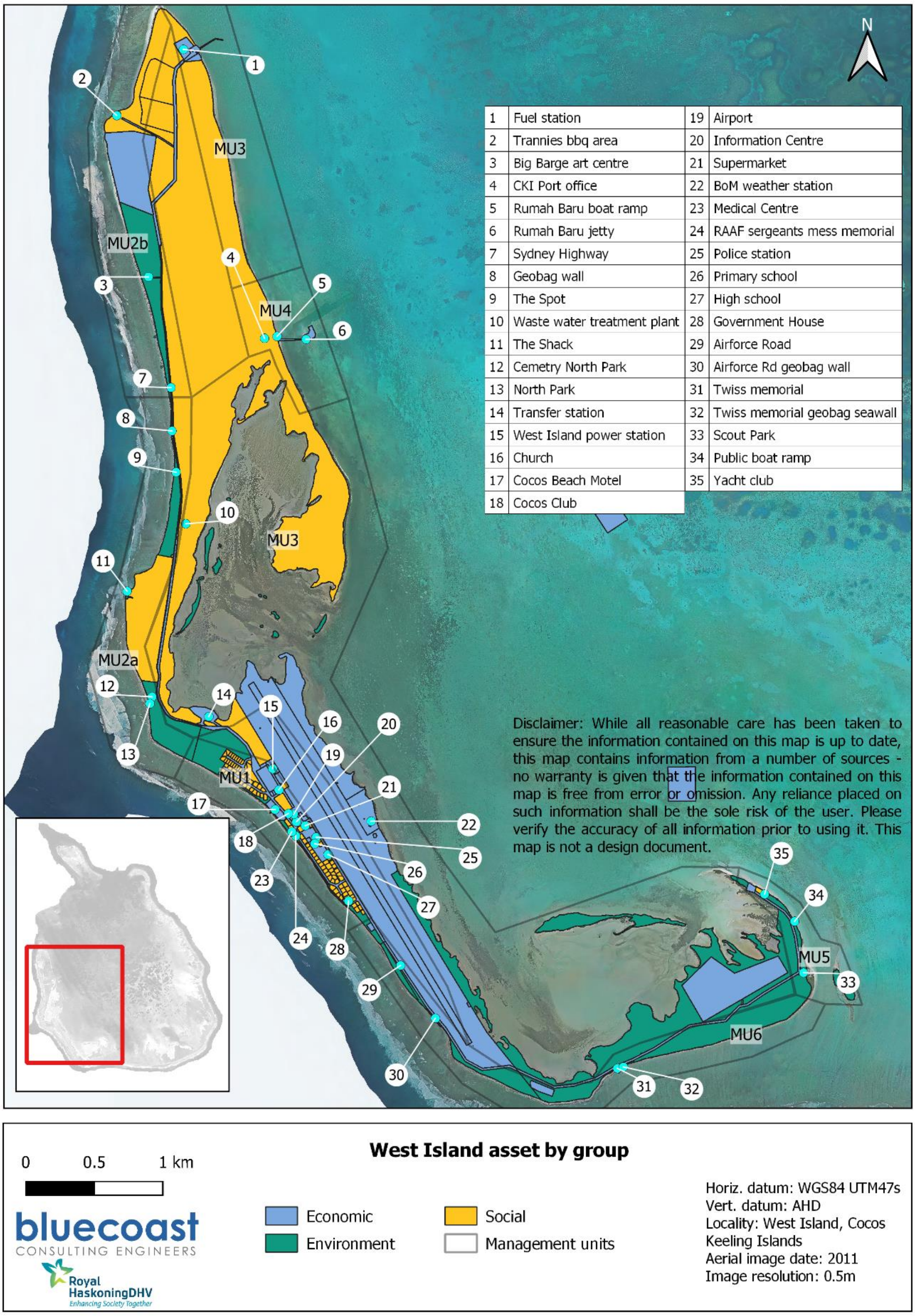

Figure 82: Map of West Island assets by group.

7.4 Likelihood (exposure)

Likelihood is the probability of erosion and/or storm surge inundation impact on existing and future assets and their values (AS5334-2013). Within the context of the vulnerability assessment, likelihood is used to consider the exposure of an asset to coastal hazards. The GIS asset databases and hazard mapping extents were utilised as the basis of identification and evaluation.

As likelihood can be subjective, the likelihoods were defined based on the predicted hazard extents for the various planning periods as recommended in WAPC (2019). This approach assumes that for any given planning period the likelihood of the hazard occurring up to the calculated hazard line for that timeframe is at least 'possible'. A graphical example is shown in **Figure 83**. The adopted likelihood rating for each planning period is provided in **Table 34.**

Maps showing the assets exposed to erosion and inundation hazard on Home Island for the 2118 planning period are provided in **Figure 84**and **Figure 85**, respectively. Similarly, exposure on West Island is mapped in **Figure 86** and **Figure 87**. **Table 35** and **Table 36** provides the number of assets in the inventory exposed to the respective hazards, including a breakdown by asset group, from both Home Island and West Island, respectively.

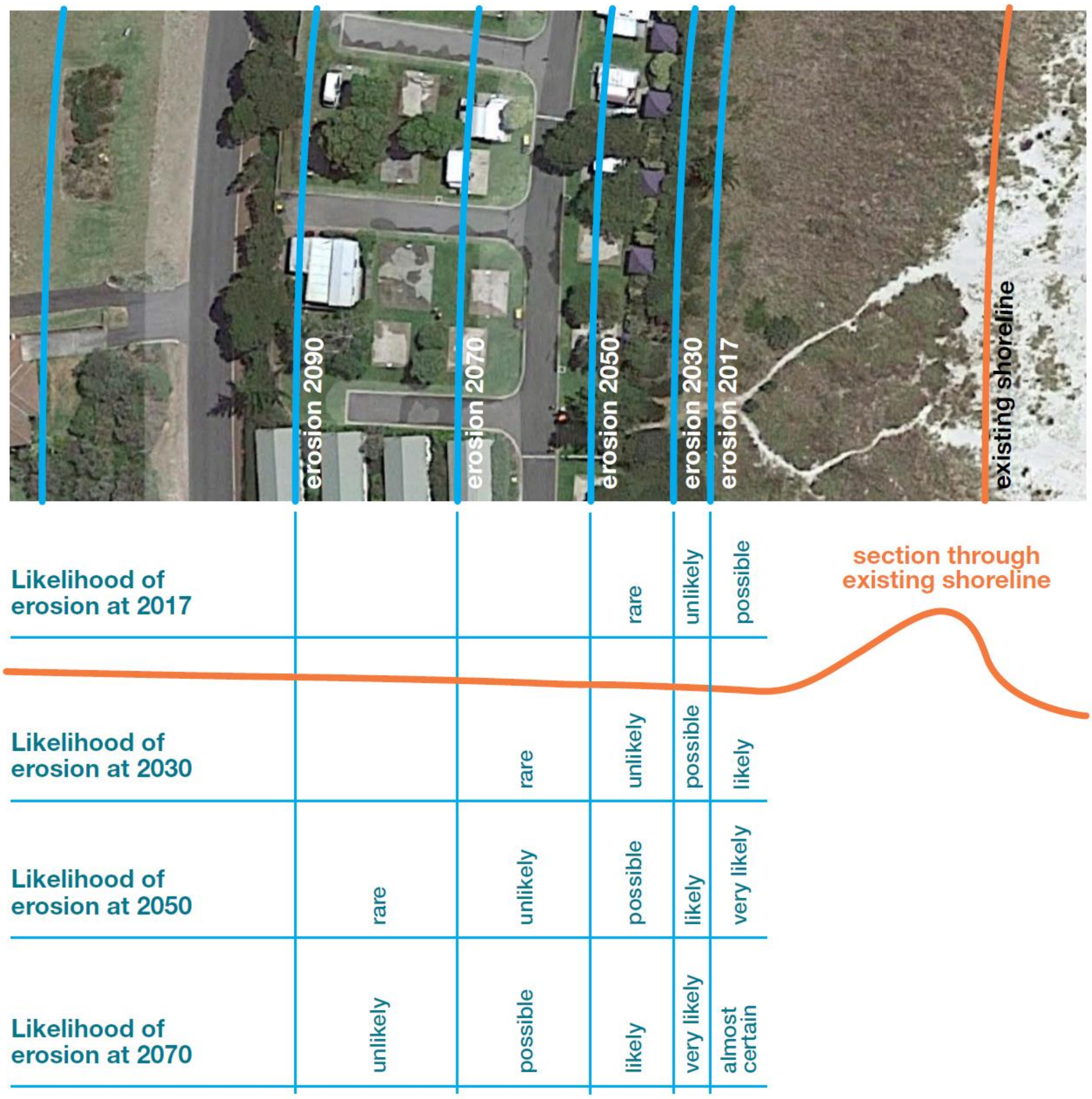

Figure 83: Example of likelihood (or exposure) of erosion hazard for different timeframes (source: WAPC, 2019).

Table 34: Adopted likelihood rating for risk assessment (source: WAPC, 2019).

Likelihood rating		Planning period		
		2018	2068	2118
Hazard line	2018	Possible	Likely	Very likely
	2068	Unlikely	Possible	Likely
	2118	Rare	Unlikely	Possible

Table 35: Number of assets possibly exposed to erosion hazards by island and asset group.

Planning period	Home Island (251 assets)				West Island (268 assets)			
	Enviro.	Socio.	Econ.	Total	Enviro.	Socio.	Econ.	Total
2018	18	2	27	**47**	24	6	21	**51**
2068	26	15	48	**89**	29	31	60	**120**
2118	26	39	56	**121**	27	63	80	**170**

Table 36: Number of assets possibly exposed to inundation hazards by island and asset group.

Planning period	Home Island (251 assets)				West Island (268 assets)			
	Enviro.	Socio.	Econ.	Total	Enviro.	Socio.	Econ.	Total
2018	24	58	48	**130**	32	28	45	**105**
2068	26	128	69	**223**	32	71	87	**190**
2118	27	148	74	**249**	32	86	96	**214**

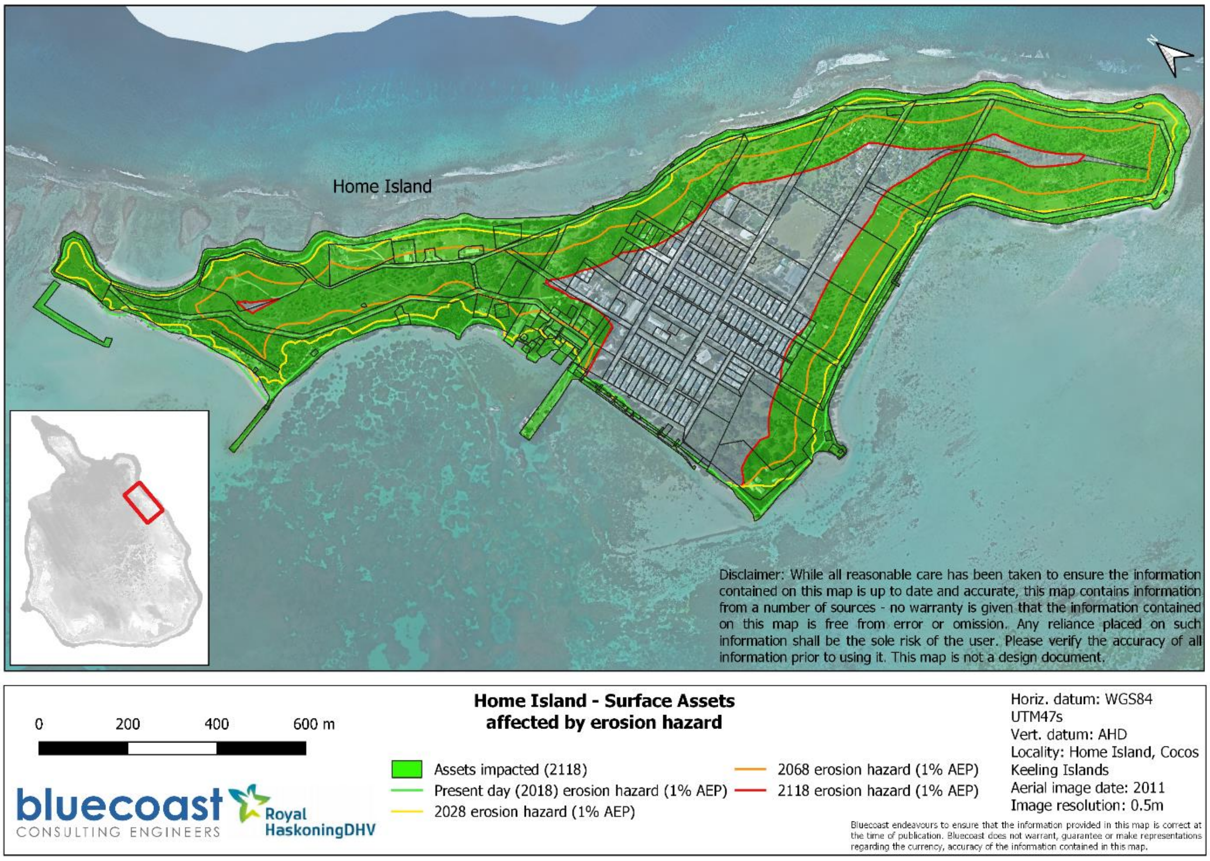

Figure 84: Surface assets possibly exposed to erosion in 2118 planning period on Home Island.

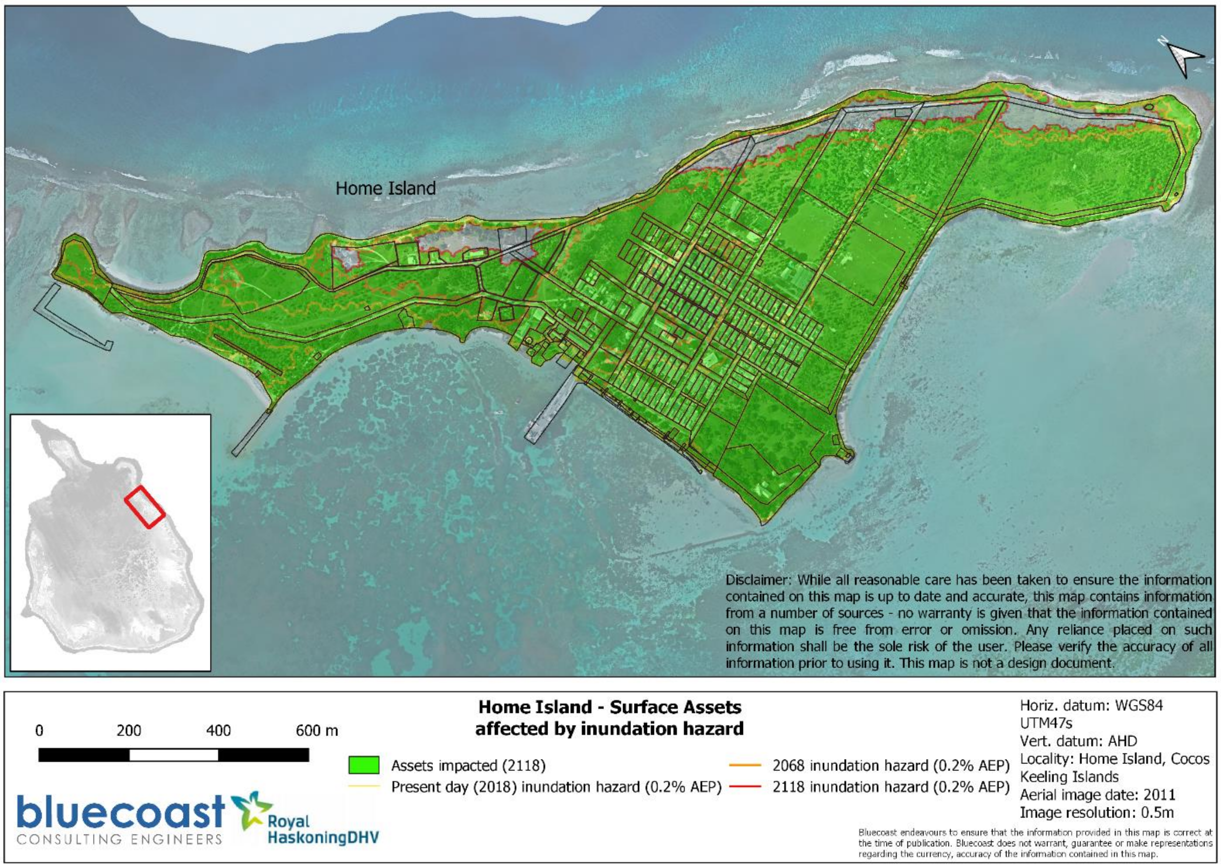

Figure 85: Surface assets possibly exposed to inundation in 2118 planning period on Home Island.

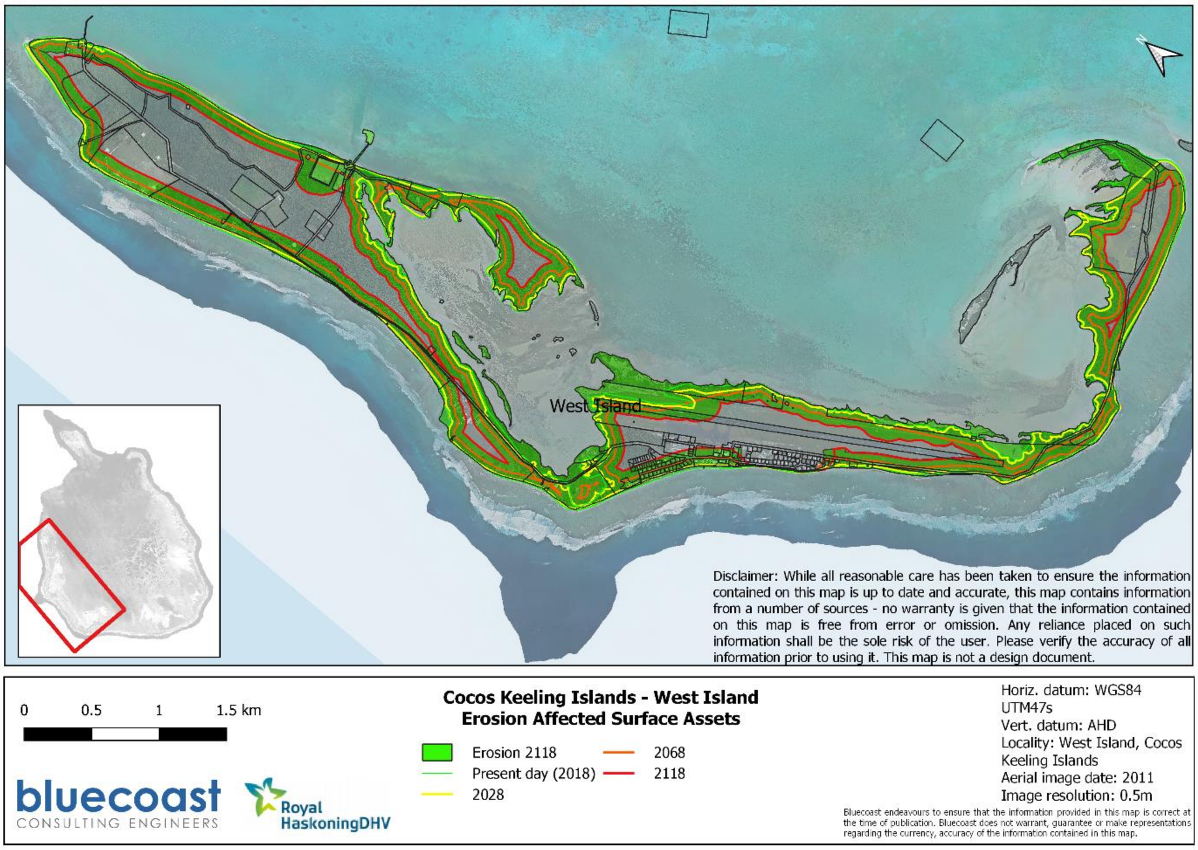

Figure 86: Surface assets possibly exposed to erosion in 2118 planning period on West Island.

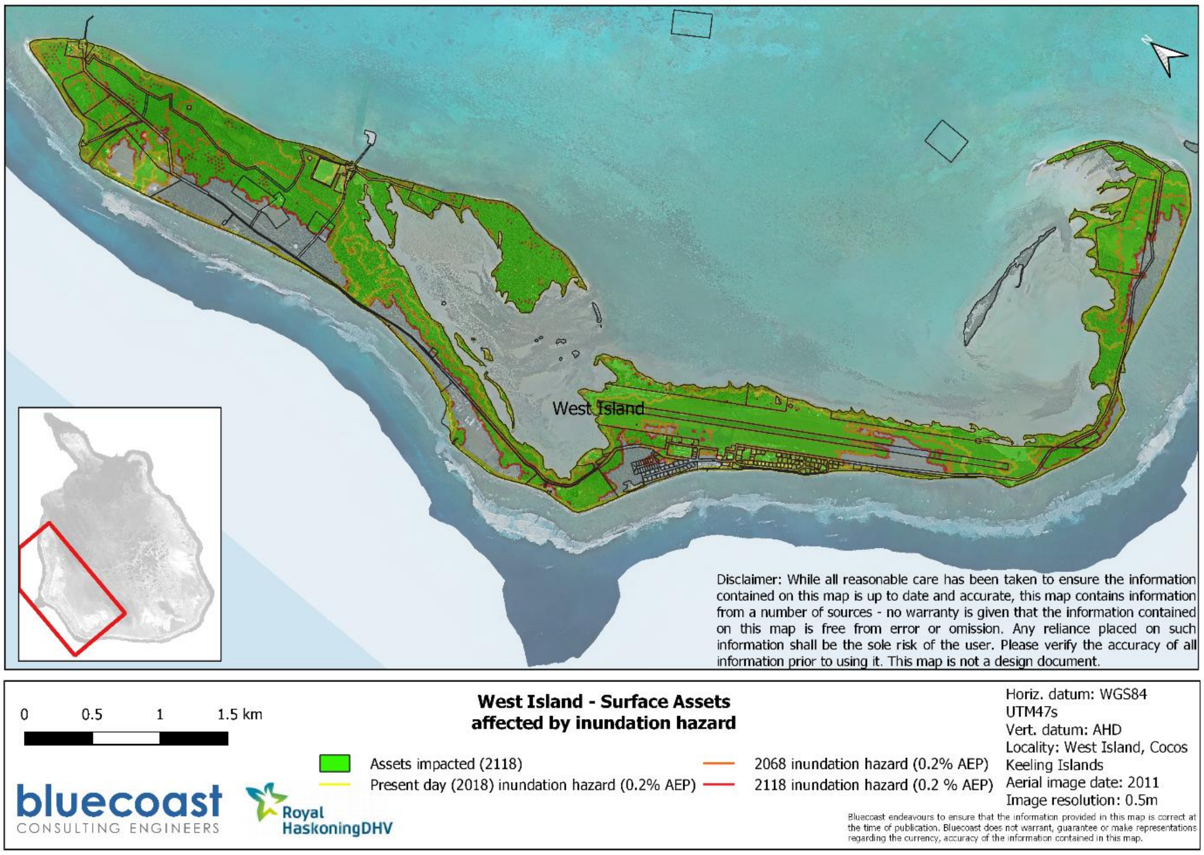

Figure 87: Surface assets possibly exposed to inundation in 2118 planning period on West Island.

7.5 Consequence (sensitivity)

Consequence is the impact of erosion and inundation on existing and future assets and the value assigned to that asset. Within the context of the vulnerability assessment, consequence is used to consider the sensitivity of an asset to coastal hazards. Three impact categories were defined to qualitatively assess the asset's sensitivity. These impact categories align with the asset groups being:

- Environment
- Social
- Economic

The scale of consequences for the Cocos (Keeling) Islands was adopted after WAPC, 2019, based on the asset group classifications. The adopted consequence scale is described in **Table 37**. It is recommended that the adopted consequence be tested, and if necessary, tailored for the Cocos (Keeling) Islands application by incorporate community values (e.g. as gathered from risk workshops or values surveys). Further adjustments are also recommended to ensure consistency with the Shire of the Cocos (Keeling) Islands' risk management framework.

Table 37: Consequence scale for each impact category (after WAPC, 2019).

Rating	Environment (including heritage)	Social	Economic
Insignificant	Minimal damage to local environmental assets; recovery may take less than six months	Minimal short-term inconveniences to services, employment, wellbeing, finances or culture (e.g. < 5% of community affected), neighbourhood loss, many alternative sites exist.	Permanent loss or damage to property, plant and equipment, finances < $10,000, or 2% of annual operating budget.
Minor	Environmental damage to local environmental asset that could be reversed or offset, local alternate habitat exists.	Small to medium disruption to services, employment wellbeing, finances or culture (e.g. < 10% of community affected), local loss, many suitable alternative sites exist.	Permanent loss or damage to property, plant and equipment, finances > $10,000 - $100,000, or 2 - 5% of annual operating budget.
Moderate	Environmental damage to local environmental asset that could be reversed or offset, no alternate habitats exist.	Minor injury. Major short-term or minor long-term disruption to services, employment wellbeing, finances or culture (e.g. < 25% of community affected), regional loss, limited suitable alternative sites exist.	Permanent loss or damage to property, plant and equipment, finances > $100,000 - $2 million, or 5 - 10% of annual operating budget.
Major	Irreversible damage to local environmental asset that would compromise its viability, local alternate habitat exists.	Serious injury. Medium term disruption to services, employment wellbeing, finances or culture (e.g. < 50% of community affected), national loss, very limited suitable alternative sites exist.	Permanent loss or damage to property, plant and equipment, finances > $2 - $5 million, or 10 - 20% of annual operating budget.
Catastrophic	Irreversible damage to local environmental asset that would compromise its viability, no alternate habitats exist.	Loss of life and serious injury. Large long-term or permanent loss of services, employment wellbeing, finances or culture (e.g. > 75% of community affected), international loss, no suitable alternative sites exist.	Permanent loss or damage to property, plant and equipment, finances > $5 million, or > 20% of annual operating budget.

Table 38: Consequence scale applied to each asset group for erosion hazard.

Assets	Consequence	Reason (erosion)
Environment		
Beaches, coastal barrier systems and foreshore reserves.	**Major**	The Cocos (Keeling) Islands is an island community with a strong connection to the ocean. Erosion and permanent loss of land due to the actions of the sea can leave the community feeling vulnerable. The role of the beach, beach ridges and dunes (where present), as well as the fringing reef, in providing a buffer to protect land and property is well recognised.

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Assets	Consequence	Reason (erosion)
		Beach amenity itself is generally rated highly by the community, for instance due to the perceived scenic, recreation or environmental value. It is not understood if this is the case at CKI, however, there is a large portion of the community for which tourism is a critical source of livelihoods. Beaches, particularly Kite Beach, Trannies Beach, Turtle Beach, Direction Island beaches are important for the island's visitors. Most of the Cocos (Keeling) Islands beaches will generally recover from storm erosion events, although following large storm events this can take several years, during which time the beach may be less usable. Sea level rise has already commenced at measured rates; therefore, it might be expected recovery following storms to become increasingly subdued. Foreshore reserves will remain functional even if reduced in size by erosion. However, these areas also serve as a buffer to allow roll back and therefore retention of the protection and amenity afforded by the foreshore.
Social		
Foreshore amenity (picnic facilities, BBQ, toilets)	**Moderate**	There will be some financial and social costs associated with erosion impacting specific facilities within foreshore reserves (e.g. BBQs, shelters, paths etc). However, there are several the facilities on Home Island and West Island and given that the exposure to erosion hazard varies in any given event there will be alternative unaffected options for foreshore amenity still available to the community.
Residential development	**Major**	For the public, other community assets may rate more highly. However, given the remote location of the Cocos (Keeling) Islands, replacing residential building is difficult. For the individual owner, this asset is of very high importance. Losses in relation to erosion are irreversible.
Hospital, school, cyclone shelter, club house, cemetery, mosque/church	**Major**	Such facilities are socially vital, while the building is typically highly financially costly to build and fit out, making relocation of the physical asset difficult. An example is the West Island Medical Centre which is semi-protected by geobag seawall but located in an erosion hotspot.
Economic		
Roads, jetties, boat ramps, ferry terminals, pump station, wastewater disposal, waste disposal, desalination plant, power generator, fuel depot, commercial/ industrial/ commonwealth development and infrastructure	**Major**	Roads are the key conduits for traffic flow within the island community. Damage or loss that blocks or impedes these routes would indeed cause major disruption to the community. As a group of islands; jetties, boat ramps and ferry terminals are key services for community members, compared with other transport infrastructure. Impacts from storm waves may also cause damage to these assets (albeit reversible). Pump station, wastewater disposal, waste disposal, desalination plant, power generator and fuel depots all provide a vital service to social health and functioning on the islands.

Table 39: Consequence scale applied to each asset group for inundation hazard.

Assets	Consequence	Reason (inundation)
Environment		
Beaches, coastal barrier systems and foreshore reserves.	**Insignificant**	Beaches are regularly inundated, and this is of little consequence. It is an inherent function of the service that a beach provides the coastline. Inundation of foreshore reserves over a short period (a few hours), resulting in a minor nuisance to the community, and causing little to no damage to the value of this asset. This is particularly the case at Cocos where rapid infiltration of overwash flows can occur.
Social		
Foreshore amenity (picnic facilities, BBQ, toilets)	**Minor**	The impact of inundation would occur over a short period (a few hours), resulting in a minor nuisance to the community, and causing little to no damage to the value of this asset.
Residential development	**Major**	The Cocos (Keeling) Islands are low-lying islands and widespread flooding presents major impacts on these assets. Major coastal inundation is associated with tropical cyclones, while rare, these can have major consequences with inundation occurring concurrently to wind and wave damage. For the individual owner, this asset is of very high importance. The economic impact from inundation of private residential property could potentially be substantial, particularly given the remote location and difficulty in sourcing materials for repair.
Hospital, school, cyclone shelter, club house, cemetery, mosque/church	**Catastrophic**	Such facilities are socially vital, while the building is typically highly financially costly to build and fit out, making relocation of the physical asset difficult. During periodic inundation events, damages or loss of services from this asset is of significant impact to community.
Economic		
Roads, jetties, boat ramps, ferry terminals, pump station, wastewater disposal, waste disposal, desalination plant, power generator, fuel depot, commercial/ industrial/ commonwealth development and infrastructure	**Major**	Roads are the key conduits for traffic flow within the island community. Inundation across these road causes impacts upon the safety and access for community particularly during storms where access is important. The South End Road on West Island is regularly inundated causing limited or no access to Scout Park, Pulu Maria, Yacht Club and Kite Beach, all of which are important tourist attractions. Jetties, boat ramps and ferry terminals are important features servicing most of the island community members, compared with other transport infrastructure. Pump station, wastewater disposal, waste disposal, desalination plant, power generator and fuel depots all provide a vital service to social health and functioning on the islands. The impacts from inundation may potentially have significant environmental and community impacts, even where this is reversible.

7.6 Asset risk rating

The following levels are considering appropriate when assessing climate change risks for settlements and infrastructure:

- Low risks would typically be addressed through routine maintenance and day to day operations.
- Moderate risks would require a change to the design or maintenance regime of assets.
- High risks require detailed research and appropriate planning (or design).
- Extreme risks would require immediate action to mitigate.

Using the risk level matrix in **Table 40** the level of risk for each asset arising from the consequence and likelihood scales, were calculated. The risk level is an important element of the CVA. To enable forward planning the risk level across assets was determined for each planning period. Consideration of risk tolerances is beyond the scope of this assessment.

Table 41 and **Table 42** provides an aggregation of the risks rating across assets by island and planning period for erosion and inundation hazards, respectively.

Table 40: Risk matrix adopted to assess asset vulnerability.

Likelihood	Consequences				
	Insignificant	Minor	Moderate	Major	Catastrophic
Almost Certain	L	M	H	E	E
Likely	L	M	M	H	E
Possible	L	L	M	H	E
Unlikely	L	L	M	M	H
Rare	L	L	L	M	M

L= low, M=medium, H=high and E=extreme

Table 41: Risk rating for assets identified as being at risk to erosion hazards by island and asset group.

Planning period	Home Island (250 assets)				West Island (268 assets)			
	Low	Med.	High	Extreme	Low	Med.	High	Extreme
2018	4	84	0	**0**	4	122	0	**0**
2068	0	80	40	**0**	2	128	47	**0**
2118	0	42	78	**0**	0	59	118	**0**

Table 42: Risk rating for assets identified as being at risk to inundation hazards by island and asset group.

Planning period	Home Island (250 assets)				West Island (268 assets)			
	Low	Med.	High	Extreme	Low	Med.	High	Extreme
2018	23	0	196	**3**	33	157	3	0
2068	24	0	116	**108**	33	104	77	3
2118	24	0	25	**199**	27	29	153	8

7.7 Adaptive capacity

The adaptive capacity is about understanding and reviewing the ability of an asset to adjust or be modified in a way that makes them better equipped to deal with potential impacts from coastal hazards (WAPC, 2019). A simple example is the capacity of a coastal protection structure to be upgraded to provide a greater level of protection to landward assets. However, the capacity needs to be considered in the context of real-world constraints such as monetary resources, community values, and environmental impacts. Adaptive capacity has been assessed independently for coastal erosion/ recession and inundation.

The adaptive capacity scale, as presented in **Table 43**, has been established for the Cocos (Keeling) Islands' assets based on their function, services and assumed values. The adopted scale was then applied to the asset groups (economic, environmental and social) as shown in **Table 44**.

Table 43: Adaptive capacity scale adopted for the CKI vulnerability assessment.

Adaptive capacity scale	Description
No adaptation required	Potential impact has insignificant effect on asset. Controls are re-established naturally or with ease before more damage would likely occur.
Very high	Good adaptive capacity. Functionality restored easily. Adaptive systems restored at a relatively low cost or naturally over time.
High	Decent adaptive capacity. Functionality can be restored, although additional adaptive measures should still be considered. Natural adaptive capacity restored slowly over time under average conditions.
Moderate	Small amount of adaptive capacity. Difficult but possible to restore functionality through repair and redesign.
Low	Little or no adaptive capacity. Potential impact would destroy all functionality. Redesign required.

Table 44: Adaptive capacity applied to each asset group.

Assets	Adaptive capacity	
	Erosion	Inundation
Environment		
Beaches, coastal barrier systems and foreshore reserves.	Moderate	Very high
Social		
Foreshore amenity (picnic facilities, BBQ, toilets)	Moderate	High
Residential development	Low	Low
Hospital, school, cyclone shelter, club house, cemetery, mosque/church	Low	Low
Economic		
Roads, jetties, boat ramps, ferry terminals, pump station, wastewater disposal, waste disposal, desalination plant, power generator, fuel depot, commercial/ industrial/ commonwealth development and infrastructure	Low	Low

7.8 Vulnerability assessment

Finally, the adaptive capacity and the risk rating of each asset has been combined to establish the vulnerability associated with each identified asset over each of the planning periods. Like that of the risk rating, four levels of vulnerability are typically defined after WAPC (2019) as:

- Extreme – Asset has minimal to no ability to adapt to impacts of coastal hazards without additional support. Significant further adaptation required to ensure asset not lost. Reconsideration of design required if vulnerability cannot be reduced. Risk management measures will need to be a priority.
- High – Asset has limited ability to adapt to impacts of coastal hazards. Immediate to short-term risk management measures required.
- Medium – Asset has some ability to adapt to impacts of coastal hazards. Short-term to medium-term risk management measures required.
- Low – Asset has high resilience and can adapt to impacts of coastal hazards without additional support. No immediate risk management measures required other than monitoring.

The adopted vulnerability scale matrix is provided in **Table 45.**

Table 45: Coastal vulnerability matrix adopted for the Cocos (Keeling) Islands assessment.

Adaptive capacity	Risk rating			
	Low	Moderate	High	Extreme
Low	M	H	E	E
Moderate	L	M	H	E
High	L	L	M	H
Very high	L	L	L	M
No adaptation required	L	L	L	M

L= low, M=medium, H=high and E=extreme

Table 46 and **Table 47** provides an aggregation of the vulnerability rating across assets by island and planning period for erosion and inundation hazards, respectively. A summary of the vulnerability of key assets on West Island and Home Island is provided in **Table 48**. Detailed maps showing asset vulnerability are provided in **Volume II (Maps 9 to 21)**.

Table 46: Vulnerability rating for assets identified as being at risk on Home Island (251 assets).

Planning period	Erosion				Inundation			
	Low	Med.	High	Extreme	Low	Med.	High	Extreme
2018	4	19	65	0	23	0	196	3
2068	0	12	79	29	24	0	116	108
2118	0	10	45	65	24	0	25	199

Table 47: Vulnerability rating for assets identified as being at risk on West Island.

Planning period	Erosion				Inundation			
	Low	Med.	High	Extreme	Low	Med.	High	Extreme
2018	2	31	93	0	30	3	157	3
2068	0	13	137	27	30	3	104	80
2118	0	6	78	93	30	3	23	161

Table 48: Summary of vulnerability of key assets on West Island and Home Island.

Description	Management unit	Island	Type	Erosion vulnerability			Inundation vulnerability		
				2018	2068	2118	2018	2068	2118
Cocos Beach Motel	MU1	West Island	Economic	High	High	Extreme	High	Extreme	Extreme
Information Centre	MU1	West Island	Social	Medium	High	High	High	Extreme	Extreme
West Island Power Station	MU1	West Island	Economic	Medium	Medium	Medium	High	High	Extreme
Police Station	MU1	West Island	Social	Medium	Medium	Medium	High	Extreme	Extreme
RAAF Sergeants Mess Memorial	MU1	West Island	Environment	Medium	High	High	Low	Low	Low
Primary School	MU1	West Island	Economic	Medium	Medium	Medium	High	High	Extreme
Airport	MU1	West Island	Economic	High	Extreme	Extreme	High	Extreme	Extreme
High School	MU1	West Island	Economic	Medium	Medium	Medium	High	High	Extreme

Description	Management unit	Island	Type	Erosion vulnerability			Inundation vulnerability		
				2018	2068	2118	2018	2068	2118
Cocos Club	MU1	West Island	Social	Medium	High	High	High	High	Extreme
Medical Centre	MU1	West Island	Social	High	High	Extreme	High	Extreme	Extreme
Government House	MU1	West Island	Economic	High	High	Extreme	High	High	Extreme
Supermarket	MU1	West Island	Social	Medium	High	High	High	High	Extreme
Sydney Highway	MU1	West Island	Economic	High	Extreme	Extreme	High	Extreme	Extreme
Cemetry North Park	MU2a	West Island	Social	High	High	Extreme	Medium	High	Extreme
Geobag Wall	MU2a	West Island	Economic	High	Extreme	Extreme	High	Extreme	Extreme
The Spot	MU2a	West Island	Environment	Low	Medium	Medium	Low	Low	Low
North Park	MU2a	West Island	Environment	Low	Medium	Medium	Low	Low	Low

Description	Management unit	Island	Type	Erosion vulnerability			Inundation vulnerability		
				2018	2068	2118	2018	2068	2118
Big Barge Art Centre	MU2b	West Island	Economic	High	High	Extreme	Medium	Medium	Medium
Trannies Bbq Area	MU2b	West Island	Social	High	Extreme	Extreme	High	Extreme	Extreme
Transfer Station	MU3	West Island	Economic	High	Extreme	Extreme	High	Extreme	Extreme
Waste Water Treatment Plant	MU3	West Island	Economic	Medium	High	High	Medium	High	High
Fuel Station	MU3	West Island	Economic	High	High	Extreme	High	Extreme	Extreme
Bom Weather Station	MU3	West Island	Economic	High	High	Extreme	High	Extreme	Extreme
Twiss Memorial	MU3	West Island	Environment	Medium	Medium	Medium	Low	Low	Low
Airforce Road	MU3	West Island	Economic	High	Extreme	Extreme	High	Extreme	Extreme
The Shack	MU3	West Island	Social	Medium	Medium	High	Medium	Medium	Medium

Description	Management unit	Island	Type	Erosion vulnerability			Inundation vulnerability		
				2018	2068	2118	2018	2068	2118
Rumah Baru Boat Ramp	MU4	West Island	Economic	High	Extreme	Extreme	High	Extreme	Extreme
CKI Port Office	MU4	West Island	Economic	High	Extreme	Extreme	High	Extreme	Extreme
Rumah Baru Jetty	MU4	West Island	Economic	High	Extreme	Extreme	High	Extreme	Extreme
Scout Park	MU5	West Island	Social	High	High	Extreme	Extreme	Extreme	Extreme
Yacht Club	MU5	West Island	Social	High	Extreme	Extreme	Extreme	Extreme	Extreme
Public Boat Ramp	MU5	West Island	Economic	High	Extreme	Extreme	High	Extreme	Extreme
Airforce Rd Geobag Wall	MU6	West Island	Economic	High	Extreme	Extreme	High	Extreme	Extreme
Twiss Memorial Geobag Seawall	MU6	West Island	Economic	High	Extreme	Extreme	High	Extreme	Extreme
Oceania House	MU7	Home Island	Economic	High	High	Extreme	High	Extreme	Extreme

Description	Management unit	Island	Type	Erosion vulnerability			Inundation vulnerability		
				2018	2068	2118	2018	2068	2118
Yacht Club	MU7	Home Island	Economic	High	Extreme	Extreme	High	Extreme	Extreme
Watchtower	MU7	Home Island	Environment	Medium	Medium	Medium	Low	Low	Low
Home Island Jetty	MU7	Home Island	Economic	High	Extreme	Extreme	High	Extreme	Extreme
Public Boat Ramp	MU7	Home Island	Economic	High	Extreme	Extreme	High	Extreme	Extreme
Supermarket	MU7	Home Island	Economic	High	High	Extreme	High	High	Extreme
Doctor	MU7	Home Island	Social	High	High	Extreme	High	Extreme	Extreme
Desalination Intake Bores	MU7	Home Island	Environment	Medium	Medium	Medium	Low	Low	Low
Shire Of Cocos Office	MU7	Home Island	Social	High	Extreme	Extreme	Extreme	Extreme	Extreme
Home Island Power Station	MU8	Home Island	Economic	High	High	Extreme	Medium	High	High

Description	Management unit	Island	Type	Erosion vulnerability			Inundation vulnerability		
				2018	2068	2118	2018	2068	2118
Wastewater Treatment Plant	MU8	Home Island	Economic	High	High	Extreme	Medium	High	High
Cemetry	MU8	Home Island	Social	High	Extreme	Extreme	Extreme	Extreme	Extreme
Rubbish Tip	MU8	Home Island	Economic	High	Extreme	Extreme	High	Extreme	Extreme
Mosque	-	Home Island	Social	Medium	Medium	Medium	Extreme	Extreme	Extreme
District High School	-	Home Island	Social	Medium	Medium	Medium	High	Extreme	Extreme
Cyclone Shelter	-	Home Island	Social	Medium	Medium	Medium	High	High	Extreme
Museum	-	Home Island	Social	High	High	Extreme	High	High	Extreme

8 Summary and future recommendations

A comprehensive coastal processes, coastal hazard and coastal asset vulnerability assessment has been undertaken for the southern atoll of the Cocos (Keeling) Islands. Review of previous studies and information, (minimum) 12-months metocean data collected across eight monitoring sites, site observations, and various numerical modelling investigations have informed a conceptual coastal processes understanding of the islands.

Following the CHRMAP guidelines (WAPC, 2019), the coastal hazard extents of erosion and inundation at West Island and Home Island have been determined to identify built and natural assets at risk for the present day, 2068 and 2118 planning horizons. A summary of the key findings is provided in the following:

Coastal inundation

- The coastal inundation assessment was completed with reference to an event with a 0.2% chance of exceedance per year, otherwise referred to as the 500-year ARI event and comprises:
    - Peak steady water level, i.e. tide, storm surge and sea level rise.
    - Wave-driven water level, i.e. wave setup and wave runup.
- Coastal inundation at the ocean-facing shorelines is dominated by wave-driven water levels (i.e. due to wave setup and overwash/ overtopping) whereas inundation on the lagoon side is mainly controlled by still water levels (i.e. tide and storm surge).
- Due to limitations of the coupled hydrodynamic and wave model the complex fringing coral reef wave processes are not correctly resolved in this investigation with differences in the wave-driven inshore sea levels of over 1m lower compared to those simulated by the Xbeach model. This has significant implications on the predicted coastal inundation presented herein due to reduced wave overwash/ overtopping. Areas where wave over-overtopping is expected based on the coastal barrier elevation have been annotated on the coastal inundation maps. These include the low-lying northern and southern tips of West Island, the central part of West Island (north of the settlement) along Sydney Highway as well as the northern tip of Home Island.
- It has been assumed the coral reef crest and platforms are static. Vertical growth of the fringing coral reef could significantly reduce the wave-driven allowances for the future sea level rise scenarios applied herein and therefore reduce predicted inundation extents.

Coastal erosion

- Allowances for storm erosion for a 100-year ARI event (S1) have been determined by erosion modelling using Xbeach and SBEACH.
- To estimate the S2 allowance, long term historical shoreline movement trends were examined using aerial photography and vegetation line position information spanning a 32-year period, from 1987 to 2019.
- Following the recommendation in SPP 2.6, a form of the Bruun rule (Bruun, 1962) was used for calculation of a CPA distance based on the vertical SLR component. Moreover, SPP 2.6 states that the allowances for erosion on coasts with fringing reefs should generally be determined using the methods specified for sandy coasts.
- The formal coastal protection works along West Island and Home Island settlement were assumed to be designed and constructed to withstand a 100-year ARI design event.
- Given the high allowance for SLR erosion recommended in SPP 2.6, the erosion hazard for the future planning horizon 2068 and 2118 is deemed overly conservative for the coral atoll application at Cocos (Keeling) Islands and should not be relied on.

Assets vulnerability

On both Home Island and West Island, the erosion and shoreline recession as well as coastal inundation are threatening high value tourism as well essential infrastructure. In summary, no assets were assigned ‘extreme’ vulnerability to erosion for the 2018 planning horizon while 93 and 65 were identified in the ‘high’ vulnerability for West Island and Home Island, respectively. Likewise, 3 assets were identified with ‘extreme’ vulnerability to coastal inundation for the 2018 planning horizon on both islands while 157 and 196 assets were assigned a ‘high’ vulnerability rating for West Island and Home Island, respectively.

Future recommendations

The following further recommendations are provided for consideration for future stages of the CHRMAP process:

- The gap analysis Section 2.6 identified that at present no long-term record of coastal survey data is available at Cocos (Keeling) Islands. The project team has worked with the Shire to train local staff in undertaking RTK beach transect surveys to allow more regular and on-going data collection. Future studies will benefit from the longer-term data in resolving the likelihood of any on-going coastal erosion response.
- Other key investigations that would address assumptions made in quantifying the coastal

erosion hazard were identified in Section 2.6, including geotechnical investigations of the substrata to detect less-erosive layers (e.g. coral boulder ridges), collection and analysis of sediment data and spatial measurements of nearshore currents to verify the conceptual understanding of the sediment transport processes.

- SPP 2.6, section 4.9 states *"Acknowledging that for most islands the allowance would preclude development, variation should be considered on a case-by-case basis."* This will need to be further considered at later stages of the CHRMAP and should be based on the latest available science and understanding of the natural resilience of atolls and specifically the Cocos (Keeling) Islands. Misunderstanding of the natural resilience will lead to maladaptation and possibly to rendering the islands uninhabitable by the middle of this century.
- The erosion hazard allowances adopted herein assumed that existing (permanent) coastal protection structures have been designed to withstand a 100-year ARI design event. However, there is no clear evidence of the design standard of such structures on Cocos (Keeling) Islands. It is therefore recommended to undertake a detailed engineering condition assessment of the existing structures (including estimating the design standards retrospectively) and update the erosion hazard allowances presented herein if required. Changes to the erosion hazard allowance at coastal structure locations would directly impact the asset exposure behind such structures.
- This study has followed the requirements of SPP 2.6 in relation to applying the S3 allowance for erosion due to sea level rise. As per the discussion in Section 6.6.6, this is unlikely to be a useful way to characterise risk and vulnerability of an atoll. It is recommended that future stages consider a refined approach to determining S3.
- The two-dimensional hydrodynamic and wave numerical modelling undertaken within the scope of this CVA was unable to accurately simulate the complex fringing coral reef wave processes observed at Cocos (Keeling) Islands. Two-dimensional Xbeach (or similar modelling) is recommended to refine wave-driven S4 allowance around the atoll.
- The interaction between ocean water levels and groundwater is not well understood and could pose a significant risk to the island's freshwater supplies due to saltwater intrusion. Detailed studies to determine the level of risk would be recommended.
- It is important to communicate, consult and involve key stakeholders and the wider community to provide, share and obtain information. It was beyond the scope of this CVA to formally engage with stakeholders or formally consult with the community. It is suggested that provision of a risk workshop, or alternative stakeholder consultation,

should be considered prior to the implementation of any management actions which rely on the results of this vulnerability assessment.

As part of the CHRMAP process the next steps include:

- Confirmation that the consequence rating reflects the current community and stakeholder values. This may require further stakeholder and community engagement focused on the assets identified to have the highest vulnerability.
- Identification and evaluation of existing controls, the existing coastal protection structures.
- Re-evaluate the need for a more suitable approach to the determination of S3 and considered the impact that would have on the vulnerability assessment presented herein.
- Determining tolerable risk levels for each of the assets identified as vulnerable.
- Identification and evaluation of adaptation options.
- Develop short and long-term implementation plans, with a priority focus on assets identified at being immediately vulnerable.

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Maps

Summary:

Map 1 to **Map 6** present the resulting coastal inundation hazard maps for the 2018, 2068 and 2118 planning period for Home Island and West Island.

Map 7 and **Map 8** present the resulting coastal erosion hazard for the 2018, 2068 and 2118 planning periods for Home Island and West Island.

Map 9 to **Map 14** present the resulting asset vulnerability maps due to coastal inundation for the 2018, 2068 and 2118 planning period for Homes Island and West Island.

Map 15 to **Map 20** present the resulting asset vulnerability maps due to coastal erosion for the 2018, 2068 and 2118 planning period for Homes Island and West Island.

Appendix A – Numerical Model Development

A1 Hydrodynamic model

Deltares’ Delft3D-Flow Flexible Mesh was adopted for simulating tidal as well as wind and wave driven flows and resulting sediment transport. Delft3D is a comprehensive two or three-dimensional numerical modelling system. It is recognised as industry leading software for application in coastal free-surface flow modelling. The unstructured mesh provides the optimal degree of flexibility in representing complex coastlines and bathymetries. High spatial resolution can be applied in areas of interest while larger mesh elements can be used where less detail is required, saving on computational time. It has been adopted in similar projects globally and is proven to provide reliable results to inform coastal vulnerability assessments.

The following paragraphs describe the setup and calibration of the hydrodynamic model. The hydrodynamic model was coupled with the D-Waves spectral wave model which is described in the subsequent section.

A1.1 Model domain

The model extent, computational grid as well as the adopted bathymetry for the hydrodynamic model are shown in Figure 88. The grid resolution ranges from up to 1km in offshore areas to 10m in nearshore and up to 5m in land areas. The grid resolution was selected based on the resolution of the available bathymetry data and the minimum required resolution to accurately describe the simulated processes.

The 2011 LiDAR data was adopted for all land areas, while the 2012 marine LiDAR data was used for nearshore bathymetry in areas down to 25m water depth. In deeper areas, bathymetric data was derived from the General Bathymetric Chart of the Oceans (GEBCO, 2014). All elevation data has been corrected to Australian Height Datum (AHD).

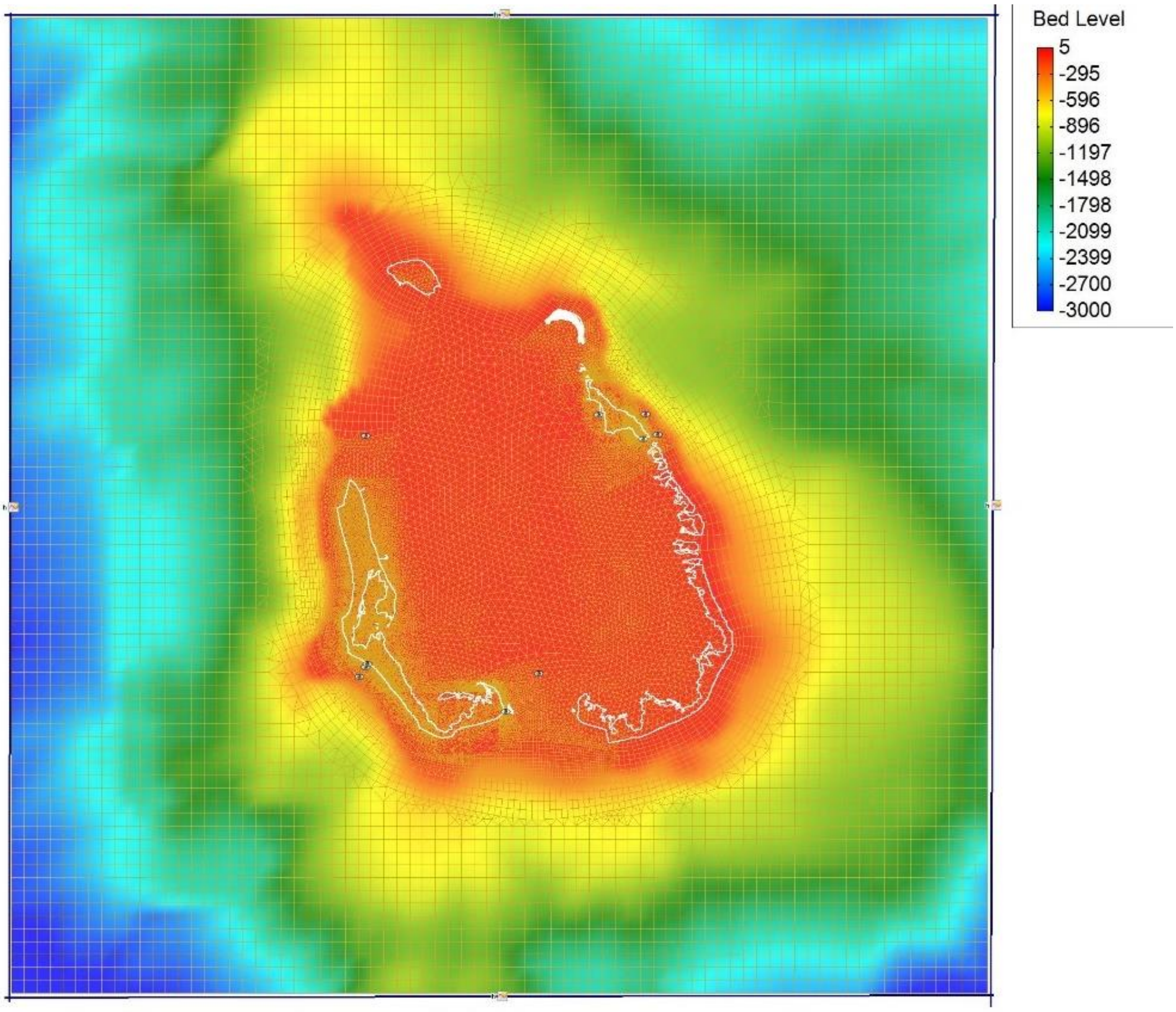

Figure 88: Model extent, computational grid and bathymetry used for the hydrodynamic model.

A1.2 Model setup

The two-dimensional, depth-averaged hydrodynamic model was coupled to the spectral wave model to simulate tide, wind and wave driven flows. A spatially varying bed roughness (Manning) was adopted to represent the various bottom types, e.g. sandy bottom, land and coral reefs (see Figure 89). Wind effects were included using the wind drag coefficient described in Smith and Banke (1975). The simulation time step was 10-minutes while wind and wave boundaries were updated every hour.

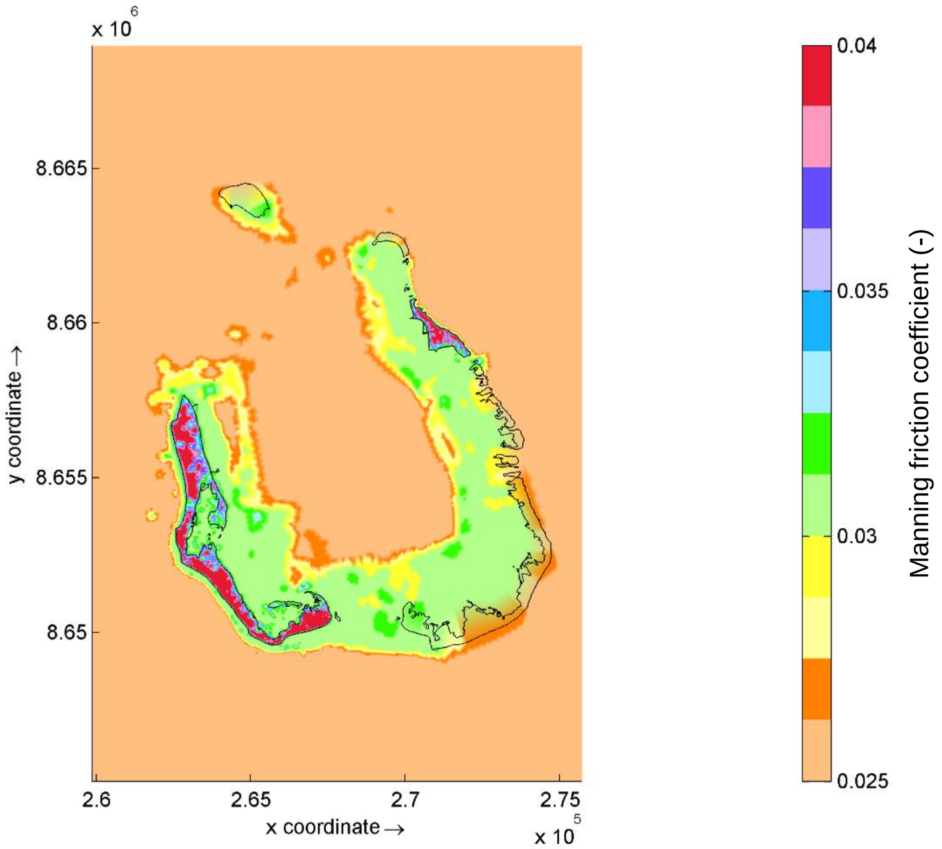

Figure 89: Map of spatially varying bed roughness (Mannings coefficient).

A1.3 Boundary conditions

Astronomical tidal heights derived from the TPXO Global Tidal Model (Egbert and Svetlana, 2002) were included at the offshore boundaries. Time-varying wind speed and direction has been applied uniformly over the model domain derived from the CKI Airport measurements. Wave radiation stresses were included across the model domain via the coupled spectral wave model described herein.

For the inundation assessment, further input was included using point discharges around the wave exposed CKI coastline based on information acquired through the detailed nearshore wave modelling and wave overtopping investigations (see further details in Section 5.2 and in subsequent sections of this Appendix).

A1.4 Calibration

A ten-day period was selected for the model calibration which is representative of (i) an ambient metocean climate with typical wave heights and winds and (ii) extreme conditions during the large swell event that occurred on 24th July 2018.

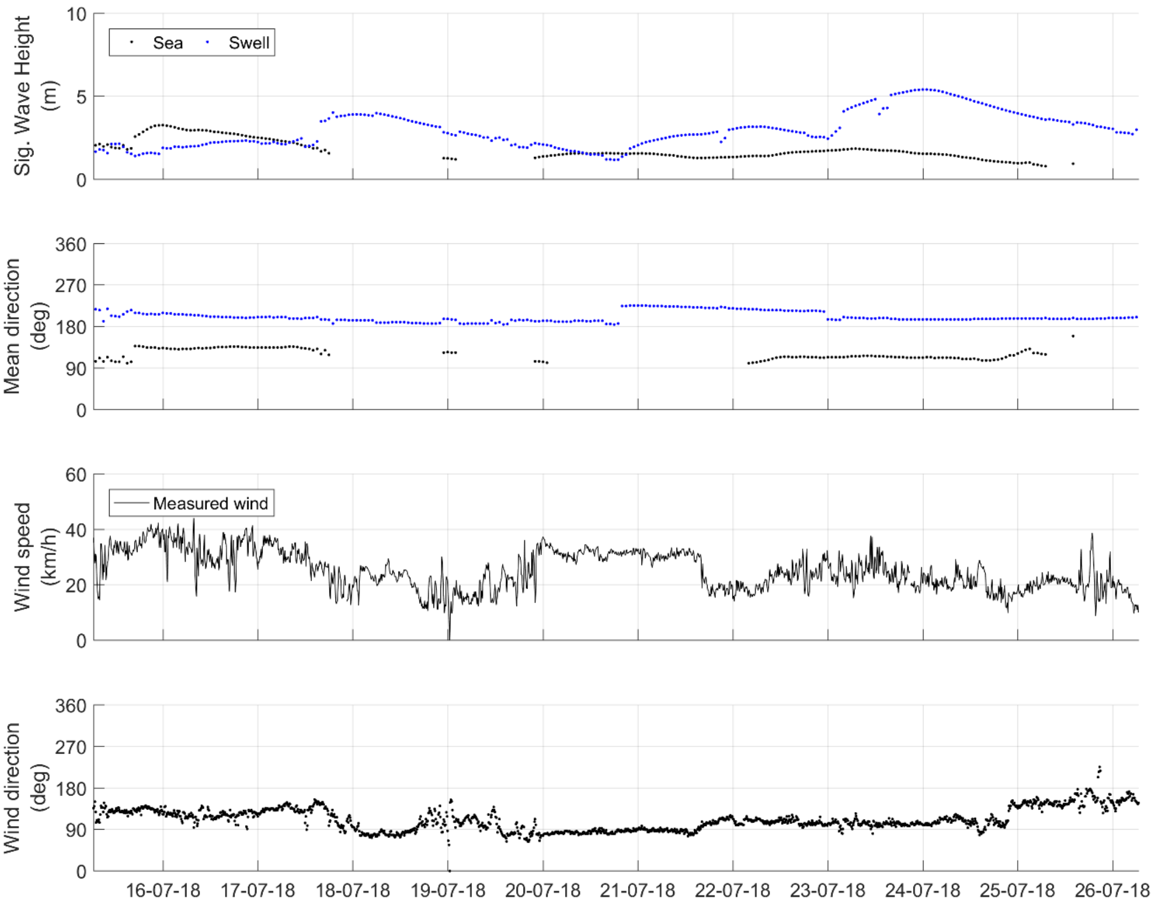

Figure 90: Metocean conditions applied to the model boundaries for the adopted calibration period.

Following several iterations of mesh and temporal resolutions as well as the selection of boundaries within the hydrodynamic model setup, the model was deemed sufficiently calibrated to water levels and currents for the adopted period. In general, reasonable agreement between measured and modelling was achieved. Following calibration some discrepancies were still apparent, however, the overall calibration was considered suitable for the representation of circulation patterns around the southern atoll and within the lagoon for the purposes of the inundation assessment. Further, consideration to offshore current speeds and direction and the associated drivers of these will be given in the subsequent modelling investigations of the CVA.

Some of the differences between the modelled and measured data can be explained by the use of the 2012 marine LiDAR bathymetry data, which contains errors, and possible morphological changes to the present-day bathymetry. This is particularly important for the monitoring sites at the Western Entrance (CK03) and the shallow southern lagoon site (CK04). Currents in these areas are spatially variable due to changes in water depths and channel morphology. To demonstrate the spatial variability of the currents at these sites, a comparison of the modelled currents (using the 2012 bathymetry data) and the recent current measurements (in 2019) at nearby locations are also provided. These present a better agreement of the modelled data, however some discrepancies in the current magnitudes remain. Furthermore, current speed and direction maps showing the spatial variability are presented in **Section 4** in the main report.

At the outer atoll monitoring sites (CK01a and CK02) wave driven currents are the dominant component and are temporally highly variable due the complex nearshore wave processes. The model does not fully resolve the complex nearshore wave driven hydrodynamics that occur at the reef edge (e.g. drainage of trapped reef top water levels). In addition, large-scale ocean currents have not been included in this assessment.

Nevertheless, the order of magnitude of current speeds and the mean current directions agree well with the measured data at all sites which was deemed most important to represent the flow circulation around the atoll. Hence, for the application of the coupled spectral wave and hydrodynamic model in this study the discrepancies are considered acceptable and reef top wave processes are further investigated using the nearshore wave model, Xbeach.

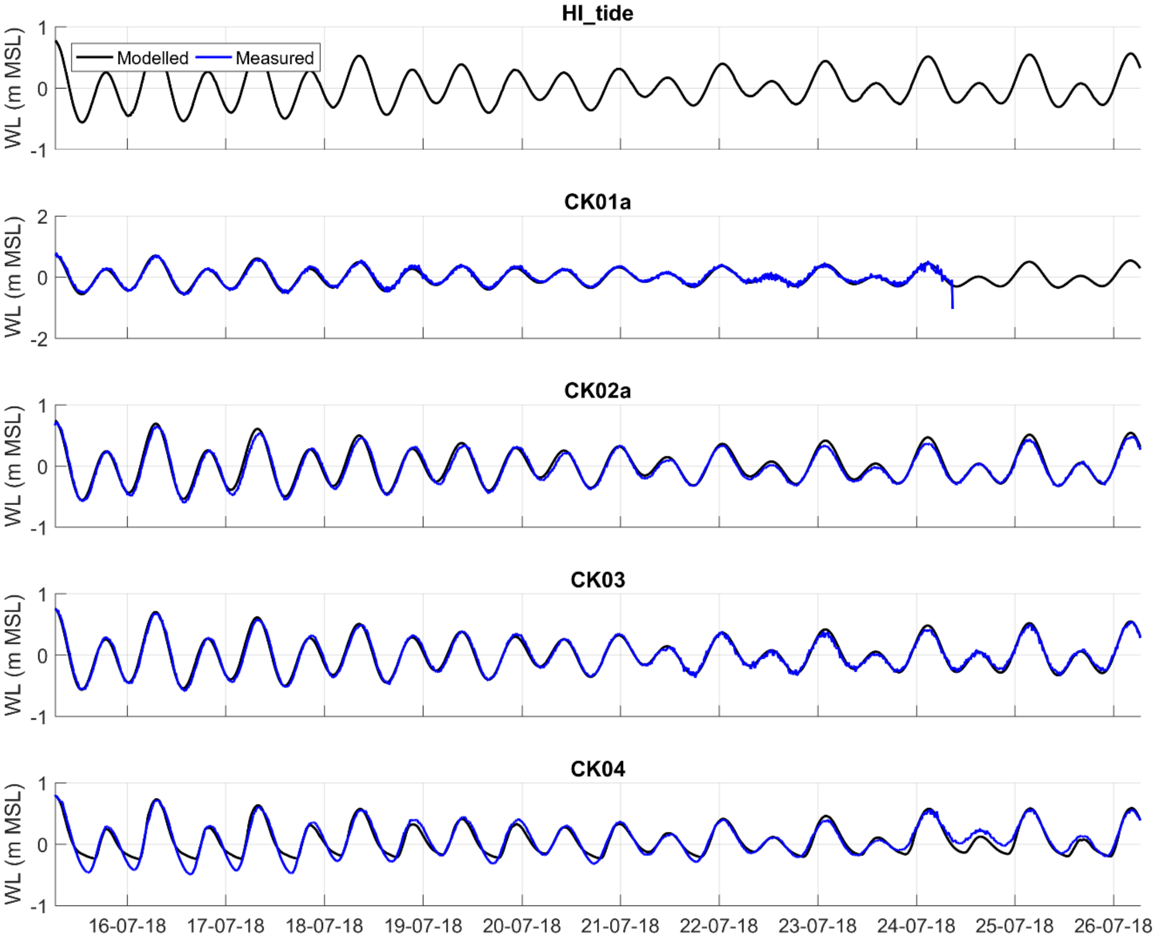

Figure 91: Comparison of measured and modelled water level during a 10-day period in July 2018.

Note, no measured data was available at the Home Island tide gauge during this period.

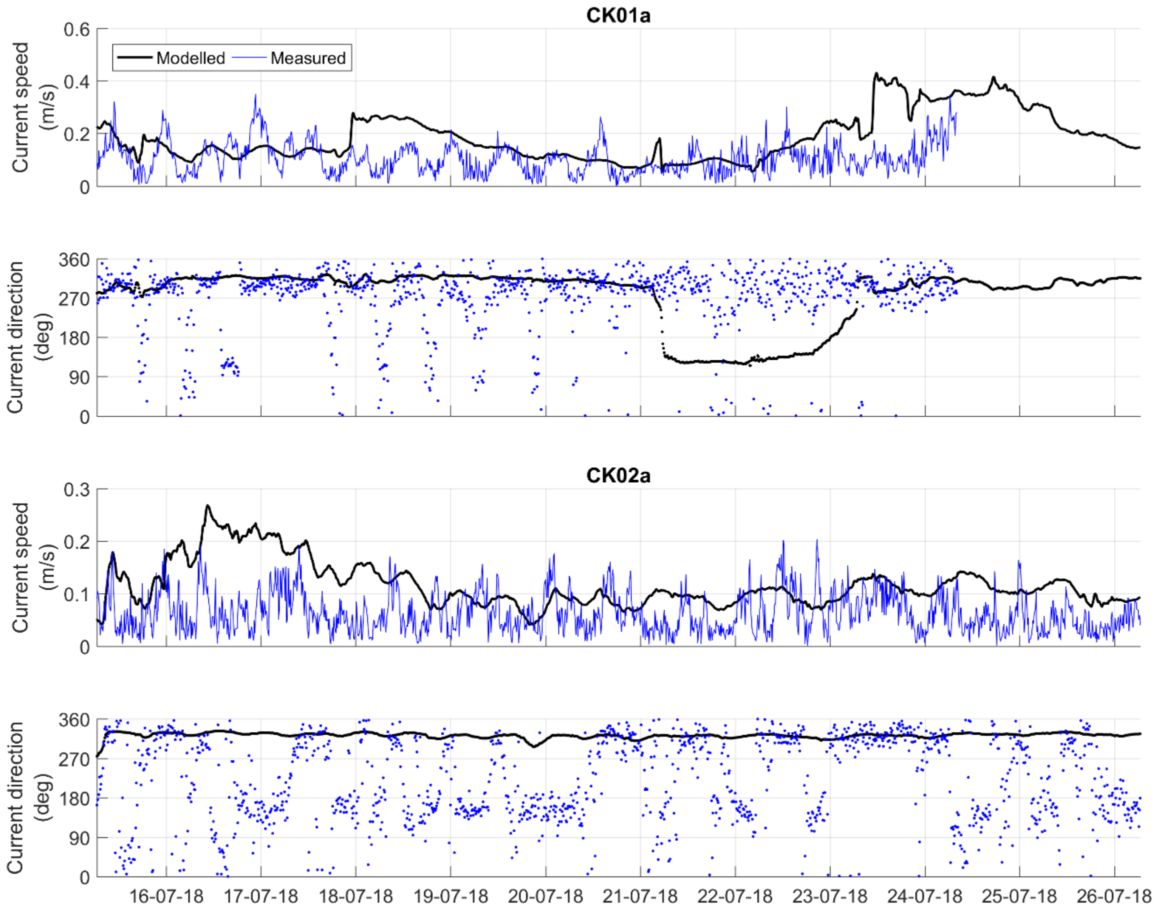

Figure 92: Comparison of measured and modelled currents during a 10-day period in July 2018 at the offshore monitoring sites.

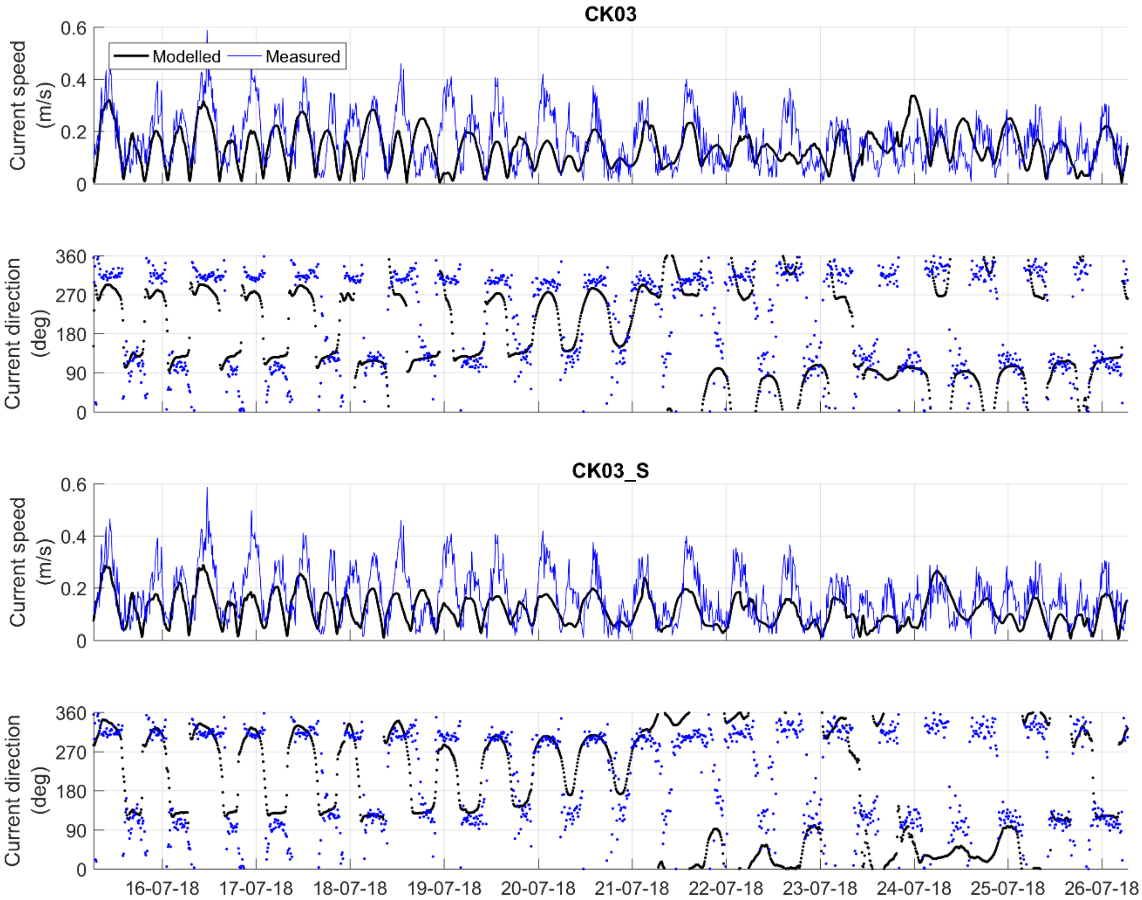

Figure 93: Comparison of measured and modelled currents during a 10-day period in July 2018 at two sites within Western Entrance: CK03 – the CVA monitoring site and CK03_S a site just to the south of the monitoring site.

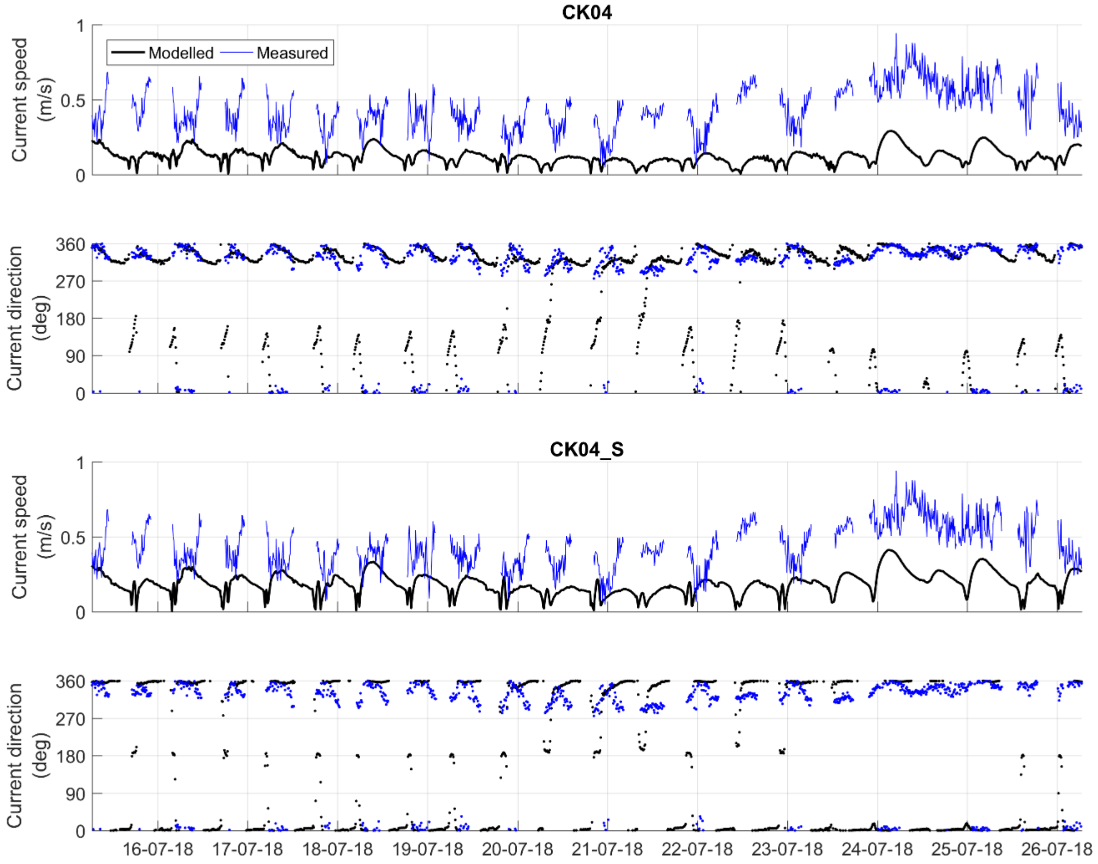

Figure 94: Comparison of measured and modelled currents during a 10-day period in July 2018 at two sites within the southern lagoon: CK04 – the CVA monitoring site and CK04_S a site just to the south of the monitoring site.

A1.5 Validation

Due to the strong influence of waves on the nearshore hydrodynamics during the calibration period, a second simulation period was selected during lower-energy wave conditions. However, while the period can be considered to represent relatively low-energy wave conditions for CKI, the offshore swell wave heights were still between 1 to 2m significant wave height (from south direction, see **Figure 95**). So, waves are still likely to be the dominant driver of nearshore currents at the offshore monitoring sites. Timeseries comparisons of the measured and modelled currents are shown in **Figure 96** to **Figure 98.** Improvements of the simulated currents are particularly evident for the Western Entrance site (CK03) which is tidally dominated during such periods with relatively low-energy wave conditions. A comparison of the east-west and north-south current magnitudes between the measured data at CK03 over the one-year monitoring period and the model results for the one-week period in January 2019 is shown in **Figure 99**. This comparison shows that the simulated current axis at the Western Entrance closely aligns with the measured data and that the model reproduces the small bias of higher ebb currents compared to flood currents at this location.

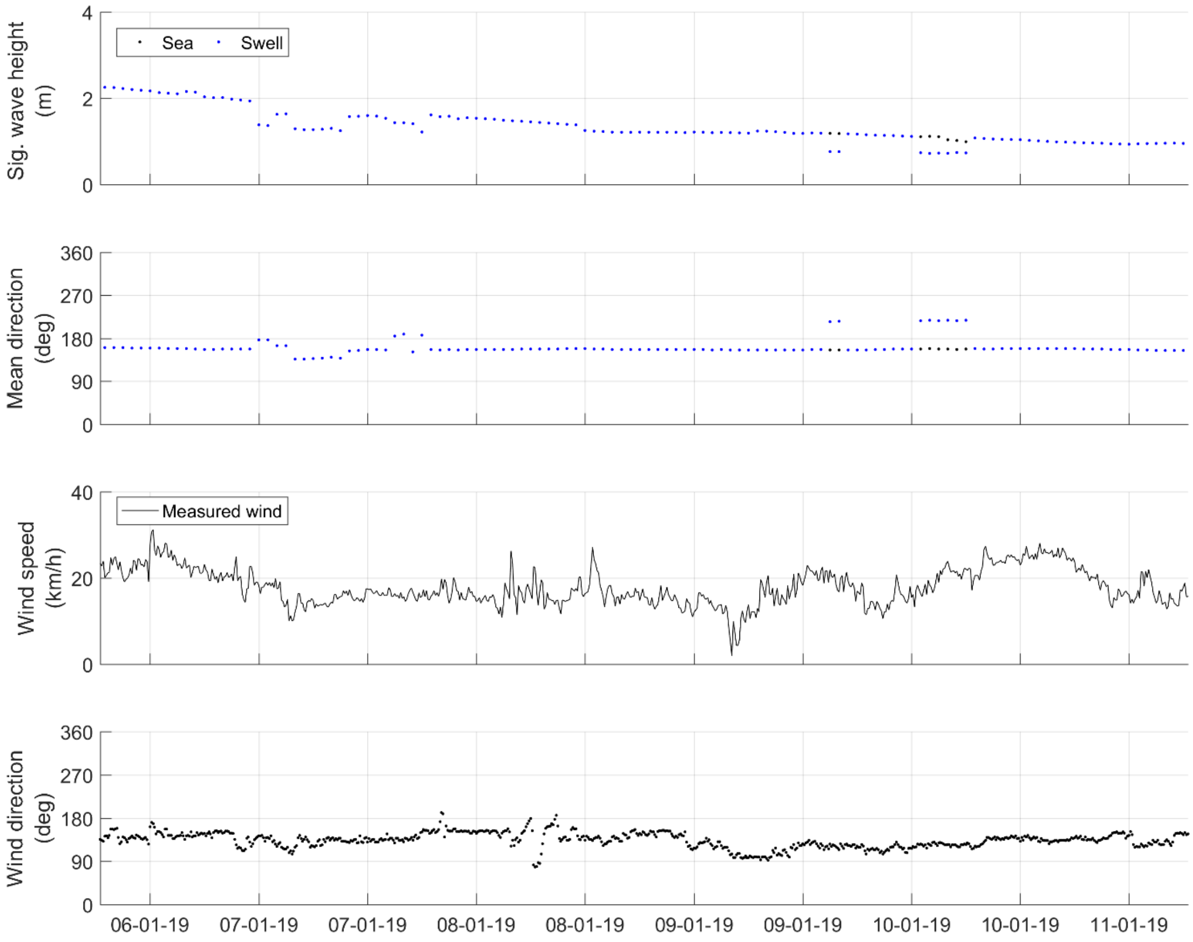

Figure 95: Metocean conditions applied to the model boundaries for the adopted lower-energy period during model validation.

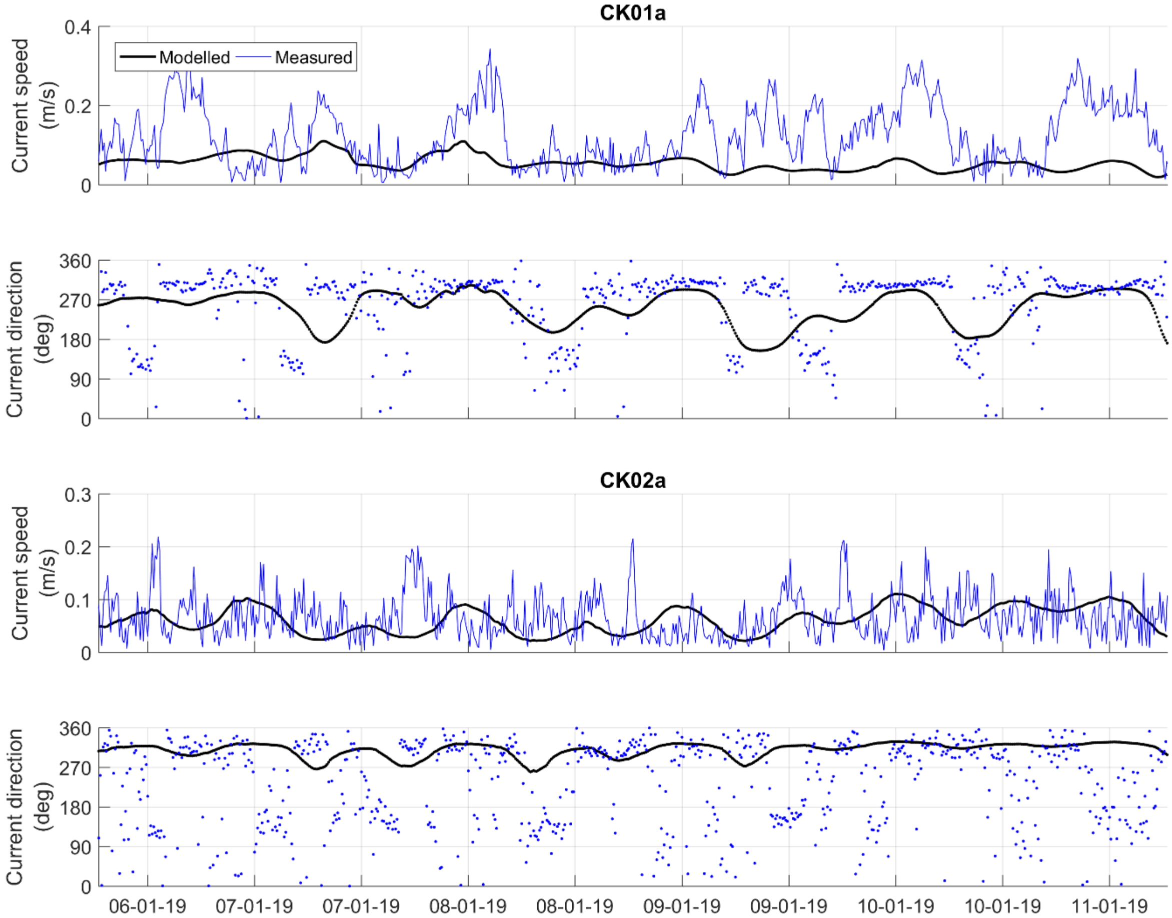

Figure 96: Comparison of measured and modelled currents during a one-week period in January 2019 at the offshore sites.

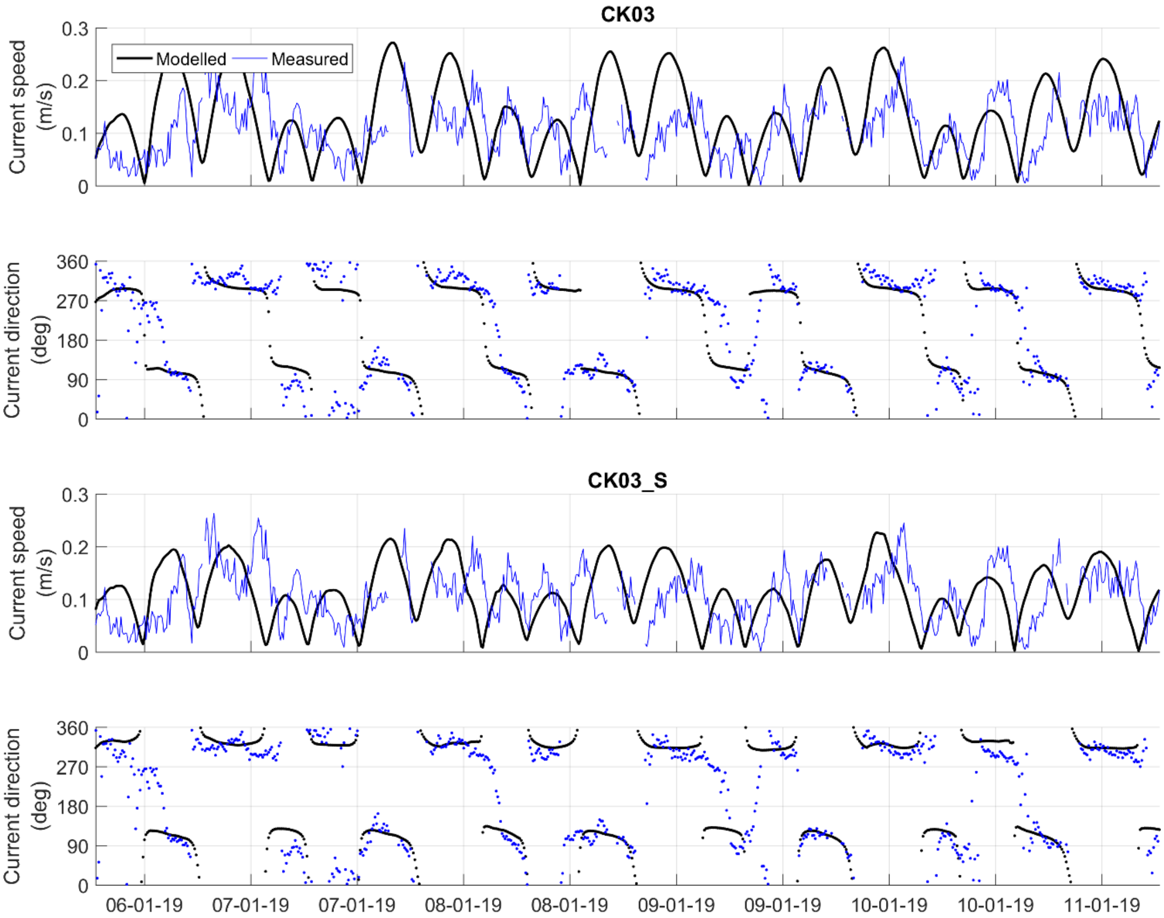

Figure 97: Comparison of measured and modelled currents during a one-week period in January 2019 at the Western Entrance site (CK03 – top two panels) and a site approximately 400m to south (CK03_S – bottom two panels).

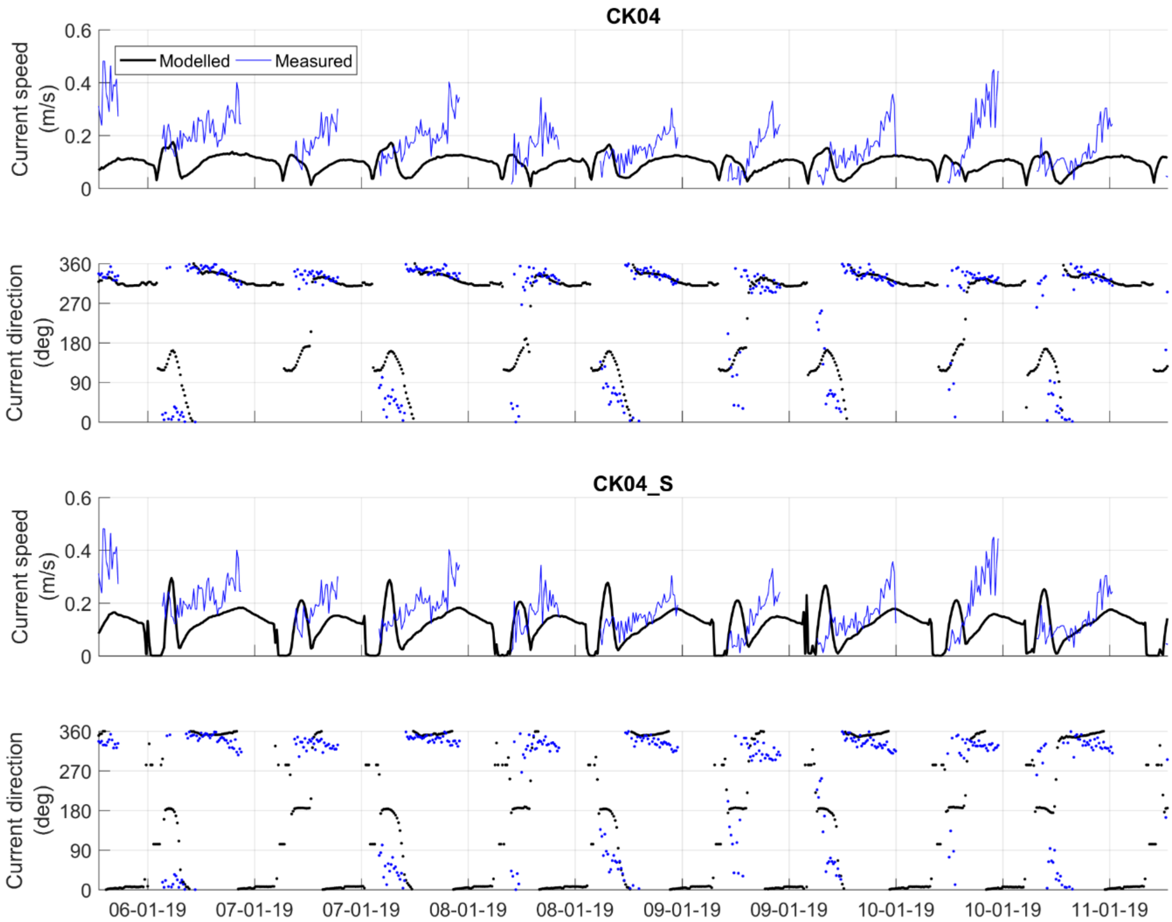

Figure 98: Comparison of measured and modelled currents during a one-week period in January 2019 at the southern lagoon site (CK04 – top two panels) and a site approximately 240m to south (CK04_S – bottom two panels).

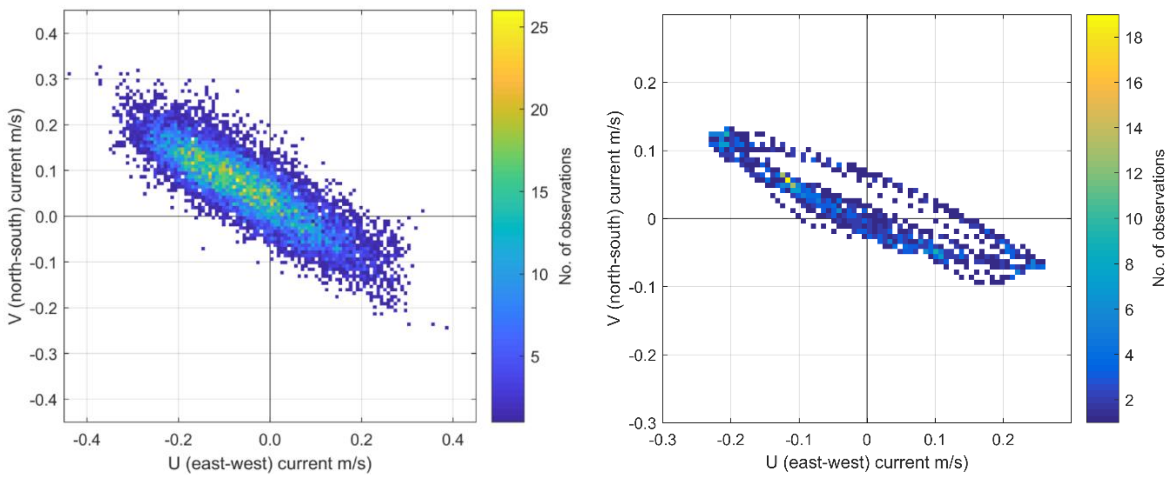

Figure 99: East-west and north-south current magnitudes at site CK03 for the (left) one-year of measured data and (right) model results from the one-week simulation in January 2019.

A1.5.1 Sediment transport module

The D-Morphology module of the Deflt3D FM suite has been used to assess sediment transport patterns at CKI. This sediment transport and morphology module supports both bedload and suspended load transport of non-cohesive sediments due to waves and currents. The module was run in conjunction with the coupled wave and hydrodynamic model described herein. A uniform median grain size diameter of 0.35mm and dry sand density of 1,600kg/m^3 was applied throughout the model domain. A spatially varying layer thickness of sand was adopted as follows (see **Figure 100)**:

- 0m of sand over outer fringing reef flats
- 1m of sand over beach and islands
- 3m of sand within the central lagoon

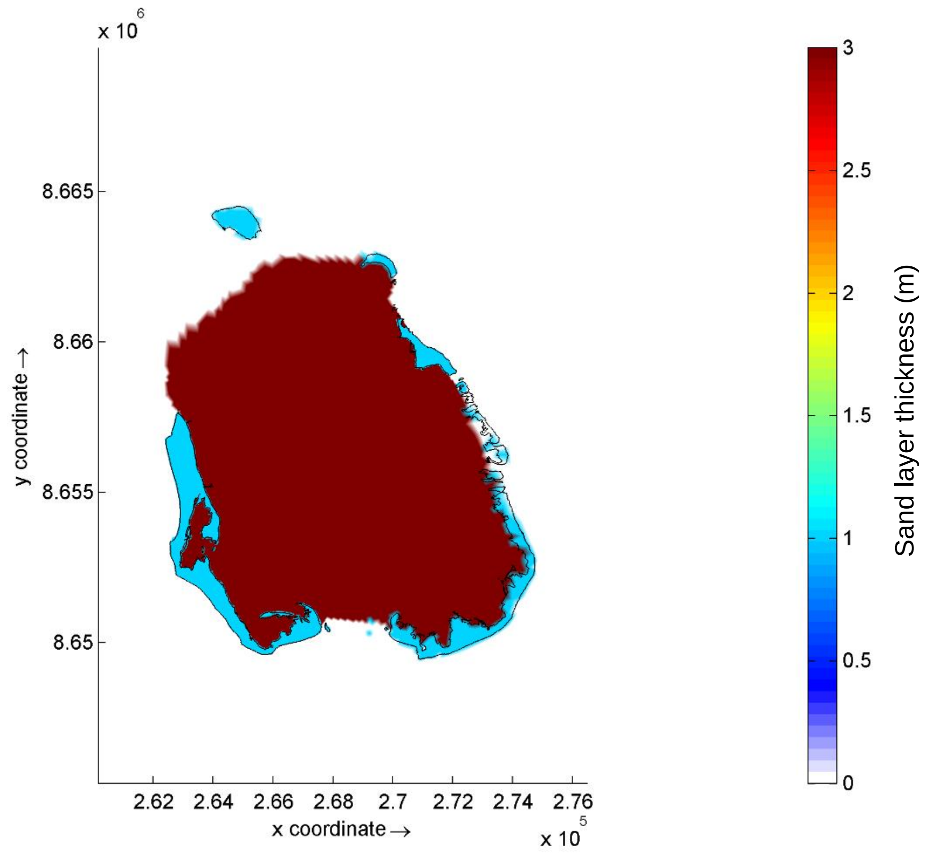

Figure 100: Map of spatially varying initial sand layer thickness for sediment transport simulations.

Spectral wave model

Deltares' D-Waves spectral wave model was used for this study. D-Waves utilises the widely adopted third generation Simulating WAves Nearshore (SWAN) engine to simulate wave propagation, wave generation by wind, non-linear wave-wave interactions and dissipation.

The spectral wave model was used to determine the nearshore wave climate at the study site and gain an understanding of its effect on coastal processes. Furthermore, the D-Waves model was adopted to simulate tropical cyclone generated waves.

A1.5.2 Model domain

Two spectral wave model domains were adopted for this study:

- A regional domain to propagate sea and swell waves from global wave model extraction locations inshore to the nearshore areas of CKI. The model grids outer extents are defined by -11.3° latitude, 95.9° longitude to -12.7° latitude, 97.8° longitude. Several nested grids with the following resolutions have been included:
    - Regional domain with 1km spatial resolution;
    - Transitional domain with 300m resolution;
    - Nearshore domain with 100m resolution;
    - West Island and Home Island domain with 40m resolution.
- An ocean domain to simulate wind wave growth during tropical cyclone conditions extending 300km either side of the southern atoll of CKI with 7km resolution in offshore areas and 300m resolution in nearshore areas.

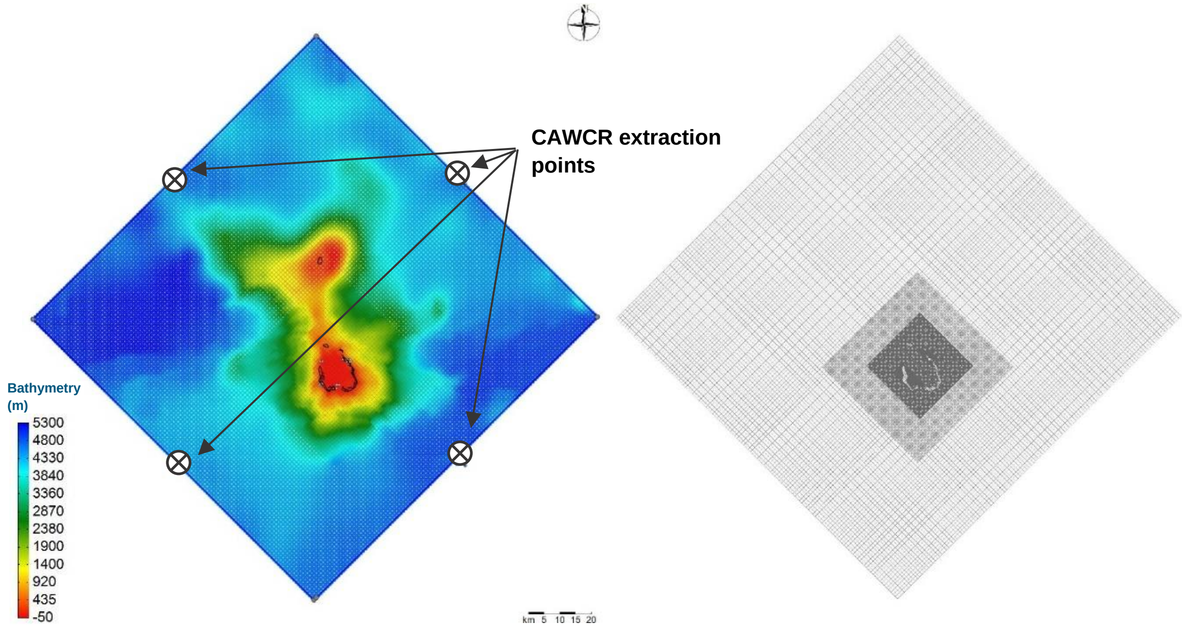

Figure 101: Regional spectral wave model domain extent, (left) bathymetry and (right) nested grids. The CAWCR global wave model extraction points are also shown.

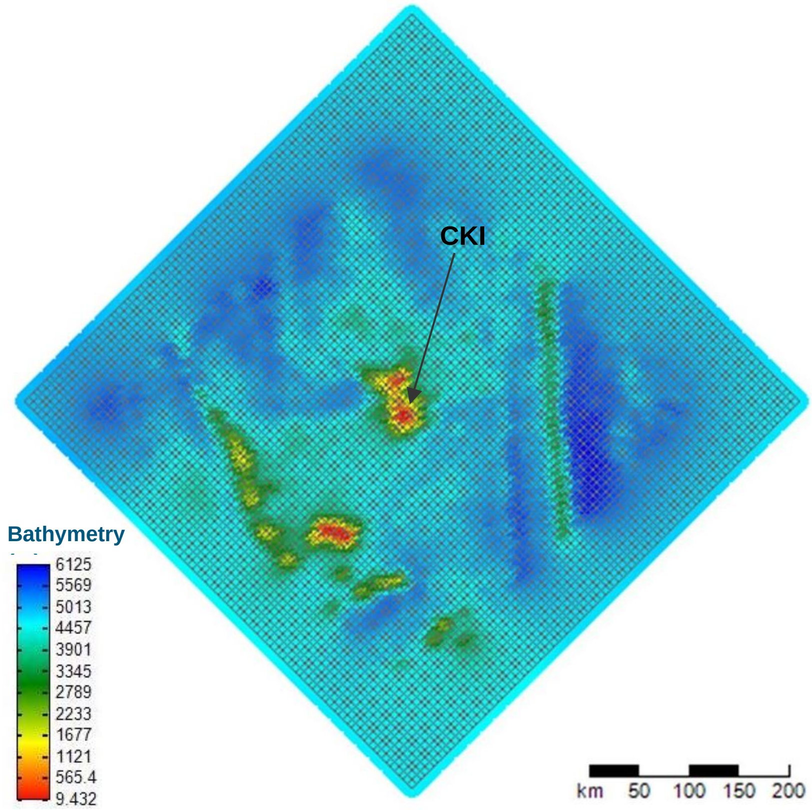

Figure 102: Ocean spectral wave model domain extent and bathymetry for tropical cyclone *simulations.*

A1.5.3 Model setup

The spectral wave model was set up using the third-generation physics and included wind wave growth, white capping (Komen et al., 1984), quadruplets, wave breaking and refraction. The regional spectral wave model was run in stationary mode while the ocean domain was run in the non-stationary mode to allow accurate simulation of the spatially varying tropical cyclone wind fields. The bottom friction was defined using the empirical JONSWAP model (coefficient of 0.067) after Hasselmann et al. (1973).

A1.5.4 Boundary conditions

The open (offshore) boundaries of the regional spectral wave model were forced using the CAWCR global wave hindcast data (see extraction points in **Figure 101)**. The hindcast data is open access data provided at hourly intervals at 0.4 degrees spatial resolution and includes separate sea and swell wave fractions. For the Indian Ocean location of CKI and its bimodal wave climate, it was deemed necessary to force the spectral wave model with both sea and swell fractions. Therefore, the CAWCR swell fraction was applied to the western boundaries and the sea fraction was applied to the eastern boundaries of the regional spectral wave model. Sea level variations were included using measured data from the Home Island tide gauge.

For tropical cyclone simulations, the spatially and time varying wind fields (described above) that were generated using the parametric wind model by Holland (2010) were applied to the ocean model domain. No additional open boundary forcing was used.

A1.5.5 Calibration

The wave model was calibrated for two simulation periods:

- A 10-day period including the extreme swell event that occurred around 24th July 2018 (see **Figure 121)**; and
- The passage of tropical cyclone Savannah (described above) in March 2019.

While these two model calibration periods are relatively short, they maximise the 12-month measured data set by carefully selecting representative ambient and extreme conditions (i.e. ambient conditions, an extreme long period south-west swell event and a tropical cyclone). As extreme wave conditions are required to be simulated for the inundation assessment, a focus was given to the large swell event in July 2018.

Following a series of sensitivity tests including various grid resolutions and boundary forcing the modelled was deemed capable of reproducing the measured wave conditions at both the eastern and western exposed coastline as well as within the central lagoon. A timeseries comparison of the measured and modelled wave conditions during the July 2018 swell event is provided in

Figure 103 to Figure 105 for the West Island and Home Island monitoring sites. A high-resolution map showing the spatial distribution of wave heights at West Island and Home Island during high-energy wave conditions is provided in **Figure 106.**

The comparison shows that the model is capable of accurately reproducing the measured wave conditions during both, low and high energetic wave conditions. It is also evident that the wave heights at the monitoring site within the Western Entrance (CK03) are spatially highly variable and depend on the channel morphology. As the nearshore bathymetry is derived from the 2012 LiDAR data this may explain the difference between modelled and measured wave heights at this site. Some deviations are evident in the modelled wave periods which is inherent to the offshore boundary conditions derived from the CAWCR wave hindcast and the mixed swell and sea spectrum, however, for the purpose of this study this is considered acceptable.

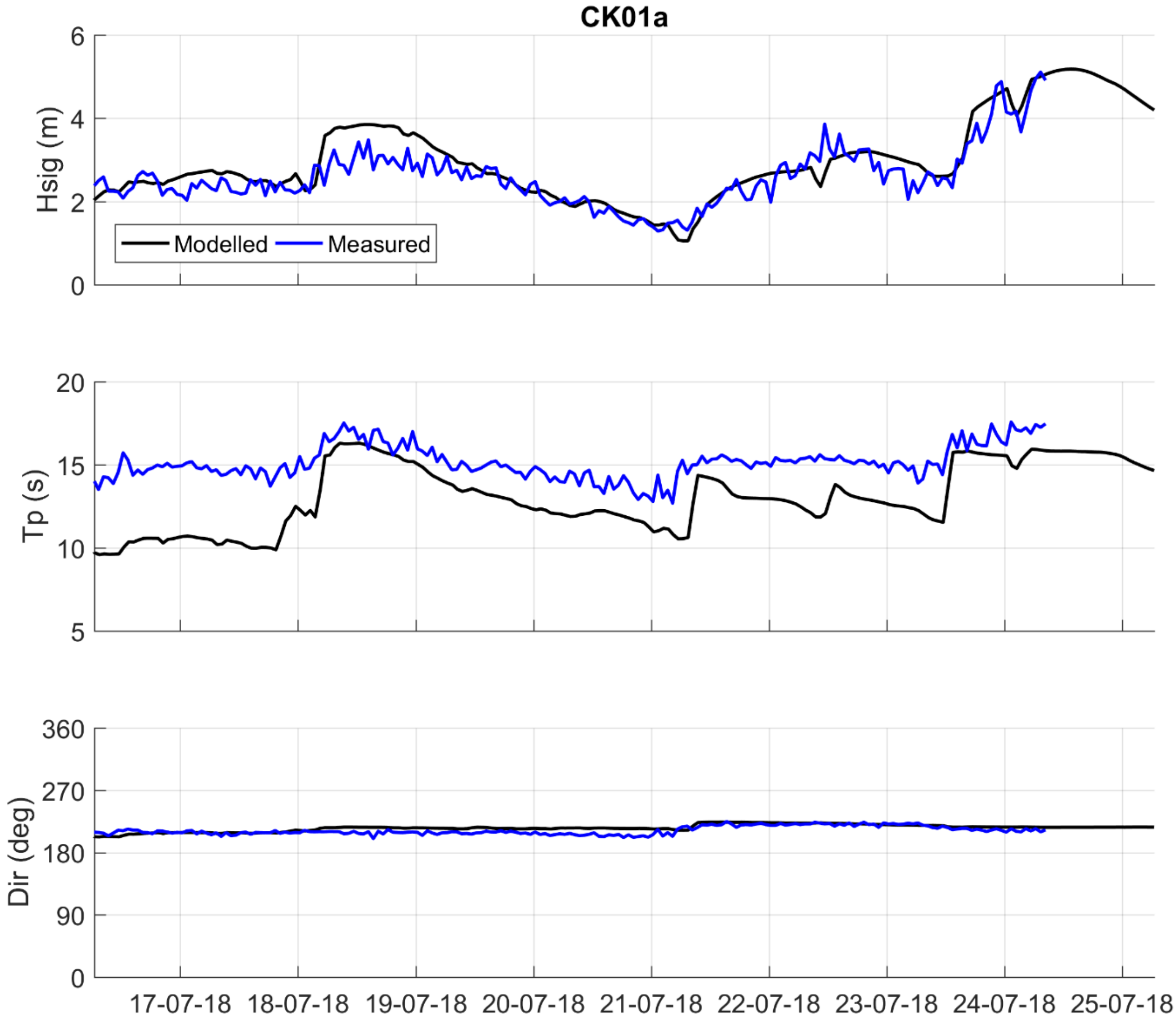

Figure 103: Time-series comparison of measured and modelled wave conditions at the West Island Settlement site (CK01a) during the July 2018 swell event.

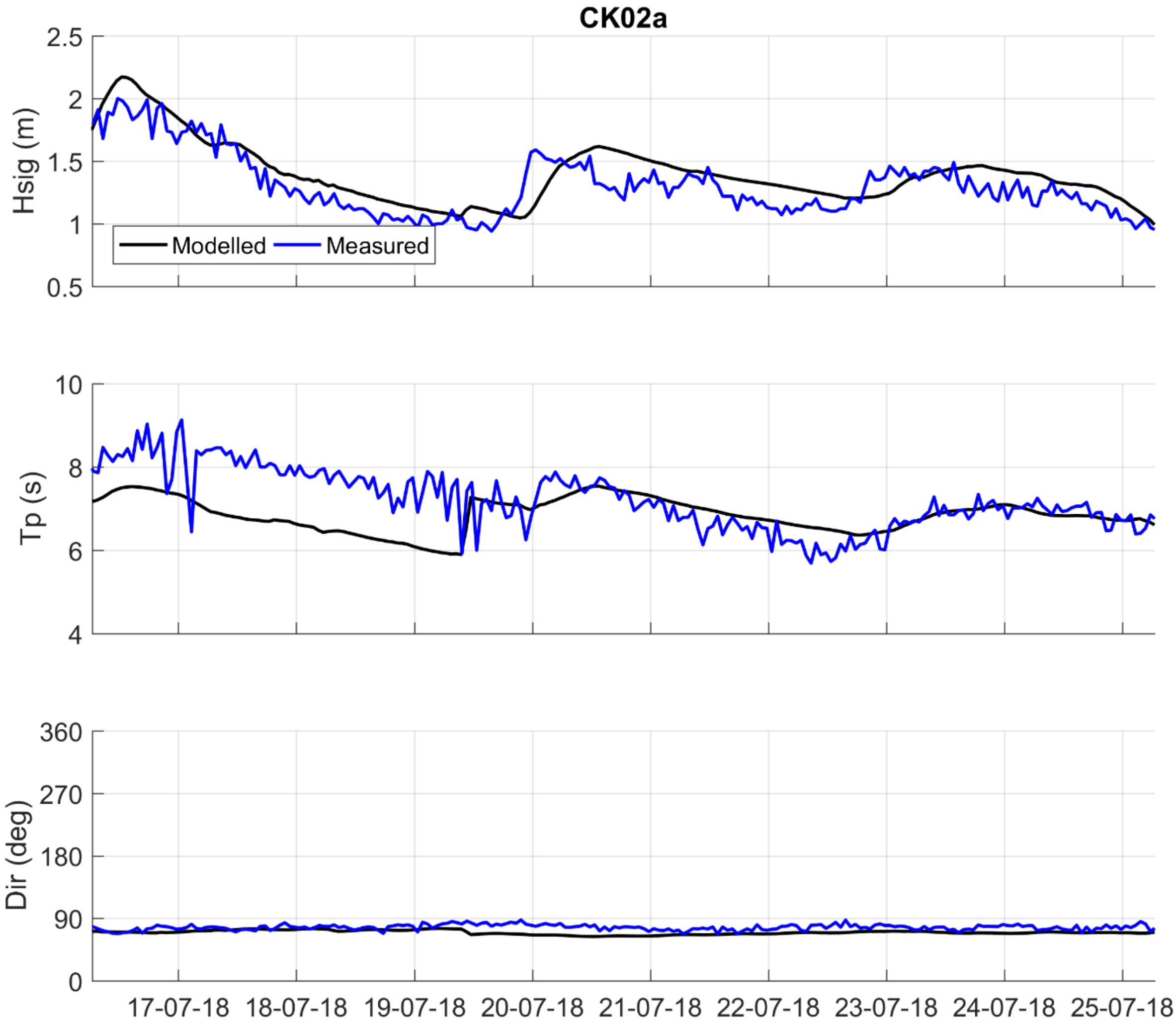

Figure 104: Timeseries comparison of measured and modelled wave conditions at the Home Island site (CK02a) during the July 2018 swell event.

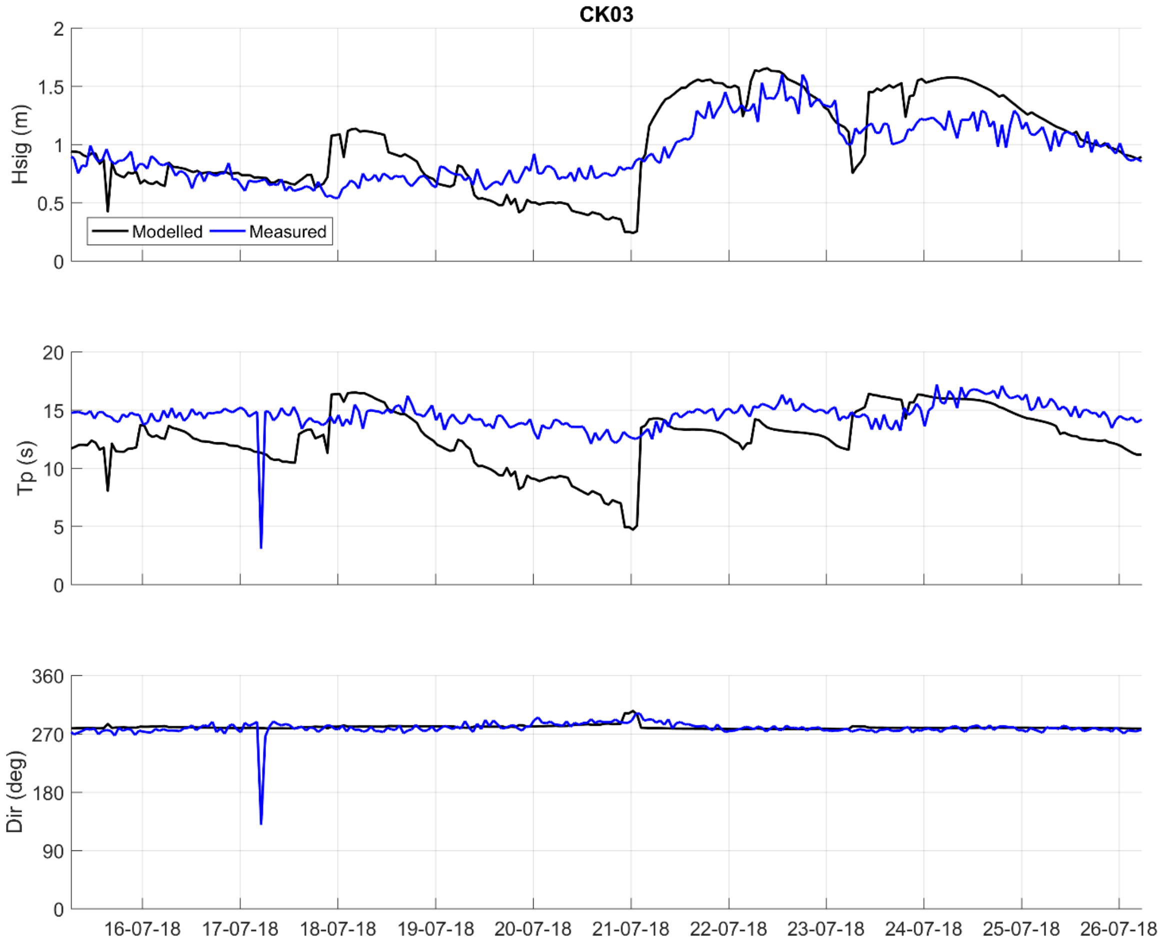

Figure 105: Timeseries comparison of measured and modelled wave conditions at the Western Entrance site (CK03) during the July 2018 swell event.

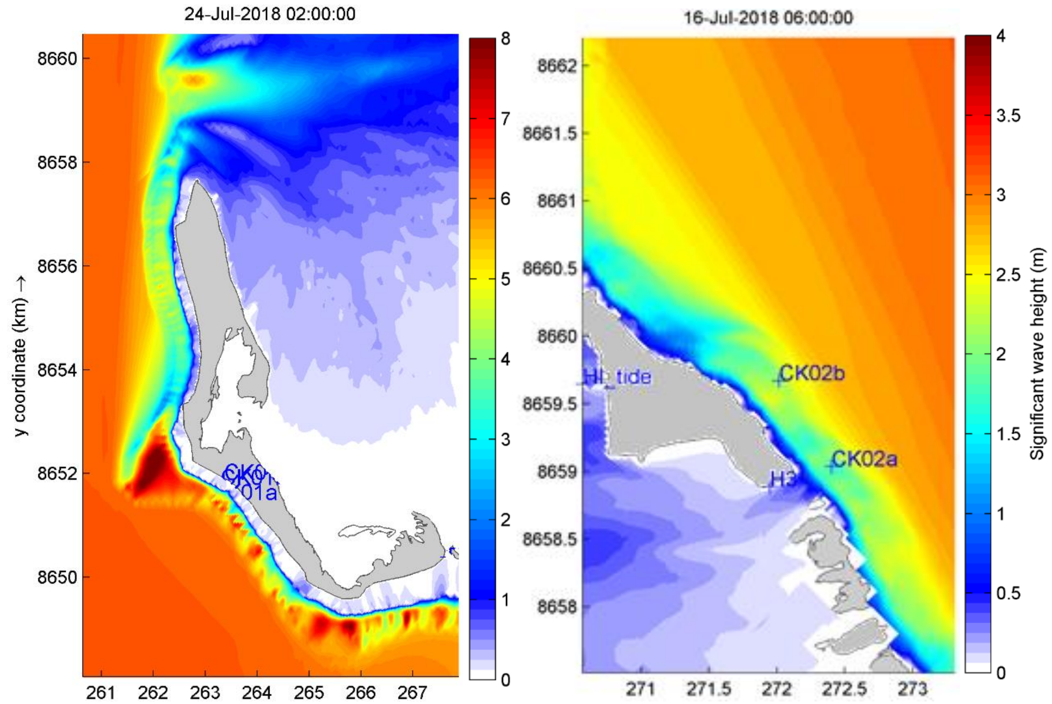

Figure 106: Close up of simulated wave heights during (left) high-energy swell conditions at West Island and (right) high-energy sea conditions at Home Island.

A1.5.6 Tropical cyclone validation

Tropical Cyclone Savannah had passed CKI about 110km to the west of the islands when it intensified to a category 1 system (BoM, 2019). The passage of this tropical cyclone resulted in the largest significant wave heights of 3.7m (from north-east direction) recorded off the eastern coastline of Home Island during the CKI CVA metocean monitoring period. The CAWCR offshore wave conditions as well the measured nearshore conditions during this period are presented in **Figure 108** and highlight the under-estimation of wave heights in the CAWCR data.

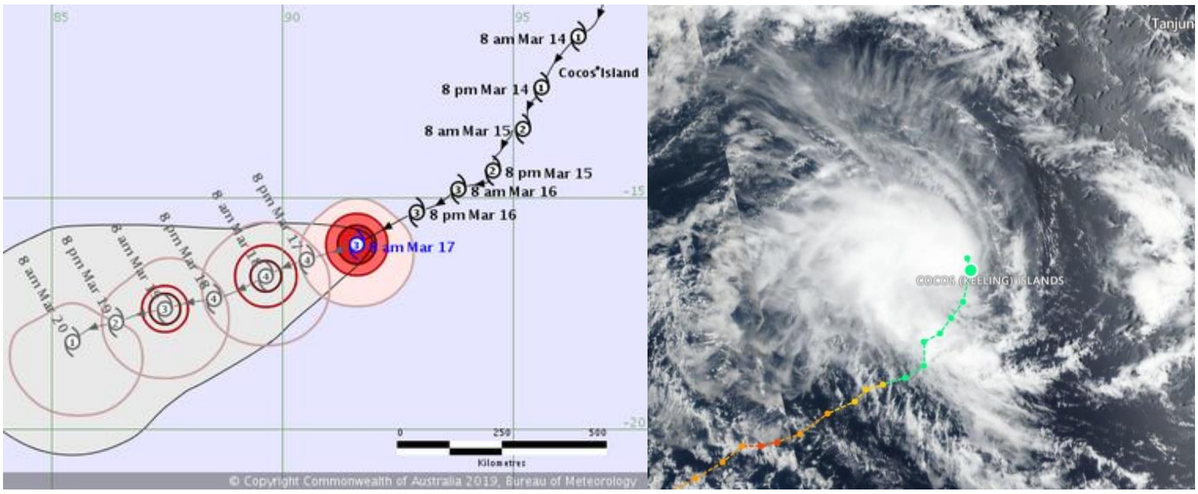

Figure 107: Tropical cyclone Savannah passing CKI on 14 March 2019 (source BoM).

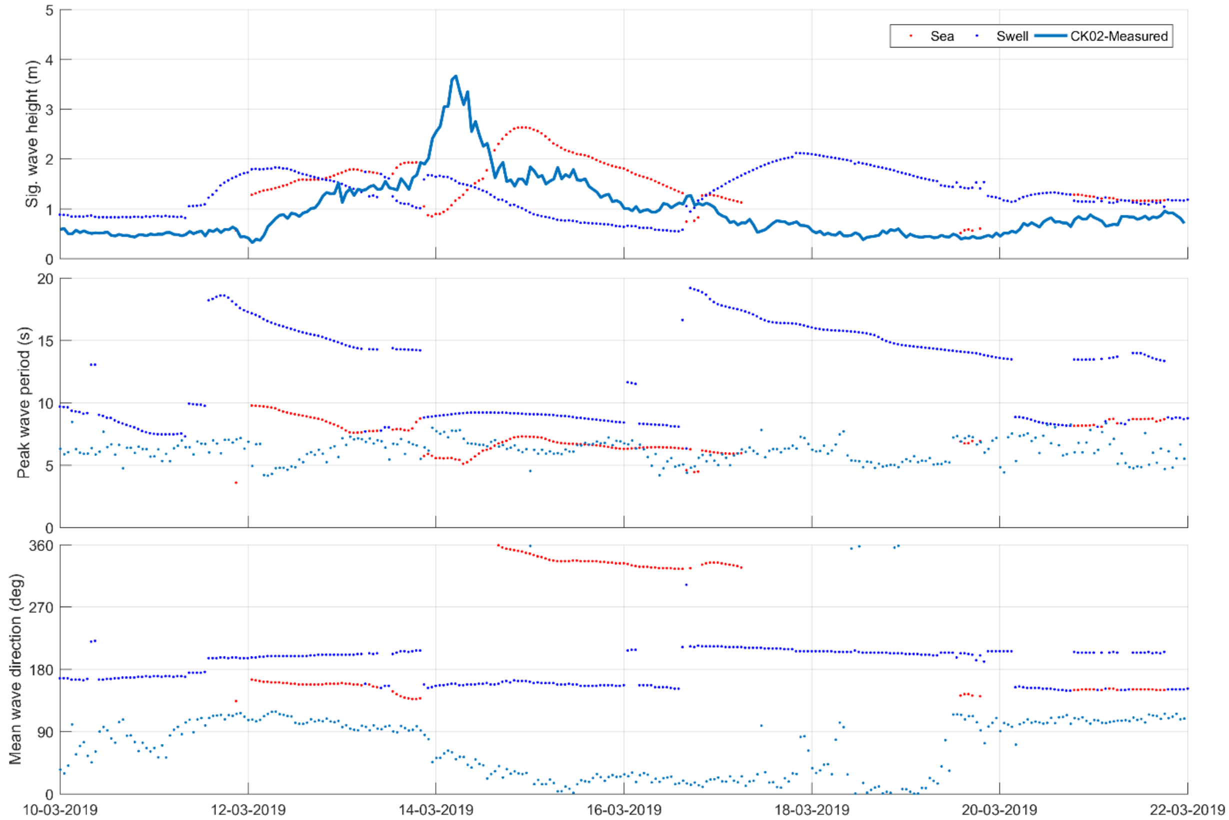

Figure 108: Time-series of offshore swell and sea wave conditions (CAWCR) and measured nearshore wave conditions at Home Island (CK02) during the passage of TC Savannah.

Following the tropical cyclone modelling approach outlined above, the Holland (2010) wind field and estimated peak wind speed and direction were validated using data recorded wind data during the passage of TC Savannah in March 2019. The parametric wind field and a comparison of the modelled and measured wind speed are shown in **Figure 109** and **Figure 110**, respectively. A reasonable agreement was achieved between and the measured and modelled wind speeds and directions. As a result, the tropical wind model is considered sufficiently accurate of peak cyclonic conditions.

Estimated wind speeds at CKI are strongly dependent on the shape and radius of the tropical cyclone wind fields. The shape of real tropical cyclone wind fields is often dependent on the synoptic wind fields surrounding the cyclone and interaction with other weather systems in the atmosphere. Such effects are not included in the simplified parametric wind models and hence the objective of this validation is to replicate peak wind speeds and wind direction rather than accurate description of the entire spatial wind field. Maximum wind speeds and resulting highest wave heights are typically found close to the centre of the cyclonic system, therefore excluding the synoptic wind and pressure field was considered acceptable for this assessment.

A comparison of the modelled and measured wave heights during the passage of TC Savannah is shown in **Figure 111.** The comparison suggests that the wave conditions simulated using the parametric wind fields for this event are in close agreement with the measured data. While some differences in the shape of the modelled wave heights are evident, the peak wave heights and directions are well reproduced. It is noted that the measured wave conditions present a mixed wave climate of the tropical cyclone generated waves as well as underlying sea and well waves. The latter are not included in the tropical cyclone simulations as only the extreme waves are of interest in the assessment and modelled therein.

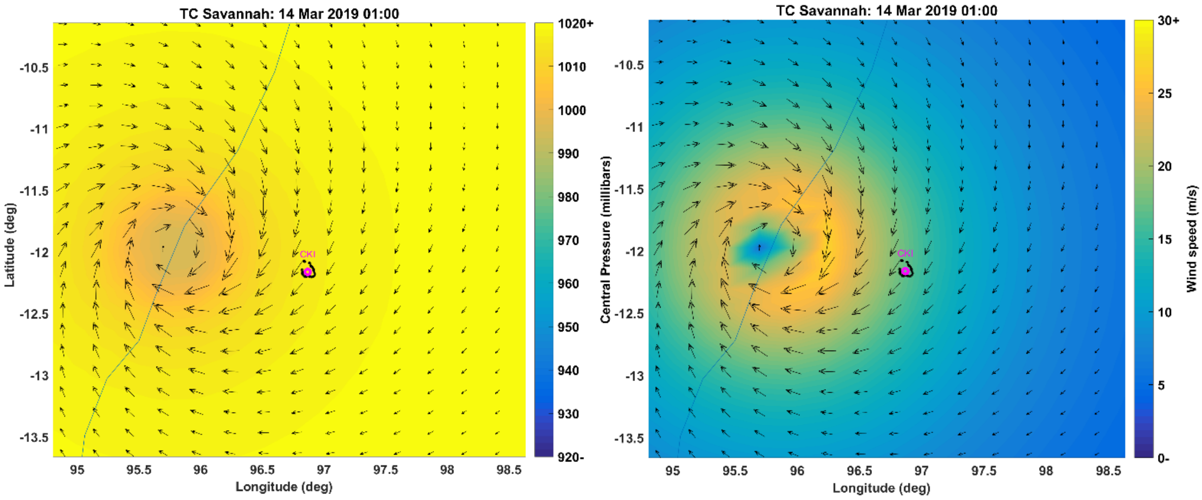

Figure 109: Parametric tropical cyclone (left) pressure field and (right) wind field for TC Savannah produced using the Holland (2010) model.

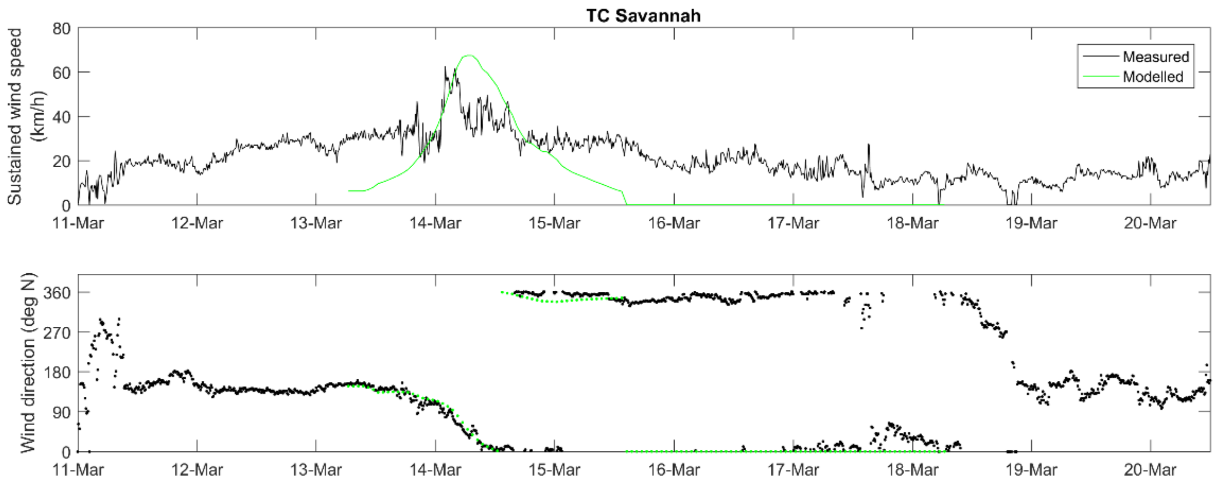

Figure 110: Comparison of measured wind data at CKI and estimated wind speeds using the Holland (2010) model for TC Savannah.

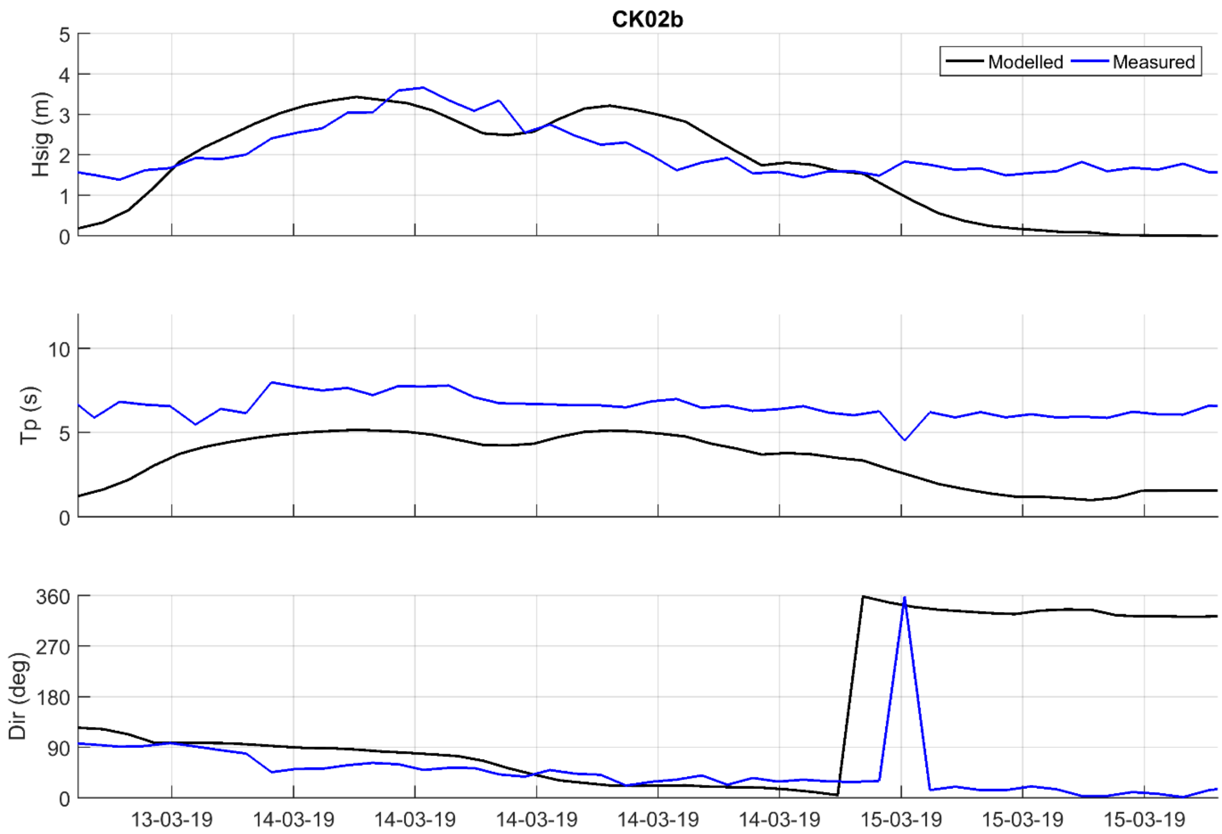

Figure 111: Timeseries comparison of measured and modelled (using the Holland, 2010 wind field) wave conditions at the Home Island monitoring site (CK02b) during the passage of TC Savannah.

Nearshore wave model

High-resolution nearshore wave simulations were undertaken at three selected locations around CKI using the Xbeach model. The locations of the three Xbeach profile models are shown in Figure 112. The selected areas are believed to represent a variety of different coastal orientations and exposures around CKI. The nearshore wave model was used to simulate a series of extreme wave conditions and generate a look-up table of wave conditions and nearshore water levels atop the reef flats.

A1.5.7 Model domain

The bathymetry for the cross-shore profiles was generated combining RTK profile data (July and October 2018) and marine LiDAR (2012) data (**Figure 113)**. The LiDAR data was used to define deeper areas, while the RTK data was used to define the reef flat, beach and the dune. An irregular grid was defined for each of the profiles with ~10m cell size offshore, ~5m cell size at the reef crest and decreasing from there towards the shoreline where the cell size is ~0.2m. The three representative sites modelled were:

- **West Island Settlement (CK01)**

  The CK01 transect is located approximately 280m north of the Cocos Beach Motel at the northern extent of the settlement. The adopted coastal profile at this site is 537m long and the top of the reef crest emerges above the sea surface during low tide. The reef flat extends 310m from the reef crest up to the shore where there is a dune that is 4.9m high.

- **North West Island (WI_GSC02)**

  This site is located on the north-western part of West Island, approximately 2.7 kilometres north of site CK01. The profile is 522m long (**Figure 113**) and the reef crest does not emerge at this site. A geotextile sand container seawall protects the shoreline in front of Sydney Highway.

- **Home Island (HI03)**

  This site is on the ocean (eastern) shoreline of Home Island. The profile at this site is 362m long. The crest of the reef is higher and wider in comparison to the CK01 profile and the reef flat is shallower (**Figure 115**). For the dry beach profile, data from the RTK transects undertaken in July 2019 was used and for the lower areas (below 0m AHD) the profile was extracted from the 2012 marine LiDAR data.

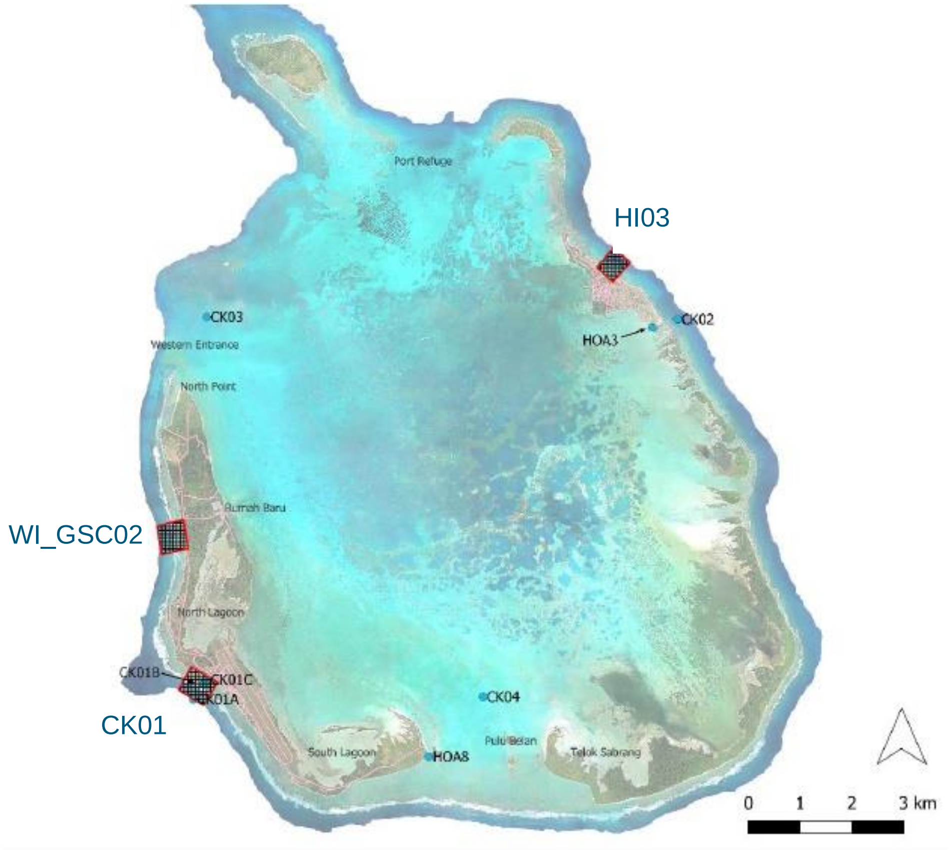

Figure 112: Locations of Xbeach profile models (red polygons) and metocean monitoring sites (blue dots).

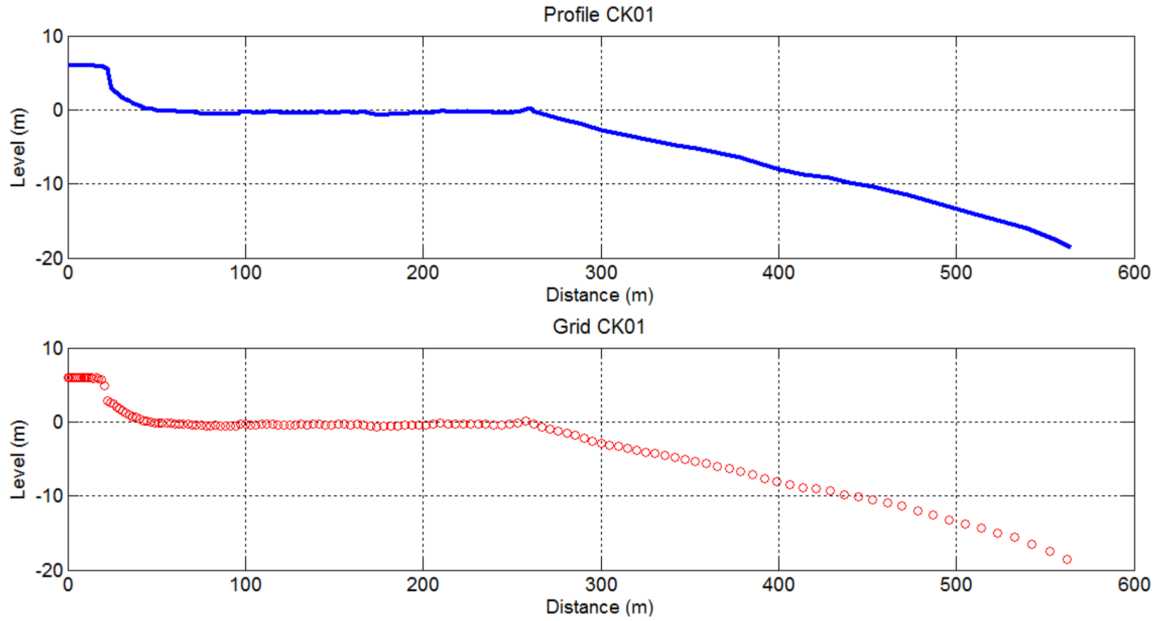

Figure 113: Adopted coastal profile (elevation to AHD) and grid for the West Island Settlement site (CK01).

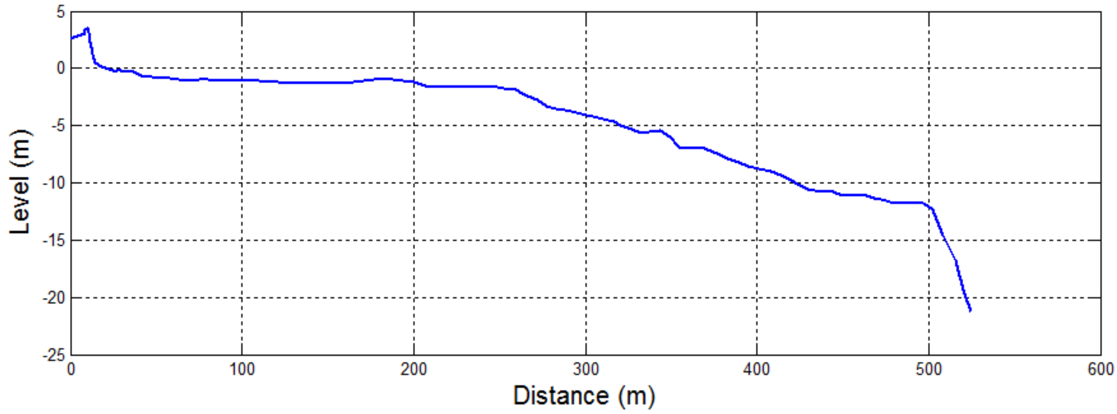

Figure 114: Adopted coastal profile (elevation to AHD) at the north-west West Island site (WI_GSC02).

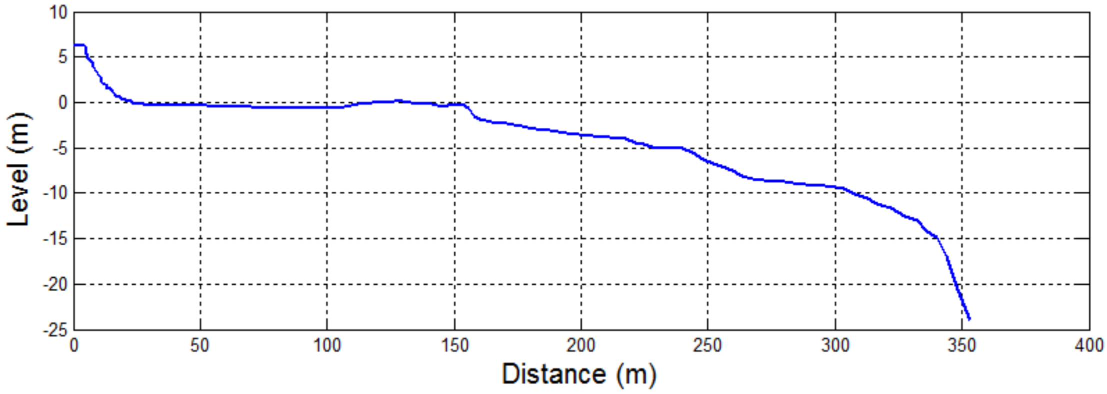

Figure 115: Adopted coastal profile (elevation to AHD) at site HI03.

A1.5.8 Model setup

The one-dimensional Xbeach model was adopted for this study. The model was set up in surfbeat mode which estimates short-wave motion by solving the wave action equation. Wave-driven currents, long waves and run-up and run-down of long waves are included. The wave breaking model of Roelvink (1993) was utilised in the model with a gamma factor of 0.55. Wave dissipation by bottom friction was modelled using a friction coefficient. Model calibration resulted in a wave friction coefficient of 0.01.

A series of sensitivity tests were carried out for the profile at CK01 to assess the impact of model parameters on modelled wave heights, water level and run-up. A six-hour period during the peak of the 24th July 2018 event, was run in both, surfbeat and non-hydrostatic (nh) mode of the Xbeach model. Using the non-hydrostatic mode, depth-averaged flow due to waves and currents are computed using the non-linear shallow water equations, including a non-hydrostatic pressure. In this computationally demanding mode, incident-band (short wave) run-up and overwashing are fully resolved and have been compared to the results from the surfbeat mode. As expected, it was found that the surfbeat mode provides accurate results for this investigation, as most of the nearshore wave energy is contained within the infragravity band.

A1.5.9 Boundary conditions

A time-varying JONSWAP spectra was used to force the open boundary of the models. The offshore boundary data was taken from the wave measurements at site CK01a (~18m depth) and site CK02 (~13m depth). Time-varying tidal signal was also taken from the measured data.

For the production scenarios, wave conditions from the spectral wave model were used to generate JONSWAP spectra that represent the extreme wave conditions at the reef edge.

A1.5.10 Calibration

Calibration and validation were undertaken using the water level and wave data collected at the reef top monitoring sites at CK01c (~0.5m depth) to ensure that the expected wave transmission and increased wave setup across the reef flat during the selected events is correctly resolved.

Figure 116 presents a timeseries comparison of the modelled and measured significant wave height and water level at CK01c site for the July 2018 swell event and demonstrates good agreement with the observed wave conditions (i.e. +/- 10cm). Modelled peak significant wave heights were slightly overestimated and hence, peak water levels were slightly underestimated (less wave breaking induced setup). However, the 1D profile model is considered adequate for the purpose of this study with consideration of its simplification of the complex reef wave processes (cross-shore and alongshore).

A comparison of the measured and modelled 1% wave setup during the calibration event is provided in **Figure 117**. It is evident that the model is capable in reproducing the extreme wave setup levels as described in **Section 4.3**

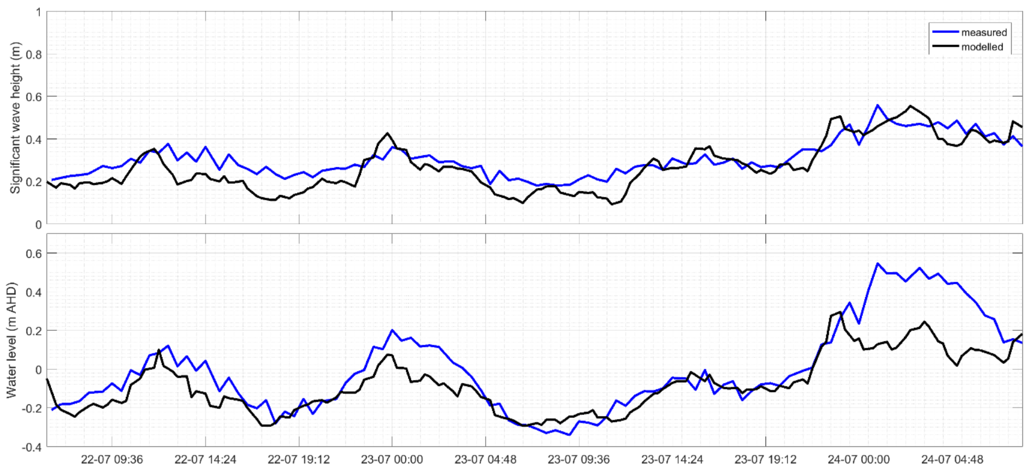

Figure 116: Comparison between measured significant wave height and nearshore (mean) water level and Xbeach model output during the July 2018 swell event at the West Island Settlement (CK01c) site.

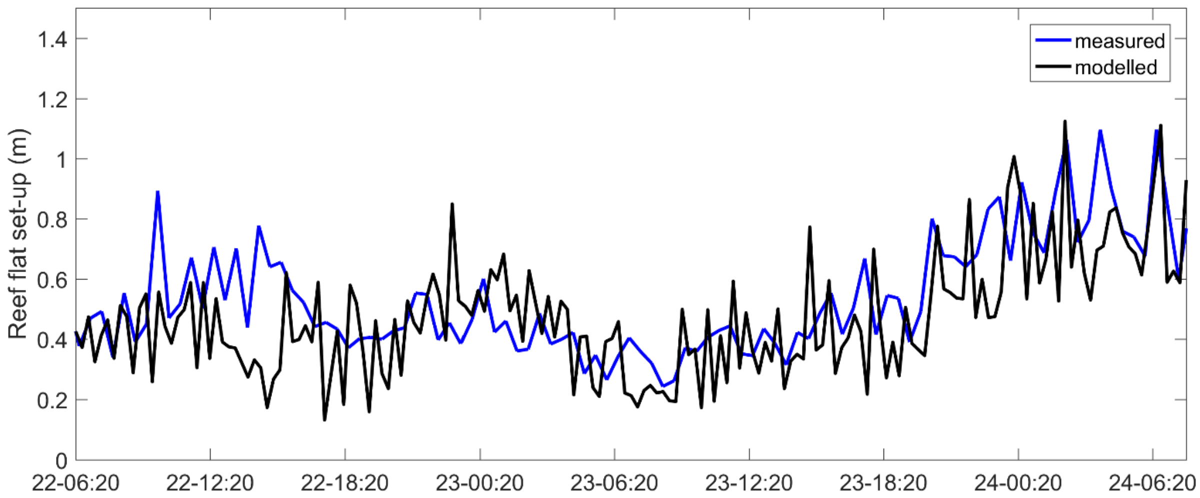

Figure 117: Comparison between measured and modelled reef top wave setup during the July 2018 swell event at the West Island Settlement (CK01c) site.

Overtopping calculations

Overtopping volumes were calculated using the EurOtop formulae described in EurOtop (2018). The overtopping estimates were calculated using input from the nearshore (Xbeach) wave modelling and structure dimensions from the RTK surveys. These pre-calculated overtopping volumes were implemented into the numerical modelling system using a sub-grid structure technique (i.e. 'pumps') also called lateral inflow boundaries which use the predefined overtopping discharge curve for ocean facing structures on West Island for the given scenario. Once overtopping is activated the model will allow discharge of sea water to the area in the lee of the structure (see schematic in **Figure 118**).

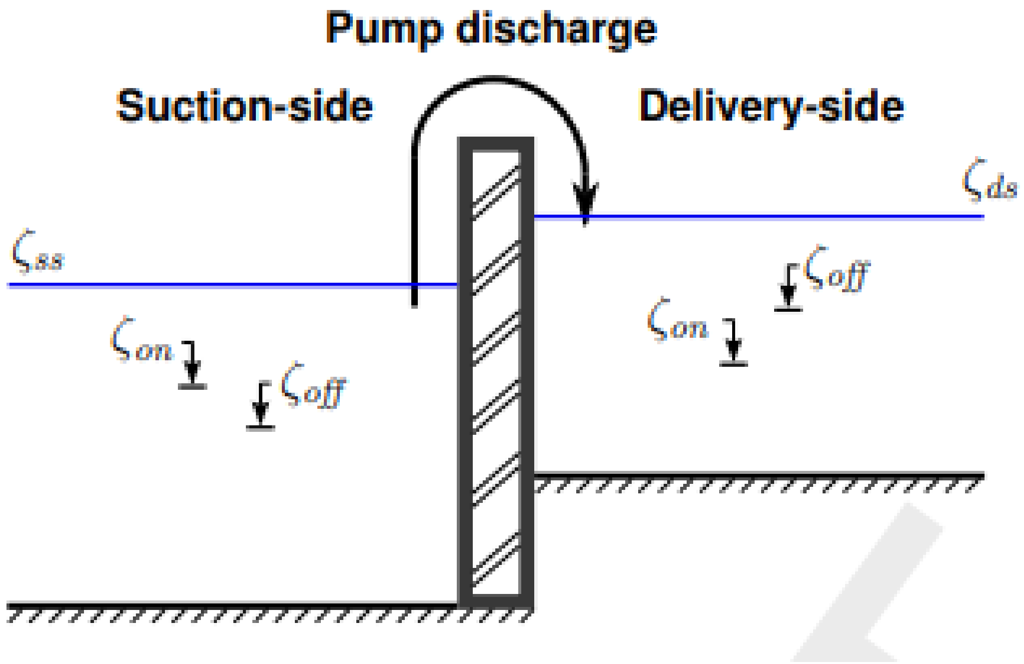

Figure 118: Schematic of Deflt3d FM sub-grid structure 'pump' used to apply wave overtopping estimates to the hydrodynamic modelling in this study (source: Deltares).

A1.5.11 Coastal structures dimensions

An overview of the ocean facing coastal structures on West Island and the adopted dimensions are provided in **Table 49**.

Table 49: Summary of coastal structure dimensions adopted in the overtopping calculations.

Structure ID	Name	Structure characteristics				
		Length (m)	Slope (1V: H)	Crest level (m AHD)	Crest width (m)	Roughness coefficient
CKIW02	Trannies revetment	56	0.75	1.9	2.0	0.9
CKIW03	Sydney Highway revetment	300	0.70	2.9	1.5	0.9
CKIW04	Medical Centre revetment	46	0.75	4.4	1.0	0.9
CKIW05	William Keeling revetment	410	1.25	4.3	2.5	0.9
CKIW06	Settlement concrete revetment	223	1.00	4.0	0.5	0.5
CKIW07	Settlement concrete seawall	60	0.10	2.0	0.2	1.0
CKIW08	Runway revetment	80	0.80	3.5	1.5	0.9
CKIW09	Twiss revetment	65	2.00	2.8	2.0	0.9

Figure 119: Coastal structures locations on West Island (left) and example of a low overtopping event in February 2019 at CKI08 (right).

A1.5.12 Calibration

The overtopping estimates have been calibrated in order to reproduce the known overtopping areas and approximate inundation extents of the July 2018 swell event (see RHDHV, 2018b). A map showing the affected areas derived from debris lines identified during a site visit and photographic evidence in comparison to the simulated inundation extents from the high-resolution hydrodynamic model including the EurOtop overtopping volumes is presented in **Figure 120** and **Figure 121**. The calibrated discharge curves for each of the coastal structures were able to closely reproduce the observed overtopping occurrences.

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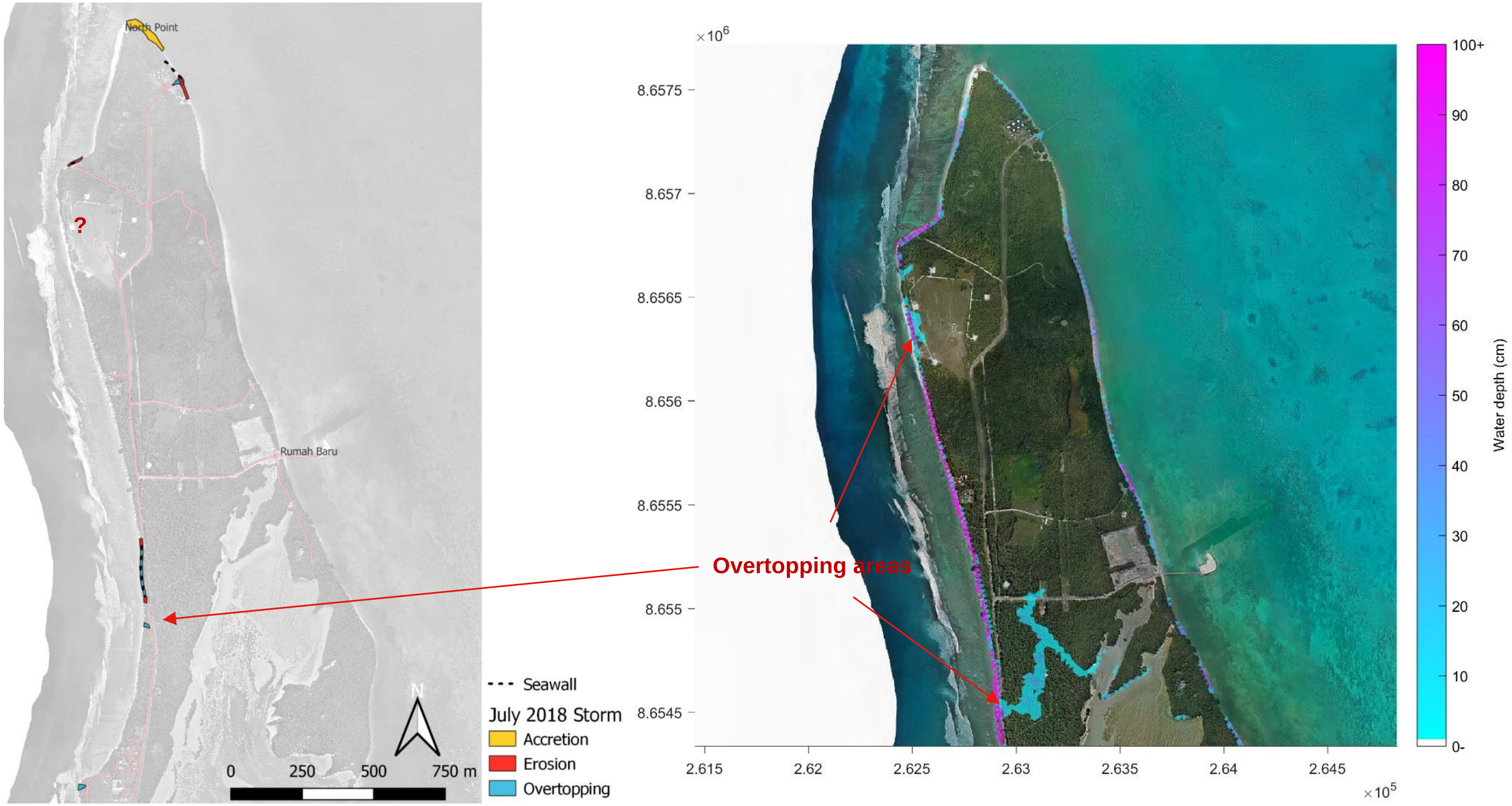

Figure 120: Observed overtopping areas (blue) during the 24th July 2018 swell event (left, RHDHV 2018b) and simulated inundation depth using the hydrodynamic model including the EurOtop discharge curves (right) for the northern part of West Island.

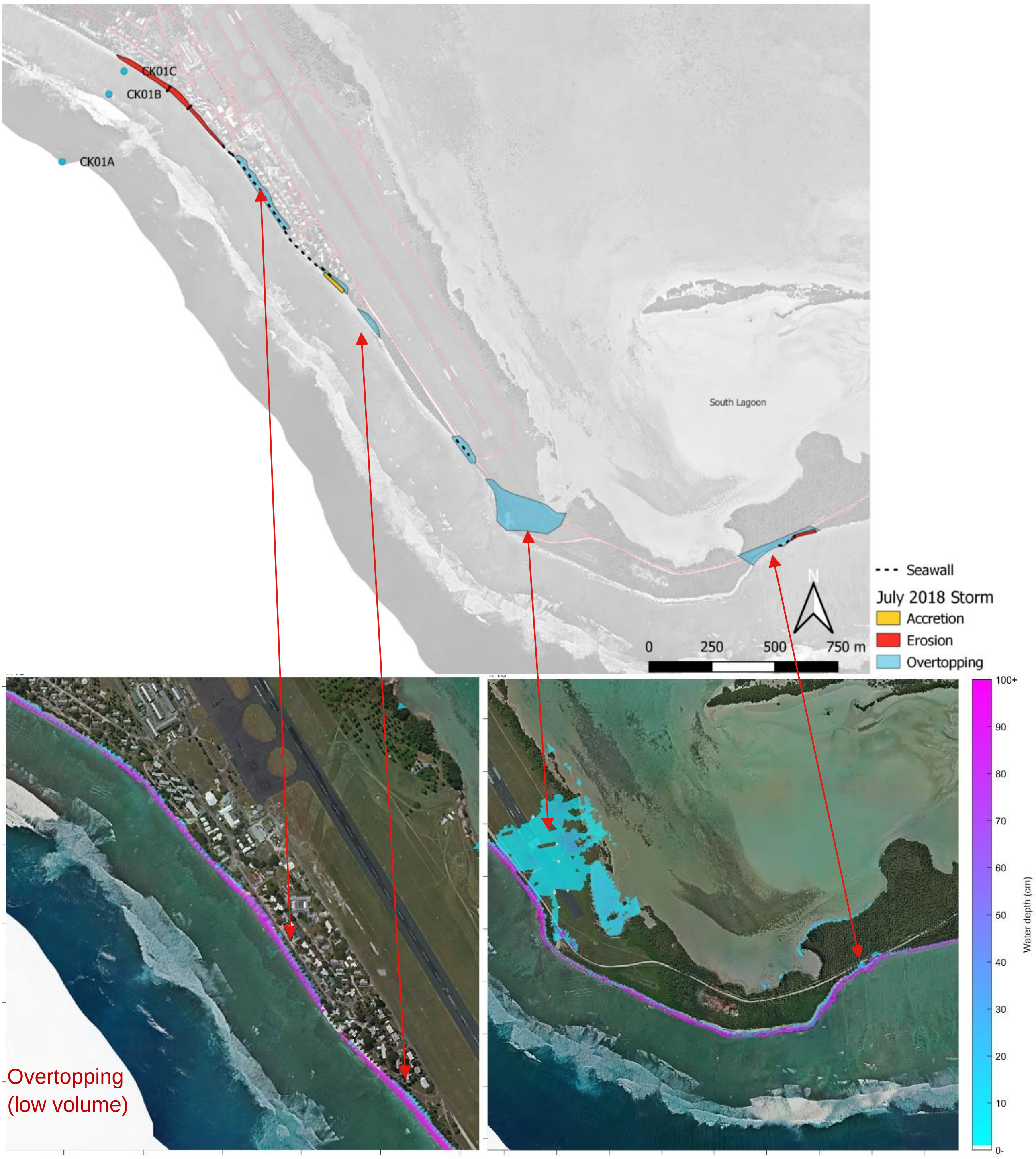

Figure 121: Observed overtopping areas (blue) during the 24th July 2018 swell event (top, RHDHV 2018b) and simulated inundation depth using the hydrodynamic model including the EurOtop discharge curves (bottom) for the southern part of West Island.

A1.5.13 Overtopping discharge curves

An example of the calculated discharge curves for a series of water level and planning scenarios is provided in Figure 122. For the sea level rise scenarios for the 2068 and 2118 planning periods significant overtopping occurs at all stages of the adopted tidal curve which results in large discharge volumes to landward areas.

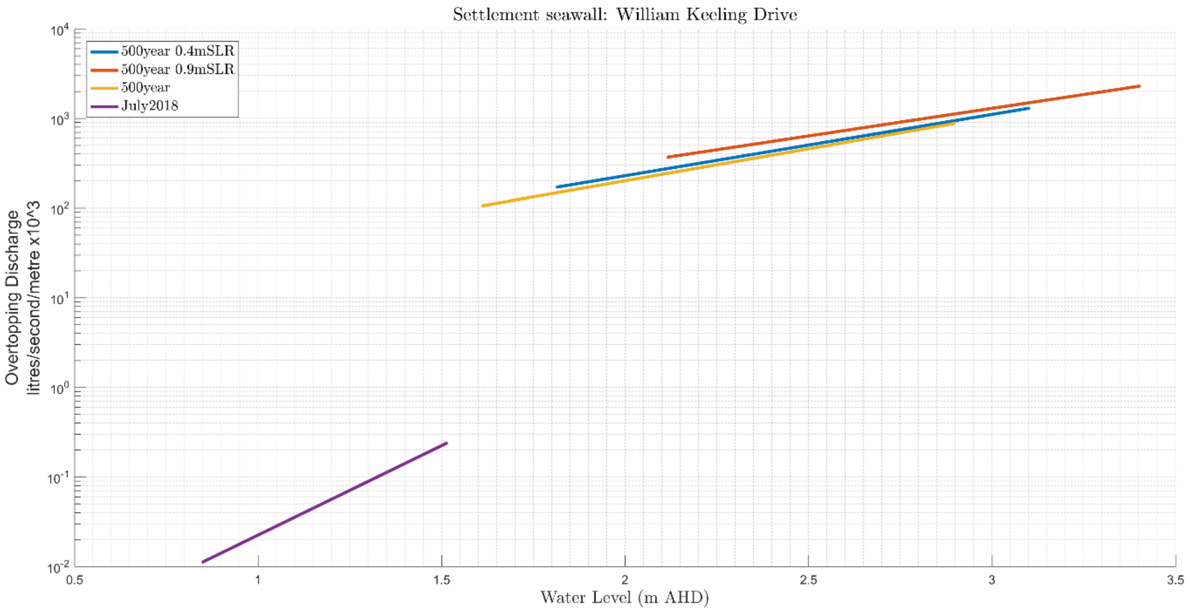

Figure 122: Example of estimated wave overtopping discharge volumes at the William Keeling Drive geotextile sand container revetment for a range of wave and water level scenarios.

Appendix B – Detailed Coastal Inundation Maps

Still water inundation

500-year ARI (2018)

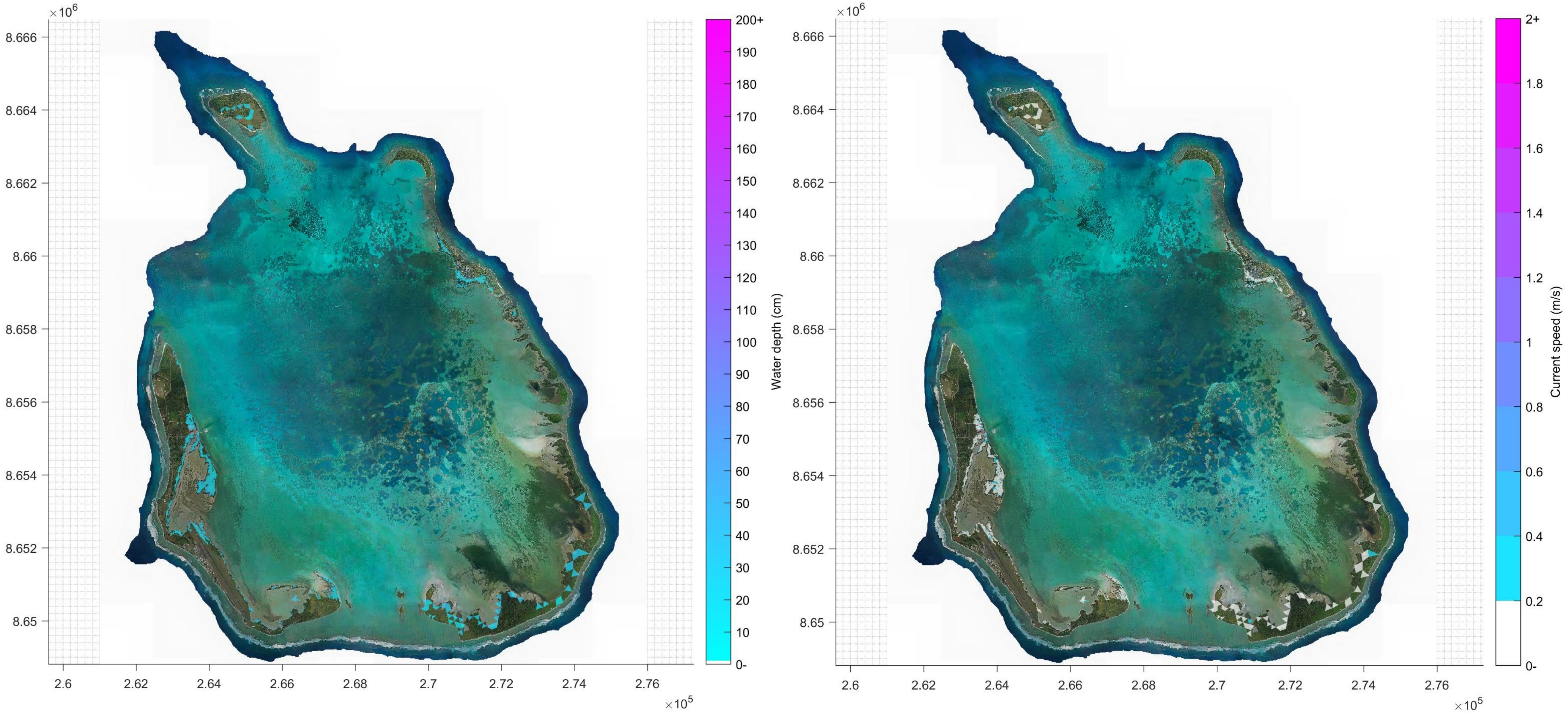

Figure 123: Map of maximum inundation depth (left) and maximum current speed (right) for the entire southern atoll during the 500-year (year 2018) still water level scenario.

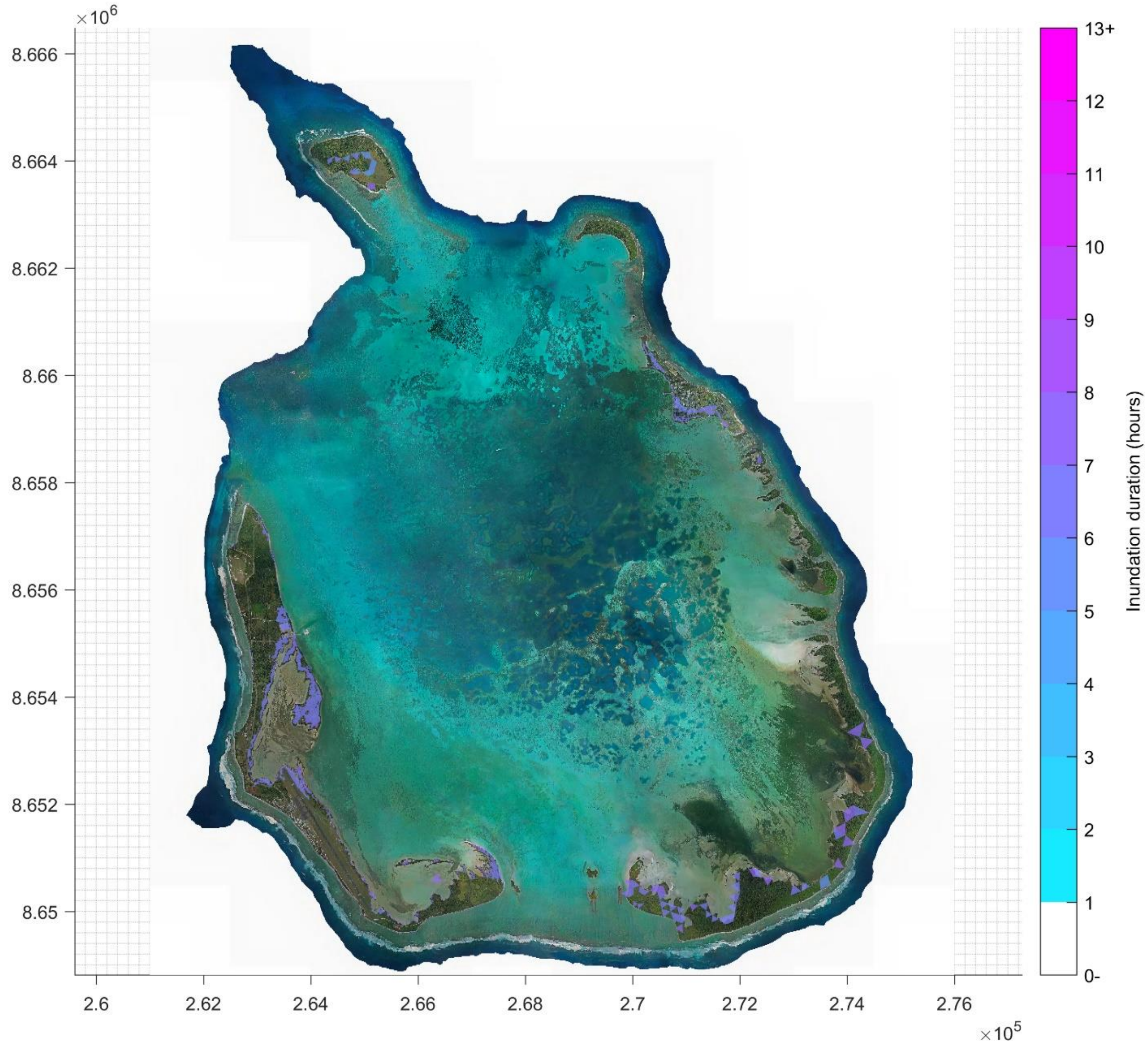

Figure 124: Map showing inundation durations for the entire southern atoll during the 13-hour simulation period for the <u>500-year (year 2018) still water level</u> scenario.

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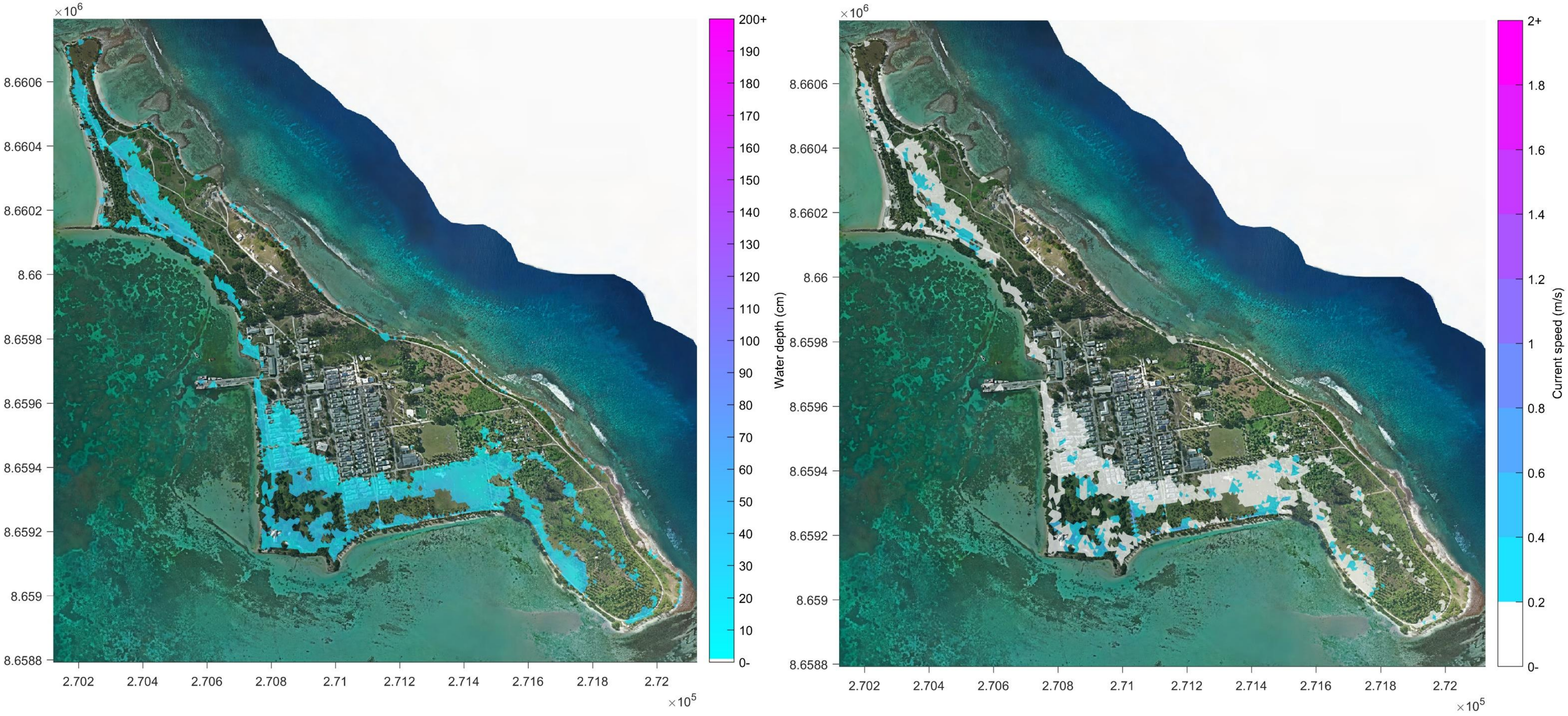

Figure 125: Map of maximum inundation depth (left) and maximum current speed (right) for inundated areas on Home Island during the 500-year (year 2018) still water level scenario.

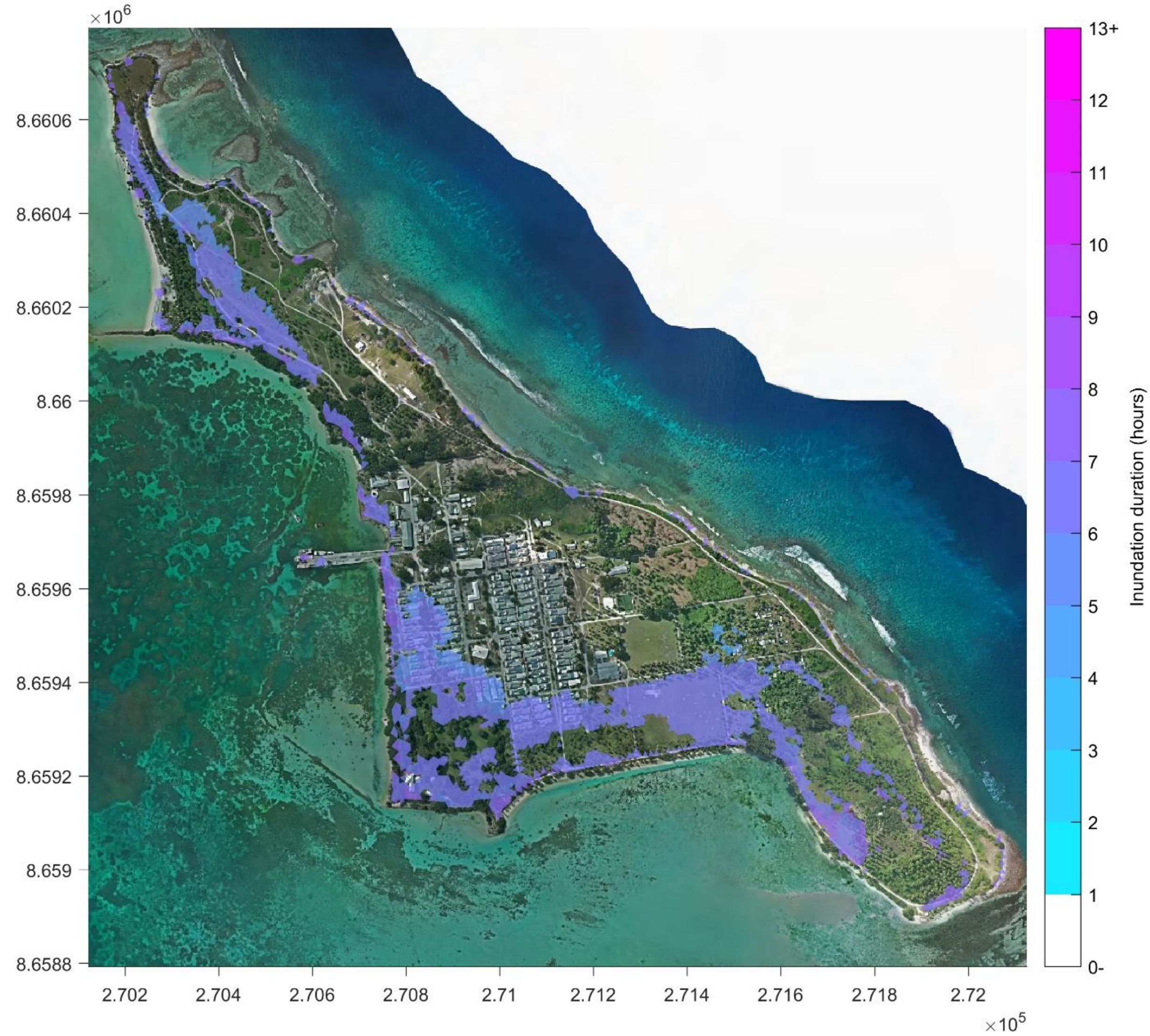

Figure 126: Map showing inundation durations on Home Island during the 13-hour simulation period for the 500-year (year 2018) still water level scenario.

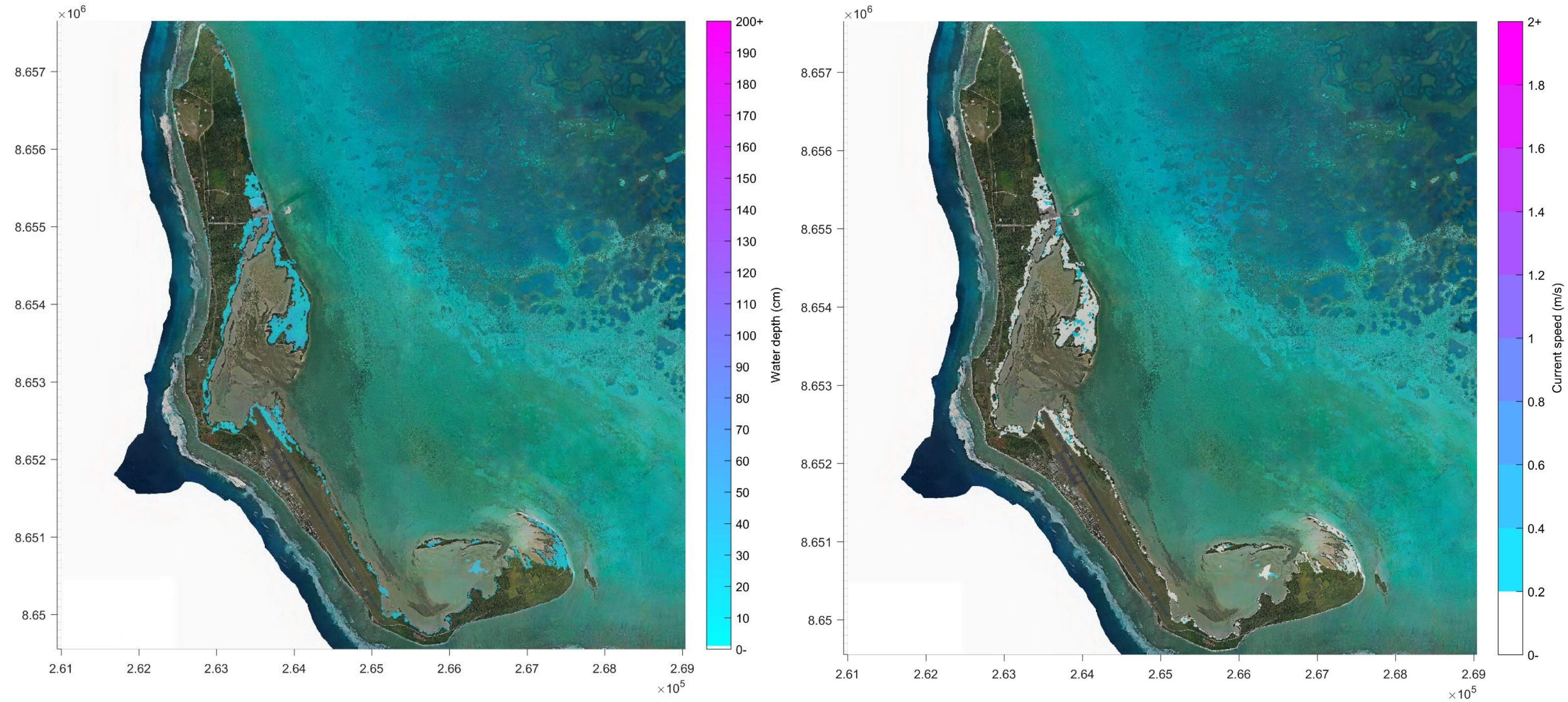

Figure 127: Map of maximum inundation depth (left) and maximum current speed (right) for inundated areas on West Island during the 500-year (year 2018) still water level scenario.

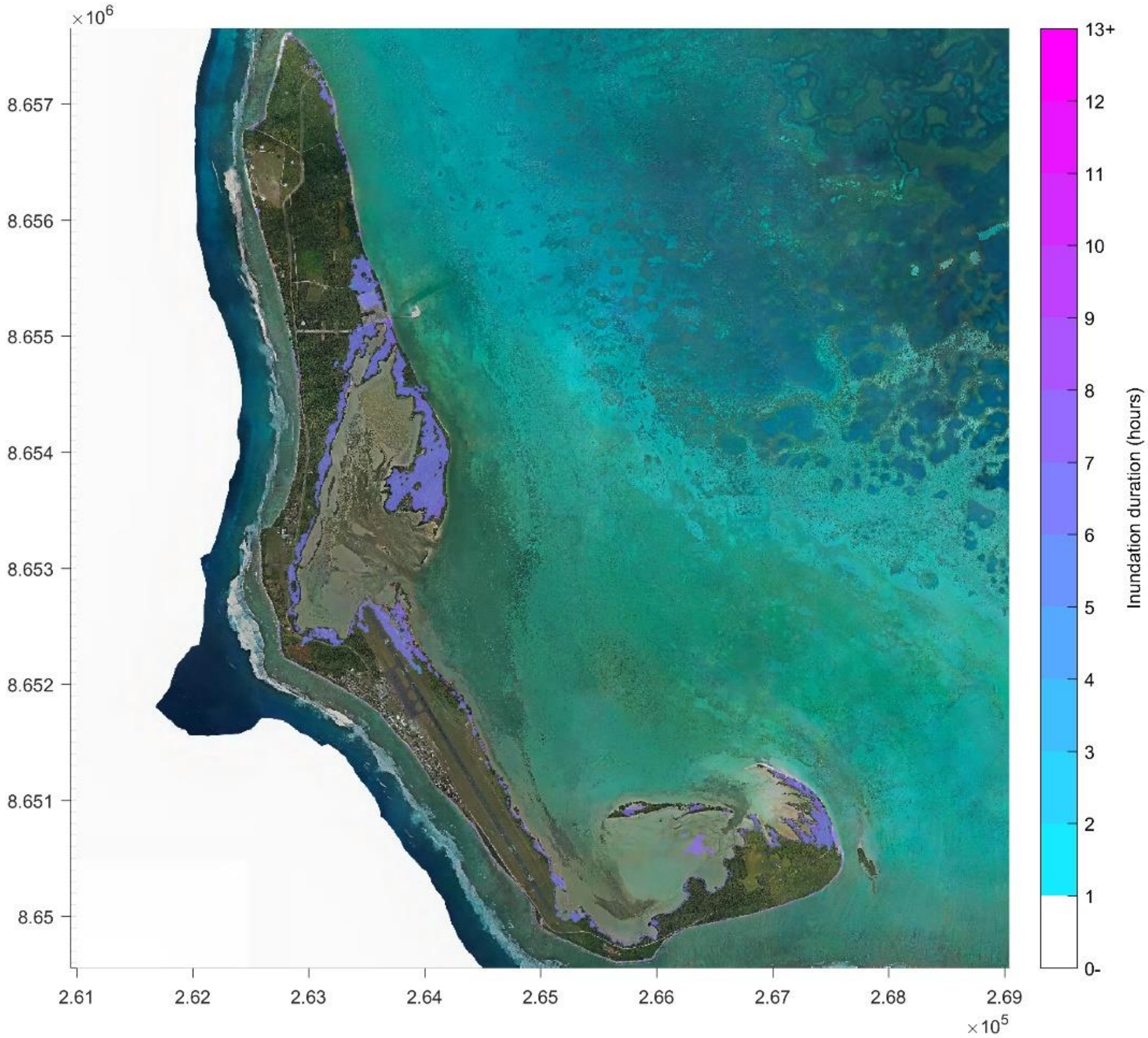

Figure 128: Map showing inundation durations on West Island during the 13hour simulation period for the 500-year (year 2018) still water level scenario.

500-year ARI + 0.4m sea level rise (2068)

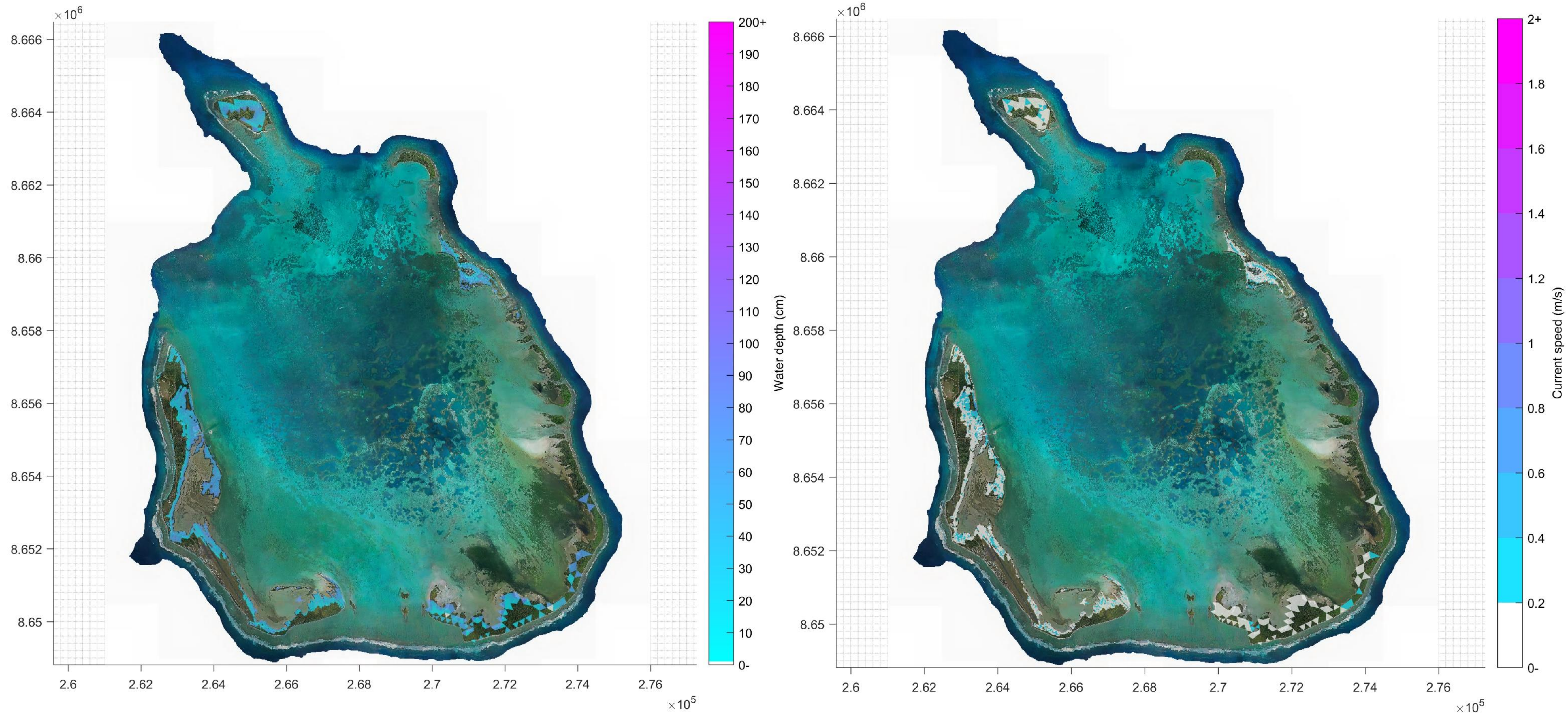

Figure 129: Map of maximum inundation depth (left) and maximum current speed (right) for the entire southern atoll during the 500-year + 0.4m sea level rise (year 2068) still water level scenario.

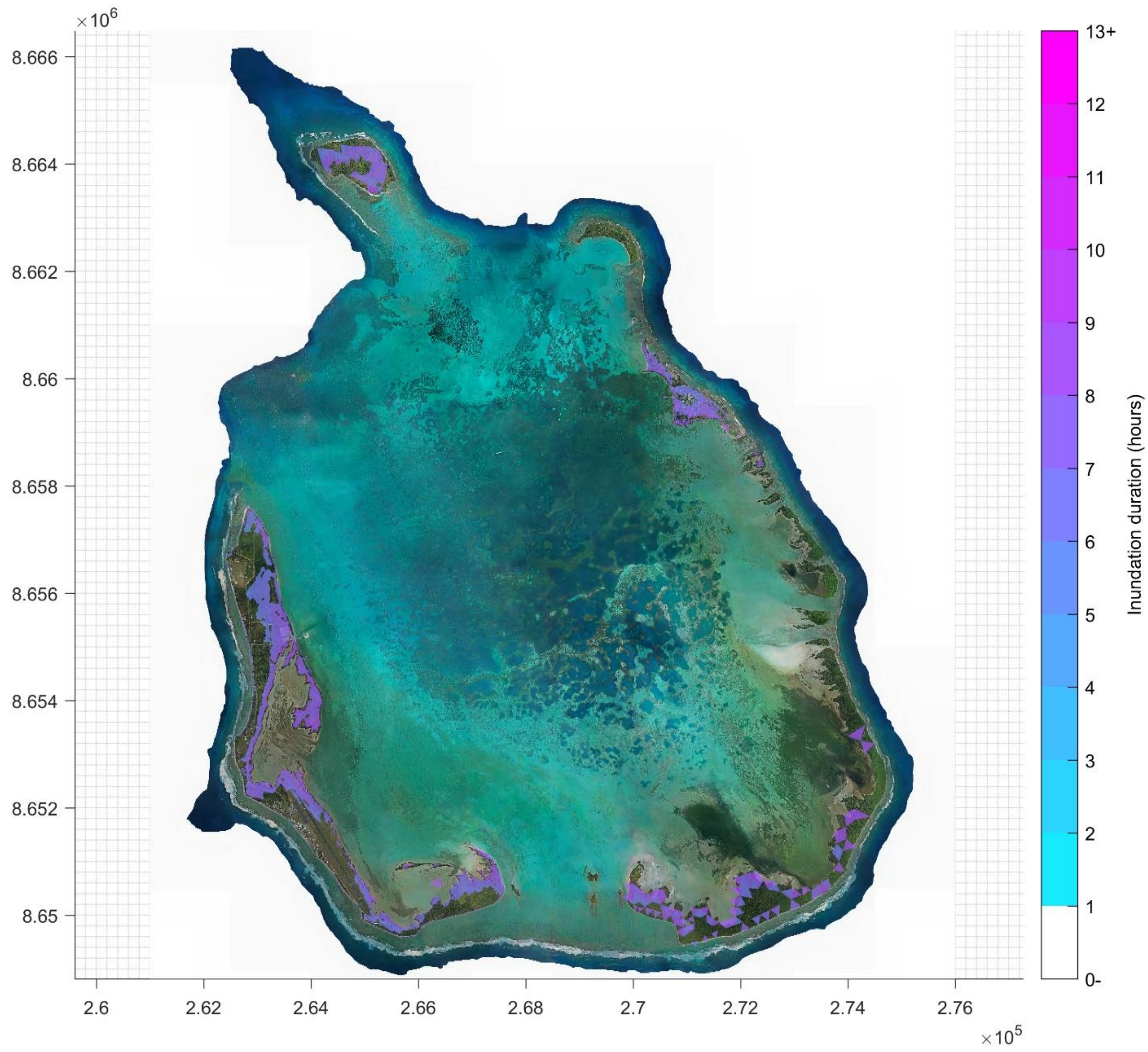

Figure 130: Map showing inundation durations for the entire southern atoll during the 13-hour simulation period for the 500-year + 0.4m sea level rise (year 2068) still water level scenario.

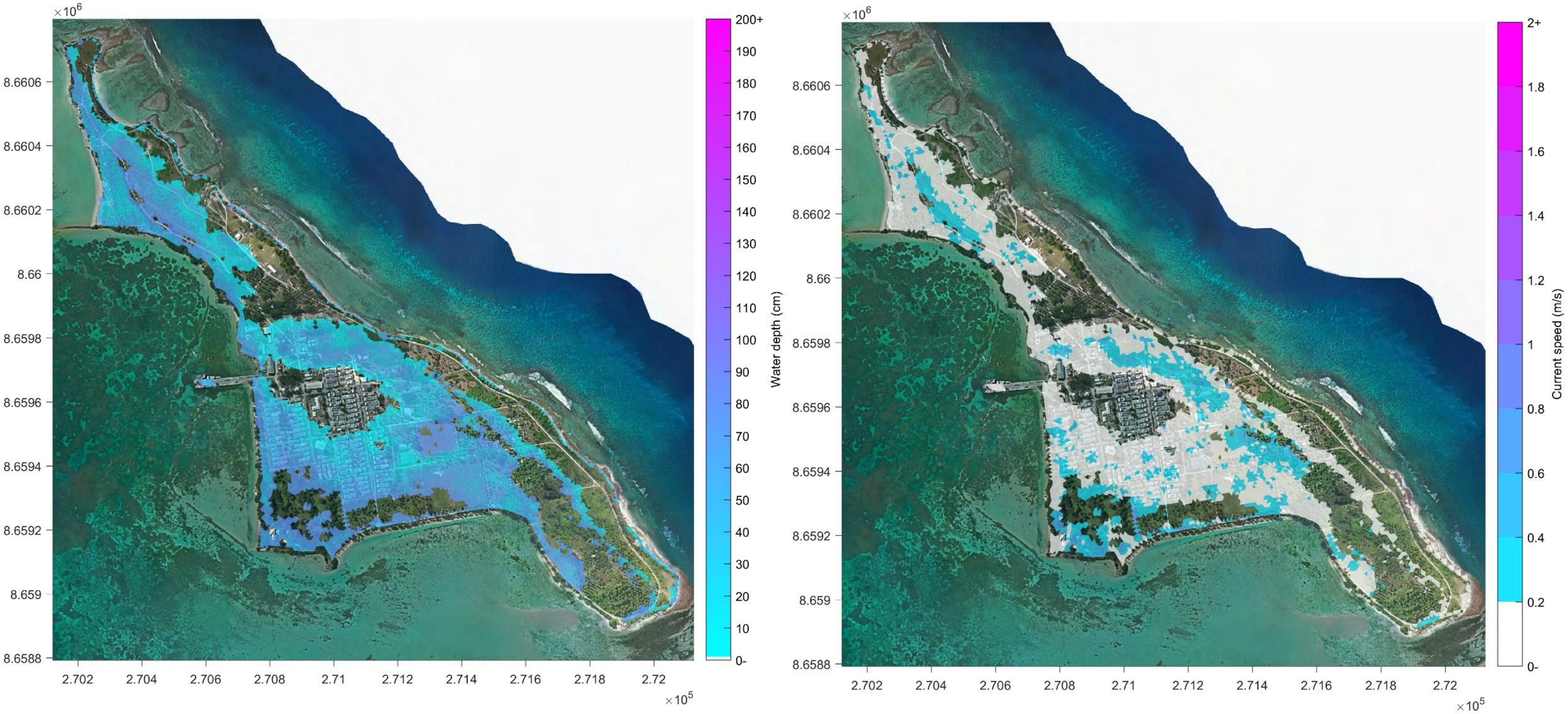

Figure 131: Map of maximum inundation depth (left) and maximum current speed (right) for inundated areas on Home Island during the 500-year + 0.4m sea level rise (year 2068) still water level scenario.

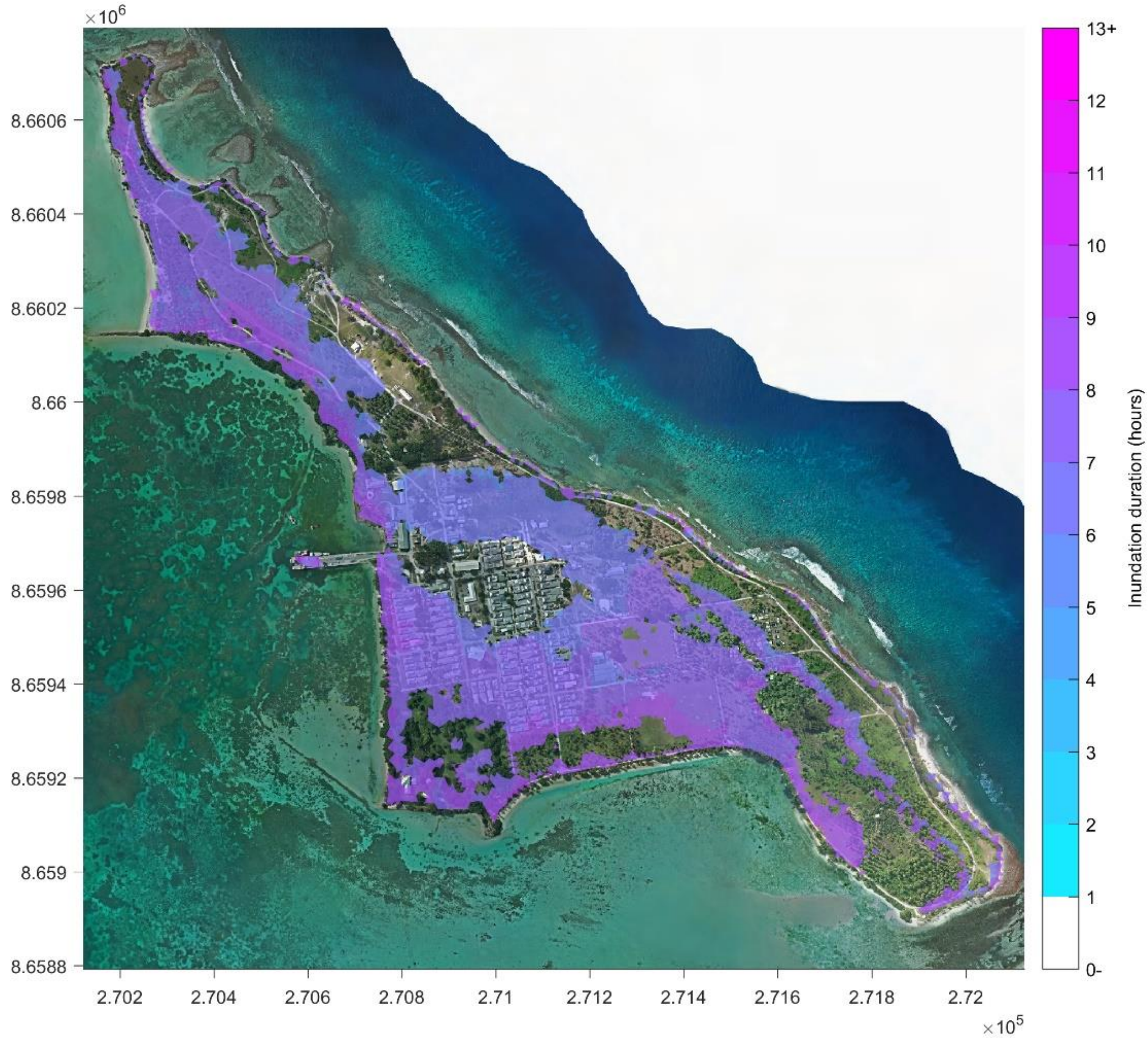

Figure 132: Map showing inundation durations on Home Island during the 13-hour simulation period for the 500-year + 0.4m sea level rise (year 2068) still water level scenario.

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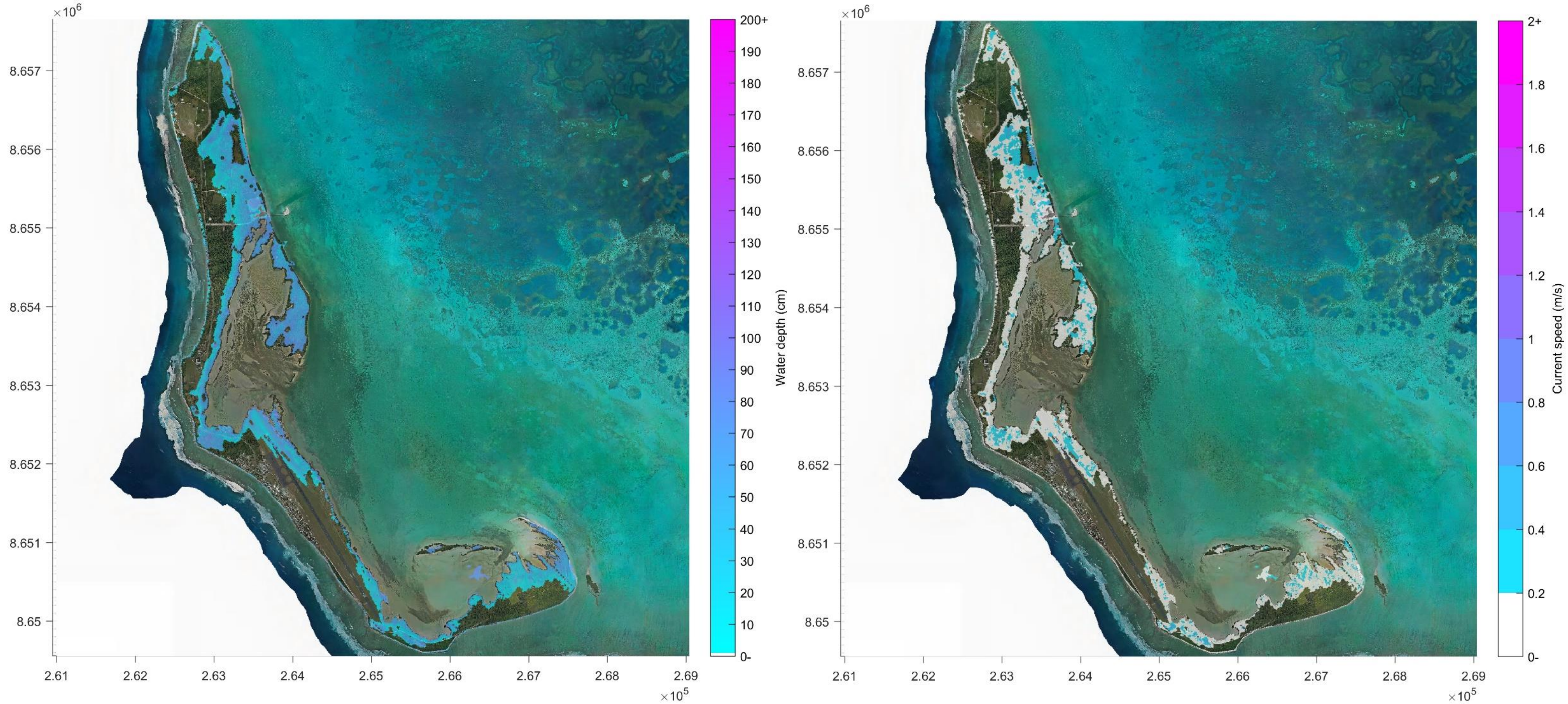


Figure 133: Map of maximum inundation depth (left) and maximum current speed (right) for inundated areas on West Island during the 500-year + 0.4m sea level rise (year 2068) still water level scenario.

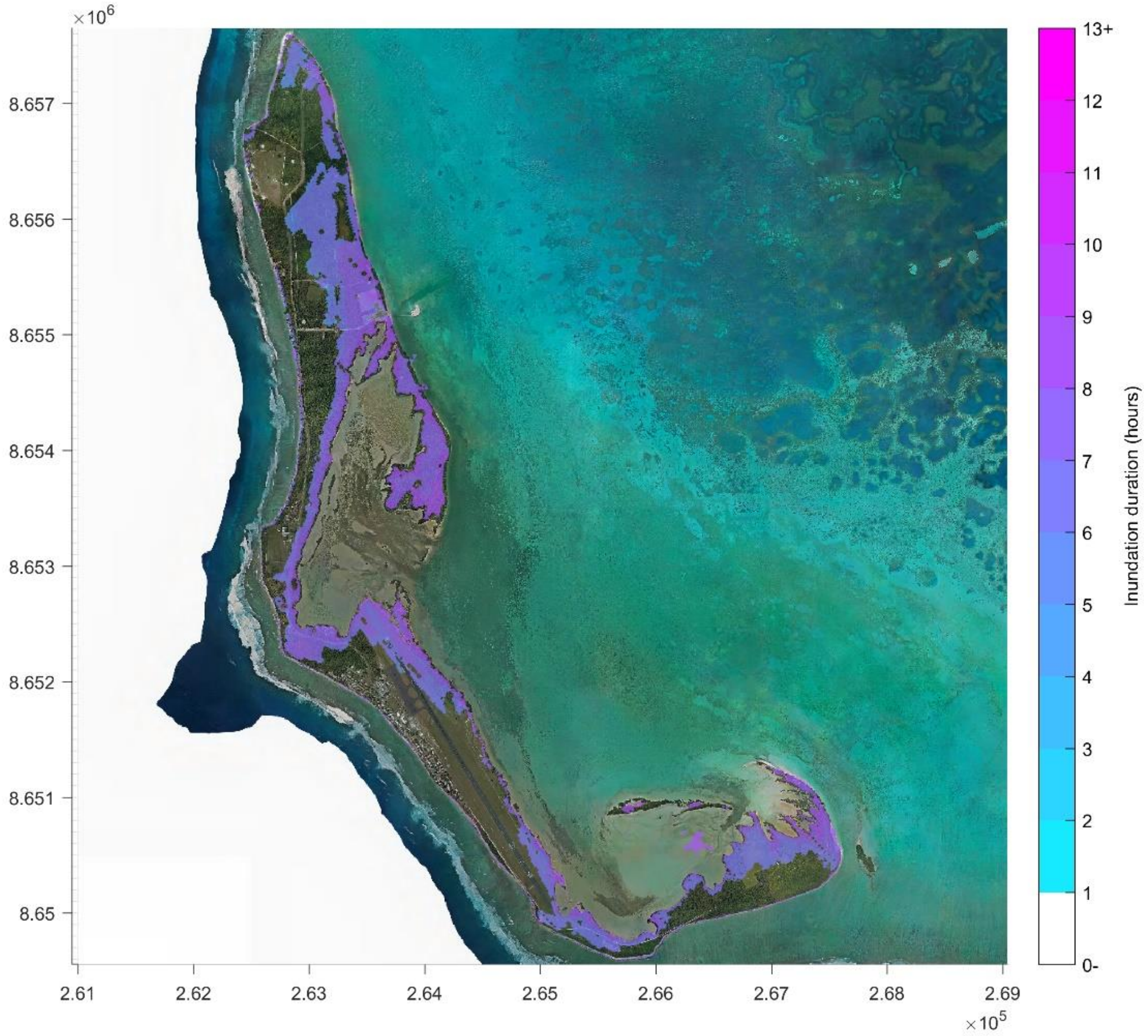


Figure 134: Map showing inundation durations areas on West Island during the 13hour simulation period for the 500-year + 0.4m sea level rise (year 2068) still water level scenario.

500-year ARI + 0.9m sea level rise (2118)

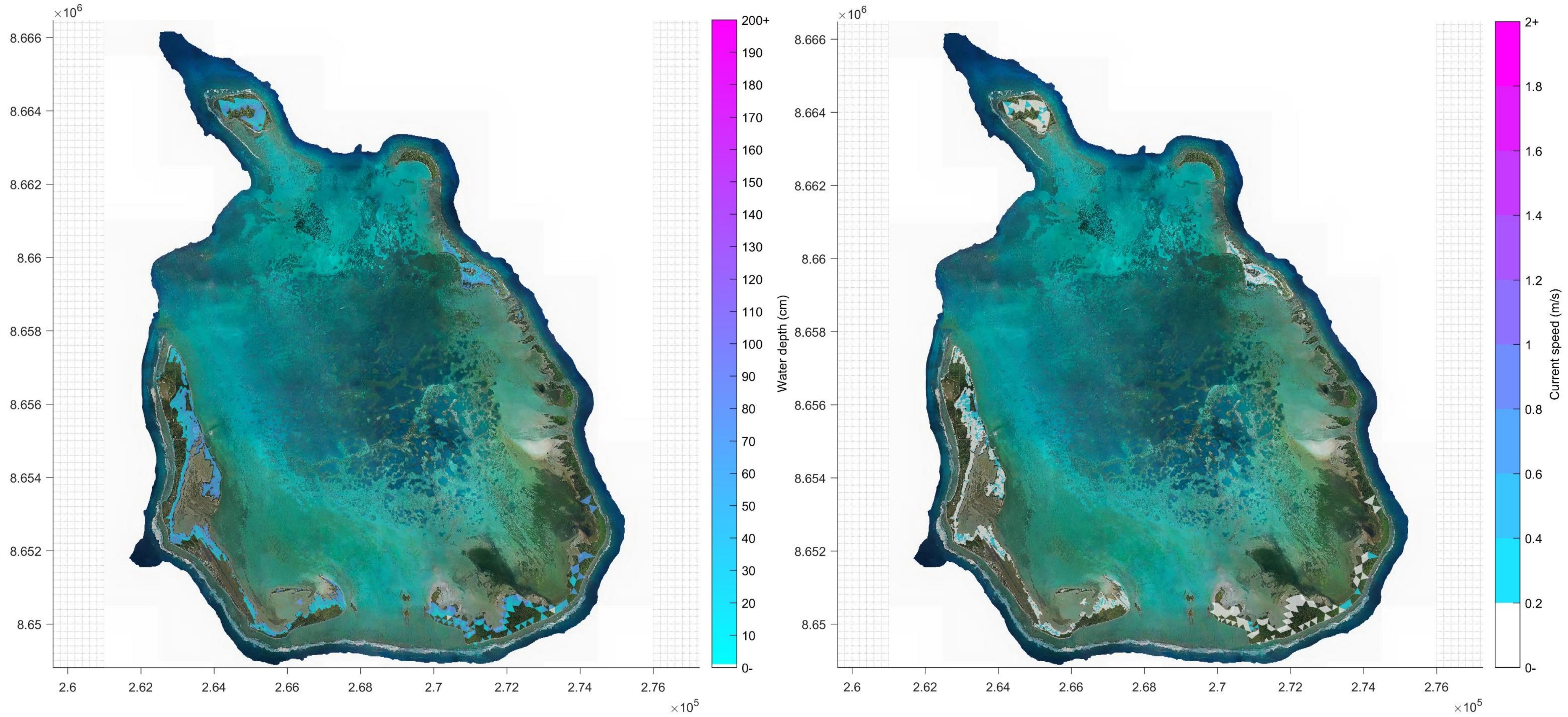


Figure 135: Map of maximum inundation depth (left) and maximum current speed (right) for the entire southern atoll during the 500-year + 0.9m sea level rise (year 2118) still water level scenario.

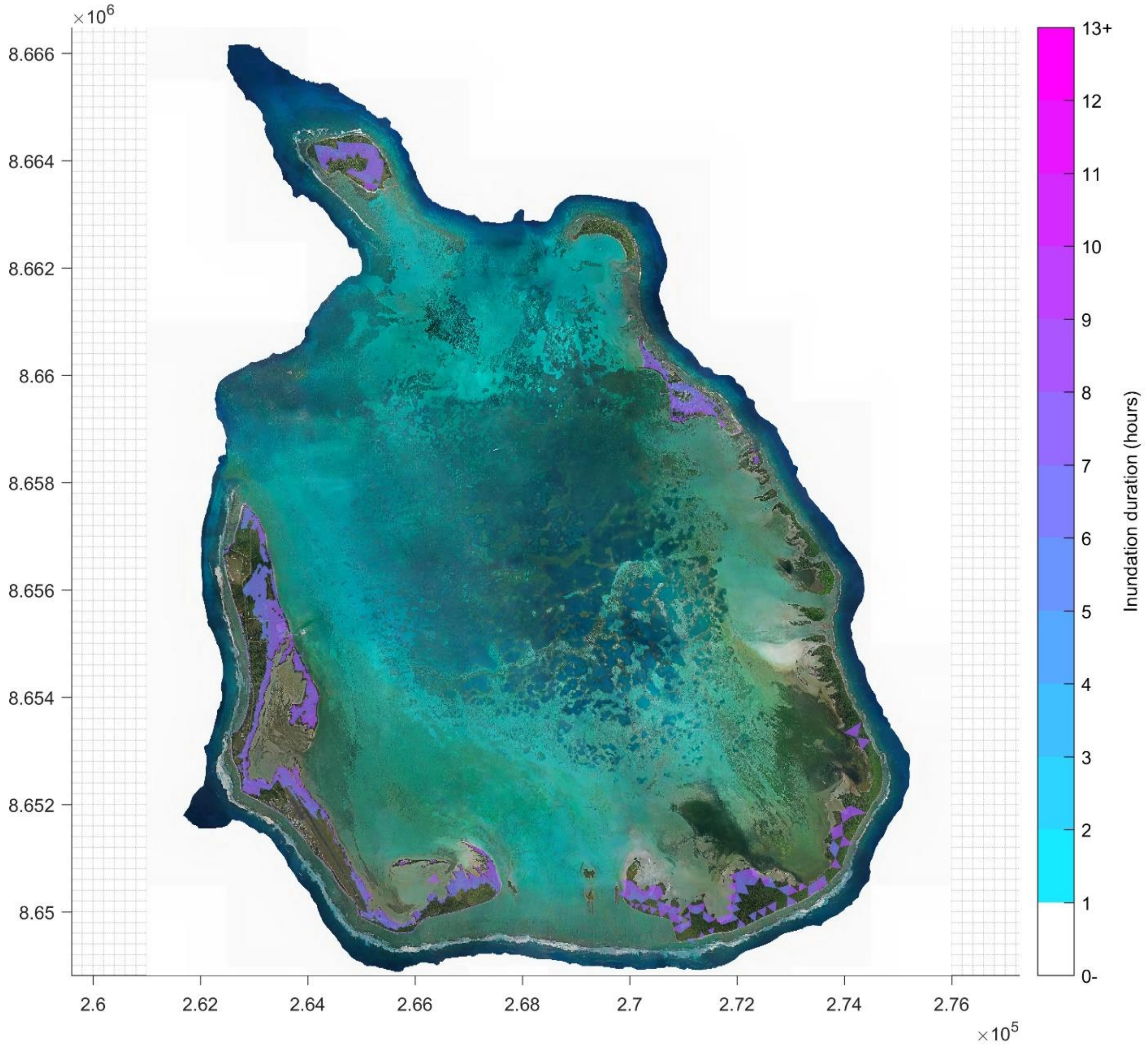


Figure 136: Map showing inundation durations for the entire southern atoll during the 13-hour simulation period for the 500-year + 0.9m sea level rise (year 2118) still water level scenario.

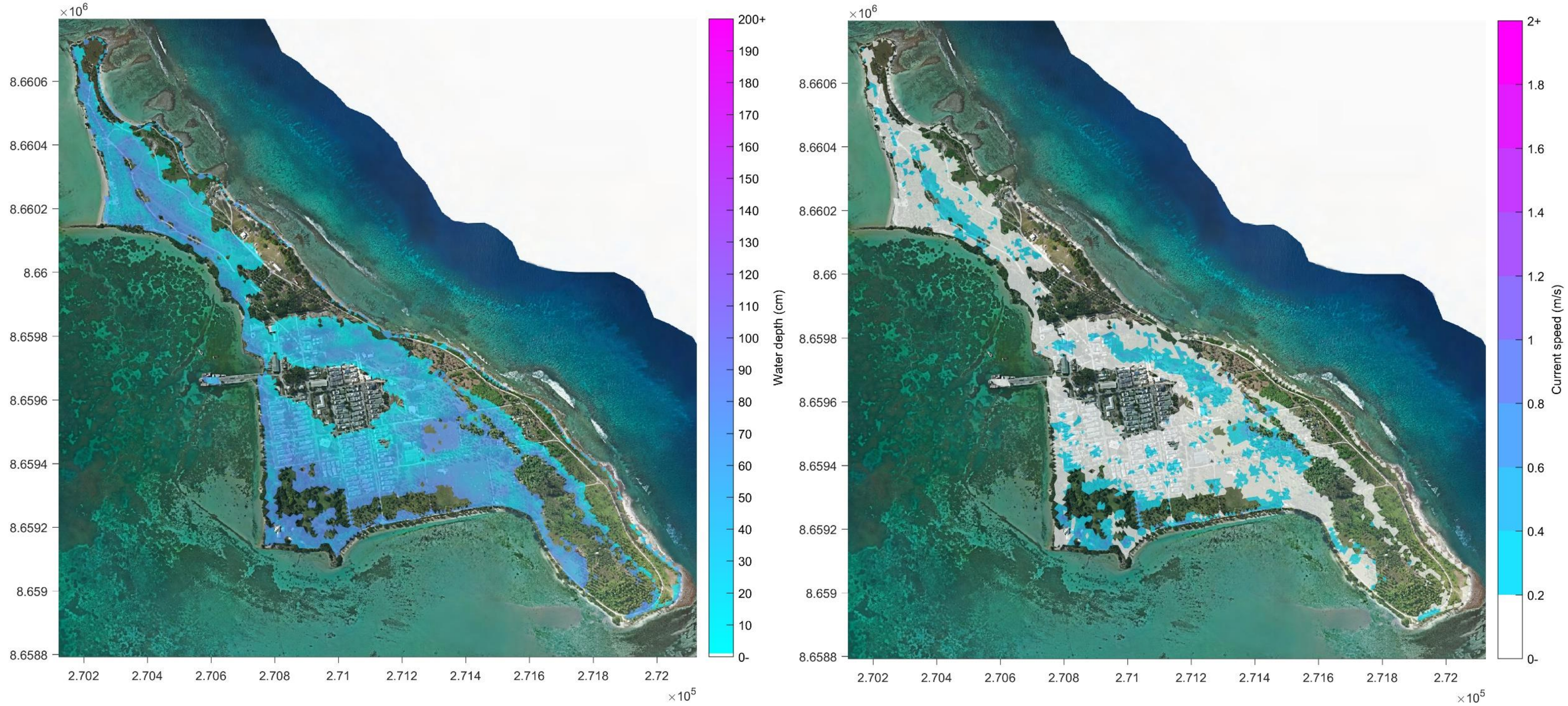


Figure 137: Map of maximum inundation depth (left) and maximum current speed (right) for inundated areas on Home Island during the 500-year + 0.9m sea level rise (year 2118) still water level scenario.

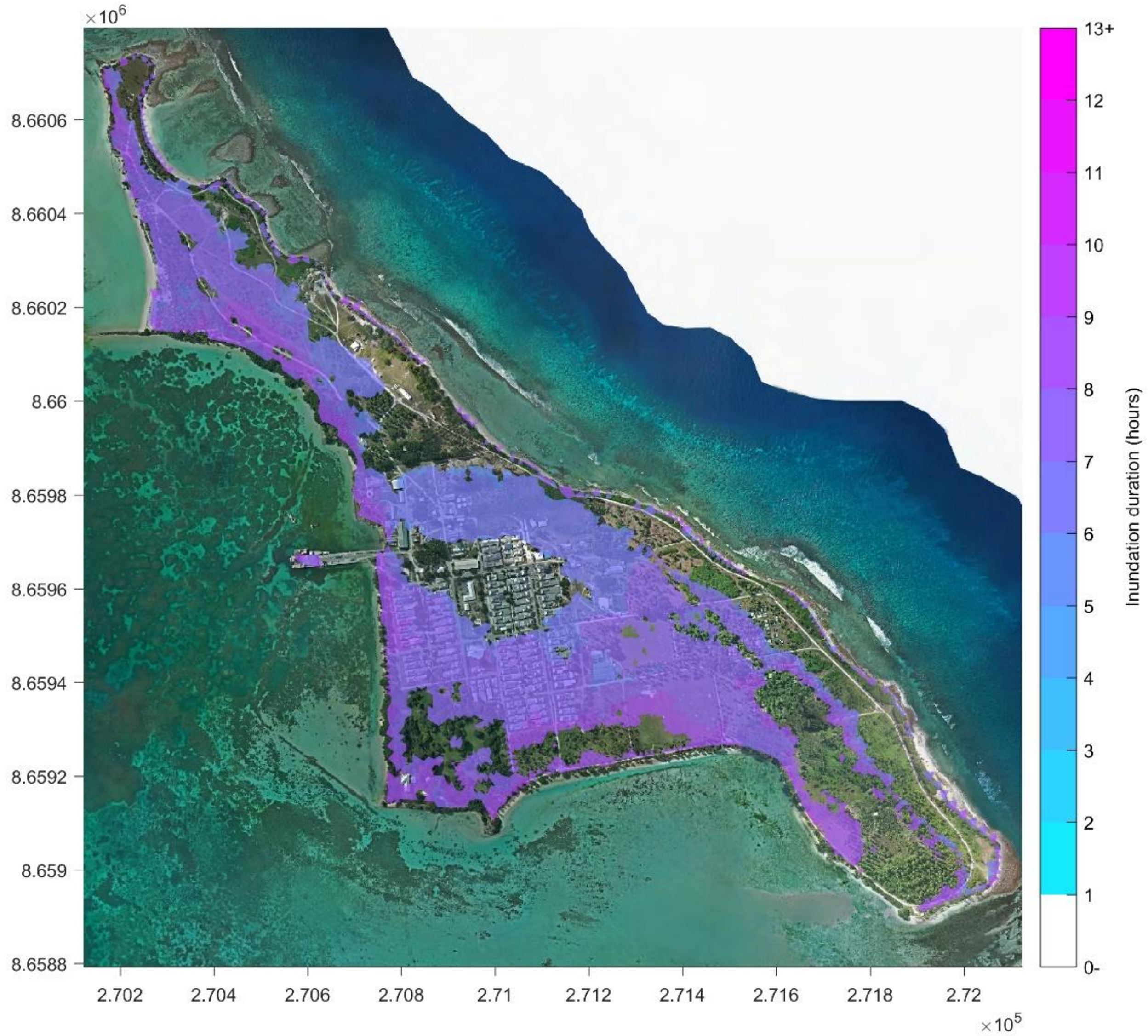


Figure 138: Map showing inundation durations on Home Island during the 13-hour simulation period for the 500-year + 0.9m sea level rise (year 2118) still water level scenario.

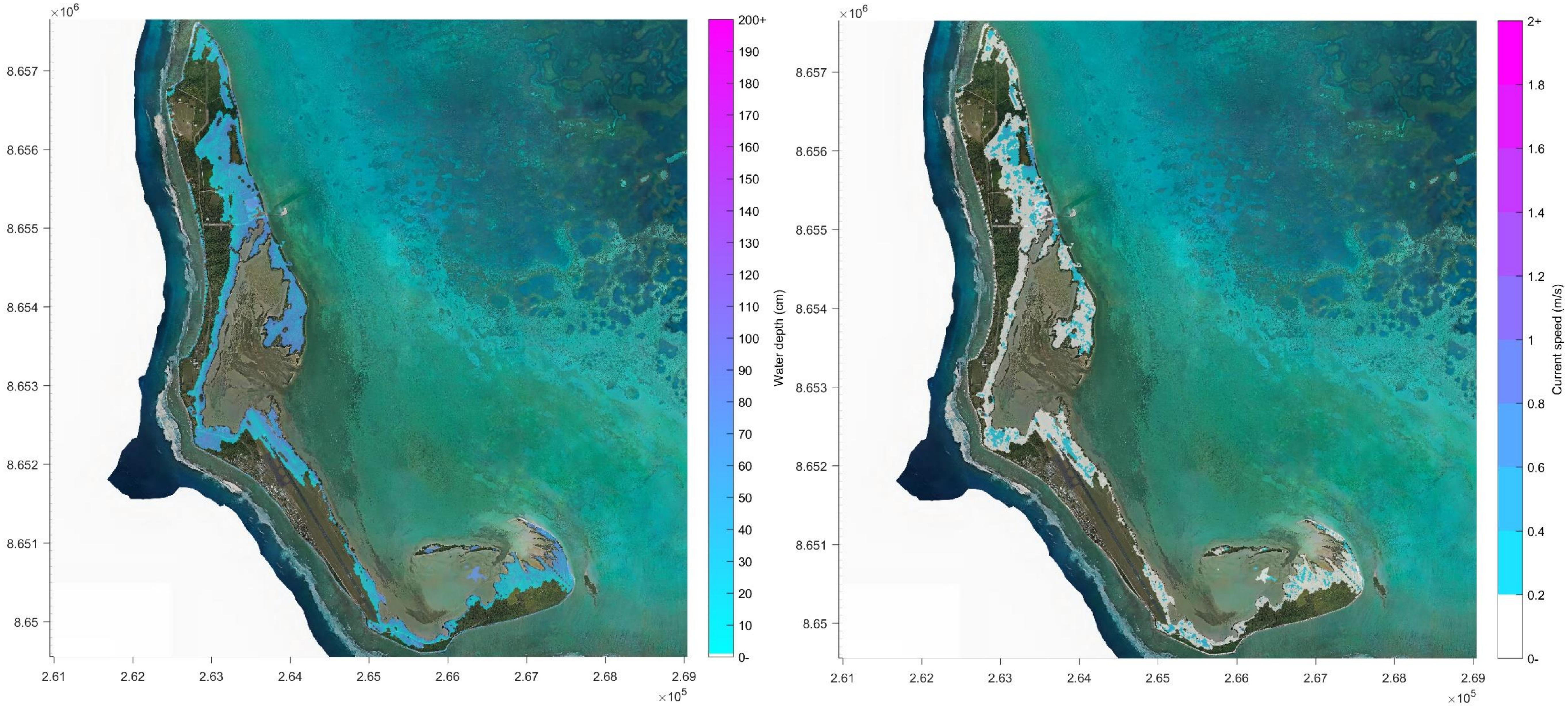


Figure 139: Map of maximum inundation depth (left) and maximum current speed (right) for inundated areas on West Island during the 500-year + 0.9m sea level rise (year 2118) still water level scenario.

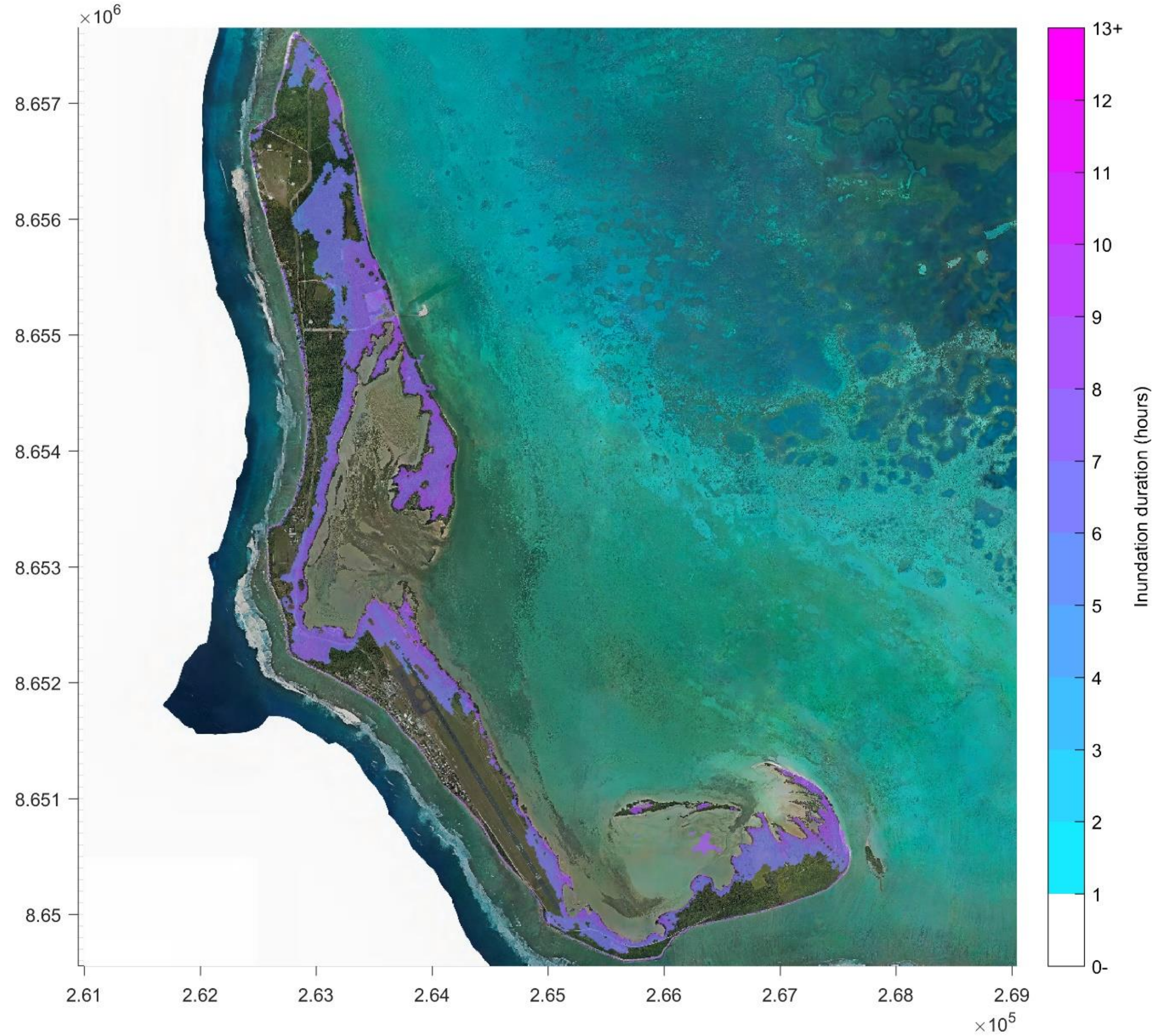


Figure 140: Map showing inundation durations on West Island during the 13hour simulation period for the 500-year + 0.9m sea level rise (year 2118) still water level scenario.

Wave-driven Coastal Inundation

500-year ARI (2018)

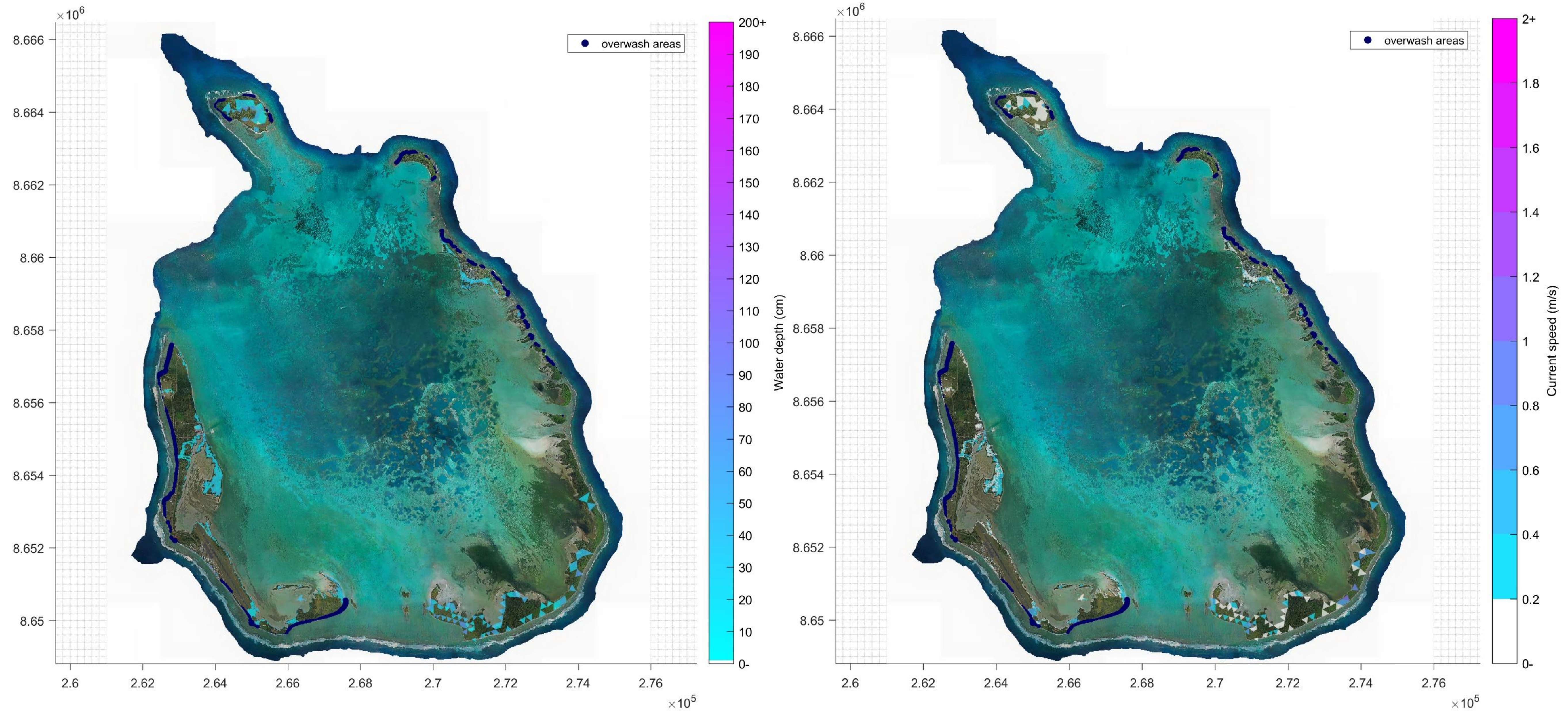


Figure 141: Map of maximum inundation depth (left) and maximum current speed (right) for the entire southern atoll during the 500-year (year 2018) still water level plus wave overtopping and indicative overwash (dark blue circles) scenario.

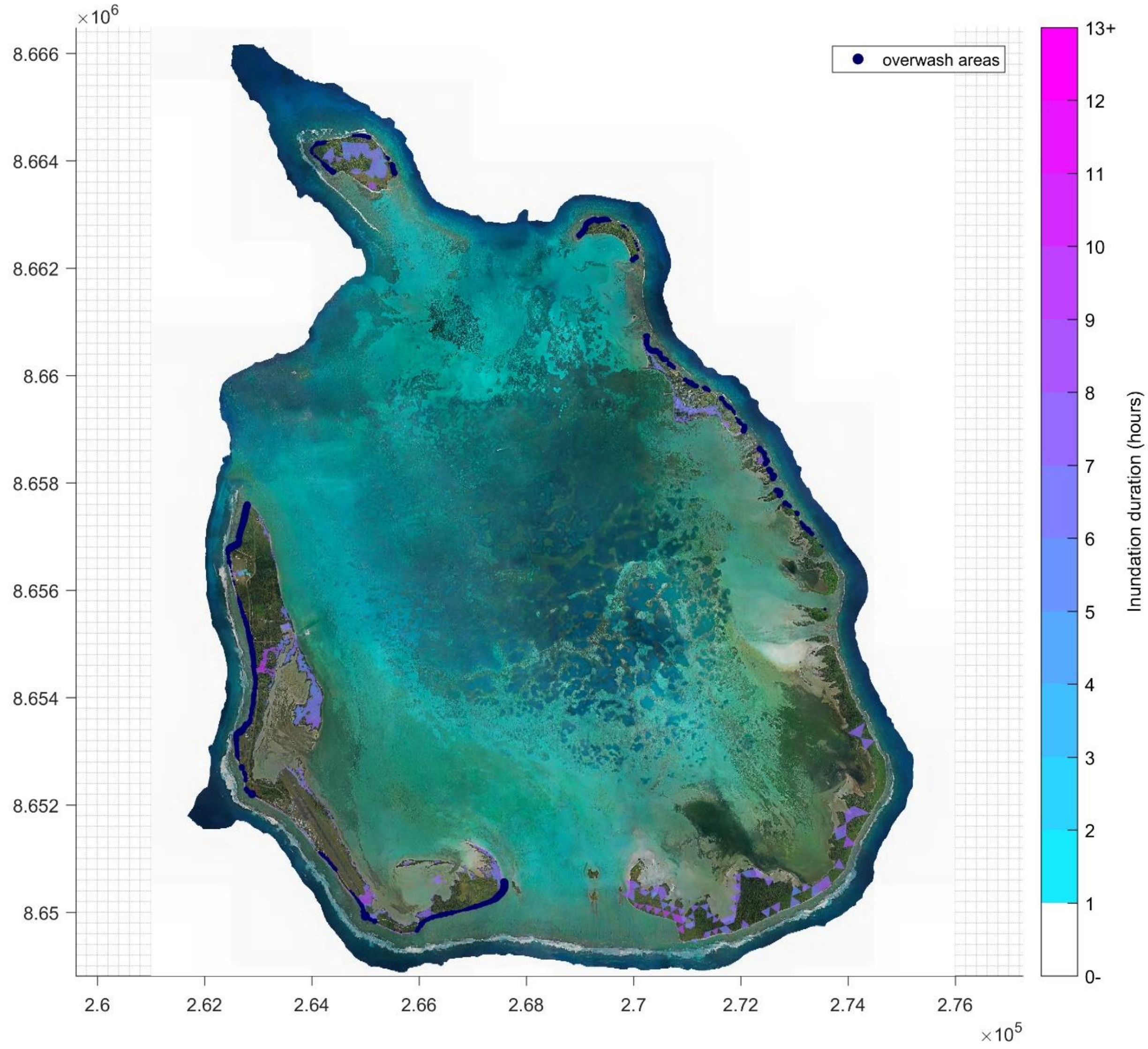


Figure 142: Map showing inundation durations for the entire southern atoll during the 13-hour simulation period for the 500-year (year 2018) still water level plus wave overtopping and indicative overwash (dark blue circles) scenario.

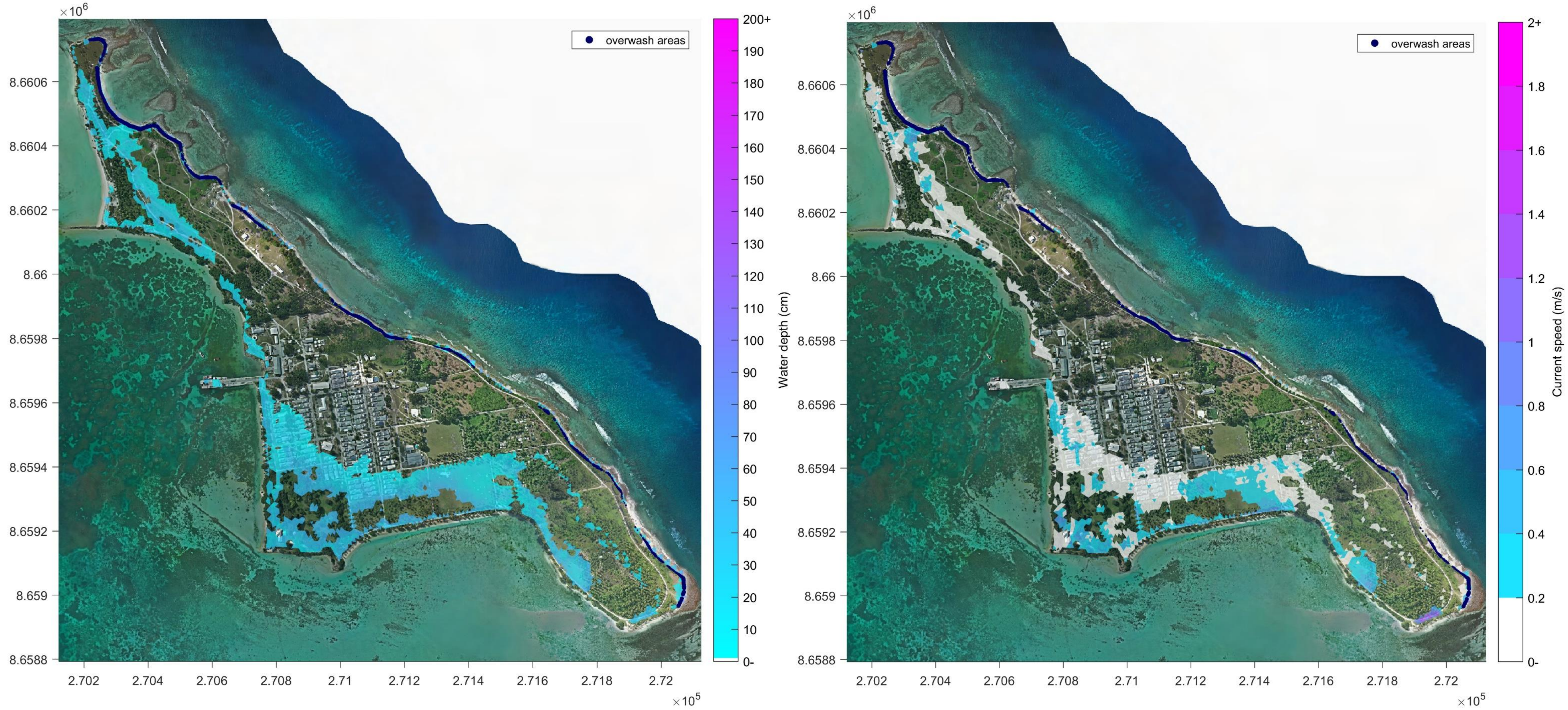


Figure 143: Map of maximum inundation depth (left) and maximum current speed (right) for inundated areas on Home Island during the *<u>500-year (year 2018) still water level plus wave overtopping and indicative overwash (dark blue circles)</u>* *scenario.*

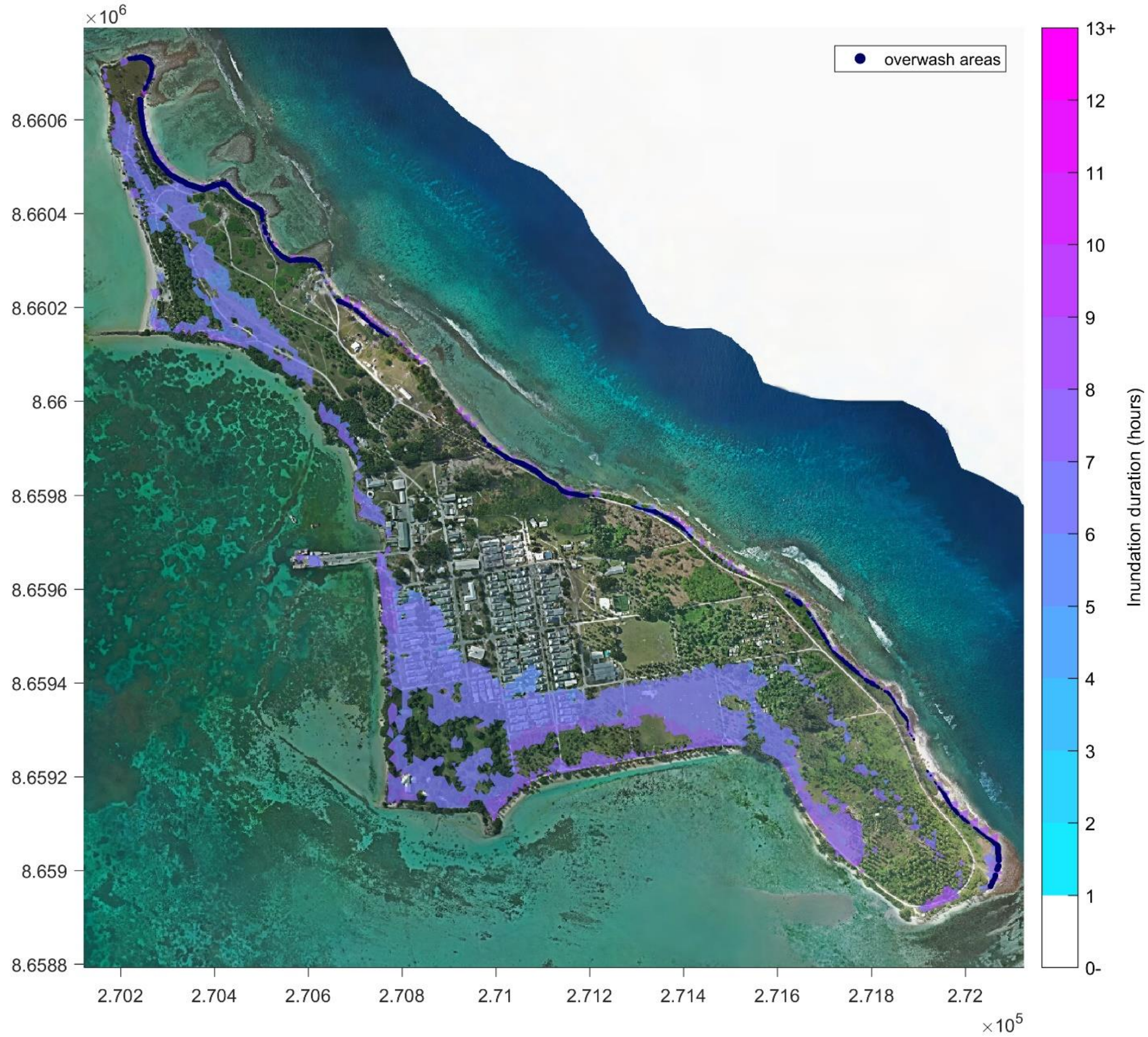


Figure 144: Map showing inundation durations on Home Island during the 13-hour simulation period for the 500-year (year 2018) still water level plus wave overtopping and indicative overwash (dark blue circles) scenario.

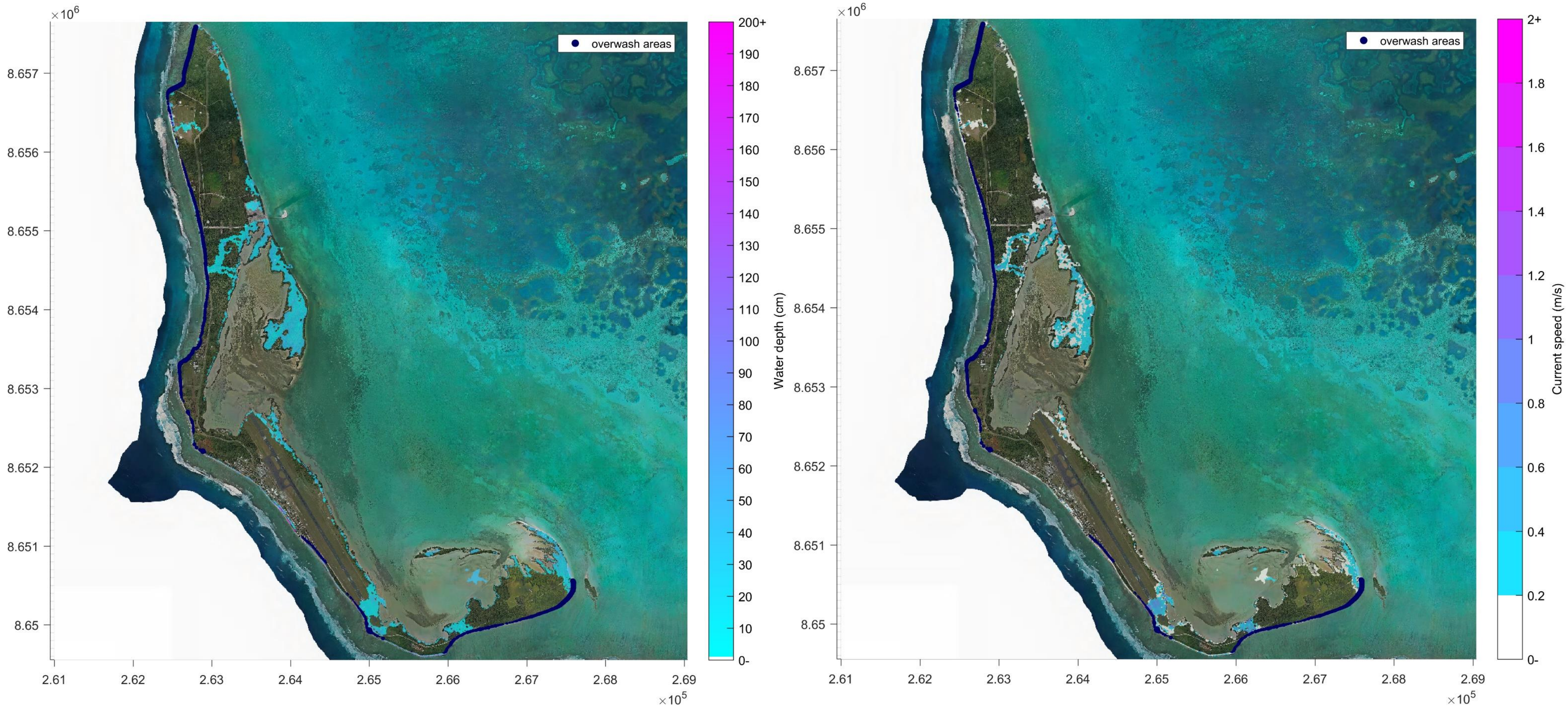


Figure 145: Map of maximum inundation depth (left) and maximum current speed (right) for inundated areas on West Island during the 500-year (year 2018) still water level plus wave overtopping and indicative overwash (dark blue circles) scenario.

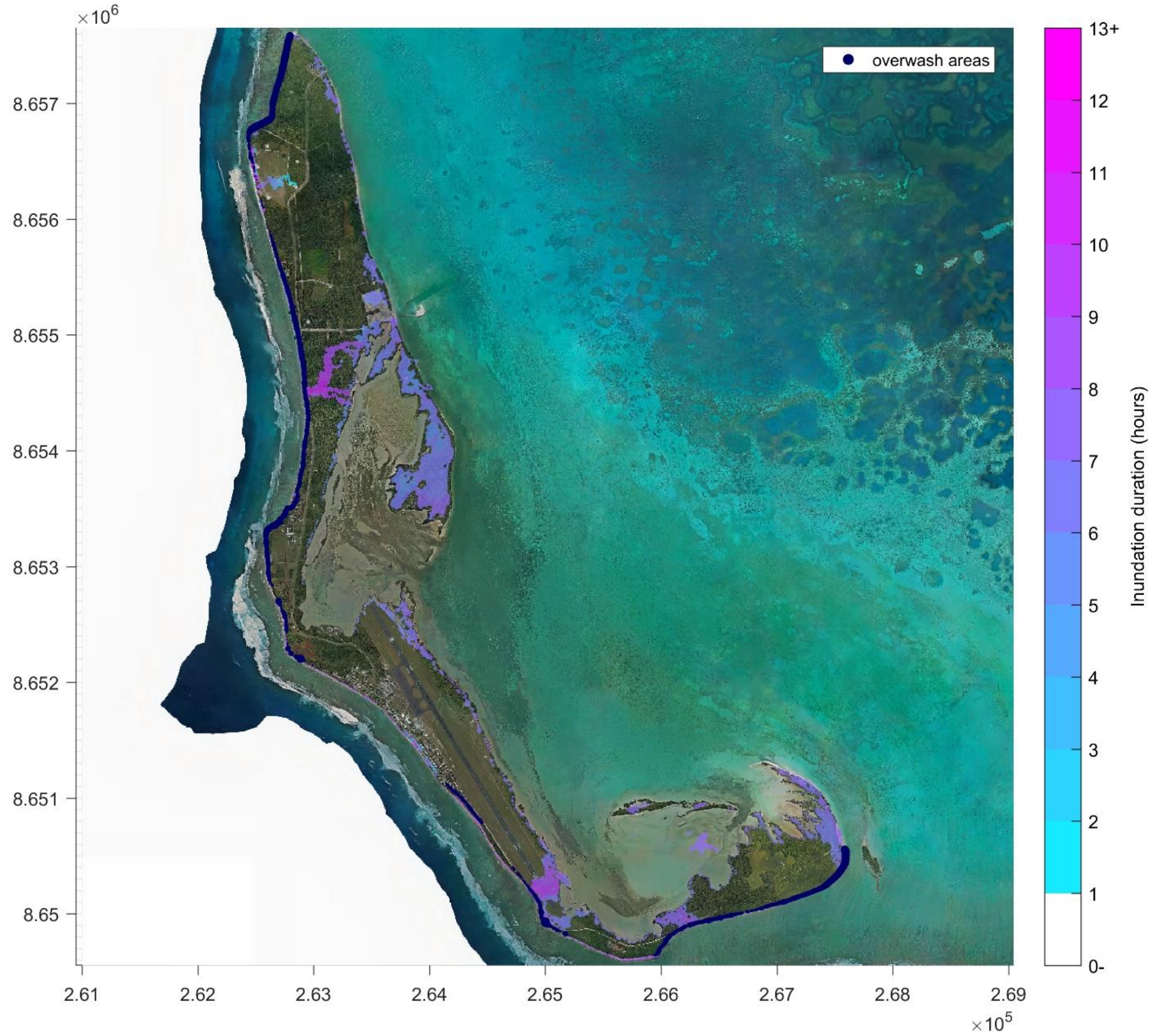


Figure 146: Map showing inundation durations on West Island during the 13hour simulation period for the 500-year (year 2018) still water level plus wave overtopping and indicative overwash (dark blue circles) scenario.

500-year ARI + 0.4m sea level rise (2068)

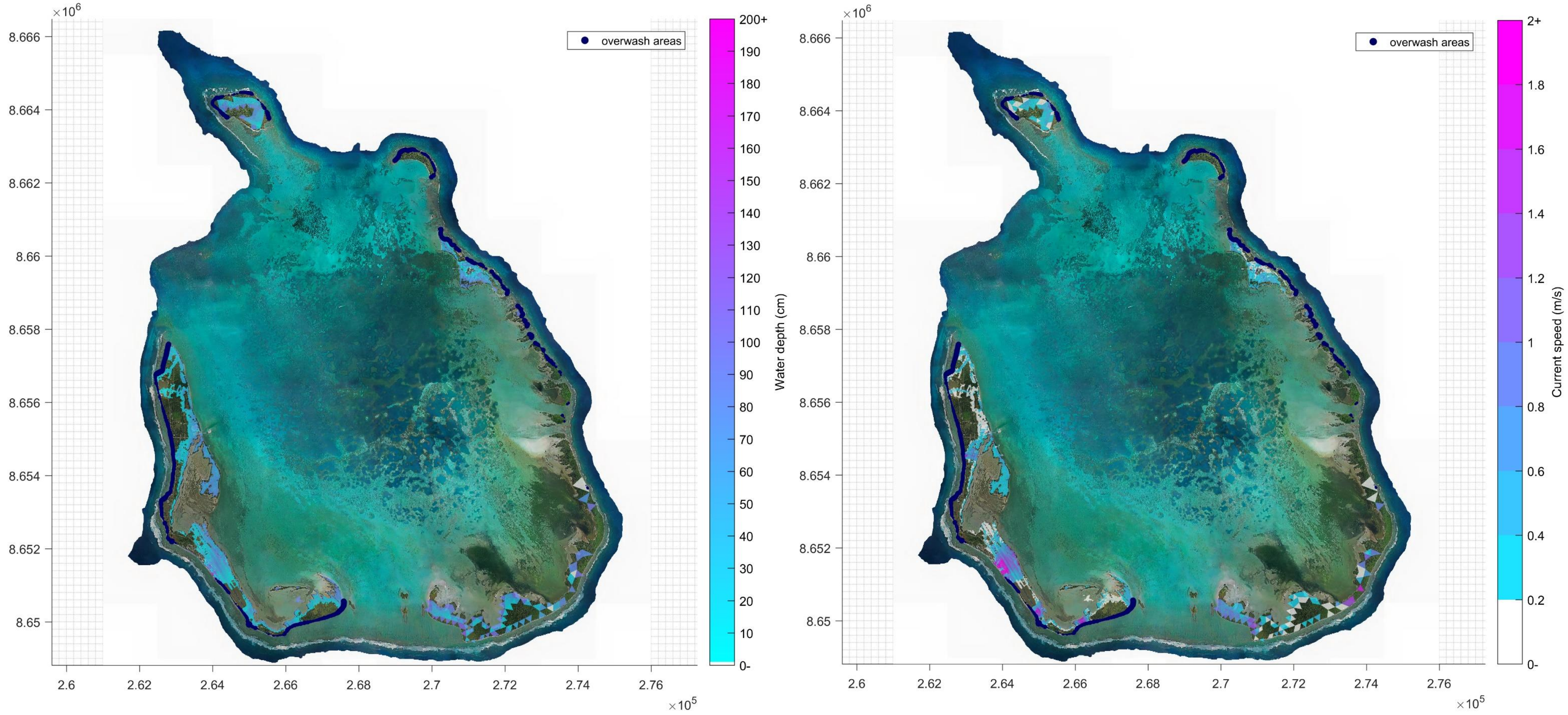


Figure 147: Map of maximum inundation depth (left) and maximum current speed (right) for the entire southern atoll during the 500-year + 0.4m sea level rise (year 2068) still water level plus wave overtopping and indicative overwash (dark blue circles) scenario.

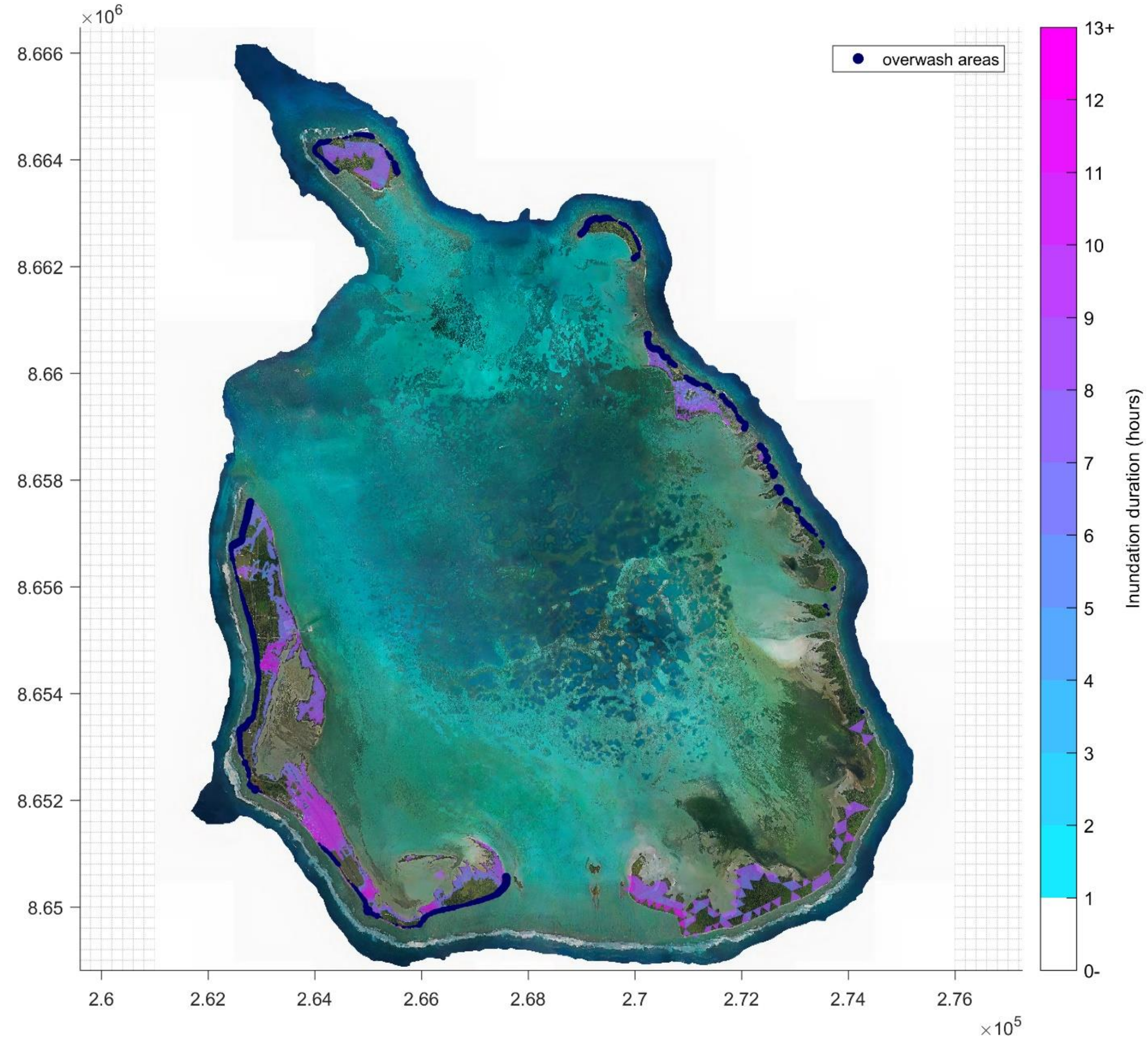


Figure 148: Map showing inundation durations for the entire southern atoll during the 13-hour simulation period for the 500-year + 0.4m sea level rise (year 2068) still water level plus wave overtopping and indicative overwash (dark blue circles) scenario.

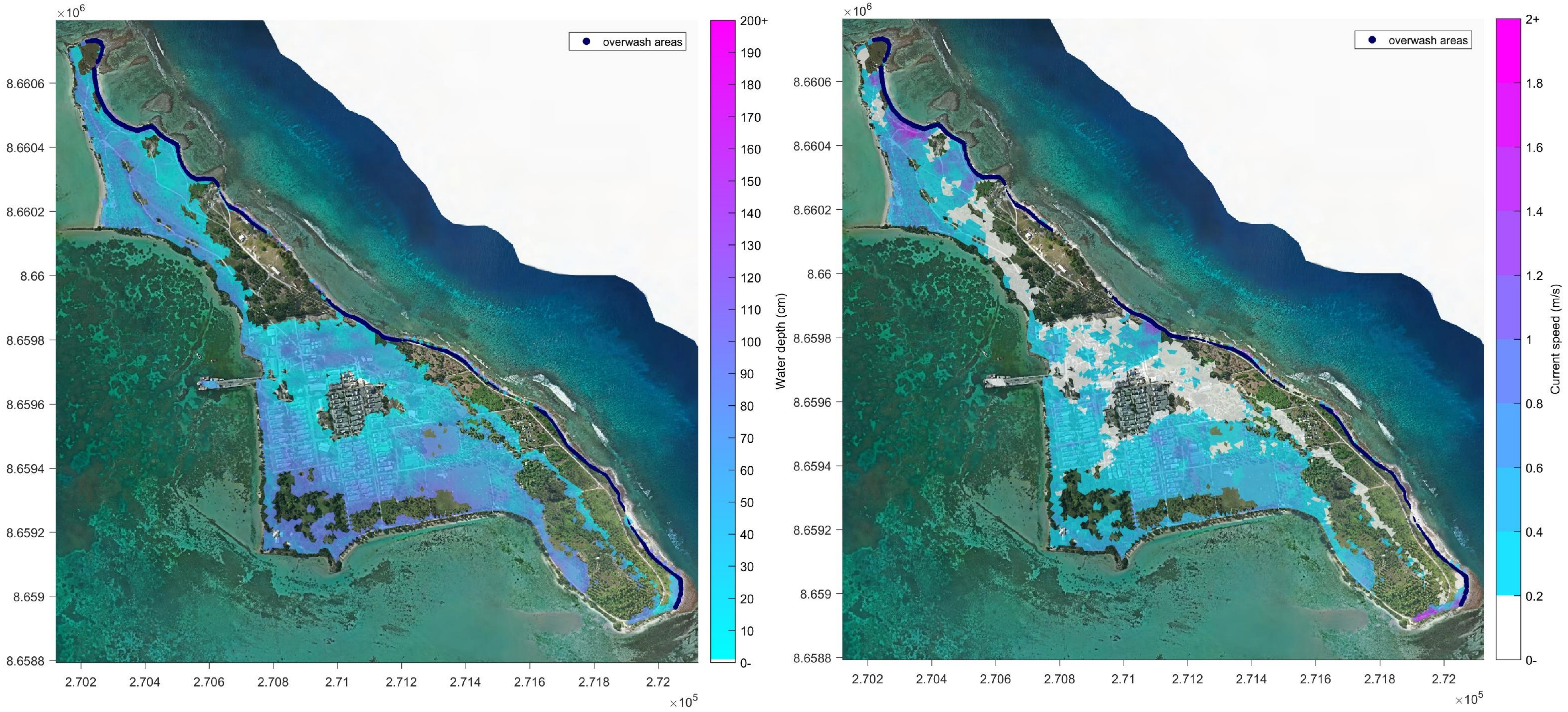


Figure 149: Map of maximum inundation depth (left) and maximum current speed (right) for inundated areas on Home Island during the 500-year + 0.4m sea level rise (year 2068) still water level plus wave overtopping and indicative overwash (dark blue circles) scenario.

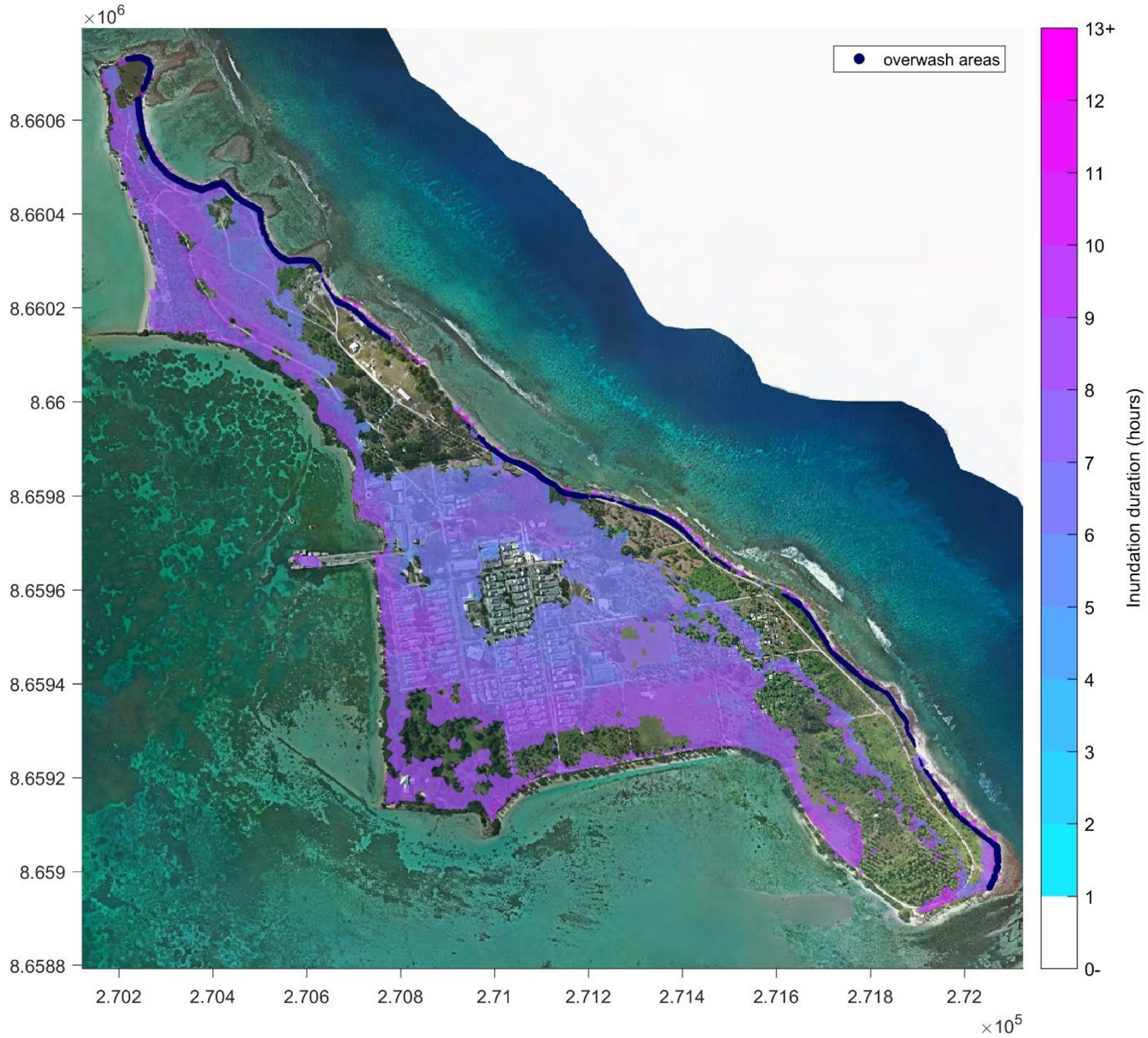


Figure 150: Map showing inundation durations on Home Island during the 13-hour simulation period for the 500-year + 0.4m sea level rise (year 2068) still water level plus wave overtopping and indicative overwash (dark blue circles) scenario.

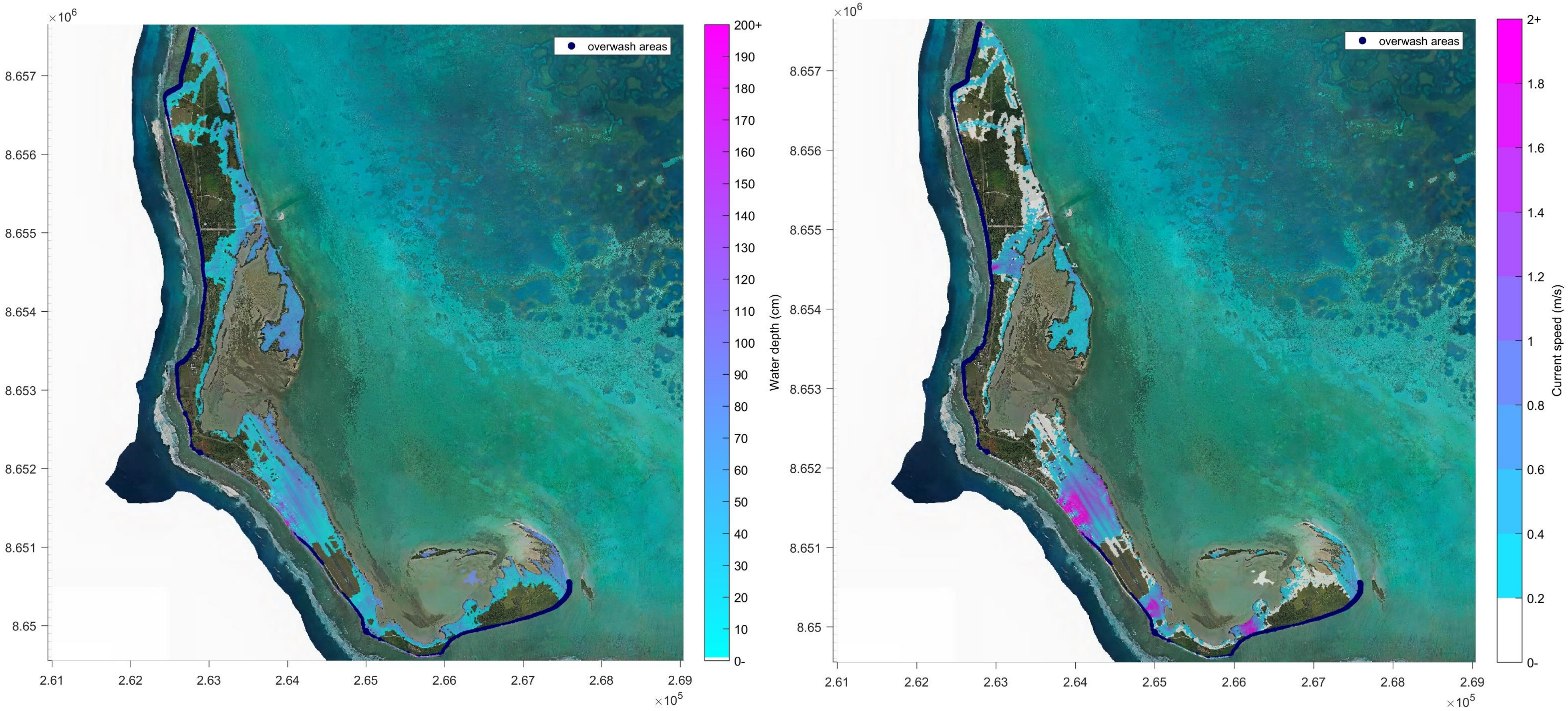


Figure 151: Map of maximum inundation depth (left) and maximum current speed (right) for inundated areas on West Island during the 500-year + 0.4m sea level rise (year 2068) still water level plus wave overtopping and indicative overwash (dark blue circles) scenario.

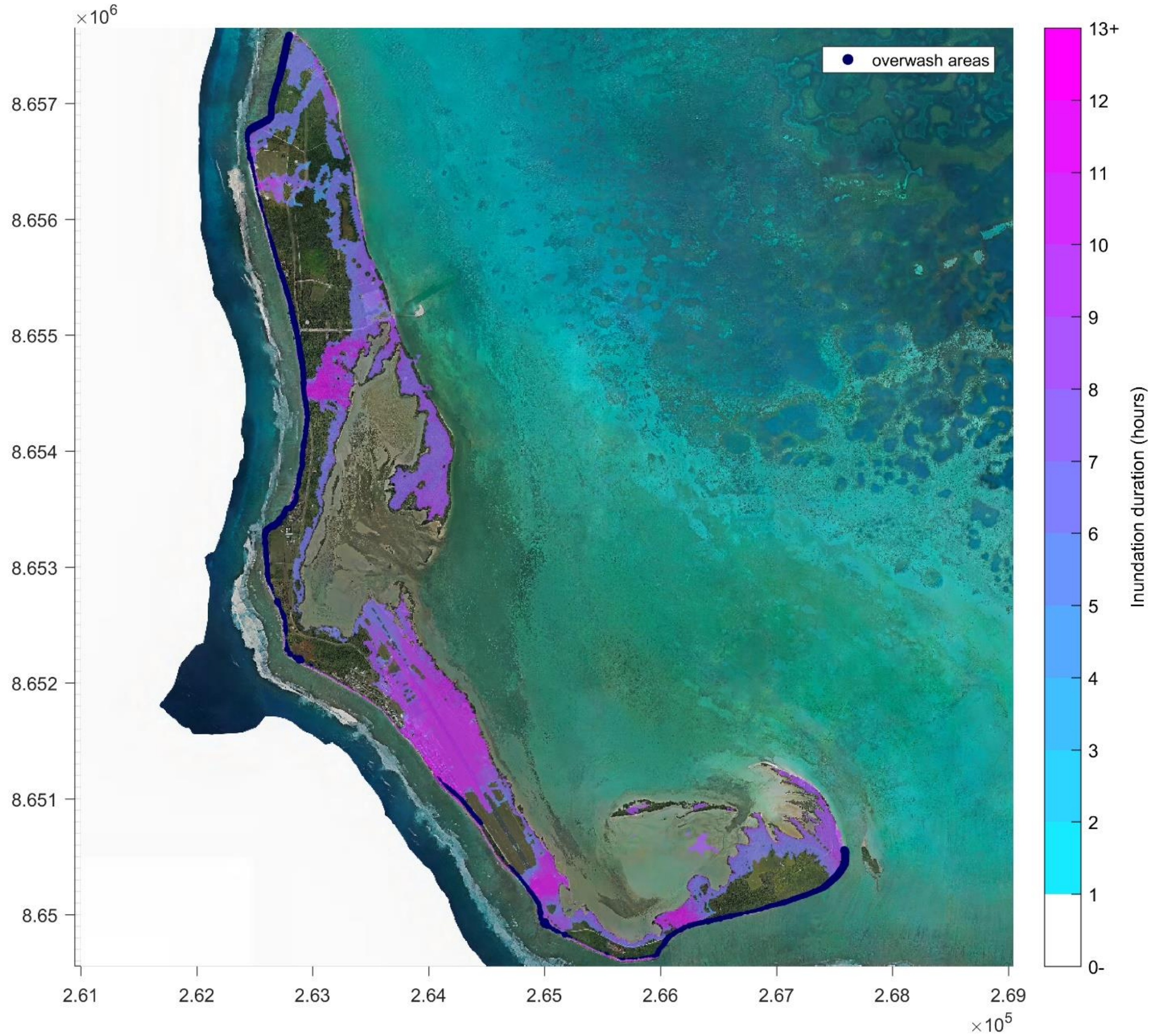


Figure 152: Map showing inundation durations on West Island during the 13hour simulation period for the 500-year + 0.4m sea level rise (year 2068) still water level plus wave overtopping and indicative overwash (dark blue circles) scenario.

500-year ARI + 0.9m sea level rise (2118)

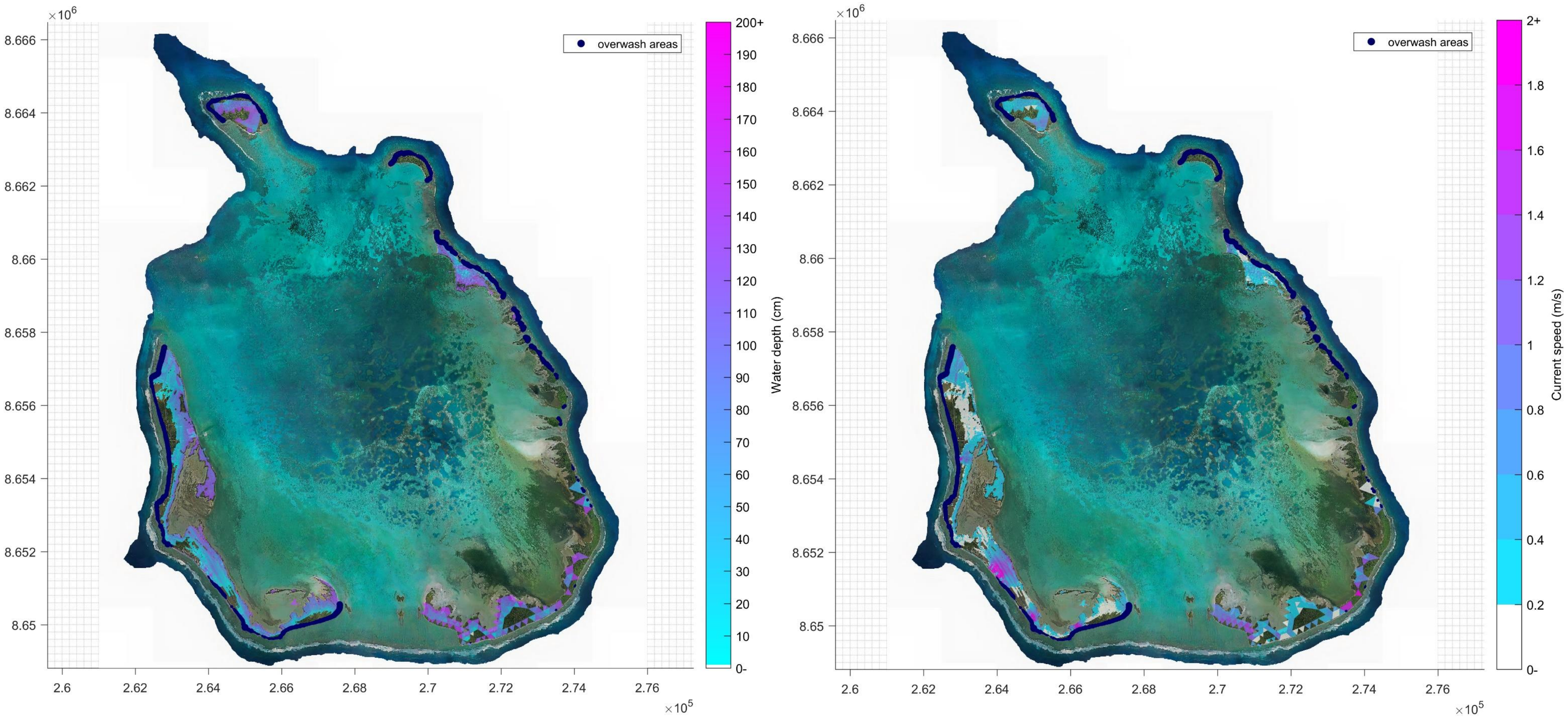


Figure 153: Map of maximum inundation depth (left) and maximum current speed (right) for the entire southern atoll during the 500-year + 0.9m sea level rise (year 2118) still water level plus wave overtopping and indicative overwash (dark blue circles) scenario.

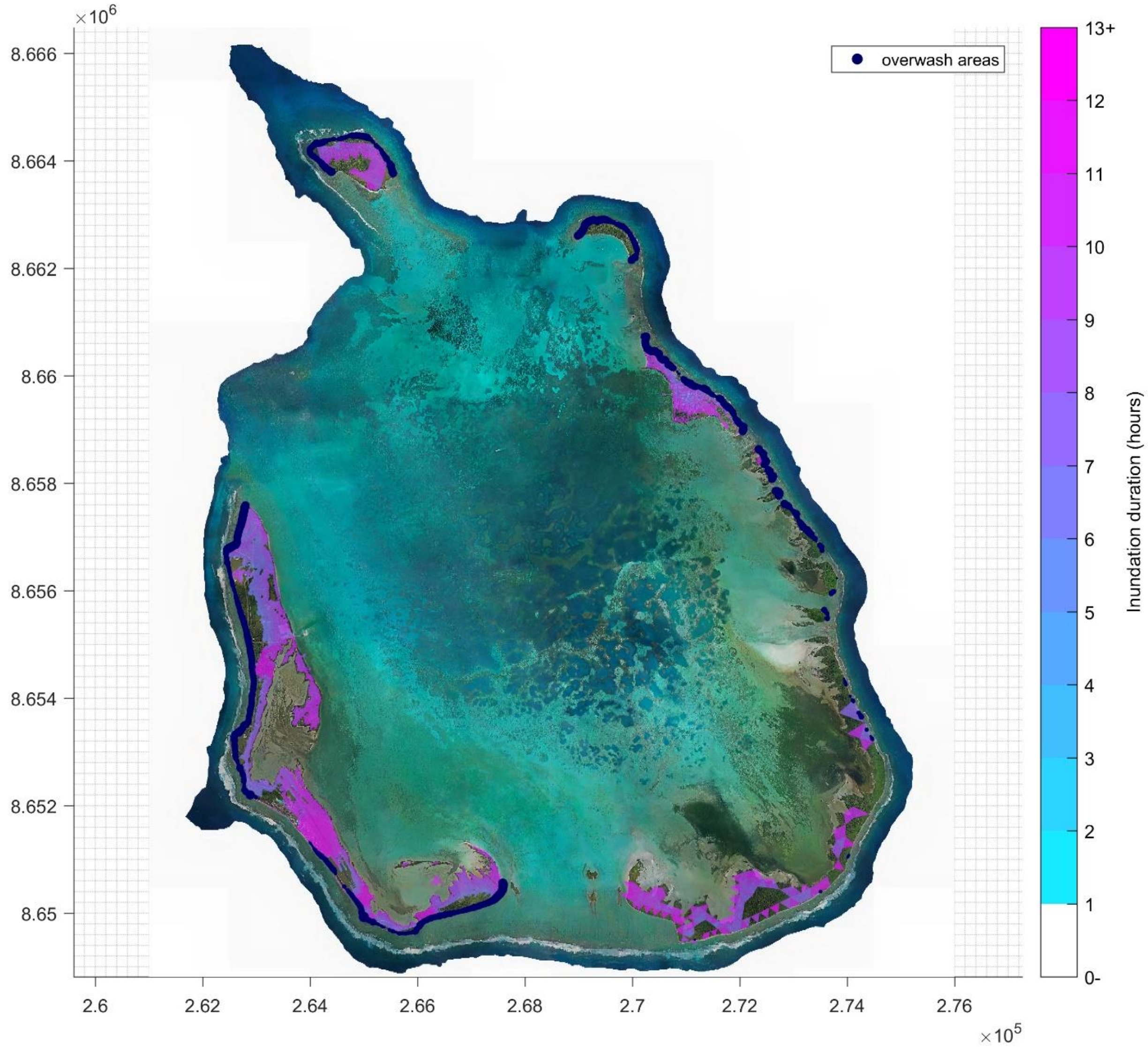


Figure 154: Map showing inundation durations for the entire southern atoll during the 13-hour simulation period for the 500-year + 0.9m sea level rise (year 2118) still water level plus wave overtopping and indicative overwash (dark blue circles) scenario.

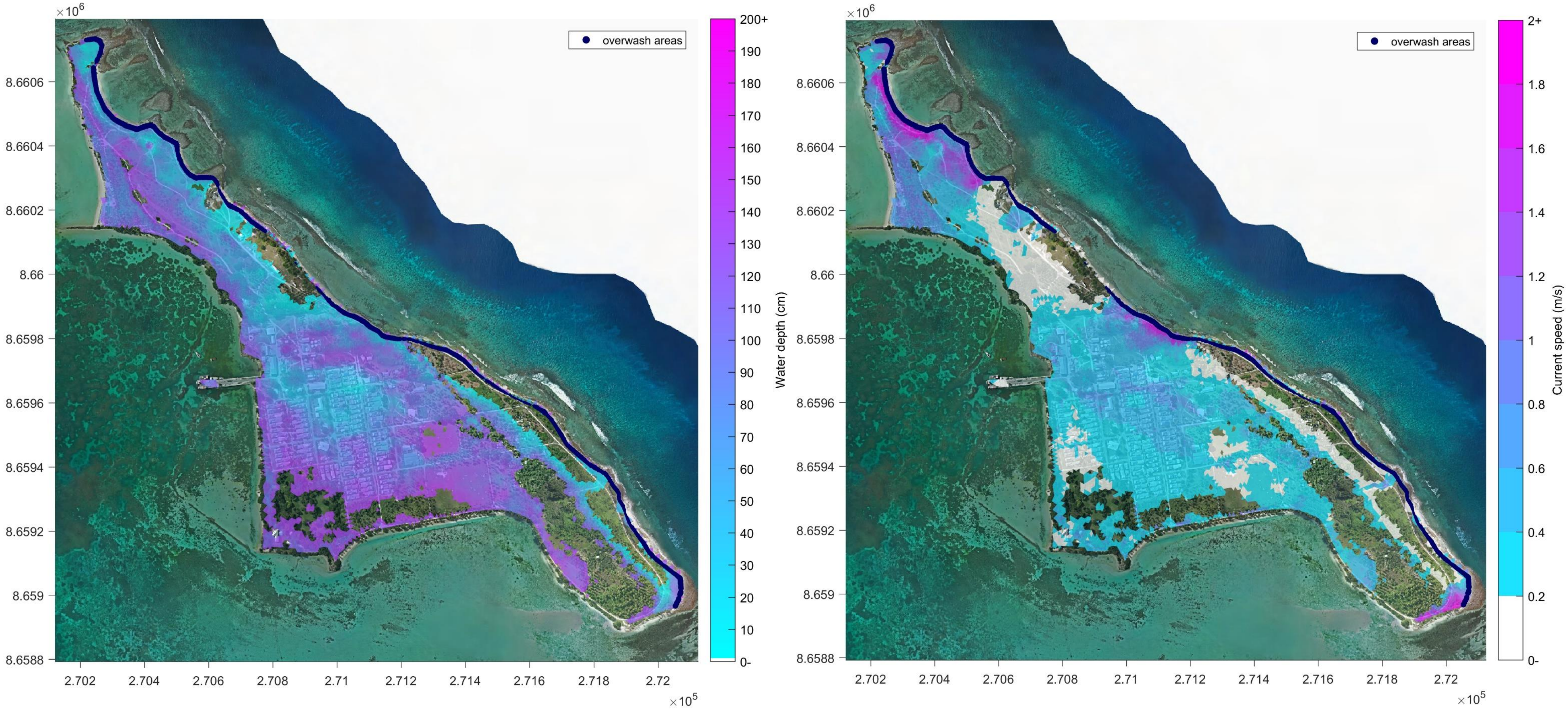


Figure 155: Map of maximum inundation depth (left) and maximum current speed (right) for inundated areas on Home Island during the *500-year + 0.9m sea level rise (year 2118) still water level plus wave overtopping and indicative overwash (dark blue circles)* *scenario.*

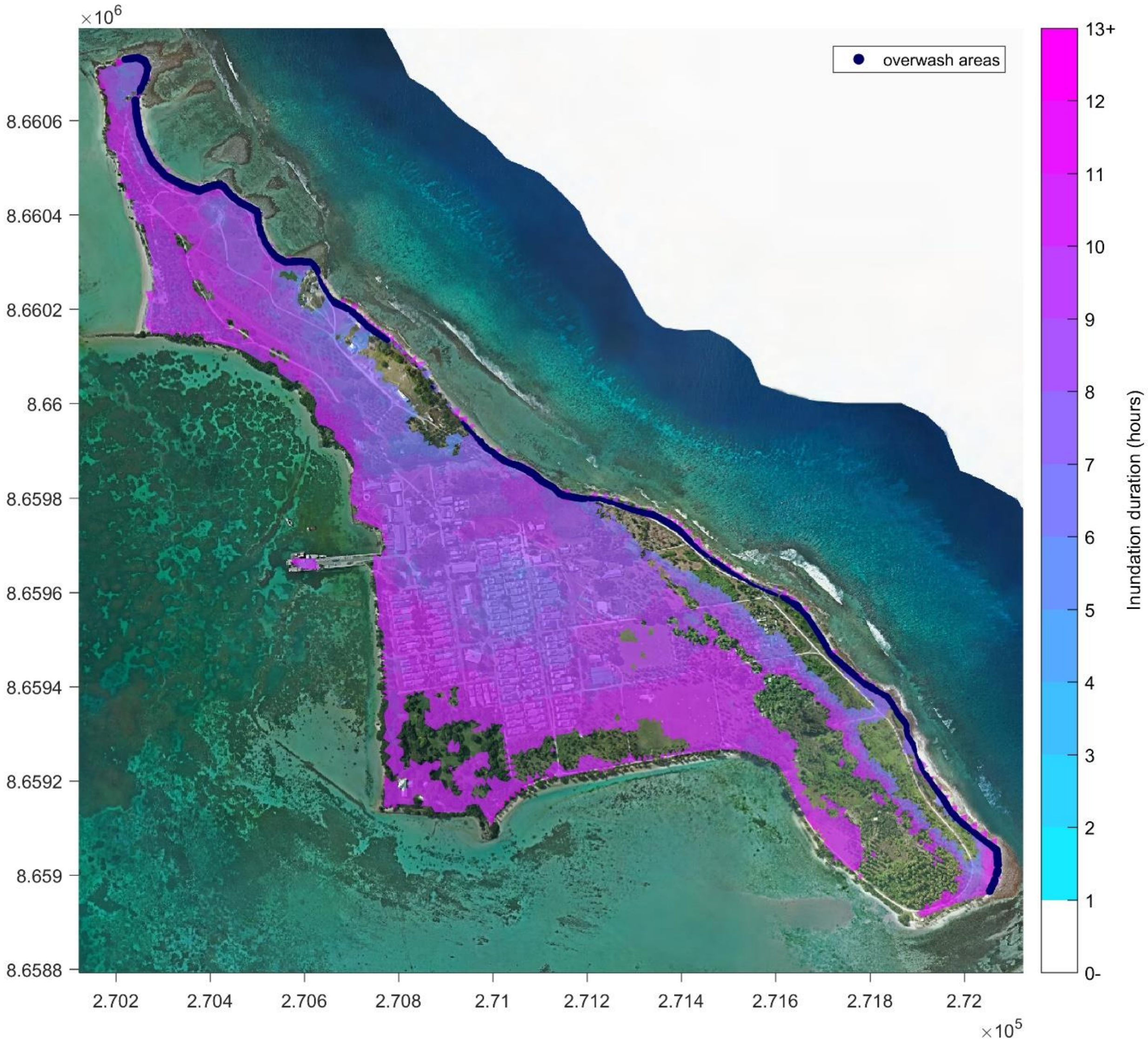


Figure 156: Map showing inundation durations on Home Island during the 13-hour simulation period for the 500-year + 0.9m sea level rise (year 2118) still water level plus wave overtopping and indicative overwash (dark blue circles) scenario.

Royal HaskoningDHV

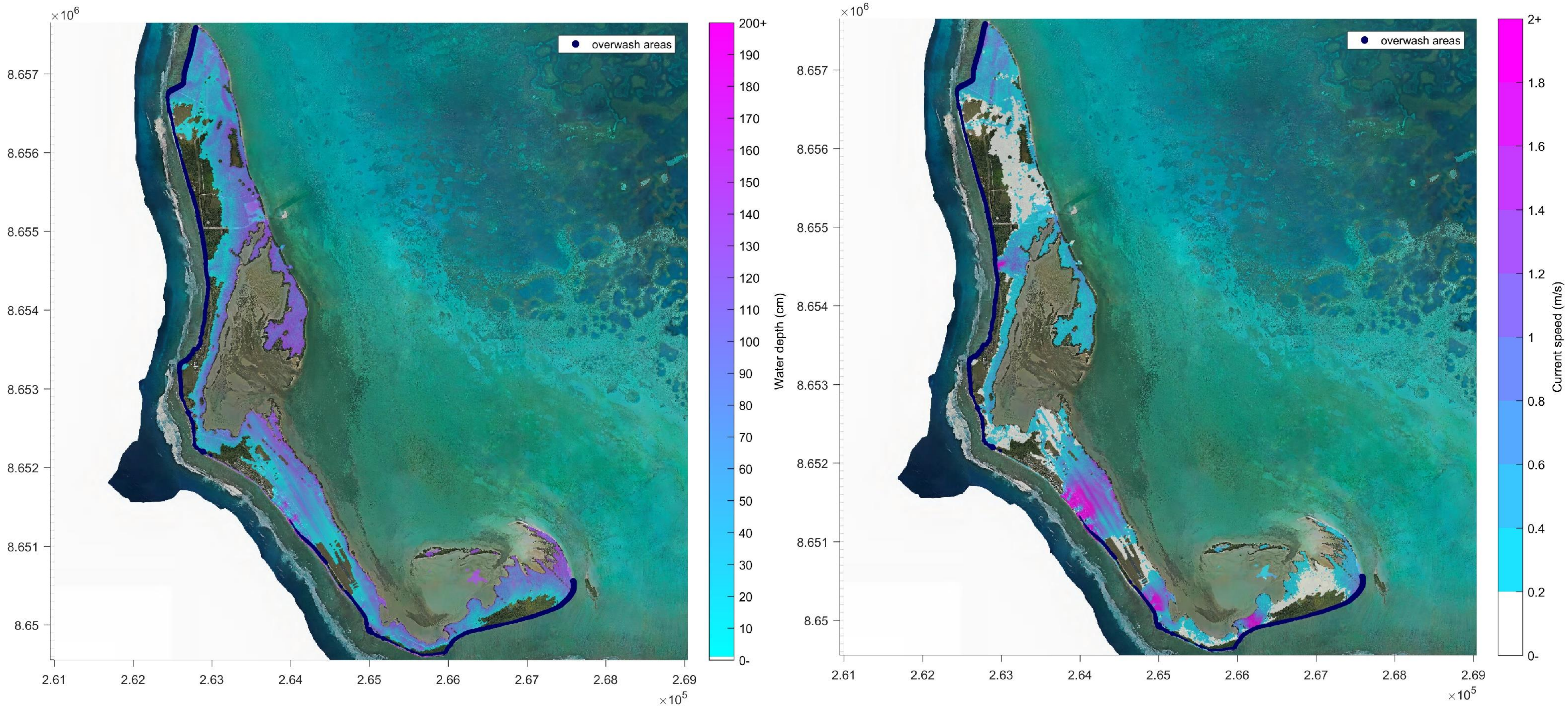


Figure 157: Map of maximum inundation depth (left) and maximum current speed (right) for inundated areas on West Island during the 500-year + 0.9m sea level rise (year 2118) still water level plus wave overtopping and indicative overwash (dark blue circles) scenario.

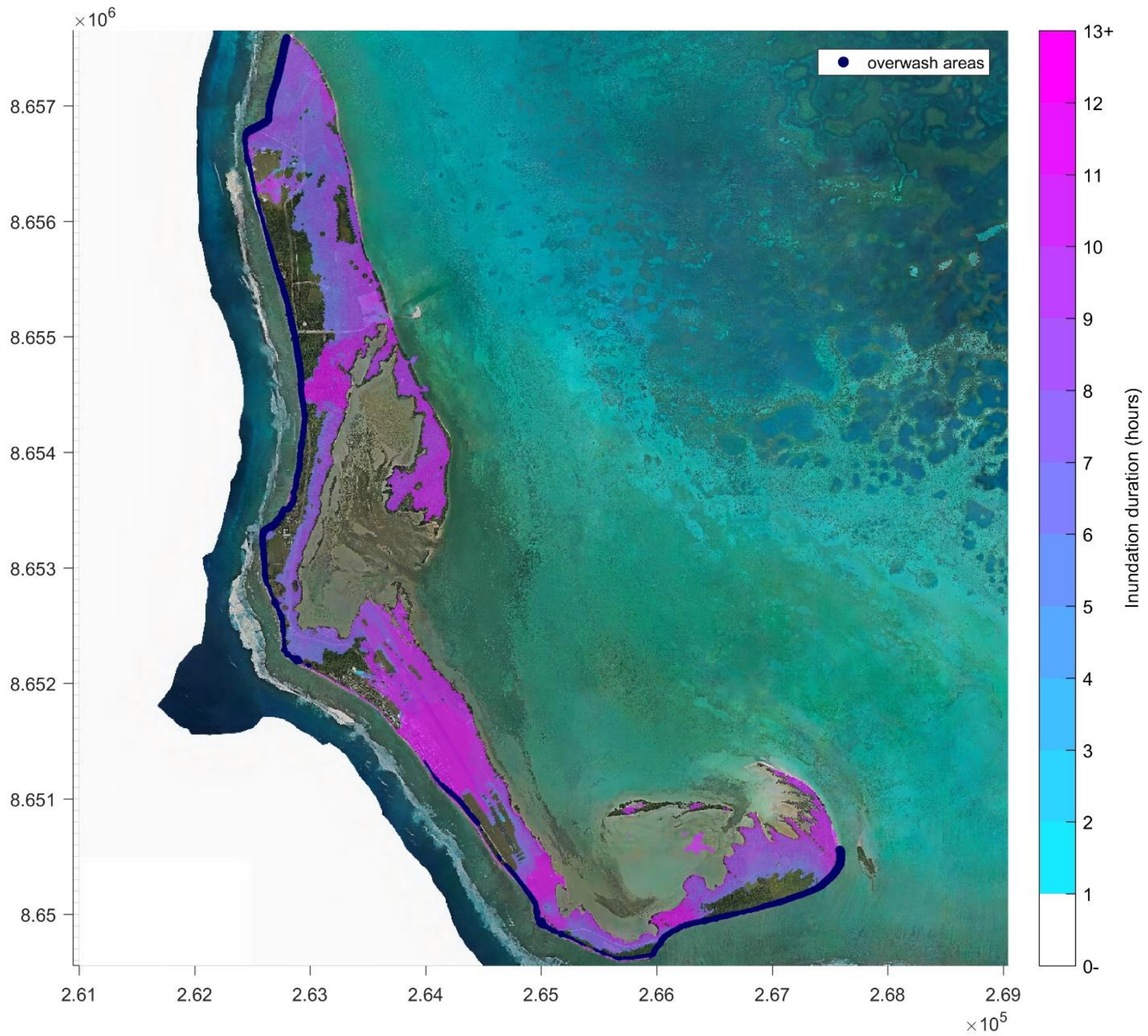


Figure 158: Map showing inundation durations on West Island during the 13hour simulation period for the 500-year + 0.9m sea level rise (year 2118) still water level plus wave overtopping and indicative overwash (dark blue circles) scenario.

Appendix C – Historical Shoreline Change

Available shoreline Data

The available aerial photography data for use in analysing changes to the shoreline over time is summarised below in Table 50.

Table 50: Overview of aerial imagery for Cocos (Keeling) Islands.

Year	Source	Description	Coverage
1987	AECOM	Vegetation lines provided by AECOM from previous studies. The 2011 data was believed to be inaccurate.	West Island Home Island
June and July 2006	Google Earth	Google Earth geo-rectified images were used to digitise the vegetation line.	West Island Home Island
June and July 2012			West Island Home Island
April 2016			West Island Home Island
October 2018	Drone Aerials**	Images from drone surveys were used to digitise the vegetation line. Image resolution was of ~2cm/pixel.	West Island Settlement
February 2019			Old Fuel Jetty Rumah Baru

** Additional drone imagery and survey was collected by the project team to inform the study and for the benefit of the study but was not a scoped item. An initial trial drone survey was part of the scope and the data has been provided for that survey but the data from the additional drone exercises will be retained by the project team.

West Island

Using vegetation lines provided from previous studies and new data digitised as part of the CVA, the relative vegetation line changes at selected locations on West Island were determined. Representative analysis zones were selected to ensure coverage of key areas and location of coastal structures across the Island. **Figure 159** shows each of these selected analysis locations in the context of the distinct management units previously outlined. Visual and numerical analysis of the results was completed to ensure observed historical trends were representative and aligned to the key morphological features of each management unit.

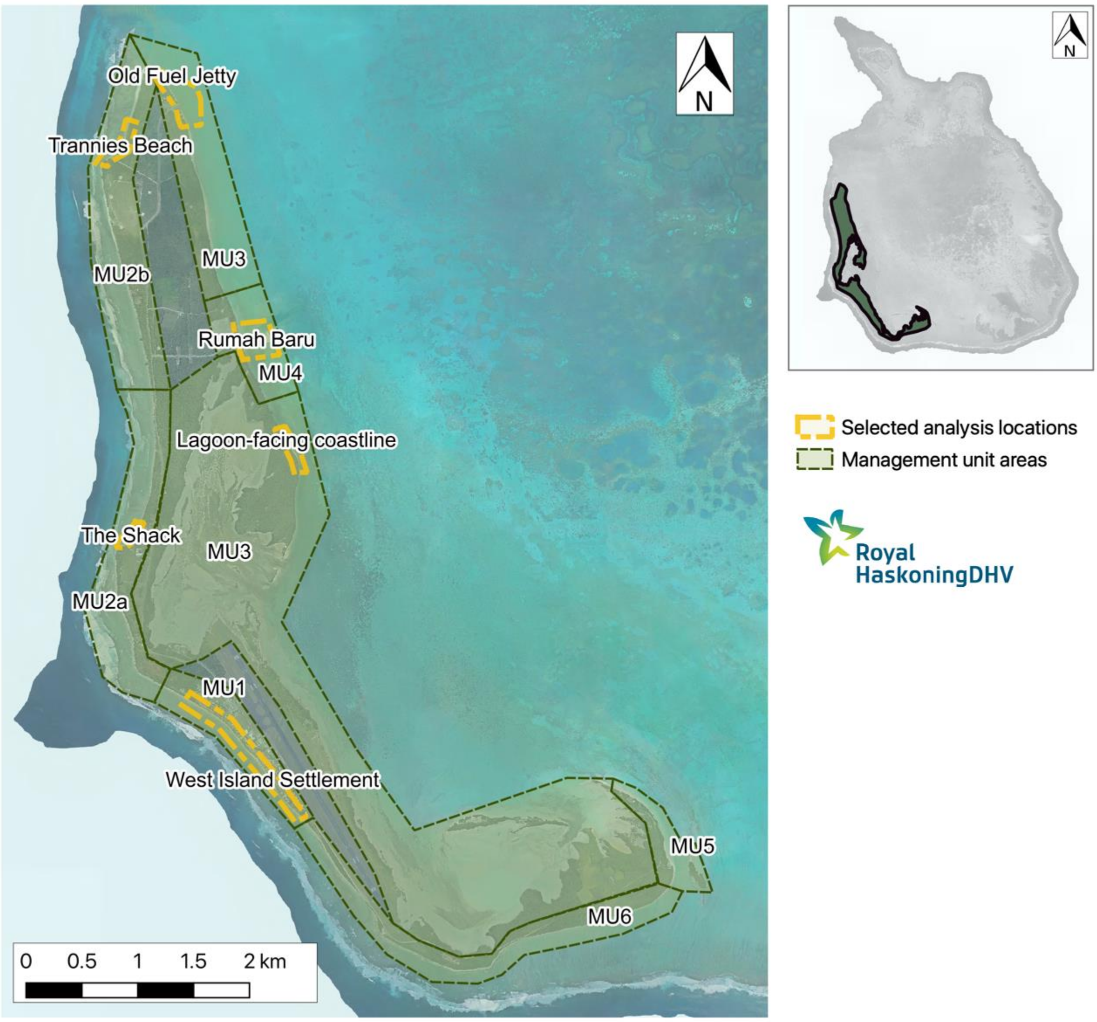
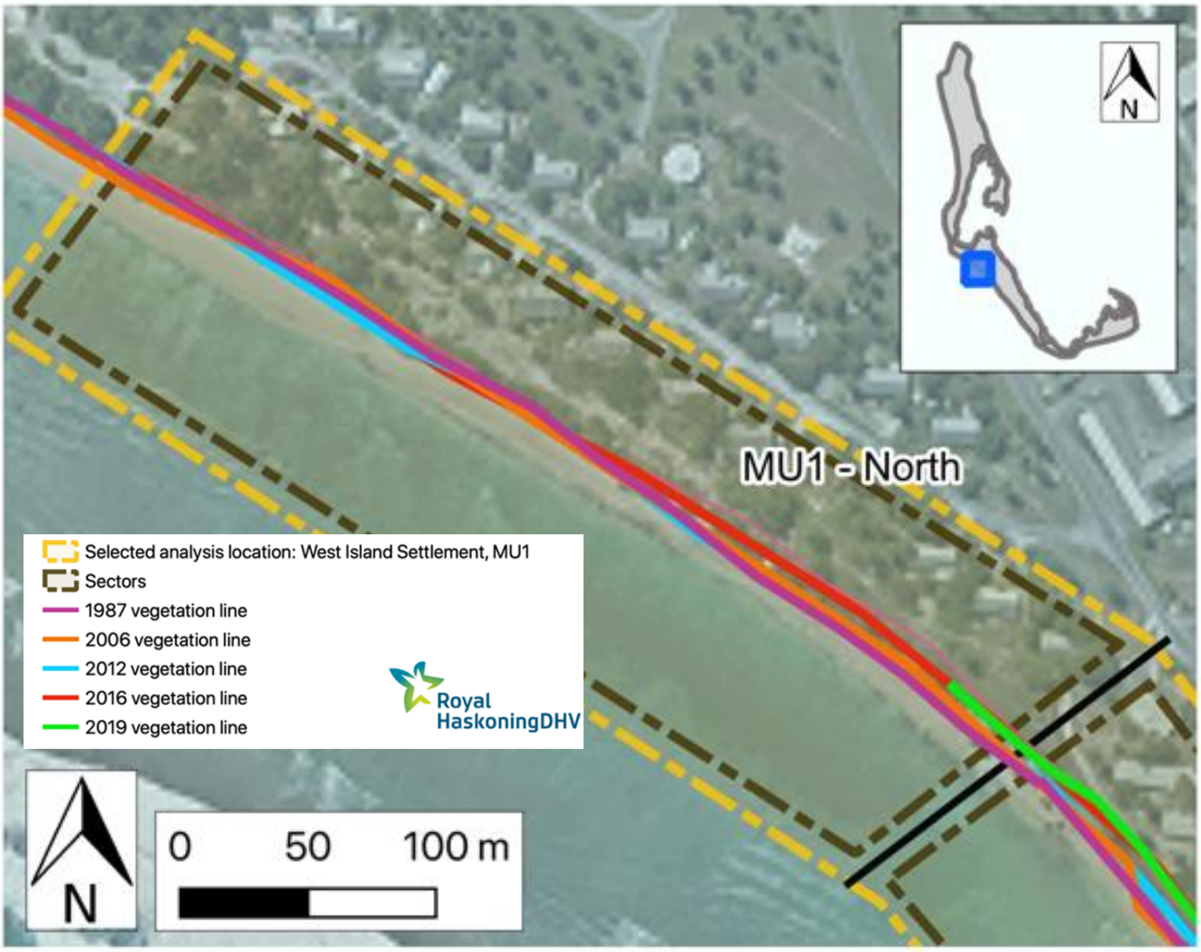


Figure 159: Selected locations for analysis of historical vegetation lines on West Island.

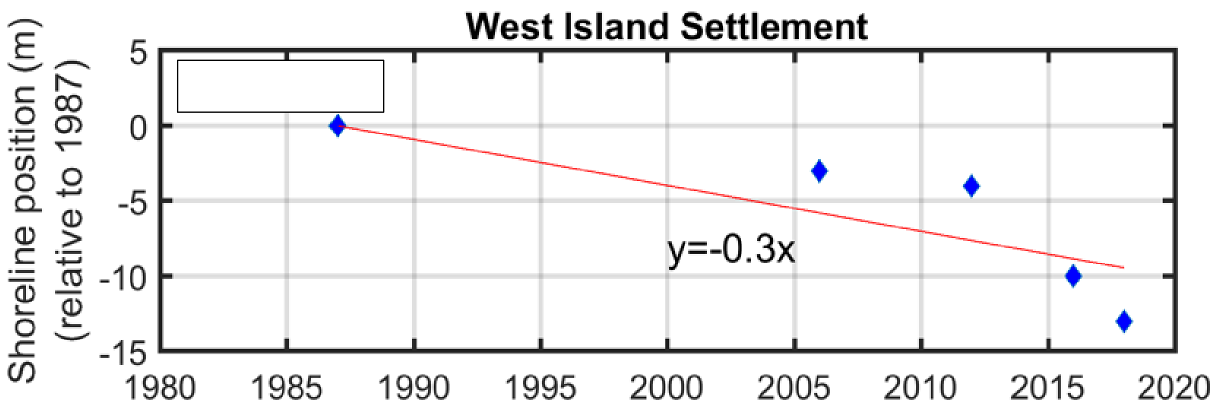
Management Unit 1

The selected analysis area within MU1 comprised the 1.6-kilometre long shoreline adjacent to the West Island settlement. This area consists predominantly of a sandy beach with various coastal protection structures distributed along its length. To clearly distinguish between spatially varying trends, the management unit was divided into three sectors, MU1-North, MU1-Middle and MU1-South (see **Figure 160**).

MU1-North is a 550-metre long section of the shoreline backed by the West Island Settlement where 90 residential lots as well as commercial and industrial assets are located. There are also four low-crested concrete groynes located along the shoreline. The top panel of **Figure 160** shows that since 1987, the vegetation line has been continuously retreating with the rate of retreat increasing since 2012. MU1-Middle is a 700-metre long sector of the shoreline which is protected by the Medical Centre GSC Revetment (constructed in 2014) and the William Keeling GSC Revetment (constructed in 2017). **Figure 160** shows that the recession rate in this sector is lower than in MU1-North. The recent increase in shoreline position within this sector between 2015 and 2019 is explained by a 15-metre shoreline fill that was placed in 2017. MU1-South is a 400-metre long sector of the shoreline toward the southern end of the West Island Settlement. The Government House Seawall as well as a slab seawall are coastal protection structures in this sector. The vegetation line in this sector is observed to be the most stable in MU1.

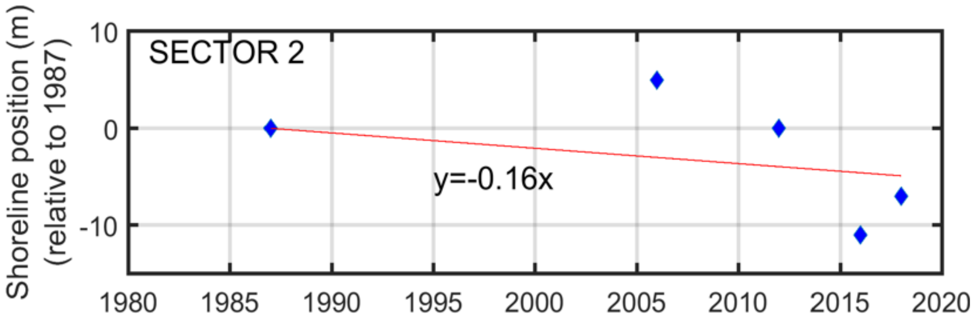


MU1 - North
Selected analysis location: West Island Settlement, MU1
Sectors
1987 vegetation line
2006 vegetation line
2012 vegetation line
2016 vegetation line
2019 vegetation line
Royal HaskoningDHV
N
0
50
100 m
N



West Island Settlement
Shoreline position (m) (relative to 1987)
5
0
-5
-10
-15
1980
1985
1990
1995
2000
2005
2010
2015
2020
y=-0.3x


MU1 - North
MU1 - Middle
N
Selected analysis location: West Island Settlement, MU1
Sectors
1987 vegetation line
2006 vegetation line
2012 vegetation line
2016 vegetation line
2019 vegetation line
Royal HaskoningDHV
N
0 50 100 m


Shoreline position (m) (relative to 1987)
SECTOR 2
y=-0.16x
10
0
-10
1980
1985
1990
1995
2000
2005
2010
2015
2020

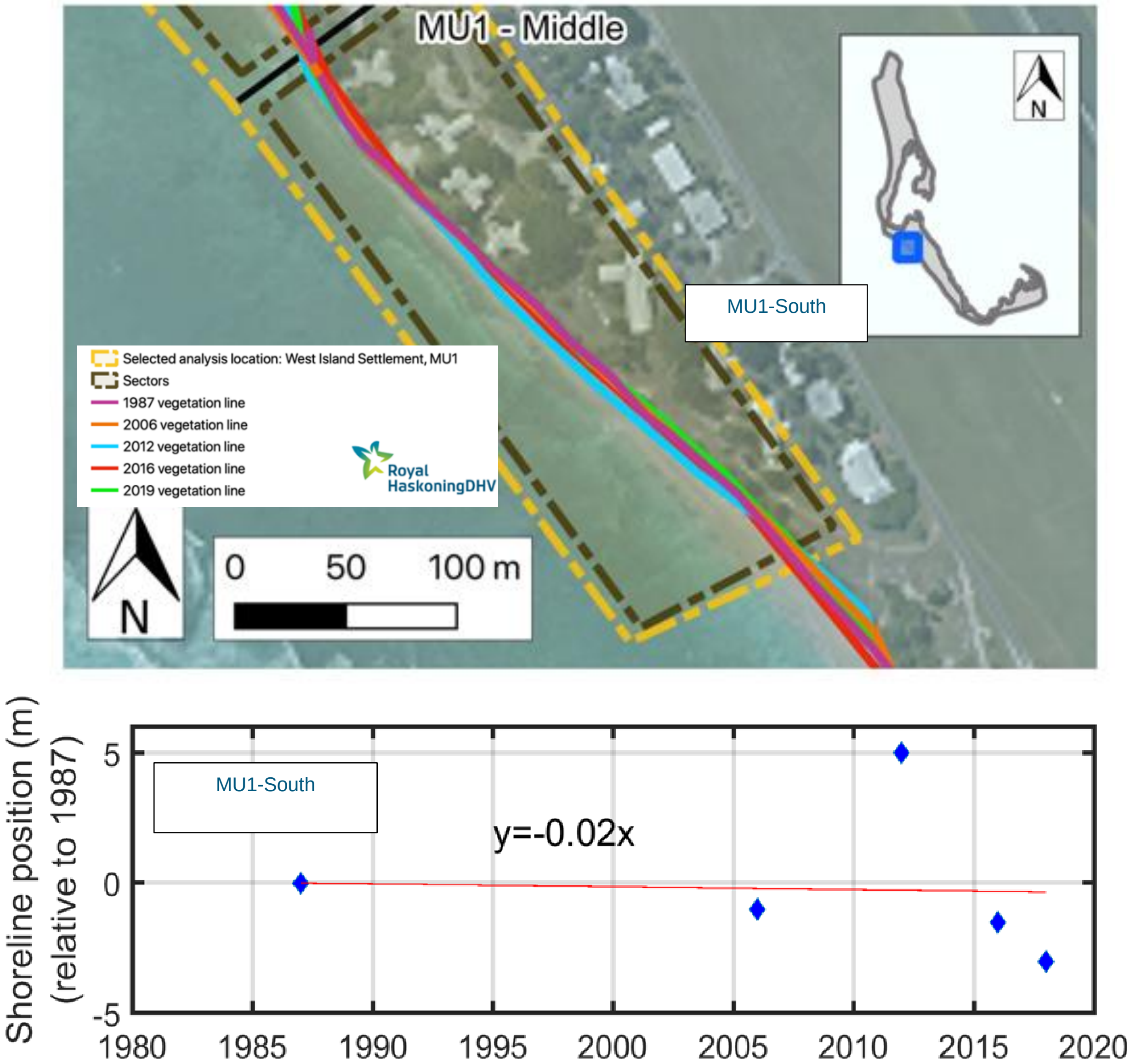


Figure 160: Historical vegetation lines at the West Island Settlement within MU1, split across the three sectors. A time series of vegetation line position and regression analysis for each sector is also shown.

Management Unit 2a

The selected analysis location within MU2a was The Shack. At the site, a coral boulder apron/spit extends into reef to the north and there are no coastal protection structures in place. The vegetation line analysis was carried out directly to north of The Shack, up to where the shoreline re-orients eastward by approximately 70° (**Figure 161**). Analysis of aerial photographs shows that since 1987 the vegetation line has receded at a rate of approximately 2.63 metres per year. A 51-metre recession can be observed from 1987 to 2006 (Figure 161**Figure 161**).

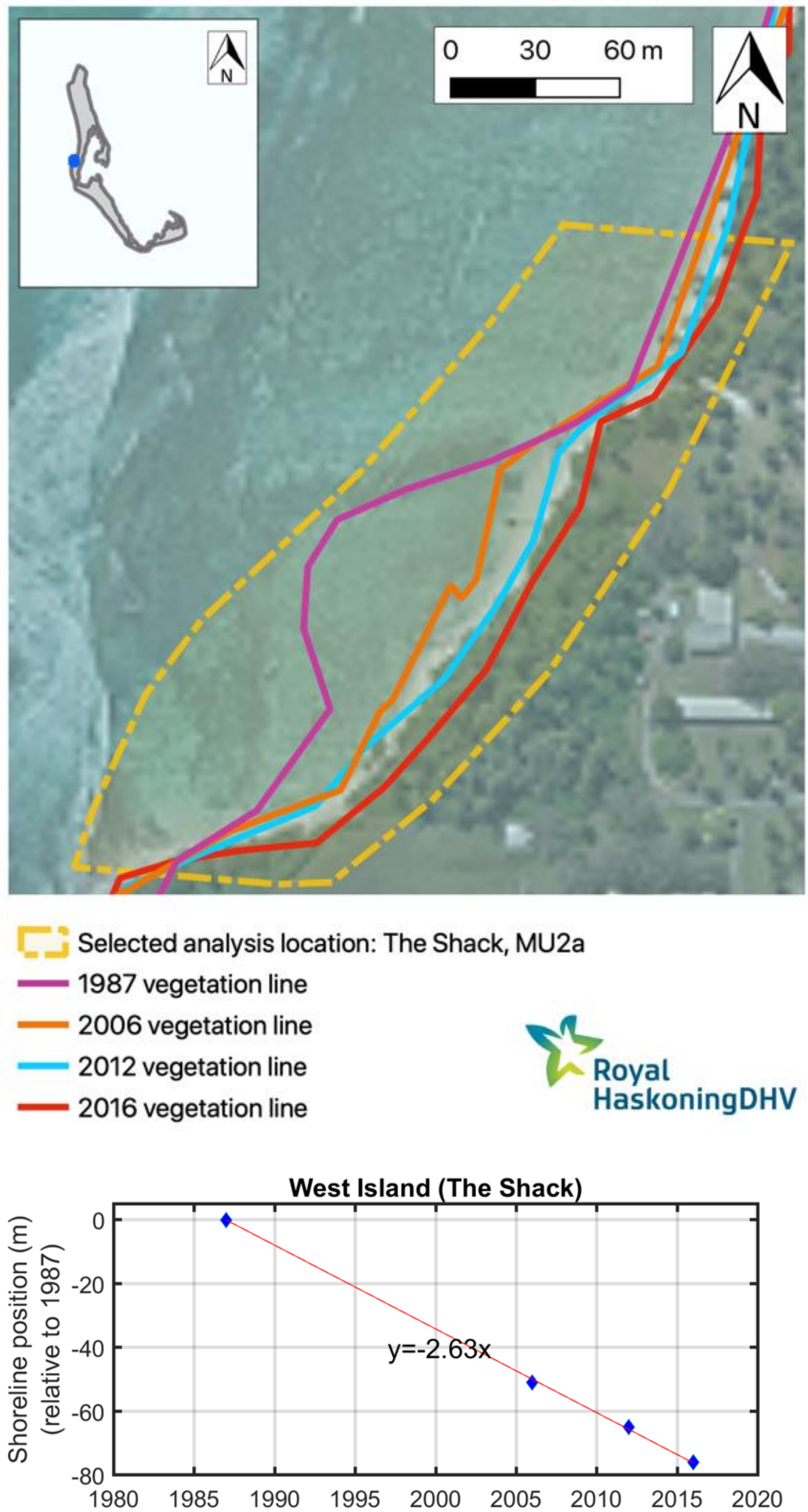


Figure 161: Left: Historical vegetation lines at the 'The Shack' within MU2a. Right: Time series of vegetation line position and regression analysis for the site.

Management Unit 2b

The selected analysis location within MU2b was Trannies Beach. Since different vegetation line evolution patterns were observed, the zone was divided into two sectors, MU2b-North and MU2b-South (see **Figure 162**). MU2b-South is backed by a barbeque and picnic area and, a GSC revetment was constructed several years ago at this location. **Figure 162** shows that from 1987 to 2006 the vegetation line has receded but following construction of the revetment the vegetation line has remained stable. In MU2b-North, the vegetation line eroded significantly (-15 metres) between 1987 and 2006. However, since 2006, the vegetation line has advanced by 30 metres (1.2 metres/year). This is also assumed to be the result of the revetment.

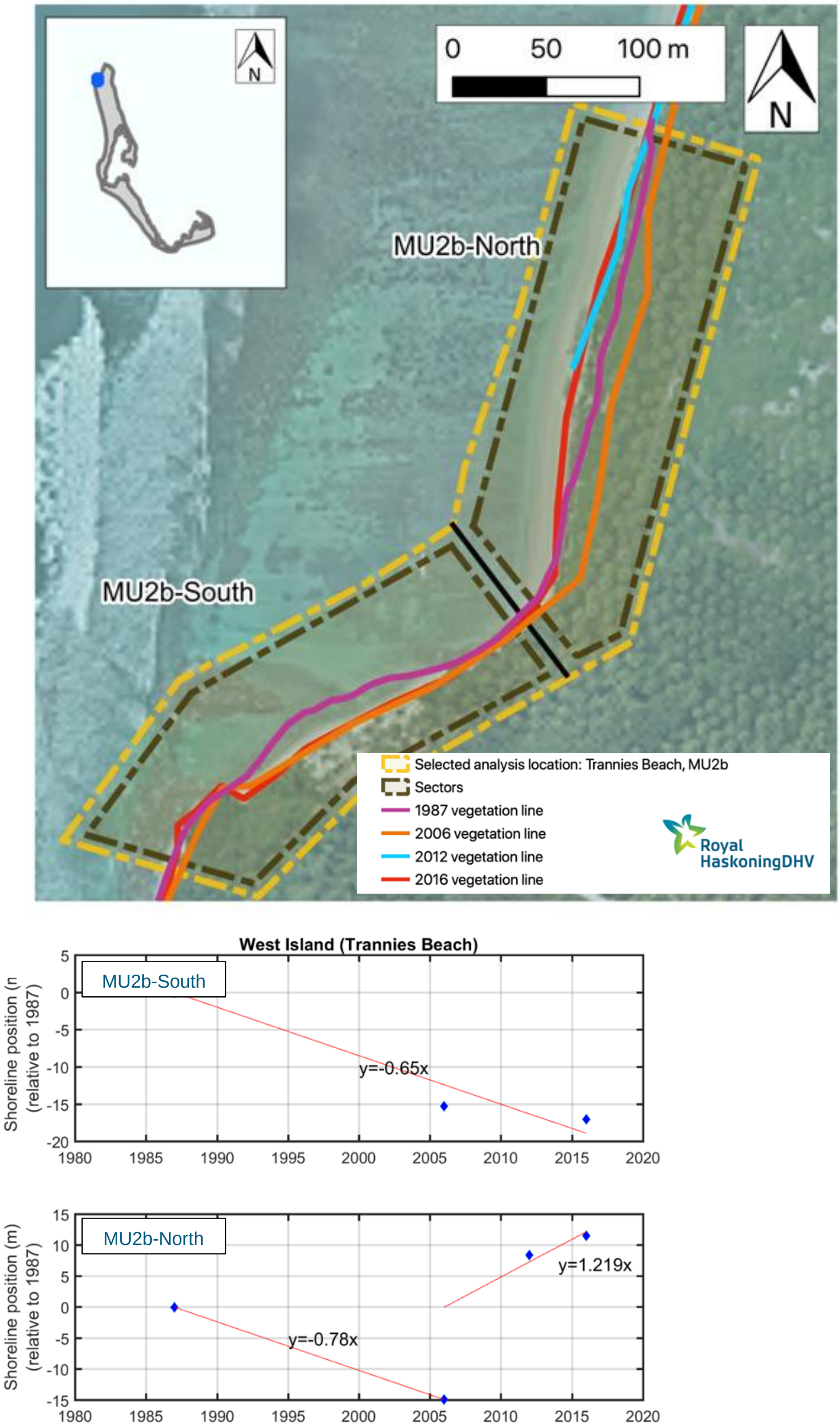


Figure 162: (Top) Historical vegetation lines at the Trannies Beach within MU2b. (Bottom) Time series of vegetation line position and regression analysis for each sector.

Management Unit 3

The first selected analysis location within MU3 was the Old Fuel Jetty. To assess the impact of the jetty structure, the area was divided into two sectors, MU3-North and MU3-South. The vegetation line evolution was observed to be similar in both sectors. The Site Visit report (DoT, 2019) suggests that the whole area is highly dynamic and subject to large variations in the position of the vegetation line. Indeed, aerial photographs indicate that from 1987 to 2006 the vegetation line retreated 73 and 66 metres in MU3-North and MU3-South respectively (see **Figure 163**). The vegetation line recession rate during this period was approximately 3 metres/year. Whilst still receding, the recession rate from 2006 to 2019 reduced to 2.3 metres/year and 1 metres/year, in MU3-North and MU3-South, respectively.

The second analysis location within MU3 was the 500-metre long lagoon-facing beach south of Rumah Baru. This area was selected as it was considered representative of the West Island lagoon-facing shoreline. **Figure 164** shows that there are no significant differences in the vegetation line position since 1987. This trend was observed along the majority of the lagoon-facing vegetation line. As such, no regression analysis has been conducted.

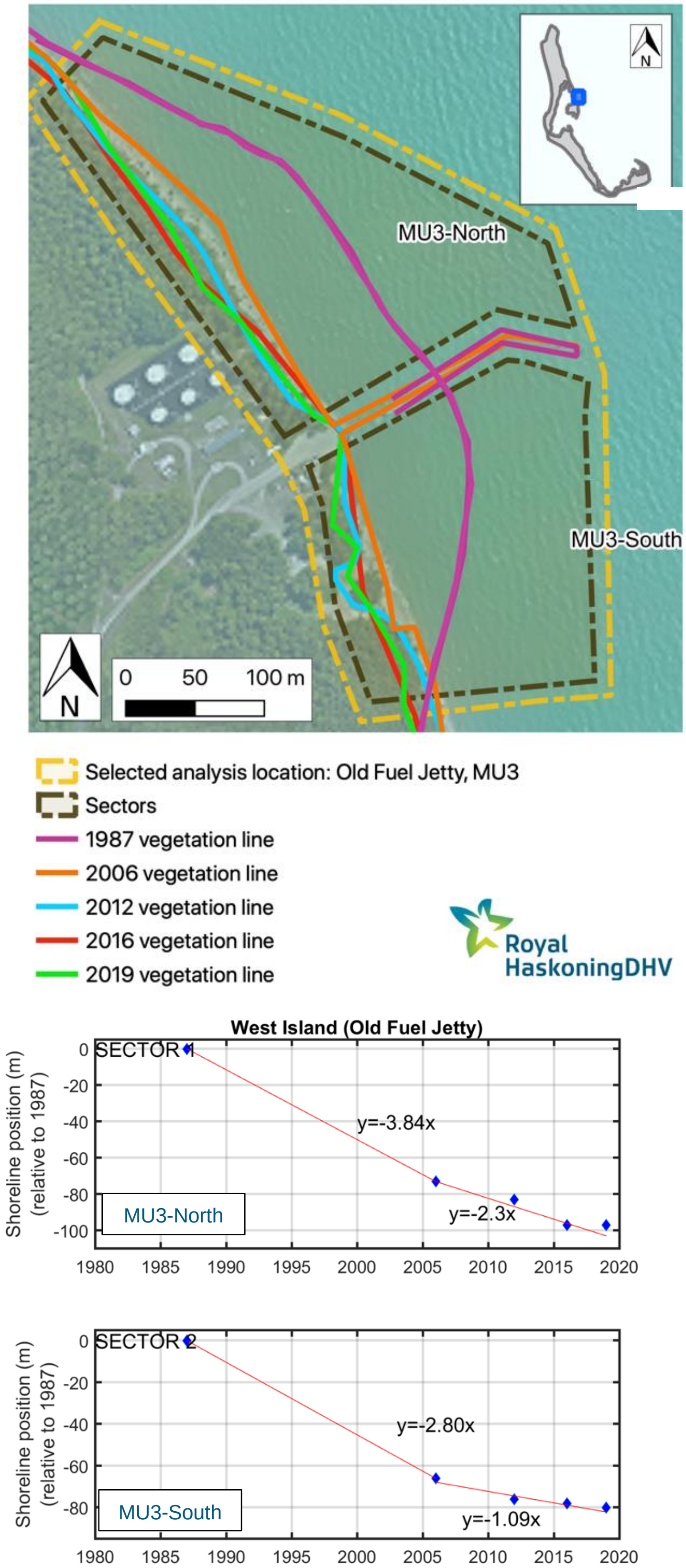


Figure 163: Left: Historical vegetation lines at the Old Fuel Jetty within MU3. Right: Time series of vegetation line position and regression analysis for each sector.

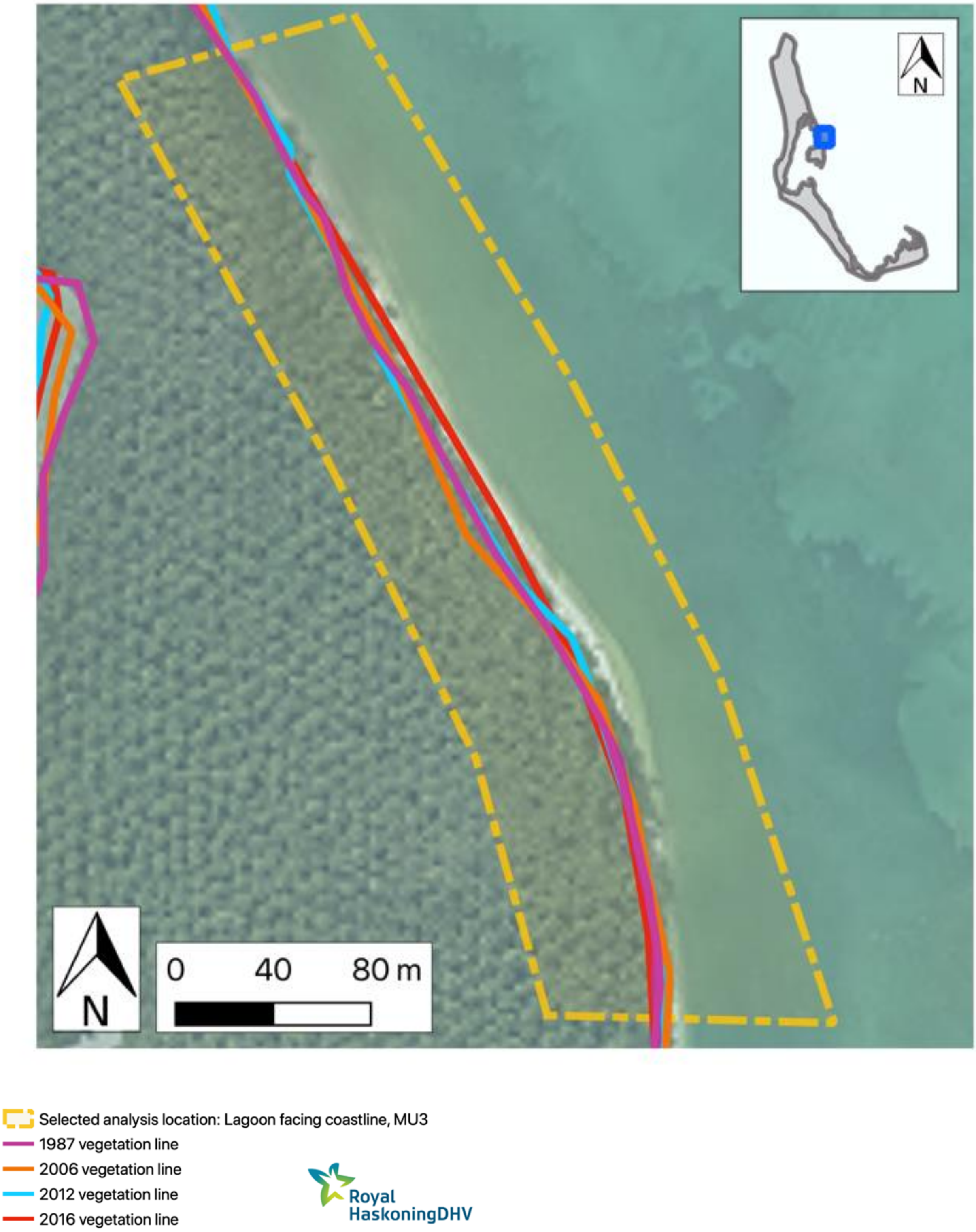


Figure 164: Historical vegetation lines at Lagoon facing coastline south of Rumah Baru within MU3.

Management Unit 4

The selected analysis location within MU4 was the Rumah Baru port facility which was constructed in 2011. Long-term trends based on the historical vegetation lines analysis suggest this area is relatively stable (**Figure 165**). As such, no regression analysis has been conducted.

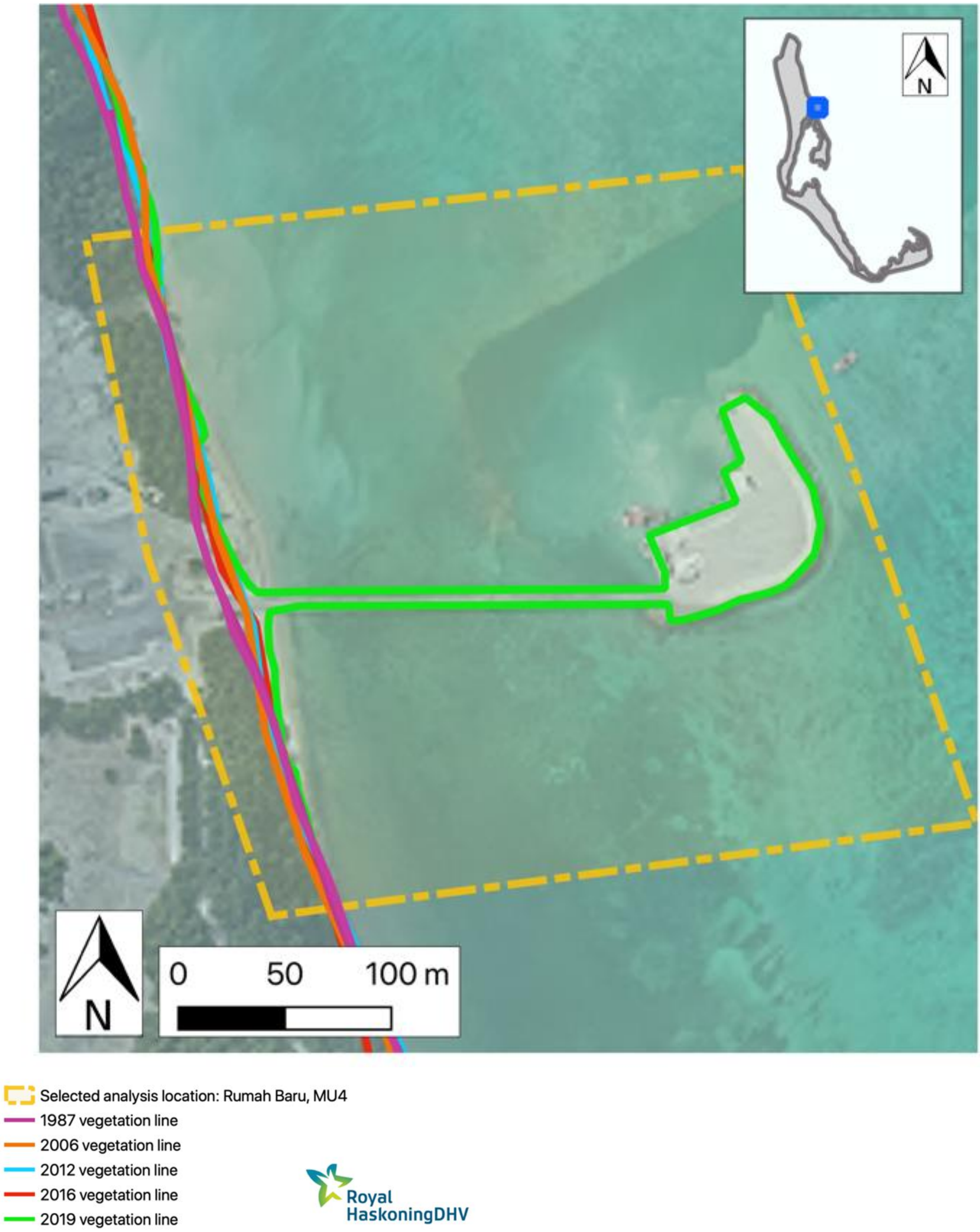


Figure 165: Historical vegetation lines at the Rumah Baru port facility within MU4.

Home Island

An identical analysis approach was undertaken to analyse the changes in vegetation lines on Home Island. This was done at selected locations across the different management units as indicted in **Figure 166**.

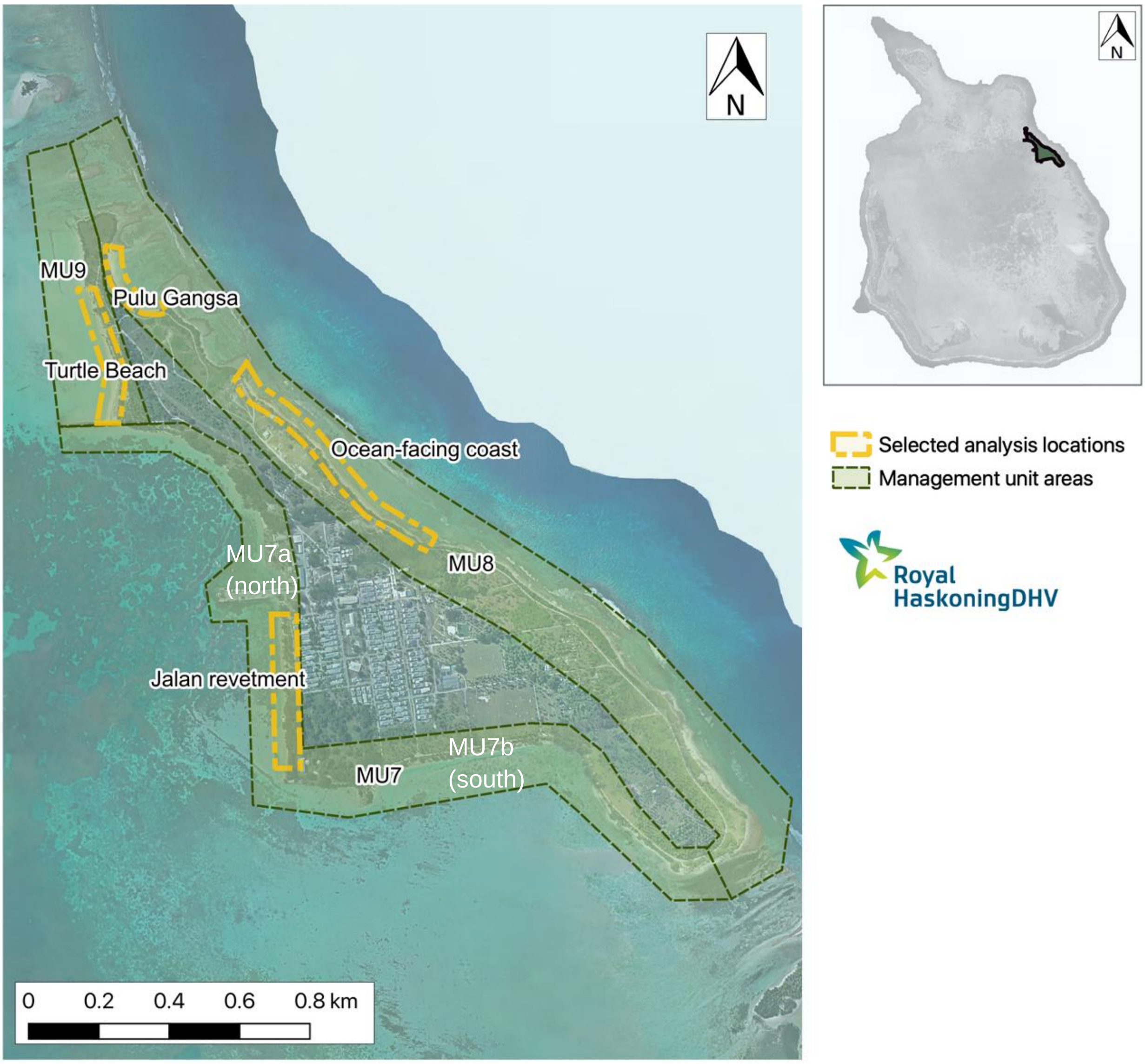


Figure 166: Selected locations for analysis of historical vegetation lines on West Island.

Management Unit 7

The selected analysis location within MU7 was the Jalan revetment. This area extends south from the harbour jetty to the park surrounding Oceania House at its southern end. A GSC revetment was periodically extended over time at this location, with the age of the structure between two to five years old. To accurately capture spatial trends, the analysis area has been separated into two sectors, MU7-North and MU7-South. As seen in **Figure 167**, the vegetation line in MU7-North has remained stable between 1987 and 2016, and as such no regression plot is presented for this sector. **Figure 167** shows that the vegetation line in MU7-South has accreted uniformly (0.59 metres/year) between 1987 and 2016.

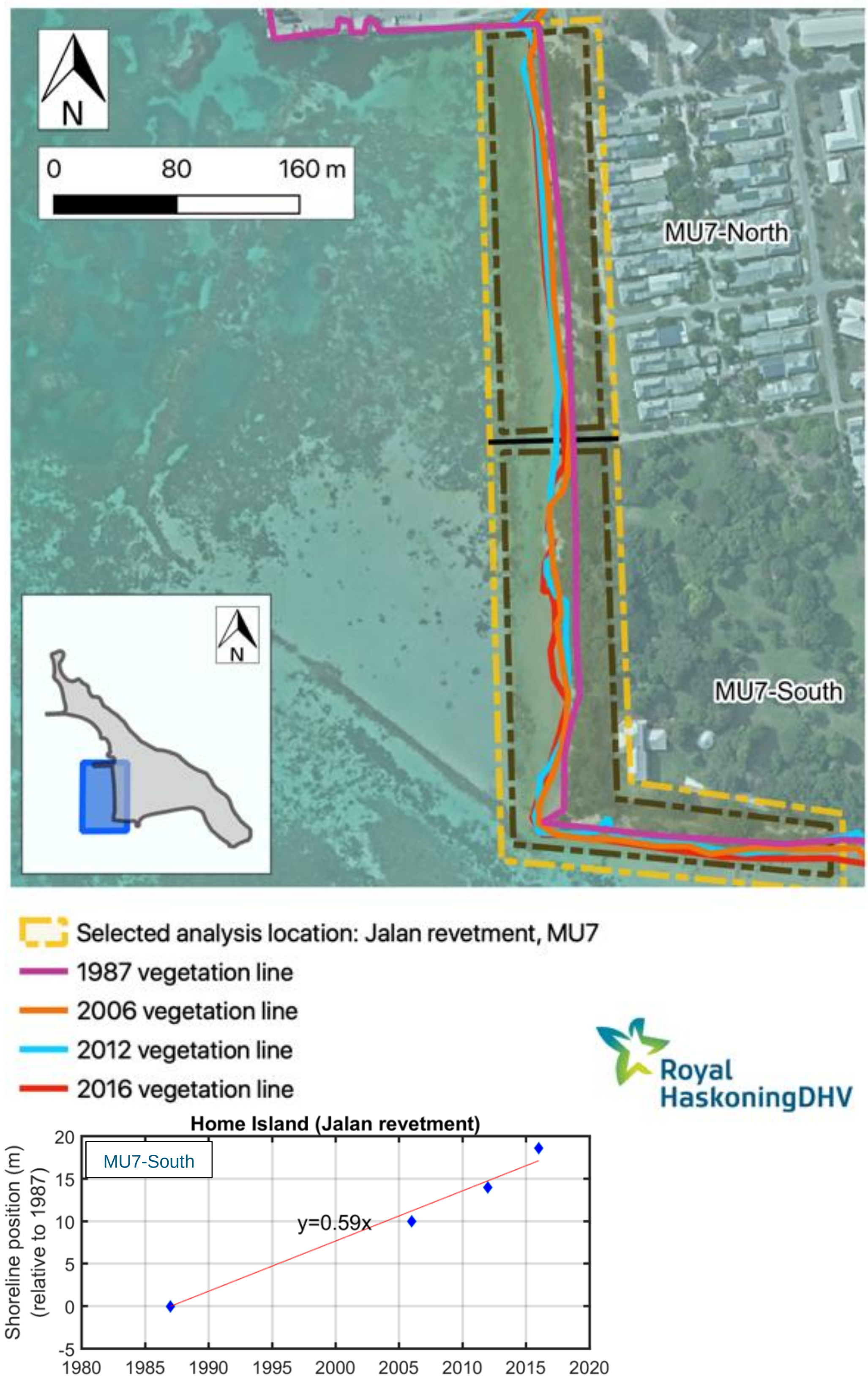


Figure 167: Left: Historical vegetation lines at the Jalan revetment within MU7. Right: Time series of vegetation line position and regression analysis for MU7-South.

Management Unit 8

Two areas were selected for analysis within MU8. The first was Pulu Gangsa, a 250-metre long pocket beach which is well protected by fringing reef. Analysis of aerial photography shows that since 1987, the vegetation line has progressed seaward at a rate of 0.6 metres/year, with the vegetation line advancing 21 metres (**Figure 168**). The second selected area within MU8 was an 800-metre long representative stretch of ocean-facing shoreline. **Figure 169** shows that the vegetation line has been stable at this location since 1987, and as such no regression plot has been provided.

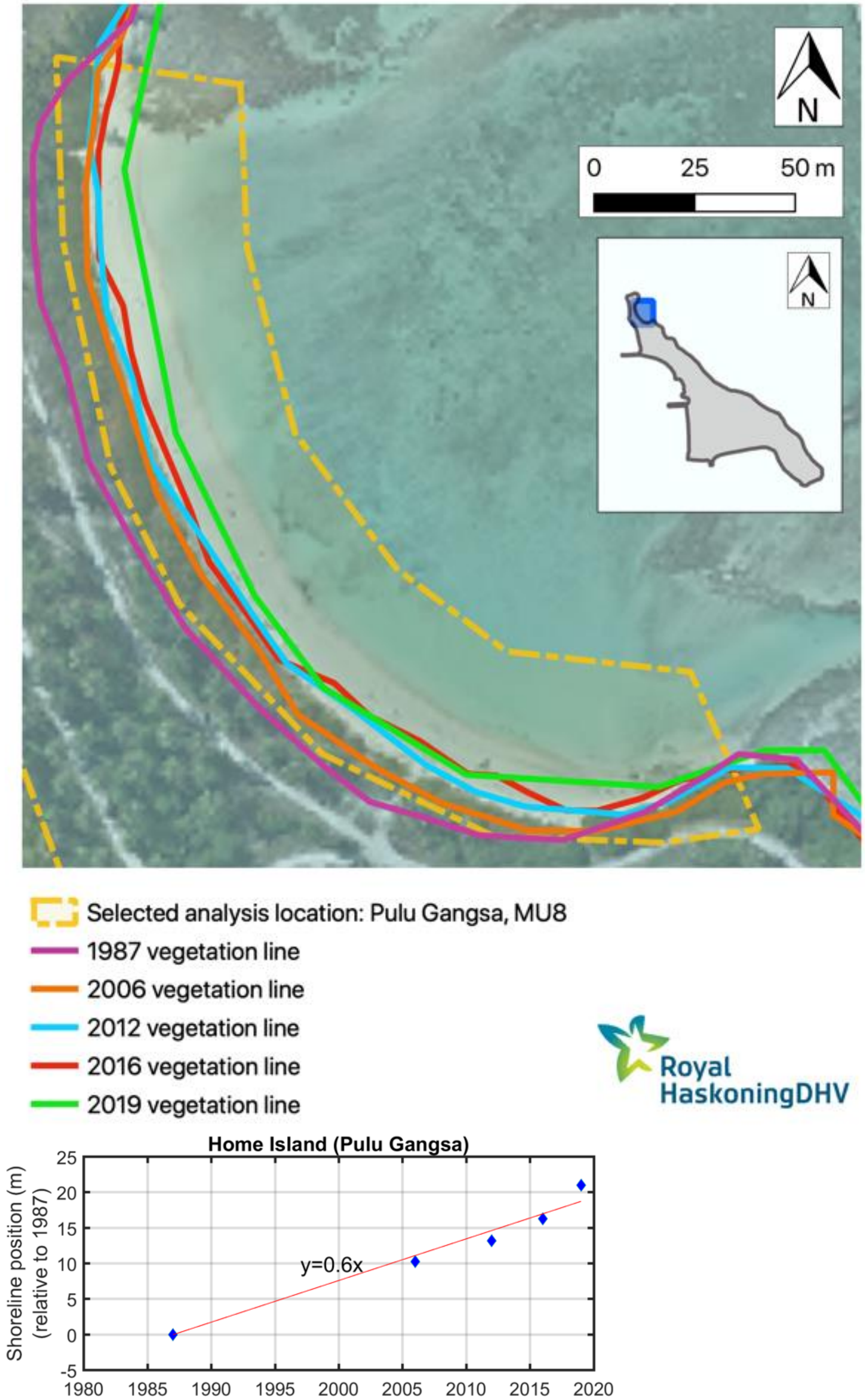


Figure 168: Left: Historical vegetation lines at Pulu Gangsa within MU8. Right: Time series of vegetation line position and regression analysis at the site.

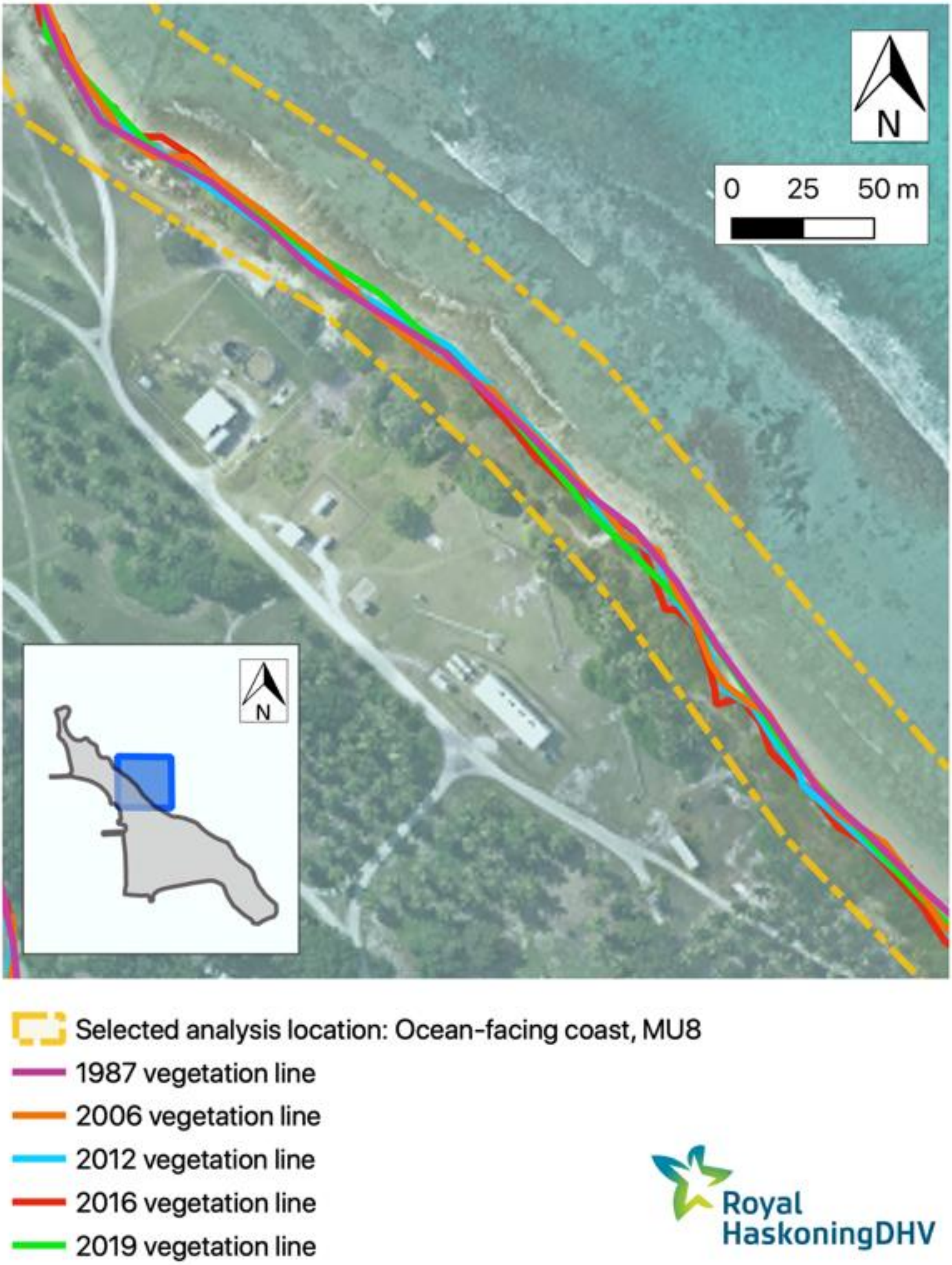


Figure 169: Historical vegetation lines at the ocean-facing coastline of MU8.

Management Unit 9

The selected analysis location within MU9 was the 400-meter long Turtle Beach. The zone was divided into three sectors to accurately capture spatially varying trends (**Figure 170**). MU9-North experienced recession between 1987 and 2016 at a rate of 0.86 metres/year. Minor accumulation was observed in MU9-Middle, where the vegetation line advanced approximately 6 metres. In MU9-South, the vegetation line advanced at a rate of 1 metre/year from 1987 to 2016. The concurrent recession and accretion pattern along the beach seems to suggest that sand is being transported alongshore from MU9-North to MU9-South. However, it is understood that sand is regularly extracted from MU9-North and used for construction and coastal management purposes. This may account for the losses observed in Sector 1 and would imply that Turtle Beach is net accretionary and only the sand extractions in MU9-North have led to the observed recessionary trend.

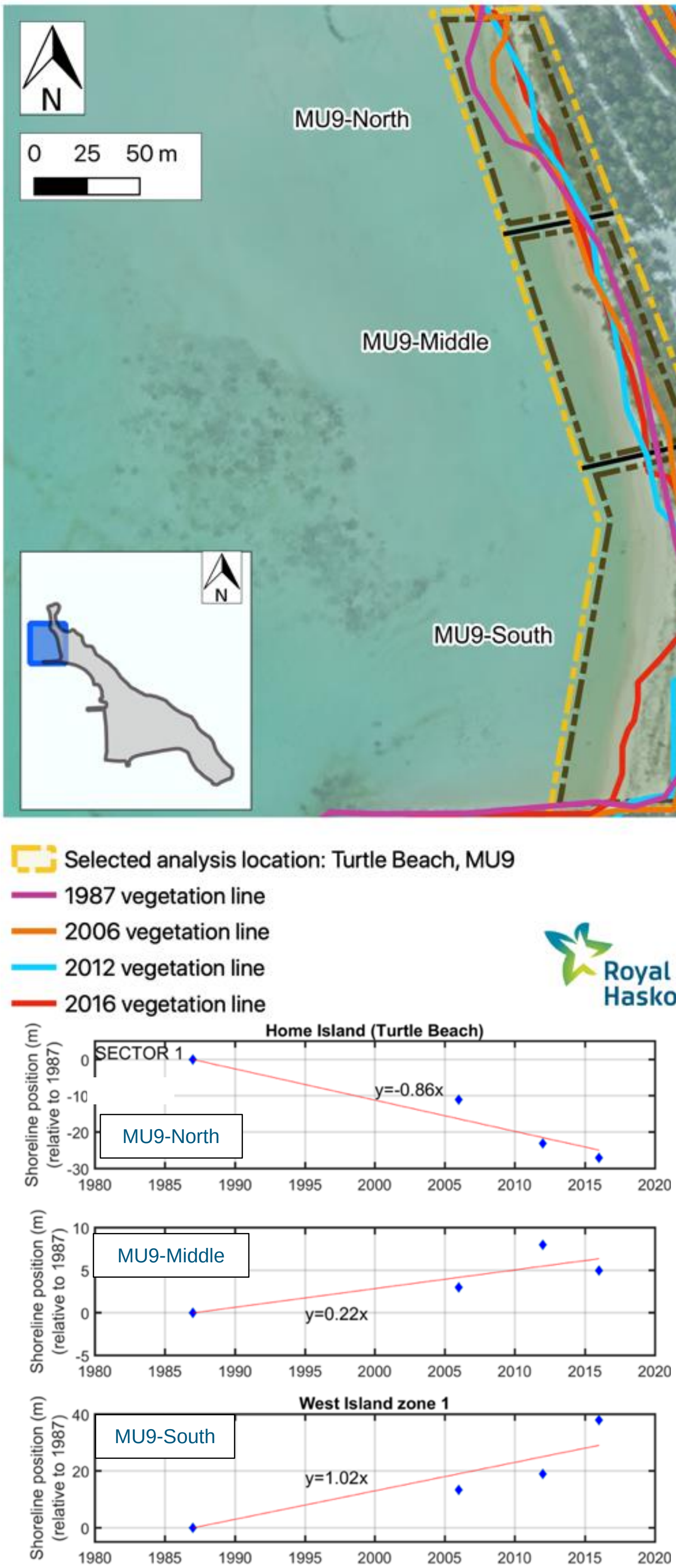


Figure 170: Left: Historical vegetation lines at Turtle Beach within MU9. Right: Time series of vegetation line position and regression analysis for each sector.

Appendix D – Storm Erosion Modelling

XBeach erosion model (ocean-facing shorelines)

Model development

The XBeach model was used to analyse the erosion extent for ocean-facing beaches. The XBeach model is a process-based model that is commonly used to determine nearshore morphological changes. It covers a wide set of cross-shore processes (i.e. return flow, wave asymmetry, wave rollers and long waves). The morphodynamic processes include bed load and suspended sediment transport, dune face avalanching, bed update and breaching. Because of the inclusion of long waves (or infragravity waves) XBeach is specifically suitable to model morphological changes of the nearshore area, beaches, dunes and backbarrier during storms.

A series of shoreline profiles were established across the study area and subjected to design water levels and wave heights representative of a 100-year ARI storm. The input beach profiles for the model were taken from the latest beach profile surveys (July 2018 and July 2019) undertaken as part of the CVA.

The profiles CBM01, WI16, HI09 and HI03 were selected as they are representative of each of the ocean-facing profiles (see **Figure 171**). CBM01 and WI16 profiles are erosion hot spots backed by residential lots and the airstrip respectively. HI09 and HI03 are located at the only two beach areas that are at Home Island. Note that lagoon-facing profiles were modelled using SBEACH and are presented in the subsequent section of this Appendix.

XBeach was run in surfbeat mode. In surfbeat mode short-wave motion is solved using the wave action equation. Wave-driven currents, long waves and runup and rundown of long waves are included. The empirically calculated short wave runup was included in the surfbeat mode simulations for sediment transport/morphology. The wave breaking model of Roelvink (1993) was utilised in the model with a gamma factor of 0.55. Wave dissipation by bottom friction was modelled using a friction coefficient and model calibration resulted in a wave friction coefficient of 0.01. A time varying JONSWAP spectra was used as boundary conditions.

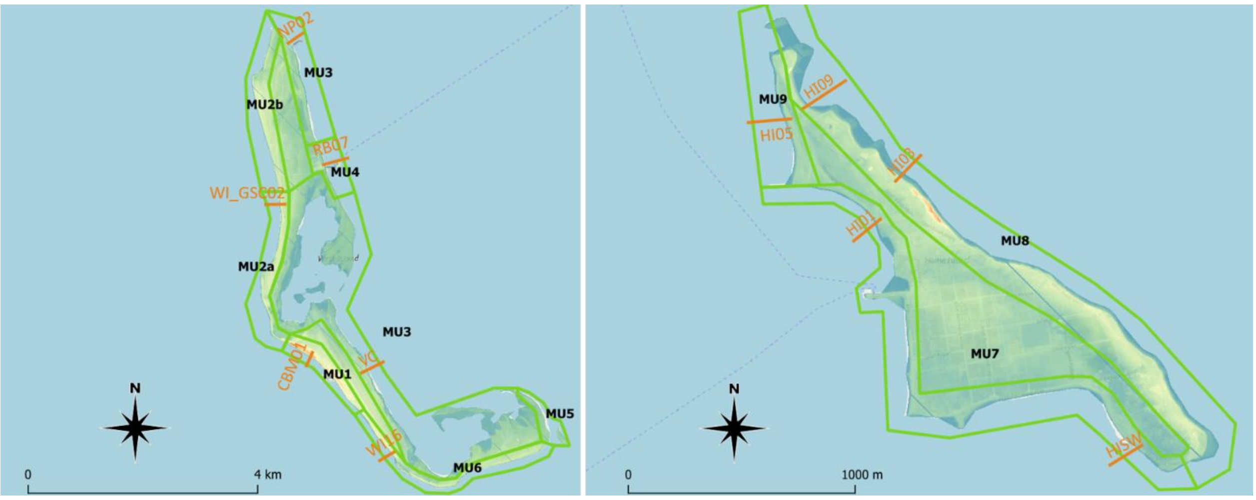


Figure 171: Selected ocean-facing and lagoon-facing profiles.

Model calibration

The calibration of the XBeach model to observed hydrodynamics and wave conditions was undertaken using the water level and wave data collected at the reef top monitoring sites at CK01. The hydrodynamic and wave calibration was used to ensure wave transformation and the wave set-up across the reef flats was accurately replicated in the model.

For the morphological response, the CBM01 profile was adopted. It is located at one of the worst erosion spots observed along the West Island settlement and nearby the CK01 wave and water level measurements. At this site, survey data for the beach and dune areas is available that describes pre-event and post-event conditions for the July 2018 swell event (RHDHV, 2018a). The 2012 LiDAR data was used for the reef flat and deeper areas and an irregular grid like CK01 was defined. The irregular grid was defined with ~10m cell size offshore, ~5m cell size at the reef crest and decreasing from there towards the shoreline where the cell size is ~0.2m.

The formulation presented by Soulsby- Van Rijn (Soulsby, 1997; van Rijn, 1984) was used to calculate the equilibrium sediment concentration with D_{50}=0.5mm and D_{90}=8.5mm. The sediment grain sizes were based on nearby sand samples (SS08 and SS09) presented in DoT, 2017. The reef flat was defined as non-erodible. The morphology of the beach face was found most sensitive to the factor of onshore transport due to wave skewness and asymmetry. The final calibrated model used a value of 0.1 for skewness and 0.05 for asymmetry.

XBeach model calibration results for the beach storm response are shown in **Figure 172**.

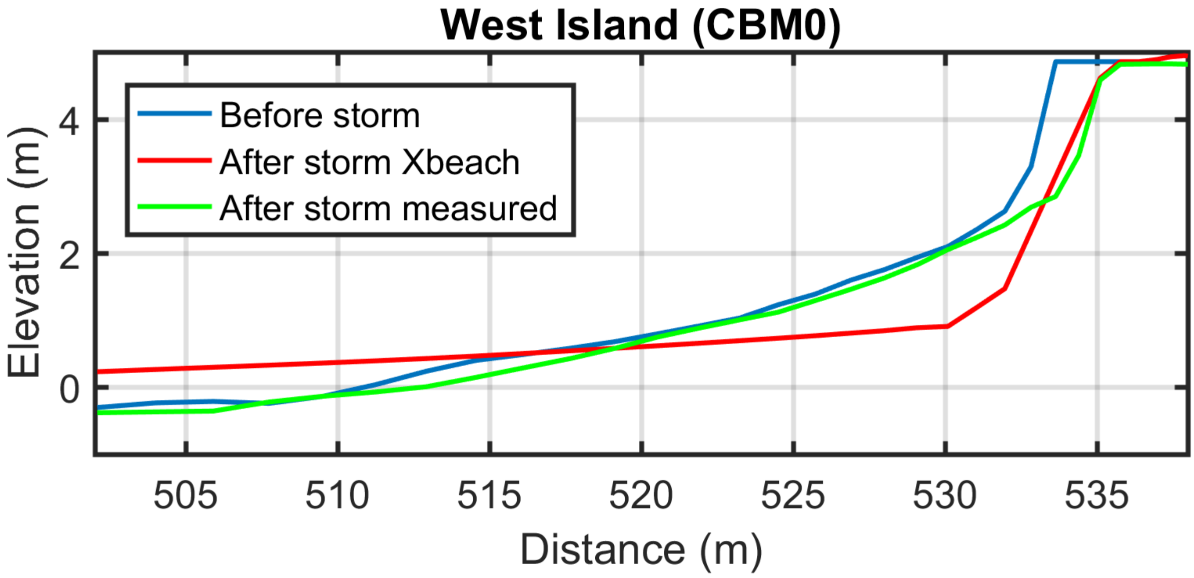


Figure 172: Comparison between measured coastal profile and the output of the XBeach model (datum AHD).

Figure 172 shows that the erosion of the upper part of the profile (above 2.5m AHD) is well represented in the model. Lower down in the profile (between 0.5m and 2.5m AHD) XBeach tends to overpredict the observed storm erosion as well as the storm deposition on the reef flats (below +0.5m and seaward of chainages <520m). There are several possible explanations for these differences. The lack of observed storm deposition on the reef flats is likely to be explained by northward longshore sediment transport, which is not represented in the XBeach profile model, rapidly removing any storm deposits. The lack of erosion observed at the toe of the beach ridge/dune (from x=520m to x=532m) is likely to be best explained by the coral rubble and other larger grained material that is more resistant to erosion observed in this part of the profile (see **Figure 173**) but not represented in the XBeach model. Another possibility is that the post-storm measured profile was captured in October providing time for beach recovery of the lower profile following the July storm event.

Figure 173: Photographs of XBeach calibration site shortly after the July event showing the coral rubble and other debris exposed along the lower profile (source Karen Willshaw).

Table 51 presents a detailed comparison of the upper beach/dune including the landward distance the erosion scarp moved and dune erosion volume. These calculations were carried out for the profile area above ~2.4m AHD.

Table 51: Comparison between measured and modelled erosion distances and eroded sand volumes (above 2.4m AHD).

Source	Erosion distance (m)	Eroded volume (m^3/m)
Measured	-1.40	3.2
XBeach	-1.32	3.0

Design storm erosion inputs

Based on detailed analysis two synthetic tropical cyclones, each with an estimated 100-year ARI at Home Island and West Island, respectively were adopted as the design storms. These synthetic cyclones were developed as part of the coastal inundation assessment (Task 7) in RHDHV (2020). The cyclone on West Island had a duration of 14 hours and the cyclone on Home Island is 48 hours in duration.

The wave and water level inputs supplied to the model for each transect are shown in **Figure 174**. Wave data for these events were extracted from the spectral wave model described in RHDHV (2020) at the seaward end of each beach profile. The water level was defined by adopting a high spring tide from the measured data at CK03 and adding an allowance for surge. It is noted that the peak total water level is 1.17m AHD, which is close to the 100-year ARI still water level determined for Home Island (RHDHV, 2020)

Sediment parameters were obtained from Task 2 – Data Review and Gap Analysis (RHDHV, 2018b), the mean D_{50} (mm) and D_{90} (mm) for each of the selected transects were used. These values ranged from 0.5 – 8.4mm in West Island and 0.5 - 0.8mm in Home Island.

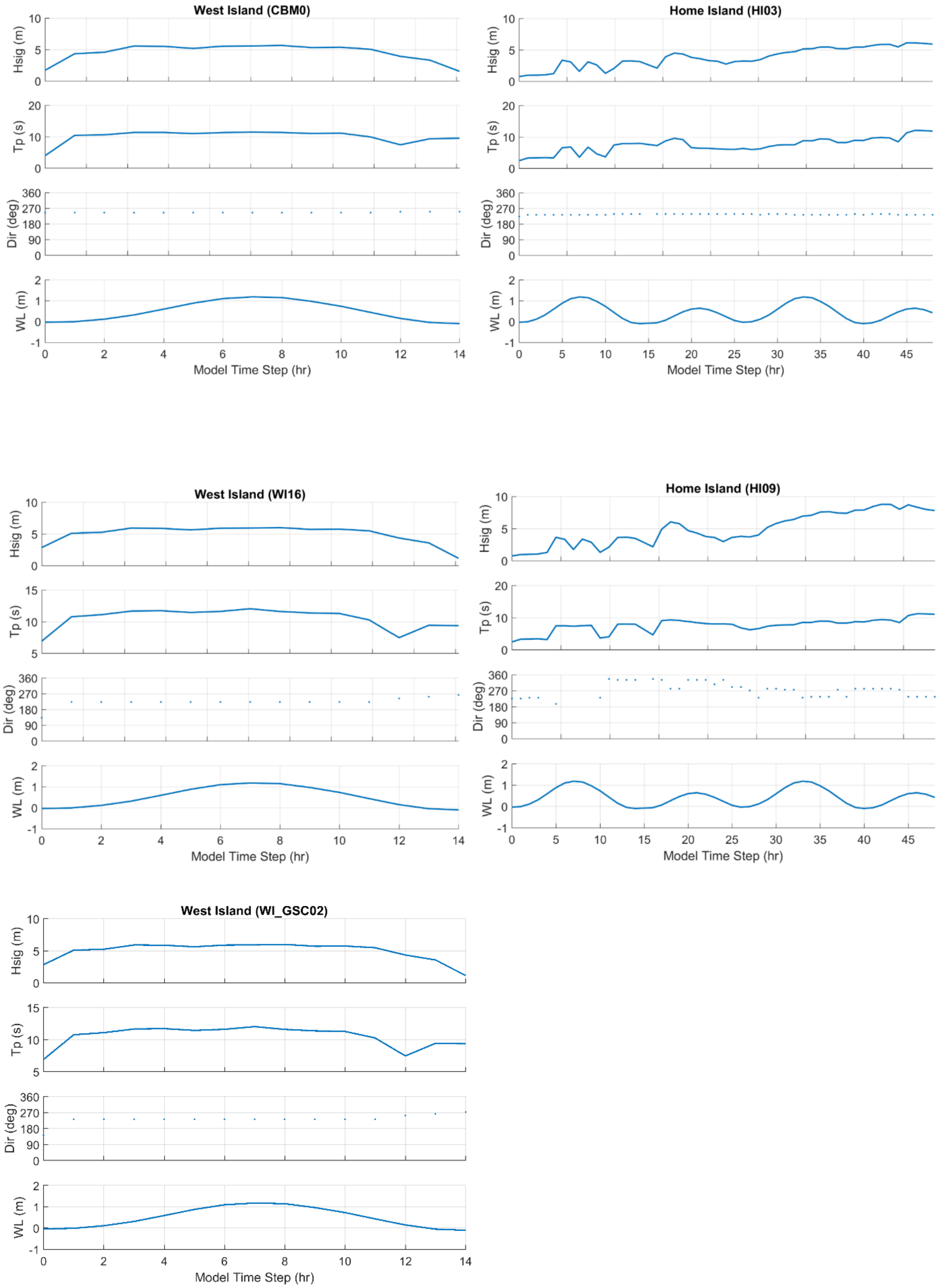


Figure 174: Boundary condition (significant wave height, peak period, wave direction (Xbeach convention) time series at the seaward end of the profiles.

Model results

A comparison between the initial and final profile for each transect is presented (**Figure 175** to **Figure 179**).

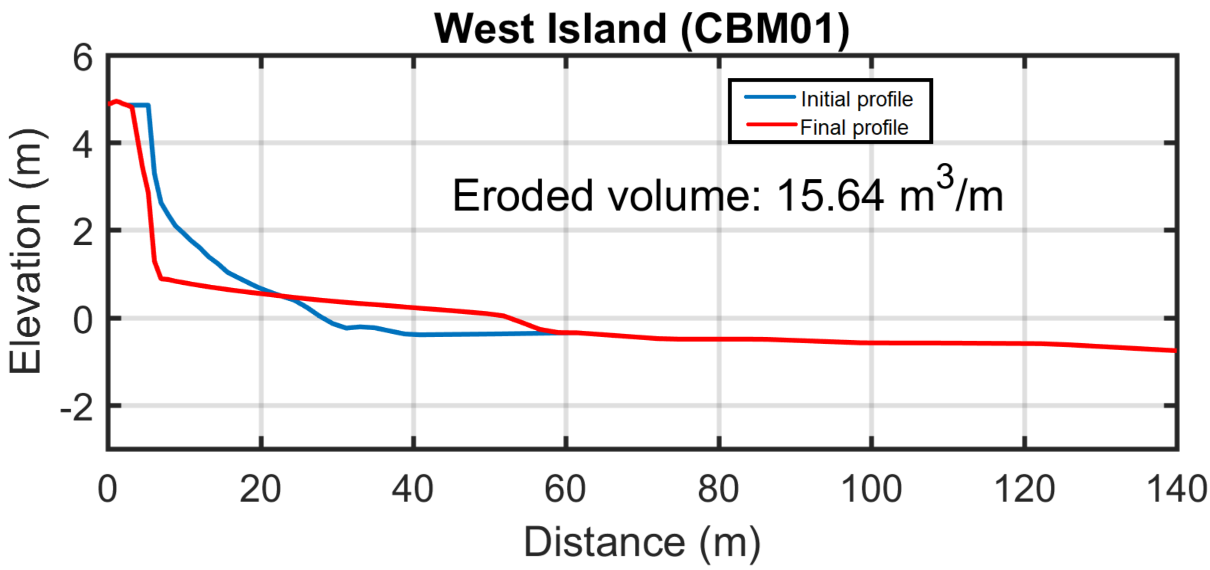


Figure 175: 100-year ARI storm erosion at CBM01 profile (initial profile = pre-storm, final profile = eroded profile).

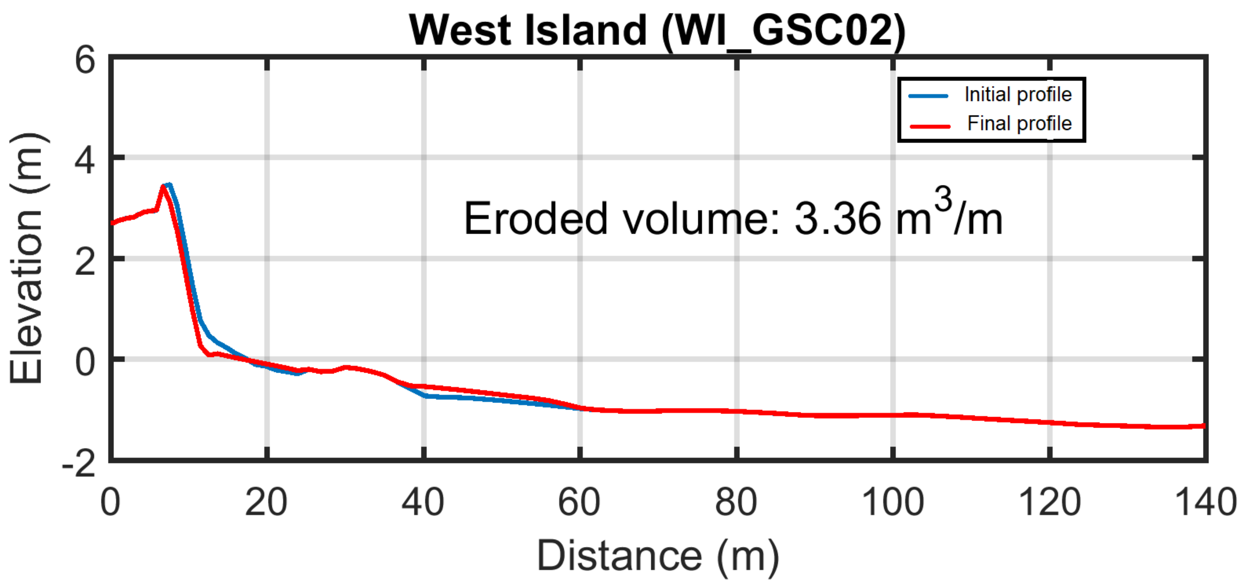


Figure 176: 100-year ARI storm erosion at WI_GSC02 profile (initial profile = pre-storm, final profile = eroded profile).

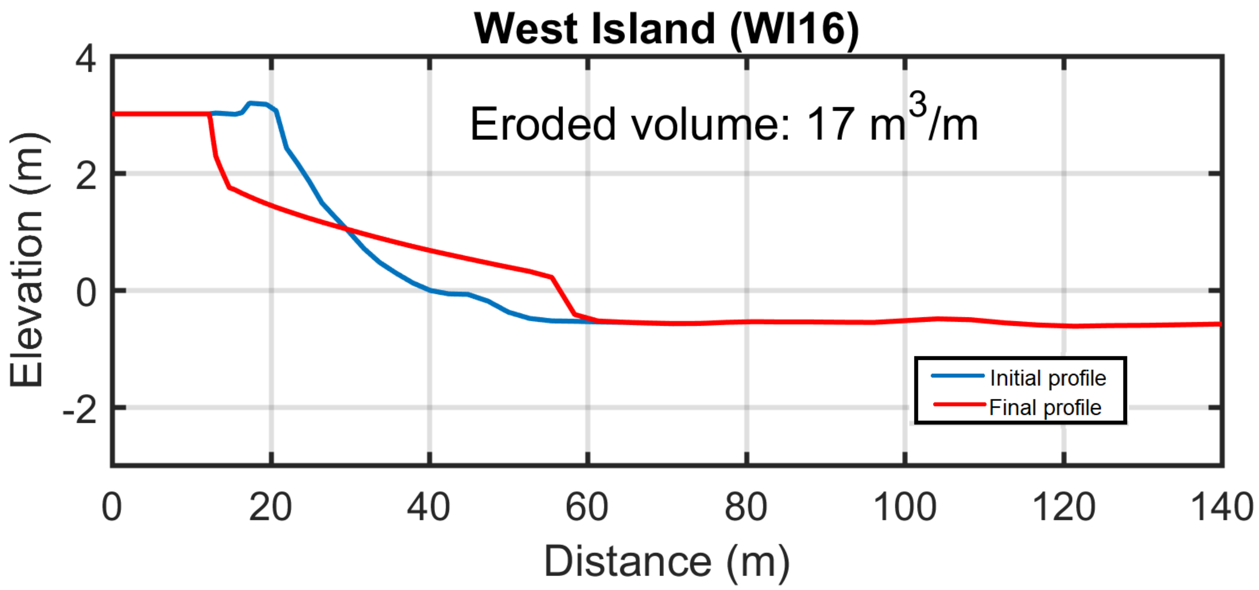


Figure 177: 100-year ARI storm erosion at WI16 profile (initial profile = pre-storm, final profile = eroded profile).

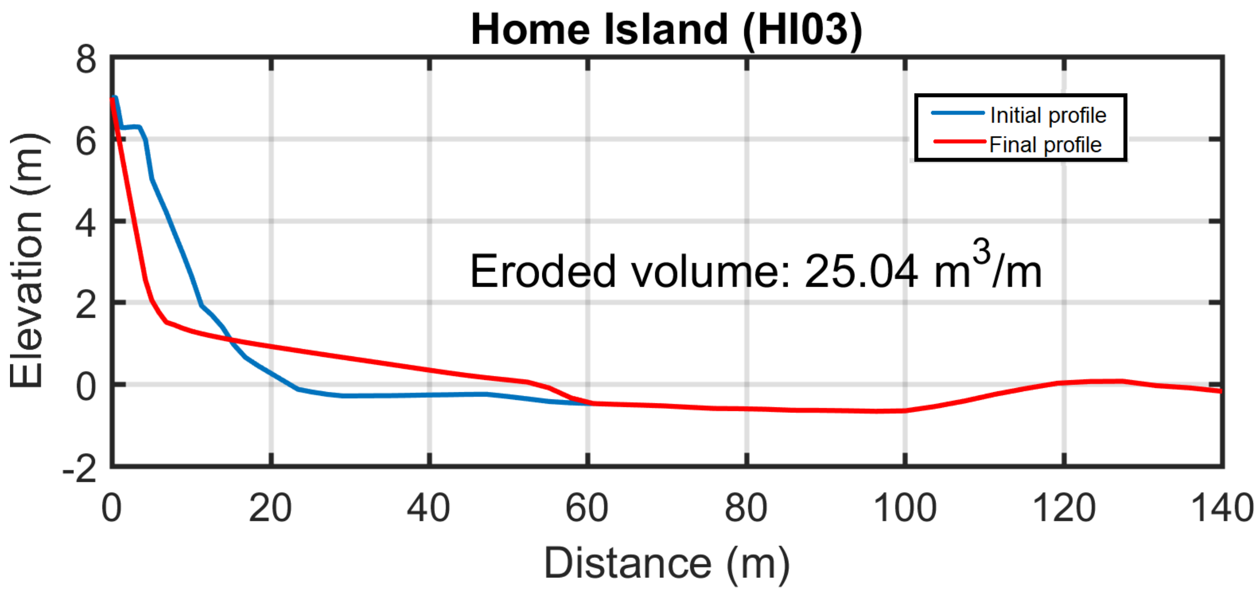


Figure 178: 100-year ARI storm erosion at HI03 profile (initial profile = pre-storm, final profile = eroded profile).

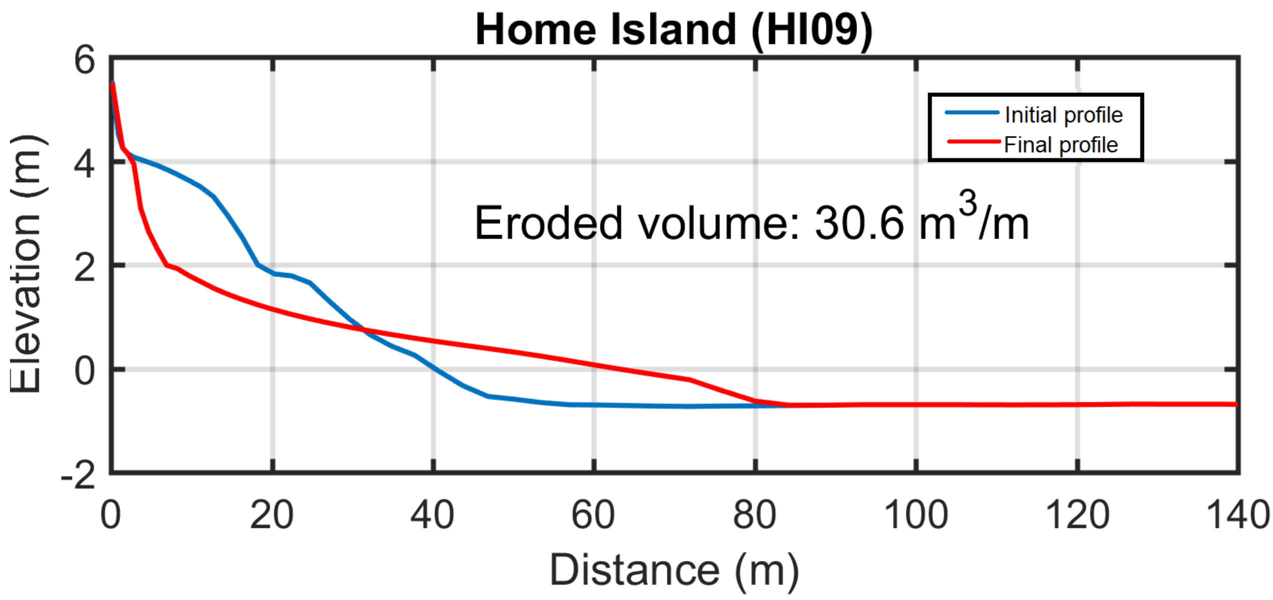


Figure 179: 100-year ARI storm erosion at HI09 profile (initial profile = pre-storm, final profile = eroded profile).

SBEACH erosion model (lagoon facing shorelines)

SBEACH model inputs

Pre-storm beach profiles

A series of shoreline profiles were established across the study area and subjected to design water levels and wave heights representative of a 100-year ARI storm. The input beach profiles for the model were taken from the latest (July 2019) beach profiles extracted from the 2012 LiDAR dataset.

The profiles RB07, NP02, HI01 and HI05 were selected as they are representative of each of the beach lagoon sectors. Additionally, another two profiles were selected, one located to the east of the airport runway on West Island (CKI Visitor Centre (VC) profile) and the other on the south west end of Home Island (South West profile) (see **Figure 171**).

Sediment grain sizes

Sediment parameters were obtained from Task 2 – Data Review and Gap Analysis RHDHV (2018b). The median grain size D50 (mm) for each of the selected transects was adopted for the SBEACH modelling. These values ranged from 0.29 – 0.4mm in West Island and 0.2-0.22mm in Home Island. A maximum avalanching slope of 15° to the horizontal has also been incorporated.

Storm time series

It is common practise in Western Australia to use three repeats of the severe storm sequence when adopting SBEACH for erosion modelling on sandy shoreline. Following this practise, three successive synthetic tropical cyclones with an estimated 100-year ARI return period have been adopted as the design storm. This synthetic cyclone was developed as part of the coastal inundation assessment (Task 7) (RHDHV, 2020).

The storm track resulted in peak wind speeds of 71m/s from east to west across the lagoon and also from west to east once the cyclone moved over CKI, therefore representing worst-case conditions for both coastlines. This event had a duration of approximately 48 hours. During the first 24 hours lagoon waves were generated due to strong easterly wind and then, as it moved across the island, it produced waves due to strong westerly wind across the lagoon. Therefore, the first 24 hours were used as boundary conditions for the profiles located on West Island and the last 24 hours were used to model the profiles located on Home Island.

The storm time series and water level input into SBEACH can be seen in **Figure 180**. Wave data from this storm were extracted from the spectral wave model described in RHDHV (2020) at the seaward end of each beach profile. The water level was adopted as a high spring tide from the measured data at CK03 and adding an allowance for surge. The peak of the total water level is 1.17m, similar to 100-year still water level determined for Home Island (RHDHV, 2020).

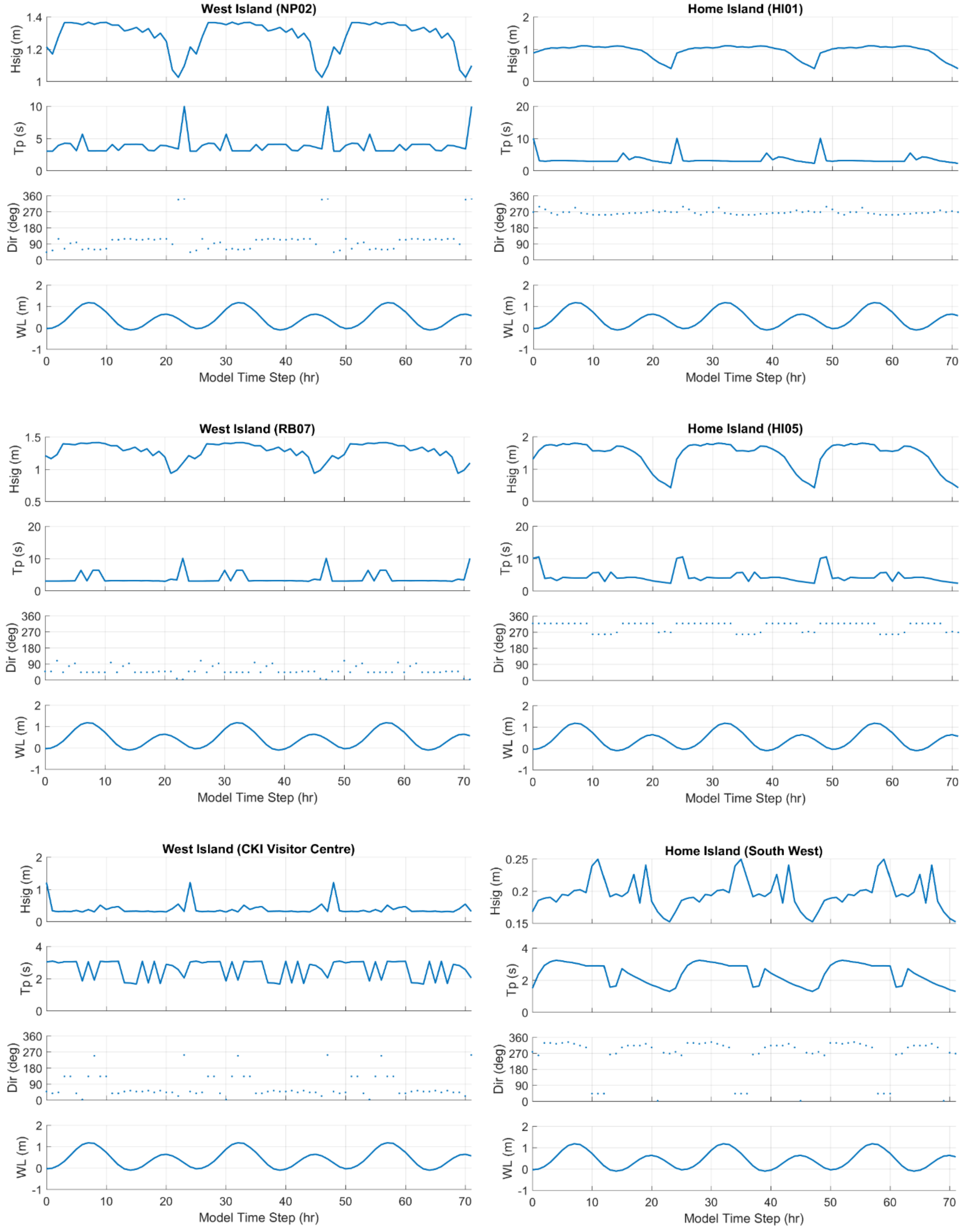


Figure 180: Input storm time series used for SBEACH erosion modelling.

Model results

A comparison between the initial and final beach profile for each transect location is presented in **Figure 181** to **Figure 186**Figure 181: 100-year ARI storm erosion at HI05 profile (initial profile = pre-storm, final profile = eroded profile).Figure 175. Results are summarised in **Table 52**.

Table 52: Eroded sand volume, maximum recession of the shoreline (level 0m) and the HSD.

Profile	Management Unit	Allowance distance (m)		Eroded volume (m^3/m)
		Shoreline (0m AHD)	Dune (~1.5m AHD)	
HI05	MU9	-1.4	-0.5	12.6
HISW	MU7	-0.4	-0.1	0.6
HI01	MU7	-5.0	-1.3	5.9
NP02	MU3	-1.5	-1.2	2.6
VC	MU3	0.0	0.0	2.4
RB07	MU4	-3.7	-2.0	7.1

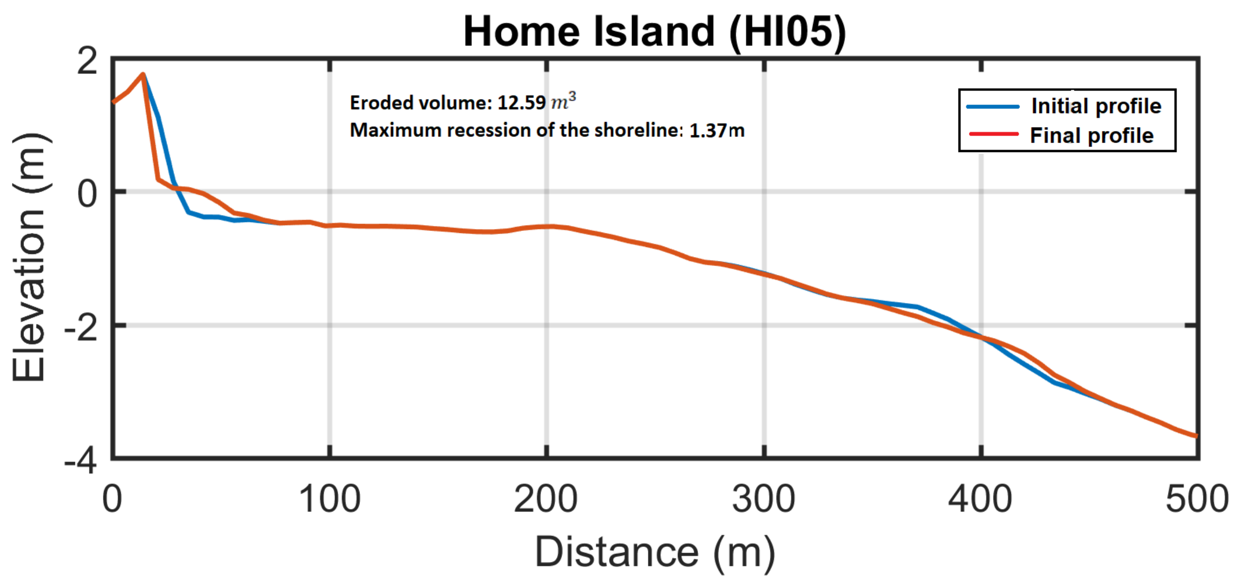


Figure 181: 100-year ARI storm erosion at HI05 profile (initial profile = pre-storm, final profile = eroded profile).

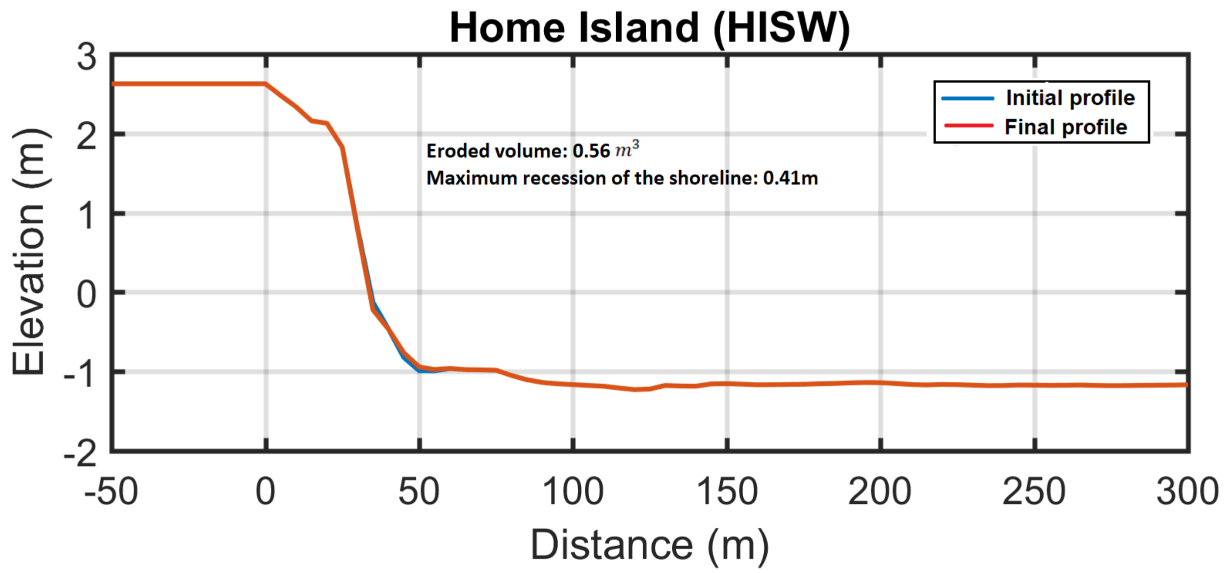


Figure 182: 100-year ARI storm erosion at HISW profile (initial profile = pre-storm, final profile = eroded profile).

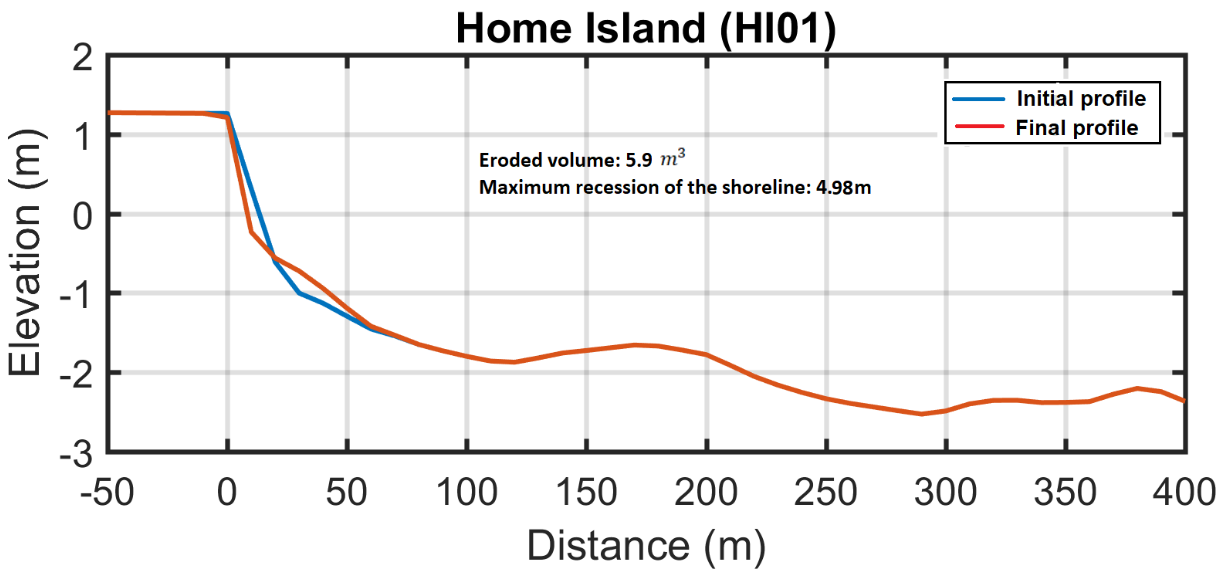


Figure 183: 100-year ARI storm erosion at HI01 profile (initial profile = pre-storm, final profile = eroded profile).

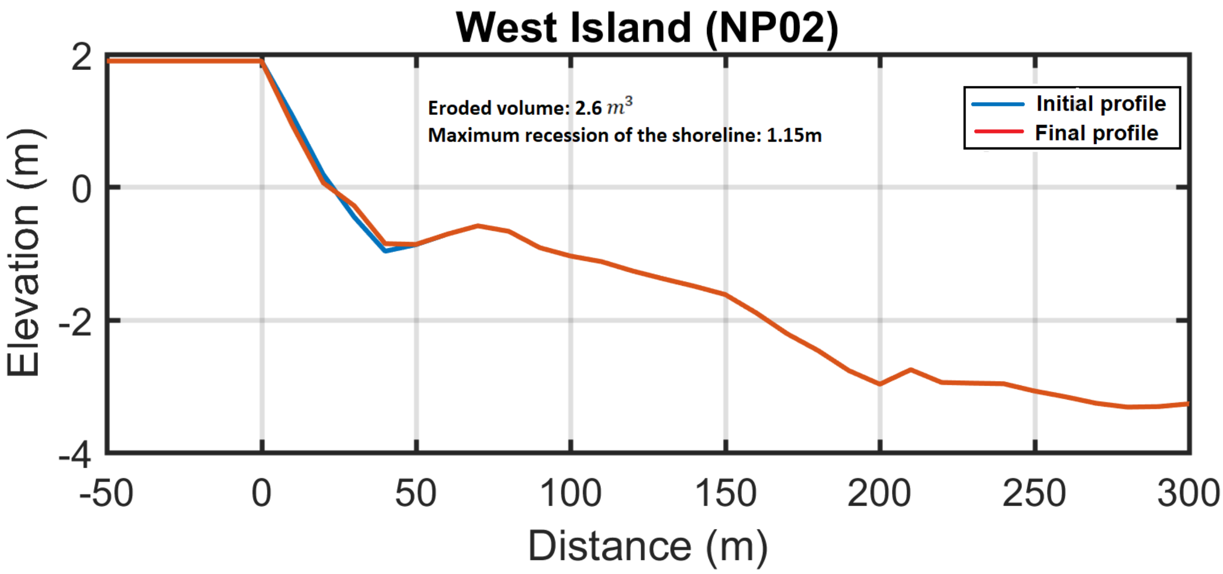


Figure 184: 100-year ARI storm erosion at HI02 profile (initial profile = pre-storm, final profile = eroded profile).

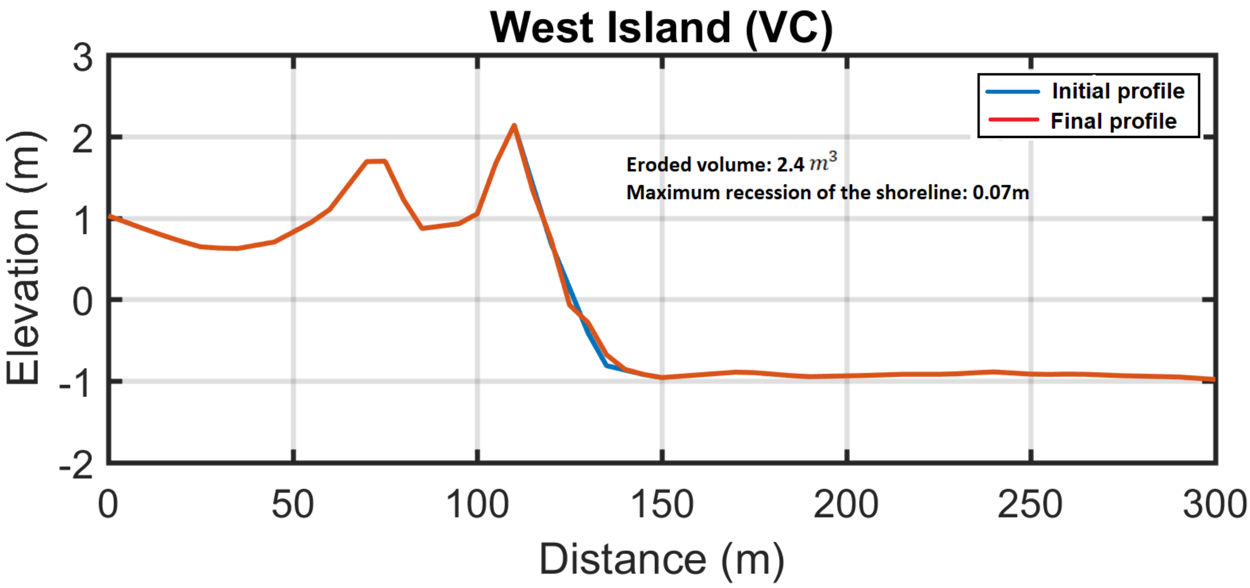


Figure 185: 100-year ARI storm erosion at VC profile (initial profile = pre-storm, final profile = eroded profile).

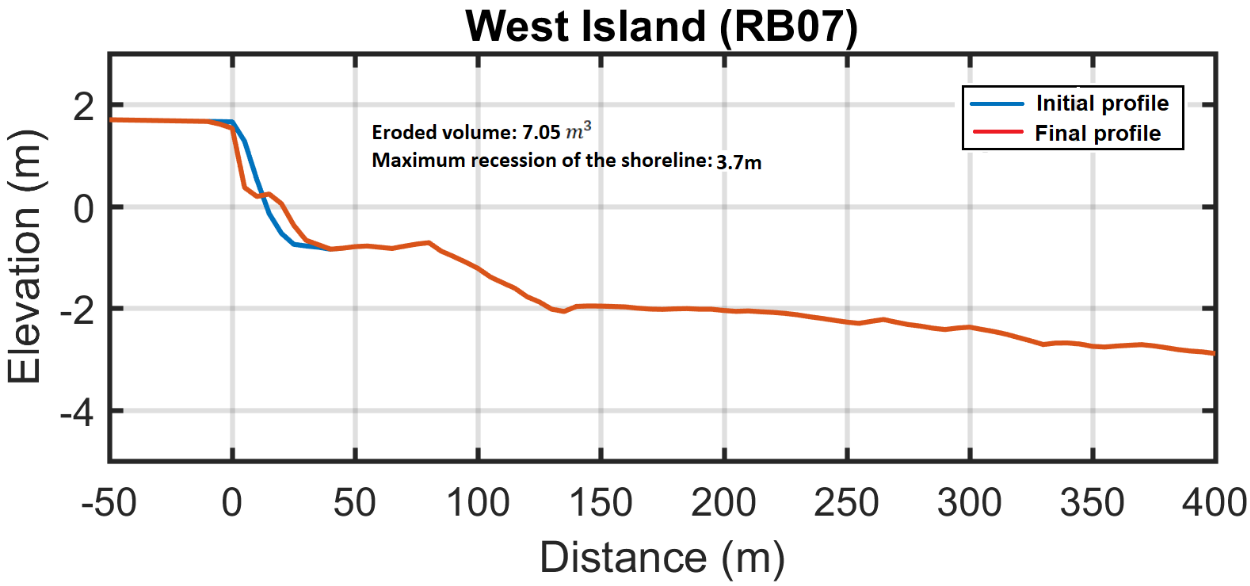


Figure 186: 100-year ARI storm erosion at RB07 profile (initial profile = pre-storm, final profile = eroded profile).

Appendix E – Coastal Asset Database

LOT NUMBER	ADDRESS	DESCRIPTION	ZONING	AREA (SQM)	CENTER LATITUDE	CENTER LONGITUDE	LOT TYPE	OWNER	ASSET GROUP	SECONDARY DESCRIPTION	ISLAND	PHOTO LINK	MANAGEMENT UNIT	EROSION 2018	EROSION 2028	EROSION 2068	EROSION 2118	INUNDATION 2018	INUNDATION 2068	INUNDATION 2118
1106		RESERVE	GENERAL USEAGE	844,512	-12.117036	96.899434	FHOLD	COCOS KEELING ISLANDS SHIRE	Environment	park	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/719/719_2018-07-06%2013-39-00.png	MU7	YES	YES	YES	YES	YES	YES	YES
225		RESERVE		4,657	-12.117593	96.895427	FHOLD	COCOS KEELING ISLANDS SHIRE	Environment	park	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/719/719_2018-07-06%2013-39-00.png		NO	NO	NO	NO	NO	YES	YES
223		Mosque		3,040	-12.11857	96.89557	FHOLD	COCOS KEELING ISLANDS SHIRE	Social	mosque	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/718/718_2018-07-06%2013-37-54.png		NO	NO	NO	NO	YES	YES	YES
1106		Stormwater Pipe			-12.1147	96.896418		COCOS KEELING ISLANDS SHIRE	Economic	outflow	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/714/714_2018-07-06%2013-16-13.png	MU8	YES	YES	YES	YES	YES	YES	YES
1106		Power Station			-12.1135	96.894051		COCOS KEELING ISLANDS SHIRE	Economic	HI Power station	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/712/712_2018-07-06%2013-11-55.png	MU8	NO	NO	YES	YES	NO	NO	YES
1106		Fuel Station			-12.1129	96.893434		COCOS KEELING ISLANDS SHIRE	Economic	fuel station	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/711/711_2018-07-06%2013-10-12.png	MU8	NO	NO	YES	YES	NO	NO	YES
1106		WWTP			-12.1127	96.893199		COCOS KEELING ISLANDS SHIRE	Economic	Wastewater Treatment Plant	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/710/710_2018-07-06%2013-09-06.png	MU8	NO	NO	YES	YES	NO	NO	YES
1106		Refuse Station			-12.1096	96.890136		COCOS KEELING ISLANDS SHIRE	Economic	tip	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/708/708_2018-07-06%2012-54-38.png	MU8	YES	YES	YES	YES	YES	YES	YES
1106		Cemetry			-12.1081	96.88853		COCOS KEELING ISLANDS SHIRE	Social	cemetry	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/707/707_2018-07-06%2012-43-38.png	MU8	YES	YES	YES	YES	YES	YES	YES
1106		HISTORIC			-12.1096	96.889829		COCOS KEELING ISLANDS SHIRE	Environment	traditional turtle trap	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/706/706_2018-07-06%2012-42-06.png	MU9	YES	YES	YES	YES	NO	NO	NO
		DESAL			-12.1116	96.889431		COCOS KEELING ISLANDS SHIRE	Economic	Desalination Intake Bores	Home Island		MU9	NO	NO	YES	YES	NO	YES	YES
1106		Pondok			-12.1116	96.889431		COCOS KEELING ISLANDS SHIRE	Environment	pondok	Home Island		MU9	NO	NO	YES	YES	NO	YES	YES
1106		Pondok			-12.1123	96.890482		COCOS KEELING ISLANDS SHIRE	Environment	pondock	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/697/697_2018-07-06%2012-11-15.png	MU7	YES	YES	YES	YES	YES	YES	YES
1106		Potable Water Station			-12.1124	96.891818		COCOS KEELING ISLANDS SHIRE	Economic	potable water pump.station	Home Island			NO	NO	NO	YES	YES	YES	YES
1106		Satellite Communications			-12.1157	96.893556		COCOS KEELING ISLANDS SHIRE	Economic	Satellite communications	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/689/689_2018-07-06%2011-48-58.png	MU7	NO	YES	YES	YES	YES	YES	YES
1106		Patrick Ports			-12.1159	96.893704		COCOS KEELING ISLANDS SHIRE	Economic	patrick ports	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/688/688_2018-07-06%2011-47-55.png	MU7	YES	YES	YES	YES	YES	YES	YES
1106		Dry Dock Slip			-12.1162	96.893981		COCOS KEELING ISLANDS SHIRE	Economic	dry dock slip	Home Island		MU7	NO	YES	YES	YES	YES	YES	YES
1106		HISTORIC			-12.122	96.905203		COCOS KEELING ISLANDS SHIRE	Environment	traditional shelling site?	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/676/676_2018-07-06%2009-34-21.png	MU8	YES	YES	YES	YES	NO	NO	YES
		Pondok			-12.1235	96.904174		COCOS KEELING ISLANDS SHIRE	Environment	shelter	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/673/673_2018-07-06%2009-26-46.png	MU7	YES	YES	YES	YES	YES	YES	YES
1106		Boat Ramp			-12.1204	96.899193		COCOS KEELING ISLANDS SHIRE	Economic	boat ramp	Home Island		MU7	YES	YES	YES	YES	YES	YES	YES
1106		Boat Ramp			-12.1207	96.89718		COCOS KEELING ISLANDS SHIRE	Economic	boat ramp	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/669/669_2018-07-06%2009-12-40.png	MU7	YES	YES	YES	YES	YES	YES	YES
1106		Yacht Club			-12.1214	96.895786		COCOS KEELING ISLANDS SHIRE	Economic	yacht club	Home Island		MU7	YES	YES	YES	YES	YES	YES	YES
1106		HISTORIC			-12.1216	96.895814		COCOS KEELING ISLANDS SHIRE	Environment	Batu Bulat	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/665/665_2018-07-06%2009-06-28.png	MU7	NO	YES	YES	YES	YES	YES	YES
232		RESERVE		3,428	-12.116854	96.894038	FHOLD	COCOS KEELING ISLANDS SHIRE	Environment	park	Home Island		MU7	YES	YES	YES	YES	YES	YES	YES
0		Boat Ramp			-12.1191	96.893795			Economic	boat ramp	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/658/658_2018-07-06%2008-52-03.png	MU7	YES	YES	YES	YES	YES	YES	YES
0		RESERVE		8,241	-12.118194	96.89383	ROAD		Environment	foreshore park	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/657/657_2018-07-06%2008-50-48.png	MU7	YES	YES	YES	YES	YES	YES	YES
0		RESERVE			-12.1188	96.893759			Environment	foreshore park	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/657/657_2018-07-06%2008-50-48.png	MU7	NO	YES	YES	YES	YES	YES	YES
0		RESERVE			-12.1177	96.893883			Environment	picnic table	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/651/651_2018-07-06%2008-45-02.png	MU7	NO	NO	NO	NO	YES	YES	YES
1000	LOT 1000 JALAN PANTAI COCOS (KEELING) ISLANDS 6799	HISTORIC	SPECIAL USE	12,612	-12.120636	96.894316	FHOLD	LEIST, LLOYD CHARLES	Environment	oceania house	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/661/661_2018-07-06%2008-58-40.png	MU7	YES	YES	YES	YES	YES	YES	YES
1107		RESERVE		2,449	-12.119599	96.89373	FHOLD	COCOS KEELING ISLANDS SHIRE	Environment	park benches	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/652/652_2018-07-06%2008-45-39.png	MU7	YES	YES	YES	YES	YES	YES	YES
1107		RESERVE			-12.1178	96.893682		COCOS KEELING ISLANDS SHIRE	Environment	park benches	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/652/652_2018-07-06%2008-45-39.png	MU7	YES	YES	YES	YES	YES	YES	YES
1107		RESERVE			-12.1174	96.893661		COCOS KEELING ISLANDS SHIRE	Environment	bench	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/648/648_2018-07-06%2008-42-38.png	MU7	YES	YES	YES	YES	YES	YES	YES
1107		Boat Ramp			-12.1168	96.893591		COCOS KEELING ISLANDS SHIRE	Economic	public boat ramp	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/644/644_2018-07-06%2008-37-24.png	MU7	NO	YES	YES	YES	YES	YES	YES
341		Gesciences Australia Site			-12.1899	96.834693		COMMONWEALTH OF AUSTRALIA	Economic	GA seismic sration	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/769/769_2018-07-11%2013-41-12.png	MU3	YES	NO	NO	YES	NO	YES	YES
0		Boat Ramp			-12.1187	96.89377			Economic	boat ramp	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/656/656_2018-07-06%2008-49-55.png	MU7	YES	YES	YES	YES	YES	YES	YES
0		Boat Ramp			-12.1172	96.893689			Economic	boat ramp	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/647/647_2018-07-06%2008-42-05.png	MU7	YES	YES	YES	YES	YES	YES	YES
0		ROAD		2,260	-12.11651	96.894195	ROAD		Economic	Jetty Road	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/643/643_2018-07-06%2008-36-28.png	MU7	YES	YES	YES	YES	YES	YES	YES
0		ROAD		1,915	-12.116501	96.8943	ROAD		Economic	ROAD	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/643/643_2018-07-06%2008-36-28.png	MU7	YES	YES	YES	YES	YES	YES	YES
0		Picnic Park			-12.1204	96.899313			Environment	picnic spot	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/672/672_2018-07-06%2009-19-19.png	MU7	YES	YES	YES	YES	YES	YES	YES
0		Boat Yard			-12.1139	96.894681			Environment	boat yard	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/713/713_2018-07-06%2013-13-11.png	MU8	NO	YES	YES	YES	YES	YES	YES
246		COMMUNICATIONS			-12.1164	96.893941			Economic	mobile network tower	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/685/685_2018-07-06%2011-43-58.png	MU7	YES	NO	YES	YES	NO	YES	YES
233		Foreshore Park			-12.1193	96.89375			Environment	foreshore park	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/659/659_2018-07-06%2008-52-50.png	MU7	YES	YES	YES	YES	YES	YES	YES
233		Picnic Table			-12.1182	96.893691			Environment	picnic table	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/655/655_2018-07-06%2008-48-43.png	MU7	YES	YES	YES	YES	YES	YES	YES
233		Boat Ramp			-12.1176	96.893679			Economic	boat ramp	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/650/650_2018-07-06%2008-44-04.png	MU7	YES	YES	YES	YES	YES	YES	YES
233		Seat			-12.1175	96.893644			Environment	concrete seat	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/649/649_2018-07-06%2008-43-14.png	MU7	NO	YES	YES	YES	YES	YES	YES
233		Picnic Table			-12.1171	96.89361			Environment	picnic table	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/646/646_2018-07-06%2008-41-12.png	MU7	NO	YES	YES	YES	YES	YES	YES
242	JALAN MELATI	Supermarket			-12.1158	96.893818			Economic	supermarket	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/687/687_2018-07-06%2011-46-18.png	MU7	YES	NO	YES	YES	NO	YES	YES
239		PONDOK		1,151	-12.115453	96.893557	FHOLD		Environment	pondok	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/690/690_2018-07-06%2011-51-24.png	MU7	YES	YES	YES	YES	YES	YES	YES
239		Pondok			-12.1154	96.893479			Environment	pondok	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/690/690_2018-07-06%2011-51-24.png	MU7	YES	YES	YES	YES	YES	YES	YES
		Rubble groyne			-12.1125	96.889188			Economic	remnant groyne	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/699/699_2018-07-06%2012-17-15.png	MU7	YES	YES	YES	YES	YES	YES	YES
		Historical Monuments			-12.1155	96.893351			Environment	historical site	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/692/692_2018-07-06%2011-53-17.png	MU7	YES	YES	YES	YES	YES	YES	YES
		Home Island Jetty			-12.1166	96.893394			Economic	Home Island jetty	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/683/683_2018-07-06%2011-41-11.png	MU7	NO	YES	YES	YES	YES	YES	YES
		Historic Watchtower Site			-12.1152	96.898102			Environment	watchtower site	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/679/679_2018-07-06%2010-01-20.png	MU8	NO	YES	YES	YES	YES	YES	YES
		Boat Ramp			-12.118	96.893597			Economic	boat ramp	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/654/654_2018-07-06%2008-47-17.png	MU7	YES	YES	YES	YES	YES	YES	YES
		Septic Tank			-12.1179	96.893606			Economic	septic tank	Home Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/653/653_2018-07-06%2008-46-30.png	MU7	YES	YES	YES	YES	YES	YES	YES
339		HISTORIC		22,565	-12.120418	96.895208	CROWN	COMMONWEALTH OF AUSTRALIA	Environment	OCEANIA HOUSE	Home Island		MU7	YES	YES	YES	YES	YES	YES	YES
338	JALAN PANTAI	ROAD	FORESHORE PROTECTION AND NATURE CONSERVATI ON	6,736	-12.121331	96.893785	CROWN	COMMONWEALTH OF AUSTRALIA	Economic	ROAD	Home Island		MU7	YES	YES	YES	YES	YES	YES	YES
0		ROAD		906	-12.115958	96.894193	ROAD		Economic		Home Island			NO	NO	YES	YES	NO	YES	YES
0		ROAD		2,391	-12.116806	96.900294	ROAD		Economic	ROAD	Home Island		MU8	NO	YES	YES	YES	YES	YES	YES
0		ROAD		1,980	-12.117941	96.901793	ROAD		Economic	ROAD	Home Island		MU8	NO	YES	YES	YES	YES	YES	YES
0		ROAD		12,247	-12.117985	96.896939	ROAD		Economic	ROAD	Home Island		MU7	NO	YES	YES	YES	YES	YES	YES
0		ROAD		8,340	-12.116816	96.896359	ROAD		Economic	ROAD	Home Island		MU7	NO	YES	YES	YES	YES	YES	YES
0		ROAD		2,542	-12.11899	96.895167	ROAD		Economic	ROAD	Home Island		MU7	NO	NO	NO	NO	YES	YES	YES
0		ROAD		554	-12.119289	96.895349	ROAD		Economic	ROAD	Home Island			NO	NO	NO	NO	YES	YES	YES
0		ROAD		648	-12.11947	96.895669	ROAD		Economic	ROAD	Home Island			NO	NO	NO	NO	YES	YES	YES
0		ROAD		1,047	-12.119461	96.896028	ROAD		Economic	ROAD	Home Island			NO	NO	NO	YES	YES	YES	YES
0		ROAD		1,110	-12.119316	96.896468	ROAD		Economic	ROAD	Home Island			NO	NO	NO	NO	YES	YES	YES
0		ROAD		2,978	-12.118974	96.896916	ROAD		Economic	ROAD	Home Island			NO	NO	NO	YES	YES	YES	YES
0		ROAD		7,065	-12.118837	96.899634	ROAD		Economic	ROAD	Home Island		MU8	NO	YES	YES	YES	YES	YES	YES
0		ROAD		1,238	-12.118559	96.897387	ROAD		Economic	ROAD	Home Island			NO	NO	NO	NO	YES	YES	YES
0		ROAD		973	-12.118527	96.89585	ROAD		Economic	ROAD	Home Island			NO	NO	NO	NO	NO	YES	YES
0		ROAD		974	-12.118614	96.895281	ROAD		Economic	ROAD	Home Island			NO	NO	NO	NO	YES	YES	YES
0		ROAD		1,860	-12.117393	96.896677	ROAD		Economic	ROAD	Home Island			NO	NO	NO	NO	NO	YES	YES
0		ROAD		1,861	-12.117631	96.895133	ROAD		Economic	ROAD	Home Island			NO	NO	NO	NO	NO	YES	YES
0		ROAD		1,861	-12.117543	96.895702	ROAD		Economic	ROAD	Home Island			YES	NO	NO	NO	NO	YES	YES
0		ROAD		1,488	-12.117236	96.897699	ROAD		Economic	ROAD	Home Island			NO	NO	NO	NO	NO	YES	YES
0		ROAD		2,047	-12.116196	96.894902	ROAD		Economic	ROAD	Home Island			NO	NO	NO	YES	NO	YES	YES
0		ROAD		1,790	-12.116229	96.895561	ROAD		Economic	ROAD	Home Island			NO	NO	NO	YES	NO	YES	YES
0		ROAD		1,224	-12.116091	96.897011	ROAD		Economic	ROAD	Home Island		MU8	YES	NO	YES	YES	NO	YES	YES
0		ROAD		1,102	-12.116169	96.895999	ROAD		Economic		Home Island			NO	NO	NO	YES	NO	YES	YES
0		ROAD		12,665	-12.112775	96.892063	ROAD		Economic	HI north track	Home Island		MU7	NO	YES	YES	YES	YES	YES	YES
0		ROAD		528	-12.115594	96.893803	ROAD		Economic		Home Island		MU7	YES	YES	YES	YES	YES	YES	YES
0		ROAD		9,553	-12.12034	96.89959	ROAD		Economic	ROAD	Home Island		MU7	NO	YES	YES	YES	YES	YES	YES
0		ROAD		1,089	-12.120519	96.896165	ROAD		Economic	ROAD	Home Island		MU7	NO	YES	YES	YES	YES	YES	YES

0		ROAD		1,354	-12.120269	96.89711	ROAD		Economic	ROAD	Home Island		MU7	NO	YES	YES	YES	YES	YES	YES
0		ROAD		1,839	-12.119456	96.900556	ROAD		Economic	ROAD	Home Island		MU7	NO	NO	YES	YES	YES	YES	YES
0		ROAD		14,957	-12.122732	96.903098	ROAD		Economic	ROAD	Home Island		MU7	NO	YES	YES	YES	YES	YES	YES
0		ROAD		1,883	-12.114698	96.894709	ROAD		Economic		Home Island		MU8	NO	NO	YES	YES	NO	YES	YES
0		ROAD		1,995	-12.113433	96.893673	ROAD		Economic	ROAD	Home Island		MU8	NO	NO	NO	YES	NO	NO	YES
0		ROAD		10,117	-12.115427	96.897214	ROAD		Economic	ROAD	Home Island		MU8	NO	YES	YES	YES	YES	YES	YES
2		ROAD		241	-12.116505	96.896032	FHOLD		Economic	ROAD	Home Island			YES	NO	NO	NO	NO	YES	YES
1		ROAD		464	-12.117472	96.896183	FHOLD		Economic	ROAD	Home Island			YES	NO	NO	NO	NO	NO	YES
1		ROAD		448	-12.118714	96.896377	FHOLD		Economic	ROAD	Home Island			YES	NO	NO	NO	YES	YES	YES
1		ROAD		717	-12.11773	96.894492	FHOLD		Economic	ROAD	Home Island			YES	NO	NO	NO	YES	YES	YES
2		ROAD		380	-12.118711	96.894652	FHOLD		Economic	ROAD	Home Island			NO	NO	NO	NO	YES	YES	YES
1		ROAD		298	-12.116181	96.893991	FHOLD		Economic		Home Island		MU7	NO	NO	YES	YES	NO	YES	YES
244		ROAD		59	-12.115881	96.894072	FHOLD		Economic		Home Island			YES	NO	YES	YES	NO	YES	YES
210		ROAD		3,835	-12.117369	96.898315	FHOLD		Economic	ROAD	Home Island		MU8	NO	NO	NO	NO	NO	YES	YES
254		Refuse Station		9,468	-12.111761	96.892501	FHOLD		Economic	TIP	Home Island		MU8		YES	YES	YES	YES	YES	YES
		GSC seawall								Home Island GSC seawall	Home Island		MU7		YES	YES	YES	YES	YES	YES
		RESERVE						COCOS KEELING ISLANDS SHIRE	Environment	park	Home Island		MU7		YES	YES	YES	YES	YES	YES
33		AIR FORCE		180,526	-12.199456	96.858258	FHOLD		Economic	Defense Operations	South Island		MU3		YES	YES	YES	YES	YES	YES
341		AIRPORT		985,509	-12.191639	96.834037	FHOLD	COMMONWEALTH OF AUSTRALIA	Economic	Airport	West Island		MU1		YES	YES	YES	YES	YES	YES
0		POWER STATION		3,340	-12.185013	96.827997	RESVE	COMMONWEALTH OF AUSTRALIA	Economic	West Island Power Station	West Island		MU1		NO	NO	NO	NO	YES	YES
		Power Station			-12.1852	96.827933		STATE OF WA	Economic	West Island Power Station	West Island		MU1		NO	NO	NO	NO	YES	YES
349		Medical Centre		2,458	-12.188477	96.829449	FHOLD	COMMONWEALTH OF AUSTRALIA	Social	Medical Centre	West Island		MU1		NO	NO	YES	NO	YES	YES
		RUMAH BARU			-12.1565	96.830542		Commonwealth	Economic	Rumah Baru	West Island		MU4		YES	YES	YES	YES	YES	YES
100		RESERVE		550,797	-12.200437	96.855843	FHOLD	COCOS KEELING ISLANDS SHIRE	Environment	WI LAGGON STH	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/632/632_2018-07-05%2017-06-14.png	MU3		YES	YES	YES	YES	YES	YES
228		POWER		72	-12.203939	96.852397	FHOLD		Economic	substation 13	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/632/632_2018-07-05%2017-06-14.png	MU6		NO	YES	YES	YES	YES	YES
0	LOT 209 AIRSTRIP ROAD/MET.OFFICE COCOS (KEELING) IS	BUREAU OF METEOROLOGY WEATHER STATION, AIRPORT, ALEXANDER STREET	SPECIAL USE	41,198	-12.187863	96.833975	RESVE	COMMONWEALTH OF AUSTRALIA	Economic	BUREAU OF METEOROLOGY WEATHER STATION, AIRPORT, ALEXANDER STREET	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/761/761_2018-07-11%2013-21-07.png	MU3		YES	YES	YES	YES	YES	YES
0	AIRSTRIP ROAD	Gesciences Australia Site			-12.1874	96.833566		COMMONWEALTH OF AUSTRALIA	Economic	BUREAU OF METEOROLOGY WEATHER STATION, AIRPORT, ALEXANDER STREET	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/761/761_2018-07-11%2013-21-07.png	MU3		NO	NO	YES	NO	YES	YES
341		AIRPORT			-12.1891	96.834799		COMMONWEALTH OF AUSTRALIA	Economic	IOTT tower	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/768/768_2018-07-11%2013-39-25.png	MU3		NO	YES	YES	NO	YES	YES
341		Water Supply			-12.1823	96.827043		COMMONWEALTH OF AUSTRALIA	Economic	water supply point	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/753/753_2018-07-11%2012-39-28.png			NO	NO	NO	NO	YES	YES
335		FUEL STATION		12,311	-12.137523	96.82334	FHOLD	COMMONWEALTH OF AUSTRALIA	Economic	fuel station solar lighting	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/581/581_2018-07-04%2010-27-15.png	MU3		YES	YES	YES	YES	YES	YES
335		FUEL STATION			-12.1376	96.823095		COMMONWEALTH OF AUSTRALIA	Economic	fuel station solar lighting	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/581/581_2018-07-04%2010-27-15.png	MU3		NO	YES	YES	YES	YES	YES
335		FUEL STATION			-12.1377	96.823191		COMMONWEALTH OF AUSTRALIA	Economic	fuel station amenities	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/580/580_2018-07-04%2010-24-47.png	MU3		YES	YES	YES	YES	YES	YES
1106		Pondok			-12.1218	96.895796		COCOS KEELING ISLANDS SHIRE	Environment	Pondok Abang	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/663/663_2018-07-06%2009-03-46.png	MU7		YES	YES	YES	YES	YES	YES
167		Pondok			-12.1961	96.83487		COMMONWEALTH OF AUSTRALIA	Environment	Airport Beach Pondok	West Island		MU6		YES	YES	YES	YES	YES	YES
167		Fire Hydrant			-12.1947	96.83409		COMMONWEALTH OF AUSTRALIA	Economic	fire hydrant connection	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/774/774_2018-07-11%2014-30-25.png	MU1		NO	NO	YES	NO	NO	YES
167		RESERVE			-12.1921	96.831207		COMMONWEALTH OF AUSTRALIA	Environment	picnic table	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/572/572_2018-07-03%2016-52-58.png	MU1		NO	NO	NO	YES	YES	YES
167		RESERVE			-12.1915	96.830846		COMMONWEALTH OF AUSTRALIA	Environment	bench	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/571/571_2018-07-03%2016-50-33.png	MU1		NO	NO	NO	YES	YES	YES
328	SYDNEY HIGHWAY	CROWN		102,826	-12.182226	96.821057	CROWN	COMMONWEALTH OF AUSTRALIA	Environment	VACANT	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/613/613_2018-07-04%2016-35-36.png	MU1		YES	YES	YES	YES	YES	YES
328		RESERVE			-12.1807	96.819844		COMMONWEALTH OF AUSTRALIA	Environment	North Park	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/613/613_2018-07-04%2016-35-36.png	MU2a		YES	YES	YES	YES	YES	YES
167		RESERVE			-12.1897	96.829579		COMMONWEALTH OF AUSTRALIA	Environment	beach park picnic table	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/577/577_2018-07-03%2017-11-34.png	MU1		NO	NO	NO	YES	YES	YES
167		Memorial			-12.1893	96.829383		COMMONWEALTH OF AUSTRALIA	Environment	RAAF Sergeants Mess Memorial	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/576/576_2018-07-03%2017-10-31.png	MU1		NO	YES	YES	YES	YES	YES
167		Carpark			-12.1895	96.82942		COMMONWEALTH OF AUSTRALIA	Social	beach park carpark	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/575/575_2018-07-03%2017-09-32.png	MU1		NO	YES	YES	YES	YES	YES
167		RESERVE			-12.1907	96.830272		COMMONWEALTH OF AUSTRALIA	Environment	park bench	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/574/574_2018-07-03%2017-06-10.png	MU1		NO	NO	NO	YES	YES	YES
0		Defense Buildings		4,128	-12.185644	96.828376	RESVE	COMMONWEALTH OF AUSTRALIA	Economic	SPECIAL USE	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/749/749_2018-07-11%2012-32-00.png	MU1		NO	NO	NO	NO	YES	YES
100		Communications Array			-12.1997	96.840663		COCOS KEELING ISLANDS SHIRE	Economic	airfield communications array	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/772/772_2018-07-11%2014-02-54.png	MU3		YES	YES	YES	YES	YES	YES
100		WWTP			-12.1687	96.82186		COCOS KEELING ISLANDS SHIRE	Economic	WI Wastewater Treatment Plant	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/607/607_2018-07-04%2016-09-41.png	MU3		NO	NO	YES	NO	NO	YES
100		Geosciences Australia Site			-12.1541	96.826729		COCOS KEELING ISLANDS SHIRE	Economic	GA SITE	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/603/603_2018-07-04%2015-46-34.png	MU4		NO	YES	YES	YES	YES	YES
100		Gesciences Australia Site			-12.1454	96.824652		COCOS KEELING ISLANDS SHIRE	Economic	GA SITE	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/600/600_2018-07-04%2015-22-08.png	MU3		NO	NO	YES	NO	YES	YES
100		RUMAH BARU			-12.1569	96.827808		COCOS KEELING ISLANDS SHIRE	Economic	ferry terminal public carpark	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/591/591_2018-07-04%2011-32-29.png	MU4		NO	YES	YES	YES	YES	YES
100		RUMAH BARU			-12.1569	96.827279		COCOS KEELING ISLANDS SHIRE	Economic	container storage	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/590/590_2018-07-04%2011-31-18.png	MU4		NO	YES	YES	YES	YES	YES
100		RUMAH BARU			-12.1567	96.827531		COCOS KEELING ISLANDS SHIRE	Economic	ferry terminal office	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/589/589_2018-07-04%2011-30-00.png	MU4		NO	YES	YES	NO	YES	YES
100		RUMAH BARU			-12.1567	96.827661		COCOS KEELING ISLANDS SHIRE	Economic	ferry terminal water tank	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/588/588_2018-07-04%2011-28-48.png	MU4		NO	YES	YES	NO	NO	YES
100		RUMAH BARU			-12.1567	96.827748		COCOS KEELING ISLANDS SHIRE	Economic	ferry terminal toilet block	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/587/587_2018-07-04%2011-28-14.png	MU4		NO	YES	YES	NO	NO	YES
0		RUMAH BARU		759	-12.156816	96.828117	ROAD	COCOS KEELING ISLANDS SHIRE	Economic	ferry emergency evacuation point	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/586/586_2018-07-04%2011-27-17.png	MU4		NO	YES	YES	YES	YES	YES
100		RESERVE		219,054	-12.153396	96.819821	FHOLD	COCOS KEELING ISLANDS SHIRE	Environment	The Spot Public area	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/605/605_2018-07-04%2016-04-38.png	MU2b		YES	YES	YES	YES	YES	YES
100		RESERVE			-12.1654	96.82157		COCOS KEELING ISLANDS SHIRE	Environment	The Spot Public area	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/605/605_2018-07-04%2016-04-38.png	MU2a		YES	YES	YES	YES	YES	YES
100		The Barge Art Centre			-12.1526	96.820537		COCOS KEELING ISLANDS SHIRE	Economic	big barge art centre	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/601/601_2018-07-04%2015-31-11.png	MU2b		NO	YES	YES	NO	NO	NO
100		AIRPORT			-12.1859	96.832174		COCOS KEELING ISLANDS SHIRE	Economic	airfield storage	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/760/760_2018-07-11%2013-19-20.png	MU3		NO	NO	YES	NO	YES	YES
100		RESERVE			-12.1417	96.817875		COCOS KEELING ISLANDS SHIRE	Environment	Trannies bbq area	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/583/583_2018-07-04%2010-36-55.png	MU2b		YES	YES	YES	YES	YES	YES
100		RESERVE		292,835	-12.202359	96.856459	FHOLD		Environment	WI OCEAN STH	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/634/634_2018-07-05%2017-10-43.png	MU3		YES	YES	YES	YES	YES	YES
217		HISTORIC		34	-12.204865	96.850779	FHOLD		Environment	Twiss memorial	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/634/634_2018-07-05%2017-10-43.png	MU6		YES	YES	YES	YES	YES	YES
216		RESERVE		2,400	-12.198687	96.86326	FHOLD		Social	scout park	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/631/631_2018-07-05%2016-54-51.png	MU5		NO	YES	YES	YES	YES	YES
100		Boat Ramp			-12.1952	96.862702			Economic	public boat ramp	West Island		MU5		YES	YES	YES	YES	YES	YES
215		Yacht Club		3,397	-12.193393	96.860577	FHOLD		Social	Yacht Club	West Island		MU5		YES	YES	YES	YES	YES	YES
135	AIR FORCE ROAD	Fire Hydrant			-12.1897	96.831041		COMMONWEALTH OF AUSTRALIA	Economic	POLICE HOUSE	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/784/784_2018-07-11%2014-41-30.png	MU1		NO	NO	NO	NO	YES	YES
162	AIR FORCE ROAD	Fire Hydrant			-12.1933	96.83325		DICKS, DILYS ELIZABETH	Economic	VACANT LAND, AIR FORCE ROAD.	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/776/776_2018-07-11%2014-33-06.png	MU1		NO	NO	NO	NO	YES	YES
162	AIR FORCE ROAD	Fire Hydrant			-12.1934	96.833323		DICKS, DILYS ELIZABETH	Economic	VACANT LAND, AIR FORCE ROAD.	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/775/775_2018-07-11%2014-32-07.png	MU1		NO	NO	NO	NO	YES	YES
169	NELSON MANDELA WALK	SCHOOL	PUBLIC PURPOSE - SCHOOL	11,433	-12.190412	96.830969	CROWN	COMMONWEALTH OF AUSTRALIA	Economic	SCHOOL, AIRFORCE ROAD	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/783/783_2018-07-11%2014-39-51.png	MU1		NO	NO	NO	NO	YES	YES
169		Bus Stop			-12.1904	96.83149		COMMONWEALTH OF AUSTRALIA	Economic	SCHOOL, AIRFORCE ROAD	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/783/783_2018-07-11%2014-39-51.png	MU1		NO	NO	NO	NO	YES	YES
170	NELSON MANDELA WALK	POWER		6,991	-12.189255	96.830189	RESVE	COMMONWEALTH OF AUSTRALIA	Economic	substation	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/788/788_2018-07-11%2014-45-46.png	MU1		NO	YES	YES	NO	YES	YES

209	AIR FORCE ROAD	Gesciences Australia Site			-12.1883	96.833982		COMMONWEALTH OF AUSTRALIA	Economic	BUREAU OF METEOROLOGY WEATHER STATION, AIRPORT, ALEXANDER STREET	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/763/763_2018-07-11%2013-26-15.png	MU3		NO	NO	YES	NO	YES	YES
327		CROWN		211,459	-12.174941	96.819598	CROWN	COMMONWEALTH OF AUSTRALIA	Social	VACANT	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/610/610_2018-07-04%2016-24-46.png	MU3		YES	YES	YES	YES	YES	YES
327		RESERVE			-12.1736	96.81828		COMMONWEALTH OF AUSTRALIA	Environment	the shack	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/610/610_2018-07-04%2016-24-46.png	MU2a		YES	YES	YES	YES	YES	YES
169		Bus Stop			-12.1904	96.83149		COMMONWEALTH OF AUSTRALIA	Economic	SCHOOL, AIRFORCE ROAD	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/783/783_2018-07-11%2014-39-51.png	MU1		NO	NO	NO	NO	YES	YES
206		TRANSMITTER SITE		32,022	-12.143427	96.818931	CROWN	STATE OF WA	Economic	TRANSMITTER SITE, CIVIL AVIATION AUTHORITY (CAA)	West Island		MU2b		YES	YES	YES	YES	YES	YES
209	AIR FORCE ROAD	BUREAU OF METEOROLOGY SITE			-12.1886	96.834302		COMMONWEALTH OF AUSTRALIA	Economic	BUREAU OF METEOROLOGY WEATHER STATION, AIRPORT, ALEXANDER STREET	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/766/766_2018-07-11%2013-34-36.png	MU3		NO	YES	YES	YES	YES	YES
313	BUFFETT CLOSE	TRANSFORMER		35	-12.185038	96.825992	CROWN	COMMONWEALTH OF AUSTRALIA	Economic	substation 20	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/623/623_2018-07-05%2015-28-25.png	MU1		NO	NO	YES	NO	NO	YES
169		Bus Stop			-12.1904	96.83149		COMMONWEALTH OF AUSTRALIA	Economic	SCHOOL, AIRFORCE ROAD	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/783/783_2018-07-11%2014-39-51.png	MU1		NO	NO	NO	NO	YES	YES
0		RESERVE		81,230	-12.183657	96.824245	RESVE	COMMONWEALTH OF AUSTRALIA	Environment	sand quarry	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/615/615_2018-07-04%2016-42-19.png	MU1		YES	YES	YES	YES	YES	YES
0		RESERVE			-12.1844	96.82379		COMMONWEALTH OF AUSTRALIA	Economic	sand quarry	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/615/615_2018-07-04%2016-42-19.png	MU1		YES	YES	YES	YES	YES	YES
335		RUMAH BARU			-12.1376	96.823253		COMMONWEALTH OF AUSTRALIA	Economic	rama baru boat ramp	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/584/584_2018-07-04%2011-23-16.png	MU4		YES	YES	YES	YES	YES	YES
335		FUEL STATION			-12.1376	96.823058		COMMONWEALTH OF AUSTRALIA	Economic	fuel station solar lighting	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/581/581_2018-07-04%2010-27-15.png	MU3		NO	YES	YES	YES	YES	YES
341		Fire Hydrant			-12.2033	96.841145		COMMONWEALTH OF AUSTRALIA	Economic	fire hydrant connection	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/773/773_2018-07-11%2014-28-54.png	MU3		NO	YES	YES	NO	YES	YES
30		PONDOK		3,283	-12.193101	96.859839	FHOLD		Economic	nth kite shelter	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/628/628_2018-07-05%2016-27-24.png	MU5		YES	YES	YES	YES	YES	YES
29		REFUSE STATION			-12.206				Economic	sludge storage	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/635/635_2018-07-05%2017-13-32.png	MU6		NO	YES	YES	NO	YES	YES
		Bus Stop			-12.1864	96.827415			Economic	bus stop	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/793/793_2018-07-11%2015-08-59.png	MU1		NO	NO	YES	NO	NO	NO
		weather equipment			-12.1882	96.83028			Economic	Weather vane	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/792/792_2018-07-11%2014-48-26.png	MU1		NO	NO	NO	NO	YES	YES
		Fire Hydrant			-12.1884	96.830278			Economic	fire hydrant connection	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/791/791_2018-07-11%2014-47-55.png	MU1		NO	NO	NO	NO	YES	YES
		Groundwater Monitoring Station			-12.1907	96.831685			Economic	groundwater monitoring	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/781/781_2018-07-11%2014-38-45.png	MU1		NO	NO	NO	NO	YES	YES
		Fire Hydrant			-12.1907	96.831709			Economic	fire hydrant connection and substation	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/780/780_2018-07-11%2014-38-14.png	MU1		NO	NO	NO	NO	YES	YES
		Fire Hydrant			-12.192	96.832508			Economic	fire hydrant connection	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/778/778_2018-07-11%2014-35-13.png	MU1		NO	NO	NO	NO	YES	YES
		Bus Stop			-12.1924	96.832438			Economic	bus stop	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/777/777_2018-07-11%2014-34-04.png	MU1		NO	NO	NO	NO	YES	YES
		Emergency Lighting			-12.1853	96.827966			Social	emergency lighting genset	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/750/750_2018-07-11%2012-33-00.png	MU1		NO	NO	NO	NO	YES	YES
		Pondok			-12.1938	96.86161			Social	kayak hut	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/626/626_2018-07-05%2016-08-42.png	MU5		YES	YES	YES	YES	YES	YES
		Fire Hydrant			-12.1854	96.825602			Economic	fire connection	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/624/624_2018-07-05%2015-29-49.png	MU1		NO	NO	YES	NO	NO	NO
25		REFUSE STATION		23,286	-12.181667	96.822732	FHOLD		Economic	Wet Tip	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/614/614_2018-07-04%2016-39-15.png	MU3		YES	YES	YES	YES	YES	YES
227		REFUSE STATION		21,016	-12.161903	96.82948	FHOLD		Economic	Wet tip	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/595/595_2018-07-04%2012-44-00.png	MU4		YES	YES	YES	YES	YES	YES
		CIBR groyne			-12.1879	96.827635			Economic	WI Motel CIBR groyne	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/567/567_2018-07-03%2016-17-09.png	MU1		YES	YES	YES	YES	YES	YES
		Ceebee Wall			-12.1931	96.831696		COMMONWEALTH OF AUSTRALIA	Economic	Govt House Ceebee Wall	West Island		MU1		YES	YES	YES	YES	YES	YES
		GSC seawall			-12.1902	96.829893			Economic	William Keeling Cres. Geobag Wall	West Island		MU1		YES	YES	YES	YES	YES	YES
		GSC seawall			-12.2045	96.851579			Economic	Twiss Memorial Geobag Seawall	West Island		MU6		YES	YES	YES	YES	YES	YES
		GSC seawall			-12.2017	96.83873			Economic	Airforce Rd Geobag Wall	West Island		MU6		YES	YES	YES	YES	YES	YES
		Private Road							Economic	Air Force Operations	West Island		MU3		NO	NO	NO	NO	NO	YES
0		ROAD		48,541	-12.205461	96.84525	ROAD		Economic	ROAD	West Island		MU3		YES	YES	YES	YES	YES	YES
0		RESERVE		82,462	-12.205677	96.843179	RESVE	COMMONWEALTH OF AUSTRALIA	Environment	WI OCEAN STH	West Island		MU3		YES	YES	YES	YES	YES	YES
334		FUEL STATION		7,351	-12.137965	96.823582	CROWN	COMMONWEALTH OF AUSTRALIA	Economic		West Island		MU3		YES	YES	YES	YES	YES	YES
198	BEACON HEIGHTS ROAD	ROAD		126	-12.185021	96.82443	RESVE	COMMONWEALTH OF AUSTRALIA	Economic	ROAD	West Island		MU1		NO	YES	YES	NO	NO	NO
0		AIRPORT		1,920	-12.184588	96.827711	RESVE	COMMONWEALTH OF AUSTRALIA	Economic	SPECIAL USE	West Island		MU1		NO	NO	NO	NO	YES	YES
100		RESERVE		83,860	-12.196919	96.839114	FHOLD	COCOS KEELING ISLANDS SHIRE	Environment	AIRPORT/LAGOON	West Island		MU3		YES	YES	YES	YES	YES	YES
100		RESERVE		13,996	-12.198341	96.836153	FHOLD	COCOS KEELING ISLANDS SHIRE	Environment	AIRPORT OCEAN	West Island		MU6		YES	YES	YES	YES	YES	YES
100		RESERVE		407	-12.179132	96.828009	FHOLD	COCOS KEELING ISLANDS SHIRE	Environment	LAGOON ISLANDS	West Island		MU3		YES	YES	YES	YES	YES	YES
126	26 QANTAS CLOSE/GOVT. HSE COCOS (KEELING) ISLANDS 6	CROWN	RESIDENTIAL R15	2,240	-12.19374	96.832796	RESVE	COMMONWEALTH OF AUSTRALIA	Economic	HOUSE 26, ADMINISTRATOR'S RESIDENCE.	West Island		MU1		NO	YES	NO	NO	YES	YES
141	41 WILLIAM KEELING CRESCENT/IOTHS STAFF COCOS (KEEL	CROWN	RESIDENTIAL R15	1,044	-12.189734	96.830224	CROWN	COMMONWEALTH OF AUSTRALIA	Economic	RESIDENCES	West Island		MU1		NO	NO	NO	YES	YES	YES
166	AIR FORCE ROAD	RESERVE	FORESHORE PROTECTION AND NATURE CONSERVATI ON	1,994	-12.195464	96.83437	CROWN	COMMONWEALTH OF AUSTRALIA	Economic	SURVEY MARK	West Island		MU6		YES	YES	YES	YES	YES	YES
168	HAJIDUN LANE	POWER		75	-12.192079	96.832096	RESVE	COMMONWEALTH OF AUSTRALIA	Economic	TRANSFORMER SITE	West Island		MU1		NO	NO	NO	NO	YES	YES
176	NELSON MANDELA WALK	POWER	PARKS AND RECREATION	130	-12.188885	96.830396	CROWN	COMMONWEALTH OF AUSTRALIA	Economic	TRANSFORMER SITE LOC 176	West Island		MU1		NO	NO	YES	NO	YES	YES
179	SYDNEY HIGHWAY	RESERVE		9,209	-12.187218	96.828573	RESVE	COMMONWEALTH OF AUSTRALIA	Social	PARK	West Island		MU1		NO	NO	YES	NO	YES	YES
187	EMDEN WALK & ALEXANDER ST	RELIGIOUS		1,137	-12.18639	96.82825	CROWN	COMMONWEALTH OF AUSTRALIA	Social	church	West Island		MU1		NO	NO	YES	NO	YES	YES
188	LOT 188 EMDEN WALK/SHELL SHEDS COCOS (KEELING) ISLA	AIRPORT	COMMERCIAL	522	-12.186497	96.828065	RESVE	COMMONWEALTH OF AUSTRALIA	Economic	SHELL WORKSHOP	West Island		MU1		NO	NO	YES	NO	YES	YES
189	LOT 189 EMDEN WALK/OFFICE SHELL COCOS (KEELING) ISL	AIRPORT	COMMERCIAL	569	-12.186568	96.827945	CROWN	COMMONWEALTH OF AUSTRALIA	Economic	SHELL OFFICE AND WORKSHOP, EMDEN WALK.	West Island		MU1		NO	NO	YES	NO	YES	YES
190	LOT 190 EMDEN WALK/ENIC INTERCOM TOWER COCOS (KEELI	AIRPORT	COMMERCIAL	705	-12.186649	96.827802	CROWN	ENIC COCOS KEELING ISLANDS PTY LTD	Economic	SYDNEY HIGHWAY & EMDEN WALK.	West Island		MU1		NO	NO	YES	NO	YES	YES
197	BEACON HEIGHTS ROAD	ROAD		165	-12.185977	96.825871	CROWN	COMMONWEALTH OF AUSTRALIA	Economic	ROAD	West Island		MU1		NO	YES	YES	NO	NO	NO
199		ROAD		100	-12.188353	96.828689	CROWN	COMMONWEALTH OF AUSTRALIA	Economic	ROAD	West Island		MU1		NO	YES	YES	NO	NO	NO
221	WILLIAM KEELING CRESCENT	HISTORIC	FORESHORE PROTECTION AND NATURE CONSERVATI ON	15	-12.190427	96.830063	RESVE	COMMONWEALTH OF AUSTRALIA	Environment	MEMORIAL	West Island		MU1		NO	NO	NO	YES	YES	YES
319	SYDNEY HIGHWAY	COMMUNICATIONS		118	-12.188437	96.829164	RESVE	COMMONWEALTH OF AUSTRALIA	Economic	TOWER	West Island		MU1		NO	NO	YES	NO	YES	YES
323	SYDNEY HIGHWAY	AIRPORT	SPECIAL USE	1,033	-12.18477	96.827241	CROWN	COMMONWEALTH OF AUSTRALIA	Economic	SPECIAL USE	West Island		MU1		NO	NO	NO	NO	YES	YES
333		BUS STATION		90	-12.138379	96.822338	CROWN	COMMONWEALTH OF AUSTRALIA	Social		West Island		MU3		NO	NO	YES	NO	YES	YES
0		ROAD		2,122	-12.180557	96.820302	ROAD		Economic	ROAD	West Island		MU3		YES	YES	YES	NO	NO	YES
0		ROAD		3,826	-12.175083	96.820721	ROAD		Economic	ROAD	West Island		MU3		NO	YES	YES	NO	YES	YES
0		ROAD		23,132	-12.202903	96.839685	ROAD		Economic	ROAD	West Island		MU3		YES	YES	YES	YES	YES	YES
0		ROAD		4,430	-12.184733	96.825993	ROAD		Economic	ROAD	West Island		MU1		NO	NO	YES	NO	NO	YES
346		AIRPORT		42	-12.185992	96.828388	FHOLD	COMMONWEALTH OF AUSTRALIA	Economic	SPECIAL USE	West Island		MU1		NO	NO	NO	NO	YES	YES

0		FUEL STATION		15,365	-12.137339	96.822421	RESVE	COMMONWEALTH OF AUSTRALIA	Economic	STORAGE	West Island		MU3		YES	YES	YES	YES	YES	YES
3006		ROAD		136	-12.184167	96.824621	FHOLD	COMMONWEALTH OF AUSTRALIA	Economic	ROAD	West Island		MU1		NO	NO	YES	NO	NO	NO
0		ROAD		3,620	-12.143239	96.820909	ROAD		Economic	ROAD	West Island		MU2b		NO	YES	YES	NO	YES	YES
0		ROAD		28,466	-12.141118	96.82173	ROAD		Economic	ROAD	West Island		MU2b		NO	NO	YES	YES	YES	YES
0		ROAD		3,585	-12.152329	96.820755	ROAD		Economic	ROAD	West Island		MU2b		NO	NO	YES	NO	NO	NO
0		ROAD		8,785	-12.159439	96.82119	ROAD		Economic	ROAD	West Island		MU2b		YES	YES	YES	YES	YES	YES
0		ROAD		3,521	-12.155608	96.820923	ROAD		Economic	ROAD	West Island		MU2b		NO	YES	YES	NO	NO	NO
0		ROAD		5,728	-12.157851	96.822847	ROAD		Economic	ROAD	West Island		MU2b		NO	YES	YES	NO	NO	YES
0		ROAD		6,954	-12.15725	96.827377	ROAD		Economic	ROAD	West Island		MU4		NO	YES	YES	YES	YES	YES
0		ROAD		7,276	-12.159092	96.828939	ROAD		Economic	ROAD	West Island		MU4		NO	YES	YES	YES	YES	YES
0		ROAD		2,066	-12.15396	96.821381	ROAD		Economic	ROAD	West Island		MU2b		NO	NO	YES	NO	NO	NO
0		ROAD		38,190	-12.15311	96.824058	ROAD		Economic	ROAD	West Island		MU4		YES	YES	YES	YES	YES	YES
226		RUMAH BARU		150	-12.156927	96.828043	FHOLD		Economic	Rumah Baru	West Island		MU4		NO	YES	YES	YES	YES	YES
		AIRPORT							Economic	Runway	West Island		MU3		YES	YES	YES	YES	YES	YES
		GSC SEAWALL							Economic	Sydney Hwy Geobag Wall	West Island		MU2a		YES	YES	YES	YES	YES	YES
0		ROAD		31,310	-12.175549	96.820749	ROAD		Economic	ROAD	West Island		MU1		YES	YES	YES	YES	YES	YES
167	WILLIAM KEELING CRESCENT	RESERVE	FORESHORE PROTECTION AND NATURE CONSERVATI ON	34,881	-12.195859	96.834511	CROWN	COMMONWEALTH OF AUSTRALIA	Environment	FORESHORE	West Island		MU1		YES	YES	YES	YES	YES	YES
		WAREHOUSES, WORKSHOPS, INDUSTRIAL							Economic	INDUSTRIAL	West Island		MU1		NO	NO	YES	NO	YES	YES
0		RESERVE		81,230	-12.183657	96.824245	RESVE	COMMONWEALTH OF AUSTRALIA	Environment	sand quarry	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/615/615_2018-07-04%2016-42-19.png	MU1		YES	YES	YES	YES	YES	YES
341		Water Supply			-12.1823	96.827043		COMMONWEALTH OF AUSTRALIA	Economic	water supply point	West Island	https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/753/753_2018-07-11%2012-39-28.png			NO	NO	NO	NO	YES	YES
41		High School		10,540	-12.1185	96.89782	FHOLD		Social	district high school		https://bcoastcomau.sharepoint.com/sites/Projects/Shared%20Documents/P18005-Cocos%20Keeling%20Islands%20CVA/03_Technical%20Data/03_GIS/Coastal%20Asset%20Survey/Pictures/coastal%20asset%20survey/716/716_2018-07-06%2013-33-25.png			NO	NO	NO	NO	YES	YES