Patrick Ports

Cocos Keeling Islands
Coastal Management Plan

January 2017

Executive summary

Sand management on the Cocos (Keeling) Islands (CKI) has been an ongoing issue with seasonal and storm erosion placing assets on the external coast of West Island in particular at risk. Coastal erosion risk on the island has been compounded by limited sand sources suitable for use in construction of foreshore protection measures. In addition, ongoing sand extraction and construction of structures affecting longshore currents have altered local sediment transport pathways.

CKI Port has sought assistance from GHD to provide an update of the 2000 Coastal Management Plan including but not limited to the following:

- The impact on the areas within port bounds on CKI where sand is currently being harvested;
- A sand sourcing management plan which needs to include an assessment and identification of sustainable sand sources on both West Island and Home Island for future sand extraction, including extraction limits; and
- An updated investigation into sediment movement within the atoll.

To address the issues and develop a Sand Management Strategy for CKI, GHD has undertaken the following works, which are documented in this report:

- Stage 1: Desktop study and sediment transport modelling supported by remotely sensed geomorphology and benthic habitat mapping to investigate sediment transport patterns and define the sediment budget to inform the sand management strategy (refer Numerical Modelling Report in Appendix A);
- Stage 2: Ground-truthing of results by site investigations and site specific surveys along with implementation of on ground measures that will be used to monitor sand levels at specific locations; and
- Stage 3: Development of an updated Coastal Management Plan which focusses on the management of sand resources on the islands.

The sediment transport modelling study results were used to determine the locations of sand accretion within the atoll. These were then assessed in further detail to ascertain whether they were potentially suitable for sand extraction for coastal erosion works in the future. 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.

Once the modelling was completed, a GHD coastal engineer and survey personnel flew to CKI to ground truth the modelling results against observations and local knowledge, to discuss the results with CKI Port, the Shire and the Department of Infrastructure and Regional Development representatives and undertake on ground surveys to determine available sand volumes at the nominated locations.

These results were analysed in conjunction with the numerical modelling results and understanding of the general coastal processes to form the updated Coastal Management Plan. A summary of the results is provided in Table 1.

Table 1 Summary of Extraction Locations

Location	Volume Available (September 2016) (m3)	Max Annual Extraction Volume*	Order of Priority	Comments/Conditions
North Point Sand Bank	650,000	NA	5	Not recommended
Rumah Baru Facility / Shire Boat Ramp	2,800 (to MSL)	10,000	1	First priority is to keeping the boat ramp clear, extraction for coastal protection purposes requires application to and approval by the Port prior to commencing.
Bob's Folley to north of Rumah Baru	13,300 (to MSL)	30,000	2	Extraction needs to be for a specified purpose (ie coastal protection) and requires application to and approval by the Port prior to commencing. Note that over excavation of this area may adversely impact the amount of sediment available at Rumah Baru.
South End	NA	NA	4	Only by express permission on case by case basis
Turtle Beach	1,400 (to MSL)	2,000	3	Not preferred, only by express permission on case by case basis

*Max annual extraction volume is an estimate only based on anticipated ambient conditions. Monitoring of the locations as described in the previous sections will dictate how much sediment can ultimately be removed

Of the sites identified, the area around Rumah Baru and north to Bob's Folley on West Island were identified as the most appropriate sources for ongoing sand extraction for the purposes of coastal erosion works (primary) and others as considered appropriate. Turtle Beach on Home Island is a current extraction site, however the study indicates that the available volume is likely to be low and there are a number of restrictions associated with extraction of sand from this location.

All areas identified sit with the Port Limits of Cocos (Keeling) Islands, with the exception of South End on West Island. All requests for sand extraction need to be accompanied by an application form which outlines the need for sand, volume required, timeframe and proposed location.

Table of contents

Table index

Figure index

Appendices

1. Introduction

1.1 Background

Sand management on the Cocos (Keeling) Islands (CKI) has been an ongoing issue with seasonal and storm erosion placing assets on the external coast of West Island in particular at risk. Coastal erosion risk on the island has been compounded by limited sand sources suitable for use in construction of foreshore protection measures. In addition, ongoing sand extraction and construction of structures affecting longshore currents have altered local sediment transport pathways.

CKI Port is seeking assistance from GHD to provide an update of the 2000 Coastal Management Plan to include but not limited to the following:

- The impact on the areas within port bounds on CKI where sand is currently being harvested;
- A sand sourcing management plan which needs to include an assessment and identification of sustainable sand sources on both West Island and Home Island for future sand extraction, including extraction limits; and
- Updated investigation into sediment movement within the atoll.

To address the issues and develop a Sand Management Strategy for CKI, GHD has undertaken the following works, which are documented in this report:

- Stage 1: Desktop study and sediment transport modelling supported by remotely sensed geomorphology and benthic habitat mapping to investigate sediment transport patterns and define the sediment budget to inform the sand management strategy (refer Numerical Modelling Report in Appendix A);
- Stage 2: Ground-truthing of results by site investigations and site specific surveys along with implementation of on ground measures that will be used to monitor sand levels at specific locations; and
- Stage 3: Development of an updated Coastal Management Plan which focusses on the management of sand resources on the islands.

1.2 Purpose of this report

The purpose of this investigation is to assist the CKI Port by providing an improved understanding of sediment transport on Cocos (K) Islands, improved understanding of the impacts that current sand extraction is having on the island and to prepare a sand management plan to assist in future management to minimise impacts of erosion on the island.

1.3 Scope and limitations

The scope of works is as noted above in Section 1.1.

The Coastal Management Plan (CMP) should be read in conjunction with the 2000 Coastal Management Plan and is considered an update of key areas only. The background information provided in the 2000 CMP still remains applicable unless noted otherwise in this report.

This report: has been prepared by GHD for Patrick Ports and *may only be used and relied on by Patrick Ports for the purpose agreed between GHD and the Patrick Ports as set out in section 1.2 of this report.*

GHD otherwise disclaims responsibility to any person other than Patrick Ports arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared this report on the basis of information provided by Patrick Ports and others who provided information to GHD (including Government authorities)], which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

The opinions, conclusions and any recommendations in this report are based on information obtained from, and testing undertaken at or in connection with, specific sample points. Site conditions at other parts of the site may be different from the site conditions found at the specific sample points.

Investigations undertaken in respect of this report are constrained by the particular site conditions, such as the location of buildings, services and vegetation. As a result, not all relevant site features and conditions may have been identified in this report.

Site conditions (including the presence of hazardous substances and/or site contamination) may change after the date of this Report. GHD does not accept responsibility arising from, or in connection with, any change to the site conditions. GHD is also not responsible for updating this report if the site conditions change.

2. Review of Existing Data and Studies

A number of studies and reviews have been conducted on the Cocos (Keeling) Islands pertaining to coastal processes, erosion works and mitigation measures. A brief review of the reports most relevant to this study are included below.

2.1 Previous Coastal Management Related Studies

2.1.1 Coastal Management Plan (GHD 2000)

A coastal management plan was developed by GHD in 2000 for the then Department of Transport and Regional Services, to assist in developing guidelines for future development on the island to ensure that development was sustainable in the long term. Setback values for various sections of West Island were presented in light of known coastal processes at the time.

Sea level rise estimates in 2001 to 2030 were in the range of 8 to 21 cm (best estimate of 18 cm) and to 2070 were 21 to 77 cm (best estimate of 44 cm). A 20 cm allowance for sea level rise was adopted for design water levels. Setback allowance as a result of sea level rise was recommended to be 5 m for areas of high relief and 10 m for lagoon shorelines.

Areas identified for protection by coastal engineering structures if trends of erosion continued were identified on West Island near the northern end at the Shell Fuel Farm, Trannies beach, a section of Sydney Highway 500 m south of Rumah Baru turn off, in front of the Medical Centre and in front of houses on Qantas Close.

Development constraints recommended that building construction should be restricted within 20 m of the RL +3.0 m MSL contour for both future residential and other use, industrial commercial etc.

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.

While a number of studies have been undertaken since 2000, which build on the knowledge in this report, the majority of the background information remains relevant. An update on the main conclusions of the 2000 report is provided below in Table 2:

Table 2 Update to 2000 Coastal Management Plan Actions

2000 CMP Conclusion/observation	2016 Update
Coastal buffer areas should be provided to allow for coastline movement. In most areas the 20m provisionally allowed for in planning to date is appropriate. Exceptions to this are areas of spit formation near the southern entrance and on the northern end of West Island.	Coastal buffers should still be provided to allow for coastline movement, however may need to be increased from the 20m recommendation due to impacts from sea level rise. New developments should be assessed on a case by case basis with reference to the WA State Coastal Planning Policy (SPP 2.6) in lieu of any other guidance and the outcomes of the storm surge study undertaken by SEA 2001.
Shoreline movement near the West Island Jetty may continue and threaten the Tank farm in future. Works to secure the abutment of the West Island Jetty may slow this trend and formation of an additional hard point in the coastal alignment north of the tank farm is also desirable.	Shoreline movement near the West Island Jetty has continued and a GSC seawall has been constructed to protect the Fuel (Tank) Farm and abutment of the West Island Jetty, refer section 2.2.8 and 2.2.9. The jetty is no longer required for ferry operations and is a recreational asset only. The adjacent

	ablutions block has been under threat from erosion in recent times, however there is currently a sand buffer in front of it (September 2016). The area continues to be dynamic and vulnerable to erosion particularly in persistent northerly events.
New land being transferred to private ownership should be designed such that coastal buffer zones remain under public control.	No change
Building works should not be permitted within the coastal buffer zone unless specific arrangements are made in the design process to allow for erosion.	No change
Ad hoc construction of seawalls to protect private property should be prevented.	No change
The upgrading of the existing seawall (currently under construction) at Qantas Close should be extended as required. Similar works may be required at the Medical Centre.	The upgrading of the existing Seebee wall at Qantas Close will be required in the future to manage the flanking erosion damage. It is understood that this is scheduled to occur in conjunction with the William Keeling Crescent Seawall construction, scheduled for 2017. The existing seawall at the Medical Centre was replaced with a new GSC seawall in 2014. This may require upgrade and extension to the north in the future (as noted in GHD 2014 report) and should be monitored for storm damage.
Sydney Highway should eventually be relocated away from the beach in the area approximately 500m south of the Rumah Baru turnoff. This should be provided for in planning future works and service alignments at this stage. Actual construction can be delayed until erosion threatens the pavement.	The Shire was opted to maintain the existing alignment of Sydney Highway and has constructed a GSC seawall in 2016 to manage the erosion risk. This wall should be monitored for storm damage and flanking erosion and may require further upgrade in the future (or relocation of Sydney Highway eastwards if erosion persists.
Sand extraction may be carried out to a limited extent from: The sand slug south of West Island Jetty (approximately 3,000m3); and The inland portion of the sand dunes at Beacon Heights (approximately 10,000m3).	Sand extraction locations and volumes are amended as per this report, refer Section 6 for summary. The recommended locations are Rumah Baru, Rumah Baru north to Bob's Folley and Turtle Beach on Home Island (limited). Beacon Heights is not considered a viable source for sand extraction for coastal works as the available volume is significantly less than in 2000. It should still be considered as a source for sand of sand for playground bases, landscape requirements, etc, with an application to the Commonwealth required for approval prior to extraction. Volumes should be limited to less than 300m3.
Very large volumes of sand and fill (sand / shingle) are available in the natural sink area adjacent to the south entrance. The south east spit areas of West Island can yield sustainable sand extraction rates of at least 1000m3/year if a sand trap is constructed. Removal in the order of 100,000m3 of accumulated sand in the entrance fan and SW spit is acceptable. This could be removed and	Construction of a sand trap is not recommended as this will interrupt the natural flow of sediment northwards into the lagoon. The volume available for sand reclamation at the southern end of West Island is considered to be low and given that it is a highly mobile location of sediment which

stockpiled in association with other works such as the Rumah Baru Freight and Passenger Facility.	feeds into the lagoon (rather than being a sink), it is advised not to use this as a source of sand unless explicitly requested and approved.
Current sand extraction rates at Home Island appear sustainable.	Please refer to updated extraction rates in Section 5.7 of this document which limits extraction on Home Island to a sustainable level.

2.1.2 Erosion engineering and scoping study – West Island Cocos (Keeling) Islands: preliminary design report (GHD 2014)

Site assessment and survey of erosion risk areas on West Island, Cocos (Keeling) Islands was conducted by GHD to identify critical areas at risk of erosion requiring maintenance, upgrade or construction of coastal protection structures.

Recent severe storms with sea conditions from the west were reported to have caused significant erosion along predominantly the west coast of West Island. Based on the review of existing reports and studies, a site inspection undertaken in May 2014 and discussions with key stakeholders, five critical areas were identified:

1. Settlements including William Keeling Crescent, Cocos Beach Motel, West Island Hospital and the existing Seabee and concrete wall;
2. North Point / Fuel Farm / West Island Jetty
3. Sydney Highway
4. Twist Memorial
5. South End Runway

Preliminary design options were developed based on historical knowledge and digital shoreline analysis to assess shoreline recession and accretion and determination of design parameters. A number of options were considered in terms of types of structures and materials with Geotextile Sand Container (GSC) seawalls considered to be the most appropriate. Recommended designs utilised 0.75m^3 GSCs, similar to those already used at the Fuel Farm, Hospital and South End Runway, enabling construction and maintenance to be undertaken by local personnel, managed by either the Department of Infrastructure or the Shire.

Preliminary cost estimates for design at the 5 identified sites varied from $325,000 at the South End Runway to $3.8M and $4.9M for protection of the land along the Cocos Beach Motel and along William Keeling Crescent.

Alongside recommended design options, the report included details of recommended maintenance actions, cost estimates including design and maintenance and recommendations for monitoring changes including photo monitoring, coastline mapping, annual surveys and aerial photography analysis.

2.2 General

2.2.1 Physical controls on development of lagoon deposits and lagoon infilling in the Indian Ocean atoll (Kench 1998)

The objective of the investigations undertaken in this report was to explore the development of lagoon sand bodies in the Cocos (Keeling) Islands under the control of wave and tide induced currents.

The results of the report presented the following significant implications for the nature and history of lagoon infilling:

1. A rapid slow down and cessation of sand apron/flat progradation and infilling of the Cocos lagoon in contrast to previous studies.
2. Infill of the lagoon has become increasingly dependent upon sediment transported from outside of the lagoon such as the external reef sources.
3. The lagoon infill will take significantly longer than 4000 years as previously suggested.

2.2.2 Rumah Baru Studies

A number of studies were undertaken as part of the Rumah Baru Freight and Passenger Facility design development including wave studies (primarily in the lagoon), littoral transport and coastal process studies and some preliminary geotechnical investigations. During the construction of the facility, data was collected on climatic conditions experienced over the construction period and beach sand sediment characteristics.

The studies focused on the lagoon side of West Island as this is where the development is located.

2.2.3 SEA storm surge study (2001)

The SEA (2001) study involved the following tasks (from the executive summary):

1. An analysis of historical tropical cyclone activity in the region within a 500 km radius of the atoll leading to a series of statistical relationships for intensity, frequency and track;
2. Verification of a numerical wind and pressure model of tropical cyclones against airport weather station records for a "top 10" selection of historical cyclones;
3. Numerical modelling of resultant storm surge, wave and wave setup phenomena for each of the “top 10" cyclones;
4. Verification of the storm surge model against recorded storm surge values at Home Island jetty tide gauge;
5. Construction of a statistical simulation model capable of integrating the various components of storm tide level (astronomical tide, inverted barometer effect, surface wind stress and breaking wave setup);
6. Verification of the statistical model against long-term wind speeds from the airport weather station and against long-term tide levels;
7. Probabilistic analysis of combined storm surge, tide and wave setup levels at inshore (lagoon) and offshore (reef flat) sites;
8. Estimates of wind speed (mean and gust) and wave height as a function of return period;
9. Predicted levels of total storm tide (and its components) for 10, 50, 100, 500 and 1000 year ARI (Average Recurrence Interval or Return Period) and the assessment of inundation levels at nominated island locations.

The study showed that the local ocean response to tropical cyclone forcing on the outer atoll is likely to be dominated by the effects of breaking wave setup but, for sites in the lagoon, by locally generated wind stress. Overall, breaking wave setup dominates total water levels. Figure 2 illustrates the storm tide phenomenon acting on the outer atoll sites. Note that wave runup was not included in the SEA (2001) study.

The term “total storm tide level” discussed here refers to the “MWL” in Figure 1 below.

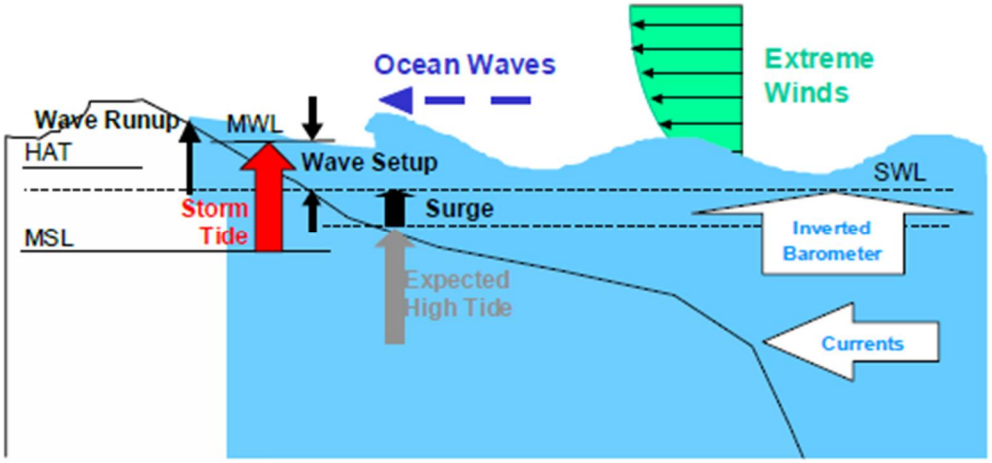


Figure 1 Factors influencing extreme water levels on the outer atoll (from SEA 2001 and Harper et al. 2001)

The various numerical models used and the assumptions made were tested as much as possible against measured data but it was noted that there is a significant absence of recorded wave height and period information and very limited water level information for the site (other than the long term tide gauge on Home Island). The longest period of measurement of any data is that for wind speed and direction at the Airport on West Island. In addition, information on reef flat characteristics (widths, levels, and slopes) which are potentially important controlling parameters for breaking wave setup, was relatively sparse. In order to account for some of these latter deficiencies, sensitivity tests to some important parameters were included.

Table 3 summarises the estimated storm tide threat for the base case of the 1% (or upper envelope) breaking wave setup component. The report also detailed a number of sensitivity tests which could produce slightly higher water levels than these depending on the exact choice of parameters. The 50 year and 1000 year ARI values are indicated for a number of critical locations in terms of the absolute water level relative to MSL and also the water level relative to a nominal local ground level (inundation is indicated by a positive value). The encounter probability is also indicated on the basis of a 50 year risk horizon, which shows the chance of equalling or exceeding the indicated levels at least once during any 50 year period. No allowance for possible Greenhouse-induced sea level rise was included in these values.

Table 3 Summary of base case 1% storm tide levels (from Table 6.2 (GHD/SEA 2001))

Site #	Name	Typical Ground Level (m CKIHD)	1% Storm Tide Level at indicated Return Period (m CKIHD)		
			50	100	500
	Whole Atoll		2.7	2.9	3.3
1	Trannies_Beach	2.0	1.7	1.8	2.0
2	West_Is_Jetty	1.5	0.9	0.9	1.1
3	Rumah_Baru	1.1	0.9	1.0	1.2
4	Quarantine_N	3.2	1.7	1.9	2.2
5	Airport_N	2.5	1.0	1.0	1.3
6	North_Park	3.5	1.7	1.8	2.0

Site #	Name	Typical Ground Level (m CKIHD)	1% Storm Tide Level at indicated Return Period (m CKIHD)		
			50	100	500
8	Airport_Settlement	4.0	1.69	1.82	2.07
9	Airport_S	2.8	1.61	1.74	2.00

2.2.4 West Island Erosion (GHD 2009)

This report presented an overview of the erosion that had occurred, methods that could be used to control future damage and offered recommendations as to the way forward to mitigate and manage the issues at the following three sites:

- Site – 1: Along Sydney Highway, to the south of the exit to Rumah Baru;
- Site – 2: Coastline between the existing medical centre and north of the existing concrete seawall and also the coastline south of the existing seawall; and
- Site – 3: Along the gravel road, south of the settlement, that runs parallel to the runway.

Site investigations and a review of historic data were carried out to assess the erosion conditions at each site. Four commonly used shore protection methods were explored as treatment options for each site including, Do nothing/nourish only, Breakwaters, Groynes and Sea Walls. Shore protection methods are varied and sometimes a combination of two or more options is used.

Based on the preliminary site investigation, it was recommended that the best course of action was likely to be a combination of seawalls and groynes constructed of either concrete precast units or geosynthetic sand containers (GSCs), or a combination of both. In order to determine the best plan of action to prevent continuing erosion and associated problems it was recommended that the following studies should be undertaken as a way forward:

A detailed site investigation to more accurately determine beach profiles, levels of risk and assign priorities;

1. Sediment grain size analysis;
2. A review of all existing data and studies, particularly for West Island;
3. A study of the wave climate and determination of design conditions for each of the affected regions taking into account the findings of the recently completed climate change study;
4. Determination of the short and long term rates of erosion for each site by analysis of historical aerial photography;
5. Prioritisation of the various affected areas based on the short and long term erosion rates and possible damage to infrastructure that ongoing erosion may cause;
6. Preliminary design solutions for the sites with associated cost estimate;
7. Detailed design in order of prioritisation of the sites.

2.2.5 Climate change risk assessment for the Australian Indian Ocean Territories (Maunsell/AECOM 2009/2010)

A review of climate change and the potential impacts to the Cocos (Keeling) Islands was published by Maunsell Australia Pty Ltd in 2009 and updated in 2010.

Based on the investigations carried out, the report made the following future climate change projections for the Indian Ocean Territories (IOT) which includes the Cocos Islands:

- Increased seasonal air temperature ranging from 0.6°C warmer by 2030 to 1.8°C warmer by 2070;
- Increased sea surface temperature by 0.6°C in 2030 which may reach 1.8°C by 2070;
- Due to a high level of uncertainty, the projection of rainfall changes are difficult to identify, except that the driest seasons may become drier for both Territories and that the wet season may become wetter on Christmas Island;
- An average sea level rise of 14 centimetres in 2030 and 40 centimetres by 2070 for both Territories and up to 1.1 m by the end of the 21st Century (worst case scenario); and
- An increase in the number of intense tropical cyclones (TC) and storm events by 2030, and a decrease by 2070.

The report found that, “in general, the projected changes in climate reviewed here will likely lead to physical coastal impacts that will potentially threaten crucial infrastructure including the airfield, and in time, the settlements on Home and West Island.” Table 4 is a summary of the sensitivity of natural systems to climate change as presented in the report.

Table 4 Summary of projected impacts of climate change

Location	Expected Coastal Sensitivity to Projected Changes in Climate
Exposed Lagoon Coast	Accelerated movement of sediment slug from north to south is likely with more energetic wave conditions as a result of more intense storms. Possible loss of storm erosion buffer at the northern end leading to exposure of tree roots, tree felling, infrastructure damage and loss of beach amenity and ecosystem loss. However, erosion here will be markedly less than on exposed ocean coasts. Deposition of sediment in the southern end of the lagoon is likely to continue initially as the slug accumulates to the south. Lower lying areas such as Rumah Baru are likely to be subject to inundation both as result of sea level rise and superimposition of elevated surges in extreme events. Overtopping and ponding inland, in particular where basin type profiles occur.
Sheltered Lagoon Coast	Relatively low-lying areas of the sheltered lagoon coast likely to be prone to inundation risk due to sea level rise. Flooding may lead to reduction of narrow, low lying beaches in particular along the coast of West island where artificial reinforcements mean there is no room for horizontal beach adjustment. Sedimentation of the lagoon is likely to be initially accelerated as material eroded from the ocean side and deposited on the lagoon side of the eastern and south eastern rim.
Exposed Ocean Coast Western Rim	Possible erosion of beaches with undermining of tree line/tree felling, loss of coastal vegetation, degradation of coastal protection works and progressive loss of coastal land. Increased overtopping of existing seawall along Qantas Close, decrease in buffer zone between wave action and infrastructure. Potential surface overflow over land with subsequent ponding, particularly in basin profile locations. Combination of this effect with inundation on opposite lagoon side may lead to narrowing of the distance between the lagoon and ocean side of the islands.
Exposed Ocean Coast Eastern Rim	It is likely that changes in sea level and flow along the islands of the eastern rim of the southern atoll will not result in net erosion or

	accretion. Rather, the islands are subject to redistribution perhaps with a reconfiguration of the horseshoe shape currently extending from east to west. Conversely, on Home Island, although some protection is offered along some of its oceanside by conglomerate platform and high ridge, erosion is likely where platform is not continuous. Sand ridge not as stable as shingle or rubble.

2.2.6 Cocos (Keeling) Islands Coastal Engineering Investigation (DoT 2010)

In autumn 2009 the federal Attorney-General's Department (AGD) requested preliminary coastal engineering advice for the Cocos (Keeling) Islands from the Department of Transport (DoT). Advice was requested regarding:

1. Erosion concerns on West Island, including options for its management; and
2. Assessment of the current state of various beaches of interest.

The report summarised the results of onsite inspections and made recommendations for the costal engineering issues occurring along the coastline. It was found that a number of assets had insufficient setback and were at threat at several locations along the West Island coastline. Table 5 summarises the sections of coast that were considered to be at risk of coastal erosion/inundation during extreme events.

Table 5 Sections of coastline at risk (Information sourced from DoT 2010)

Site name	Location description	Location coordinates	Main risk	Setback Distance	Notes
Twist memorial	~1.3 kms SE of end of runway on Air Force Road	12°12.288' S 96°51.046' E	Erosion and inundation	~6 m road to beach	Rock platform not continuous – vulnerable to erosion
Southern culverts	Adjacent to southern end of runway	12°12.250' S 96°50.420' E	Inundation	~40 m road to beach	Subject to flooding (Figure 9) – low 25 m gap in foredune
Air Force Road	Adjacent to runway 100 m from S end	12°12.068' S 96°50.305' E	Erosion	<5 m wide between road and erosion scarp for ~75 m	Natural rock platform to S stops. Terminal scour N of previously dumped rubble. Chronic erosion will continue to N.
Settlement	William Keeling Crescent and southern houses		Erosion	Average ~10 m from beach erosion scarp to pine logs at road	Old seawalls failing. Narrow buffer for erosion along a large section of coast. Hospital seawall needs maintenance.
Quarantine station	Western boundary of Q. Station	12°10.379' S 96°49.141' E	Erosion	~4 m from corner fence post to beach erosion scarp	Present shoreline very different to 2003 cadastre – significant erosion may have occurred. Track access prohibited
Sydney highway	~1.3 kms N of Q. Station	12°09.614' S 96°49.264' E to 12°09.868' S 96°49.297' E	Erosion	~5 to 10 m width between erosion scarp on beach and bitumen	~500 m section of coast with narrow buffer for erosion.

High priority recommendations contained in the report have been summarised here:

For 2010/2011 -

- Water levels should continue to be monitored at Home Island wharf by the BoM.
- Winds should continue to be monitored hourly on West Island by the BoM.
- Beach survey to be conducted around the coast of West Island and Home Island.
- Field photographs to be taken monthly of areas of concern, and archived.
- Conduct photo-monitoring of all five seawalls twice per year during September and March.
- Relevant reports on coastal processes etc.to be compiled and archived, particularly those which have been prepared for the Rumah Baru freight facility.
- Cyclone inundation modelling should be carried out for the CKI
- The gap in the foredune near the southern culverts on Air Force Road to be filled by a small vegetated dune or subject to further work, geosynthetic sand containers.
- Air Force Road to be nourished with sand from the southern end of the island (near the yacht club) for short-term protection during/after extreme events as required.
- Hospital seawall to be maintained.
- The Quarantine Station could be nourished with sand from the northern point of the island for short-term protection during/after extreme events (i.e. as required).

For 2014 –

- Directional wave data should be collected in the northern end of the lagoon.
- Historical hydrographic and coastal survey data to be reviewed and summarised by survey extent, method and date of collection etc. and archived by the DoT.
- Historic aerial photography is archived by the Attorney-General's Department and Landgate (W.A.) for ease of future access.
- Photography is collected for the CKI every five to ten years by either an aerial flight or satellite photography.
- Major maintenance of the older southern seawall to be undertaken, or its replacement planned.
- The older northern seawall to be left to fail. Medium to long-term planning must be undertaken to identify a management strategy for the coast adjacent to William Keeling Crescent between House 1 and the hospital.
- A review of coastal processes and sediment transport should be conducted to assist in determining net and seasonal trends.
- Long term planning for the CKI to be considered. Broad coastal management options for the settlement – retreat, adapt or defend – need to be decided.
- Geological investigation, initially by literature review, to be undertaken to determine the extent and nature of rock at Home Island and West Island, reef growth rates, and if there is any vertical movement of the CKI. A geosynthetic sand container seawall be further investigated to address the erosion at Air Force Road.
- Long term planning should consider relocating the effected section of Air Force Road further east or potentially to the other eastern side of the runway.

- Medium term planning should consider relocating the boundary of the Quarantine Station further east.
- Medium term planning should consider relocating sections of Sydney Highway further east.

2.2.7 Beach Erosion Protection Options (ARUP 2012)

Arup was commissioned by the Department of Regional Australia (DRA) to provide advice on potential short-term remedial options to address the immediate erosion issues while more long-term measures are considered.

The following five locations along the northern and western coastline of West Island which were experiencing significant erosion that was threatening landside infrastructure were investigated:

1. North Point jetty and seawall;
2. William Keeling Crescent (fronting Health Centre/ Clinic);
3. William Keeling Crescent (fronting houses);
4. Air Force Road, by southern end of air field runway; and
5. Sydney Highway (by Trannies Beach).

Metocean data, historical observations and recent observations was then used to investigate the causes of the erosive conditions occurring along the shoreline. Based on the ARUP's investigations, short term remedial options were developed to provide solutions which would prevent further erosion of the coastline for a 2 to 5 year period until long term solutions could be implemented. The short term solutions which were investigated included the use of geotextile bag revetments, rock revetments, gabion revetments, grout/block matt systems and sand nourishment.

Based on the investigations carried out, the report made a recommendation for the use of geotextile bags as the best option to be implemented to achieve short term erosion protection. This decision was made based on the fact that this treatment had generally performed well enough at other sites around the island and offered an option that would be easy to construct with locally sourced labour and materials. The five sites were then prioritised and site specific recommendations made, as shown in Table 6.

Table 6 ARUP 2010 recommendations in order of priority

Reference	Location Description	Recommended short term measures
S1	North Point jetty and seawall	South of jetty: Replace the damaged section of existing GSC revetment footprint and curve back to shoreline beyond toilet block and septic system with raised crest to reduce overtopping potential. Implement sand nourishment behind extended revetment extending to current shoreline near the septic tank and up to the revetment crest level to create added buffer. North of jetty: Replace existing damaged/dislodged GSCs where necessary and extend raised crest along full footprint. Localised sand nourishment behind revetment. Note: This will not protect the shoreline fronting the fuel tanks from further erosion, but given their current 30-40 m setback distance this could be considered an

		acceptable buffer zone in the short term until a more long-term shore protection measure is implemented here. The alternative of immediately installing a 100 m-long GSC revetment would be an expensive short term measure. ~20 m GSC revetment length + sand backfill ~ $100-150k
S2	William Keeling Crescent (fronting Health Centre/ Clinic)	Remove existing (damaged) GSCs where necessary; install new GSC revetment and geotextile 1-2 m seaward of existing, and backfill with sand. ~10 m GSC Revetment length + sand backfill ~ $50-75k
S3	William Keeling Crescent (fronting houses)	Clear rip-rap and debris and install new GSC revetment. ~10 m GSC revetment length + sand backfill ~ $50-75k
S4	Air Force Road, by southern end of air field runway	Repair/reinstate existing GSC revetment at its ends extending the length of the current erosion escarpment. Locally build up/widen ends with GSCs to prevent future „unzipping" of ends. ~10 m GSC revetment length + sand backfill ~ $50-75k
S5	Sydney Highway (by Trannies Beach).	Option 1: Temporarily setback most-exposed length of road eastwards until more-permanent realignment is undertaken. Option 2: Keep road in place. Clear rip-rap and debris and install new GSC revetment. ~10 m GSC revetment length + sand backfill ~ $50-75k

2.2.8 West Island Jetty Condition Assessment (GHD 2012)

Subsequent to the completion of the Rumah Baru facility on 21st September 2011, GHD was engaged by the Department of Regional Australia, Regional Development and Local Government (DRA) to update the content of the West Island Jetty Condition Assessment (GHD 2010) report and to comment on the impact of ongoing erosion at the jetty and adjacent infrastructure, due to sustained northerly swells early in 2011.

The investigations found that the jetty was in poor condition and irrespective of the final remedial option selected, the jetty would require annual inspections to maintain an up-to-date assessment of its condition and to identify areas of significant concern in a timely manner. Regular inspections were proposed to be able to better quantify the rate of corrosion, resulting in better estimates of anticipated life.

It was apparent that the jetty was nearing the end of its serviceable life and, without substantial remedial action and continuing sustained use by small pleasure craft, light vehicles and pedestrians, there was a likelihood that structural failure to portions of the jetty may occur within 6 – 12 months. The report suggested that if measures to control the use of the jetty (and therefore the loading on the structure) or remedial actions were undertaken there was an opportunity to extend the life of the jetty.

In conjunction with the condition assessment of the jetty an investigation into the erosion/accretion conditions was made. The report noted that erosion occurred in late 2010 and early 2011 due to sustained northerly swells. This erosion affected numerous areas including North Point, the fuel farm, West Island Jetty, the bus shelter and amenities building and the barge landing area. It was noted that erosion and accretion of the West Island jetty is not uncommon because the north point area is highly mobile and vulnerable to significant shoreline changes in response to variations in the wave climate.

Based on the assumption that the jetty, ablutions block and bus shelter represent non-essential infrastructure and that the fuel farm is the primary asset requiring ongoing consideration and protection, the report presented the following considerations for erosion control to be carried forward:

1. Monitor the shoreline movement in front of the fuel farm by measuring the distance to the edge of the vegetation from the fuel farm fence at 3 locations (north, middle and south) on a monthly basis. This will assist in the determination of the need for future design and allow for proactive rather than reactive management;
2. Ensure that the soakwell for the fuel bunds and the fuel intake pipeline are protected by building up the area surrounding them and taking measures to ensure that debris is not able to easily damage the pipeline. This is already underway by Island Petroleum;
3. Construct a seawall as an extension of the jetty abutment seawall, most likely to be from GSCs due to flexibility and availability of material (assuming a suitable sand source can be found);
4. Decommission the ablutions block and services;
5. Maintain the bus shelter if it is still required, otherwise decommission. Note that a decision to maintain the shelter may require erosion protection in the future;
6. If maintaining the jetty, ensure that the abutment and concrete panels are fixed correctly to ensure public safety and restrict vehicles from driving onto the jetty; and
7. Plant grass or vegetation behind the existing seawall to help prevent scour and washout behind the wall.

2.2.9 Stabilization of coastal erosion adjacent to critical West Island infrastructure – quarterly report 15 March 2014

A project to stabilise the coastline experiencing coastal erosion adjacent to some of the critical infrastructure of West Island was undertaken in 2013/2014 by the Shire of Cocos (K) Islands (SoCKI). A quarterly report has been reviewed to analyse some of the construction techniques and capabilities of the operations currently occurring on the islands.

This report stated that significant progress had been made since the last report on the 15 December 2013. Despite some minor breakdowns, the project maintained activity and continued at a rate better than that previously expected. Some of the construction activities have been listed below:

- The Shell Fuel Depot site wall construction was underway on the 28 January 2014;
- Bag filling and sewing was nearing completion;
- Bag filling peaked at around 90 bags per day with 60 to 70 a sustainable target;
- Bag sewing was maintained at 120 bags per day for two people team;
- An average of 12.5 linear metres of wall construction was maintained each day except when unfavourable weather was experienced;
- Construction of the wall was completed on the 20 February 2014;
- Plant equipment was relocated to the West Island Clinic on the 26 February; and
- The work at the clinic was completed in 10 days on the 11 March 2014 after favourable weather and tidal movements.

3. Coastal Management Issues

This section focuses on the current key coastal management issues relating to the supply and demand for sediment on the Cocos (Keeling) Islands.

3.1 Coastal Erosion

Numerous studies have investigated coastal erosion issues on the Cocos Keeling Islands (GHD 2000, 2009, DoT 2010, ARUP 2011, GHD 2014) and the potential impacts of climate change (Maunsell 2009 and AECOM 2010) on the islands. Common to all these investigations is the identification of coastal erosion on the ocean rim of the atoll islands as an ongoing hazard, particularly on West Island and the need for development of coastal protection measures to protect coastal assets.

Key erosion risk areas identified in the 2014 Erosion Engineering Assessment (GHD 2014) are shown in Figure 2 below and included:

1. Settlement including William Keeling Crescent, Cocos Beach Motel, West Island Hospital and the existing Seabee and concrete wall;
2. North Point / Fuel Farm / West Island Jetty
3. Sydney Highway
4. Twist Memorial
5. South End Runway

Numerous seawall defences have been established on West Island and include a concrete Seabee revetment, a vertical concrete panel wall and numerous GSC revetments. Availability of resources for construction of future coastal protection structures is limited on the island due to a lack of rock materials and high costs associated with importing construction materials which is further complicated by quarantine requirements.

As a result of these restrictions, recent coastal protection projects have relied heavily on the use of sand filled GSCs in the construction of seawalls with sand sourced from various sources including dredge spoil (related to the Rumah Baru project). The construction of GSC seawalls is the preferred option for construction on island as sand for GSC filling is available (although supply is finite) and the only construction materials requiring to be imported are the GSCs and geotextile underlayer. Construction can be undertaken readily using local equipment and labour, although machinery available currently restricts design to the use of small GSCs which are less stable in exposed swell conditions.

Coastal erosion is likely to continue as a result of climate change and may result in undermining and felling of coastal trees, erosion of coastal vegetation, degradation of coastal protection measures and increased overtopping of coastal protection structures (Maunsell 2009 and AECOM 2010). Given the identified erosion areas and likelihood of ongoing need for erosion protection measures on the external coast, a need has developed to identify a sustainable source of sediment for proposed and future likely projects, with the Shire currently engaged by the Department of Infrastructure and Regional Development (DIRD) to undertake construction of GSC revetments at Sydney Highway (completed) and William Keeling Crescent.

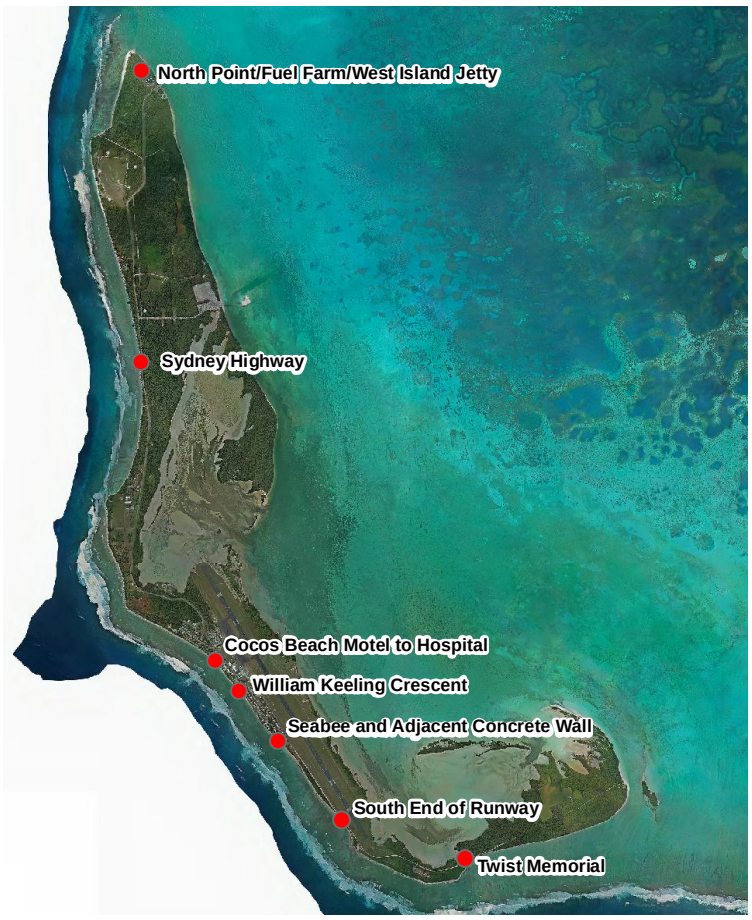


Figure 2 Location of critical erosion areas (GHD 2014)

3.1.1 Recommendations for Erosion Problem Areas

Recommendations for coastal protection structures by GHD in 2014 included:

- New GSC seawalls for the sites of William Keeling Crescent and Cocos Beach Motel at the Settlement;
- Upgrade and maintenance of the Seabee wall (upgrade tie in and repair cavities) and West Island Hospital (extending the wall further north) at the Settlement;
- Upgrade of the Fuel Farm GSC seawall to increase height and larger GSC sizing was recommended to protect against larger swells;
- Upgrades to South End Seawall with an additional layer to extend the design life; and
- Monitoring or relocation of roads or construction of GSC seawalls if retreat was not practical was recommended for Sydney Highway and South End Road/Twist Memorial.

A recent inspection of the erosion sites in September 2016 has identified that of the erosion sites identified above for new protection, upgrade or maintenance, the construction of a new GSC seawall at Sydney Highway have been completed in September 2016. The next priority area, as planned by the Shire, is the settlement along William Keeling Crescent which will incorporate the upgrade tie in required to the northern end of the Seabee wall at Qantas Close and adjoin the GCS wall constructed in front of the Medical Centre in 2014; these works are planned for early 2017.

The area around South End Road at Twist Memorial should continue to be monitored, with realignment of the road still recommended over providing formal coastal protection. The existing GSC seawalls at the Fuel Farm and the southern end of the runway should also be monitored

and may still require updating in future, particularly at the Fuel Farm where the GSC size is borderline for the wave conditions and there is flanking erosion exhibited at the northern end of the wall.

In addition to proposed works, GHD and others have made recommendations which would assist to improve knowledge of coastal processes, shoreline movement and sediment transport processes to improve decision making and identification of at risk areas. Such recommendations have included:

- Monthly photo monitoring of areas of high concern;
- Shoreline mapping;
- Regular surveying; and
- Aerial photo monitoring.

Programs to implement the collection of the above data are still recommended to be considered to aid in the long term management of coastal erosion on the island, undertaken in conjunction with collation of weather data (wind speeds, water levels, wave conditions, etc) from Bureau of Meteorology and local observations.

3.2 Sediment Accretion

Sediment deposition occurs in areas where current speeds reduce to below the critical velocity required to keep a particle entrained in the water column, or moving along the sea bed. As a result, sediment deposition is common within the lower energy environments adjacent to higher energy environments, such as areas of the lagoon adjacent the south end passage of the atoll, or where there are obstructions which influence current and wave patterns.

As described further in section 4 below, net sediment transport is south along the lagoon side of West Island from the Fuel Farm/North Point towards the settlement and north through the south end passage. The effects of the construction of the Rumah Baru freight and passenger facility on localised wave and current patterns, in conjunction with the construction of the Shire boat ramp, has resulted in the development of a small cuspate foreland (seaward accretion of beach material forming a pimple like shape). The cuspate foreland further impacts the identified alongshore sediment transport allowing sediment to accumulate on the beach in the vicinity of the Shire Boat Ramp and access jetty for Freight and Passenger Facility over time. This sediment accumulation has resulted in the requirement for maintenance (sand removal from the ramp) to maintain ramp access throughout the year.

Note that the original modelling indicated that the offshore island at Rumah Baru needed to be located 200m offshore to ensure no impact on coastal processes. While this has proven correct for longshore sediment transport, it appears to have had a greater sheltering impact than anticipated, leading to the net accumulation of sediment in the lee of the offshore island. Continued southwards movement of the sand slug at North Point to the south is also likely to be a contributing factor. As the Shire boat ramp was constructed in parallel with the Rumah Baru facility, the height and extent of the boat ramp is insufficient to surmount the sand buildup and is also impacting on this by acting as a groyne structure. Future consideration to raising and lengthening the ramp may be required. While the sediment accretion is detrimental to the boat ramp operation, it is ideal for the future protection of the Rumah Baru onshore facility to assist in protecting against inundation under sea level rise scenarios and coastal erosion under increased storm exposure.

3.3 Identified Uses of Coastal Sediment

In addition to the proposed use of sediment for foreshore stabilisation (estimated 10 – 15,000m^3), further uses for sand have been identified by the Shire for a range of projects on West and Home Island including:

- raising development levels in the small business area on Home Island;
- clean sand for children's playgrounds on both islands; and
- sand for the construction of pavers for Home Island.

The Shire has estimated a sand volume of 10,000m^3 over a 2 year period is likely required for the above mentioned development uses.

In order to manage the identified demand for sediment uses on the island over the coming years the remainder of the Coastal Management Plan will focus on identifying areas, methodologies and safe extraction limits to allow sustainable sand extraction whilst minimising the impact on adjacent areas. It should be noted that sand is a potentially finite resource and where other forms of fill material exist, these should be used in preference to beach sand, particularly for construction works where beach sand is not required.

4. Coastal Processes

This section of the report focuses on the coastal process which influence ambient sediment transport dynamics around the Cocos (K) Islands and within the lagoon to assist in identifying appropriate sources of sediment.

The main processes which affect ambient sediment transport are summarised graphically in Figure 3 below. As shown, the main processes affecting sediment transport are:

- Cross shore sediment transport driven by seasonal wave activity affecting both the external coast and the lagoon coast.
- Lagoon hydrodynamics driven by tidal flood and ebb tides and
- Long shore sediment transport driven by wave induced currents.

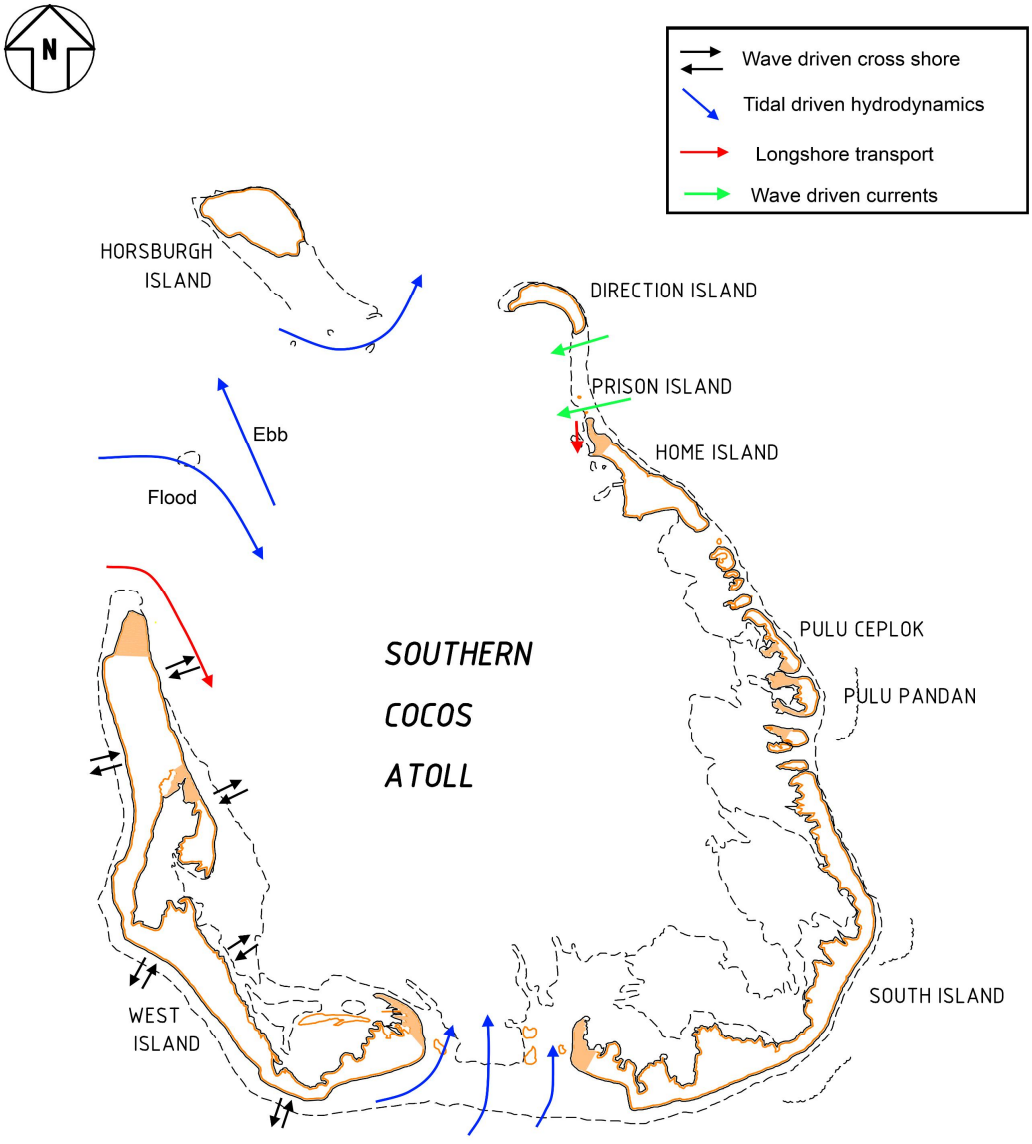


Figure 3 Sediment transport processes summary

Cyclonic activity inducing cyclonic waves and currents are also processes which affect sediment transport, but as these processes are dependent upon the path and frequency of these events and are not considered ambient conditions, they are not reliable processes to use in identifying sediment sources. As such sediment transport by cyclonic activity has not been included in this report.

To build on the available information on sediment transport processes of Cocos (K) Islands, GHD undertook numerical modelling of ambient waves, hydrodynamics and bed sediment transport by using a coupled Mike 21 Flow (Mike 21 FM), Mike 21 Spectral Wave (Mike 21 SW) and Mike 21 Sand Transport (Mike 21 ST) model. This model is only able to reflect sediment transport along the bed and suspended sediment load in the water column and is unable to resolve the movement of sediment onto and off the beach by cross shore wave processes and wind (Aeolian) processes.

A summary of the modelling results is presented here with the full modelling report available in Appendix A.

4.1 Sediments

Sediment transport dynamics, particularly the potential for sediment to be transported is influenced by the size of sediments and the critical shear stresses required to entrain the sediment into the water column.

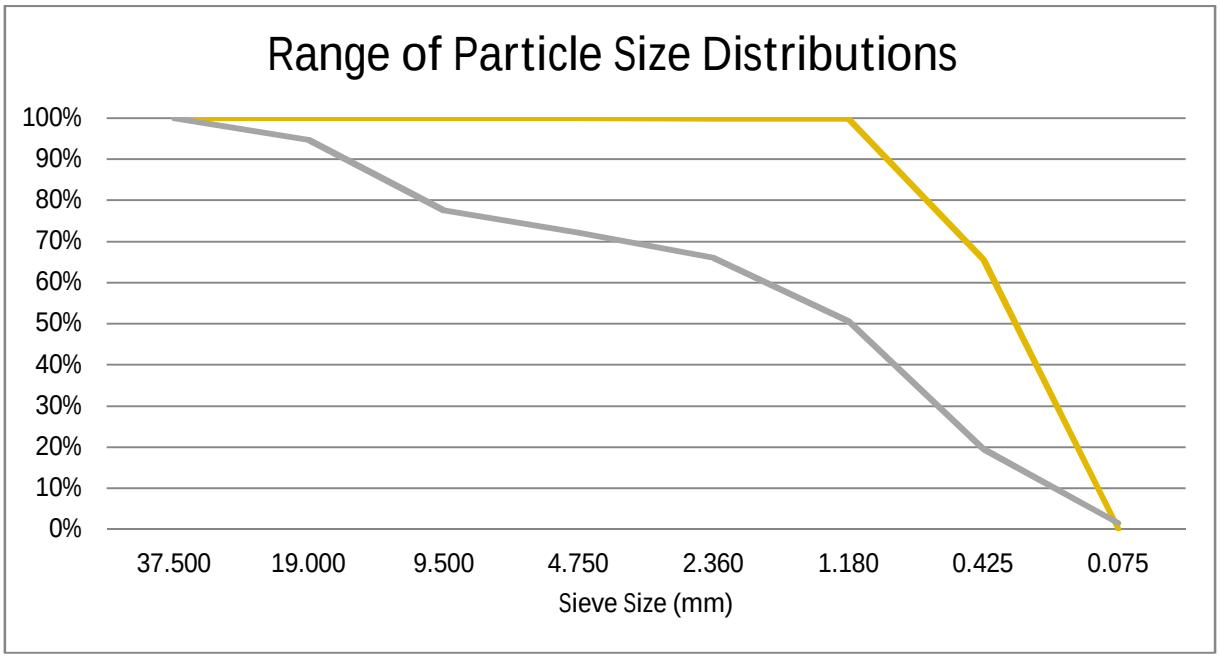


Figure 4 Range of Particle Size Distributions from Rumah Baru Construction

The range of sediment sizes sampled within the lagoon during the construction of Rumah Baru is summarised in Figure 4. The particle size of sand varies within the atoll, with coarser sand typically found at the southern end of the atoll and along the ocean beaches and finer sand found within the lagoon. This is due to smaller particles being entrained in the water column and deposited in low energy areas (such as inside the lagoon), with larger particles requiring higher energy to mobilise and therefore drop out earlier. Refer also to Section 3.3 of the 2000 Coastal Management Plan.

4.2 Geomorphology

Identification of seafloor geomorphology on a 15m grid was undertaken by EOMAPS and was determined by identification of water depth and sea floor slope. The external coast

geomorphology classification from offshore onto the islands is typically fore reef, reef crest, reef flat then land. Inside the island chain the geomorphology is generally classified as lagoon with areas of patch reef. See Appendix B for map of seafloor geomorphology classes.

4.3 Benthic habitat

Identification of benthic habitat on a 15m grid was undertaken by EOMAPS and was determined by reflectance of different wave lengths of light from satellite imagery. See Appendix B for map of benthic habitat classes. The external coast benthos is typically coral on the fore reef and reef crest and hard bottomed/dead coral on the reef crest and reef flat. The lagoon benthic habitat is more complex with seagrass areas generally in the lee of the islands, areas of coral in the central region with patches of unconsolidated sand. The southern passage is a mixture of hard bottom or dead coral and unconsolidated sediment.

Benthic habitat is an important factor influencing sediment transport as the roughness of the sea bed by features such as coral bombies and sea grass influences the height of the boundary layer. The higher the boundary layer, the greater the separation between bed sediment and the currents reducing the likelihood for the critical level of shear stress required to entrain a particular sediment grain size to be reached, refer to Figure 5.

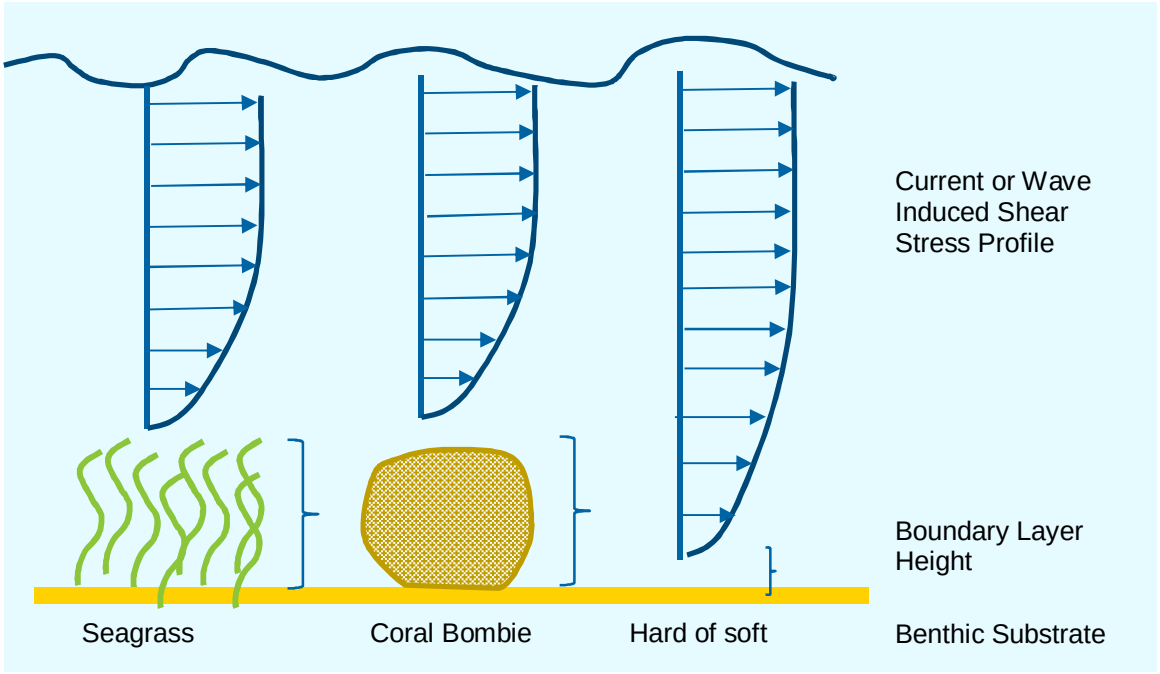


Figure 5 Benthos influence on sediment transport potential

4.4 Ambient Wave Climate

The external coasts of the Cocos (K) Islands are exposed to two main sources of wave energy; waves from the roaring forties (40°S latitude) and waves from the south east trade winds. No nearshore or lagoon measurements of waves have been undertaken within the Cocos (K) Islands. As such, existing ambient wave climate information is limited to offshore wave conditions from global wave models that have been transferred to the nearshore external coast and internal coast using numerical models.

Previously GHD undertook wave modelling to support the design of the Rumah Baru Freight and Passenger Terminal. This study focused on a small section of West Island and the lagoon and these extents were not suitable for the sedimentation study.

Therefore, GHD has undertaken modelling of various offshore wave conditions to assess the nearshore wave climate over the whole Cocos (K) Island area. A key finding of the wave

modelling indicates that regardless of direction of the offshore wave climate, the nearshore wave pattern within the lagoon and on the outer edges of the islands has little variation due to the refraction of wave energy as a result of the steep atoll bathymetry and shallow passage bathymetry at the southern end of the lagoon which significantly restricts wave energy transmission into the lagoon.

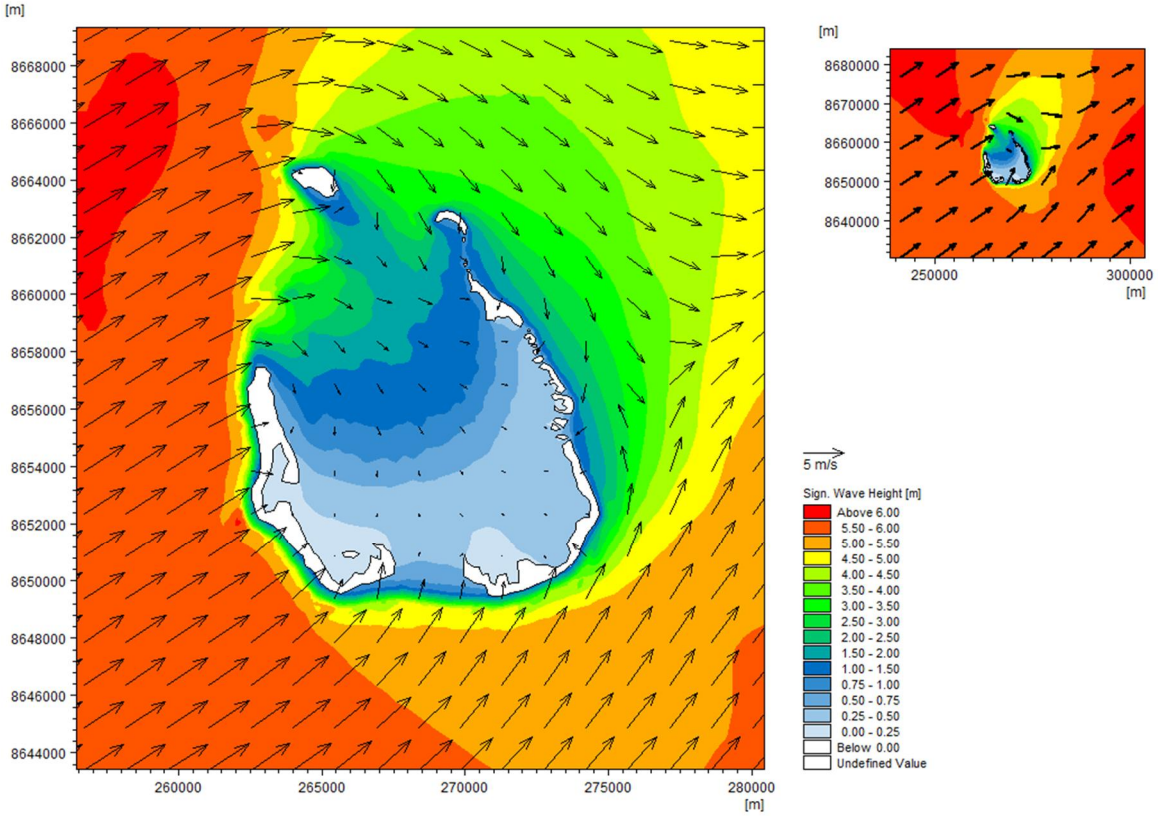


Figure 6 Example wave field during south westerly wave conditions

As indicated in Figure 6, wave energy is greatly dissipated before it reaches the shoreline by the steep rise of the coral atoll bathymetry and fore reef. Within the lagoon, wave energy is greatest at the northern end of the lagoon. On the internal coast, the largest wave conditions are experienced at the north end of the island which is exposed to waves up to 1.0 to 1.5m in ambient conditions. The central and southern end of the lagoon is generally exposed to waves less than 0.75m.

For further details on the results of simulated wave conditions and the modelling inputs refer to the Numerical Modelling Report 158451 (GHD Nov 2016) in Appendix A.

Near shore wave conditions contribute to sediment transport in two main ways, cross shore sediment transport and longshore sediment transport.

4.4.1 Cross shore sediment transport

Cross shore sediment transport describes the movement of sand from the beach to the nearshore and back.

During storm conditions, when water levels and wave energy are higher, wave action on the beach mobilises sediment from the face of the beach and frontal dune, resulting in erosion from the shore and deposition in the nearshore. This process is counterbalanced by beach regeneration processes when sand is deposited on the beach during ambient, and lower wave

period conditions. The deposited sand can then be blown up the beach by the wind to form dunes, refer to Figure 7.

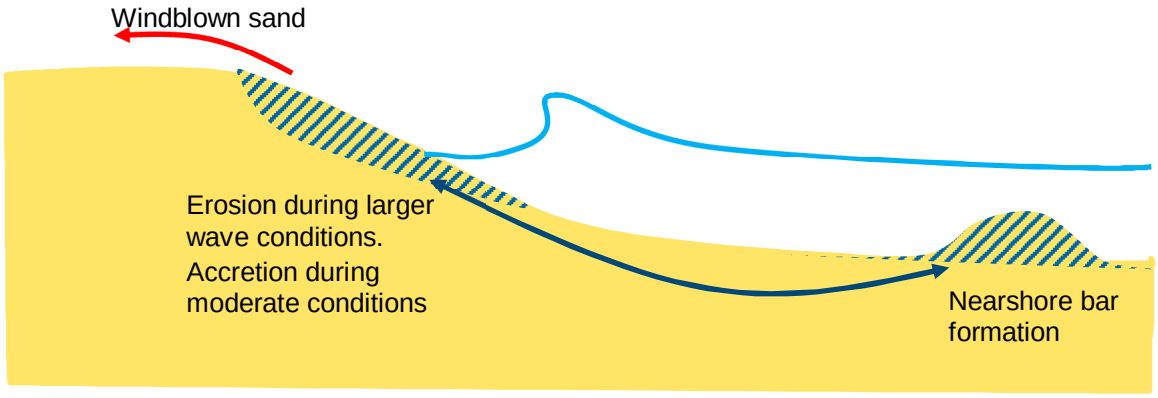


Figure 7 Cross shore sediment transport graphic

This process is the cause of beach erosion experienced on the external lagoon, such as at the South End of West Island at the Runway and has also been observed at the north end, where the low lying beach is easily eroded from the spit during moderate water levels, resulting in the need to develop protection in the form a geotextile sand container seawall at the Fuel Farm.

The model results indicate that regardless of the offshore wave direction a similar pattern of waves is experienced within the lagoon, refer to the Numerical Modelling Report attached in Appendix A for further details.

4.4.2 Longshore sediment transport

Long shore sediment transport occurs when wave trains approach a beach at an angle to the beach perpendicular. When the wave breaks on the shore it mobilises sediment which is moved offshore from the beach with the return current. The balance of the incoming wave induced current and the reflected wave current results in a net long shore current which is able to transport the mobilised sediment along the beach away from the source of the wave energy.

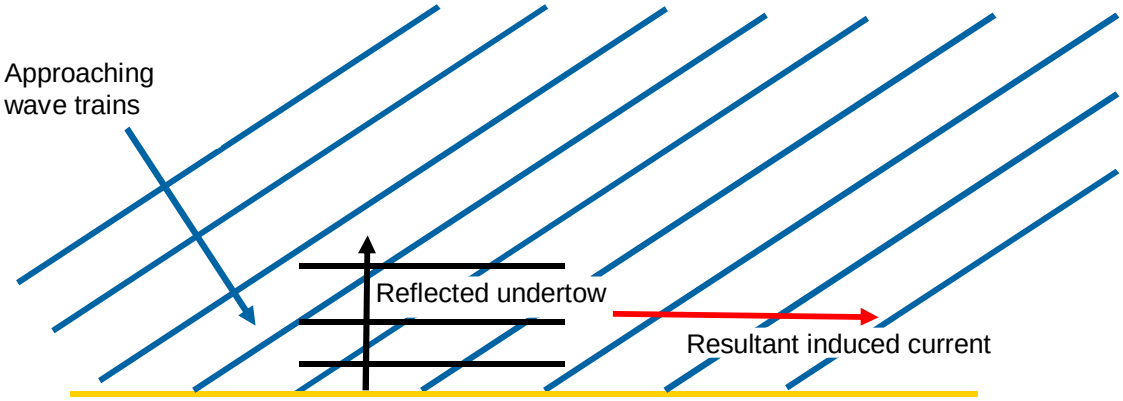


Figure 8 Wave induced longshore sediment transport

Modelled simulations indicate that the nearshore wave direction, regardless of offshore wave condition, on the lagoon side of west island between the fuel farm and Rumah Baru is typically from the northerly to north easterly sector. These conditions result is a southward longshore sediment transport pattern.

4.5 Water levels

4.5.1 Vertical datums

The vertical datum used in this project is the Cocos Keeling Island Height Datum (CKIHD) which is approximately mean sea level, unless noted otherwise.

4.5.2 Tidal planes

Tidal planes for the Cocos (Keeling) Islands measured at the Home Island tidal gauge are given below in Table 7.

Table 7 Tidal planes (Australian Hydrographic Service, 2011)

Tidal Plane (relative to Lowest Astronomical Tide)	Home Island (m CD)	CKIHD (m)
Highest Astronomical Tide (HAT)	1.5	0.85
Mean High Water Springs (MHWS)	1.2	0.55
Mean High Water Neaps (MHWN)	0.7	0.05
Mean Sea Level (MSL)	0.65	0.00
Mean Low Water Neaps (MLWN)	0.6	-0.05
Mean Low Water Springs (MLWS)	0.1	-0.55
Lowest Astronomical Tide (LAT)	0.0	-0.65
Chart Datum (CD)	0.0	-0.65

4.5.3 Sea level rise

In 2010, the Department of Transport reviewed information on mean sea level variation along the Western Australian coastline and provided recommendations on an approximate allowance for mean sea level change for coastal planning, in the form of the *Sea Level Change in Australia: Application to Coastal Planning report*, published by the Department of Transport (DoT) in 2010. The report was mainly based on information presented in the Intergovernmental Panel for Climate Change (IPCC) 2007 report and other recent publications (e.g. Pattiaratchi and Elliot 2005). Based on the information reviewed, the DoT recommended that a vertical sea level rise of 0.9m be adopted for the impact of coastal processes over a 100-yr planning timeframe and 0.3m for a 50-yr timeframe.

A review of climate change and the potential impacts to the Cocos (Keeling) Islands was published by AECOM in 2010. This report looked at historical sea level rise as recorded by the tide gauge located in the lagoon of Home Island and from satellite data. Historical records from the tide gauge were shown to be + 9.8mm/year between September 1992 and June 2007. Satellite data showed a lower rate of rise, a value of + 5.7mm/year since 1993. Based on this data, the report presents a sea level rise projection of 40.1cm by the year 2070. This value is significantly less than the 100 year planning value of 0.9m currently recommended for use by the Western Australian DoT.

4.6 Hydrodynamics

Hydrodynamic currents of the Cocos (Keeling) Islands atoll were previously studied in detail by Kench (1994) through field measurements using current meters. Kench identified that the circulation of the lagoon is tidally driven and that the role of wind on circulation was small. Kench (1994) also identified that shallow passages experience unidirectional ocean to lagoon

flow throughout tidal cycles which contributes to the net north-westward flow, exiting through the north west passage, refer to Figure 9.

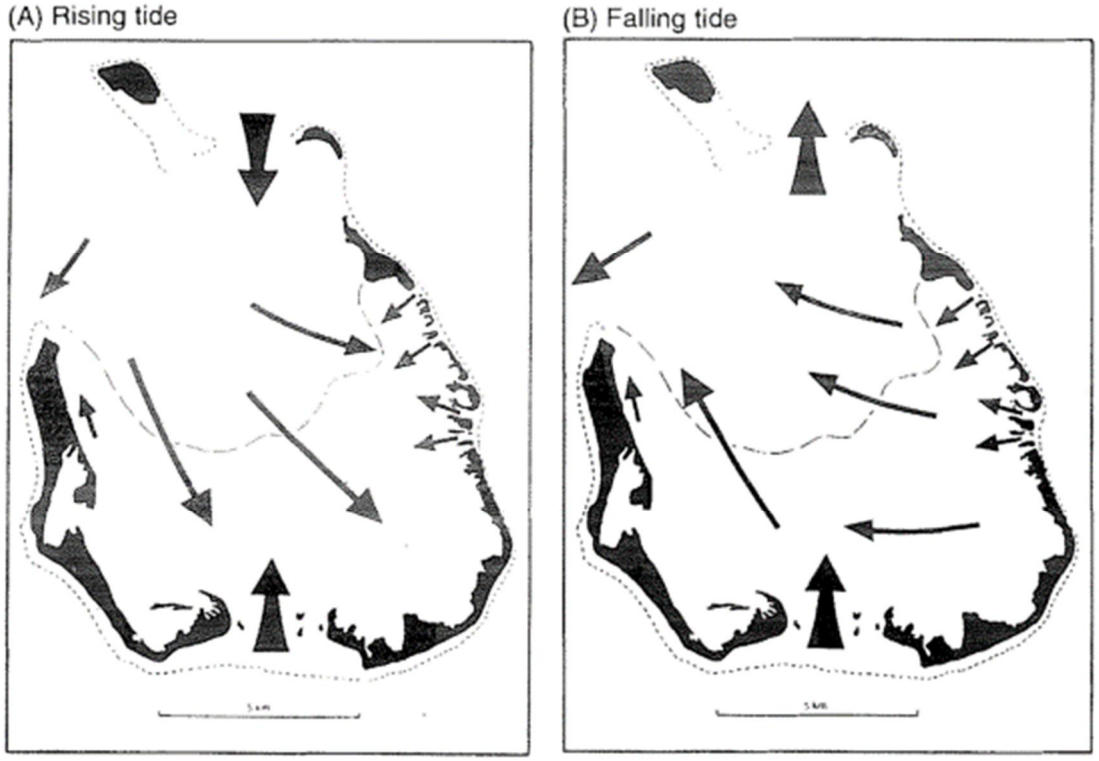


Figure 9 General circulation of the Cocos (Keeling) islands lagoon on the rising and falling tide (Kench 1994).

GHD's assessed current circulation of the rising and falling tides during a tide only forced scenario, refer to Figure 10 and Figure 11. The results of this modelling generally support Kench's observations, although the direction of currents within the lagoon appear to differ slightly, noting that Figure 9 by Kench is a general circulation map based on discrete sampling points and is not necessarily indicative of magnitude of currents. The main discrepancies between Kench's observations and those modelled by GHD is the direction of flow from the lagoon to the ocean through some of the shallow passages on the eastern side of the lagoon and the direction of the shore parallel return current along the north eastern end of West Island.

On the eastern side, around Home Island, it is thought that the circulation is more wave driven than tidally driven, particularly in the gap between the northern end of Home Island and Prison Island/Direction Island. This is supported by observations on site and the long term evolution of Prison Island westwards.

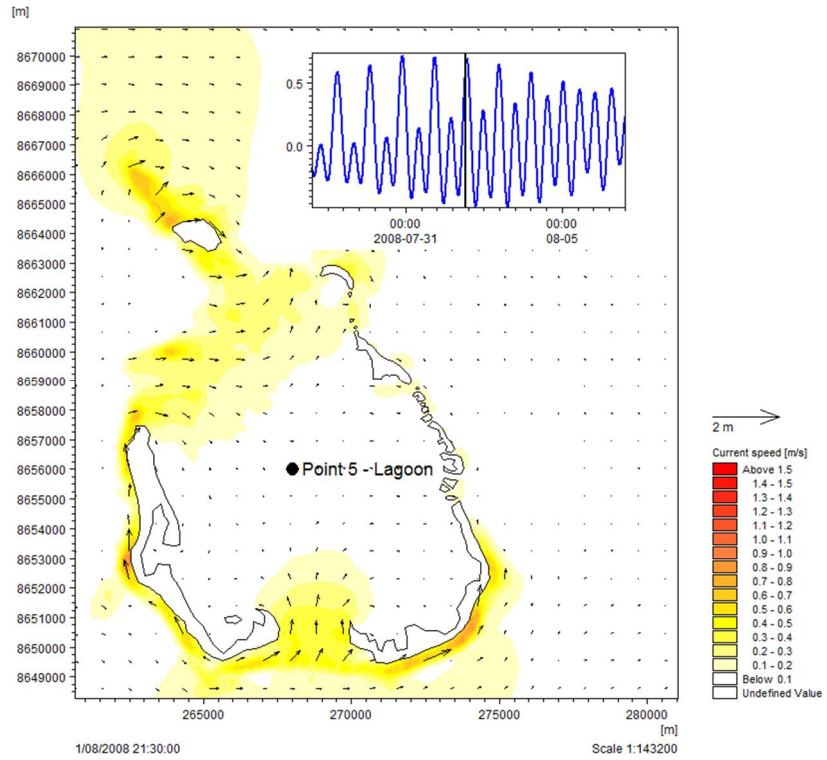


Figure 10 Lagoon circulation currents during a modelled rising (flood) tide (GHD 2016)

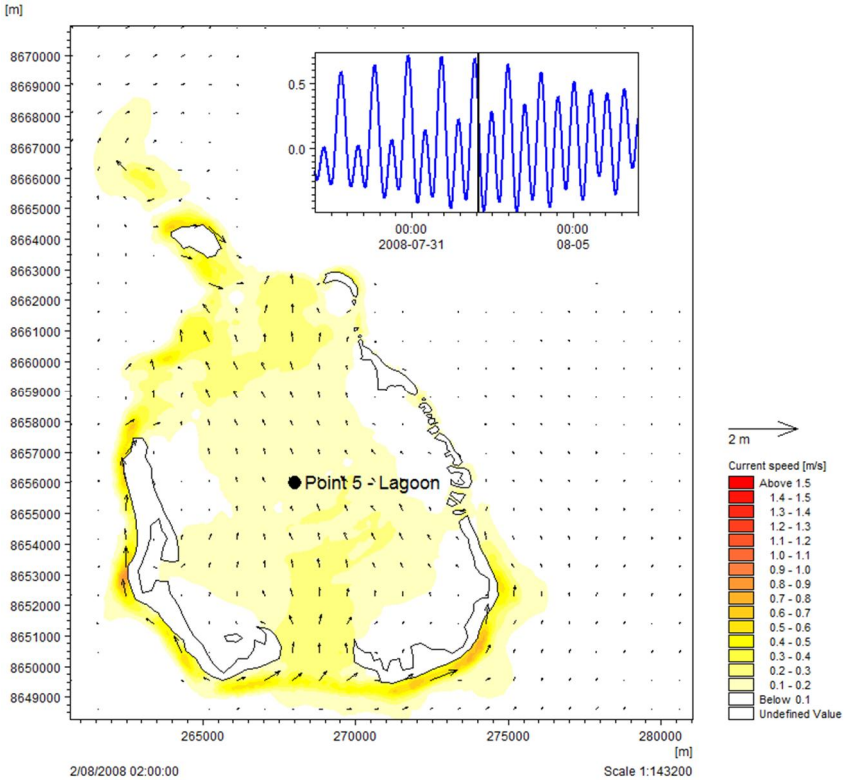


Figure 11 Lagoon circulation currents during a modelled falling (ebb) tide (GHD 2016)

4.7 Sediment Transport Modelling

4.7.1 Sediment transport potential

The results of the coupled wave and hydrodynamic model were assessed during summer and winter for a two-month duration scenario. The residual current patterns for both seasons was similar, with the magnitude of currents slightly greater in winter than in summer. Residual currents for the winter simulation in Figure 12, indicates that the areas of highest current speed occur on the external coast and outer rim of the islands. High current areas were identified at the North Point and near Sydney Highway (Trannies Beach) of West Island, across the southern Passage, on the external coast of South Island and around Horsburgh Island and through the north western and northern passages into the lagoon. Areas of high residual current speeds, exhibit high sediment transport potential, provided there is a supply of sediment into or source of sediment in the area.

In addition to high residual currents, patterns in sediment transport which indicate divergent residual currents are also likely to experience net erosion. One example of this is at the most southerly point on West Island where the near shore currents head northwest along the external coast toward the settlement on the northern side and toward the east north east on the eastern side approaching the passage. This zone of diverging currents and high residual currents identified by the modelling at the south end of West Island overlap with two erosion hot spots, where infrastructure at the South End Runway and Twist Memorial were previously identified as at risk.

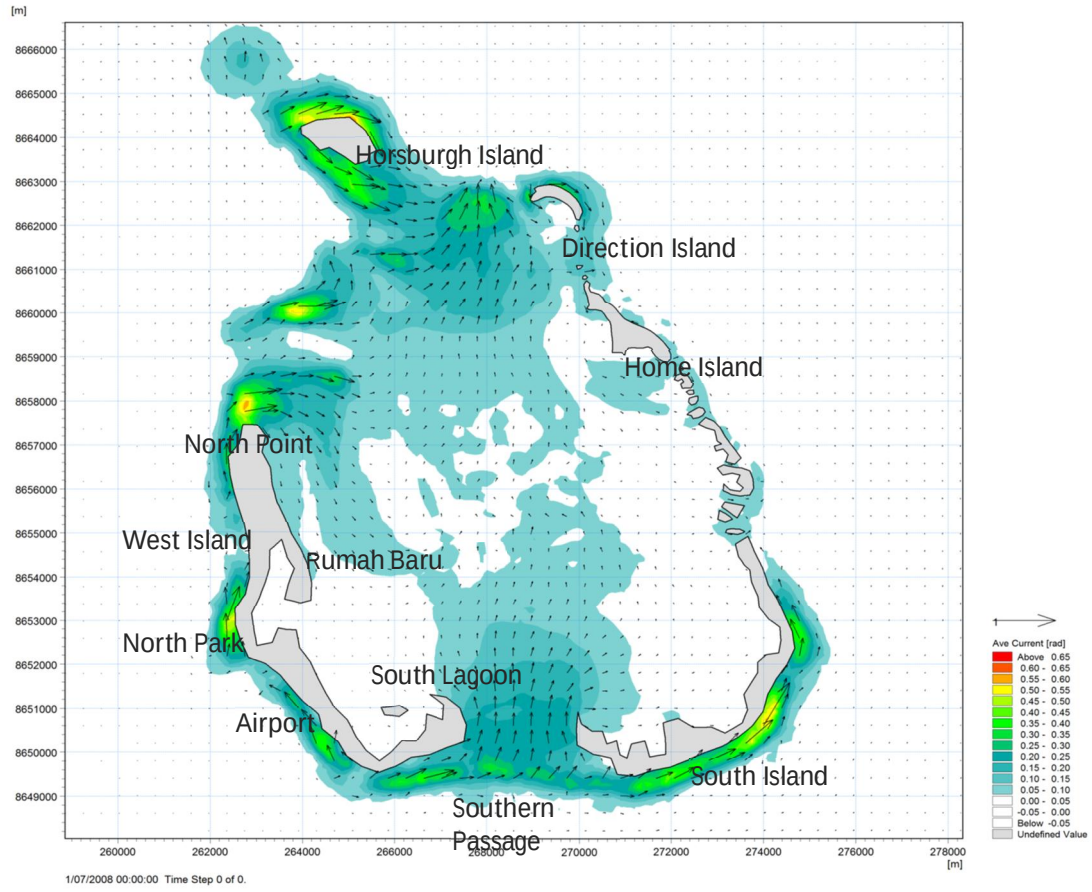


Figure 12 Residual currents - winter simulation period

4.7.2 Bed sediment transport

Modelling of sediment transport undertaken by GHD (2016) was undertaken to identify the sediment transport dynamics of the lagoon. This modelling is therefore able to identify sediment entrainment, movement and deposition within the tidal limits of the model by bed shear stresses induced by waves and currents. This modelling is unable to represent sediment transport that may occur of a result of sand being mobilised from beaches by wave breaking processes (cross shore sediment transport) or aeolian (wind) transport of sediment to or from sand dunes. This modelling was undertaken to identify sediment movement within the lagoon, and therefore the extents of the erodible bed was limited to within the lagoon.

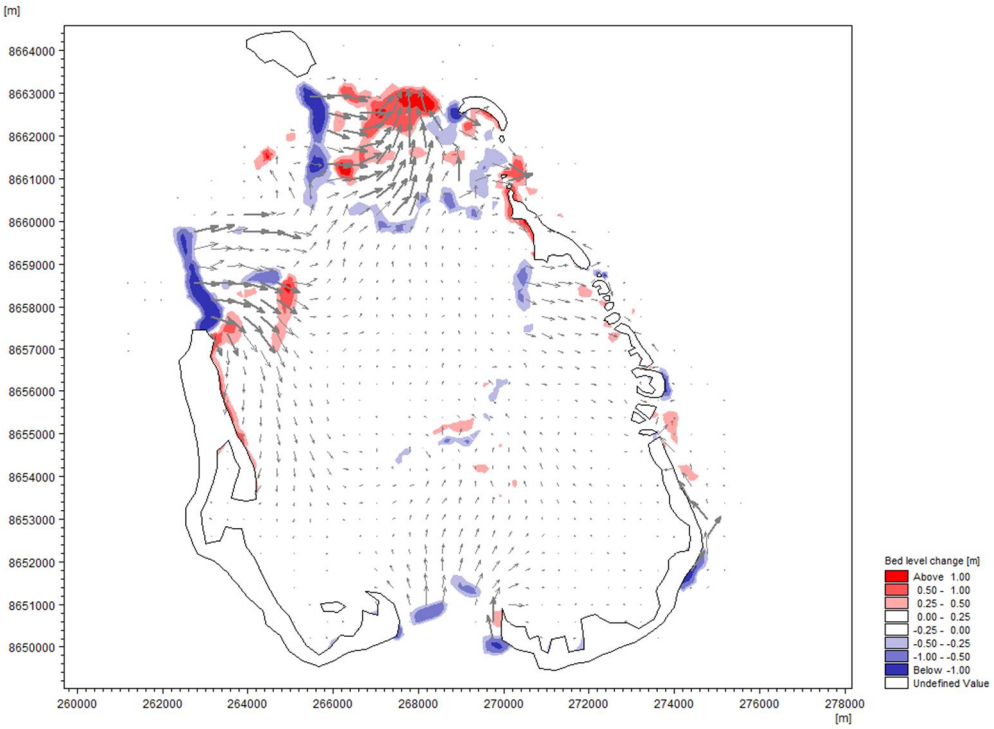


Figure 13 Bed level changes identifying erosion and accretion hot spots (based on assumed availability of sand)

Sediment transport modelling of the lagoon has identified a number of erosion and accretion hot spots. In Figure 13, erosion of the sea bed is identified at the northern end of West Island, at the southern passage and in the south of Horsburgh Island. Accretion areas with proximity to the inhabited islands were identified on the lagoon side of West Island, at Turtle Beach on Home Island and in a slug (submerged sand spit) east of the northern tip of West Island. This general pattern of erosion and accretion was confirmed by the littoral transport overview identified by GHD in 2000, Figure 14, with the exception of the sand slug at North Point.. Although not indicated in Figure 13, the low energy environment between the south lagoon and West Island is also a known sediment sink and the tip of the sand spit at the south end on West Island is also an accretionary feature.

The updated understanding of the sediment movement within the Cocos (K) Islands atoll, is summarised in Figure 15.

Verification of bed change modelling was proposed to be undertaken by comparing past hydrographic survey data sets. The 2011 LADS survey from the Australian Hydrographic Service was compared to the bathymetry maps (2015-2016) obtained by EOMAPS, and whilst the EOMAPS bathymetry data gridded to a 15m grid was suitable for the purposes of modelling, the difference in the two sampling techniques meant that format of the data was not suitable for the purpose of comparing bed level change at a finite scale.

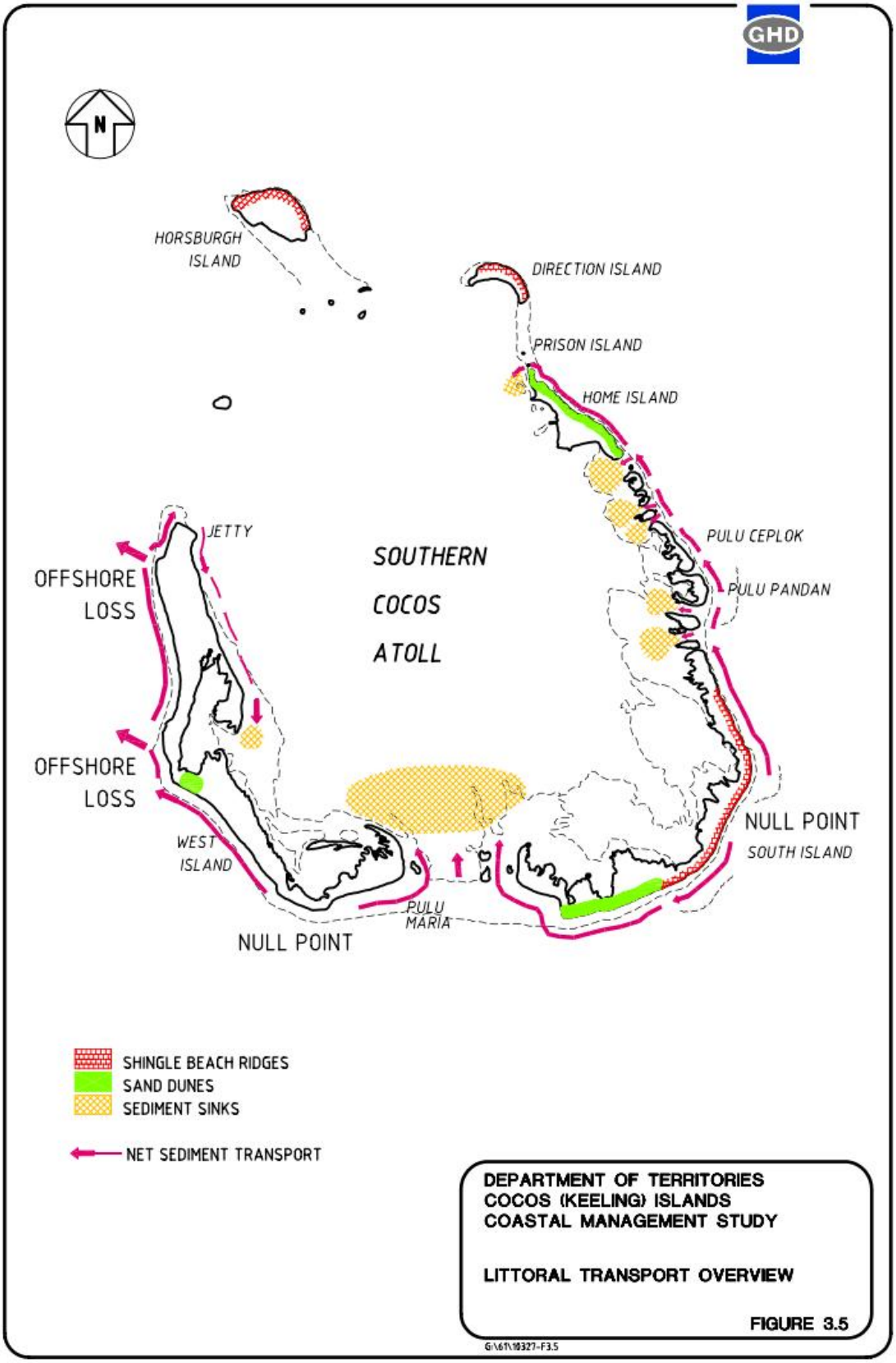


Figure 14 Littoral transport overview (GHD 2000)

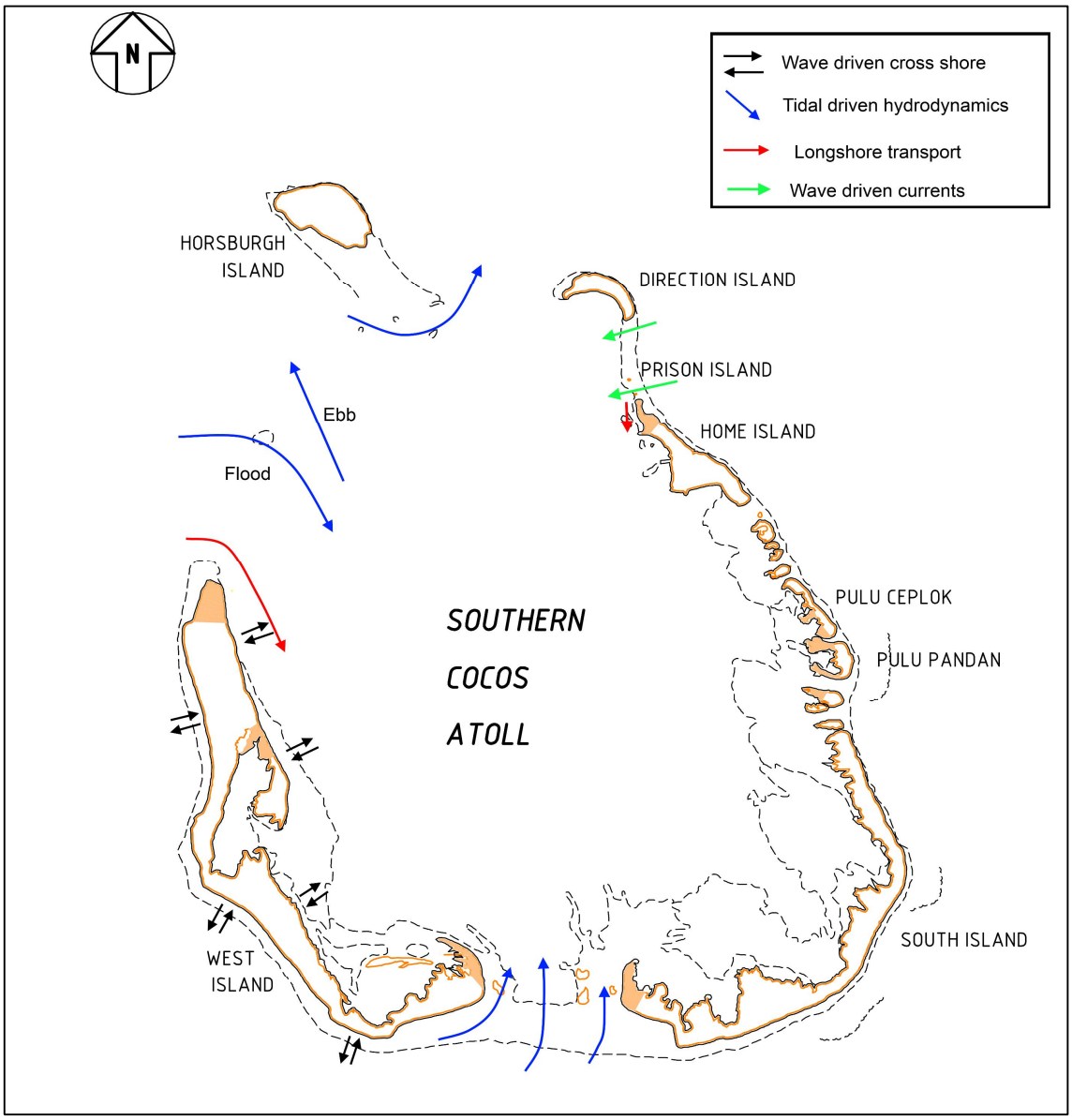


Figure 15 Sediment Transport Summary 2016

4.7.3 Sediment Transport Modelling Summary

The results of the sediment transport study have identified a number of accretion areas which would be suitable for extraction, which are discussed in Section 5.2.

5. Coastal Management Plan

This section of the report focuses on the proposed management activities to address the issues identified in Section 3.

Previous recommendations on sand extraction made by GHD in the 2000 Coastal Management Plan discussed that extraction areas should comply with the following requirements:

- All removal should be from “sink” areas where sediments are unlikely to be remobilise into the active coastal system;
- All removal should not introduce changes in seabed topography that may affect ambient conditions and beach stability;
- Land removal sites should make due allowance for flooding and fluctuations in groundwater levels during heavy rain; and
- Removal should preferably be sustainable.

In addition to these:

- Land removal sites selection should be considerate of the rate of recovery of the area from the extraction.

These factors still apply.

5.1 Environmental factors affecting construction resources

The 2000 Coastal Management Plan (GHD) noted that the extraction of construction resources (sand in this case) has several areas of potential impact on the environment apart from coastal stability. Some of these are:

- Extraction processes releasing fine material into the sea with increases in turbidity potentially smothering corals and seagrass;
- Direct damage to sensitive habitats;
- Creation of areas of poor water exchange and mosquito breeding grounds; and
- Short circuiting outflow paths from the freshwater lenses leading to a reduction in storage and increase in salinity.

These factors need to be considered in any sand extraction permit. In addition, sand extraction areas should not impact on existing vegetation onshore or offshore (seagrass), particularly where there are protected or vulnerable species such as the *Calophyllum* trees, which are prevalent along the lagoon foreshore.

5.2 Potential extraction sources

Based on the results of the modelling, site investigations and knowledge of coastal dynamics, on the Cocos Keeling Islands, the following lagoon sand sources have been identified as potential sources for sand harvesting (and are shown in Figure 16 and Figure 17):

- West Island:
  - North Point Sand Bank
  - Bob’s Folley to north of Rumah Baru
  - Rumah Baru
  - South End Sand Spit

- Home Island
  - Turtle Beach

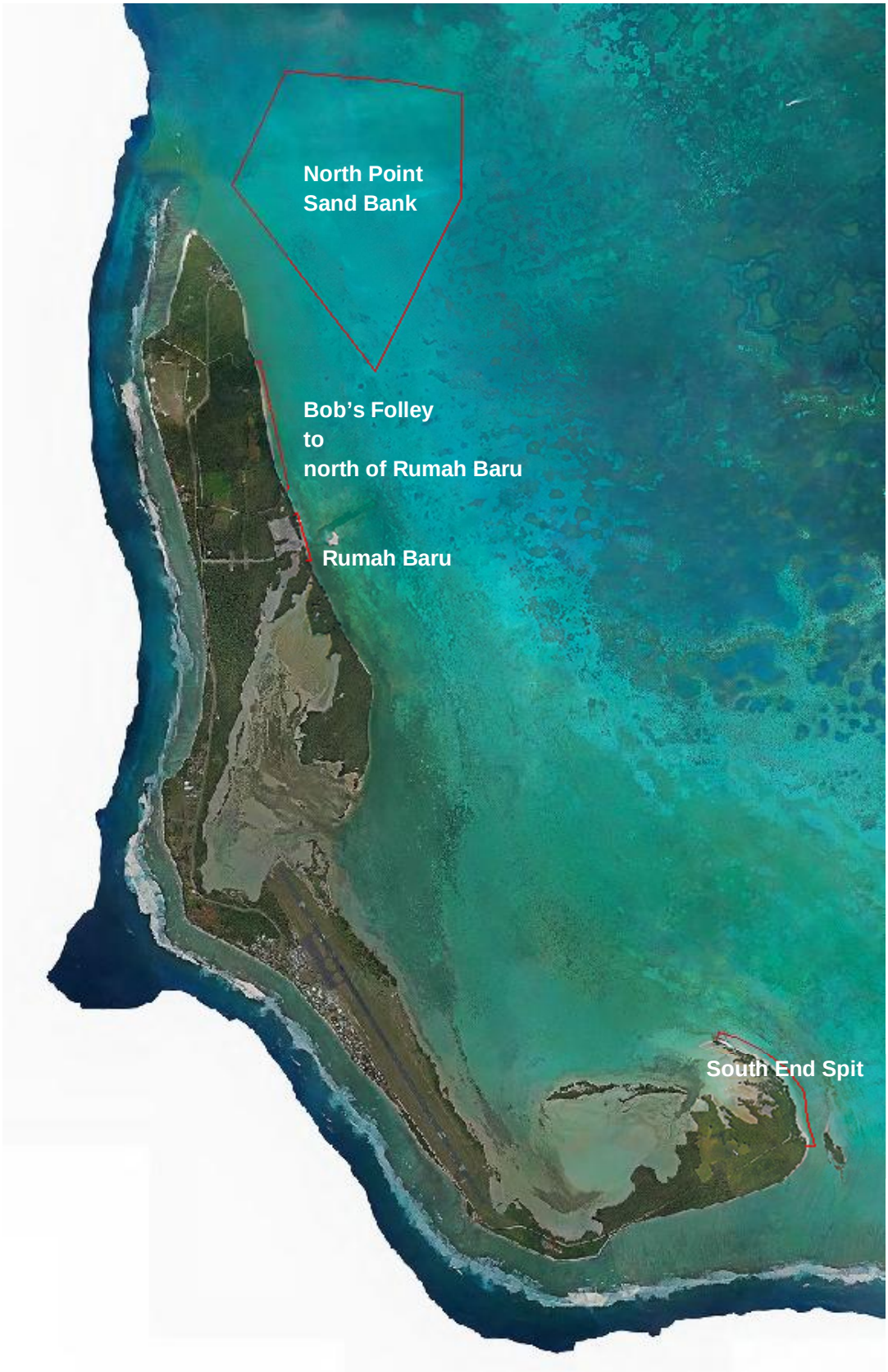


Figure 16 Sand sources on West Island

Figure 17 Home Island sand sources

It is noted that, with the exception of the South End of West Island, all proposed areas are within the Port Limit (refer Admiralty Chart AUS607) and extraction of sand is therefore under the control of the Cocos (K) Islands Port.

As per the 2000 Coastal Management Plan, sand extraction should only be permitted where it will not impact on coastal stability. Extractive industry for other sites is not prohibited under the general rural zone, however would only be permitted subject to application, advertisement and objection process under the general rural zone. Any applications that are received by Shire, Council or the Commonwealth Government, for extractive industry in the area defined as the coastal zone (for the purposes of this report) should be referred for comment. This should be by an independent coastal engineer or geomorphologist with particular experience in coral atolls, who can provide informed commentary on possible effects on coastal stability.

5.3 North Point Sand Bank

Identified in the modelling as a depositional area, the North End Sand Bank is also a persistent feature seen in aerial imagery over time as indicated by Figure 18. This was also identified in the Maunsell/AECOM 2009/2010 report which identified that this slug may accelerate southwards into the lagoon under changed future climatic conditions, such as increased storm/cyclone intensity.

Figure 18 Comparison of the North End spit from 2006 to 2015 (Source: Google Earth Pro)

5.3.1 Volume

Analysis of the contours in the area shows that there is an east west feature approximately 200 m long and 50 m wide which extends up from the background lagoon level of -5 m LAT to -1.6 m LAT. An estimate of the volume of this sand spit was undertaken assuming that if the sand bank did not exist the bathymetry would reduce uniformly across this area from -4 to -5 m. The resultant volume difference between this plane and the surveyed bathymetry is approximately 650,000 m^3.

5.3.2 Extraction Methodology

This feature is located within the lagoon and is not easily accessible by equipment on the island, therefore, extraction from this source would require dredging equipment such as suction hopper dredge and would require environmental approval. This is also a region that may be difficult to dredge except in doldrum/calm conditions as it is exposed to waves from the north and west.

5.3.3 Monitoring and Limitations

Under increased cyclonic and intense storm activity, this slug is likely to accelerate southwards, providing sediment feed to the lagoon and internal coastal locations, therefore removal of it is not recommended. There are additional practical limitations as highlighted below.

The main limitations to extracting sediment from this location are availability of suitable equipment and the mobilisation and demobilisation costs of bringing dredging equipment to the site. The volume available also assumes sediment to the full depth with no underlying reef/rock and that the material is suitable for use for GSC fill – that is – free of significant coral and consisting mainly of beach sand. It should be noted that this may not be the case, based on previous dredging campaigns undertaken elsewhere in the atoll.

This region around North Point is also known as a turtle feeding ground, so environmental factors will also need to be considered.

In addition, dredging of this feature is likely to have implications on the hydrodynamics and penetration of wave energy through the lagoon and as a result may have adverse effects on cross shore erosion processes in the North Point vicinity. Further investigation into the feasibility of this option is recommended to assess potential impacts only if no other options are available.

5.4 Rumah Baru and Boat Launching Facility

Rumah Baru and the adjacent boat ramp area have been identified as a suitable source of sediment for extraction due to the accretion that has occurred there over the last few years and the ongoing excavation required to keep this facility operational in all conditions. It is understood that up to 300m^3 per week has been removed on an ongoing basis to keep the ramp clear.

The area immediately north of the jetty has accreted considerably since the construction of Rumah Baru in 2011, as indicated by the grass which has grown back on the foreshore, the increased distance from the abutment of the jetty to the waterline, the alignment of the old boat ramp in comparison to the new and the existing survey marks showing the old coastline, refer Figure 19. It is considered that this buffer zone should be maintained, to minimise the future risk of erosion and inundation at the Rumah Baru facility, including jetty abutment and asphalted carpark areas (particularly if sea level rise scenarios are realised).

Figure 19 Clockwise from top left: Accreted area at jetty abutment; old ramp versus new ramp; old survey marks (2013); location of old survey marks on jetty

5.4.1 Location

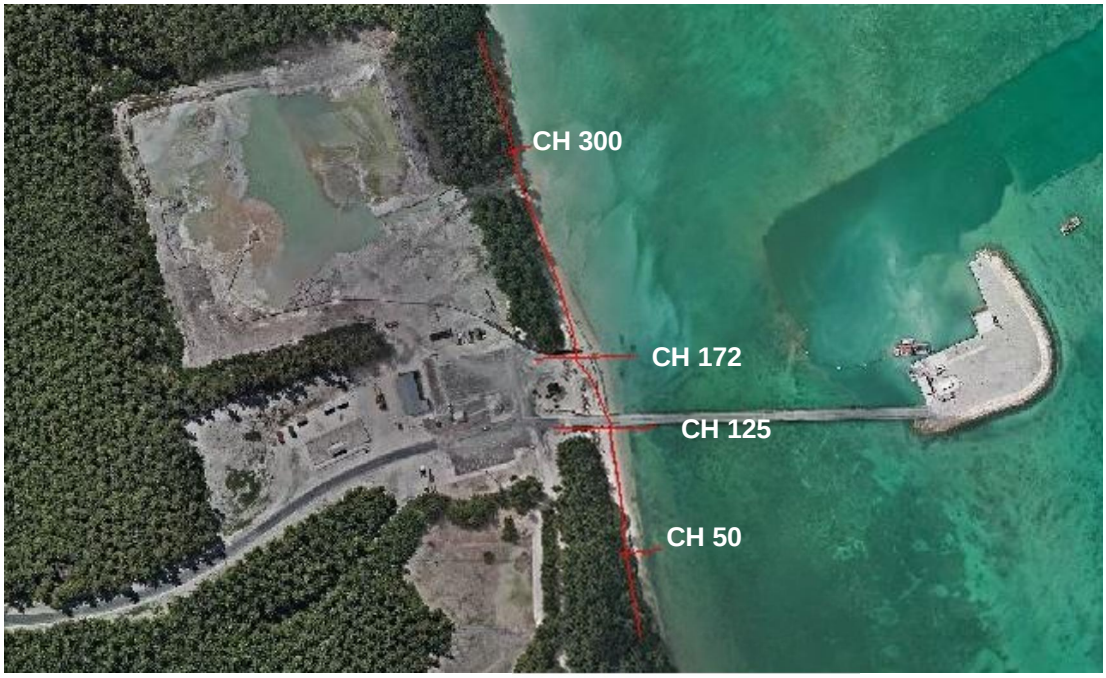


Figure 20 Rumah Baru and cross section locations

Cross sections of the beach survey undertaken by GHD in October 2016, as shown in Figure 21 indicated that the beach width, seaward of the top of beach at Rumah Baru increases from 20 m

wide in the south at section CH 50 to 25 m south of the jetty at CH125, to 35 m wide at the boat ramp and decreasing to 15 m wide north at section CH 300.

5.4.2 Volume

Estimates of material suitable to be extracted were calculated between the surveyed natural surface and different tidal planes seaward of the vegetation line (where the beach slope changes).

For the 370 m length of Rumah Baru surveyed, approximately 6,500 m^3 of material exists, if excavation to LAT was allowed. If excavation is limited to MSL, then only approximately 2,800m^3 is available.

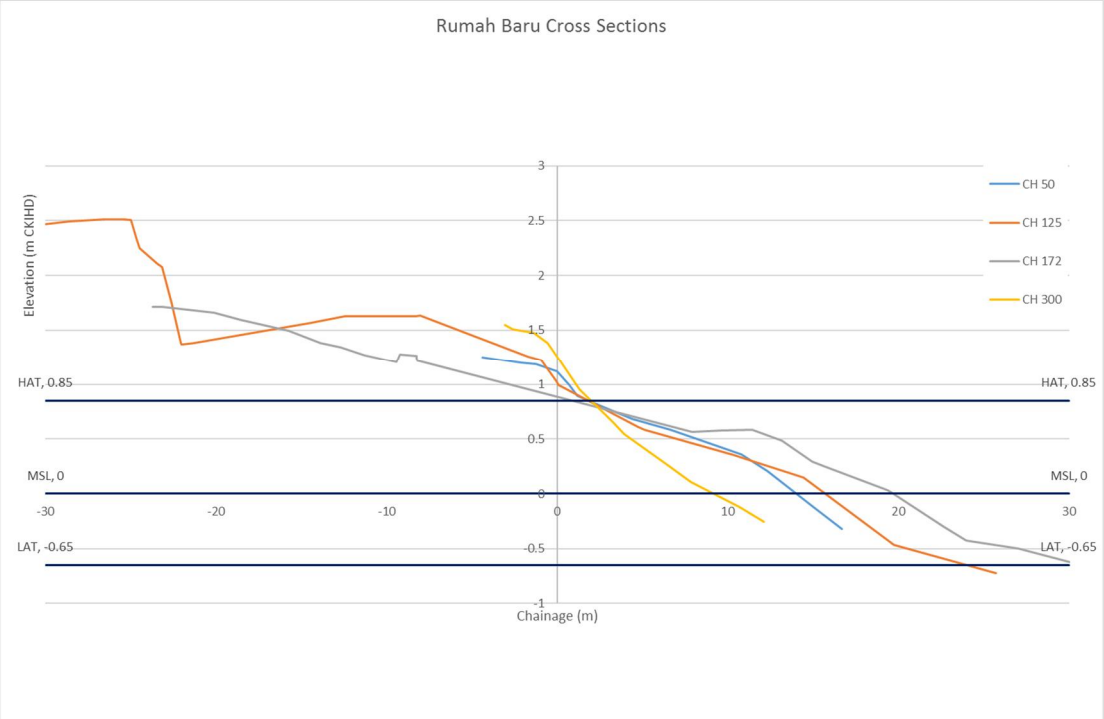


Figure 21 Beach cross sections Rumah Baru (0m Chainage indicates approximate beach crest)

At the back of the beach, to the north of the boat ramp, there is an area of stockpiled sand which is currently covered in vegetation, refer Figure 22. This stockpiled sand is estimated to equate to approx. 950m3 in volume and is recommended for use as a priority over removing sand from the beach. Care would need to be taken to minimise disturbance to vegetation (this area was partially cleared as part of the Rumah Baru project) and any vegetation remnants would need to be removed prior to using the sand for GSC filling.

Figure 22 Stockpiled sand north of Rumah Baru boat ramp

5.4.3 Extraction Methodology

Extraction of sand from Rumah Baru would be by small excavator and limited to above the MSL mark to a distance of no more than 1m below the existing surface, with the primary focus on keeping the ramp clear. Preference is for the sand to be removed by continuous scraping up the beach at a consistent depth and slope to the natural surface, rather than digging large holes, refer Figure 23. This allows the beach to recover more quickly as it is already at an equilibrium slope.

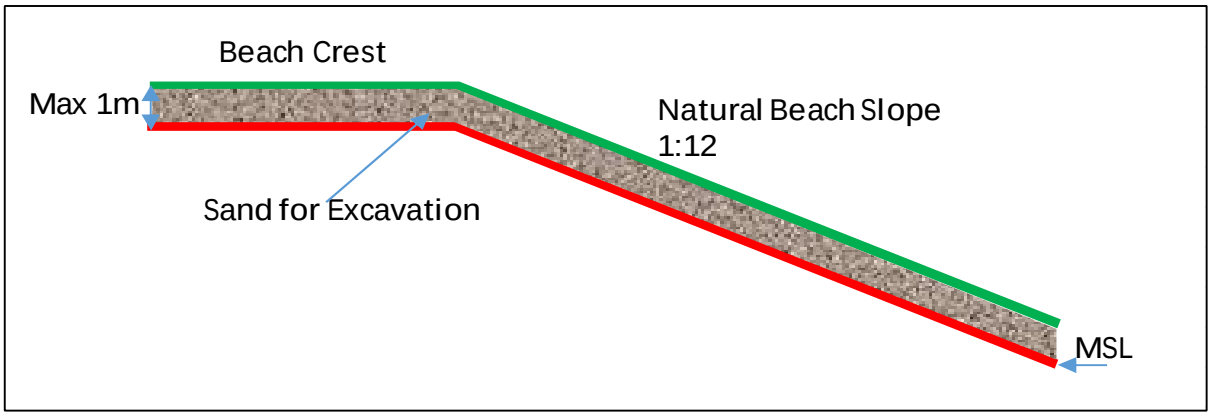


Figure 23 Typical Excavation Profile Rumah Baru

5.4.4 Monitoring and Limitations

In order to extract sand from this location is a sustainable manner, the following guidelines apply:

- No disturbance of existing vegetation, particularly *Calophyllum* trees (found towards Chainage 300)
- Sand to be extracted at natural beach profile, rather than isolated holes;
- Sand will accrete at this location under all conditions, however is likely to accelerate under sustained northerlies, due to the increased mobilisation of the sand spit at North Point southwards. Care should be taken in extracting increased volumes during these times (doldrums/cyclone season) as it will deplete sand able to be remobilised north under ambient conditions and may have a detrimental impact on the northern end of the lagoon in the long term.
- If the high tide mark (general debris/flotsam line) retreats landwards of the red arrow marker on the jetty, refer Figure 24, no excavation is to occur until sand has consistently built out at a shallow slope (1:10 – 1:12)

Figure 24 Red arrow showing landward extent of high tide mark for safe extraction

To assist with monitoring beach levels in relation to the cross sections, level markers have been provided on the piles showing levels above LAT for ease of reference regarding future levels, refer Figure 25.

Figure 25 Survey marks on jetty piles (to LAT)

5.5 Rumah Baru to Bob's Folley

The stretch of coast from Bob's Folley to north of Rumah Baru shown in Figure 27 has been identified as a potential sand source location due to the deposition of longshore sediment transport from the north end along this section of coast. Bob's Folley is the name provided to the site of the old barge ramp and is identified by a cleared area to the south of the old West Island Jetty. The southern extent of this identified section is the site of the temporary boat ramp used during the Rumah Baru project (now removed), which is accessed via the farm road off Sydney Highway.

This area of coastline seems to have been in an accreting phase for a while, with new vegetation evident at the back of the beach, refer Figure 26.

Figure 26 (L) Vegetation Growth at back of beach; (R) Looking north from Rumah Baru towards Bob's Folley

5.5.1 Location

Cross sections of the beach survey undertaken by GHD in October 2016 as shown in Figure 28 indicate that the beach width, seaward of the top of bank is fairly consistent in width at about 20 to 25 m to the LAT contour. The width landward from the top of the bank is more variable. From chainage 0 to 300, the back of beach width (to established vegetation) is narrow, increasing from about 5 to 15 m. From chainage 300 to 650 the back of beach width is more consistent at about 15 m wide. And from CH 650 to 900 the back of beach gets narrower again from 15 m to 5 m and north of CH 900 the back of beach is 5 m or less.

Figure 27 North Rumah Baru to Bob's Folley showing cross section locations and survey extents

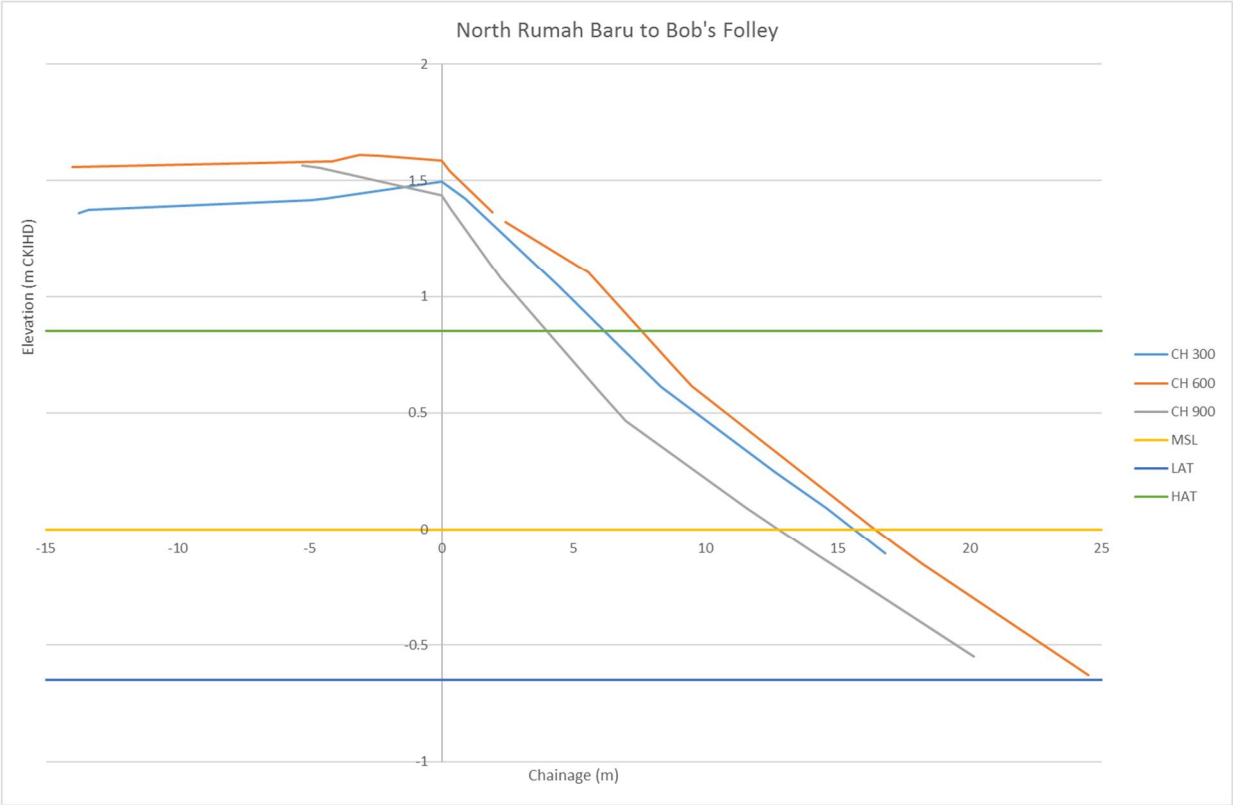


Figure 28 Beach cross sections Rumah Baru to Bob's Folley (0m Chainage indicates approximate beach crest)

5.5.2 Volume

Estimates of material suitable to be extracted were calculated between the surveyed natural surface and different tidal planes seaward of the vegetation line (where the beach slope changes).

For the approx. 900 m length of coastline surveyed, approximately 26,000m^3 of material exists, if excavation to LAT was allowed. If excavation is limited to MSL, then only approximately 13,300m^3 is available.

5.5.3 Extraction Methodology

Extraction of sand from Rumah Baru to Bob's Folley would be by small excavator and limited to above the MSL mark to a distance of no more than 1m below the existing surface. Preference is for the sand to be removed by continuous scraping up the beach at a consistent depth and slope to the natural surface, rather than digging large holes, refer Figure 29. This allows the beach to recover more quickly as it is already at an equilibrium slope.

For this section of coast, it is preferred to keep the vegetated crest intact, with excavation along the sloped beach profile only, refer Figure 29.

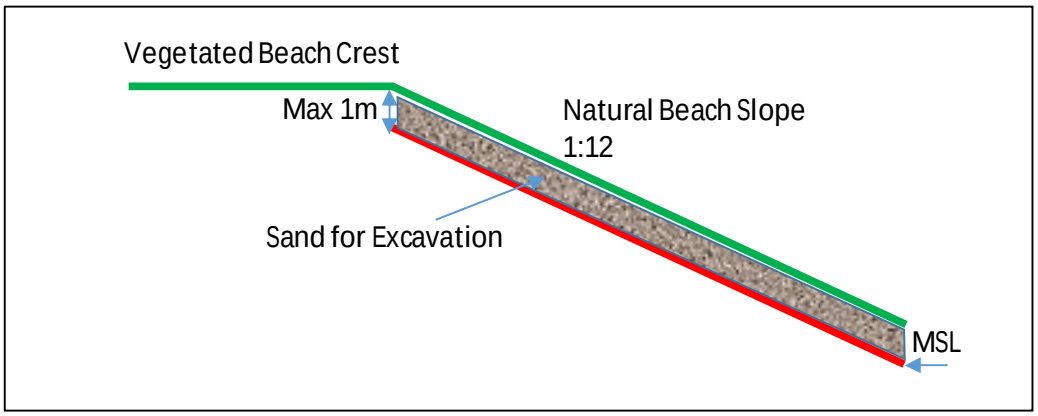


Figure 29 Typical Excavation Profile Rumah Baru to Bob's Folley

5.5.4 Monitoring and Limitations

In order to extract sand from this location is a sustainable manner, the following guidelines apply:

- No disturbance of existing vegetation, particularly *Calophyllum* trees;
- Sand to be extracted at natural beach profile, rather than isolated holes;
- Sand will accrete at this location under all conditions, however is likely to accelerate under sustained northerlies, due to the increased mobilisation of the sand spit at North Point southwards. Care should be taken in extracting increased volumes during these times (doldrums/cyclone season) as it will deplete sand able to be remobilised north under ambient conditions and may have a detrimental impact on the northern end of the lagoon in the long term;
- Preference should be given to extraction from the southern end of the profile (between Chainage 300 and 600) as this is the widest section of coastline. The northern end (towards Chainage 900) will be more sensitive to seasonal fluctuations, particularly during northerly conditions.

5.6 South End of West Island

The south end sand spit adjacent the south end passage on West Island was identified as a potential sediment source as it is an accretionary sediment feature, created by the consistent tidal driven currents through the passage regardless of the tidal stage.

While historically this has been used as a sand source location, it was for relatively small volumes (typically 20m^3 or less at a time). Preference is not to use this unless the option of Rumah Baru and north to Bob's Folley are exhausted as this is a more dynamic area of coastline and therefore there is a higher potential for adverse effects on the adjacent coastline to occur.

5.6.1 Location

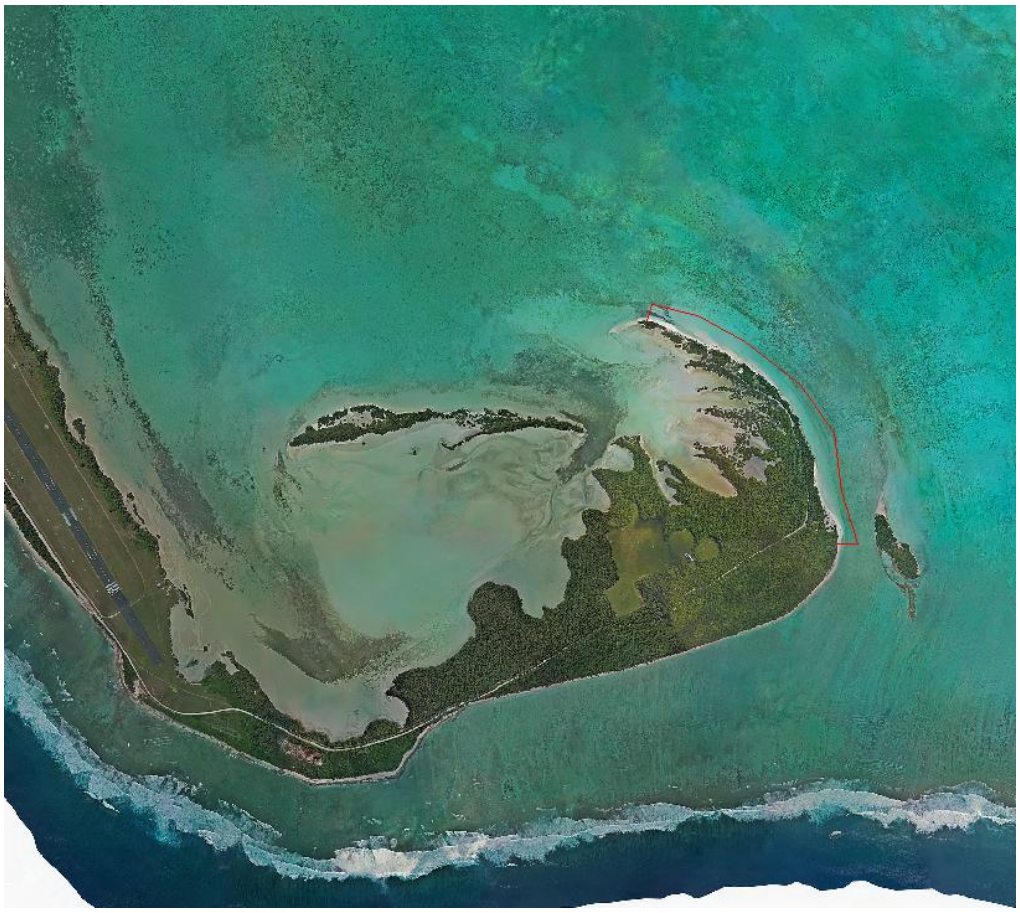


Figure 30 South End of West Island

5.6.2 Extraction Methodology

Extraction of sand at this location is not recommend.

5.7 Turtle Beach on Home Island

Turtle Beach was first identified as an accretion area from the sediment transport modelling and this was supported by desktop and field survey which identified that sand has accumulated at the southern end of the beach against a natural rubble groyne, refer Figure 31. The northern end of the beach has suffered from erosion in the past and is narrowing in width, supporting the theory of southwards transport in this area. There is a large flat offshore sand bar where the majority of the sand appears to be sitting, being pushed onshore by wind and current influences.

Sand extraction has been occurring at this beach in recent times for the purposes of GSC filling for the seawall which has been constructed along the coastline to the south of the Home Island wharf.

Figure 31 Turtle Beach, Home Island looking south towards rubble groyne (L) and north towards cemetery/Prison Island (R)

5.7.1 Location

Cross sections of the beach survey undertaken by GHD in October 2016, as shown in Figure 33 indicated that the beach width is relatively consistent along the coast at approximately 10m.

Figure 32 Turtle Beach survey area

5.7.2 Volume

Estimates of material suitable to be extracted were calculated between the surveyed natural surface and different tidal planes seaward of the vegetation line (where the beach slope changes).

For the 300m length of Rumah Baru surveyed, approximately 3.900 m^3 of material exists, if excavation to LAT was allowed. If excavation is limited to MSL, then only approximately 1.400 m^3 is available.

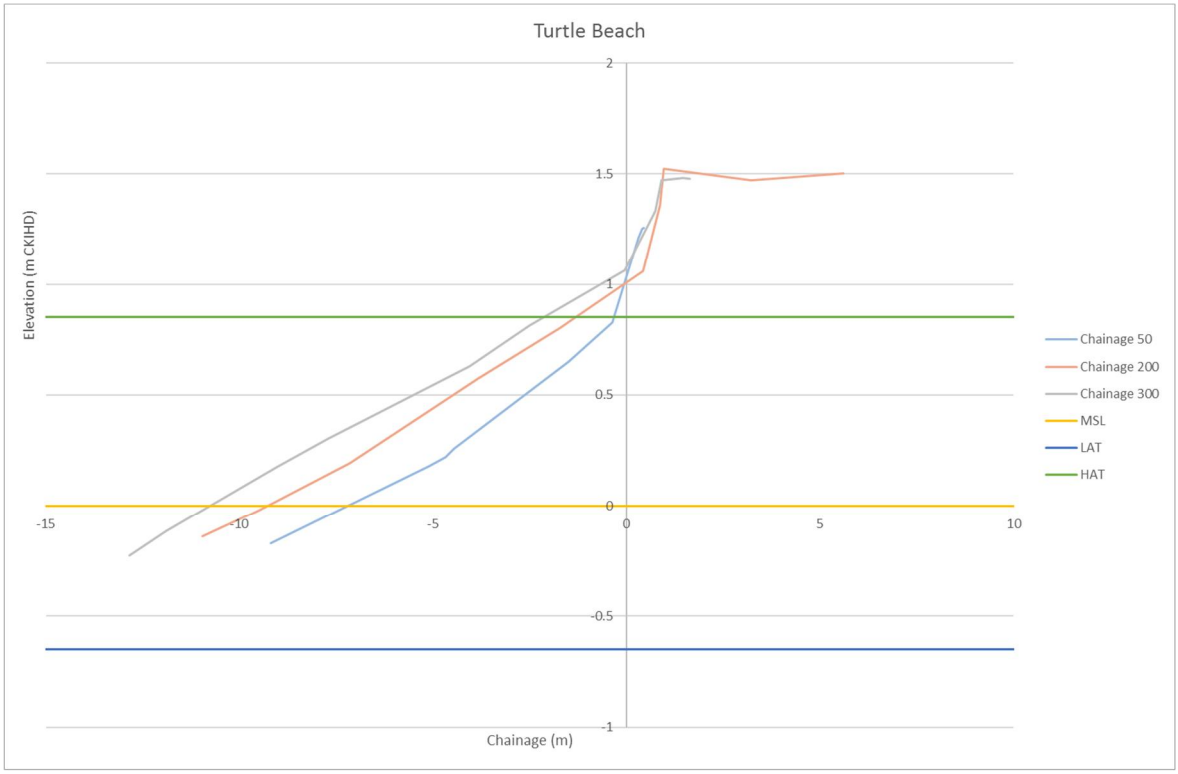


Figure 33 Beach cross sections Turtle Beach (0m Chainage indicates approximate beach crest)

5.7.3 Extraction Methodology

If extraction was to be allowed in this area, it is recommended that only small volumes are allowed and that these are concentrated at the southern end of the beach, against the rubble groyne, which acts as a natural sand trap.

Extraction of sand at Turtle Beach would be by small excavator and limited to above the MSL mark to a distance of no more than 1m below the existing surface. Preference is for the sand to be removed by continuous scraping up the beach at a consistent depth and slope to the natural surface, rather than digging large holes, refer Figure 34. This allows the beach to recover more quickly as it is already at an equilibrium slope.

As there is a track at the back of the beach and a pondok at the southern end, no excavation of the crest is recommended, only excavation of the slope.

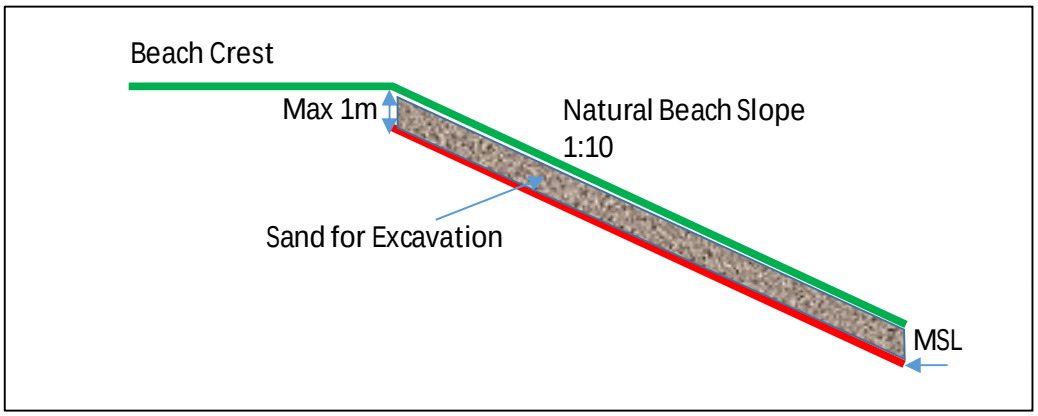


Figure 34 Excavation Profile Turtle Beach

5.7.4 Monitoring and Limitations

In order to extract sand from this location is a sustainable manner, the following guidelines apply:

- No disturbance of existing vegetation, particularly *Calophyllum* trees;
- Sand to be extracted at natural beach profile, rather than isolated holes;
- Sand accretes at the southern end of this beach and it is therefore preferred to limit the extraction to Chainages 0 – 150m to enable natural north-south longshore transport to continue. Excavation of the northern end in front of the cemetery is not recommended in order to maintain a buffer to this area in erosion events; and
- The volume available at this location is quite small and preference is that this site is used for extraction only if all other options are exhausted.

6. Summary

This study has sought to quantify the sediment transport processes of the Cocos (K) Islands in order to update the 2000 Coastal Management Plan, focussing on the management of sand resources on the island for future coastal protection works, in order to undertake these in a sustainable manner which will not exacerbate existing erosion issues or cause new ones.

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. These were then assessed in further detail to ascertain whether they were potentially suitable for sand extraction for coastal erosion works in the future. 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.

A summary of the results is provided in Table 8.

Table 8 Summary of Extraction Locations

Location	Volume Available (September 2016) (m3)	Max Annual Extraction Volume*	Order of Priority	Comments/Conditions
North Point Sand Bank	650,000	NA	5	Not recommended
Rumah Baru Facility / Shire Boat Ramp	2,800 (to MSL)	10,000	1	First priority is to keeping the boat ramp clear, extraction for coastal protection purposes requires application to and approval by the Port prior to commencing.
Bob's Folley to north of Rumah Baru	13,300 (to MSL)	30,000	2	Extraction needs to be for a specified purpose (ie coastal protection) and requires application to and approval by the Port prior to commencing. Note that over excavation of this area may adversely impact the amount of sediment available at Rumah Baru.
South End	NA	NA	4	Only by express permission on case by case basis
Turtle Beach	1,400 (to MSL)	2,000	3	Not preferred, only by express permission on case by case basis

*Max annual extraction volume is an estimate only based on anticipated ambient conditions. Monitoring of the locations as described in the previous sections will dictate how much sediment can ultimately be removed

Of the sites identified, the area around Rumah Baru and north to Bob's Folley on West Island were identified as the most appropriate sources for ongoing sand extraction for the purposes of coastal erosion works (primary) and others as considered appropriate. Turtle Beach on Home Island is a current extraction site, however the study indicates that the available volume is likely to be low and there are a number of restrictions associated with extraction of sand from this location.

All areas identified sit with the Port Limits of Cocos (Keeling) Islands, with the exception of South End on West Island. All requests for sand extraction need to be accompanied by an

application form which outlines the need for sand, volume required, timeframe and proposed location.

From an environmental perspective, all areas identified have restricted extraction to above mean sea level to minimise potential impact on seagrass habitat and marine fauna and have noted that disturbance and clearing of vegetation is not to occur.

The permitted use for sand extraction should be for coastal erosion mitigation purposes only. If sand is required for other uses, such as building development or recreation, this should be applied for on a case by case basis to the Commonwealth and alternative sources considered if appropriate (such as Beacon Heights sand pit or dredge spoil material on Home Island). Sand is still a finite resource on the island and should be maintained naturally in the system wherever possible.

.

7. References

Bicknell C, 2010, Sea Level Change in Western Australia: Application to Coastal Planning, Prepared by the Department of Transport, Perth, Western Australia.

Church, J.A., P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer and A.S. Unnikrishnan, 2013: Sea Level Change. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

AECOM, (2010), Indian Ocean Territory Climate Change Risk Assessment prepared for Commonwealth Attorney-General's Department.

ARUP, (2012), Cocos (Keeling) Islands Review of Short-Term Beach Erosion Protection Options, prepared for the Department of Regional Australia.

Coghlan IR, Carley JT, Mariani A and Cox J (2008) Research and Development Studies for ElcoMax® Elcorock® Geotextile Sand Containers, Water Research Laboratory, Manly Vale NSW Australia.

Department of Transport, (2010), Cocos (Keeling) Islands Coastal Engineering Investigation Technical Report.

GHD/SEA, (2001), Cocos (Keeling) Islands Storm Surge Study prepared for Department of Transport and Regional Services

GHD, (2001), Coastal Management Plan – Cocos (Keeling) Islands prepared for Department of Transport and Regional Services

GHD, (2001), Wave Conditions and Littoral Transport Effects of Channel and Island Construction Options at Rumah Baru, prepared for Commonwealth Department of Transport and Regional Services.

GHD, (2009), Report for Cocos (Keeling) Islands, West Island Coastal Erosion, prepared for the Attorney-General's Department.

GHD, (2012), Cocos (Keeling) Islands West Island Jetty Condition Assessment, prepared for the Department of Regional Australia.

GHD (2014), Erosion Assessment and Scoping Study – West Island, Cocos (K) Islands – Preliminary Design Report, prepared for Department of Infrastructure and Regional Development.

Hornsey WP, Carley JT, Coghlan IR, Cox RJ, (2011) Geotextile sand container shoreline protection systems: Design and application. *Geotextiles and Geomembranes 29 pp 425 to 439.*

Kench (1994) Hydrodynamic Observations of the Cocos (Keeling) Islands Lagoon, Atoll Research Bulletin No 408, Chapter 10, Smithsonian Institution Washington D.C. USA.

Kench (1998) Physical Controls on Development of Lagoon Deposits and Lagoon infilling in the Indian Ocean Atoll, *Journal of Coastal Research,* Vol: 14, No: 3 pp: 1014 – 1024..

Western Australian Planning Commission (WAPC 2013) State Planning Policy No. 2.6, State Coastal Planning Policy, Perth, Western Australia.

Aerial imagery used throughout this report is the Cocos Island 2011 Orthophotography, provided by Geoscience Australia.

Appendices

Appendix A – Numerical Modelling Report

Appendix B – EOMAP Data

Geomorphology Map

Habitat Map

Bathymetry Map

Satellite Derived Bathymetry - Australia - Cocos Island

Data Source

Satellite sensor data:	Landsat 8
Spectral bands:	8
Spatial resolution:	15m
Date and time of recording:	15th December 2015 23rd May 2016

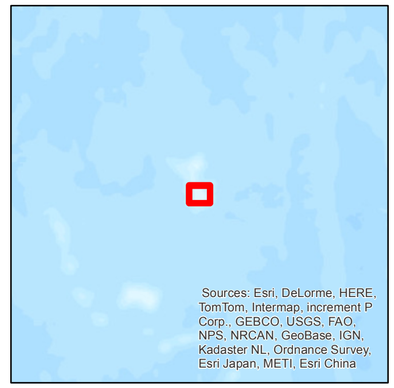
Processing method

Satellite data were processed with the Modular and Inversion System (MIP) by EOMAP. MIP is designed for the physically based assessment of water depth.

Bathymetry (LAT) [m]

0.5
-5
-10
-15
-20
-25

Overview



Spatial Reference

UTM Zone:	UTM Zone 47S
Datum:	WGS 84
EPSG code:	32747

0 0,75 1,5 3 km

© Map produced by
EOMAP GmbH & Co.KG
Earth Observation and Mapping,
Schlosshof 4
D-82229 Seefeld, Germany
Phone +49 (0)8152 - 99861-15
E-mail info@eomap.com
http://www.eomap.com

Date of creation: 2016/07/15
Version: 1.0

Seafloor Classification Habitats - Australia - Cocos Island

Data Source

Satellite sensor data:	Landsat 8
Spectral bands:	8
Spatial resolution:	15m
Date and time of recording:	15th December 2015 23th May 2016

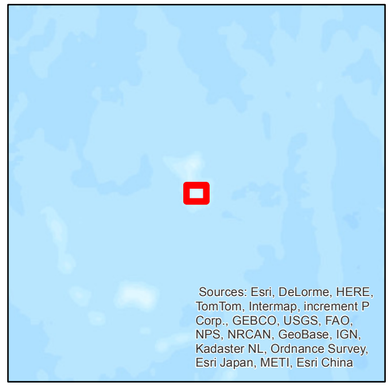
Processing method

Satellite data were processed with the Modular and Inversion System (MIP) by EOMAP. MIP is designed for the physically based assessment of water depth.

Class

- coral
- hardbottom covered with macroalgae
- hardbottom/ dead coral
- seagrass (< 50% coverage)
- seagrass (>50% coverage)
- unconsolidated sediment

Overview



Spatial Reference

UTM Zone:	UTM Zone 47S
Datum:	WGS 84
EPSG code:	32747

0 0,75 1,5 3 km

© Map produced by
EOMAP GmbH & Co.KG
Earth Observation and Mapping,
Schlosshof 4
D-82229 Seefeld, Germany
Phone +49 (0)8152 - 99861-15
E-mail info@eomap.com
http://www.eomap.com

Date of creation: 2016/07/15
Version: 1.0

Seafloor Classification Geomorphology - Australia - Cocos Island

Data Source

Satellite sensor data:	Landsat 8
Spectral bands:	8
Spatial resolution:	15m
Date and time of recording:	15th December 2015 23rd May 2016

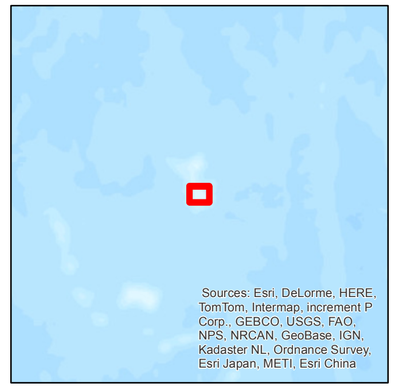
Processing method

Satellite data were processed with the Modular and Inversion System (MIP) by EOMAP. MIP is designed for the physically based assessment of water depth.

Class

- fore reef
- intertidal
- lagoon
- land
- patch reef
- reef crest
- reef flat

Overview



Spatial Reference

UTM Zone:	UTM Zone 47S
Datum:	WGS 84
EPSG code:	32747

0 0,75 1,5 3 km

Sources: Esri, DeLorme, HERE, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community

© Map produced by
EOMAP GmbH & Co.KG
Earth Observation and Mapping,
Schlosshof 4
D-82229 Seefeld, Germany
Phone +49 (0)8152 - 99861-15
E-mail info@eomap.com
http://www.eomap.com

Date of creation: 2016/07/15
Version: 1.0

Appendix C – Topographic Survey

SHEET 5

HOME ISLAND

SHEET 2

SHEET 3

COCOS KEELING ISLANDS

WEST ISLAND

SHEET 4

CHRISTMAS ISLAND

COCOS (KEELING) ISLANDS

0	ISSUED FOR INFORMATION	KSJ*	NS*	NS*	06.10.16
No.	Revision	Drawn	Checked	Approved	Date

Drawing Revisions

Note: * indicates signatures on original issue of drawing or last revision of drawing

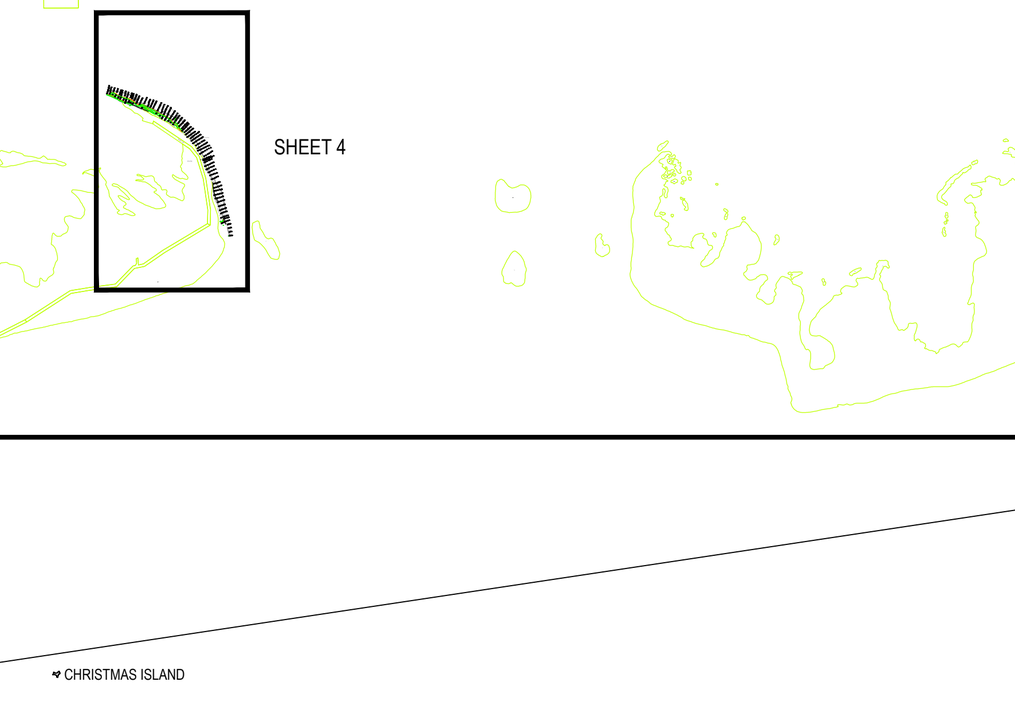
NOTES:

1. CADASTRAL BOUNDARIES SHOWN ARE SUBJECT TO SURVEY. ALL CADASTRAL INFORMATION HAS BEEN PROVIDED BY LANDGATE OCTOBER 2016. THE ACCURACY OF BOUNDARY DEFINITION IS TO THE ASSOCIATED ACCURACY STATEMENTS PROVIDED BY LANDGATE.
2. CONTOUR INTERVAL = 0.25m

N

0 250 500 750 1000 1250m

SCALE 1:25,000 AT ORIGINAL SIZE



LOCALITY PLAN

GHD

Level 10, 999 Hay Street Perth WA 6000
PO Box Y3106 Perth WA 6832 Australia
T 61 8 6222 8222 **F** 61 8 6222 8555
E permail@ghd.com.au **W** www.ghd.com

Client **PATRICK PORTS PTY. LTD.**

Project **COCOS KEELING ISLANDS SAND MANAGEMENT PLAN**

Title **FEATURE AND LEVEL SURVEY BASE SHEET - SHEET 1 OF 5**

DO NOT SCALE

Drawn	KSJ 06.10.16	Scale	1 : 25,000 @ A1
Drafting Check	NS	Surveyor	TT
Datum	CKIHD	Field Book	*
Grid	MGA 94 Zone 47	Level Book	*
Approved	N. SMITH		
Date	06.10.16		

This Drawing must not be used for Construction unless signed as Approved

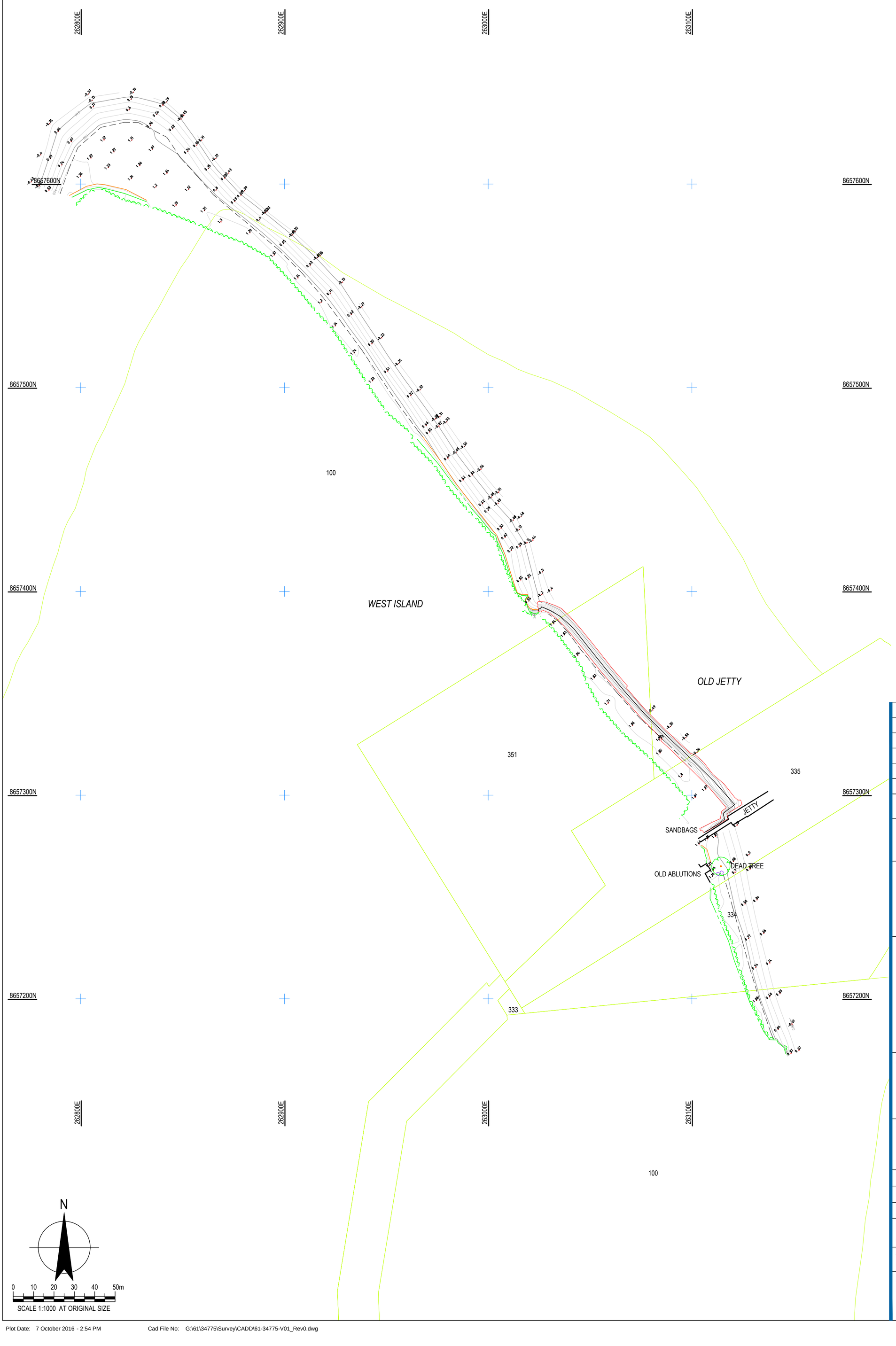
Drawing No. **61-34775-V01**

Original Size **A1**

Rev. **0**

LEGEND OF FEATURES

- SOFFIT LEVEL
- COLUMNS
- LARGE TREE
- SMALL TREE
- MEDIUM TREE
- NATURAL SURFACE
- SIGN
- LIGHT POLE (ONLY)
- CADASTRAL BOUNDARY
- BUILDING
- KERB
- WALL
- TOP OF WALL
- TOP OF BANK
- BOTTOM OF BANK
- CHANGE OF GRADE
- EDGE OF CONCRETE
- EDGE OF BITUMEN
- RAMP
- BRIDGE / JETTY
- KOPPERS LOG FENCE
- CONCRETE FOOTPATH
- EDGE OF TRACK
- BUSHLINE



NOTES:

1. CADASTRAL BOUNDARIES SHOWN ARE SUBJECT TO SURVEY. ALL CADASTRAL INFORMATION HAS BEEN PROVIDED BY LANDGATE OCTOBER 2016. THE ACCURACY OF BOUNDARY DEFINITION IS TO THE ASSOCIATED ACCURACY STATEMENTS PROVIDED BY LANDGATE.
2. CONTOUR INTERVAL = 0.25m

No.	Revision	Drawn	Checked	Approved	Date
0	ISSUED FOR INFORMATION	KSJ*	NS*	NS*	06.10.16

Drawing Revisions

Note: * indicates signatures on original issue of drawing or last revision of drawing

GHD

Level 10, 999 Hay Street Perth WA 6000
PO Box Y3106 Perth WA 6832 Australia
T 61 8 6222 8222 **F** 61 8 6222 8555
E permail@ghd.com.au **W** www.ghd.com

Client **PATRICK PORTS PTY. LTD.**

Project **COCOS KEELING ISLANDS SAND MANAGEMENT PLAN**

Title **FEATURE AND LEVEL SURVEY SHEET 2 OF 5**

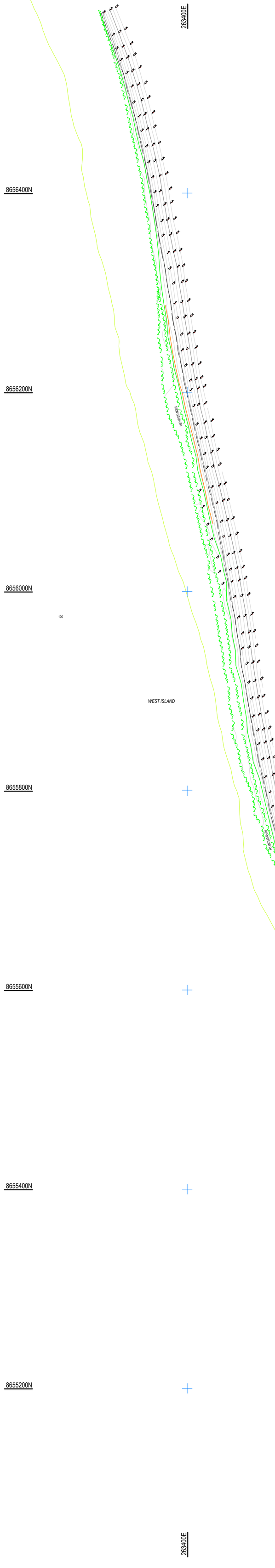
DO NOT SCALE

Drawn	KSJ 06.10.16	Scale	1 : 1000 @ A1
Drafting Check	NS	Surveyor	TT
Datum	CKIHD	Field Book	*
Grid	MGA 94 Zone 47	Level Book	*
Approved	N. SMITH	This Drawing must not be used for Construction unless signed as Approved	
Date	06.10.16		

Drawing No. **61-34775-V01**

Original Size **A1**

Rev. **0**



LEGEND OF FEATURES

- SOFFIT LEVEL
- COLUMNS
- LARGE TREE
- SMALL TREE
- MEDIUM TREE
- NATURAL SURFACE
- SIGN
- LIGHT POLE (ONLY)
- CADASTRAL BOUNDARY
- BUILDING
- KERB
- WALL
- TOP OF WALL
- TOP OF BANK
- BOTTOM OF BANK
- CHANGE OF GRADE
- EDGE OF CONCRETE
- EDGE OF BITUMEN
- RAMP
- BRIDGE / JETTY
- KOPPERS LOG FENCE
- CONCRETE FOOTPATH
- EDGE OF TRACK
- BUSHLINE

N

0 20 40 60 80 100m

SCALE 1:2000 AT ORIGINAL SIZE

NOTES:

1. CADASTRAL BOUNDARIES SHOWN ARE SUBJECT TO SURVEY. ALL CADASTRAL INFORMATION HAS BEEN PROVIDED BY LANDGATE OCTOBER 2016. THE ACCURACY OF BOUNDARY DEFINITION IS TO THE ASSOCIATED ACCURACY STATEMENTS PROVIDED BY LANDGATE.
2. CONTOUR INTERVAL = 0.25m

No.	Revision	Drawn	Checked	Approved	Date
0	ISSUED FOR INFORMATION	KSJ*	NS*	NS*	06.10.16

Drawing Revisions

Note: * indicates signatures on original issue of drawing or last revision of drawing

Level 10, 999 Hay Street Perth WA 6000
PO Box Y3106 Perth WA 6832 Australia
T 61 8 6222 8222 **F** 61 8 6222 8555
E permail@ghd.com.au **W** www.ghd.com

Client **PATRICK PORTS PTY. LTD.**

Project **COCOS KEELING ISLANDS SAND MANAGEMENT PLAN**

Title **FEATURE AND LEVEL SURVEY SHEET 3 OF 5**

DO NOT SCALE

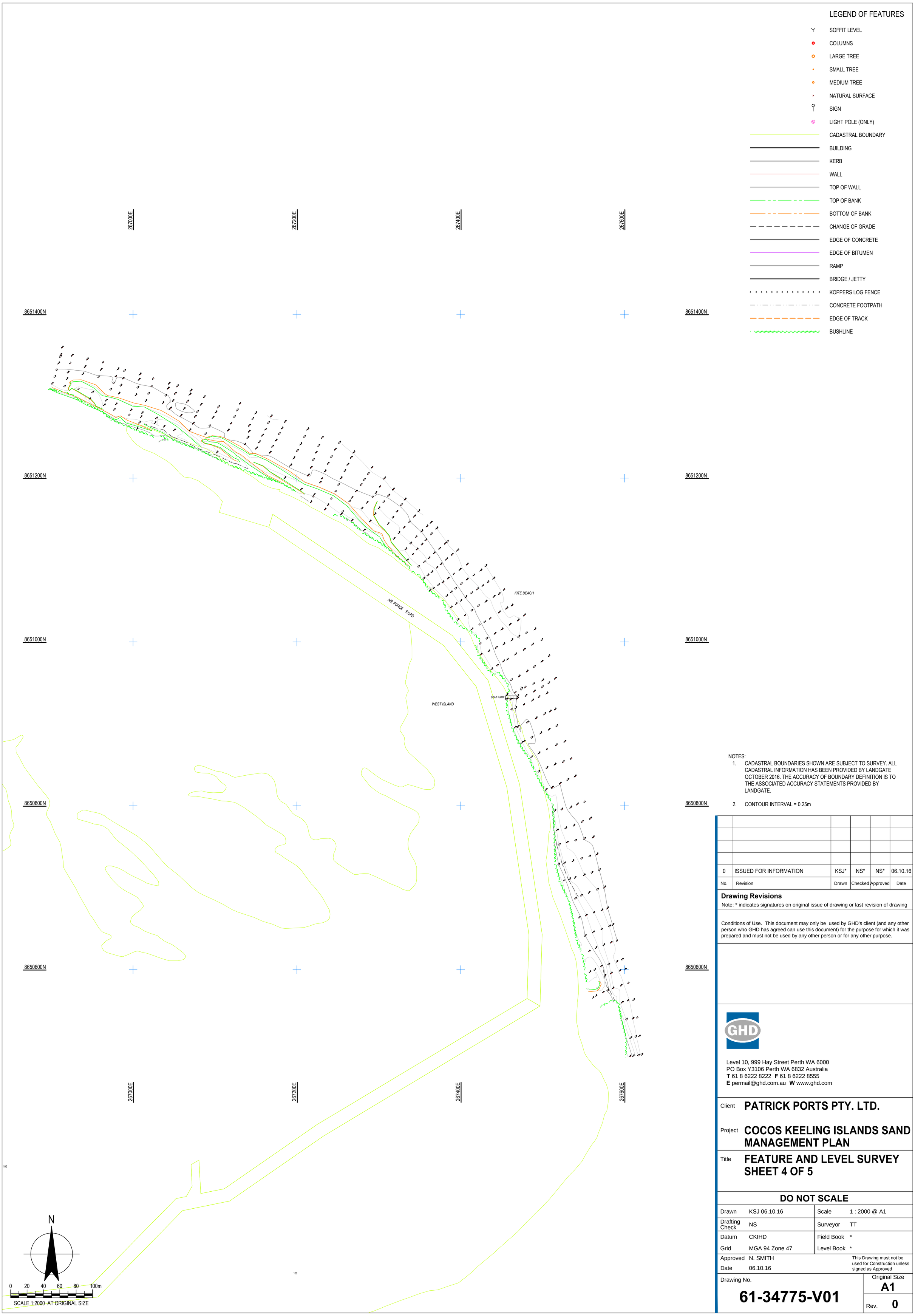
Drawn	KSJ 06.10.16	Scale	1 : 2000 @ A1
Drafting Check	NS	Surveyor	TT
Datum	CKIHD	Field Book	*
Grid	MGA 94 Zone 47	Level Book	*
Approved	N. SMITH		
Date	06.10.16		

This Drawing must not be used for Construction unless signed as Approved

Drawing No. **61-34775-V01**

Original Size **A1**

Rev. **0**



LEGEND OF FEATURES

- SOFFIT LEVEL
- COLUMNS
- LARGE TREE
- SMALL TREE
- MEDIUM TREE
- NATURAL SURFACE
- SIGN
- LIGHT POLE (ONLY)
- CADASTRAL BOUNDARY
- BUILDING
- KERB
- WALL
- TOP OF WALL
- TOP OF BANK
- BOTTOM OF BANK
- CHANGE OF GRADE
- EDGE OF CONCRETE
- EDGE OF BITUMEN
- RAMP
- BRIDGE / JETTY
- KOPPERS LOG FENCE
- CONCRETE FOOTPATH
- EDGE OF TRACK
- BUSHLINE

NOTES:

1. CADASTRAL BOUNDARIES SHOWN ARE SUBJECT TO SURVEY. ALL CADASTRAL INFORMATION HAS BEEN PROVIDED BY LANDGATE OCTOBER 2016. THE ACCURACY OF BOUNDARY DEFINITION IS TO THE ASSOCIATED ACCURACY STATEMENTS PROVIDED BY LANDGATE.
2. CONTOUR INTERVAL = 0.25m

No.	Revision	Drawn	Checked	Approved	Date
0	ISSUED FOR INFORMATION	KSJ*	NS*	NS*	06.10.16

Drawing Revisions

Note: * indicates signatures on original issue of drawing or last revision of drawing

Level 10, 999 Hay Street Perth WA 6000
PO Box Y3106 Perth WA 6832 Australia
T 61 8 6222 8222 **F** 61 8 6222 8555
E permail@ghd.com.au **W** www.ghd.com

Client **PATRICK PORTS PTY. LTD.**

Project **COCOS KEELING ISLANDS SAND MANAGEMENT PLAN**

Title **FEATURE AND LEVEL SURVEY SHEET 4 OF 5**

DO NOT SCALE

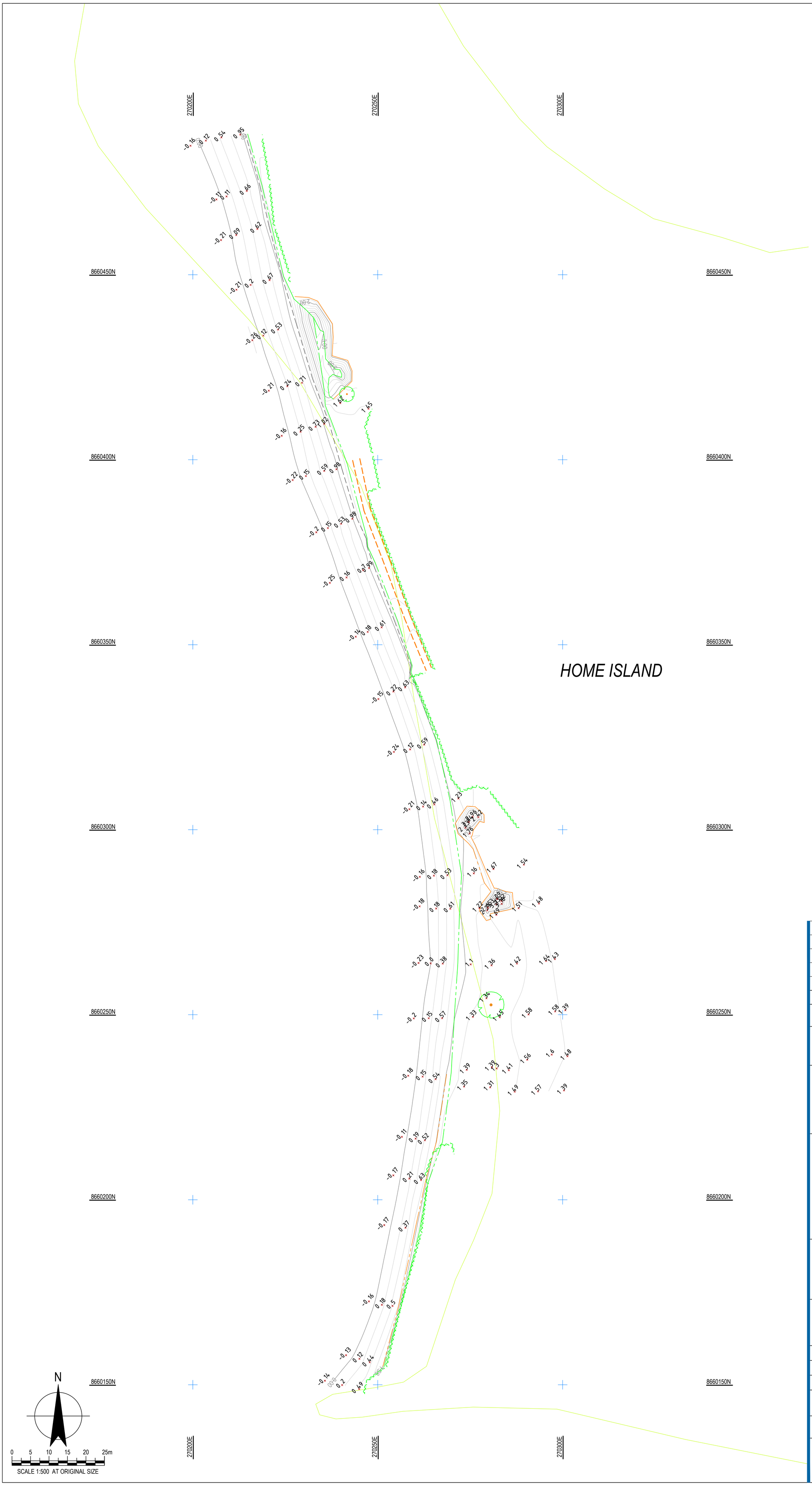
Drawn	KSJ 06.10.16	Scale	1 : 2000 @ A1
Drafting Check	NS	Surveyor	TT
Datum	CKIHD	Field Book	*
Grid	MGA 94 Zone 47	Level Book	*
Approved	N. SMITH		
Date	06.10.16		

This Drawing must not be used for Construction unless signed as Approved

Drawing No. **61-34775-V01**

Original Size **A1**

Rev. **0**



LEGEND OF FEATURES

- SOFFIT LEVEL
- COLUMNS
- LARGE TREE
- SMALL TREE
- MEDIUM TREE
- NATURAL SURFACE
- SIGN
- LIGHT POLE (ONLY)
- CADASTRAL BOUNDARY
- BUILDING
- KERB
- WALL
- TOP OF WALL
- TOP OF BANK
- BOTTOM OF BANK
- CHANGE OF GRADE
- EDGE OF CONCRETE
- EDGE OF BITUMEN
- RAMP
- BRIDGE / JETTY
- KOPPERS LOG FENCE
- CONCRETE FOOTPATH
- EDGE OF TRACK
- BUSHLINE

NOTES:

1. CADASTRAL BOUNDARIES SHOWN ARE SUBJECT TO SURVEY. ALL CADASTRAL INFORMATION HAS BEEN PROVIDED BY LANDGATE OCTOBER 2016. THE ACCURACY OF BOUNDARY DEFINITION IS TO THE ASSOCIATED ACCURACY STATEMENTS PROVIDED BY LANDGATE.
2. CONTOUR INTERVAL = 0.25m

No.	Revision	Drawn	Checked	Approved	Date
0	ISSUED FOR INFORMATION	KSJ*	NS*	NS*	06.10.16

Drawing Revisions

Note: * indicates signatures on original issue of drawing or last revision of drawing

Level 10, 999 Hay Street Perth WA 6000
PO Box Y3106 Perth WA 6832 Australia
T 61 8 6222 8222 **F** 61 8 6222 8555
E permail@ghd.com.au **W** www.ghd.com

Client **PATRICK PORTS PTY. LTD.**

Project **COCOS KEELING ISLANDS SAND MANAGEMENT PLAN**

Title **FEATURE AND LEVEL SURVEY SHEET 5 OF 5**

DO NOT SCALE

Drawn	KSJ 06.10.16	Scale	1 : 500 @ A1
Drafting Check	NS	Surveyor	TT
Datum	CKIHD	Field Book	*
Grid	MGA 94 Zone 47	Level Book	*
Approved	N. SMITH		
Date	06.10.16		

This Drawing must not be used for Construction unless signed as Approved

Drawing No. **61-34775-V01**

Original Size **A1**

Rev. **0**

GHD

GHD, 999 Hay Street, Perth, WA 6000
P.O. Box 3106, Perth WA 6832
T: 61 8 6222 8222 F: 61 8 6222 8555 E: permail@ghd.com.au

G:\61\34775\WP\158492.docx

Document Status

Revision	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
DRAFT	G Bertrand	H O'Keeffe	*H O'Keeffe	H O'Keeffe	*H O'Keeffe	20/12/16
0	G Bertrand	H O'Keeffe P O'Keeffe		P Seman		25/01/17

** denotes signature on file*

www.ghd.com