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R607 Rev 1

November 2015

City of Wanneroo

CHRMAP Part 1
Coastal Vulnerability Study & Hazard Mapping

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Executive Summary

Coastal zones can be vulnerable to adverse impacts from inundation and erosion. *State Planning Policy 2.6 – the State Coastal Planning Policy* (SPP2.6; Western Australian Planning Commission 2013) supports a risk management approach to coastal erosion and inundation. The SPP2.6 requires a Coastal Hazard Risk Management and Adaptation Plan (CHRMAP) be prepared for all areas with the potential to be vulnerable to coastal processes over the planning timeframe/s.

The City of Wanneroo (City) is responsible for the management of approximately 32 km of coastline along the rapidly expanding northern corridor of the Perth Metropolitan area. The City have chosen to complete the CHRMAP process using a staged approach. These stages are best described as follows.

- Stage 1 – coastal vulnerability study and hazard mapping.
- Stage 2 – risk assessment and adaptation planning.
- Stage 3 – City internal review and application.

Specialist coastal engineers M P Rogers & Associates Pty Ltd (MRA) were engaged by the City to complete Stage 1 of the CHRMAP process – the coastal vulnerability assessment and hazard mapping.

The scope of this investigation is to cover the risk assessment component of the CHRMAP for the entire coastline within the City of Wanneroo, stretching from Tamala Park to north of Two Rocks. A knowledge summary and gap analysis was completed to provide background to the coastal processes along the City's coastline. Previously completed coastal processes studies were also identified and where appropriate the results incorporated into this report.

Cultural, environmental and built assets that may be exposed to coastal erosion and inundation have been identified using the SPP2.6 methodology for a range of timeframes listed below.

- 2015 (present day)
- 2030
- 2050
- 2070
- 2090
- 2120

These timeframes are required in order to determine when certain infrastructure, assets or sites could become vulnerable. Furthermore, consideration of these timeframes will enable the future stages of the CHRMAP assessment to develop appropriate coastal adaptation or management measures.

The extent of coastal erosion will vary with the coastal form and geomorphology, however for the general case of sandy coasts in the SPP2.6 the following factors were considered in this report.

- (S1 Erosion) Allowance for the current risk of storm erosion.
- (S2 Erosion) Allowance for historic shoreline movement trends.
- (S3 Erosion) Allowance for erosion caused by future sea level rise.

In addition to the above factors, an allowance for uncertainty is also recommended.

Assessment of the requirements for rocky coastlines was based on the strength of rock and the subsequent potential of the rock to withstand erosion caused by coastal processes over the nominated planning timeframes. Additionally, the potential effects of wave overtopping during severe storm events was considered. Coastal structures such as groynes, breakwaters and seawalls were also considered in the context of the protection they provide, but acknowledging the requirement for ongoing maintenance by the responsible authority.

Coastal erosion hazard maps have been developed, allowing the cultural, environmental and built assets that may be exposed to erosion to be identified. The vulnerability of these assets to coastal erosion was then assessed based on their sensitivity and adaptive capacity to this erosion.

The potential exposure of areas to coastal inundation associated with severe storm surge was also assessed. This is referred to as the S4 Inundation Allowance (WAPC 2013). As required by SPP2.6, the coastal inundation assessment was completed with reference to an event with a 0.2% chance of exceedance per year, which is akin to the 500 year average recurrence interval (ARI) event.

Based on the results of the coastal hazard mapping the following table provides a summary of the assets vulnerable to coastal erosion and inundation.

Table E1A Assets Vulnerable to Coastal Erosion & Inundation

Sediment Cell	Chainage	Asset Type	Description	Potential Vulnerability Timeframe
31a (Mallee Reef Salient to Wreck Point)	1,500 m to 2,100 m	Environmental	Priority Ecological Community	2030
	1,600 m to 6,200 m	Environmental	Bush Forever Site 397	Present Day
	4,300 m to 5,050 m	Infrastructure	Sovereign Drive & residential lots	From 2050
	5,300 m	Infrastructure	Two Rocks Marina sheds	Inundation timeframe unknown
30b (Wreck Point to Yanchep Headland North)	6,300 to 10,200 m	Environmental	Bush Forever Site 397	Present Day
	8,900 to 9,000 m	Infrastructure	Beach access road	2050[1]
30a (Yanchep Headland North to Yanchep)	10,300 to 14,400 m	Environmental	Bush Forever Site 397	Present Day
	11,000 to 11,500 m	Infrastructure	Capricorn Village car-park & building	2120

Notes: 1. Vulnerability dependent on extent, level & strength of rock at the rear of beach. Geotechnical investigations would be required to identify these factors.

Table E1B Assets Vulnerable to Coastal Erosion & Inundation

Sediment Cell	Chainage	Asset Type	Description	Potential Vulnerability Timeframe
30a (Yanchep Headland North to Yanchep)	11,500 to 11,600 m	Infrastructure	Car-park	2050
	12,400 m	Infrastructure	Buildings	2070
	12,500 m	Infrastructure	Existing Yanchep SLSC	2070
	12,700 m	Infrastructure	New Yanchep SLSC	Refer Cardno (2014)
	12,700 to 13,000 m	Infrastructure	Car-parks	2030[1]
	13,000 to 13,400 m	Infrastructure	Residential lots	From 2030[1]
	13,500 to 14,400 m	Infrastructure	Roads & residential lots	From 2070
29d (Yanchep to Alkimos)	14,500 to 20,700 m	Environmental	Bush Forever Site 397	Present Day
	14,500 to 15,000 m	Infrastructure	Roads & residential lots	From 2090
	20,100 to 20,300 m	Infrastructure	Roads	From 2090
29c (Alkimos to Quinns Rock North)	20,800 to 24,700 m	Environmental	Bush Forever Site 397	Present Day
	22,700 m	Aboriginal Heritage Site	"Karli Spring"	2050
29b (Quinns Rock North to Mindarie Keys North)	Sediment Cell 29b is not being assessed in this CHRMAP[2]			
29a (Mindarie Keys North to Burns Beach Salient)	29,400 to 33,300 m	Environmental	Bush Forever Site 397	Present Day
	29,900 to 30,200 m	Infrastructure	Residential lots	2050[1]
	30,800 to 33,300 m	Environmental	Priority Ecological Community	Present Day

Notes: 1. Vulnerability dependent on extent, level & strength of rock at the rear of beach. Geotechnical investigations would be required to identify these factors.

2. The Quinns Beach Long Term Coastal Management Study aims to develop a number of management options in this sediment cell, which will affect the results of any CHRMAP assessment.

The coastal erosion hazard maps and inundation assessment will inform and guide the next stages of the CHRMAP process for the City of Wanneroo.

Table of Contents

Table of Figures

Table of Tables

1. Introduction

Coastal management generally requires understanding and prediction of coastal change over decadal timescales or longer (Short 1999). Recognising this fact the City of Wanneroo have commenced work on the development of a coastal management plan to help inform future planning and adaptation requirements for development along their coastline.

Preparation of this plan is consistent with the requirements and terminology of the amended *State Planning Policy 2.6 – the State Coastal Planning Policy* (SPP2.6; Western Australian Planning Commission 2013) which requires that a Coastal Hazard Risk Management and Adaptation Plan (CHRMAP) be prepared by the responsible management authority to cover areas where existing or proposed development could be at risk from coastal hazards over the planning timeframe. The main purpose of a CHRMAP is to define areas of the coastline that are vulnerable to coastal hazards and to outline the preferred approach to the monitoring and management of these hazards where required.

A CHRMAP can be a powerful planning tool and can help to provide clarity to existing and future developers, users, managers or custodians of the coastline. This is done by defining levels of risk exposure, management practices and adaptation techniques that the management authority (in this case the City) consider to be acceptable in response to the present and future risks posed by coastal hazards.

In 2014 the Western Australian Planning Commission (WAPC) released a Guideline document that provides a specific framework for the preparation of a CHRMAP. Figure 1.1 presents a flowchart for the risk management and adaptation process, as outlined within the CHRMAP Guidelines.

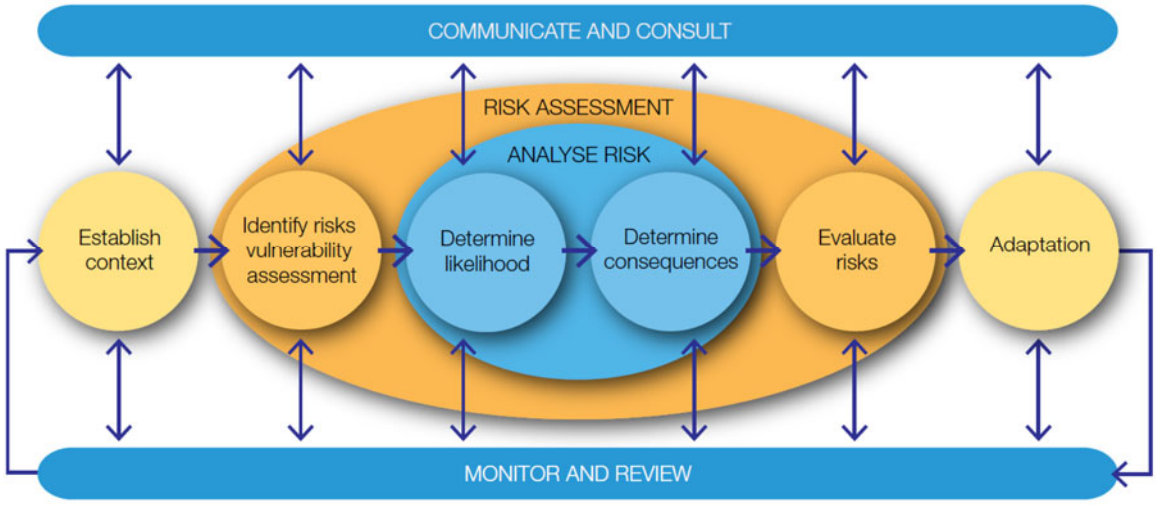

Figure 1.1 Risk management and adaptation process flowchart (source: WAPC CHRMAP Guidelines, 2014)

As presented in the flowchart, the process for the development of a meaningful CHRMAP requires a number of fundamental inputs. These inputs enable the assessment and analysis of risk, which should ultimately be informed by input received from key stakeholders and the community, to help shape the subsequent adaptation strategies.

The City of Wanneroo, being the authority responsible for the management of approximately 32 km of coastline along the rapidly expanding northern corridor of the Perth Metropolitan area, have chosen to complete the CHRMAP process using a staged approach. These stages are best described as follows.

- Stage 1 – coastal vulnerability study and hazard mapping.
- Stage 2 – risk assessment and adaptation planning.
- Stage 3 – City of Wanneroo internal review and application.

A project flow chart, including the key processes and deliverables for each stage is provided in Figure 1.2.

Specialist coastal engineers M P Rogers & Associates Pty Ltd (MRA) were engaged by the City to complete the first stage of the CHRMAP process – the coastal vulnerability assessment and hazard mapping.

The scope of this investigation, is to cover the risk assessment component of the CHRMAP for the entire coastline within the City of Wanneroo, stretching from Tamala Park to north of Two Rocks. This investigation will include the following.

- Establishing the context for the coastal vulnerability assessment.
- Literature review and gap analysis of information currently available for the coastline.
- Completion of a coastal vulnerability assessment.
- Coastal hazard mapping.

This report presents the data, methodology, and results of this assessment.

Figure 1.2 City of Wanneroo CHRMAP Project Flow Chart (Source: City of Wanneroo)

2. Context

2.1 Purpose

The expansion of the Perth Metropolitan area through the northern corridor is set to result in significant population growth within the City of Wanneroo. This population growth, coupled with the propensity for coastal development will result in continued urbanisation of the coastal fringe. The investment associated with this ongoing development of infrastructure is significant and warrants consideration of the potential risks posed by coastal hazards together with advancement of management and adaptation measures.

In addition to significant investment that is occurring within the coastal margin, Australian Standard 5334 *Climate Change Adaptation for Settlement and Infrastructure – A Risk Based Approach* (Standards Australia 2013) also identifies that other triggers, such as perceived risk and approval requirements, can warrant the development of an adaptation plan. Both of these factors are valid for the City of Wanneroo, as risks of adverse impacts on existing infrastructure and assets are present along the coastline, particularly in more established suburbs such as Quinns Rocks.

The risk posed by coastal hazards on more recently developed infrastructure is not expected to be as significant given the requirement for these new developments to adhere to the coastal setback provisions outlined within SPP2.6, which was gazetted in its earliest form in 2003. Nevertheless, assessment and quantification of the vulnerability of even recently developed infrastructure is prudent and is a requirement of the amended 2013 version of SPP2.6. This is also consistent with AS 5334, which states that the risk from climate change and the potential requirements for adaptation need to be considered over all stages of the infrastructure lifecycle.

2.2 Objectives

Understanding the vulnerability of infrastructure and other key features of the coastal zone, such as areas of landscape, biodiversity and ecosystem integrity, indigenous and cultural significance, are critical to the development of the overall CHRMAP. This first stage of the CHRMAP is focused on the assessment of coastal vulnerability over varying timeframes. Coastal hazard mapping will be completed to illustrate the areas vulnerable to coastal hazards over each of the timeframes, noting also the key features of the coastal zone together with any existing planning controls.

2.3 Scope

Assessment of the coastal vulnerability and the resultant coastal hazard mapping is to be completed in accordance with the requirements of Schedule One of SPP2.6. This schedule provides a framework for the assessment of the potential impacts of coastal hazards on the shoreline for a variety of coastal forms including (with relevance to this study) sandy coasts, rocky coasts, and mixed sandy and rocky coasts.

The extent of impacts caused by coastal hazards will vary with the coastal form and geomorphology, however for the general case of sandy coasts the following factors are considered.

- (S1 Erosion) Allowance for the current risk of storm erosion.
- (S2 Erosion) Allowance for historic shoreline movement trends.
- (S3 Erosion) Allowance for erosion caused by future sea level rise.

In addition to the above factors, an allowance for uncertainty is also recommended.

Assessment of the requirements for rocky coastlines is based on the strength of rock and the subsequent potential of the rock to withstand erosion caused by coastal processes over the nominated planning timeframes. Additionally, the potential effects of wave overtopping during severe storm events also requires consideration.

This assessment of the potential coastal vulnerability will adopt the SPP2.6 methodology for a range of timeframes. These timeframes are required in order to determine when certain infrastructure, assets or sites could become vulnerable. Furthermore, consideration of these timeframes will enable the future stages of the CHRMAP assessment to develop appropriate coastal adaptation or management measures. Timeframes considered will extend to the years 2030, 2050, 2070, 2090 and 2120.

In addition to the above, coastal structures such as groynes, breakwaters and seawalls need to be considered in the context of the protection they provide, but acknowledging the requirement for ongoing maintenance by the responsible authority.

Assessment of the S4 Inundation allowance will be completed as required by SPP2.6. The coastal inundation assessment will be completed with reference to an event with a 0.2% chance of exceedance per year, which is akin to the 500 year average recurrence interval (ARI) event.

This study will also include assessment of key environmental ecosystems in the region as well as other cultural and social features of the coastline and their potential future vulnerability.

2.4 Study Area

The coastline within the City of Wanneroo stretches from Tamala Park in the south to the northern boundary of the Perth Metropolitan Area, which is approximately 3.5 km north of Two Rocks. Figure 2.1 shows the extent of the study area. Whilst the required extent of the vulnerability study and hazard mapping is limited to the coastline within the City's jurisdiction, the actual extent of the coastal investigations will be extended to better align with the boundaries of the local sediment cells. Further details regarding this are provided in Section 3.

Figure 2.1 also shows the extent of rocky coastline as mapped by the Department for Planning and Infrastructure (DPI) for MRA (2005) and site specific geotechnical investigations, as well as the existing coastal protection structures.

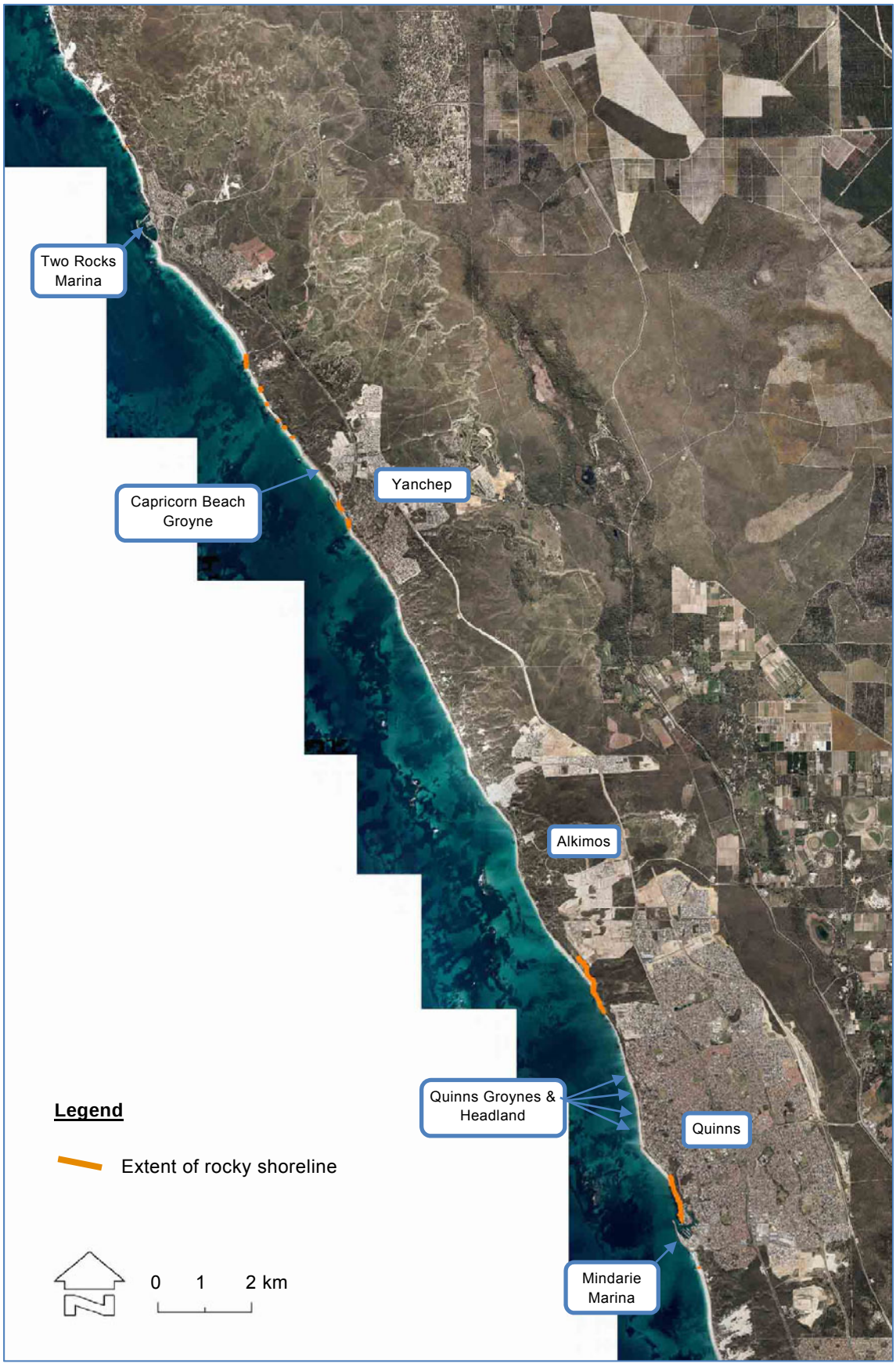

Figure 2.1 Study area

2.5 Community & Stakeholder Consultation

This phase of the project, which involves the coastal vulnerability study and hazard mapping, is primarily focused on the development of coastal vulnerability lines through adoption of the methodologies outlined within SPP2.6. During this phase of the works liaison with key stakeholders has been completed to gather relevant information for the project. Specifically, liaison has been focused on the following key stakeholders.

- City of Wanneroo.
- Department of Planning (DoP).
- Department of Transport (DoT).
- Department of Aboriginal Affairs (DAA).
- Environmental (various, refer to Appendix A)

2.6 Existing Planning Controls

Consultation has been completed with key stakeholders to understand any planning controls that could be in effect in the coastal margin. The obvious planning control along the coastline is SPP2.6, which controls where development is able to occur based on an assessment of the risk posed by coastal hazards. However, through consultation with these key stakeholders, other potential planning controls have been identified. These potential planning controls relate to areas of key environmental importance and significance and Aboriginal heritage.

Further details regarding these planning controls will be outlined within this report and included within the hazard mapping.

2.7 Success Criteria

The successful completion of this phase of the CHRMAP will deliver a coastal vulnerability assessment and coastal hazard mapping that is clear and concise. The assessment of the coastal vulnerability will be completed in accordance with the requirements of the amended SPP2.6. This will enable the completion of future phases of the CHRMAP, such as the coastal adaptation and management planning, to be founded on information that has been prepared in accordance with current planning requirements.

3. Knowledge Summary & Gap Analysis

3.1 Metocean Conditions

Any comprehensive study of coastal processes and coastal hazards must be done with knowledge of the fundamental driving forces. Consequently, an understanding of the magnitude and potential variation in the wind, waves and tide conditions is important.

3.1.1 Wind Climate

The wind regime influences coastal processes through the generation of ocean waves and currents as well as feeding dune systems with wind-blown beach sand.

The seasonal weather patterns along the Perth Metropolitan shoreline are largely controlled by the position of the so called Subtropical High Pressure Belt. This is a series of discrete anticyclones that encircle the earth at the mid-latitudes (20° to 40°). These high pressure cells are continuously moving from west to east across the southern portion of the Australian continent. A notional line joining the centres of these cells is known as the High Pressure Ridge.

In winter this ridge lies across Australia typically between 25° to 30° S, to the north of Perth (located at 32° S). During summer, the ridge moves south and lies between 35° and 40° S. This latitudinal shift in the position of the High Pressure Ridge is fundamental to the seasonal wind patterns experienced in the region.

In addition to these regional scale effects that cause seasonal variations, the meso-scale phenomenon of a land-sea breeze system is commonly experienced along the Perth Metropolitan shoreline, causing wind variations on a daily time scale. Offshore breezes are experienced in the morning, which swing around to the south-west and south in the afternoon. This is often referred to as the 'sea breeze' but is a land/sea breeze system. The effects of this land/sea breeze system can be seen in Figure 3.1, the 9am and 3pm wind rose plots for the Perth Airport.

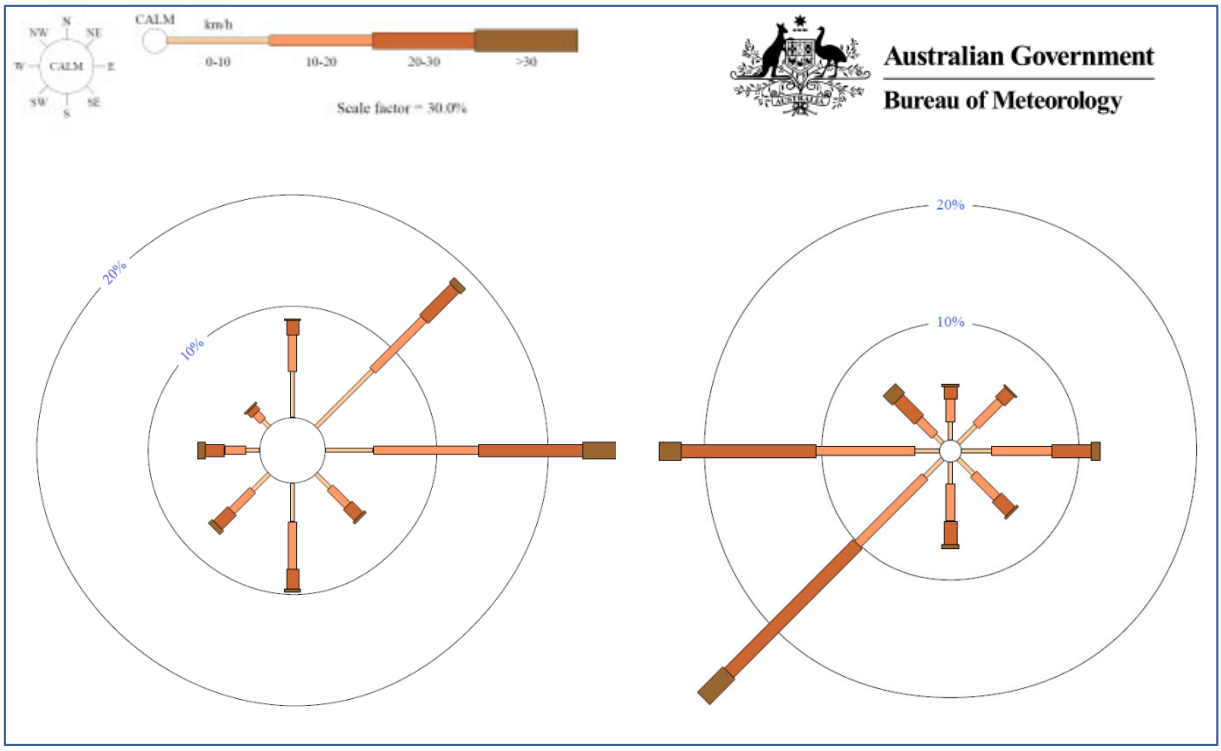

Figure 3.1 9am (left) and 3pm (right) wind rose plots at Perth Airport (BoM 2015)

3.1.2 Wave Climate

Wave measurements and observations taken in deep water (48 m) off Fremantle indicate that the Perth Metropolitan Area experiences reasonably high wave energy. The main elements of the offshore wave climate are listed below.

- Seas generated locally by the passage of cold fronts during winter. The wave heights and periods vary markedly from storm to storm. Often the wave heights exceed 4 metres and the wave periods reach 6 to 10 seconds. The direction from which these storm waves approach can range from north-west to south-west during the passage of the storm.
- Swell waves from distant storms in the Southern Indian Ocean continually reach the offshore area throughout the year. The swell waves often exceed 2 metres in height, and typical periods are between 8 and 16 seconds. The swell waves commonly approach from the south-west, and tend to be slightly smaller and more southerly in summer compared to winter.
- Seas produced by the sea breeze. The generation of these waves is limited by the duration and the offshore extent of the sea breeze system, with heights typically 0.5 to 1.5 metres and periods of 3 to 6 seconds. The direction of these waves is generally from the south-west to south.
- Severe waves caused by dissipating tropical cyclones. These storms are infrequent in the Perth Metropolitan region, however, when they do occur they cause severe conditions for short periods of time.

As the offshore waves travel toward the shore, they are greatly affected by the nearshore bathymetry and the reefs. The bathymetry of the area and reefs are shown in Figure 3.2, which

was developed using the hydrographic LiDAR survey completed by Fugro for DoP and DoT in 2009 (Fugro 2009).

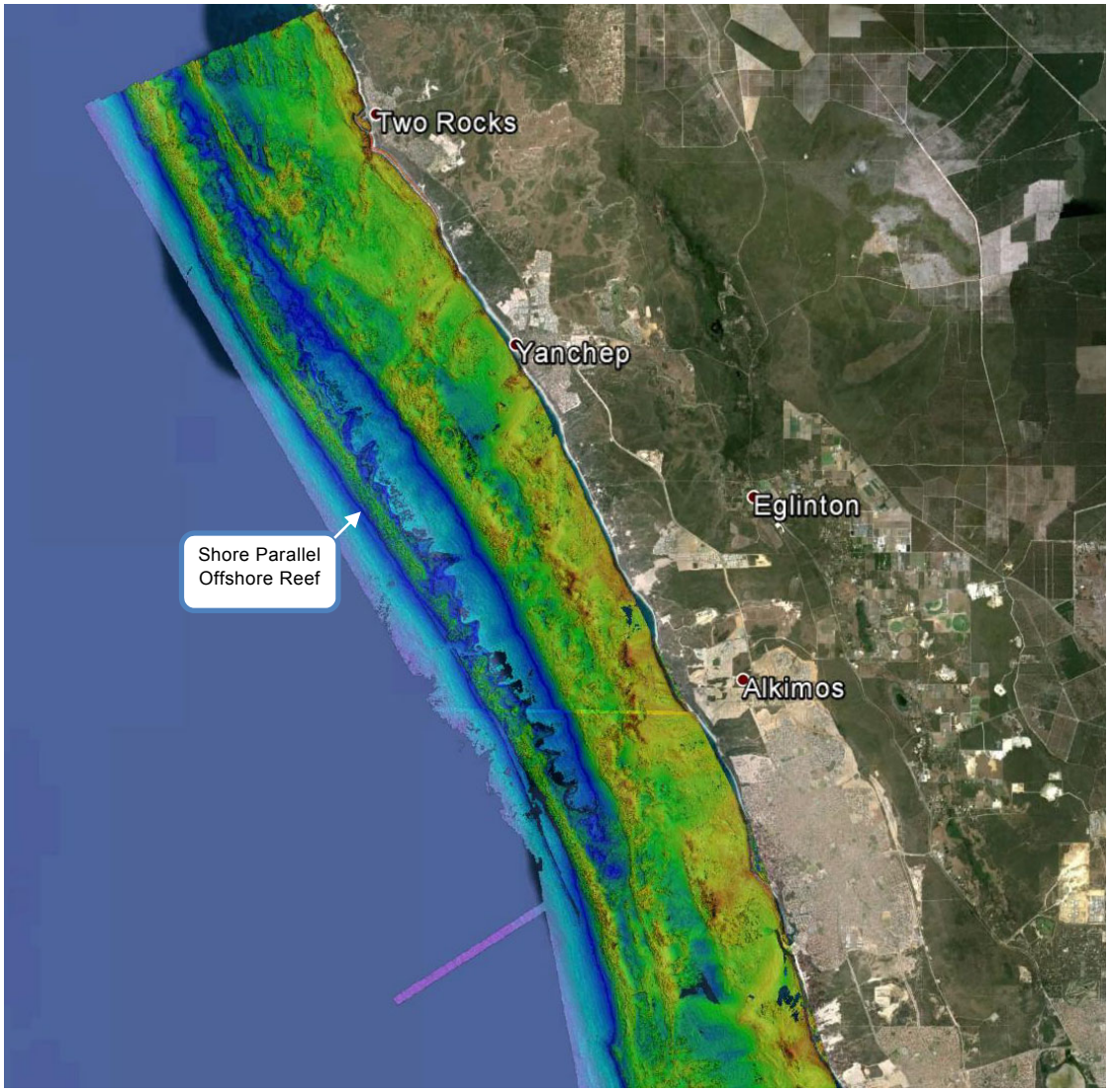

Figure 3.2 Wanneroo nearshore bathymetry (Fugro 2009)

Waves travelling to the coast at Wanneroo are modified by the following physical processes.

- Reflection off the reef faces.
- Depth limited breaking on the reef tops and in shallow areas.
- Diffraction through the gaps in the reefs.
- Attenuation due to hydraulic turbulence as the waves travel over the reefs and other areas of shallow water.
- Refraction and shoaling.

These processes act to varying degrees, and significantly modify and attenuate the waves as they approach the coast at Wanneroo. The reefs and nearshore bathymetry provide good protection

from the full force of the offshore waves. The dissipation processes are important to the stability of the coastline as the resultant waves that break on the beach are the most important factor in the transport of sand in the littoral zone.

The wave conditions and the frequency of occurrence of key wave events such as swell, sea breeze, moderate and severe storms varies on an annual basis. These key events generally dominate the movement of sediment along the Perth Metropolitan coastline and any changes in the relative occurrence can influence shoreline position. For example, a year with a particularly high number of sea breeze events and a lower than average number of storms may have a larger than average northerly sediment transport.

3.1.3 Tides & Water Levels

The astronomical tides along the Wanneroo shoreline are very similar to those at Fremantle. These tides are predominantly diurnal, namely one tidal cycle each day, and relatively limited in range. The range of the tides generally varies over about a 4 week cycle in line with the lunar cycle. Spring tides occur when the moon is new or full, resulting in a relatively large tidal range for a number of days. Neap tides occur during the moon's first and third quarter phases, resulting in a smaller tidal range for a number of days.

The daily range is typically about 0.4 m during spring tides and around 0.1 m during neap tides. Other tidal characteristics are listed in Table 3.1.

Table 3.1 Fremantle tide characteristics

	Chart Datum (mCD)	Australian Height Datum (mAHD)
Highest Astronomical Tide (HAT)	1.34	0.58
Mean Higher High Water (MHHW)	0.96	0.20
Mean Lower High Water (MLHW)	0.78	0.02
Mean Sea Level (MSL)	0.76	0.0
Mean Higher Low Water (MHLW)	0.65	-0.11
Mean Lower Low Water (MLLW)	0.53	-0.23
Lowest Astronomical Tide (LAT)	0.2	-0.56

Seasonal shifts in the sea level also occur due to meteorological effects and the action of the Leeuwin Current. Typically, the mean sea level rises 0.1 m during winter and falls 0.1 m during summer.

Given the small astronomical tides, the level of the sea generally has a secondary effect on the sand transport along the beaches, except during storm events when high water would enable the waves to attack the rear of the sandy beaches. Sustained high water levels associated with storm surge may therefore contribute to increased beach erosion.

The most extreme water levels generally occur when a storm surge coincides with a high tide and large wave climate. This is depicted in Figure 3.3.

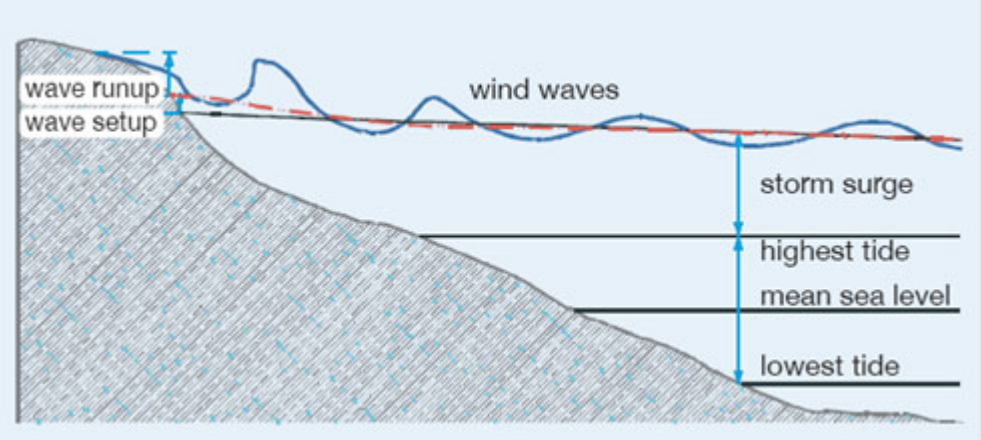

Figure 3.3 Diagram of extreme sea level

A storm surge occurs when a storm with high winds and low pressures, such as a tropical cyclone or a winter cold front, crosses the coastline. The barometric pressure difference creates a region of high water level and strong, onshore winds push water against the coastline further increasing the water level. Like the wind, waves travelling onshore can also increase water levels, which is known as wave setup. The size of the storm surge is influenced by the following factors.

- Wind strength and direction.
- Atmospheric pressure gradient.
- Seafloor bathymetry.
- Coastal topography.

In extreme storms the surge can exceed 1 m above the astronomical tide level. The highest water level recorded at Fremantle Fishing Boat Harbour to 2014 was 1.36 m above MSL (2.12 m above Chart Datum) in June 2012, associated with the passage of a winter cold front.

This storm surge mechanism is important when calculating the potential exposure of assets to coastal inundation or coastal flooding.

Longer term fluctuations or change to water levels can also be important. Water levels at Fremantle have been recorded for more than a century. This provides a comprehensive record of water levels for extreme analysis which is relevant to the study area due to its close proximity.

MRA has previously assessed that the most reliable data in this period has been measured since approximately 1950. This is due to the assessed potential for discrepancies in the earlier data due to changes in locations of the recording devices as well as changes in recording techniques. Therefore only data since 1950 has been used in this report.

The annual mean water level was calculated using the Fremantle Fishing Boat Harbour tide record between 1950 and 2014. Figure 3.4 presents the annual mean water level for this period.

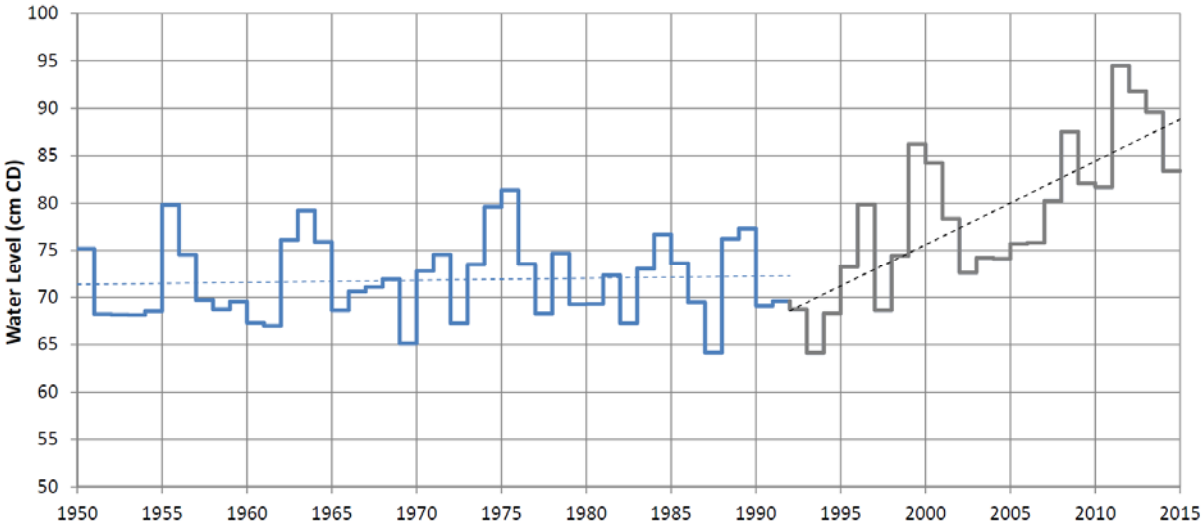

Figure 3.4 Annual mean water level at Fremantle (1950 to 2014)

Figure 3.4 shows that the mean water level over the past decade has been much higher than those of the previous decades on record. This increase in the rate of sea level rise may be in response to climate change and may continue in the future.

3.2 Coastal Processes

From a coastal engineering perspective, the most important coastal processes are generally the interaction of waves, currents and beaches to transport sediment. There are three fundamental sand transport modes which transport sand towards or away from a point on the beach. These are listed below.

- Longshore sediment transport.
- Cross-shore sediment transport.
- Wind-blown sand transport.

These coastal processes are important when calculating the potential exposure of assets to coastal erosion.

3.2.1 Longshore Sediment Transport

Simplistically, longshore sediment transport occurs in the surf zone on a sandy beach, when the breaking waves agitate the sand and place it into suspension. If the waves are approaching the beach at an angle, then a longshore current can form and this can transport the suspended sand along the beach. The suspended load is accompanied by a bed load transport where sand is rolled over the bottom by the shear of the water motion.

There can also be considerable variation in magnitude and direction of the longshore transport from season to season and year to year. In Perth, longshore sediment transport is typically towards the north in summer and south in winter. The strong sea breezes blow from the south-west in summer, creating wind waves at an angle to the shoreline. This transports sediment to the north (Masselink and Pattiaratchi 2001). In winter, severe storms generate waves from the north, swinging to the south over their duration. This typically transports sediment to the south in winter storms (Masselink and Pattiaratchi 2001).

3.2.2 Cross-shore Sediment Transport

Cross-shore sediment transport occurs when sediment is transported in either an onshore or offshore direction. During significant storm events, the strong winds generate high, steep waves and an increase in water level known as storm surge. These factors, acting in concert, allow the waves to attack the higher portion of the beach that is not normally vulnerable.

For sandy beaches, the initial width of the surf zone is often insufficient to dissipate the increased wave energy of the storm waves. The residual energy is often spent eroding the beach face, beach berm and sometimes the dunes. The eroded sand is carried offshore with return water flow where it is deposited and forms an offshore bar. Such bars can eventually grow large enough to break the incoming waves further offshore, causing the wave energy to be spent in a wider surf zone. This is shown diagrammatically in Figure 3.5.

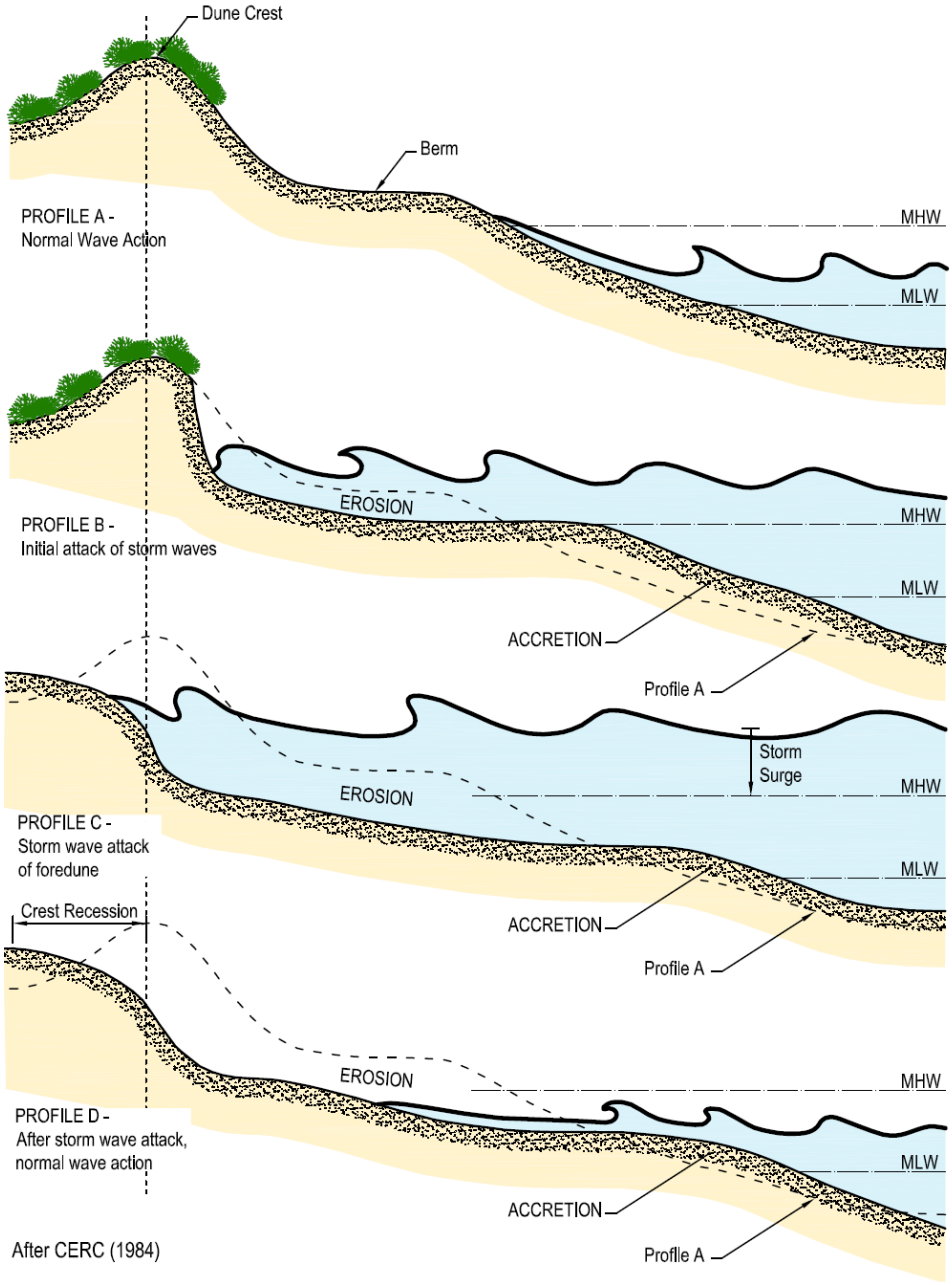

Figure 3.5 Severe storm erosion mechanism (After CERC 1984)

Erosion of sandy beaches during storms can be quite rapid and significant changes can occur in a matter of hours. Subsequent to the storm, the swell activity may move sand from offshore to the shore. This onshore process is generally at a much slower rate than the storm erosion.

3.2.3 Wind Blown Sand

The final mechanism for the movement of sediment is wind-blown sediment transport. This can move sand from the beach into nearby dunes. This is the mechanism by which coastal dunes are formed and grow. There needs to be careful management of the public use and access through coastal dunes to prevent dune blowouts occurring due to lack of vegetation. The coastal dunes form a natural buffer to accommodate the erosion during severe storms.

3.2.4 Sediment Cells

In 2012 Stul et al completed an assessment of the coastal sediment cells between Cape Naturaliste and Moore River. Within this study, Stul et al defined sediment cells as "*sections of the coast within which sediment transport proceses are strongly related*" and proposed that these cells could provide a platform for the review and management of coastal processes over varying time and spatial scales.

A sediment cell heirarchy was established that comprised primary, secondary and tertiary level cells. Characteristics of each cell level, as defined by Stul et al, are descibed below.

- Primary cells – related to large landforms and considers trends of potential change in large landform assemblages or land systems over longer coastal management timescales.
- Secondary cells – describes contemporary sediment movement on the shoreface and potential interdecadal landform response.
- Tertiary cells – confined to the reworking and movement of sediment in the nearshore and potential seasonal to interannual responses.

The adopted cell heirarchy can therefore be used to provide regional scale context to district and local level assessments.

The amended SPP2.6 (WAPC 2013) also makes reference to coastal sediment cells and notes that coastal process assessments should consider the entire sediment cell. The extent of the sediment cells defined by Stul et al along the study area shoreline are shown in Figure 3.6. This figure indicates that the City of Wanneroo coastline extends across 8 different tertiary cells. The assessment of potential impacts caused by coastal hazards for each of these 8 cells will therefore need to be determined as part of this investigation.

3.2.5 Coastal Processes Studies

More locally, a significant volume of work assessing the potential impacts of coastal processes has been completed along the City's coastline. These works have typically been completed to guide the location of new development or in response to coastal erosion issues. Information contained within these reports will provide valuable background and data for the assesment of the potential coastal vulnerability. Moreover, in areas where the reports detail the results of coastal hazard assessments that have been completed in accordance with the amended SPP2.6 these assessment results can be utilised within the current study. Table 3.2 provides a summary of the most relevant reports that are available within the area as well as details of the type of information provided within the report and its relevance to the outcomes of this study.

Figure 3.7 shows where coastal hazard assessments have been completed in accordance with the current requirements of SPP2.6 and can therefore be used for this study.

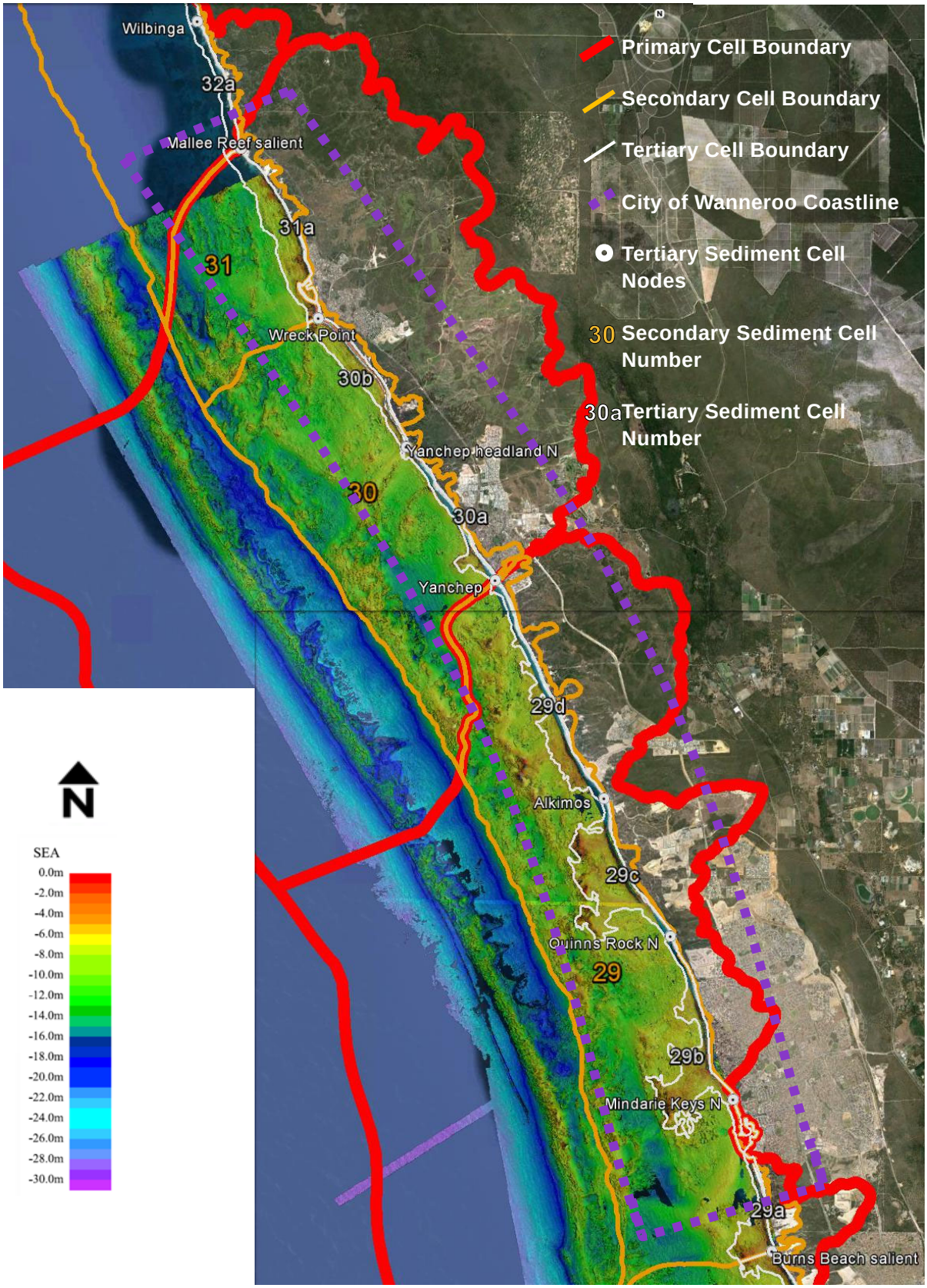

Figure 3.6 Sediment cells within the study area as defined by Stul et al (2012)

Table 3.2A Literature review of available reports, including assessment of relevance to current study

Document Title	Author	Prepared For	Year	Meets Requirements of 2013 SPP2.6	Summary SPP2.6, Planning Controls, Setback Distances.
Northern Perth Metropolitan Coast – Coastal Setback Study	MRA	Department for Planning & Infrastructure	2005	No	Northern Perth Metropolitan coastal setback assessment completed for the coast from Fremantle to Two Rocks. Based on SPP2.6 (2003). Vegetation lines obtained for job relevant.
North Two Rocks Coastal Setback Assessment (R325 R1)	MRA	Two Rocks Investments	2012	No	Based on SPP2.6 (2003) with a 90 m S3 allowance. Doesn't include a Factor of Safety. Vegetation lines to 2011 obtained for job are relevant. Freehold setbacks range from 120 to 160 m.
Capricorn Village Setback Assessment (R225 R0)	MRA	Capricorn Village JV	2008	No	Based on SPP2.6 (2003). Vegetation lines and shoreline movement to 2008 relevant.
Two Rocks Coastal Geomorphology Assessment	Department of Transport	Department of Transport	2013	No	Contains a Literature Review of reports compiled for the Two Rocks area. General consensus is erosion on the northern side of the Marina in the order of 1.2 m/yr and accretion on the southern side. Sediment samples taken in 2012/13 and are relevant for study. Rock noted on beach in areas. Study recommends that the location and extent of rock on the beach be determined through geotechnical methods.
Two Rocks Coastal Vulnerability Study – Geophysical and CPT Surveying	Aurecon	Department of Transport	2014	No	Geotechnical investigation of rock depth for a 1 km section of coastline north of Two Rocks Marina. Geophysical results match reasonably well with the CPT testing along the Sovereign Dve transect.
Two Rocks Coastal Management Plan (R361)	MRA	City of Wanneroo	2014	Yes but requires additional analysis	Study focussed on area north of Two Rocks. Assessed setback requirements for 25 year (43 m) planning horizon in line with the Draft SPP 2.6 methodology. 2 Management Options considered most feasible: Do Nothing and Groynes. Sovereign Dve may become threatened in ~45 years under Do Nothing and ~80 years under Groyne option.
Two Rocks Coastal Erosion: Evaluation of Management Options (R160)	MRA	City of Wanneroo	2006	No	Assessed setback requirements for 5 year (25 m), 15 year (40 m), 30 year (65 m) and 60 year (107 m) planning horizons using the SPP2.6 (2003) methodology. Management options were investigated but none have been implemented to date.
North Yanchep Coastal Setback Assessment – North of Groyne (R340 R2)	MRA	Capricorn Village JV	2013	Yes	Includes assessment based on Final SPP2.6 (2013). Vegetation lines to 2012 obtained for job are relevant. Freehold setbacks were calculated as 131 m. Managed Retreat adaptation option recommended for proposed public infrastructure in the foreshore reserve seaward of PPS.
North Yanchep Coastal Setback Assessment (R337 R2)	MRA	Capricorn Village JV	2013	No	Includes assessment based on Draft SPP2.6 (2013). Requires updating to be valid for Final SPP2.6 2013. Vegetation lines to 2012 obtained for job are relevant. Freehold setbacks were calculated as 148 m, including a 10 m Local Beach foreshore reserve width.
Two Rocks to Yanchep Foreshore Management Plan	City of Wanneroo	-	2007	No	Covers Yanchep (Club Capricorn Resort to Ocean Lagoon Estate) and Two Rocks (adjacent to the existing development). Majority of study area lies within Bush Forever Site 397. Includes details of significant vegetation types that should be protected. Includes reference to the Aboriginal Heritage Sites 17596 "The Limestone Reef" and 17599 "The Yanchep Beach". It is necessary to seek appropriate clearance under the Aboriginal Heritage Act prior to undertaking works in this area. Contains details of proposed FMP actions to be implemented. Limited reference to coastal vulnerability or setbacks.
Yanchep Surf Life Saving Club CHRMAP	Cardno	City of Wanneroo	2014	Yes	Includes assessment based on Final SPP2.6 (2013) & CHRMAP Guidelines. Setback to SLSC calculated to 2040 (40m), 2070 (80m) and 2110 (150m). 500 year ARI inundation calculated. Accommodation & Protect adaptation options recommended for the SLSC & associated assets.
Yanchep Lagoon Coastal Assessment Study	UWA School of Environmental Systems Engineering	City of Wanneroo		No	Study completed to assist in the siting of the Yanchep Lagoon SLSC. XBEACH model used to assess impact of 0.5 m and 1 m sea level rise. Both sea level rises resulted in 20 m of erosion. No setback or coastal vulnerability assessment completed. Study recommends that the location and extent of rock on the beach be determined through geotechnical methods.

Table 3.2B Literature review of available reports, including assessment of relevance to current study (continued)

Document Title	Author	Prepared For	Year	Meets Requirements of 2013 SPP2.6	Summary SPP2.6, Planning Controls, Setback Distances.
Lot 614 Yanchep Foreshore Management Plan	O'Brien Planning Consultants	Unknown	1997	No	Document could not be found to be reviewed.
Amberton Physical Processes Setback Assessment (R285 R2)	MRA	Stockland	2014	Yes	Includes assessment based on SPP2.6 (2013). Vegetation lines to 2013 obtained for job are relevant. Freehold setbacks were calculated as 169 m (southern 750 m) to 147 m (northern 200 m). 500 year ARI inundation calculated. Avoidance adaptation option recommended for freehold development.
Amberton Estate Foreshore Management Plan	Emerge	Stockland	2014	Yes	Includes a CHRMAP for the foreshore zone and coastal infrastructure in line with the DoP guidelines. Mentions the City of Wanneroo CHRMAP. Completed in line with the SPP2.6 2013 approach for the 30, 50 and 75 year planning horizons. Vulnerability distances are unknown and only included on Figure 12. Managed Retreat adaptation option recommended for proposed public infrastructure in the foreshore reserve seaward of PPS.
Alkimos North Coastal Village (Shorehaven) – Setback Assessment	MRA	PEET	2010	No	Setback assessment based on SPP2.6 2003. Setback distances between 93 and 150 m. Vegetation lines and shoreline movement to 2007 relevant.
North Alkimos (Shorehaven) Foreshore Management Plan	Cardno	PEET	2012	No	Includes setback assessment completed by MRA (2010). Maintain 80% of coastal vegetation on foredunes and secondary dunes based on CoW Local Biodiversity Strategy. No other planning constraints identified.
Alkimos Coastal Node CHRMAP	Essential Environmental	LandCorp	2014	Yes	Setback assessment completed in line with the SPP2.6 (2013) and in accordance with the CHRMAP guidelines. Setbacks calculated for the 20, 42, 50, 75 and 100 year planning horizons. Uses results from MRA (2013) R303 R2.
Alkimos Coastal Processes Assessment (R303 R2)	MRA	LandCorp	2013	Yes	Setback assessment completed in line with the SPP2.6 (2013) approach for the 20, 42, 50, 75 and 100 year planning horizons. Setback values vary across the length of the site.
Alkimos Marina Preliminary Sediment Modelling (R353 R0)	MRA	LandCorp	2013	No	Includes Sediment Budget covering Mindarie to Two Rocks from 1976 to 2013. Also includes detailed sediment transport modelling in the proposed Alkimos Marina location.
Alkimos Beach Foreshore Management Plan	RPS	Lend Lease	2014	No	Majority of study area lies within Bush Forever Site 397. Includes reference to the Aboriginal Heritage Site 3509 Karli Spring. No proposed access or recreation works within the Karli Spring site. Setback assessment completed by MRA (2013). Includes a CHRMAP for the foreshore zone and coastal infrastructure. Managed Retreat adaptation option recommended for proposed public infrastructure in the foreshore reserve seaward of PPS.
Alkimos Wastewater Treatment Scheme - Management Plan for Construction and Ongoing Presence of the Ocean Outlet Pipeline	Worley Parsons	Water Corporation	2008	No	The temporary construction bund and sheet piles were removed and the pipe buried 5 m below the beach and dune. No long-term impacts are expected from the ongoing presence of the ocean outlet pipeline.
Lot 9 Jindalee Setback Assessment (R258 R1)	MRA	Satterley	2011	No	Setback assessment based on SPP2.6 (2003) with a 90 m sea level rise allowance. Includes borehole geotechnical investigations to identify rock in the foreshore area. Rock above +3.5 mAHD identified in southern portion, with freehold setback calculated 50 m behind +3.5 mAHD rock. Freehold setback in northern portion of foreshore calculated at 171 m. Vegetation lines and rock extent relevant to this study.
Lot 9 Jindalee (Eden Beach) Foreshore Management Plan	EPCAD	Satterley	2013	No	Majority of study area lies within Bush Forever Site 397. Includes reference to an Aboriginal Heritage Site. Access ways modified to account for the presence of this site. Setback assessment details contained in MRA (2011).

Table 3.2C Literature review of available reports, including assessment of relevance to current study (continued)

Document Title	Author	Prepared For	Year	Meets Requirements of 2013 SPP2.6	Summary SPP2.6, Planning Controls, Setback Distances.
Lot 10 Jindalee (Jindee) Coastal Stability Study (R135 R4)	MRA	Estates Development Company	2007	No	Setback assessment based on SPP2.6 2003. Includes borehole geotechnical investigations to identify rock in the foreshore area. Rock above +3 mAHD identified along whole foreshore, with freehold setback calculated 30 m behind +3 mAHD rock. Vegetation lines and rock extent relevant to this study.
Mindarie to Quinns Rocks Foreshore Management Plan	Ecoscape	City of Wanneroo	2004	No	Limited reference to coastal vulnerability or setbacks. Covers Mindarie to Quinns Rocks. Majority of study area lies within Bush Forever Sites 397 and 322. Contains proposed FMP actions to be implemented.
Quinns Beach Long Term Coastal Management Study Stage 2	Cardno	City of Wanneroo	2015		Work in progress involving coastal processes assessment, concept options assessment and detailed design of long term coastal management measures. The Quinns Beach groyne region is not analysed in this CHRMAP.
Quinns Beach Long Term Coastal Management Study Stage 1	Cardno	City of Wanneroo	2013	No	Contains a thorough review of coastal data and information available in the area. Limited reference to coastal vulnerability or setbacks as per SPP2.6. Conceptual management options investigated. Further investigations to be completed in Stages 2 and 3.
Quinns Rocks Estate Stage 1 Foreshore Management Plan	Unknown	Unknown		No	Document could not be found to be reviewed.
Quinns Rocks Estate Stage 2 Foreshore Management Plan	Unknown	Unknown		No	Document could not be found to be reviewed.
Lot 1 The Wharf, Mindarie Foreshore Management Plan	ATA Environmental	Mirvac	2004	No	Developed in response to earthworks within Foreshore Reserve, linking development with coast. No references to coastal vulnerability or setbacks.
Mindarie Beach Foreshore Reserve Management Plan	Unknown	Unknown	1994	No	Document could not be found to be reviewed.
Tamala Park Coastal Engineering Investigation	DPI	City of Joondalup	2008	No	Little relevancy to coastal vulnerability. Investigates potential swimming beach options in the Burns Beach area. Includes summary of coastal geomorphology, including reference to sandy beach adjacent to Tamala Park.
Tamala Conservation Park Establishment Plan	DoP & WAPC		2012	No	Little relevancy to coastal vulnerability. Development within the Park will be limited.

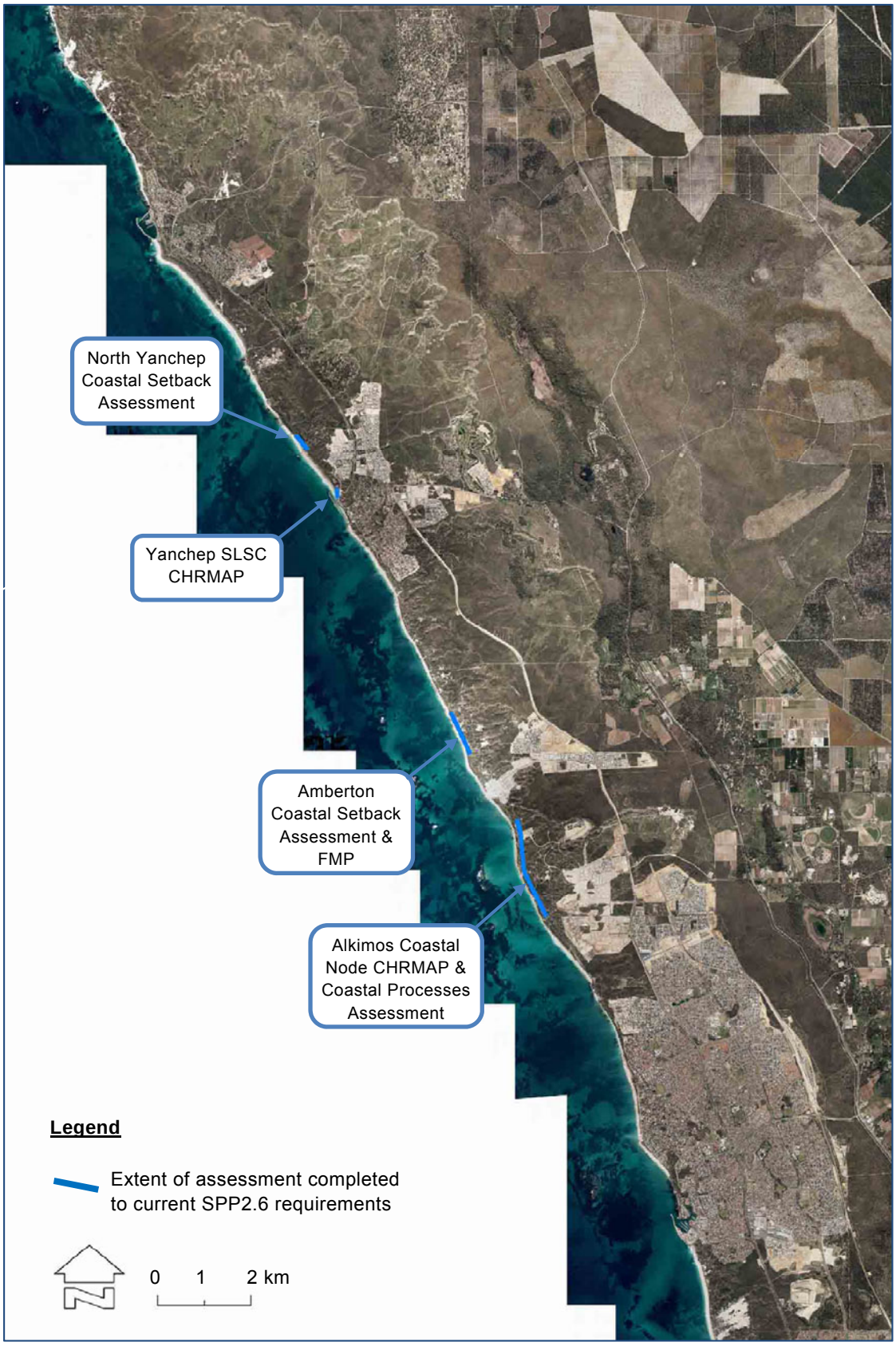

Figure 3.7 Extent of coastal hazard assessments completed in accordance with current SPP2.6 (WAPC 2013) requirements

In addition to available reports, other relevant information is also available for the study area. Specifically, historical coastal vegetation lines are available from previous studies as well as from the DoT database. The historical coastal vegetation lines have been determined from interrogation of available aerial photography in accordance with the requirements of DoT (2009) and provide valuable information on the behaviour of the shoreline over time.

The spatial and temporal coverage of the available vegetation lines is sufficient to meet the requirements of this study. These coastal vegetation lines will be analysed as part of the coastal vulnerability assessment.

3.3 Cultural Heritage

The Department of Aboriginal Affairs (DAA) keeps a register of known Aboriginal sites and other heritage places. This register is kept in accordance with the requirements of the *Aboriginal Heritage Act* (1972) to provide a reference tool which can assist land users in identifying locations where Aboriginal heritage is present. It is important to remember that in addition to the sites contained within this register, other sites may also be of significance but may be either undiscovered or unregistered. Nevertheless, all Aboriginal sites that meet the definitions of Section 5 of the *Aboriginal Heritage Act* are required to be afforded protection.

In order to determine the locations of any Aboriginal heritage sites within the study area a search of the DAA register was completed. Additional consultation was also undertaken with DAA in order to ascertain if any sites existed that were not on the register.

Figure 3.8 shows the locations of the known registered Aboriginal heritage sites. These sites will also be shown on the coastal hazard maps produced as part of this study.

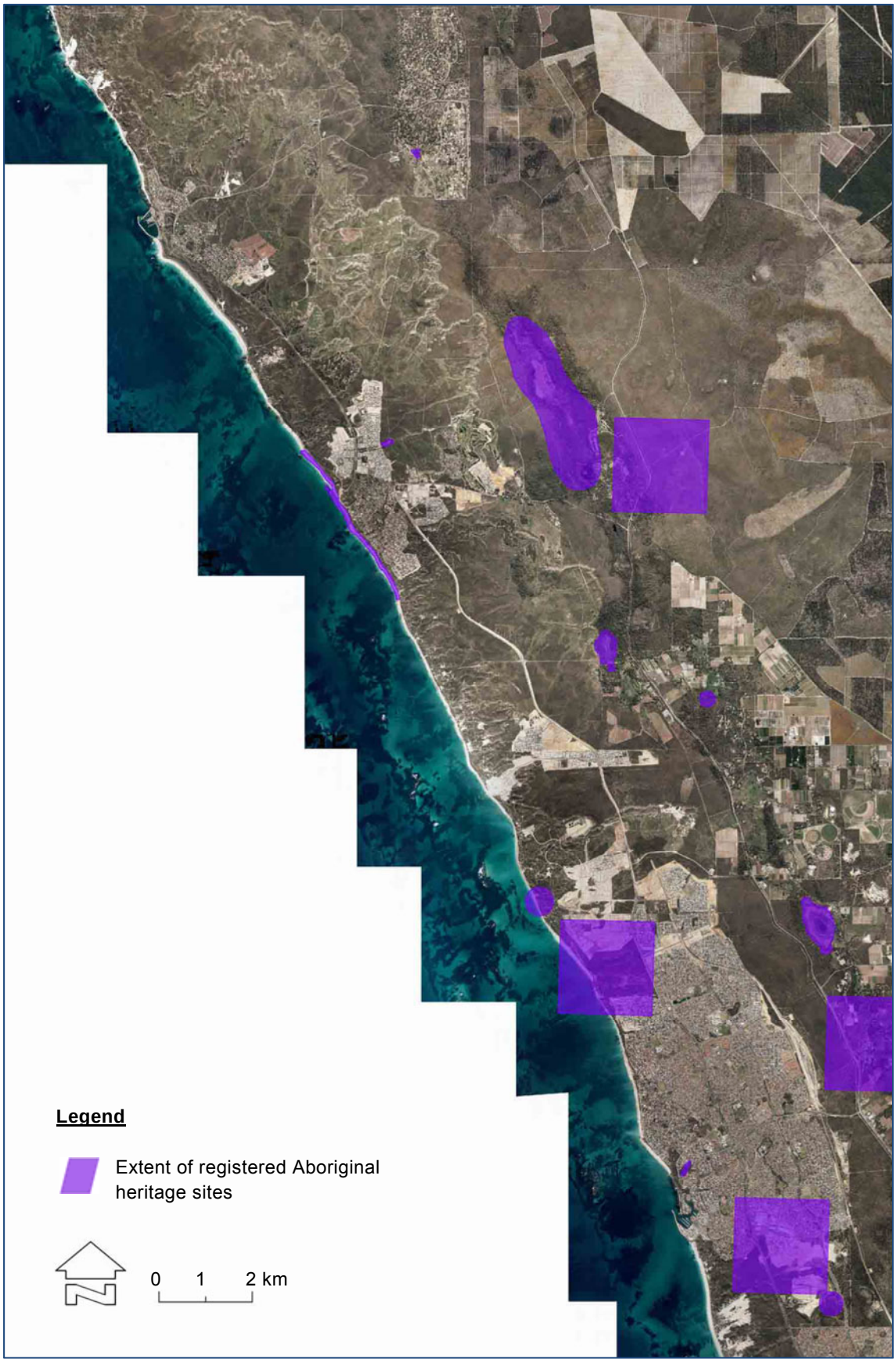

Figure 3.8 Locations of registered Aboriginal heritage sites

3.4 Environment

Eco Logical Pty Ltd completed an assessment of the ecological systems that may be vulnerable to coastal processes within the City of Wanneroo. The full Eco Logical report is contained in Appendix A. This assessment involved the following.

- Completion of a desktop study to identify the type and location of ecological systems that are considered conservation significant in the potential coastal erosion zone.
- Conduct an assessment on the vulnerability of ecological systems, including an assessment of the potential adaptive capacity of these systems.

Four ecological systems were identified as having high vulnerability due to reasons such as having few known recorded locations and record locations being restricted to coastal areas likely to be impacted by coastal erosion. The systems rated as having high vulnerability included the following.

- Conservation listed flora species *Marianthus paralius,* which has few records within the City and on the Swan Coastal Plain and is also unlikely to have good adaptive capacity as its key habitat occurs in coastal environments which may be subject to coastal erosion.
- Priority Ecological Communities *Acacia* shrublands on taller dunes (29b) and Coastal shrublands on shallow sands (29a). Both of these communities are coastally dependent and have limited adaptive capacity.
- Environmentally Sensitive Area Bush Forever Site 397 is considered to have high vulnerability as almost the entire site is within the potential coastal erosion influence zone.

Figure 3.9 shows the locations of the ecological systems with a high vulnerability to coastal hazards. These sites will also be shown on the coastal hazard maps produced as part of this study.

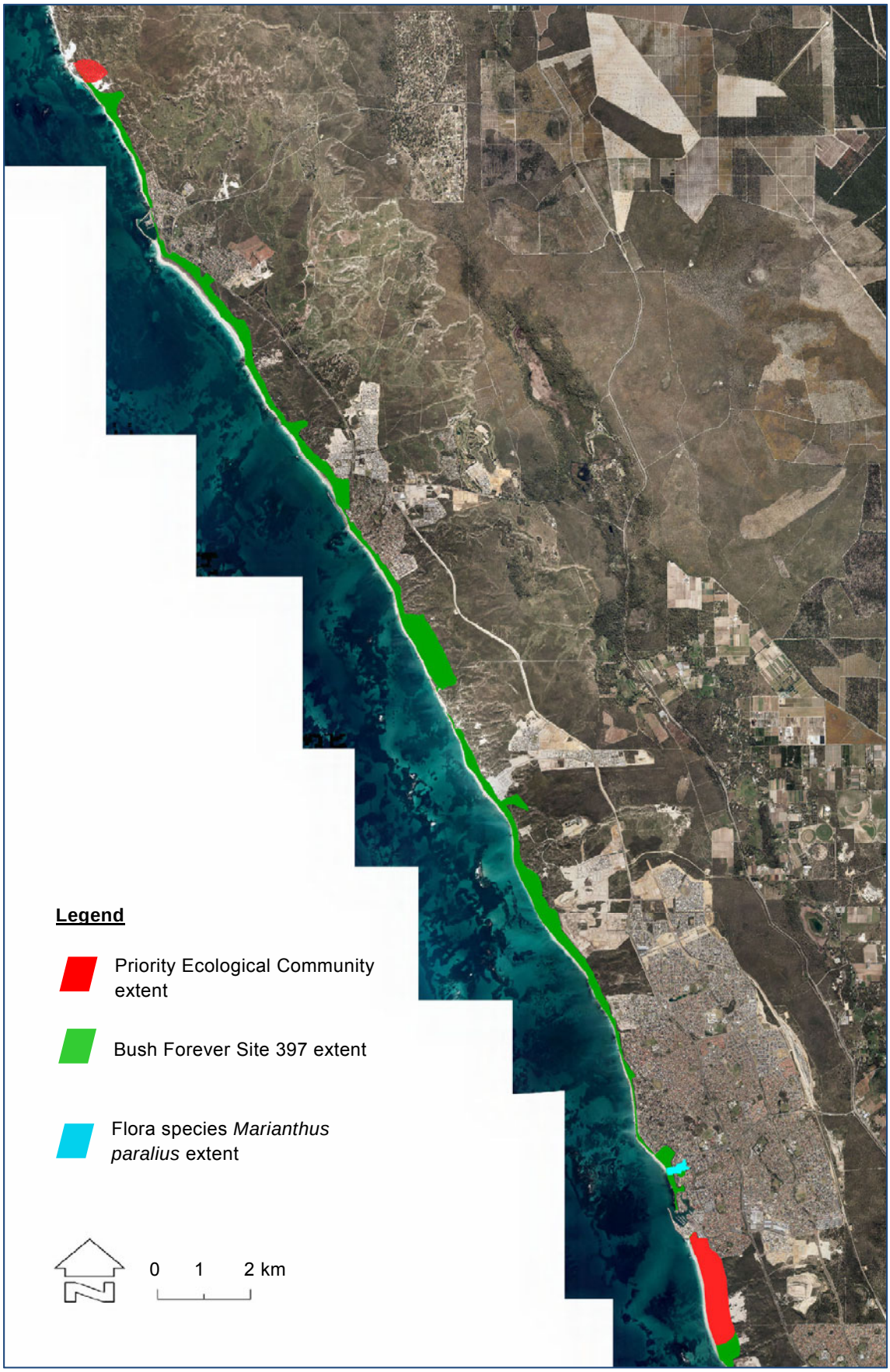

Figure 3.9 Locations of ecological systems with high vulnerability

4. Coastal Vulnerability Assessment Methodology

An integral part of the CHRMAP process is establishing an understanding of the vulnerability of assets from coastal processes and the associated hazards. The CHRMAP Guidelines (WAPC 2014) note that the vulnerability of coastal assets is a function of three overlapping elements.

- Exposure to coastal erosion and coastal inundation (flooding).
- Sensitivity to potential impacts.
- Adaptive capacity of a system.

Potential impacts are a function of exposure and sensitivity, while vulnerability is a function of potential impacts and adaptive capacity. This is presented as a flowchart in Figure 4.1.

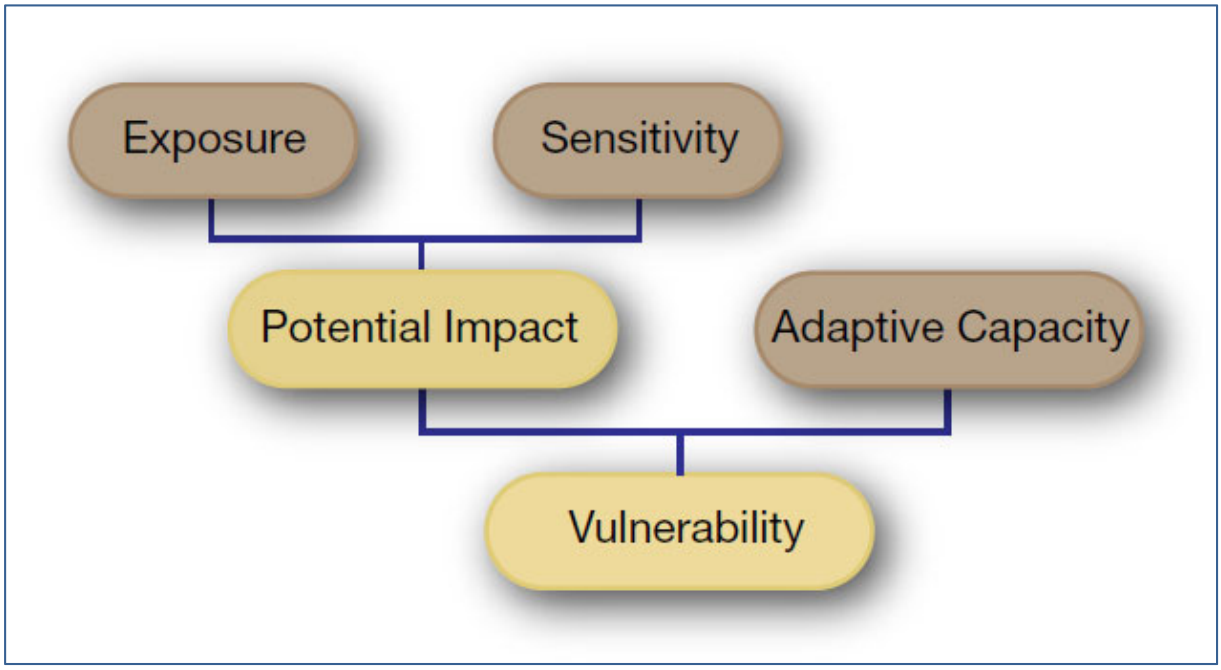

Figure 4.1 Vulnerability assessment flowchart (WAPC 2014)

Section 4.1 details the methodology used in this vulnerability assessment, as recommended in the CHRMAP Guidelines (WAPC 2014), while Sections 5 to 12 detail the findings of the coastal vulnerability assessment.

4.1 Planning Timeframes

The SPP2.6 requires assessment over a 100 year planning timeframe for siting of residential, freehold development. It is also possible to complete the assessment over shorter timeframes to analyse the risk or impact to assets over time. The timeframes that will be investigated in this CHRMAP as requested by the City are listed below.

- Present day (2015).
- 2030.
- 2050.

- 2070.
- 2090.
- 2120.

This range of shorter timeframes will allow assessment of the change in risk profile over time for both current and future assets. This can help to guide when management and adaptation actions may be required.

4.2 Sediment Cell Analysis

As detailed in Section 3.2.4 and Figure 3.6, the Wanneroo shoreline is composed of a number of primary, secondary and tertiary sediment cells. The CHRMAP guidelines and the SPP2.6 recommend the vulnerability assessment be completed for the entire sediment cell and include adjacent coastal areas as required. This CHRMAP will be completed for the eight tertiary sediment cells identified in Stul et al (2012) and presented in Figure 3.6. The exposure, sensitivity and adaptive capacity of assets within these eight tertiary sediment cells will also be determined, allowing the vulnerability to be assessed.

4.3 Exposure / Allowances for Coastal Processes

Exposure is the assessment of the physical processes such as coastal erosion and coastal inundation that impact on an asset (WAPC 2014). The methodology to identify the exposure and calculate the allowances for coastal processes follows the methodologies set out in Schedule One of the SPP2.6 (WAPC 2013).

The first step is to classify the coastal type/s within the sediment cell so that appropriate factors can be considered. Where more than one coastal type is present within each sediment cell, these will be broken down into appropriate coastal zones. Existing control structures, including natural defences such as dunes or heavily vegetated areas, or natural rock structures will also be identified for each sediment cell.

Following classification of coastal type, the allowance for erosion can be calculated. For rocky coasts, allowance for the current and future risk of erosion should be based on a geotechnical assessment of the shoreline stability. Historically, a nominal allowance of 50 m landward of competent rock of a suitable height (greater than +3.5 mAHD) is recommended for rocky coasts to account for potential erosion and wave overtopping effects. Where rock has been identified through geotechnical assessment or DPI mapping (MRA 2005) and is adjacent to a sandy shoreline, the recommended erosion allowance within the transition zone between the two coastal types must be considered on a case by case basis when developing erosion hazard maps.

For sandy coasts, the allowance for erosion is calculated through combination of a number of allowances, which are outlined below. This is based on Schedule One of the SPP2.6 (WAPC 2013).

- S1 Erosion – Allowance for the current risk of storm erosion.
- S2 Erosion – Allowance for historic shoreline movement trends.
- S3 Erosion – Allowance for erosion caused by future sea level rise.

An allowance for uncertainty is also added to these allowances to give a total setback to account for coastal erosion processes over the planning horizon. This methodology is applicable for sandy coasts or mixed sandy and rocky coasts.

The assessment methodologies for the three erosion allowances are summarised in more detail in the following sections.

4.3.1 S1 Erosion - Allowance for the Current Risk of Storm Erosion

As noted in Section 3.2.2, severe storm events have the potential to cause increased erosion to a shoreline, through the combination of higher, steeper waves generated by sustained strong winds, and increased water levels. These two factors acting in concert allow waves to erode the upper parts of the beach not normally vulnerable to wave attack.

The SBEACH computer model was developed by the Coastal Engineering Research Centre (CERC) to simulate beach profile evolution in response to storm events. It is described in detail by Larson & Kraus (1989). Since this time the model has been further developed, updated and verified based on field measurements (Wise et al 1996, Larson & Kraus 1998, Larson et al 2004).

SBEACH has also been validated locally by MRA (Rogers et al 2005). This local validation has shown that SBEACH can provide useful and relevant predictions of the storm induced erosion provided the inputs are correctly applied. These inputs include time histories of wave height, period and water elevation, as well as pre-storm beach profile and median sediment grain size.

SPP2.6 recommends that the allowance for absorbing acute erosion consider both the effects of longshore and cross shore sediment transport processes. Potential longshore transport erosion has been accommodated within the transition areas from rocky to sandy coastline as presented in the hazard mapping described in Section 4.5 of this report.

It is recommended that potential cross shore erosion be determined by modelling the impact of an appropriate storm sequence using acceptable models such as SBEACH. It is also specified that the modelled storm should have an Annual Exceedance Probability (AEP) of 1% with regard to beach erosion. This is equivalent to a storm with an Average Recurrence Interval (ARI) of 100 years.

It is widely accepted that simulating 3 repeats of a severe storm sequence that effected south west Western Australia in July 1996 provides a conservative representation of the 100 year ARI beach erosion event. A peak significant wave height of approximately 7.8 m was recorded at the South-West Rottnest wave buoy during the passage of this storm. This storm sequence had elevated water levels for a period of approximately 111 hours and caused coastal erosion at a number of locations in Western Australia. Modelling three consecutive repeats of this storm therefore simulates the effects of over 330 hours of storm conditions on the shoreline. The offshore wave conditions as recorded in approximately 50 m of water are presented in Figure 4.2.

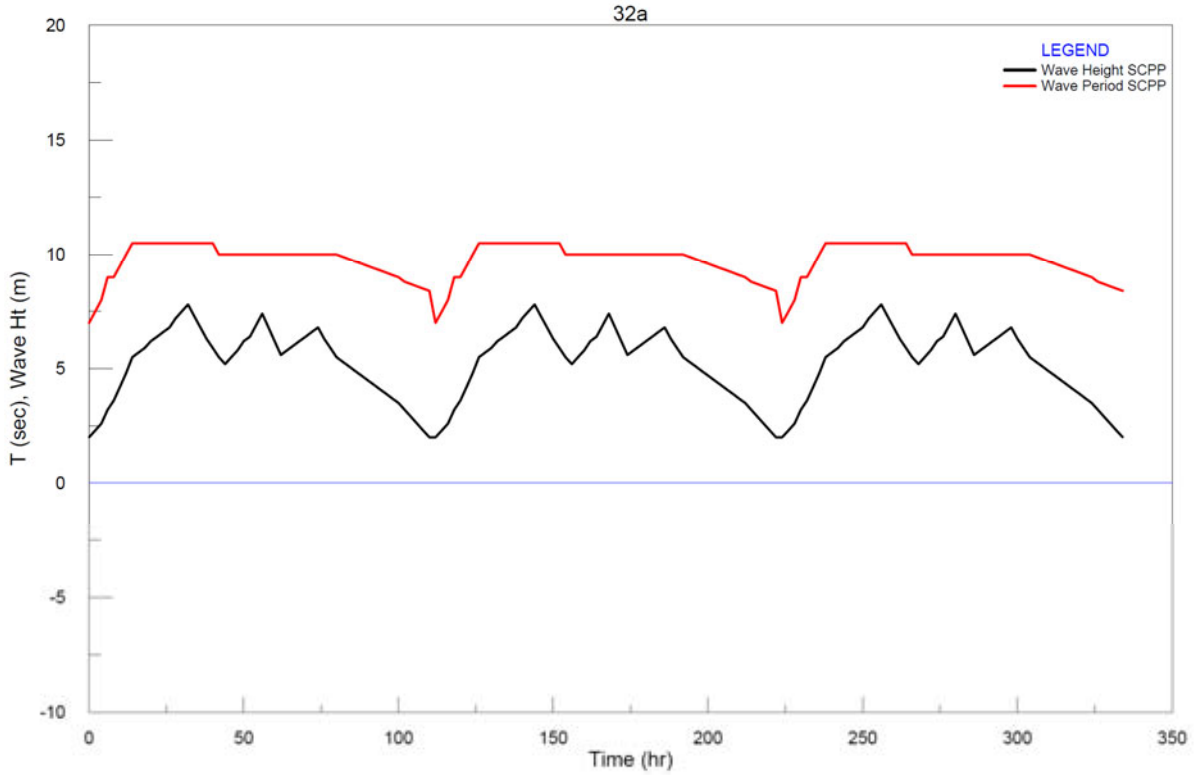

Figure 4.2 Offshore Wave Conditions

Given the complex bathymetry offshore from the City's coastline, as presented previously in Figure 3.2, the SWAN wave model was set up to transform the offshore wave conditions to the nearshore area for the July 1996 storm event. The SWAN wave model has previously been set up and calibrated for the region, detailed in MRA (2015a). The wave grid was created using LiDAR data and nautical charts. Figure 4.3 shows a spatial plot of the SWAN wave model.

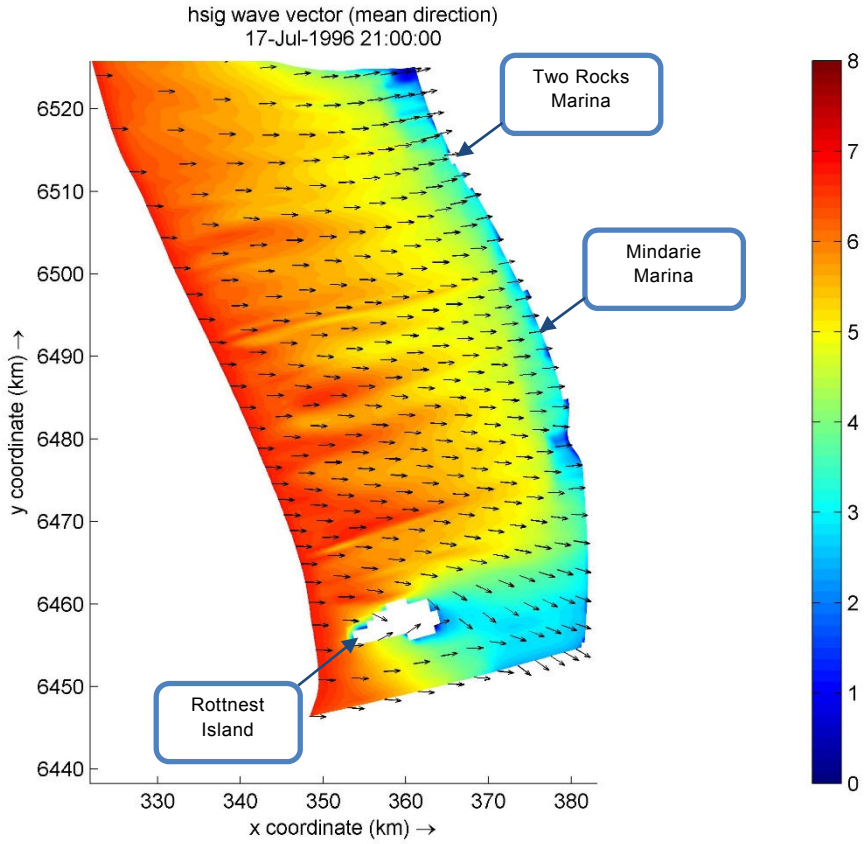

Figure 4.3 SWAN wave model spatial plot

Output from the SWAN wave model was input to the SBEACH modelling for each SBEACH profile, providing a more accurate reflection of the nearshore wave conditions during the passage of the July 1996 storm. Wave input details are provided in the relevant sections.

The S1 allowance is taken as the modelled erosion behind the Horizontal Shoreline Datum (HSD), which is defined as the landward contour corresponding to the peak water level elevation that is experienced during severe storm activity at the site. Consideration must also be given to coastal recession as a result of slope failure. For this assessment, a stable slope profile of 30 degrees from the horizontal was used as per the SPP2.6 recommendations (WAPC 2013).

Potential longshore erosion during storm events is also important, especially where there may be a gradient/transition in longshore erosion. This may be caused by an obstacle (natural or manmade) which reduces updrift longshore sediment transport and is common on the tidal reaches of inland waters, sheltered embayments and gulfs.

Further details of the SBEACH model inputs, outputs and severe storm analysis for the eight sediment cells are contained in Sections 5 to 12.

4.3.2 S2 Erosion - Allowance for Historic Shoreline Movement Trends

Physical coastal processes act on wide ranging time scales, from storm to post storm, seasonal and longer term. The continual action of these processes helps to shape the shoreline. Short term changes to the coast are captured by the S1 allowance. The S2 allowance in SPP2.6 seeks to capture the longer term changes to the shoreline that are likely to occur in the future.

Typically, the historical position of the vegetation line is estimated from aerial photographs to determine the movements of the shoreline over time. The vegetation line is often used as an indicator of the long term shoreline position, as it is less sensitive to short term changes.

The accuracy of these vegetation lines is believed to be in the order of ±5 m, depending on the resolution of the aerial photographs and the rectification process. A number of coastal vegetation lines were provided by DoT for use in this study. Not all of the vegetation lines cover the full extent of the City's shoreline. To provide a consistent baseline comparison for the shoreline movement analysis, a 2014 rectified aerial photograph covering the full length of the City's shoreline was obtained from the City. The 2014 coastal vegetation line was extracted from this aerial photograph using the methodology outlined in DoT (2009).

The shoreline movements relative to the 2014 coastal vegetation line were calculated at 100 m chainages. The 0 m chainage is located at the northern end of the 2014 aerial photograph, with the southern chainage (33,300 m) located at the southern end of Tertiary Sediment Cell 29a. Figure 4.4 shows the general position of the chainages with a spacing of 2,000 m.

The SPP2.6 notes the following for calculation of the S2 allowance.

> *The allowance for historic shoreline movement trends should generally be calculated as 100 times the historic annual rate of erosion.*
>
> *Where the historic annual rate of shoreline movement is accretion less than 0.2 metres per year the allowance for historic shoreline movement trends should be zero. Where the historic annual rate of shoreline movement is continuous accretion in excess of 0.2 metres per year and there is compelling evidence that accretion is likely to continue at the same rate for at least the next 50 years the allowance for historic shoreline movement trends should be calculated as minus 50 times the historic longer-term annual rate of accretion.*

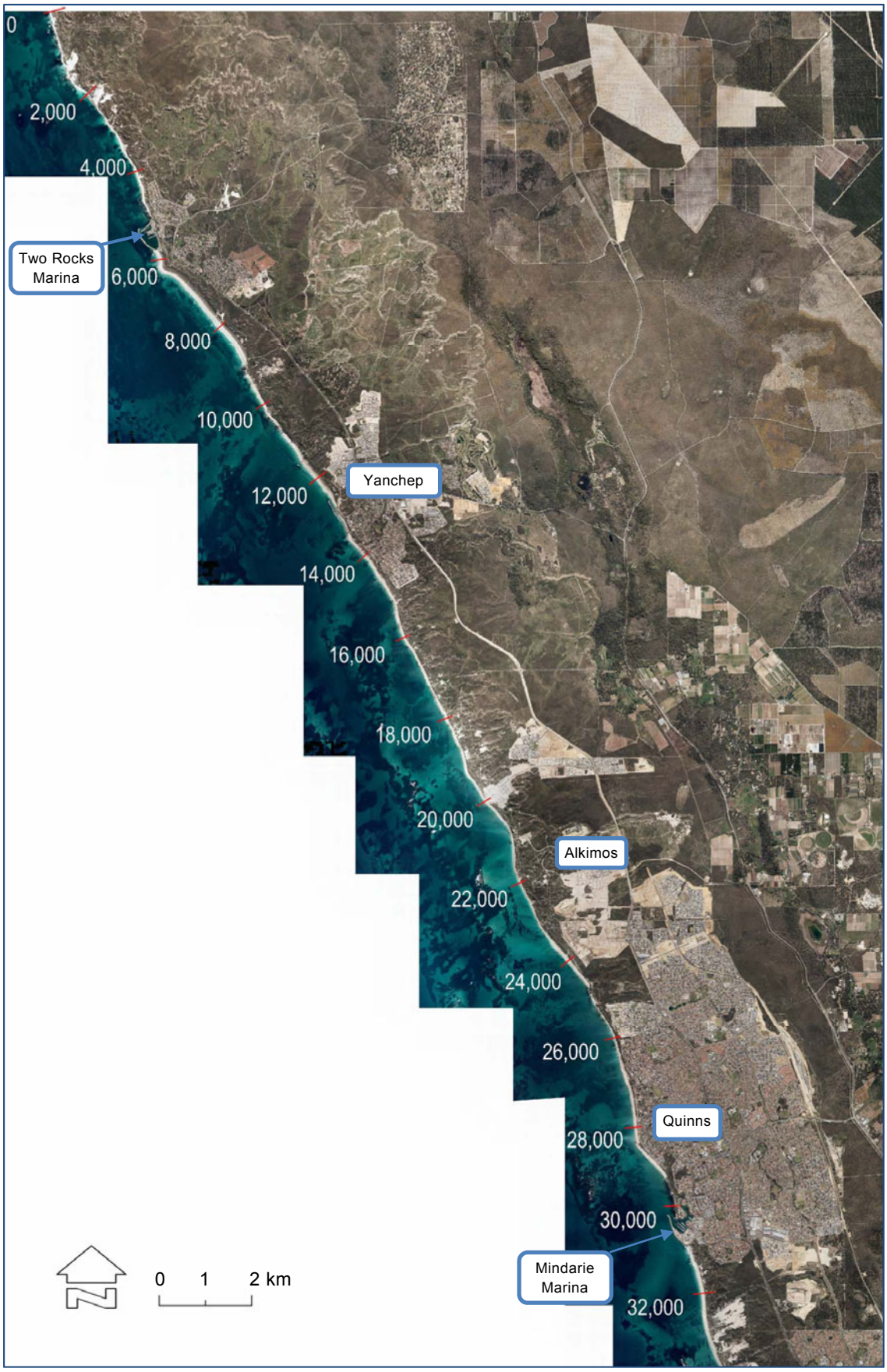

Figure 4.4 Study area chainages

Further details of the shoreline movement analysis for the eight sediment cells are contained in Sections 5 to 12.

4.3.3 S3 erosion - allowance for erosion caused by future sea level rise

The Intergovernmental Panel on Climate Change (IPCC) has presented various scenarios of possible climate change and the resultant sea level rise in the coming century. The range of these projections is shown in Figure 4.5 (IPCC 2013).

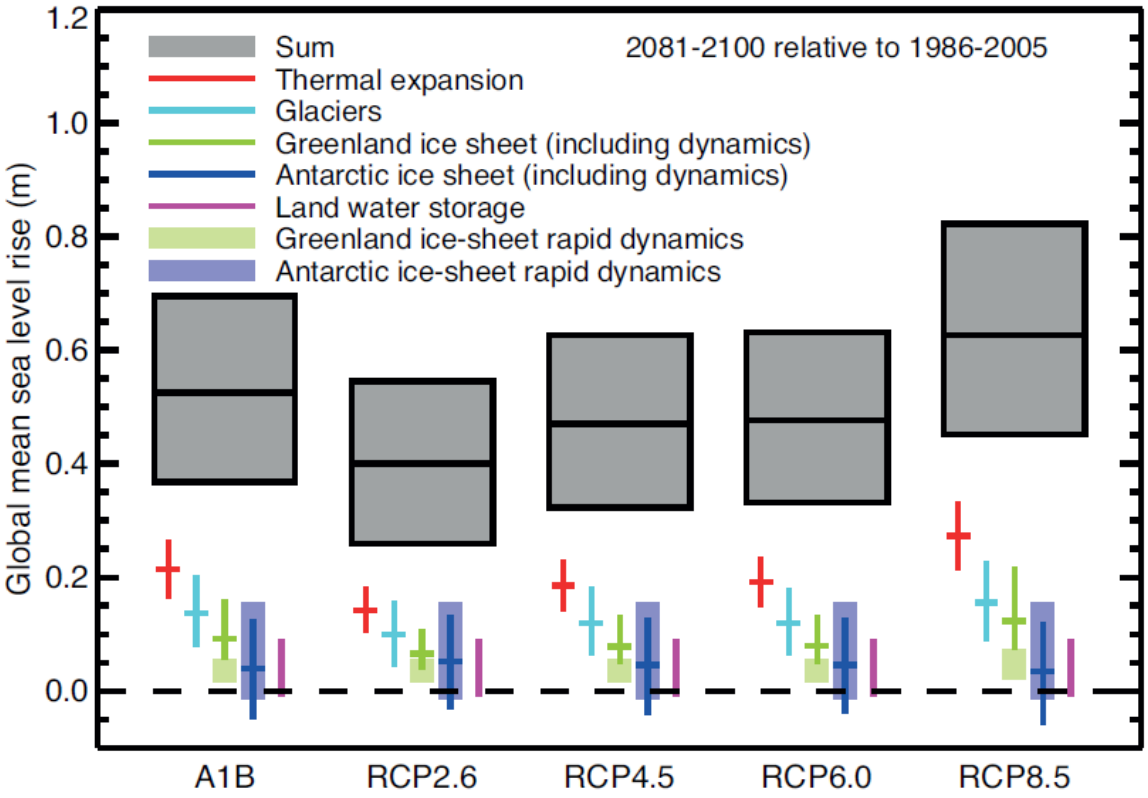

Figure 4.5 IPCC Scenarios for sea level rise (IPCC 2013)

The results of the on-going increase in sea level and the anticipated impacts of accelerated increases are difficult to predict. Nevertheless, such increases in global sea level are likely to lead to beach erosion, as a sea level rise usually results in deepening of nearshore waters, allowing larger waves to reach the shore and erode the beach face (Bird 2000).

Komar (1998) provides a reasonable treatment for sandy shores, including examination of the Bruun Rule (Bruun 1962). The Bruun Rule relates the recession of the shoreline to the sea level rise and slope of the nearshore sediment bed:

$$R = \frac{1}{\tan(\theta)} S$$

where: R = recession of the shore.

θ = average slope of the nearshore sediment bed.

S = sea level rise.

The basic notion behind the Bruun Rule is that a sea level rise would cause erosion of the upper beach, and transference of sand from the beach to the adjacent sea floor would, in due course, restore the previous transverse profile in relation to the higher sea level (Bird 2000; Komar 1998).

The SPP2.6 suggests that the allowance for erosion caused by future sea level rise on sandy coast should be calculated as 100 times the adopted sea level rise value.

DoT (2010) completed an assessment of the potential increase in sea level that could be experienced on the Western Australian coast in the coming 100 years. This assessment extrapolated work by Hunter (2009) to provide sea level rise values based on the IPCC (2007) A1FI climate change scenario projections to the year 2110. The derived sea level rise scenario was subsequently adopted by the WAPC (and SPP2.6) for use in coastal planning along the Western Australian coast. This is the sea level rise scenario adopted for this CHRMAP and is presented in Figure 4.6.

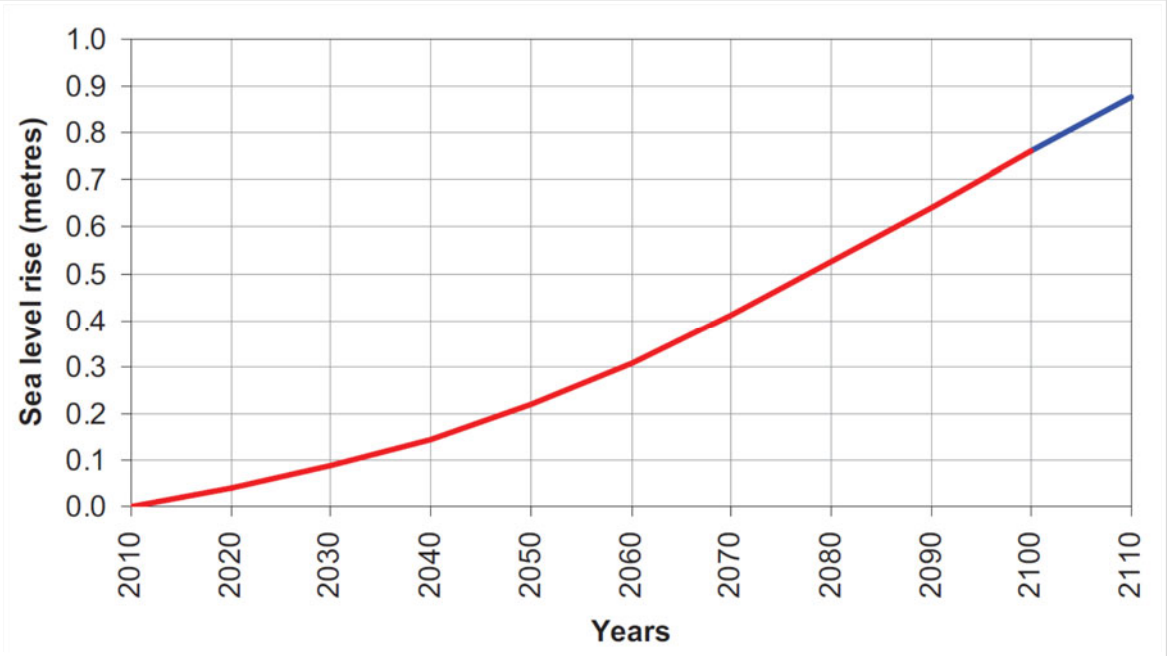

Figure 4.6 Recommended sea level rise scenario for coastal planning in Western Australia (DoT 2010)

DoT (2010) recommends assuming that the rate of global average sea level rise beyond 2100 will be a continuation of the rate of rise between 2090 and 2100. This rate is equal to 0.11 m per decade, which was extended to 2120 for the purposes of this study.

Table 4.1 summarises the sea level rise values and S3 Erosion allowances for the range of planning timeframes listed in Section 4.1. A base year of 2015 was used to determine the sea level rise values presented in Table 4.1 and used in this assessment.

Table 4.1 Sea level rise allowances

Planning Timeframe	Potential Sea Level Rise (m)	S3 Erosion Allowance (m)
2030	0.07	7
2050	0.20	20
2070	0.39	39
2090	0.62	62
2120[1]	0.97	97

Notes: 1. A sea level rise rate of 0.11 m per decade was extrapolated to determine the 2120 sea level rise as per DoT (2010).

The three erosion allowances (S1 to S3) are combined, plus a Factor of Safety of 0.2 metres per year allowance for uncertainty, to give a total exposure to coastal erosion. This is completed for the timeframes listed in Section 4.1, allowing the exposure of coastal assets to erosion to be determined.

4.3.4 S4 Inundation

Irrespective of coastal type and the presence of any coastal protection structures, the SPP2.6 requires assessment of the potential exposure of areas to coastal inundation or coastal flooding. This is named the S4 Inundation allowance within the SPP2.6. The coastal inundation assessment is to be completed with reference to an event with a 0.2% chance of exceedance per year, which is akin to the 500 year average recurrence interval (ARI) event.

The S4 inundation level is calculated using the SBEACH model, allowing the exposure of coastal assets to inundation to be determined. Results of the S4 Inundation modelling are contained in Section 13.

4.4 Sensitivity, Adaptive Capacity & Vulnerability

Sensitivity reflects the responsiveness of assets to climatic influences, and the degree to which changes in climate might affect this responsiveness (WAPC 2014). Sensitive assets are highly responsive to coastal processes and climate change. The sensitivity of assets to coastal erosion and inundation are outlined for each sediment cell, with details provided in Sections 5 to 12.

Adaptive capacity reflects the ability of assets to change in a way that makes it better equipped to deal with external influences such as climate change impacts (WAPC 2014). An example of improved adaptive capacity for an asset is the ability to pick up and relocate foreshore infrastructure when threatened by erosion. The adaptive capacity of assets to external influences are outlined for each sediment cell, with details provided in Sections 5 to 12.

Following identification of the exposure, sensitivity and adaptive capacity of assets, the vulnerability of the assets to coastal erosion and inundation can be determined.

4.5 Coastal Hazard Mapping

The creation of coastal hazard risk maps is an important output of the vulnerability assessment. These maps spatially identify the current and projected extent of vulnerability of erosion and inundation over the planning timeframes listed in Section 4.1.

Coastal hazard maps have been created for the eight tertiary sediment cells. Results can be found in the following sections.

5. Tertiary Sediment Cell 32a Erosion Allowances

Tertiary Sediment Cell 32a extends approximately 3.5 km south from Wilbinga to Mallee Reef salient. This sediment cell straddles the City of Wanneroo northern boundary as shown in Figure 5.1.

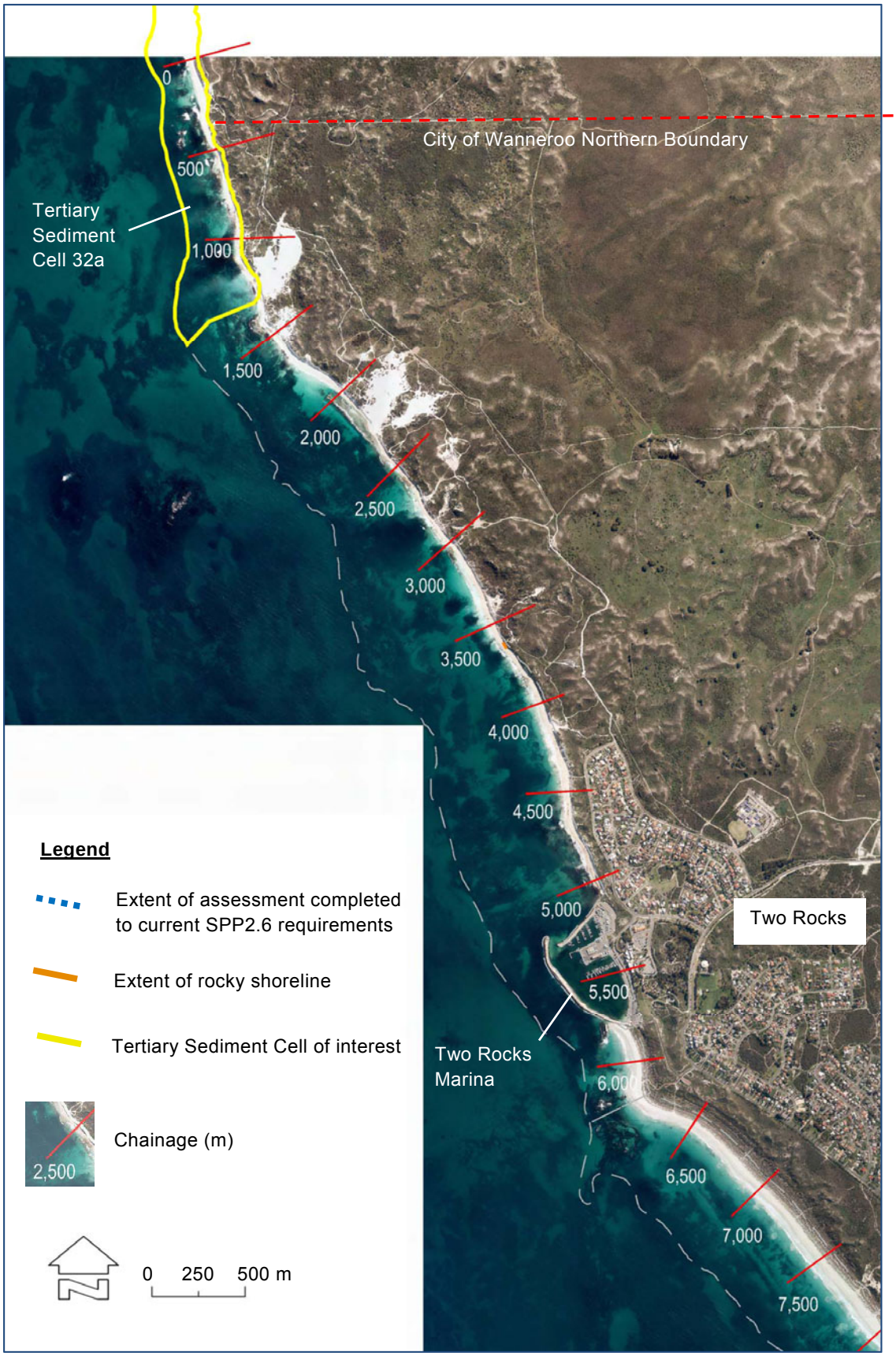

Figure 5.1 Tertiary Sediment Cell 32a location figure

5.1 Coastal Classification

The southern portion of Tertiary Sediment Cell 32a (Chainages 0 to 1,200 m) consists of sandy coastline interrupted by small patches of beachrock (Short 2006). The beaches receive waves averaging just over 1 m (Short 2006), which are likely to increase during stormy periods.

Figure 5.2 is a photograph of the beach around Chainage 800 m looking south. This photograph was taken as part of the setback assessment for the proposed North Two Rocks development and shows a relatively narrow beach and an erosion scarp at the rear of the beach.

Figure 5.2 Beach photograph at Chainage 800 m (MRA)

Only one small rock headland was identified above +3 mAHD during the site visit. This rock headland was approximately 5 m long and would not be expected to prevent erosion behind the rock. Therefore, Tertiary Sediment Cell 32a will be treated as a sandy coastline in the calculation of setbacks to account for coastal erosion processes.

5.2 Allowances for Erosion

5.2.1 S1 Erosion

An SBEACH profile was created at Chainage 800 m from a combination of on-site survey measurements and nautical charts. SWAN wave model outputs from an offshore location were input into the SBEACH model as were the water levels recorded during the July 1996 storm. The peak significant wave height (Hs) during the passage of the storm was approximately 3.2 m in around 9 m of water. A D_{50} sediment size of 0.44 mm was input into the model using results from the North Two Rocks setback assessment (MRA 2015b).

The results of the SBEACH modelling are presented in Figure 5.3.

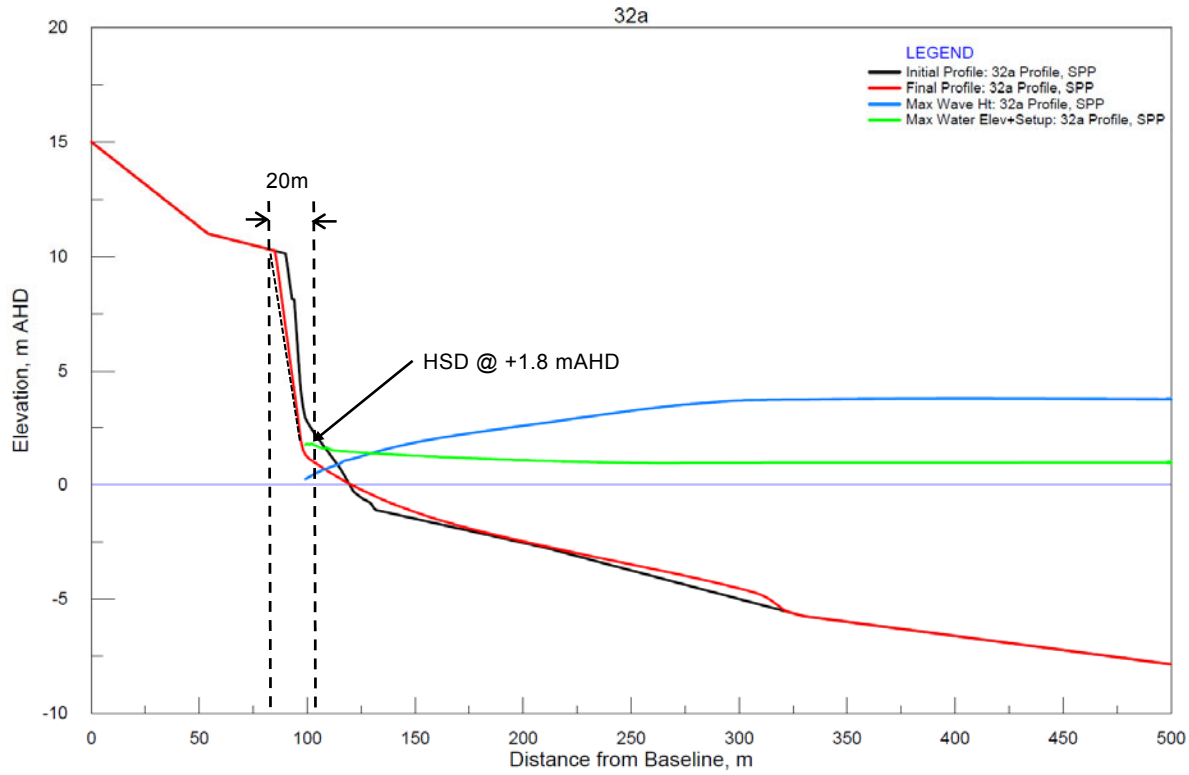

Figure 5.3 32a SBEACH model results

In this case, the HSD is +1.8 mAHD located approximately 4 m seaward of the coastal vegetation line. The modelled recession behind the HSD, including the 30° slope failure angle, is 20 m. Therefore, the S1 Erosion allowance for Tertiary Sediment Cell 32a is **20 m**.

5.2.2 S2 Erosion

A number of coastal vegetation lines were available for this stretch of coastline, as well as the 2014 rectified aerial photograph. The earliest coastal vegetation line available in this sediment cell is the 1969 line.

In addition to the available shoreline movement lines, MRA has access to a High Water Mark (HWM) survey from 1909 which was analysed as part of the North Two Rocks setback assessment (MRA 2015b). This HWM survey was included in the shoreline movement analysis as part of this study. This provides a methodology to analyse the shoreline movement over a 105 year period from 1909 to 2014. The survey sheets for the HWM Survey are contained in Appendix B.

It is understood that either the extent of debris from wave uprush or the vegetation line was used by surveyors of this time to depict the high water mark. For consistency with the other data obtained from the aerial imagery it is assumed that this survey represents the coastal vegetation line. However, if the high water mark survey was taken as the debris line, the surveyed line would be closer to the beach berm than the vegetation line. This would provide a more conservative depiction of the beach profile change over time due to the fact that the shoreline movement plan would show the shoreline to be further seaward than it actually was. This would essentially mean that any subsequent accretion of the shoreline would appear smaller than in reality, while any erosion would appear larger.

The positions of the coastal vegetation lines relative to 2014 were determined at 100 m Chainages along the coast. This is presented in Figure 5.4.

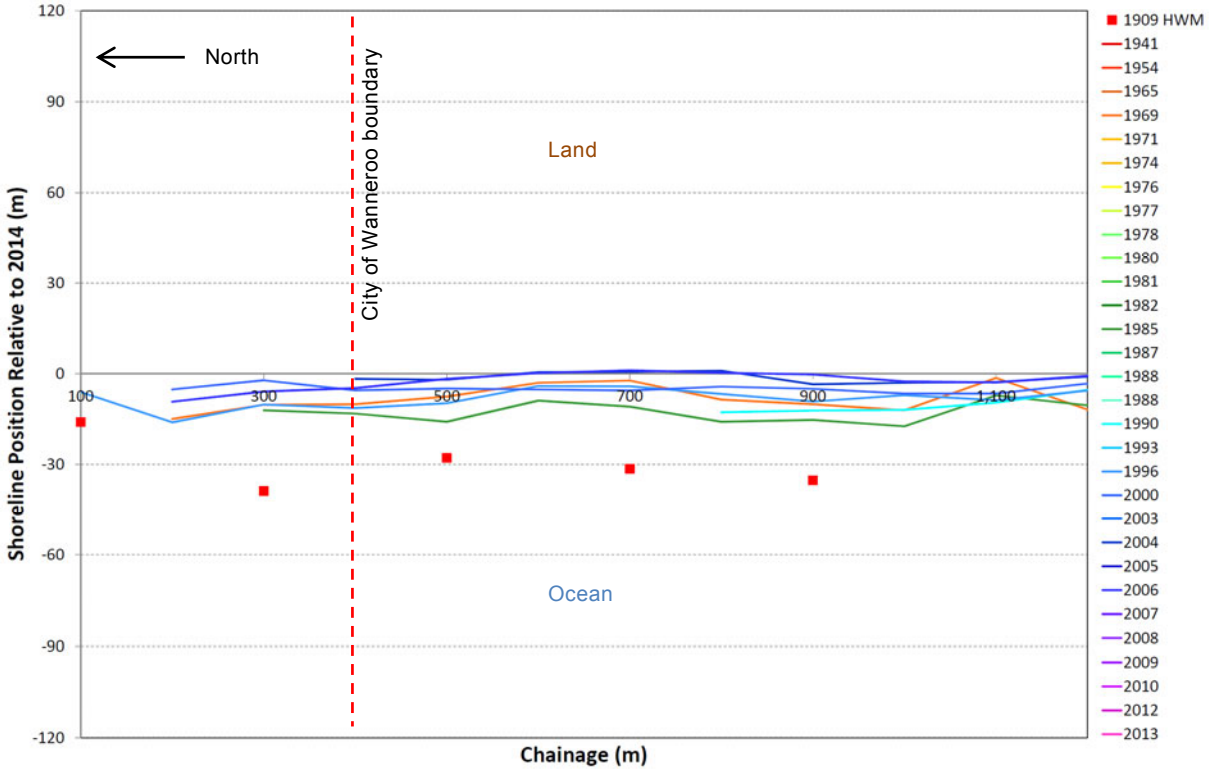

Figure 5.4 32a shoreline position relative to 2014

The annual shoreline movement rate was then calculated relative to 1969 and 1909, which is presented in Figure 5.5 on the next page.

Figure 5.5 shows the following.

- The shoreline has generally been eroding, with a maximum shoreline movement rate of around -0.35 m/yr since 1909.
- The rates over the longer term (since 1909) have typically been higher than the rates since 1969.

Based on the above information, an S2 Erosion allowance of **-0.35 m/yr** (shown in green) is considered appropriate to account for potential, future shoreline movements.

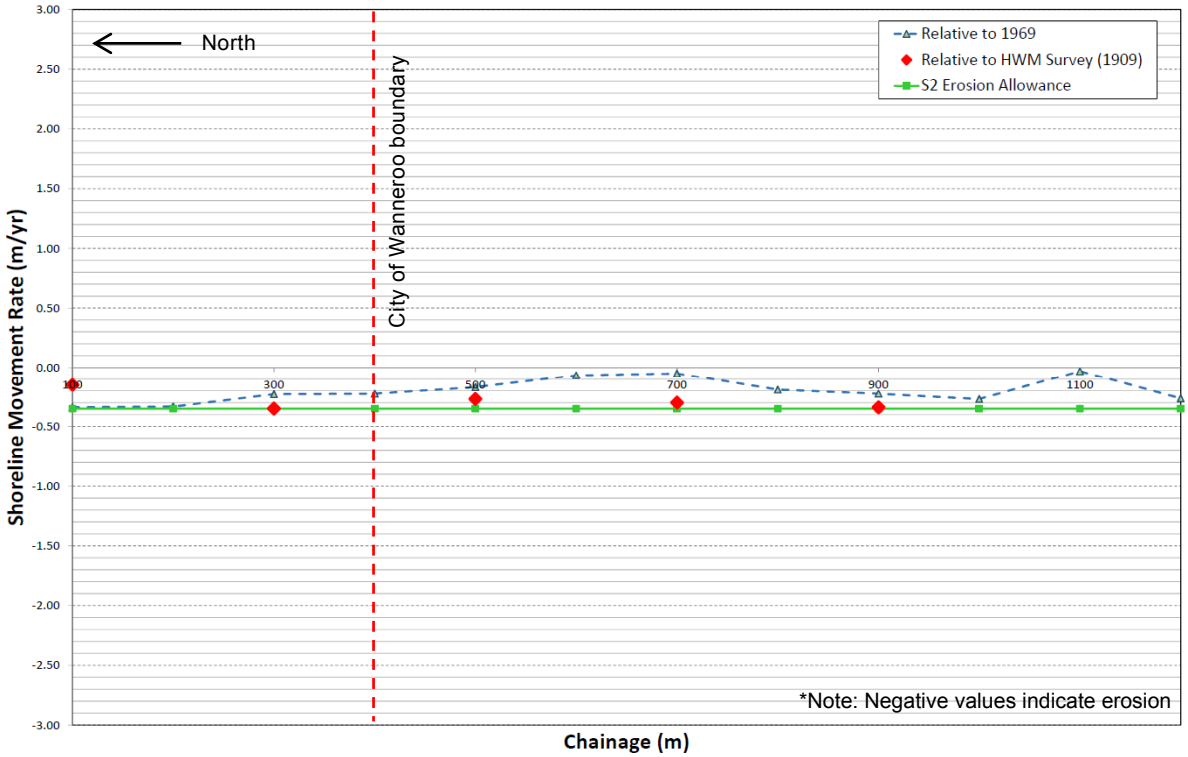

Figure 5.5 32a annual shoreline movement rate

Using a predicted shoreline movement rate of -0.35 m/yr, the appropriate S2 allowances for the range of planning timeframes are presented in Table 5.1.

Table 5.1 S2 Erosion allowances

Planning Timeframe	S2 Erosion Allowance (m)
Present day (2015)	0
2030	5
2050	12
2070	19
2090	26
2120	37

5.2.3 S3 Erosion

The S3 Erosion allowances for the range of planning timeframes were previously presented in Table 4.1.

5.2.4 Allowance for Erosion

The three erosion allowances are combined with a 0.2 m/yr allowance for uncertainty giving a total allowance for erosion. The allowances for erosion for the range of planning timeframes are presented in Table 5.2.

Table 5.2 Tertiary Sediment Cell 32a allowances for erosion

Chainages 0 to 1,200 m					
Planning Timeframe	S1 Erosion (m)	S2 Erosion (m)	S3 Erosion (m)	FOS (m)	**Allowance for Erosion[1] (m)**
Present day (2015)	20	0	0	0	**20**
2030	20	5	7	3	**35**
2050	20	12	20	7	**59**
2070	20	19	39	11	**89**
2090	20	26	62	15	**123**
2120	20	37	97	21	**175**

Notes: 1. Taken from a HSD approximately 4 m seaward of the coastal vegetation line.

The allowances for erosion were used to develop the coastal hazard mapping in Section 5.3.

5.3 Erosion Hazard Mapping

Using the work completed within Section 5.2, coastal hazard mapping has been completed to show the areas that could be vulnerable to coastal erosion over the designated timeframes. The maps are contained in Appendix C.

The mapping shows the vulnerability lines for present day (2015), 2030, 2050, 2070, 2090 and 2120. These vulnerability lines all include the allowance for acute storm erosion as required by SPP2.6. This means that for each timeframe the potential for a storm event with an annual encounter probability of 1%, or in other words a 100 year ARI event, has been included in the assessment of the vulnerable areas. This needs to be considered when reviewing the vulnerability lines in the context of assessing the potential future risk.

5.4 Sensitivity, Adaptive Capacity & Vulnerability to Erosion

The section of Tertiary Sediment Cell 32a within the City's boundaries is currently undeveloped, which means there are no significant manmade assets within the erosion exposure area. Additionally, no known Aboriginal Heritage Sites nor high vulnerability ecological systems exist within the erosion exposure area.

Given the lack of significant cultural, environmental or manmade assets within the erosion exposure area, the sensitivity and adaptive capacity are not relevant.

6. Tertiary Sediment Cell 31a Erosion Allowances

Tertiary Sediment Cell 31a extends approximately 5 km south from Mallee Reef salient to Wreck Point. Sediment Cell 31a commences at Chainage 1,300 m in the north and ends to the south of Two Rocks Marina at Chainage 6,200 m, as shown in Figure 6.1.

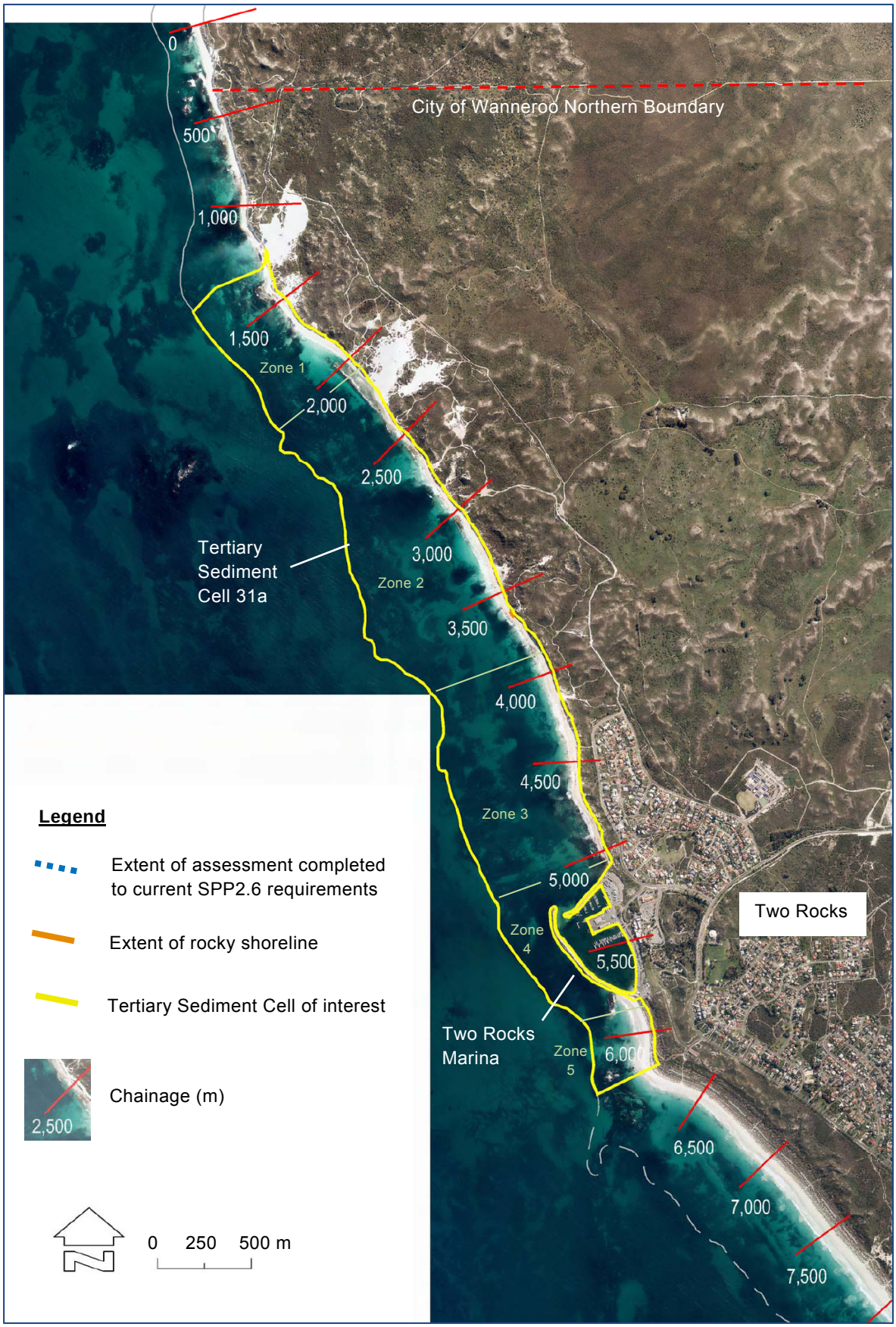

Figure 6.1 Tertiary Sediment Cell 31a location figure

6.1 Coastal Classification

Tertiary Sediment Cell 31a (Chainages 1,300 to 6,200 m) consists of sandy coastline interrupted by small patches of beachrock, with a continuous 500 m long section towards the northern end (Short 2006). The beaches receive waves averaging just over 1 m (Short 2006), which are likely to increase during stormy periods.

Two Rocks marina is located in the southern portion of Tertiary Sediment Cell 31a from Chainages 5,100 m to 5,800 m. Two Rocks marina was constructed in 1973 on what was formerly a continuous sandy shoreline. The construction of the marina is likely to have had an impact on the coastal processes within the sediment cell, which will be discussed in the following sections.

Through preliminary analysis of historical shoreline movements, MRA identified five coastal zones within Sediment Cell 31a exhibiting different long term shoreline movements. These coastal zones are outlined below.

6.1.1 Zone 1

Zone 1 (Chainages 1,300 m to 2,000 m) encompasses a coastal point, where the coastline changes direction. This area has experienced more erosion than the adjacent shoreline. Figure 6.2 is a photograph of the beach in Zone 1 around Chainage 1,900 m. An erosion scarp is visible at the rear of the beach.

Figure 6.2 Zone 1 beach photograph at Chainage 1,900 m (MRA)

6.1.2 Zone 2

Zone 2 (Chainages 2,100 m to 3,800 m) consists of a relatively straight section of shoreline that has remained relatively stable over the longer term. Figure 6.3 is a photograph of the beach in Zone 2 around Chainage 2,800 m. An accreting foredune can be seen in this section of coastline.

Figure 6.3 Zone 2 beach photograph at Chainage 2,800 m (MRA)

Within Sediment Cell 31a, a short stretch of rocky coast was identified by DPI for MRA (2005) at Chainage 3,700 m. This rock headland is less than 50 m long and would not be expected to prevent erosion behind the rock.

6.1.3 Zone 3

Zone 3 (Chainages 3,900 m to 5,000 m) on the northern side of Two Rocks marina has a significant erosion scarp at the rear of the beach. Figure 6.4 is a photograph of the beach in Zone 3 around Chainage 4,700 m looking south.

Figure 6.4 Zone 3 beach photograph at Chainage 4,700 m (MRA)

A geotechnical investigation was commissioned by the DoT which aimed to identify rock along and in front of Sovereign Drive, Two Rocks (Aurecon 2014). The study extended for over 1 km from Chainage 4,050 m to Chainage 5,050 m. A combination of Cone Penetrometer Tests (CPT) and geophysical tests were used to identify the level of the rock. The following information can be gained from the results.

- Rock exists in the dune area but the levels and strength are highly variable throughout the study area.
- Geophysical results seemed to show reasonable agreement with the CPT results. However, there are a number of locations where the geophysical showed moderate strength rock, while the CPT probe did not reach refusal, perhaps suggesting that the geophysical testing over estimates the strength of the rock.
- Competent rock (with a minimum interpreted rock strength of moderate) was not found above +3.5 mAHD at Dune Transect 4 perpendicular to Sovereign Drive. Therefore, a continuous barrier of competent rock is not believed to be present fronting Sovereign Drive.
- North of CPT 02 (Chainage 5,000 m), refusal was reached below +3.5 mAHD for all CPTs.

Given the above results, it is not clear that continuous, competent rock is present along this section of coast at appropriate levels. Therefore, this section of coast will be classified as sandy.

6.1.4 Zone 4

Zone 4 (Chainages 5,100 to 5,800 m) is Two Rocks marina. The CHRMAP guidelines and the SPP2.6 do not provide specific guidance on appropriate erosion allowances for development behind marina breakwaters or behind internal revetments. The CHRMAP guidelines outlines the following.

Consideration of these coastal processes should be based on the coastal type and each of the factors listed for that coastal type and assessment methodology as outlined in Schedule One of SPP2.6.

Referring to Section 4.3 of Schedule One of the SPP2.6.

Development that benefits from protection from coastal hazards by formal coastal protection works should be determined on a case by case basis with the allowance for coastal processes taking into account the works in question.

In this case, development inside the marina will be protected from the coastal erosion processes and therefore erosion allowances do not need to be calculated. Nevertheless, on-going maintenance of the marina breakwaters and edge walls will be required to prevent future shoreline erosion.

6.1.5 Zone 5

Zone 5 (Chainages 5,900 to 6,200 m) on the southern side of Two Rocks marina has experienced significant accretion, particularly since the construction of the marina in 1973. Figure 6.5 is a photograph of the beach in Zone 5 around Chainage 5,800 m looking south. An accreting foredune and a very wide beach can be seen in this section of coastline.

Figure 6.5 Zone 5 beach photograph at Chainage 5,800 m (MRA)

Even though Zone 5 is located within Tertiary Sediment Cell 31a, it is much more closely linked to Tertiary Sediment Cell 30b directly to the south than to Zone 4. This is due to the Two Rocks marina trapping longshore sediment transport through this area. Therefore, the results of Zone 5 will be discussed as part of Tertiary Sediment Cell 30b in Section 7.

Excluding the Two Rocks marina, Tertiary Sediment Cell 31a will be treated as a sandy coastline in the calculation of erosion allowances.

6.2 Allowances for Erosion

6.2.1 S1 Erosion

SBEACH profiles were developed for each of the zones identified in the previous section as required. The results are outlined in the following sections.

Zone 1

An SBEACH profile was created at Chainage 1,900 m from a combination of on-site survey measurements and nautical charts. SWAN wave model outputs from an offshore location were input into the SBEACH model as were the water levels recorded during the July 1996 storm. The peak significant wave height (Hs) during the passage of the storm was approximately 3.0 m in around 7 m of water. A D_{50} sediment size of 0.5 mm was input into the model using results from the North Two Rocks setback assessment (MRA 2015b).

The results of the SBEACH modelling are presented in Figure 6.6.

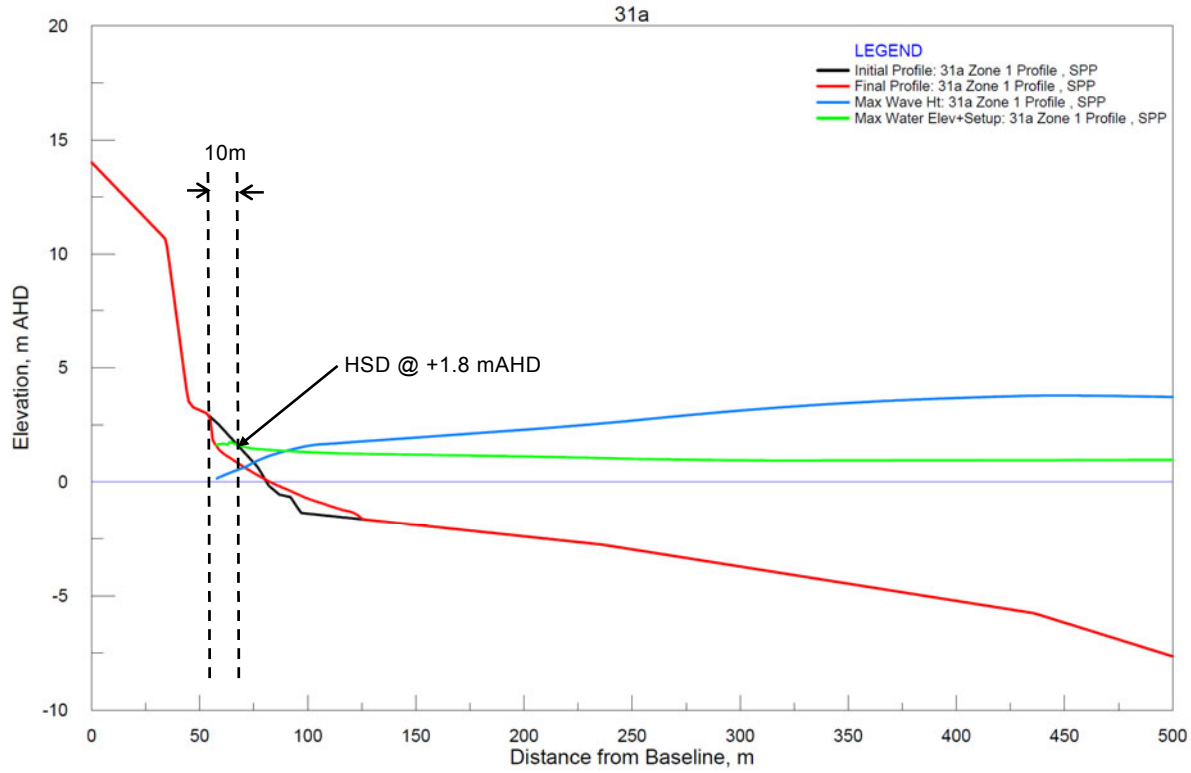

Figure 6.6 31a Zone 1 SBEACH model results

In this case, the HSD is +1.8 mAHD located approximately 16 m seaward of the coastal vegetation line. The modelled recession behind the HSD is 10 m. Therefore, the S1 Erosion allowance for Zone 1 of Tertiary Sediment Cell 31a is **10 m**.

Zone 2

An SBEACH profile was created at Chainage 2,800 m from a combination of on-site survey measurements and nautical charts. SWAN wave model outputs from an offshore location were input into the SBEACH model as were the water levels recorded during the July 1996 storm. The peak significant wave height (Hs) during the passage of the storm was approximately 2.7 m in around 7 m of water. A D_{50} sediment size of 0.49 mm was input into the model using results from the North Two Rocks setback assessment (MRA 2015b).

The results of the SBEACH modelling are presented in Figure 6.7.

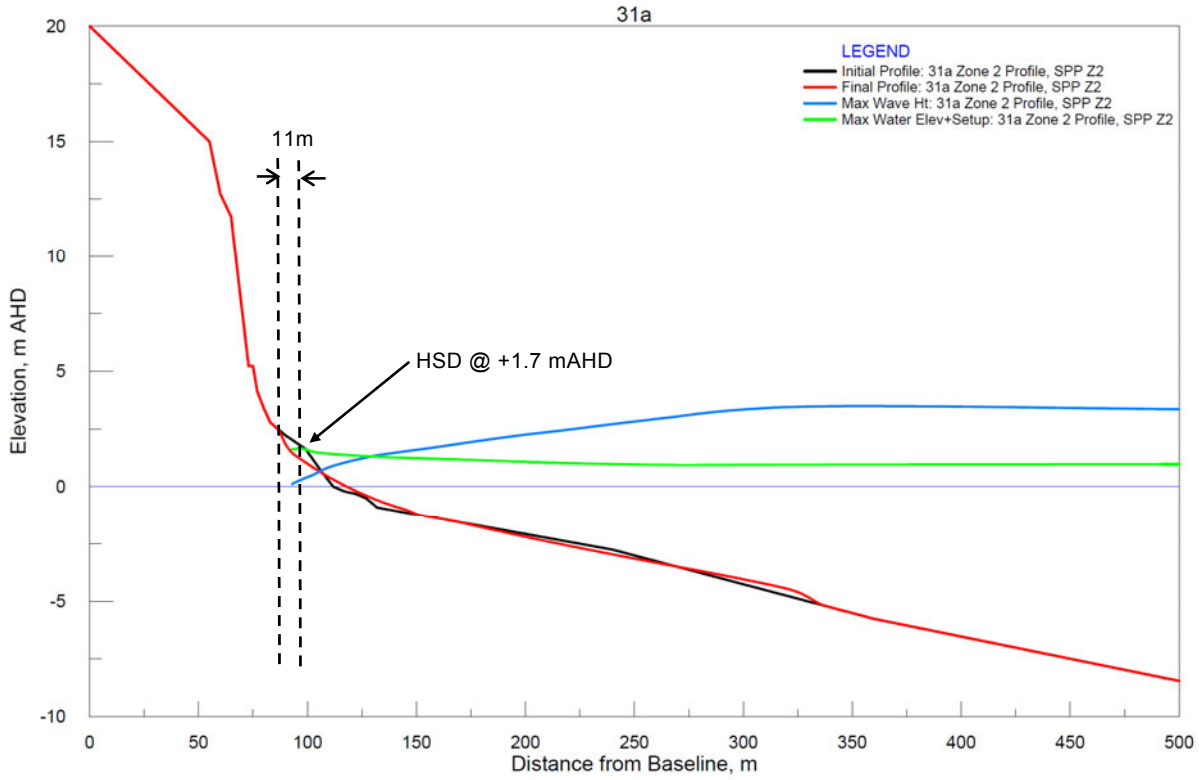

Figure 6.7 31a Zone 2 SBEACH model results

In this case, the HSD is +1.7 mAHD located approximately 16 m seaward of the coastal vegetation line. The modelled recession behind the HSD is 11 m. Therefore, the S1 Erosion allowance for Zone 2 of Tertiary Sediment Cell 31a is **11 m**.

Zone 3

An SBEACH profile was created at Chainage 4,700 m from a combination of on-site survey measurements and nautical charts. SWAN wave model outputs from an offshore location were input into the SBEACH model as were the water levels recorded during the July 1996 storm. The peak significant wave height (Hs) during the passage of the storm was approximately 3.5 m in around 10 m of water. A D_{50} sediment size of 0.49 mm was input into the model using results from the Two Rocks Coastal Assessment (MRA 2015c).

The results of the SBEACH modelling are presented in Figure 6.8.

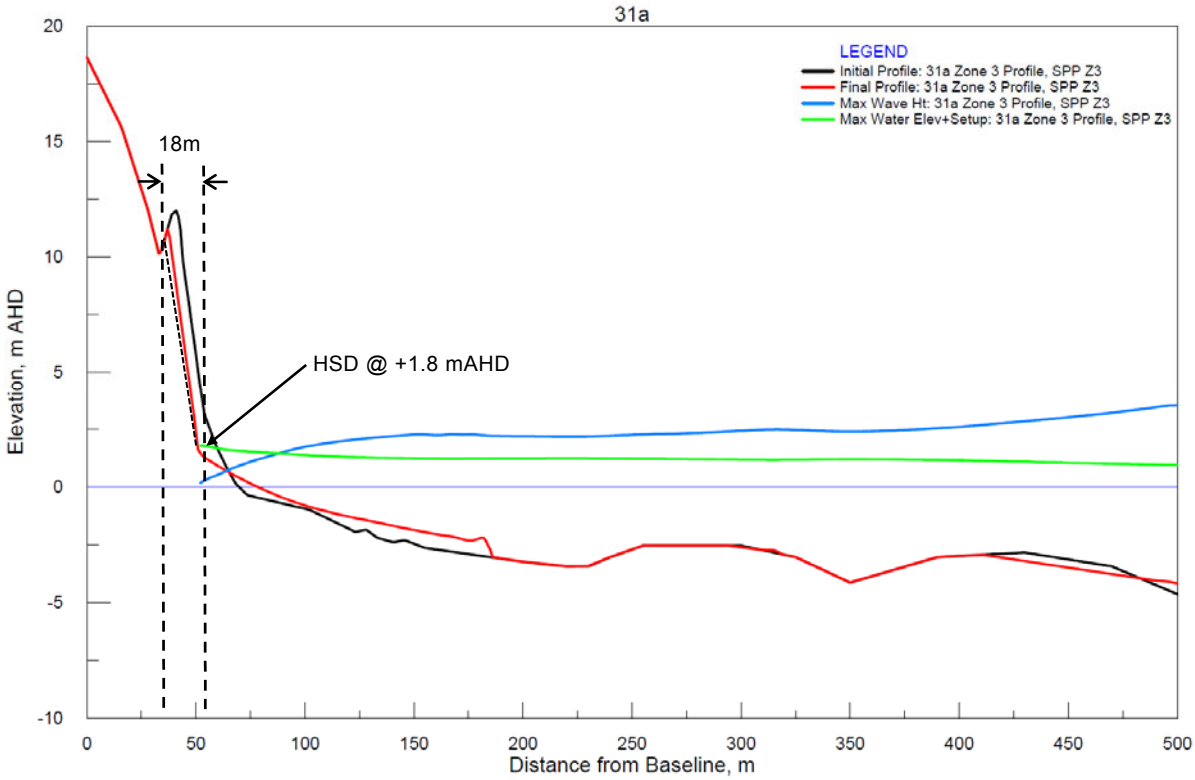

Figure 6.8 31a Zone 3 SBEACH model results

In this case, the HSD is +1.8 mAHD located approximately 3 m landward of the coastal vegetation line. The modelled recession behind the HSD, including the 30° slope failure angle, is 18 m. Therefore, the S1 Erosion allowance for Zone 3 of Tertiary Sediment Cell 31a is **18 m**.

Zone 4

The assessment of Zone 4 (Two Rocks Marina) to the requirements of SPP2.6 was previously discussed in Section 6.1.4.

Zone 5

Zone 5 is closely related to Zone 1 of Tertiary Sediment Cell 30b to the south through sediment transport pathways. Therefore, the S1 allowance for Zone 5 will be determined in assessment of Tertiary Sediment Cell 30b Zone 1 (Section 7.2.1).

6.2.2 S2 Erosion

A number of coastal vegetation lines were available for this stretch of coastline. This included the 2014 vegetation line and the 1909 HWM survey. This HWM survey extends to the northern side of Two Rocks marina and allows the shoreline movement in this area to be considered over a 105 year period from 1909 to 2014. The survey sheets for the HWM Survey are contained in Appendix B.

The positions of the coastal vegetation lines relative to 2014 were determined at 100 m Chainages along the coast. This is presented in Figure 6.9.

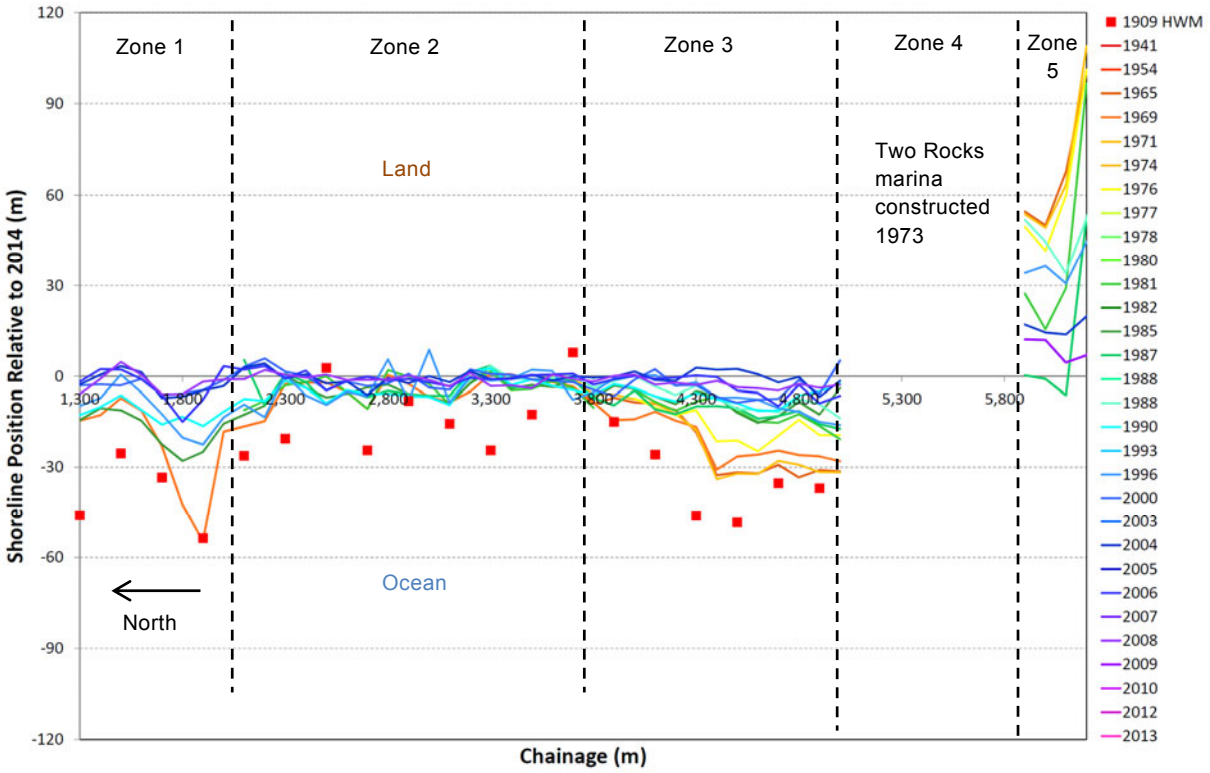

Figure 6.9 31a shoreline position relative to 2014

The Two Rocks marina was constructed in 1973. This is likely to have had a significant impact on the coastal processes adjacent to the marina. To analyse the magnitude of the impact, the annual shoreline movement rate to 2014 was calculated using the 1909 HWM survey and the 1981 vegetation line. The 1981 vegetation line is the first line that covers north and south of the marina since its construction. This provides an indication of the longer term shoreline movement rate and the shoreline movement rate since the marina was constructed. These results are presented in Figure 6.10.

Figure 6.10 shows the following general trends.

- All zones north of Two Rocks marina (1 to 3) have eroded, while Zone 5 south of Two Rocks marina has accreted significantly.
- The rates over the long term since 1909 are generally similar to those since 1981. However, the erosion rates from Chainages 4,700 m to 5,000 m immediately north of Two Rocks marina are much higher since 1981 than over the longer term (since 1909). Therefore, the shoreline movement rate adjacent to the marina has increased since the marina was constructed.

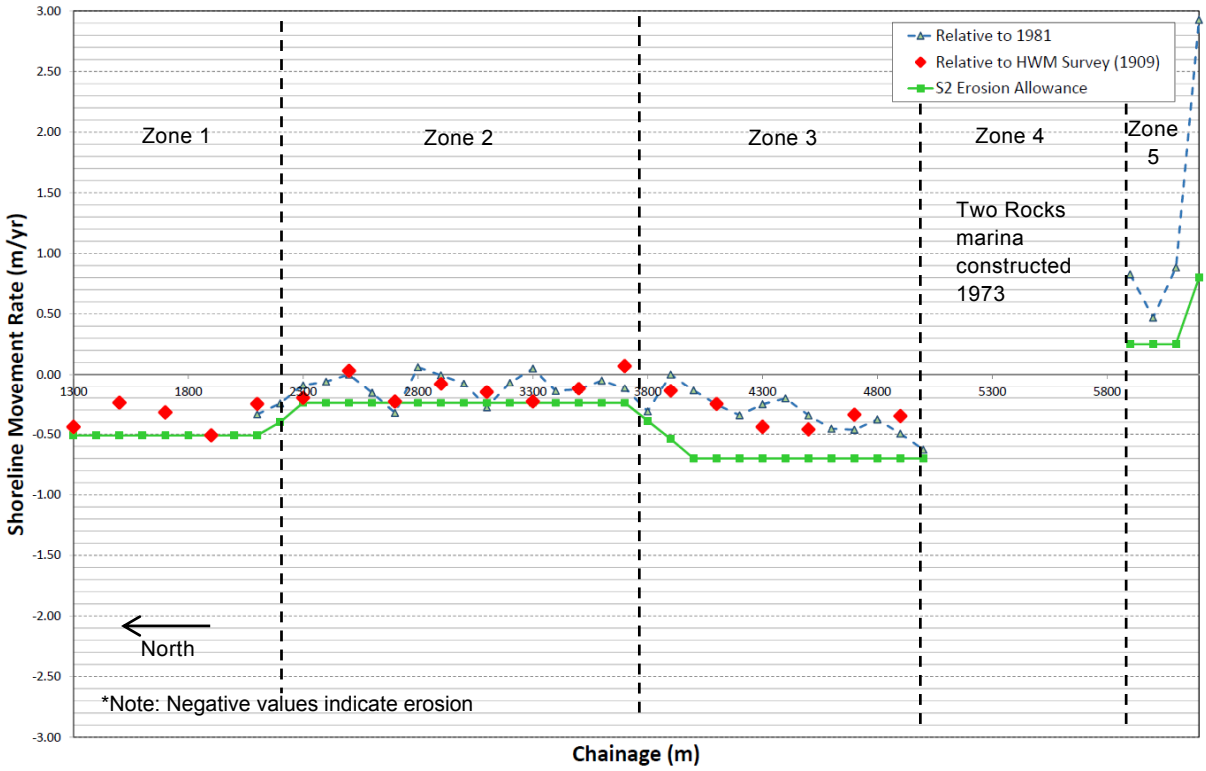

Figure 6.10 31a annual shoreline movement rate

The shoreline movements are discussed in further detail in the following sections.

Zone 1

The largest long term shoreline movement rate in Zone 1 was -0.51 m/yr at Chainage 1,900 m and is considered appropriate to account for potential, future shoreline movements in this zone. Therefore, an S2 Erosion allowance of **-0.51 m/yr** (shown in green) is recommended for Zone 1.

Zone 2

The largest long term shoreline movement rate in Zone 2 was -0.24 m/yr at Chainages 2,700 m and 3,300 m. This rate is considered appropriate to account for potential, future shoreline movements in Zone 2. Therefore, an S2 Erosion allowance of **-0.24 m/yr** (shown in green) is recommended for Zone 2.

Zone 3

The erosion rate immediately north of Two Rocks marina has increased since the marina was constructed. Shoreline movement rates from Chainages 4,700 m to 5,000 m are much higher since 1981 than the longer term since 1909. Therefore, the shoreline movement rates calculated between 1981 and 2014 will be used in Zone 3.

The largest long term shoreline movement rate in Zone 3 was -0.63 m/yr at Chainage 5,000 m immediately north of the marina. Given the shorter analysis period, an S2 Erosion allowance of **-0.7 m/yr** (shown in green) is considered appropriate to account for potential, future shoreline movements in Zone 3.

Zone 4

The assessment of Zone 4 (Two Rocks Marina) to the requirements of SPP2.6 was previously discussed in Section 6.1.4.

Zone 5

As outlined previously, Zone 5 is much more closely linked through sediment transport pathways to Tertiary Sediment Cell 30b directly to the south than to Zone 3. This is due to the influence of the Two Rocks marina on longshore transport. Therefore, the results of Zone 5 will be discussed in Section 7 which investigates Tertiary Sediment Cell 30b.

6.2.3 S3 Erosion

The S3 Erosion allowances for the range of planning timeframes were previously presented in Table 4.1.

6.2.4 Allowance for Erosion

The three erosion allowances are combined with a 0.2 m/yr allowance for uncertainty giving a total allowance for erosion. These allowances are presented in Appendix D for the range of planning timeframes.

6.3 Erosion Hazard Mapping

Using the work completed within Section 6.2, coastal hazard mapping has been completed to show the areas that could be vulnerable to coastal erosion over the designated timeframes. The maps are contained in Appendix D.

6.4 Sensitivity, Adaptive Capacity & Vulnerability to Erosion

The northern half of Tertiary Sediment Cell 31a is currently undeveloped. South of Chainage 4,300 m, the erosion hazard mapping shows that Sovereign Drive and a number of residential properties may be at risk of coastal erosion in approximately 35 to 50 years if erosion trends continue and management measures are not implemented. South of Two Rocks marina in Zone 5, beach access tracks may be at risk of erosion in the coming 100 years. These manmade assets have very little adaptive capacity to coastal erosion and are therefore considered vulnerable.

The Bush Forever Site 397 extends along the majority of the shoreline in Tertiary Sediment Cell 31a. Large amounts of this ecological system may be at risk of erosion over the coming century. The erosion hazard mapping also shows that one of the Priority Ecological Communities may be at risk of erosion. Approximately 25% of this community may be threatened by erosion. These ecological systems are considered to have limited adaptive capacity and are therefore considered vulnerable to erosion.

No known Aboriginal Heritage Sites exist within this erosion exposure area.

7. Tertiary Sediment Cell 30b Erosion Allowances

Tertiary Sediment Cell 30b extends approximately 4 km south from Wreck Point to Yanchep Headland North. Sediment Cell 30b commences at Chainage 6,300 m in the north and ends to the south at Chainage 10,200 m, as shown in Figure 7.1.

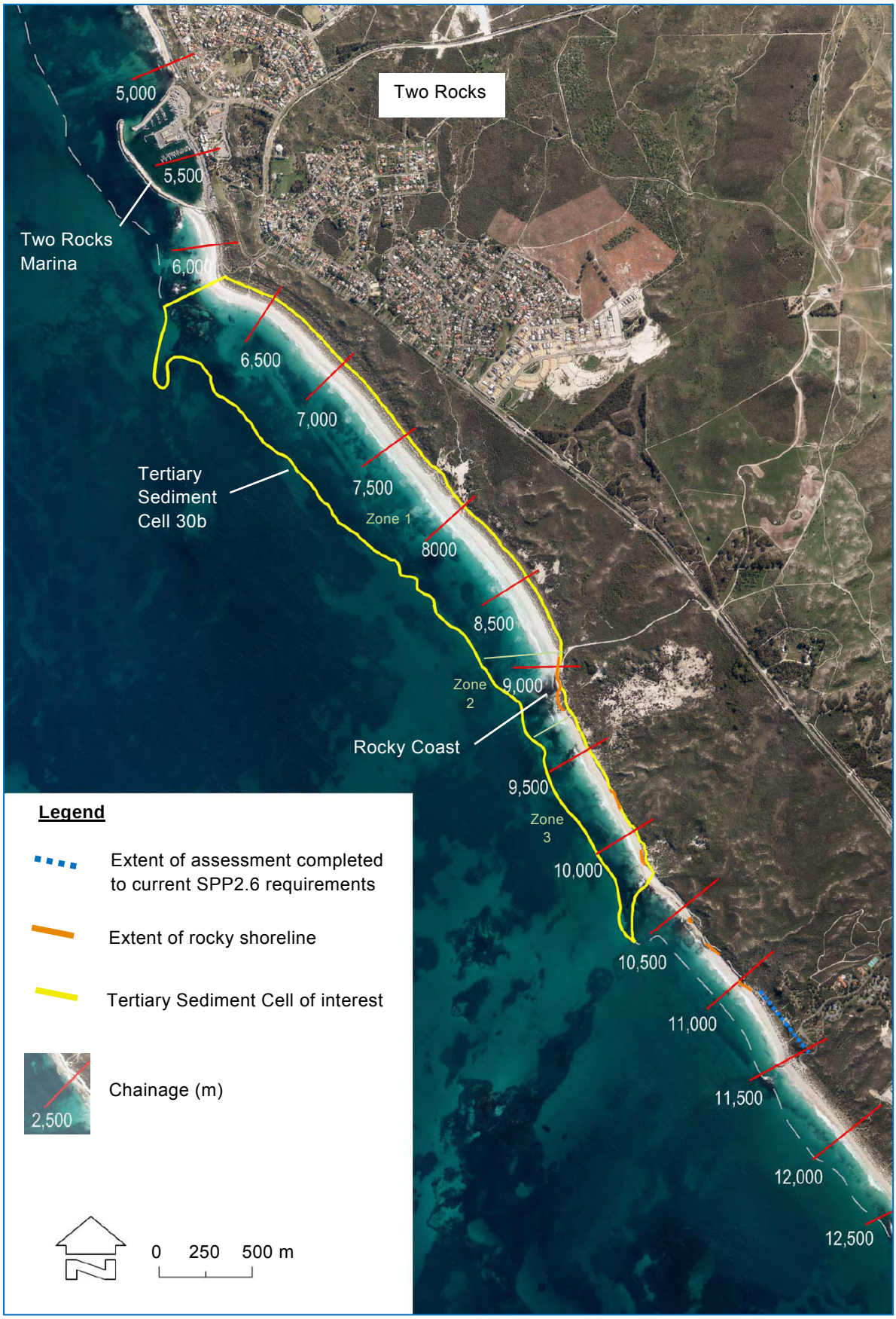

Figure 7.1 Tertiary Sediment Cell 30b location figure

7.1 Coastal Classification

Tertiary Sediment Cell 30b (Chainages 6,300 to 10,200 m) consists of sandy coastline interrupted by a small reef-attached foreland in its southern third (Short 2006). The beaches receive waves averaging just over 1 m (Short 2006), which are likely to increase during stormy periods.

Through preliminary analysis of historical shoreline movements, MRA identified three coastal zones within Sediment Cell 30b exhibiting different long term shoreline movements. These coastal zones are outlined below.

7.1.1 Zone 1

Zone 1 (Chainages 6,300 m to 8,900 m) is tied to a calcerenite reef capped by a sea stack at its northern end. This is approximately 300 m south of the Two Rocks marina. This zone consists of a wide beach with a low, accreting foredune as shown in Figure 7.2. This is similar to the beach observed in Zone 5 of Tertiary Sediment Cell 31a.

Figure 7.2 Zone 1 beach photograph Chainage 8,900 m (MRA)

The results of Zone 5 of Tertiary Sediment Cell 31a will be discussed when investigating this zone.

7.1.2 Zone 2

Zone 2 (Chainages 9,000 m to 9,200 m) consists of a limestone headland and was classified as rocky coastline by Department for Planning and Infrastructure (DPI) as part of the Northern Perth Metropolitan study (MRA 2005). This area accommodates a small car-park built to service the surf break called 'The Spot'.

7.1.3 Zone 3

Zone 3 (Chainages 9,300 m to 10,200 m) is a relatively straight and short section of beach with intermittent rock on the beach and in the dunes. This is shown in Figure 7.3. Two short sections of rock, typically less than 100 m in length, were identified by DPI through this zone.

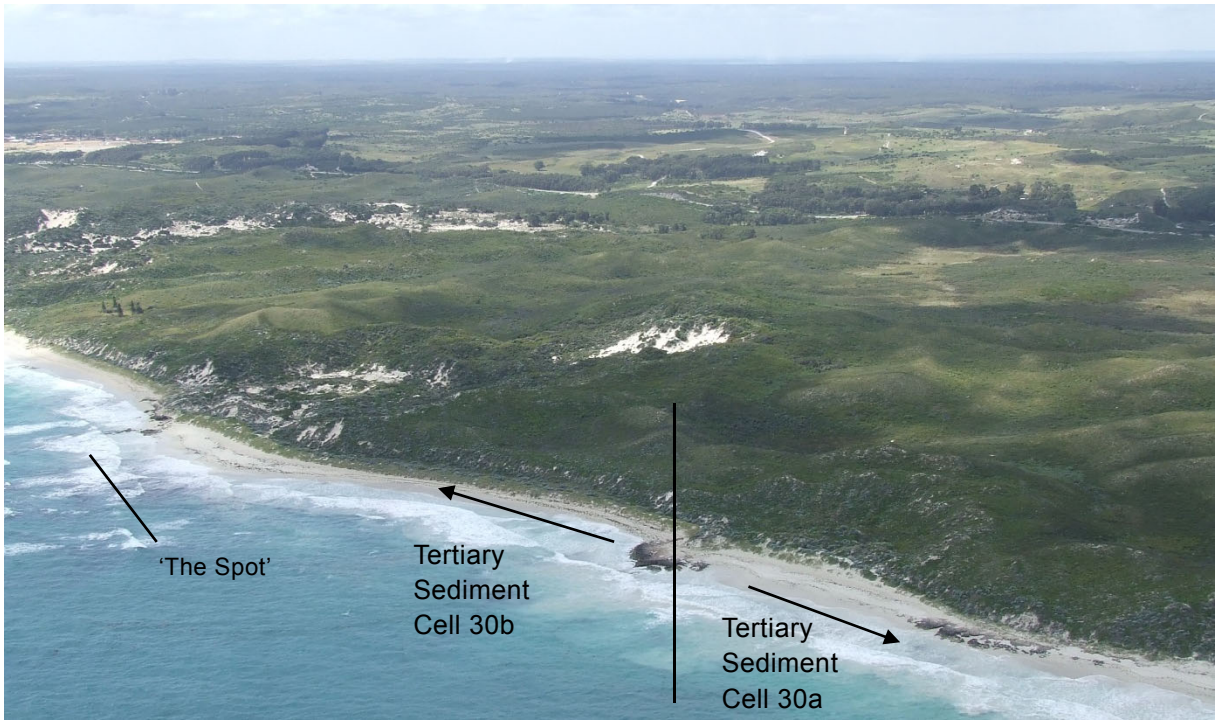

Figure 7.3 Zone 3 aerial photograph (WACoast)

Excluding the rocky coastline at Zone 2, Tertiary Sediment Cell 30b will be treated as a sandy coastline in the calculation of erosion allowances.

7.2 Allowances for Erosion

7.2.1 S1 Erosion

SBEACH profiles were developed for each of the zones identified in the previous section. The results are outlined in the following sections.

Zone 1 & Zone 5 from 31a

An SBEACH profile was created at Chainage 7,500 m using the 2009 LiDAR data (Fugro 2009). This profile is expected to be similar to the nearshore and beach profile in Tertiary Sediment Cell 31a Zone 5. Therefore, the S1 Storm Erosion results from Zone 1 will be applied to Tertiary Sediment Cell 31a Zone 5.

SWAN wave model outputs from an offshore location were input into the SBEACH model as were the water levels recorded during the July 1996 storm. The peak significant wave height (Hs) during the passage of the storm was approximately 3.0 m in around 9 m of water. A D_{50} sediment size of 0.39 mm was input into the model using results from MRA (2005).

The results of the SBEACH modelling are presented in Figure 7.4.

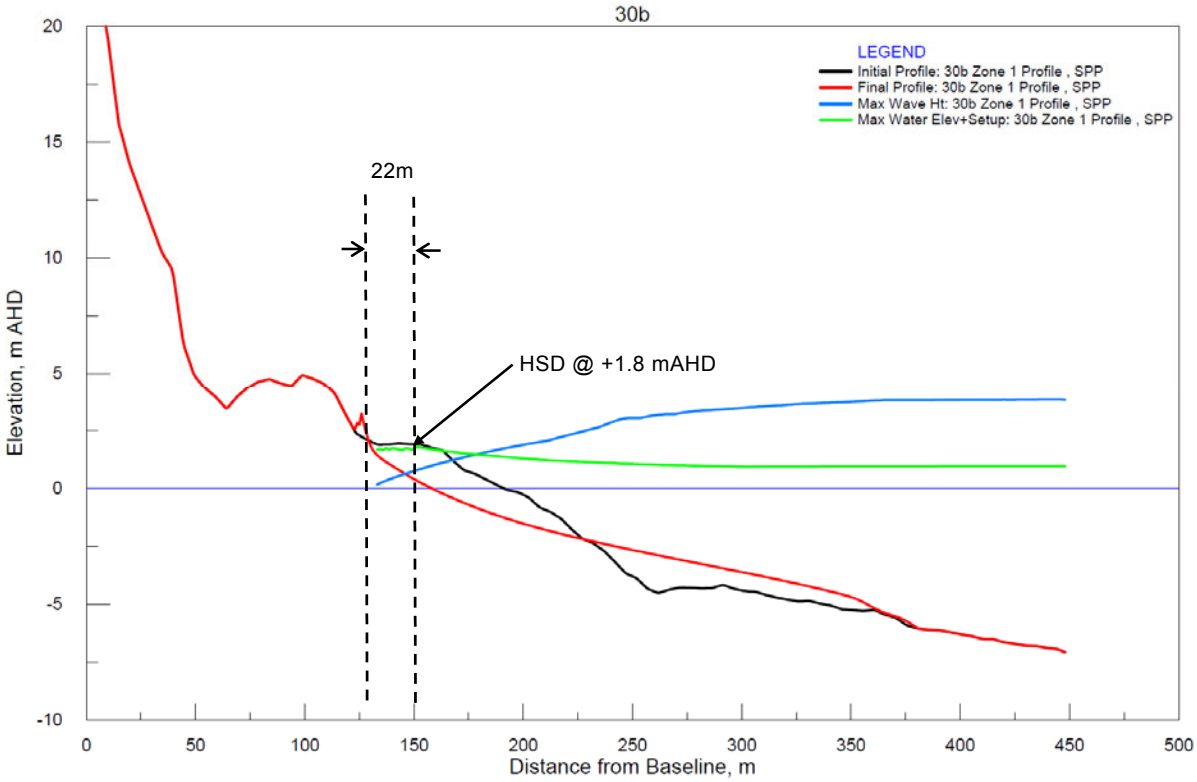

Figure 7.4 30b Zone 1 SBEACH model results

In this case, the HSD is +1.8 mAHD located approximately at the coastal vegetation line. The modelled recession behind the HSD, including the 30° slope failure angle, is 22 m. Therefore, the S1 Erosion allowance for Zone 1 of Tertiary Sediment Cell 30b is **22 m**.

Zone 2

Zone 2 is classified as rocky coastline, which does not require determination of an S1 allowance under SPP2.6.

Zone 3

An SBEACH profile was created at Chainage 10,100 m using the 2009 LiDAR data (Fugro 2009). SWAN wave model outputs from an offshore location were input into the SBEACH model as were the water levels recorded during the July 1996 storm. The peak significant wave height (Hs) during the passage of the storm was approximately 3.3 m in around 8 m of water. A D_{50} sediment size of 0.25 mm was input into the model using results from MRA (2005).

The results of the SBEACH modelling are presented in Figure 7.5.

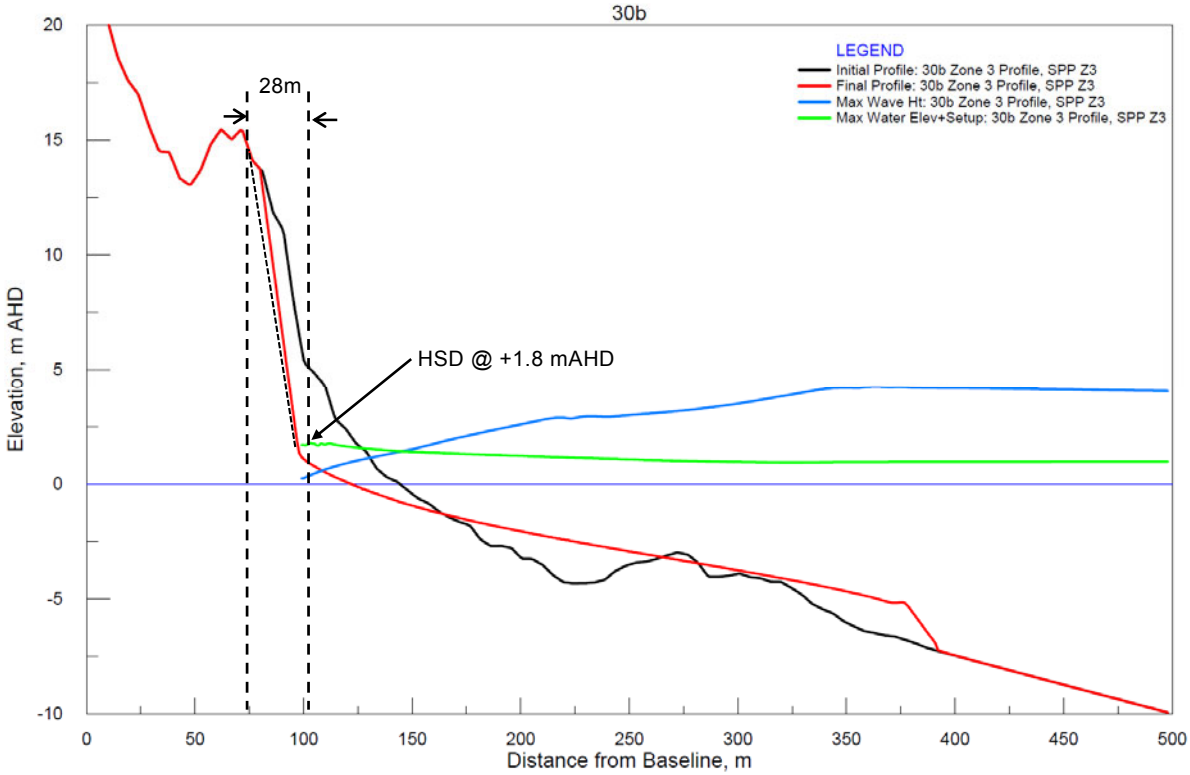

Figure 7.5 30b Zone 3 SBEACH model results

In this case, the HSD is +1.8 mAHD located approximately 11 m landward of the coastal vegetation line. The modelled recession behind the HSD, including the 30° slope failure angle, is 28 m. Therefore, the S1 Erosion allowance for Zone 3 of Tertiary Sediment Cell 30b is **28 m**.

7.2.2 S2 Erosion

A number of coastal vegetation lines were available for this stretch of coastline, including the 2014 coastal vegetation line. The positions of the coastal vegetation lines relative to 2014 were determined at 100 m Chainages along the coast. This is presented in Figure 7.6.

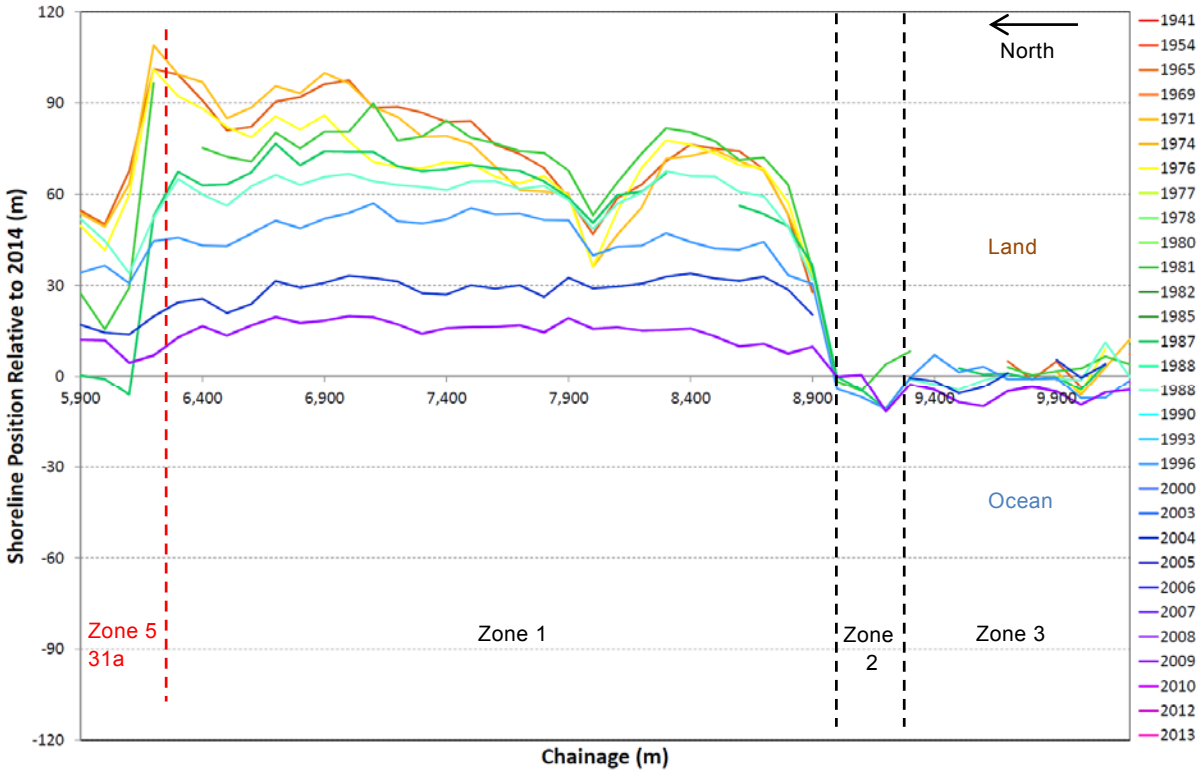

Figure 7.6 30b shoreline position relative to 2014

The Two Rocks marina was constructed in 1973. This is likely to have had a significant impact on the coastal processes adjacent to the marina. To analyse the magnitude of the impact, the annual shoreline movement rate to 2014 was calculated using the 1981 vegetation line and the longer term 1965 vegetation line. This provides an indication of the longer term shoreline movement rate and the shoreline movement rate since the marina was constructed. These results are presented in Figure 7.7.

Figure 7.7 shows the following general trends.

- The beach from Chainage 5,900 m to 8,900 m has been accreting at a rate of around 2 m per year since the marina was constructed.
- Zone 3 has remained relatively stable over the longer term (since 1965) and since the marina was constructed.

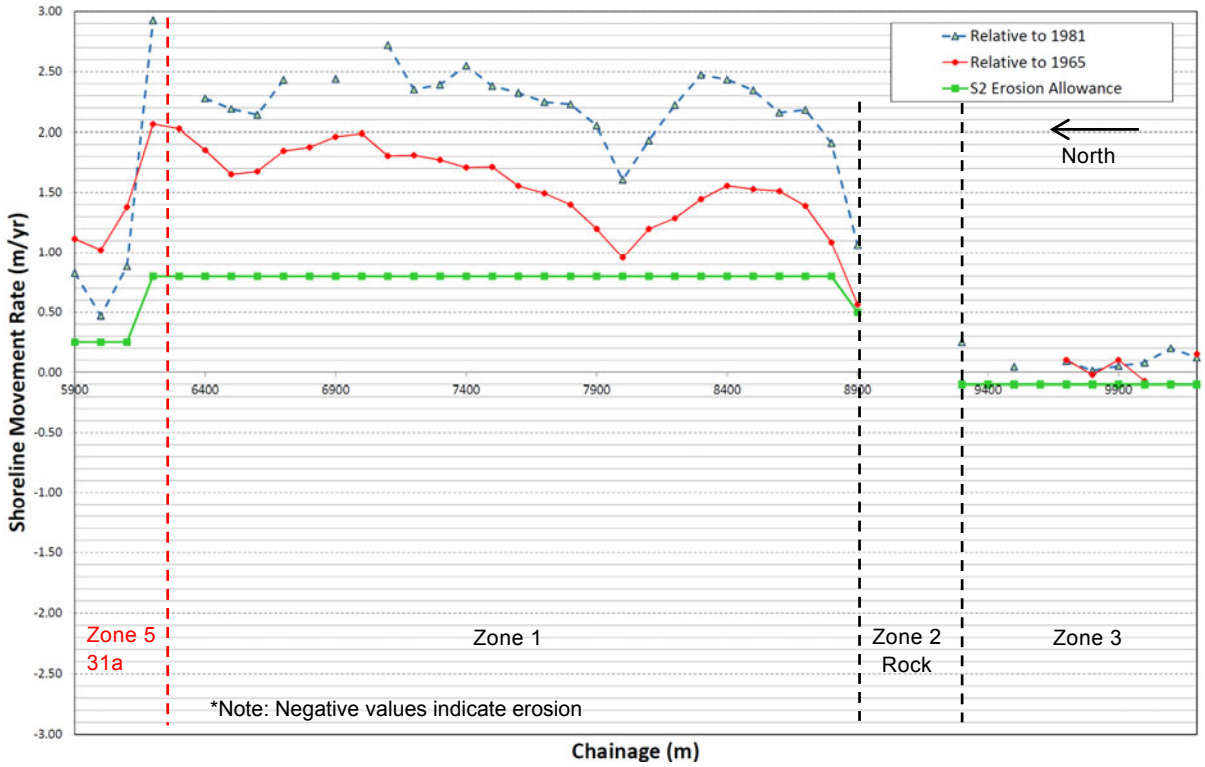

Figure 7.7 30b annual shoreline movement rate

The shoreline movements are discussed in further detail in the following sections.

Zone 1 & Zone 5 from 31a

Chainages 5,900 m to 6,100 m directly south of Two Rocks marina have accreted at a lower rate than the shoreline further to the south (Chainages 6,200 to 8,800 m). The accretion rate is in the order of 0.5 m/yr. This rate of accretion is likely to continue for the next fifty years. Therefore, under the SPP2.6 the S2 allowance for historical shoreline movement can be taken as minus 50 times the historic annual rate of erosion. This is a negative S2 Erosion allowance of **0.25 m/yr**.

The lowest annual accretion rate between Chainages 6,200 m and 8,800 m is 1.6 m/yr (Chainage 8,000 m). This shoreline has the potential to continue to accrete at this rate over the coming 50 years. Therefore, a negative S2 Erosion allowance of **0.8 m/yr** is considered appropriate for this stretch of coast.

Zone 2

The rocky headland between Chainages 8,900 m and 9,200 m will be treated as a rocky coastline under the SPP2.6.

Zone 3

Zone 3 has remained relatively stable over the long term and has generally accreted. Chainage 9,100 m has undergone net erosion of -0.1 m/yr since 1965. Therefore, an S2 Erosion allowance of **-0.1 m/yr** will be used for this zone.

7.2.3 S3 Erosion

The S3 Erosion allowances for the range of planning timeframes were previously presented in Table 4.1.

7.2.4 Allowance for Erosion

The three erosion allowances are combined with a 0.2 m/yr allowance for uncertainty giving a total allowance for erosion. These allowances are presented in Appendix D for the range of planning timeframes.

7.3 Erosion Hazard Mapping

Using the work completed within Section 7.2, coastal hazard mapping has been completed to show the areas that could be vulnerable to coastal erosion over the designated timeframes. The maps are contained in Appendix C.

7.4 Sensitivity, Adaptive Capacity & Vulnerability to Erosion

Tertiary Sediment Cell 30b is mostly undeveloped. The beach access road at the surf break 'The Spot' may be at risk of coastal erosion in the coming 30 to 40 years. The erosion in this area will depend significantly on the extent of rock behind the coastal headland. The car-park behind the rocky coastline at 'The Spot' may currently be influenced by wave overtopping. The impact of this overtopping on the car-park is likely to be minimal, so this infrastructure is not considered vulnerable to coastal erosion.

The Bush Forever Site 397 extends along the majority of the shoreline in Tertiary Sediment Cell 30b. North of 'The Spot', only small portions of Bush Forever Site 397 may be threatened by erosion over the coming century, while south of 'The Spot', all of Bush Forever Site 397 is at risk of erosion in the coming century. This environmental system is considered vulnerable to erosion, as it is limited to the foreshore reserve areas. Although the species contained within the ecological system may have a capacity to adapt (ie grow further from the coast), the system as a whole is vulnerable to erosion due to space constraints from possible, future coastal development.

No known Aboriginal Heritage Sites exist within the erosion exposure area.

8. Tertiary Sediment Cell 30a Erosion Allowances

Tertiary Sediment Cell 30a extends approximately 4 km south from Yanchep Headland North to Yanchep. Sediment Cell 30a commences at Chainage 10,300 m in the north and ends to the south at Chainage 14,400 m, as shown in Figure 8.1.

Two sections of coastline have already been assessed to the requirements of the current SPP2.6 (WAPC 2013) within this sediment cell. These are shown as blue dashed lines in Figure 8.1 and are listed below.

- Yanchep North setback assessment (MRA 2014a).
- Yanchep Surf Life Saving Club CHRMAP (Cardno 2014).

The results from these two studies will be used in this CHRMAP for consistency.

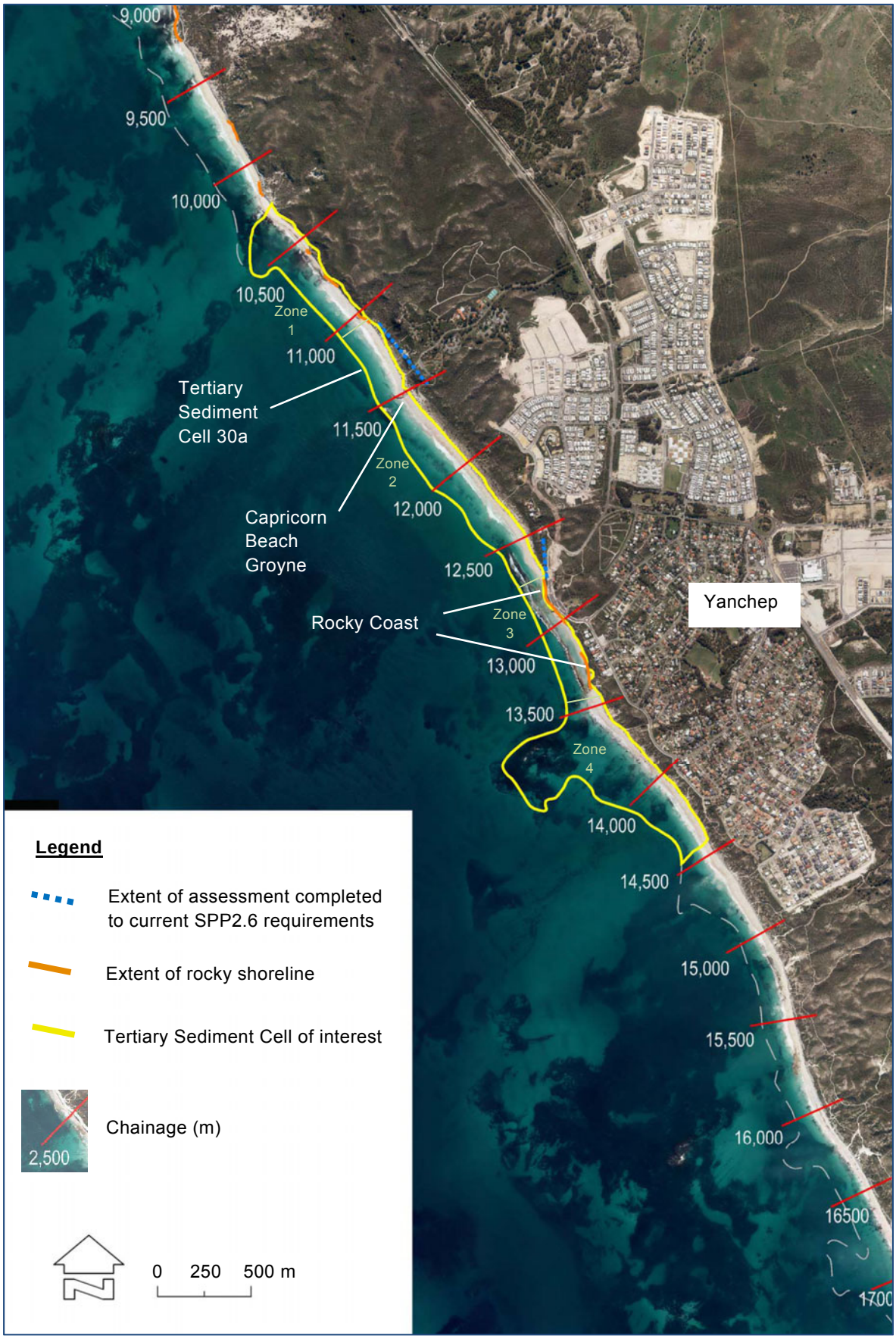

Figure 8.1 Tertiary Sediment Cell 30a location figure

8.1 Coastal Classification

The beaches receive waves averaging just over 1 m (Short 2006), which are likely to increase during stormy periods. Tertiary Sediment Cell 30a consists of a number of interesting coastal features.

- Intermittent beach rock in the north from Chainage 10,300 m to Chainage 11,100 m.
- Capricorn Beach groyne at Chainage 11,500 m.
- Yanchep Lagoon from Chainage 12,500 m to Chainage 13,400 m. The Lagoon is a 900 m long section of shore, paralleled by a beachrock reef, which is attached to the shore in the south with an opening to the north.
- Rocky coastline, as classified by DPI in 2005, from Chainage 12,800 m to 13,500 m.

These features are likely to influence the coastal dynamics within the sediment cell and will be considered in the following sections.

Through preliminary analysis of historical shoreline movements, MRA identified four coastal zones within Sediment Cell 30a exhibiting different long term shoreline movements. These coastal zones are outlined below.

8.1.1 Zone 1

Zone 1 (Chainages 10,300 m to 11,000 m) is a relatively straight and short section of beach with intermittent rock on the beach and in the dunes. This is an extension of the beach located in Zone 3 of Tertiary Sediment Cell 30b, as shown previously in Figure 7.3.

8.1.2 Zone 2

Zone 2 extends north from a short section of beach rock to the rocky coastline near the center of Yanchep Lagoon (Chainages 11,100 m to 12,700 m). This zone includes the Capricorn Beach Groyne located at Chainage 11,500 m, as shown in Figure 8.2. This groyne was constructed in 1971 (MRA 2013a). Review of historical aerial photographs suggests that the groyne became saturated around 1996 (MRA 2013a).

Figure 8.2 Capricorn Beach Groyne in Zone 2 (WACoast)

8.1.3 Zone 3

Zone 3 (Chainages 12,800 m to 13,000 m and 13,200 to 13,400 m) is a section of rocky coast identified by DPI as part of the Northern Metropolitan Setback Study (MRA 2005). This is shown in Figure 8.3. A 170 m section of coastline adjacent to Chainage 13,100 m is not fronted by competent rock in the dunes and will therefore be treated separately as a sandy coastline.

Figure 8.3 Zone 3 rocky coastline (MRA)

8.1.4 Zone 4

Zone 4 (Chainages 13,400 m to 14,400 m) extends to the south of the rocky coastline. This zone has intermittent beach rock similar to Zone 1.

Excluding the rocky coastline at Zone 2, Tertiary Sediment Cell 30a will be treated as a sandy coastline in the calculation of erosion allowances.

8.2 Allowances for Erosion

8.2.1 S1 Erosion

SBEACH profiles were developed for each of the zones identified in the previous section as required. The results are outlined in the following sections.

Zone 1

Zone 1 has similar characteristics to Tertiary Sediment Cell 30b Zone 3. Therefore, an S1 allowance of **28 m** is recommended in Zone 1 based on the results of the Tertiary Sediment Cell 30b Zone 3 SBEACH modelling (Figure 7.5).

Zone 2

Two sections of shoreline within Zone 1 have already been assessed to the requirements of the current SPP2.6 (WAPC 2013). This included the calculation of the S1 erosion allowance. The two assessments are listed below.

- Yanchep North setback assessment (MRA 2014a).
- Yanchep Beach SLSC CHRMAP (Cardno 2014).

The Yanchep North setback assessment (MRA 2014a) covers Chainage 11,100 m to 11,500 m on the northern side of the Capricorn Beach Groyne. An S1 allowance of 21 m was calculated for Yanchep North. The beach profile is expected to be relatively consistent between Chainages 11,100 m and 12,400 m. Therefore, an S1 erosion allowance of **21 m** is recommended for Chainages 11,100 m to 12,400 m.

The Yanchep Beach SLSC CHRMAP (Cardno 2014) covers Chainages 12,600 m and 12,700 m behind Yanchep Lagoon. An S1 allowance of **10 m** was recommended by Cardno (2014) for the Yanchep SLSC, which is considered appropriate for the coastline behind Yanchep Lagoon (Chainage 12,500 to 12,700 m).

Zones 3 & 4

Zone 3 is a predominantly rocky coast, with only one Chainage (13,100 m) not classified as rocky. The beach and dune profile at this chainage is expected to be similar to that observed through Zone 4.

An SBEACH profile was created at Chainage 14,000 m in Zone 4 using the 2009 LiDAR data (Fugro 2009). SWAN wave model outputs from an offshore location were input into the SBEACH model as were the water levels recorded during the July 1996 storm. The peak significant wave height (Hs) during the passage of the storm was approximately 3.2 m in around 7 m of water. A D_{50} sediment size of 0.36 mm was input into the model using results from MRA (2005).

The results of the SBEACH modelling are presented in Figure 8.4.

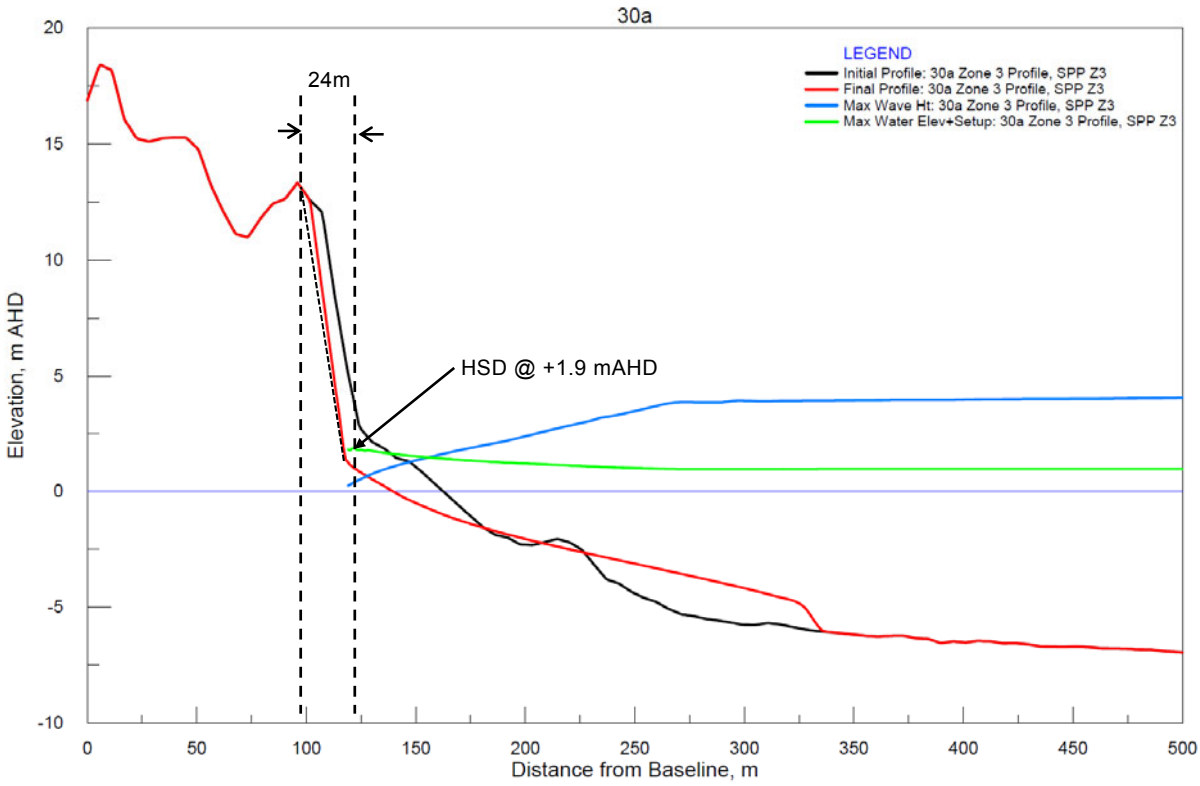

Figure 8.4 30a Zones 3 & 4 SBEACH model results

In this case, the HSD is +1.9 mAHD located approximately 3 m seaward of the coastal vegetation line. The modelled recession behind the HSD, including the 30° slope failure angle, is 24 m. Therefore, the S1 Erosion allowance for Zones 3 and 4 of Tertiary Sediment Cell 30a is **24 m**.

8.2.2 S2 Erosion

A number of coastal vegetation lines were available for this stretch of coastline, as well as the 2014 rectified aerial photograph. The positions of the coastal vegetation lines relative to 2014 were determined at 100 m Chainages along the coast. This is presented in Figure 8.5.

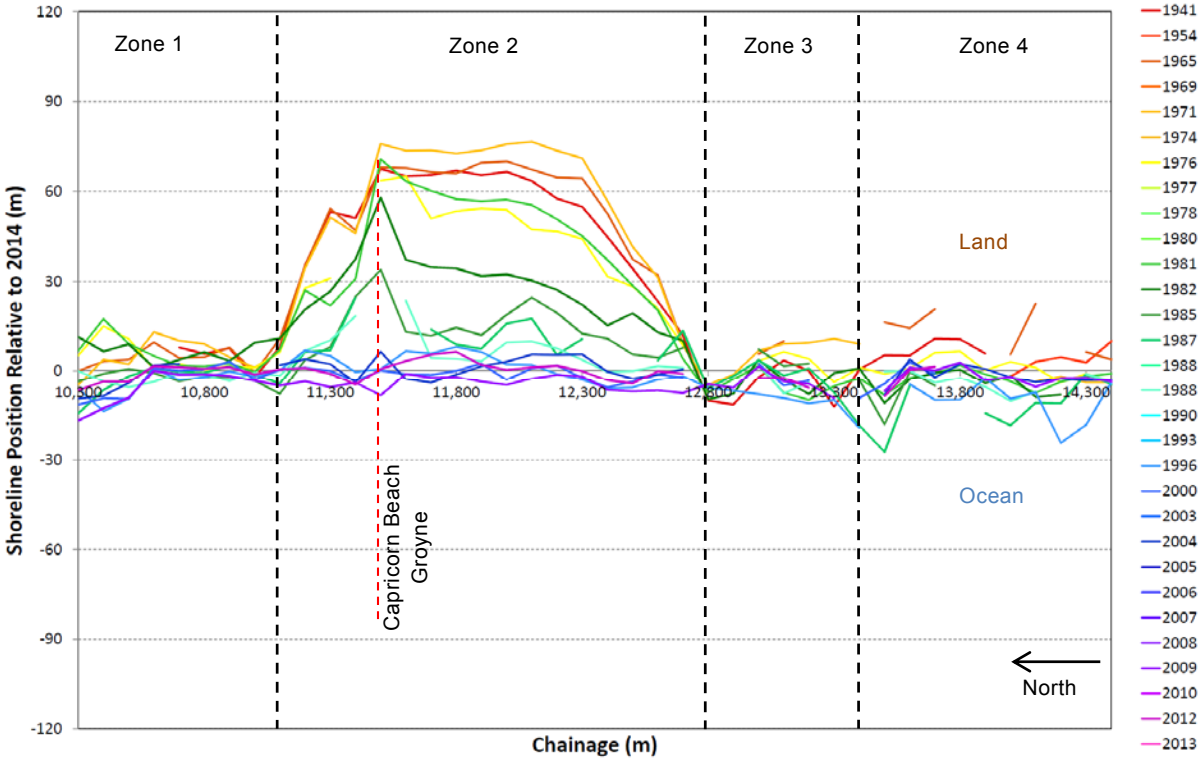

Figure 8.5 30a shoreline position relative to 2014

The Capricorn Beach Groyne was constructed in 1971 and appears to have become saturated around 1996 (MRA 2013a). To analyse the magnitude of the impact, the annual shoreline movement rate to 2014 was calculated using the 1996 vegetation line and the longer term 1941, 1954 and 1965 vegetation line. This provides an indication of the longer term shoreline movement rate and the shoreline movement rate since the groyne has become saturated. These results are presented in Figure 8.6.

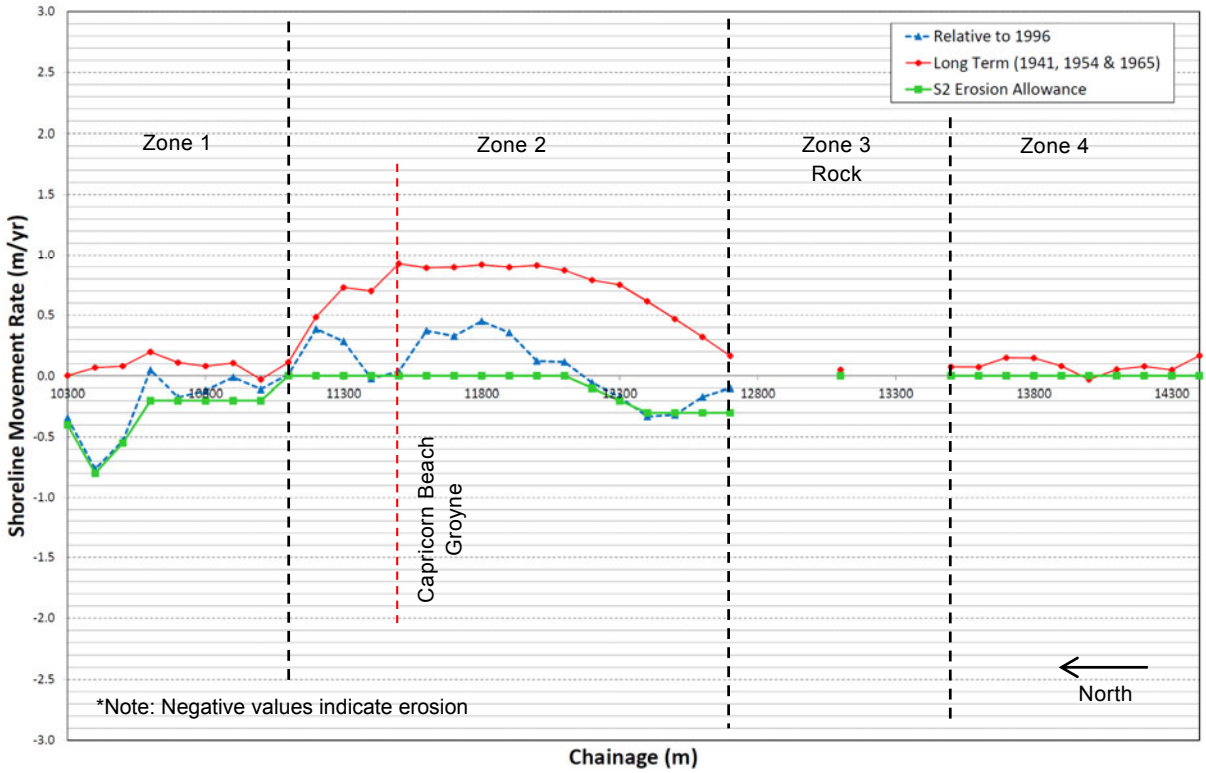

Figure 8.6 30a annual shoreline movement rate

The shoreline movements are discussed in further detail in the following sections.

Zone 1

The shoreline has been relatively stable in the longer term within Zone 1. However, since the groyne became saturated in 1996 the downdrift shoreline has eroded by up to -0.8 m/yr at Chainage 10,400 m. Therefore, a peak S2 Erosion allowance of **-0.8 m/yr** will be used for Zone 1 at Chainage 10,400 m, as shown in Figure 8.6. Appropriate S2 Erosion allowances to account for the erosion since 1996 will be used for the remaining Chainages within Zone 1 as shown in Figure 8.6.

Zone 2

Zone 2 includes two sections of shoreline previously assessed to the full requirements of the SPP2.6. These shorelines are listed below.

- Chainages 11,100 m to 11,500 m, Yanchep North setback assessment (MRA 2014a). An S2 Erosion allowance of **0 m/yr** was recommended in MRA (2014) and is considered appropriate for use in this study.
- Chainages 12,600 m and 12,700 m, Yanchep Surf Life Saving Club CHRMAP (Cardno 2014). An S2 Erosion allowance of **-0.3 m/yr** was recommended in (Cardno 2014) and is considered appropriate for use in this study.

For the remainder of the shoreline in Zone 2, the shoreline has remained relatively stable with some minor erosion from Chainages 12,200 m to Chainages 12,500 m. Figure 8.6 shows the adopted S2 Erosion allowances for the remainder of Zone 2.

Zone 3

Zone 3 is classified as a rocky shoreline except Chainage 13,100 m. This chainage has experienced minor accretion. Therefore, an S2 Erosion allowance of **0 m/yr** is recommended for this chainage in line with SPP2.6 recommendations.

Zone 4

The shoreline has been relatively stable in the longer term within Zone 4. Therefore, an S2 Erosion allowance of **0 m/yr** is recommended for Zone 4.

8.2.3 S3 Erosion

The S3 Erosion allowances for the range of planning timeframes were previously presented in Table 4.1.

8.2.4 Allowance for Erosion

The three erosion allowances are combined with a 0.2 m/yr allowance for uncertainty giving a total allowance for erosion. These allowances are presented in Appendix D for the range of planning timeframes.

8.3 Erosion Hazard Mapping

Using the work completed within Section 8.2, coastal hazard mapping has been completed to show the areas that could be vulnerable to coastal erosion over the designated timeframes. The maps are contained in Appendix C.

8.4 Sensitivity, Adaptive Capacity & Vulnerability to Erosion

8.4.1 Zones 1 & 2

The hazard mapping shows that some manmade assets in Zones 1 and 2 of Tertiary Sediment Cell 30a may at risk of coastal erosion over a range of timeframes. These are outlined below.

- The car-park and building in Capricorn Village between Chainage 11,000 m and 11,500 m may be at risk of coastal erosion in the coming century.
- The car-park north of Capricorn Beach Groyne may be at risk of coastal erosion in the coming 30 to 40 years.
- Several buildings around Chainage 12,400 m may be at risk of coastal erosion in the coming 50 to 60 years.
- The existing Yanchep SLSC at Chainage 12,500 m may be at risk of coastal erosion in the coming 50 to 60 years. The access path associated with this club may also be impacted by erosion over a shorter timeframe.
- The proposed new Yanchep SLSC around Chainage 12,700 m may also be at risk of coastal erosion. Details of erosion risk, adaptation and management strategies for this SLSC can be found in Cardno (2014).

These manmade assets have limited capacity to adapt to coastal erosion and are therefore considered vulnerable to erosion.

Two registered Aboriginal Heritage Sites exist in Zones 1 and 2; “Yanchep Beach” and “Yanchep Lagoon”. Both of these sites have a degree of adaptive capacity. The shape and position of “Yanchep Beach” may change with erosion but there is still likely to be a beach in the area over

the coming century. “Yanchep Lagoon” is similar, as the relative position of the lagoon to the beach and the depth of the lagoon may change over time but the lagoon will still remain in some form. Therefore, these sites are not considered vulnerable to erosion.

In Zones 1 and 2, a large proportion of Bush Forever Site 397 is at risk of coastal erosion in the coming century. This environmental system is considered vulnerable to erosion, as it is limited to the foreshore reserve areas. Although the species contained within the ecological system may have a capacity to adapt (ie grow further from the coast), the system as a whole is vulnerable to erosion due to space constraints.

8.4.2 Zones 3 & 4

The hazard mapping shows that some manmade assets in Zones 3 and 4 of Tertiary Sediment Cell 30a may be at risk of coastal erosion over a range of timeframes. These are outlined below.

- The car-park and access road between Chainages 12,700 m and 13,000 m and a number of residential lots between Chainage 13,000 m and 13,400 m may be at risk of coastal erosion in the coming 30 to 40 years. The erosion in this area will depend significantly on the extent of rock behind the coastal headlands and rock at Yanchep. Geotechnical investigations would be required to confirm the depth, competency and extent of rock through this area.

- South of the Rocky Coastline, a number of residential lots and roads may be at risk of coastal erosion in the coming 50 to 70 years. The number of properties threatened may increase over the 105 year planning timeframe.

These manmade assets have limited adaptive capacity to coastal erosion and are therefore considered vulnerable to erosion.

The two Aboriginal Heritage sites “Yanchep Beach” and “Yanchep Lagoon” are also located in Zones 3 and 4. Hazard mapping shows that these sites may be at risk of erosion but due to their adaptive capacity, are not considered vulnerable to erosion.

All of Bush Forever Site 397 is at risk of erosion in the coming century in Zones 3 and 4. This ecological system is considered vulnerable due to limited space for adaptation or retreat.

9. Tertiary Sediment Cell 29d Erosion Allowances

Tertiary Sediment Cell 29d extends approximately 6 km south from Yanchep to Alkimos. Sediment Cell 29d commences at Chainage 14,500 m in the north and ends to the south at Chainage 20,700 m, as shown in Figure 9.1.

Within this sediment cell, the Amberton development has already been assessed to the requirements of the current SPP2.6 (WAPC 2013). This is shown as a blue dashed line in Figure 9.1, extending from Chainage 18,000 m to 19,000 m. The results of this study will be used in this CHRMAP for consistency (MRA 2014b).

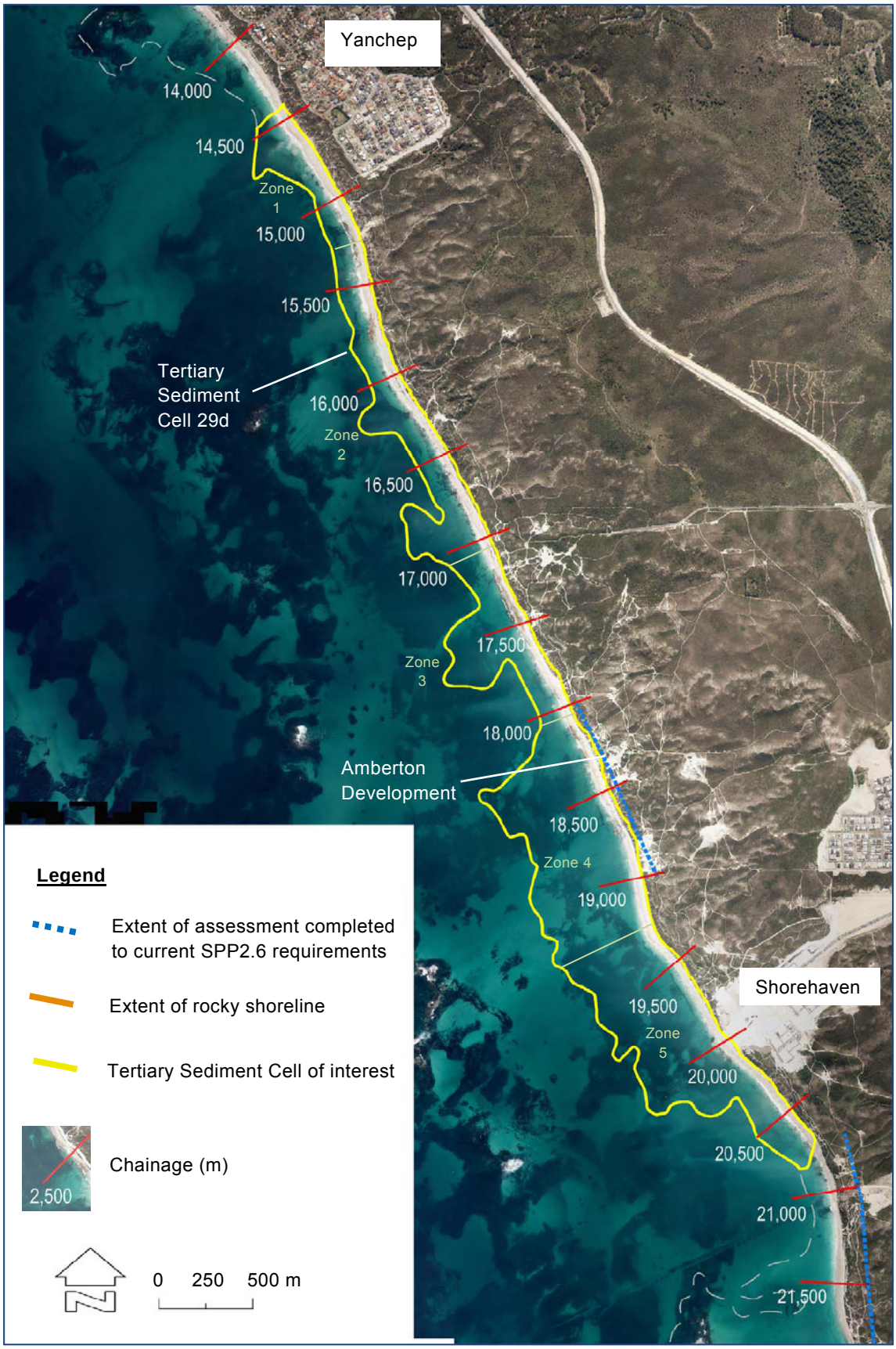

Figure 9.1 Tertiary Sediment Cell 29d location figure

9.1 Coastal Classification

The beaches in Tertiary Sediment Cell 29d typically receive waves averaging just over 1 m (Short 2006), which are likely to increase during stormy periods. The shoreline is predominately sandy, however sections of partly exposed beach rock were noted by Short (2006) and are visible in areas within the swash zone. This was not classified as a rocky coastline by DPI in 2005.

Through preliminary analysis of historical shoreline movements, MRA identified five coastal zones within Sediment Cell 29d exhibiting different long term shoreline movements. These coastal zones are outlined below.

9.1.1 Zone 1

Zone 1 (Chainage 14,500 m to 15,200 m) has a nor-north west alignment in front of the Yanchep townsite. The southern end of this zone commences at a short length of beach rock. This is similar to Zone 4 in Tertiary Sediment Cell 30a. Zone 1 and the northern end of Zone 2 are presented in Figure 9.2.

Figure 9.2 Zone 1 and Zone 2 aerial photograph (WACoast)

9.1.2 Zone 2

Zone 2 (Chainage 15,300 m to 17,000 m) commences on the northern side of Pipidinny Rocks, a prominent section of beach rock. This zone has a more north-south alignment than Zone 1 and appears to have experienced net erosion in the longer term.

9.1.3 Zone 3

Zone 3 (Chainage 17,100 m to 18,000 m) is a predominantly sandy beach with some intermittent beach rock. This zone encompasses Pipidinny Rocks, which are shown in Figure 9.3. This zone has been relatively stable over the longer term but given the absence of rock above the beach berm and in the dunes is considered a sandy coastline.

Figure 9.3 Zone 3 Pipidinny Rocks (WACoast)

9.1.4 Zone 4

Zone 4 (Chainage 18,100 m to 19,200 m) is on the northern side of a prominent point (at Chainage 19,300 m). This zone has typically experienced net erosion over the longer term.

9.1.5 Zone 5

Zone 5 (Chainage 19,300 m to 20,700 m) is on the southern side of the prominent point (at Chainage 19,300 m). This zone has typically experienced net accretion over the longer term.

Given the above review, Tertiary Sediment Cell 29d will be treated as a sandy coastline in the calculation of erosion allowances.

9.2 Allowances for Erosion

9.2.1 S1 Erosion

SBEACH profiles were developed for each of the zones identified in the previous section as required. These are outlined in the following sections.

Zone 1

Zone 1 has similar characteristics to Tertiary Sediment Cell 30a Zone 4. Therefore, an S1 allowance of **24 m** is recommended in Zone 1 based on the results of the Tertiary Sediment Cell 30b Zone 3 SBEACH modelling (Figure 8.4).

Zones 2 & 3

The beach profile through Zones 2 and 3 is expected to be similar. An SBEACH profile was created at Chainage 16,500 m in Zone 2 using the 2009 LiDAR data (Fugro 2009). SWAN wave model outputs from an offshore location were input into the SBEACH model as were the water levels recorded during the July 1996 storm. The peak significant wave height (Hs) during the passage of the storm was approximately 3.3 m in around 7 m of water. A D_{50} sediment size of 0.36 mm was input into the model using results from MRA (2005).

The results of the SBEACH modelling are presented in Figure 9.4.

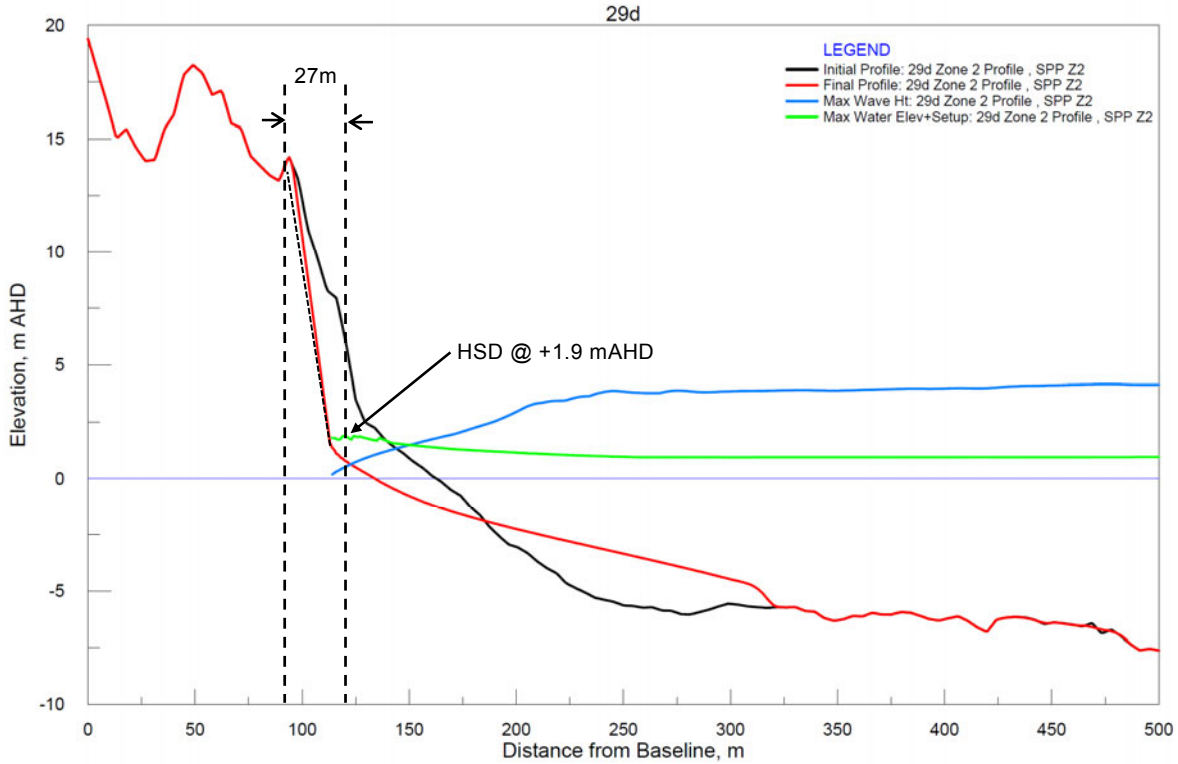

Figure 9.4 29d Zones 2 & 3 SBEACH model results

In this case, the HSD is +1.9 mAHD located approximately 7 m landward of the coastal vegetation line. The modelled recession behind the HSD, including the 30° slope failure angle, is 27 m. Therefore, the S1 Erosion allowance for Zones 2 and 3 of Tertiary Sediment Cell 29d is **27 m**.

Zone 4

The Amberton setback assessment (MRA 2014b) has already been completed to the requirements of the current SPP2.6, including the calculation of the S1 erosion allowance. This assessment extends from Chainage 18,000 m to 19,000 m and is considered appropriate for the whole of Zone 4. An S1 allowance of **37 m** was calculated for Amberton and is recommended for Zone 4 of Tertiary Sediment Cell 29d.

Zone 5

An SBEACH profile was created at Chainage 19,600 m using the LiDAR survey (Fugro 2009). SWAN wave model outputs from an offshore location were input into the SBEACH model as were the water levels recorded during the July 1996 storm. The peak significant wave height (Hs) during the passage of the storm was approximately 3.1 m in around 7 m of water. A D_{50} sediment size of 0.33 mm was input into the model using results from the Shorehaven setback assessment (MRA 2010).

The results of the SBEACH modelling are presented in Figure 9.5.

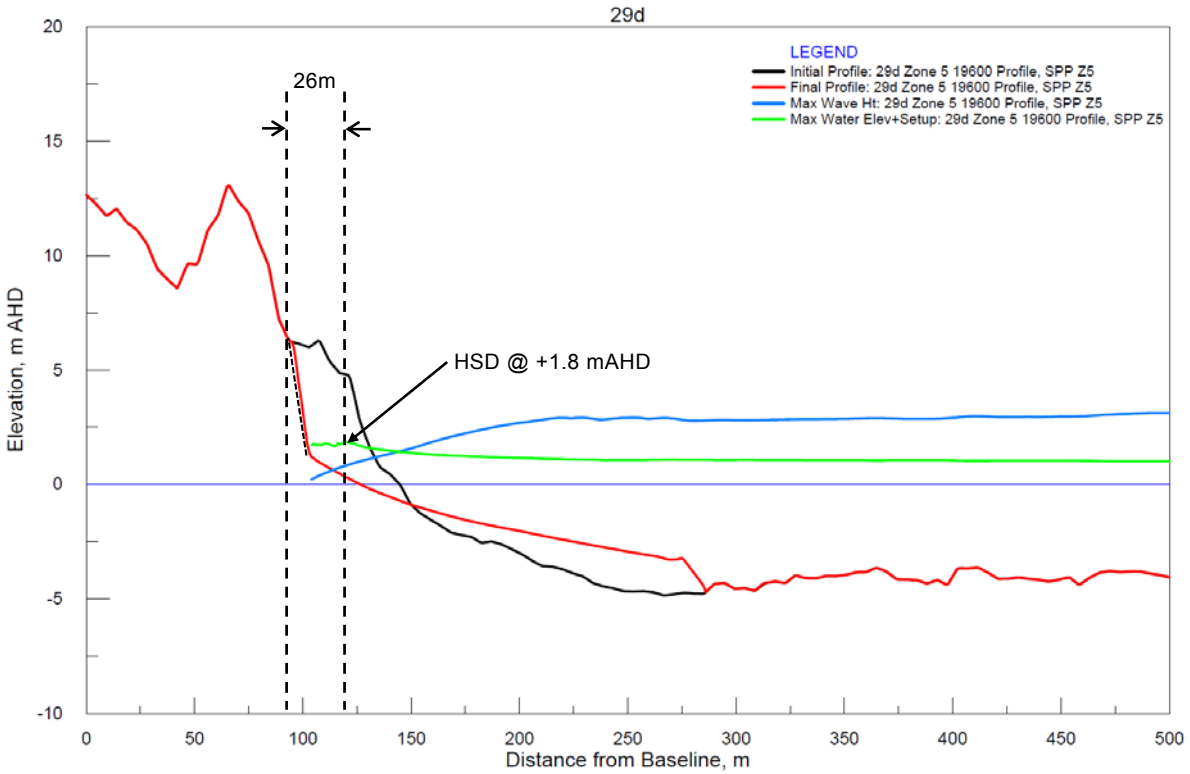

Figure 9.5 29d Zone 5 SBEACH model results

In this case, the HSD is +1.8 mAHD located approximately 6 m landward of the coastal vegetation line. The modelled recession behind the HSD, including the 30° slope failure angle, is 26 m. Therefore, the S1 Erosion allowance for Zone 5 of Tertiary Sediment Cell 29d is **26 m**.

9.2.2 S2 Erosion

A number of coastal vegetation lines were available for this stretch of coastline, including the 2014 coastal vegetation line.

In addition to the available shoreline movement lines, MRA has access to a HWM survey from 1908 which was analysed as part of the Amberton (MRA 2014b) and Alkimos (MRA 2013b) setback assessments. This HWM survey was included in the shoreline movement analysis as part of this study and extends from Chainages 17,100 m to 23,700 m. This provides the ability to analyse the shoreline movement over a 106 year period from 1908 to 2014. The survey sheets for the HWM Survey are contained in Appendix E.

It is understood that either the extent of debris from wave uprush or the vegetation line was used by surveyors of this time to depict the high water mark. For consistency with the other data obtained from the aerial imagery it is assumed that this survey represents the coastal vegetation line. However, if the high water mark survey was taken as the debris line, the surveyed line would be closer to the beach berm than the vegetation line. This would provide a more conservative depiction of the beach profile change over time due to the fact that the shoreline movement plan would show the shoreline to be further seaward than it actually was. This would essentially mean that any subsequent accretion of the shoreline would appear smaller than in reality, while any erosion would appear larger.

The positions of the coastal vegetation lines relative to 2014 were determined at 100 m chainages along the coast. This is presented in Figure 9.6.

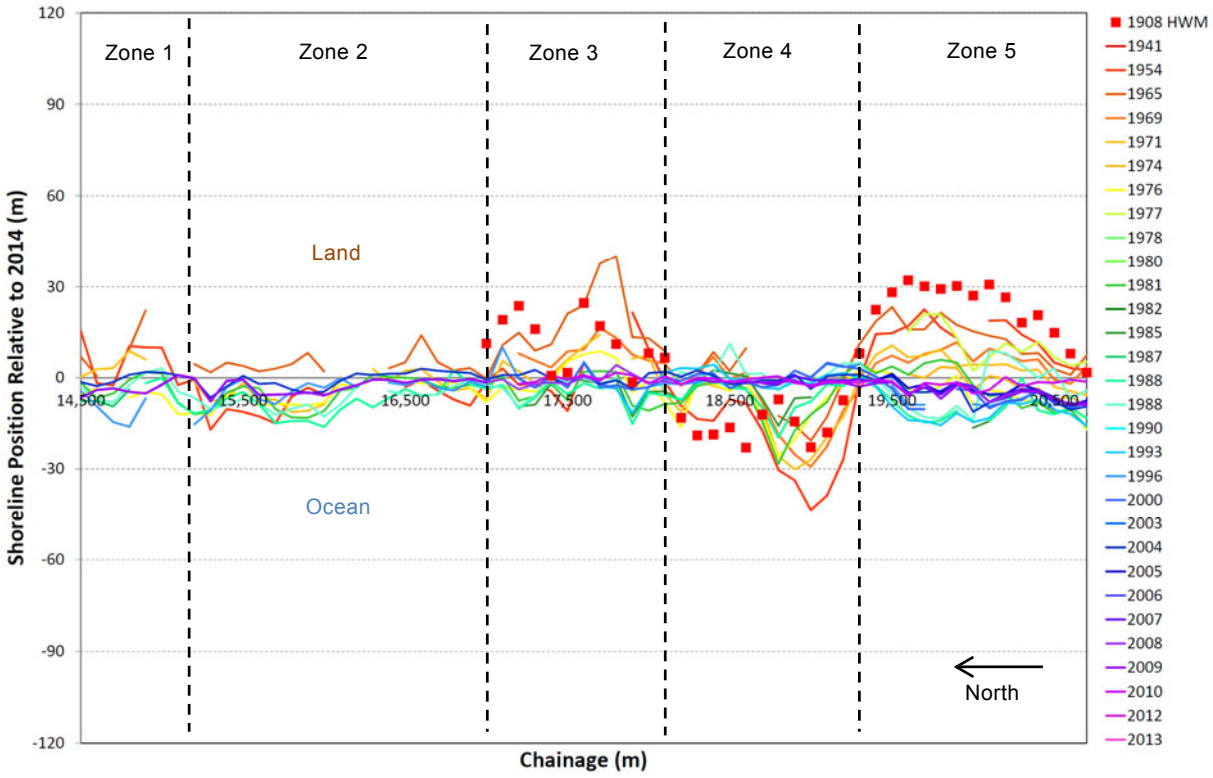

Figure 9.6 29d shoreline position relative to 2014

The annual shoreline movement rate to 2014 was calculated using the 1954 vegetation line and the 1908 HWM Survey. These results are presented in Figure 9.7.

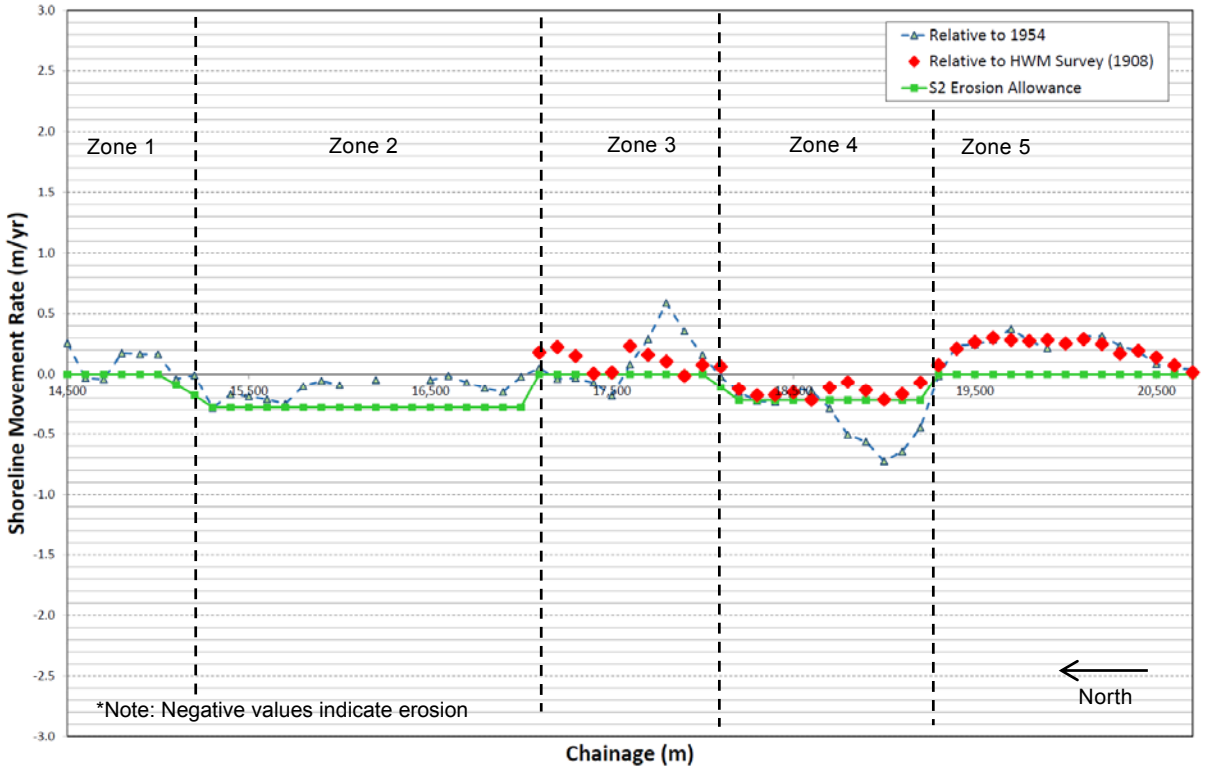

Figure 9.7 29d annual shoreline movement rate

The shoreline movements are discussed in further detail in the following sections.

Zone 1
Zone 1 has been relatively stable since 1954, with minor accretion at most chainages. An S2 Erosion allowance of **0 m/yr** is recommended in Zone 1.

Zone 2
Zone 2 has experienced minor erosion of up to -0.28 m/yr since 1954. An S2 Erosion allowance of **-0.28 m/yr** is recommended in Zone 2.

Zone 3
Zone 3 has been relatively stable since 1908, with minor accretion at all chainages. An S2 Erosion allowance of **0 m/yr** is recommended in Zone 3.

Zone 4
Zone 4 includes the Amberton development (Chainages 18,000 m to 19,000 m) which has previously been assessed to the full requirements of the SPP2.6 (MRA 2014b).

Through analysis of the 1908 HWM Survey, an S2 erosion allowance of 0 m was used in MRA (2014b) at Chainage 18,000 m increasing over a 200 m transition area to -0.22 m/yr between Chainages 18,200 m to 19,000 m. These S2 erosion allowances are considered appropriate for this study given the shoreline movements over the 106 year analysis period.

The **-0.22 m/yr** S2 Erosion allowance was extended to include Chainages 19,100 m and 19,200 m within Zone 4.

Zone 5
Zone 5 has experienced net accretion of up to 0.4 m/yr over the longer term. Under the SPP2.6 a negative S2 erosion allowance could be used in this zone. However, since the mid 1990's this zone has experienced net shoreline recession. Given the complexity of the historical shoreline movements, a **0 m/yr** S2 Erosion allowance is recommended in Zone 5.

9.2.3 S3 Erosion
The S3 Erosion allowances for the range of planning timeframes were previously presented in Table 4.1.

9.2.4 Allowance for Erosion
The three erosion allowances are combined with a 0.2 m/yr allowance for uncertainty giving a total allowance for erosion. These allowances are presented in Appendix D for the range of planning timeframes.

9.3 Erosion Hazard Mapping
Using the work completed within Section 9.2, coastal hazard mapping has been completed to show the areas that could be vulnerable to coastal erosion over the designated timeframes. The maps are contained in Appendix C.

9.4 Sensitivity, Adaptive Capacity & Vulnerability to Erosion
Tertiary Sediment Cell 29d is mostly undeveloped, with residential lots and road infrastructure located between Chainages 14,500 m and 15,000 m and the new Shorehaven development currently being constructed.

Hazard mapping shows that some residential lots and road (between Chainage 14,500 m and 15,000 m) may be at risk of coastal erosion in around 80 years' time. Roads being constructed between Chainages 20,100 m and 20,300 m may also be at risk from coastal erosion from 2090. Infrastructure within these areas has low adaptive capacity, so is considered vulnerable to coastal erosion.

The Bush Forever Site 397 extends along the majority of the shoreline in Tertiary Sediment Cell 29d. A large proportion of this site may be at risk of coastal erosion over the coming century. This environmental system is considered vulnerable to erosion, as it is limited to the foreshore reserve areas. Although the species contained within the ecological system may have a capacity to adapt (ie grow further from the coast), the system as a whole is vulnerable to erosion due to space constraints from possible, future coastal development.

Aboriginal Heritage Site "Yanchep Beach" is also located in the northern portion of Tertiary Sediment Cell 29d. Hazard mapping shows that this site may be at risk of erosion but due to its capacity to adapt is not considered vulnerable to erosion.

10. Tertiary Sediment Cell 29c Erosion Allowances

Tertiary Sediment Cell 29c extends approximately 4 km south from Alkimos to Quinns Rocks North. Sediment Cell 29c commences at Chainage 20,800 m in the north and ends to the south at Chainage 24,700 m, as shown in Figure 10.1.

Within this sediment cell, the Alkimos development has already been assessed to the requirements of the current SPP2.6 (WAPC 2013). This is shown as a blue dashed line in Figure 10.1, extending from Chainage 20,800 m to 22,800 m. The results of this study will be used in this CHRMAP for consistency (MRA 2013b).

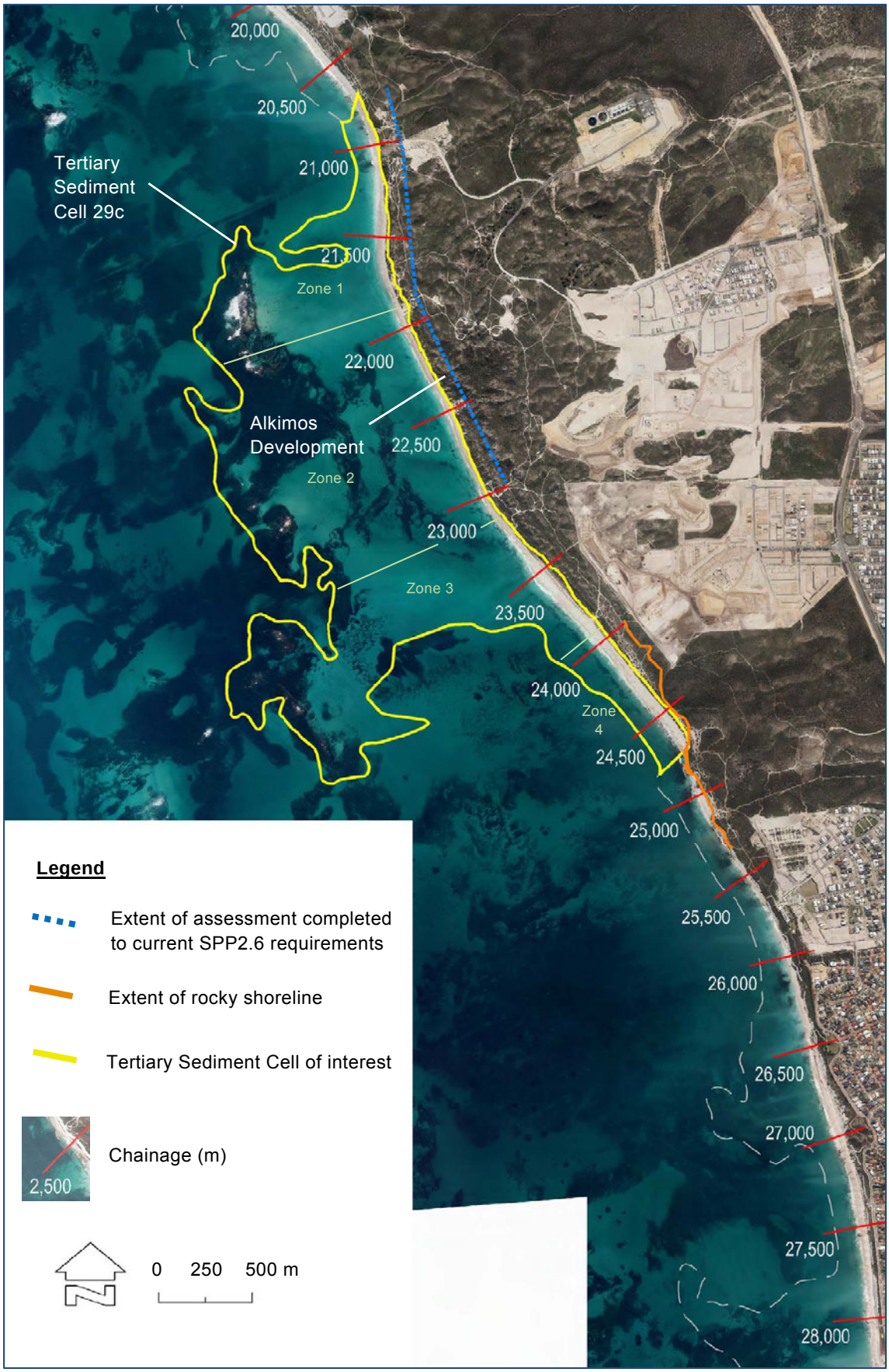

Figure 10.1 Tertiary Sediment Cell 29c location figure

10.1 Coastal Classification

The beaches in Tertiary Sediment Cell 29c typically receive waves averaging less than 1 m (Short 2006), which are likely to increase during stormy periods. The shoreline is predominately sandy, however a geotechnical assessment completed for the Lot 9 Jindalee found rock above +3.5 mAHD behind the dunes between Chainages 24,000 m and 24,700 m (MRA 2011).

Through preliminary analysis of historical shoreline movements, MRA identified four coastal zones within Sediment Cell 29c exhibiting different long term shoreline movements or shoreline classification. These coastal zones are outlined below.

10.1.1 Zone 1

Zone 1 (Chainage 20,800 m to 21,800 m) is a curved section of shoreline, with a wide flat beach backed by a small primary dune fronting a substantial secondary dune system. The overall beach characteristics are similar to those observed in Zone 2. These features are shown in Figure 10.2.

Figure 10.2 Zone 1 beach photograph Chainage 21,200 m (MRA)

This zone also has limestone rock outcrops present in the dune system. The majority of this limestone was noted as being between chainage 21,100 m and 21,400 m. Previous investigations in the area have failed to find continuous rock at elevations that would significantly impact the results of the coastal processes assessment (MRA 2013b).

10.1.2 Zone 2

Zone 2 (Chainage 21,900 m to 23,100 m) is relatively exposed, with a wide flat beach backed by substantial sand dunes with an estimated primary dune crest height in excess of +15 mAHD. The beach remains relatively uniform for the length of this section of shoreline. A typical example of the shoreline in this sector is shown in Figure 10.3.

Figure 10.3 Zone 2 beach photograph Chainage 22,500 m (MRA)

This photograph indicates that the beach experiences heavy 4WD use which may be impacting on vegetation growth in this section.

10.1.3 Zone 3

Zone 3 (Chainage 23,200 m to 23,900 m) is to the south of a change in shoreline direction, as shown in Figure 10.4. This beach has an erosion scarp between Chainage 23,200 m and 23,400 m and then a low foredune between Chainage 23,400 m and 24,00 m.

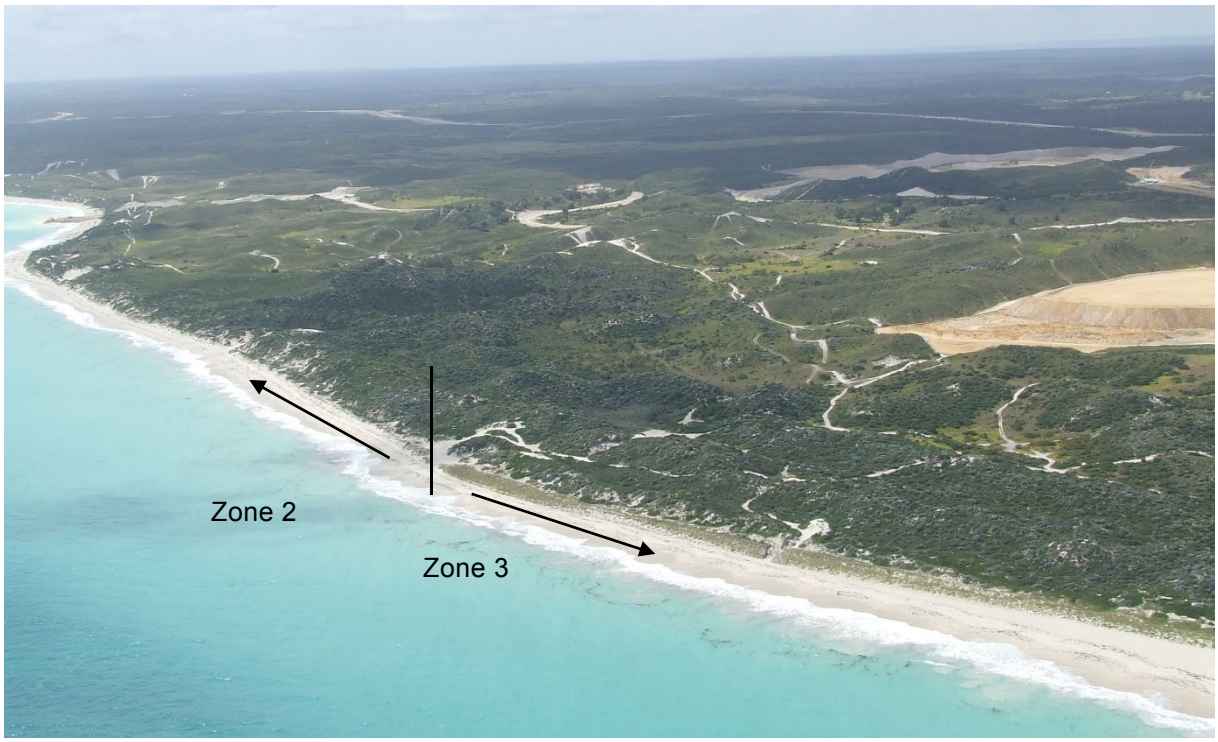

Figure 10.4 Zone 2 & 3 aerial photograph of border (WACoast)

10.1.4 Zone 4

Zone 4 (Chainage 24,000 m to 24,700 m) is classified as a rocky coastline under the SPP2.6, as a geotechnical investigation completed for Lot 9 Jindalee found continuous competent rock within the dunes above +3.5 mAHD. Results of these investigations can be found in MRA (2011).

10.2 Allowances for Erosion

10.2.1 S1 Erosion

SBEACH profiles were developed for each of the zones identified in the previous section as required. These are outlined in the following sections.

Zone 1

Based on the results of the Alkimos setback assessment (MRA 2013b) the following S1 allowances are recommended for Zone 1.

- Chainages 20,800 m and 20,900 m = **30 m**.
- Chainage 21,000 m to 21,800 m = **16 m**.

Zone 2

Based on the results of the Alkimos setback assessment (MRA 2013b) an S1 allowance of **42 m** is recommended for Zone 2 (Chainages 21,900 to 22,700 m).

Zone 3

An SBEACH profile was created at Chainage 23,500 m from a combination of on-site survey measurements and nautical charts. SWAN wave model outputs from an offshore location were input into the SBEACH model as were the water levels recorded during the July 1996 storm. The peak significant wave height (Hs) during the passage of the storm was approximately 2.8 m in around 6 m of water. A D_{50} sediment size of 0.33 mm was input into the model using results from the Shorehaven setback assessment (MRA 2010).

The results of the SBEACH modelling are presented in Figure 10.5.

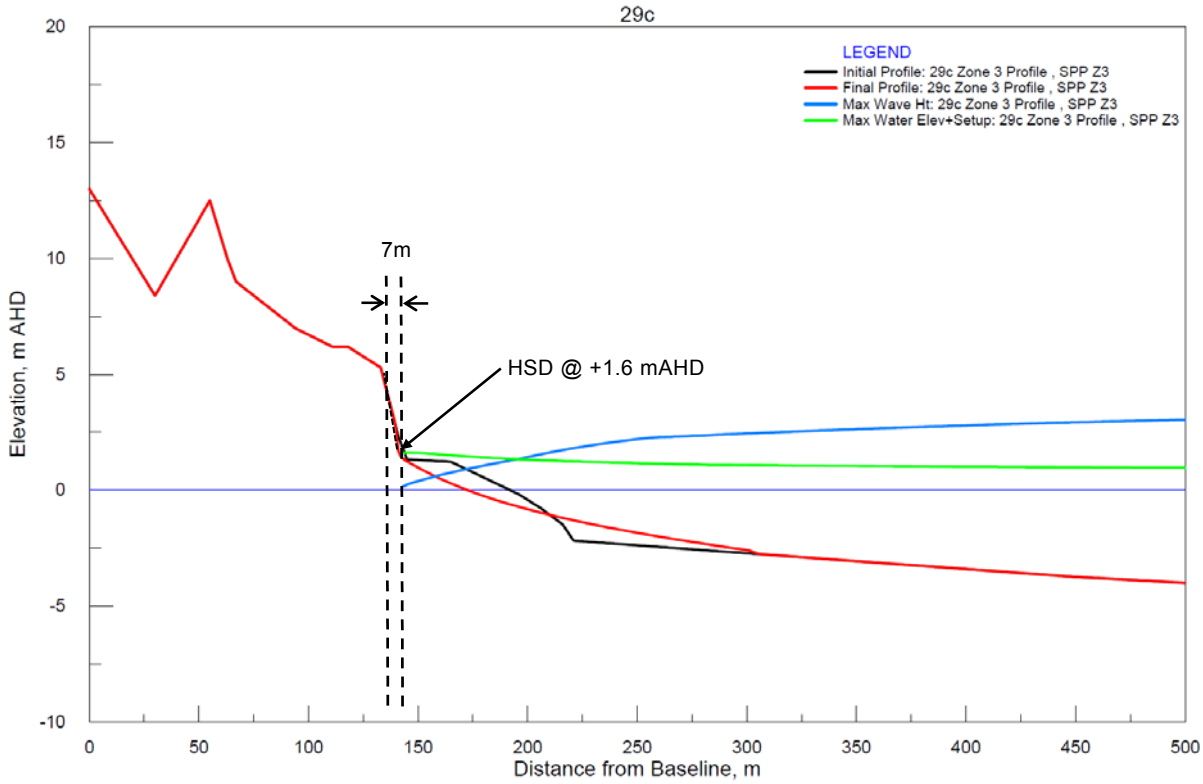

Figure 10.5 29c Zone 3 SBEACH model results

In this case, the HSD is +1.6 mAHD located approximately 4 m landward of the coastal vegetation line. The modelled recession behind the HSD, including the 30° slope failure angle, is 7 m. Therefore, the S1 Erosion allowance for Zone 3 of Tertiary Sediment Cell 29c is **7 m**.

Zone 4

Zone 4 is classified as rocky coastline, which does not require determination of an S1 allowance under SPP2.6.

10.2.2 S2 Erosion

A number of coastal vegetation lines were available for this stretch of coastline, including the 2014 coastal vegetation line and the 1908 HWM survey.

The HWM survey was analysed as part of the Amberton (MRA 2014b) and Alkimos (MRA 2013b) setback assessments and included in the shoreline movement analysis as part of this study. This provides a methodology to analyse the shoreline movement over a 106 year period from 1908 to 2014. The survey sheets for the 1908 HWM Survey are contained in Appendix E.

The positions of the coastal vegetation lines relative to 2014 were determined at 100 m chainages along the coast. This is presented in Figure 10.6.

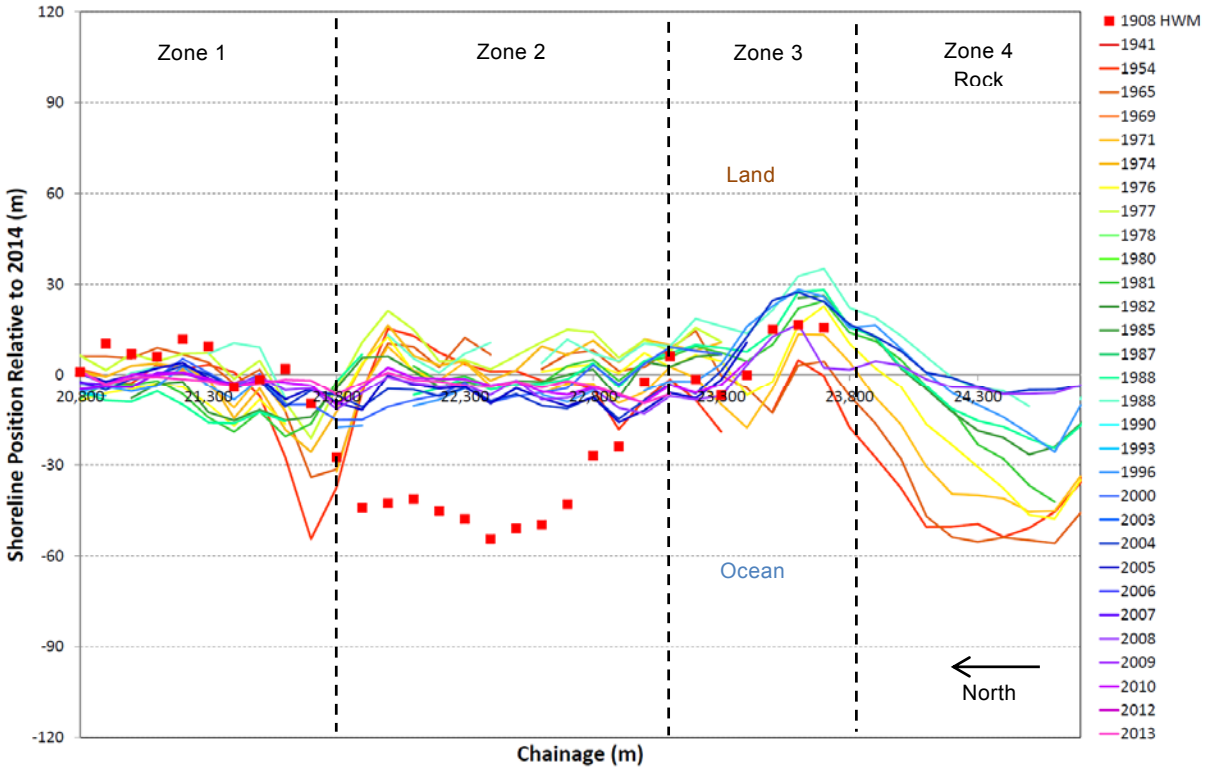

Figure 10.6 29c shoreline position relative to 2014

The annual shoreline movement rate to 2014 was calculated using the 1954 vegetation line and the 1908 HWM Survey. These results are presented in Figure 10.7.

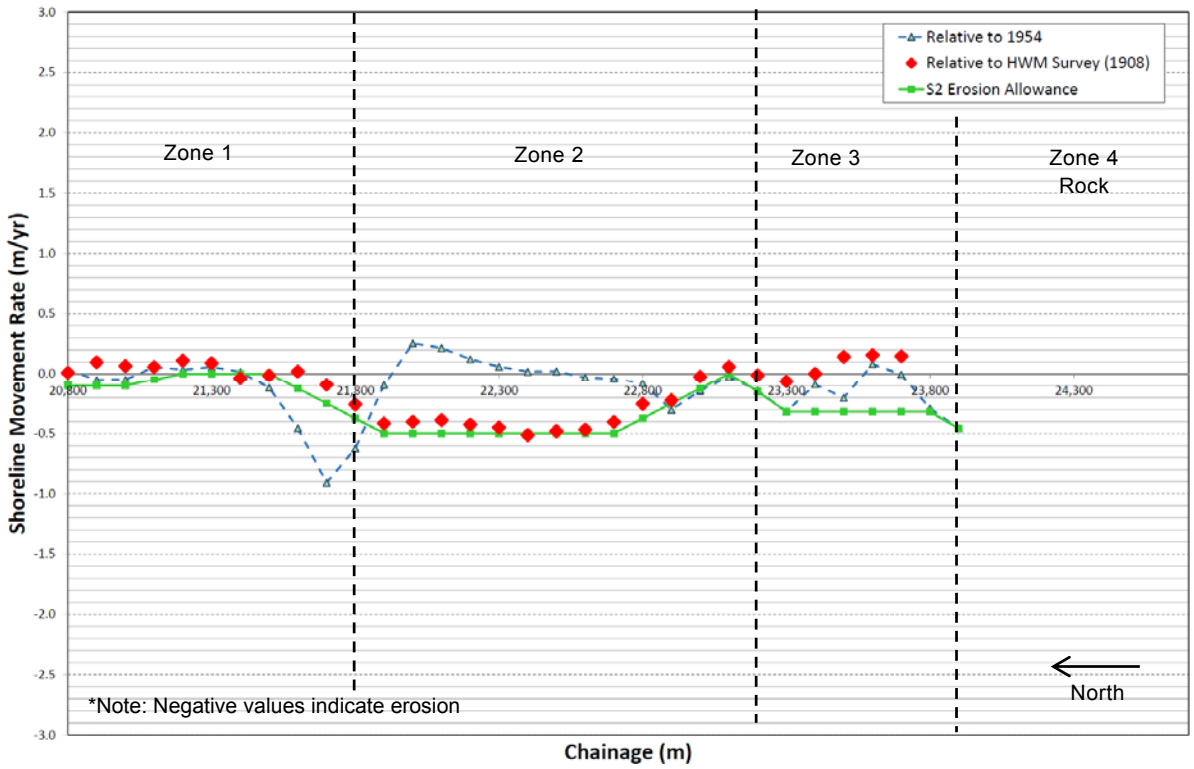

Figure 10.7 29c annual shoreline movement rate

The shoreline movements are discussed in further detail in the following sections.

Zones 1 & 2

Zones 1 and 2 include the Alkimos development (Chainages 20,800 m to 22,800 m) which has previously been assessed to the full requirements of the SPP2.6 (MRA 2013b).

Through analysis of the 1908 HWM Survey and the 1954 vegetation line, the following S2 erosion allowances were used in MRA (2013b).

- Chainage 20,800 m to 21,000 m has an S2 Erosion allowance of **-0.1 m/yr**.
- Chainage 21,200 m to 21,500 m has an S2 Erosion allowance of **0 m/yr**.
- Chainage 21,900 m to 22,700 m has an S2 Erosion allowance of **-0.5 m/yr**.

Transitions between the different S2 allowances have been allowed for in MRA (2013b) and are reflected in these results. These S2 Erosion allowances are considered appropriate for this study given the shoreline movements over the 106 year analysis period.

Zone 3

Zone 3 has generally experienced erosion of up to -0.46 m/yr since 1954. An S2 Erosion allowance of **-0.32 m/yr** will be used for Chainages 23,300 m to 23,900 m, increasing to **-0.46 m/yr** at Chainage 23,900 m.

Zone 4

Zone 4 is classified as a rocky shoreline under SPP2.6 through geotechnical investigations within the dune (MRA 2011). Therefore, an S2 allowance is not relevant for this zone.

10.2.3 S3 Erosion

The S3 Erosion allowances for the range of planning timeframes were previously presented in Table 4.1.

10.2.4 Allowance for Erosion

The three erosion allowances are combined with a 0.2 m/yr allowance for uncertainty giving a total allowance for erosion. These allowances are presented in Appendix D for the range of planning timeframes.

10.3 Erosion Hazard Mapping

Using the work completed within Section 10.2, coastal hazard mapping has been completed to show the areas that could be vulnerable to coastal erosion over the designated timeframes. The maps are contained in Appendix C.

10.4 Sensitivity, Adaptive Capacity & Vulnerability to Erosion

Tertiary Sediment Cell 29c is mostly undeveloped, with new development being constructed at Lot 9 Jindalee between Chainages 23,000 m and 24,000 m. The approved setback line for Lot 9 Jindalee is landward of the calculated 2120 erosion allowance (MRA 2011). Therefore, the development is not expected to be at risk of erosion to 2120.

The Bush Forever Site 397 extends along the majority of the shoreline in Tertiary Sediment Cell 29c. A large proportion of this site may be at risk of coastal erosion over the coming century. This environmental system is considered vulnerable to erosion, as it is limited to the foreshore reserve

areas. Although the species contained within the ecological system may have a capacity to adapt (ie grow further from the coast), the system as a whole is vulnerable to erosion due to space constraints from possible, future coastal development.

Aboriginal Heritage Site “Karli Spring” is located in Tertiary Sediment Cell 29c, around Chainage 22,700 m. Hazard mapping shows that this site may be at risk of erosion in the coming century. The adaptive capacity of a spring is likely to be low, as it is unlikely to naturally move if eroded. This means that this site is likely to be vulnerable to coastal erosion.

11. Tertiary Sediment Cell 29b Erosion Allowances

Tertiary Sediment Cell 29b extends approximately 4.5 km south from Quinns Rocks North to Mindarie Keys North. Sediment Cell 29b commences at Chainage 24,800 m in the north and ends to the south at Chainage 29,200 m, as shown in Figure 11.1.

The management of this sediment cell is currently being assessed by Cardno. The first stage of the study (Coastal Processes Assessment) was completed in May 2015. Subsequent stages of the study (Concept Options Assessment and Detailed Design) are currently scheduled for completion in early 2016. This sediment cell will not be considered further in this report, as the Quinns Beach Long Term Coastal Management Study aims to develop a number of management options, which will affect the results of any CHRMAP assessment.

Figure 11.1 Tertiary Sediment Cell 29b location figure

12. Tertiary Sediment Cell 29a Erosion Allowances

Tertiary Sediment Cell 29a extends approximately 4 km south from Mindarie Keys North to Burns Beach Salient. Sediment Cell 29a commences at Chainage 29,400 m in the north and ends to the south at Chainage 33,300 m, as shown in Figure 12.1.

Figure 12.1 Tertiary Sediment Cell 29a location figure

12.1 Coastal Classification

The beaches in Tertiary Sediment Cell 29a typically receive waves averaging around 1 m (Short 2006), which are likely to increase during stormy periods.

Through preliminary analysis of historical shoreline movements, MRA identified three coastal zones within Sediment Cell 29a exhibiting different long term shoreline movements or shoreline classification. These coastal zones are outlined below.

12.1.1 Zone 1

Zone 1 (Chainage 29,400 m to 30,200 m) is a rocky coast as defined by DPI (MRA 2005). An aerial photograph of Zone 1 is shown in Figure 12.2 on the northern side of Mindarie Marina.

Figure 12.2 Aerial photograph of Zone 1 & Zone 2 (WACoast)

12.1.2 Zone 2

Zone 2 (Chainage 30,300 m to 30,900 m) covers Mindarie Marina, which was constructed in 1989 along a rocky stretch of shoreline. The CHRMAP guidelines and the SPP2.6 do not provide specific guidance on appropriate erosion allowances for development behind marina breakwaters or behind internal revetments. The CHRMAP guidelines outlines the following.

Consideration of these coastal processes should be based on the coastal type and each of the factors listed for that coastal type and assessment methodology as outlined in Schedule One of SPP2.6.

Referring to Section 4.3 of Schedule One of the SPP2.6.

Development that benefits from protection from coastal hazards by formal coastal protection works should be determined on a case by case basis with the allowance for coastal processes taking into account the works in question.

In this case, development inside the marina will be protected from the coastal erosion processes and therefore erosion allowances do not need to be calculated. Nevertheless, on-going maintenance of the marina breakwaters and edge walls will be required to prevent future shoreline erosion.

12.1.3 Zone 3

Zone 3 (Chainage 29,400 m to 33,300 m) extends south from the southern breakwater of Mindarie Marina, as shown in Figure 12.3. This zone consists of a sandy shoreline with intermittent beach rock at the northern end. A change in shoreline direction exists around Chainage 33,000 m.

Figure 12.3 Aerial photograph of Zone 3 (WACoast)

The City of Wanneroo's southern local government boundary is located within Zone 3 at around Chainage 32,900 m.

12.2 Allowances for Erosion

12.2.1 S1 Erosion

SBEACH profiles were developed for each of the zones identified in the previous section as required. These are outlined in the following sections.

Zone 1

Zone 1 is classified as rocky coastline, which does not require determination of an S1 allowance under SPP2.6.

Zone 2

The assessment of Zone 2 (Mindarie Marina) to the requirements of SPP2.6 was previously discussed in Section 12.1.2.

Zone 3

An SBEACH profile was created at Chainage 32,000 m using the 2009 LiDAR data (Fugro 2009). SWAN wave model outputs from an offshore location were input into the SBEACH model as were the water levels recorded during the July 1996 storm. The peak significant wave height (Hs) during the passage of the storm was approximately 3.0 m in around 7 m of water. A D_{50} sediment size of 0.27 mm was input into the model using results from Stul (2005).

The results of the SBEACH modelling are presented in Figure 12.4.

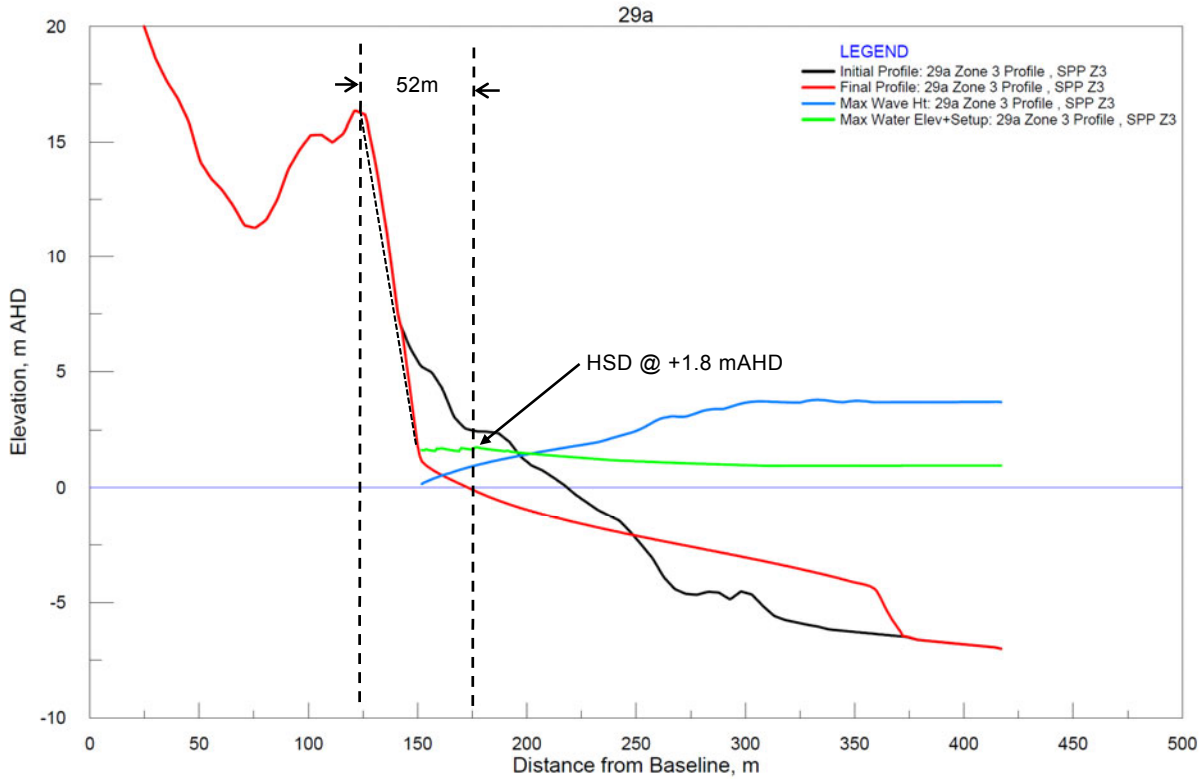

Figure 12.4 29a Zone 3 SBEACH model results

In this case, the HSD is +1.8 mAHD located approximately 9 m seaward of the coastal vegetation line. The modelled recession behind the HSD, including the 30° slope failure angle, is 52 m. Therefore, the S1 Erosion allowance Zone 3 of Tertiary Sediment Cell 29a is **52 m**.

12.2.2 S2 Erosion

A number of coastal vegetation lines were available for this stretch of coastline, including the 2014 coastal vegetation line. The positions of the coastal vegetation lines relative to 2014 were determined at 100 m chainages along the coast. This is presented in Figure 12.5.

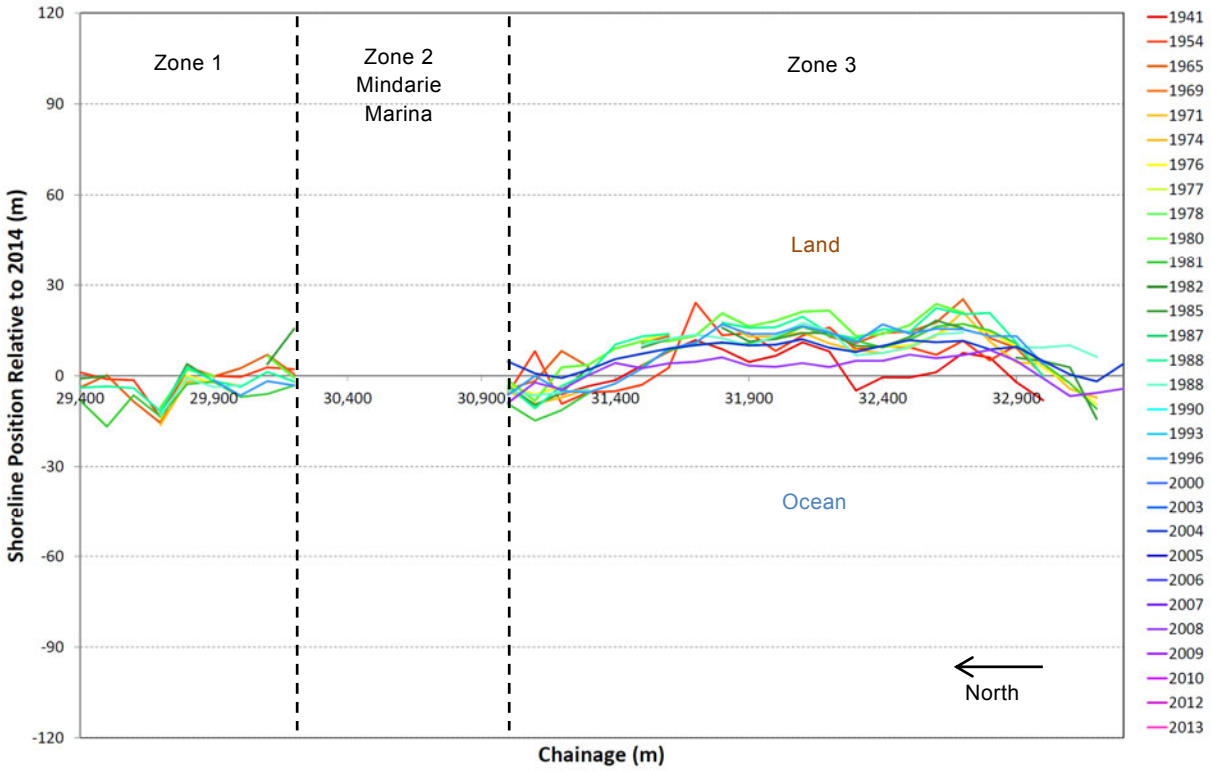

Figure 12.5 29a shoreline position relative to 2014

The annual shoreline movement rate to 2014 was calculated using the 1954 and 1971 vegetation lines. The 1954 vegetation line does not extend the full length of the sediment cell. These results are presented in Figure 12.6.

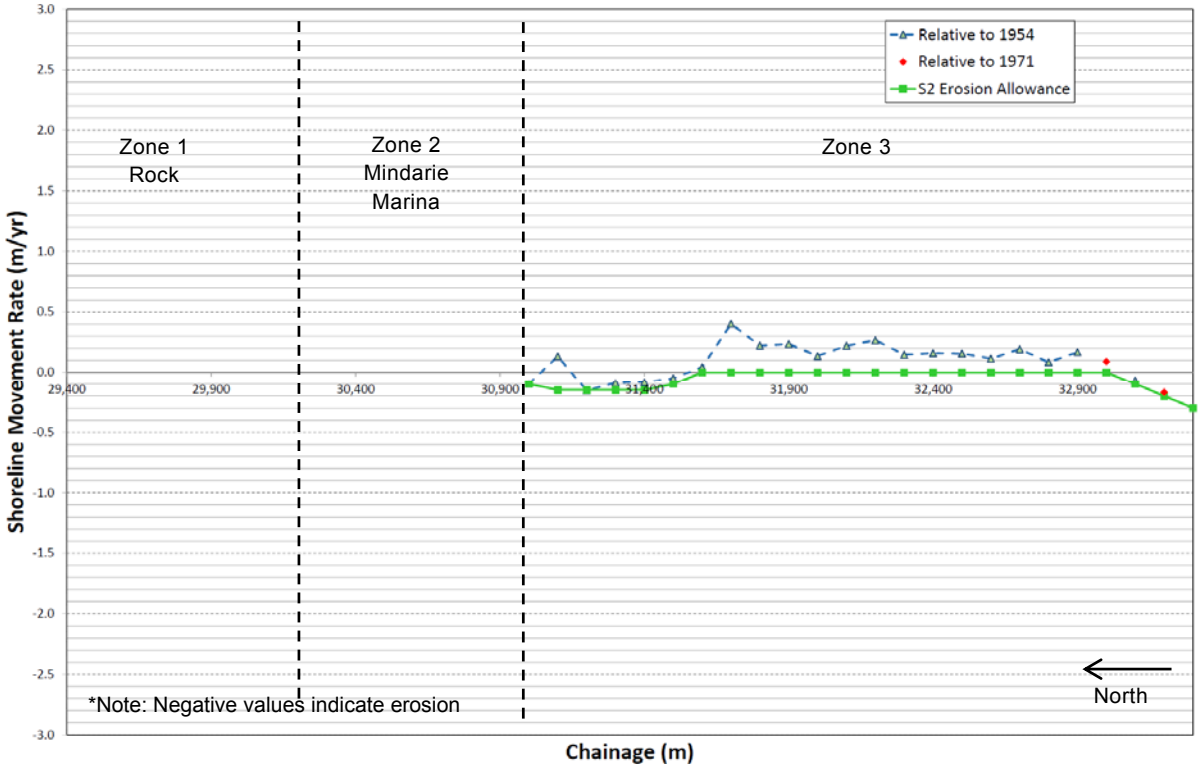

Figure 12.6 29a annual shoreline movement rate

The shoreline movements are discussed in further detail in the following sections.

Zone 1
Zone 1 is a rocky coast as classified by DPI (MRA 2005). Therefore, an S2 allowance is not relevant for this zone.

Zone 2
The assessment of Zone 2 (Mindarie Marina) to the requirements of SPP2.6 was previously discussed in Section 12.1.2.

Zone 3
Zone 3 has three different shoreline movement trends, which require different S2 erosion allowances as outlined below.

- The shoreline between Chainage 31,000 m and 31,500 m has generally experienced erosion of up to -0.15 m/yr since 1954. Therefore, an S2 Erosion allowance of **-0.15 m/yr** is recommended through this area.

- The shoreline between Chainage 31,600 m and 33,000 m has accreted by up to 0.4 m/yr since 1954. Given that most of the shoreline has accreted by less than 0.2 m/yr, an S2 Erosion allowance of **0 m/yr** is recommended through this area.

- The shoreline changes direction at around Chainage 33,000 m. The chainages south of this have generally eroded up to -0.3 m/yr. An S2 Erosion allowance of **-0.3 m/yr** is recommended for Chainage 33,300 m with transition allowances.

12.2.3 S3 Erosion
The S3 Erosion allowances for the range of planning timeframes were previously presented in Table 4.1.

12.2.4 Allowance for Erosion
The three erosion allowances are combined with a 0.2 m/yr allowance for uncertainty giving a total allowance for erosion. These allowances are presented in Appendix D for the range of planning timeframes.

12.3 Erosion Hazard Mapping
Using the work completed within Section 12.2, coastal hazard mapping has been completed to show the areas that could be vulnerable to coastal erosion over the designated timeframes. The maps are contained in Appendix C.

12.4 Sensitivity, Adaptive Capacity & Vulnerability to Erosion
Hazard mapping shows that man-made infrastructure may be at risk of coastal erosion within Zone 1 behind the rocky coast. The infrastructure and potential timeframe for erosion are outlined below.

- Sections of the coastal footpath may currently be at risk of erosion from wave overtopping. The extent of overtopping would depend on the level of the rock through the area. Even so, the impact of this overtopping on the coastal path is likely to be minimal, so this asset is not considered vulnerable to erosion.

- Some residential lots between Chainage 29,900 m and 30,200 m may be at risk of coastal erosion in approximately 50 to 60 years. The extent of erosion will be highly dependent on the strength of the rock through this area. A geotechnical investigation would be required to identify the strength of the rock and likely resistance to wave erosion effects.

Three high vulnerability ecological communities exist within Tertiary Sediment Cell 29a.

- The conservation listed flora species *Marianthus paralius,* is located behind rocky coast and is therefore not considered vulnerable to coastal erosion.

- A Priority Ecological Community is located between Chainages 30,800 m and 33,300 m. Around 30 to 40% of this community may be at risk of coastal erosion in the coming century. The Eco Logical report (2015) considered this community to have limited adaptive capacity and is therefore considered vulnerable to erosion.

- The Bush Forever Site 397 extends along the majority of the shoreline in Tertiary Sediment Cell 29a. Some of this site is located behind rock to the north of Mindarie Marina and is unlikely to be at risk of coastal erosion. Hazard mapping suggests the section south of Mindarie Marina may be at risk of erosion over the coming century. This area has been earmarked as the Tamala Conservation Park by DoP and WAPC (WAPC 2012), which is up to 1.5 km wide in locations. This area is unlikely to be developed in the future, allowing a significant area for conservation protection. Therefore, Bush Forever Site 397 is not considered vulnerable to erosion through this area.

No registered Aboriginal Heritage sites are located within the erosion exposure area Tertiary Sediment Cell 29a.

13. Inundation Allowance

SPP2.6 requires assessment of the potential exposure of areas to coastal inundation or coastal flooding. This is named the S4 Inundation allowance within the SPP2.6. The coastal inundation assessment is to be completed with reference to an event with a 0.2% chance of exceedance per year, which is akin to the 500 year ARI event.

A long term water level record is available from the Fremantle Harbours. MRA has previously reviewed this water level record and completed an extreme analysis on the data after de-trending for observed sea level rise. This assessment was completed for the most reliable period of record which is considered to be the period from 1950 to present. Results of the extreme analysis are provided in Figure 13.1.

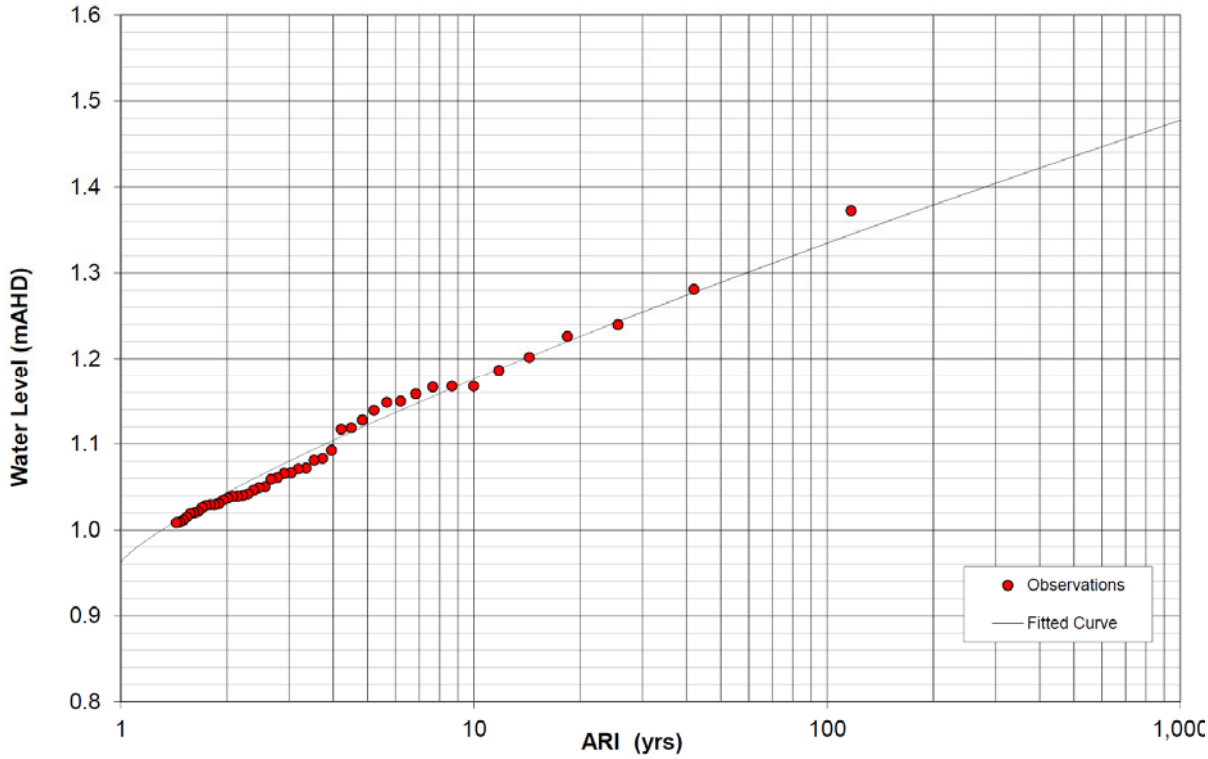

Figure 13.1 Results of extreme water level analysis for Fremantle

Using the results of the extreme analysis, the 500 year ARI event is estimated to be around +1.44 mAHD.

Two marinas are located along the Wanneroo shoreline; Two Rocks Marina and Mindarie Marina. Although the marina breakwaters provide protection from coastal erosion hazards, increased water levels due to storm surge will still be present within the protected waters of the breakwaters. This is because the water inside the breakwaters is hydraulically connected to the open ocean.

The coastal inundation levels outside the marina breakwaters are likely to be higher than inside due to the increased wave activity and associated wave setup, which is depicted in Figure 3.3. Therefore, it is necessary to assess these two cases separately, as their different exposure to the open ocean will result in different inundation levels. These inundation assessments are summarised in the following sections.

13.1 Open Ocean Shoreline

The extreme analysis presented in Figure 13.1 provides an estimate of the peak water levels observed within the Fremantle Fishing Boat Harbours, however on an exposed coastline other processes act to increase the peak steady water level – such as setup by waves breaking in the nearshore zone.

Dean and Walton (2008) provide a comprehensive review of investigations into the extent of wave setup on beaches. The review includes work by Hansen (1978); Guza and Thorton (1981); Holman and Sallenger (1985); Nielsen (1988); Davis and Neilsen (1988); King et al (1990); Yanagishima and Katoh (1990); Greenwood and Osborne (1990); Hanslow and Nielsen (1993); Lentz and Raubenheimer (1999); Raubenheimer, Guza and Elgar (2001) and Stockdon et al (2006). These investigations were completed on a variety of different beach types throughout the world, including in the North Sea, Japan, USA and Australia.

Results from each of the different investigations show varying levels of wave setup for a variety of reasons, including measurement difficulties. However, each of the studies indicated that wave setup does occur in the nearshore area. In particular, findings from many of the studies show that the majority of this setup occurs on the beachface.

Dean and Walton (2008) determined that, as an average over all of the studies, the amount of wave setup was approximately 0.19 times the significant wave height (standard deviation of 0.09). Furthermore, many of the studies found that maximum wave setup values (as opposed to average) were often in the order of half the breaking wave height.

Given the findings of the aforementioned investigations show that the majority of wave setup occurs on the beachface, this wave setup is not expected to be included in the water levels that have been recorded within the Fremantle Fishing Boat Harbour. This is due to the fact that the water level records within the Fremantle Fishing Boat Harbour have been recorded within waters that are sheltered from wave breaking effects, particularly those on a beachface. As a result, these recorded water levels would not include the nearshore wave effects. The effects of nearshore wave setup should therefore be added to the extreme water level determined from the Fremantle Fishing Boat Harbour records to provide a reasonable estimate of the peak steady water levels at Rockingham.

SBEACH modelling was completed with the 500 year ARI water level in conjunction with the approximate 5 year ARI wave height. This combination of wave and water levels is considered appropriate for the assessment of the 500 year ARI water level. Modelling the 500 year ARI wave height with the 500 year ARI water level is likely to result in a storm event with a return period of many thousands of years, which is considered overly conservative.

The SBEACH modelling suggests the nearshore wind and wave setup from the 5 m contour to the beach could range from around 0.9 m to around 1.4 m along the Wanneroo coastline.

As a result, the following potential inundation levels should be considered as part of the coastal hazard risk assessment and adaptation planning in order to comply with the requirements of SPP2.6. It should be noted that these levels do not include the potential effects of wave run-up, which may need to be considered for infrastructure located close to the beach face.

Table 13.1 Open ocean shoreline 500 year ARI inundation levels

Component	Present Day (2015)	2030	2050	2070	2090	2120
500 yr ARI water level in Fremantle Fishing Boat Harbour (mAHD)	+1.44	+1.44	+1.44	+1.44	+1.44	+1.44
Allowance for nearshore setup (wind and wave) (m)	1.36	1.36	1.36	1.36	1.36	1.36
Allowance for Sea Level Rise (m)	-	0.07	0.2	0.39	0.62	0.97
Total Water Level (mAHD)	**+2.8**	**+2.9**	**+3.0**	**+3.2**	**+3.4**	**+3.8**

New freehold development within the foreshore should be mindful of the potential inundation levels presented in Table 13.1.

A review of the present day risk of storm surge inundation was completed for the exposed, open ocean shoreline. The LiDAR survey (Fugro 2009) was compared to the calculated +2.8 mAHD inundation level. This review revealed the following assets/sites on the exposed shoreline may currently be at risk of inundation during the 500 year ARI storm surge event.

- Beach access paths between Chainage 6,100 to 6,300 m south of Two Rocks marina.
- "Yanchep Beach" and "Yanchep Lagoon" Aboriginal Heritage sites.

These types of assets are unlikely to be impacted by short term inundation, so they are not considered vulnerable. A similar review was completed for the 2120 storm surge inundation risk, with a +3.8 mAHD storm surge level. No additional assets were identified as potentially being inundated during the 500 year ARI storm surge event in 2120.

13.2 Marinas

Even with the protection of the breakwaters there is the potential for local wind and wave setup within the marinas. Winds blowing across the water inside the marina are likely to generate waves and subsequent wave setup, as well as causing wind setup, albeit on a much smaller scale than on the open ocean coastline. Local setup in the order of around 0.3 m could be expected in the 500 year ARI storm. Table 13.2 presents the 500 year ARI inundation levels for the range of planning timeframes within the marinas.

Table 13.2 Marina 500 year ARI inundation levels

Component	Present Day (2015)	2030	2050	2070	2090	2120
500 yr ARI water level in Fremantle Fishing Boat Harbour (mAHD)	+1.44	+1.44	+1.44	+1.44	+1.44	+1.44
Allowance for nearshore setup (wind and wave) (m)	0.30	0.30	0.30	0.30	0.30	0.30
Allowance for Sea Level Rise (m)	-	0.07	0.2	0.39	0.62	0.97
Total Water Level (mAHD)	**+1.7**	**+1.8**	**+1.9**	**+2.1**	**+2.4**	**+2.7**

Lower development levels may be appropriate for leasehold commercial and industrial development within marinas, depending on the nature of the development. For example, an industrial hard stand area, which has a requirement to be close to the water's edge and at a functionally lower level, may have a reduced development level. These areas may be inundated during extreme water level events but are unlikely to be impacted by short term inundation.

A review of the present day risk of storm surge inundation was completed for the land protected by the marina breakwaters and edge walls. The LiDAR survey (Fugro 2009) was compared to the calculated +1.7 mAHD inundation level. This review revealed the following assets/sites on the exposed shoreline may currently be at risk of inundation during the 500 year ARI storm surge event.

- Marina hardstand areas and boat ramp within Two Rocks marina. These types of assets are unlikely to be impacted by short term inundation, so they are not considered vulnerable.
- Promenade, internal beach and landscaping within Mindarie marina. Again, these types of assets are unlikely to be impacted by short term inundation, so they are not considered vulnerable.

A similar review was completed for the 2120 storm surge inundation risk, with a +2.7 mAHD storm surge level. The following additional assets may be at risk of inundation during the 500 year ARI storm surge event in 2120.

- The two sheds located on the Two Rocks marina hardstand area and a portion of the boat trailer parking on the eastern edge of the marina waterbody. The car-park is unlikely to be impacted by storm surge inundation, so is not considered vulnerable. The industrial sheds may be impacted by short term inundation, so these are considered vulnerable to inundation during the 500 year ARI storm surge event in 2120. A detailed survey of the finished floor level of these sheds would be required to determine the likely timeframe for initial inundation risk.

- Landscaped areas fronting some residential lots on the southern marina edge. These types of assets are unlikely to be impacted by short term inundation, so they are not considered vulnerable.

14. Summary & Conclusions

Specialist coastal engineers M P Rogers & Associates Pty Ltd were engaged by the City of Wanneroo to complete the first stage of the Coastal Hazard Risk Management and Adaptation Planning process – the coastal vulnerability assessment and hazard mapping.

The scope of this investigation covers the risk assessment component of the CHRMAP for the entire coastline within the City of Wanneroo, stretching from Tamala Park to north of Two Rocks. This investigation has included the following.

- Establishing the context for the coastal vulnerability assessment.
- Literature review and gap analysis of information currently available for the coastline.
- Completion of a coastal vulnerability assessment.
- Coastal erosion hazard mapping.

This report has presented the data, methodology, and results of this assessment. The manmade infrastructure, ecological systems and registered Aboriginal Heritage sites identified as vulnerable to coastal erosion and inundation are summarised in Table 14.1.

Table 14.1A Assets Vulnerable to Coastal Erosion & Inundation

Sediment Cell	Chainage	Asset Type	Description	Potential Vulnerability Timeframe
31a (Mallee Reef Salient to Wreck Point)	1,500 m to 2,100 m	Environmental	Priority Ecological Community	2030
	1,600 m to 6,200 m	Environmental	Bush Forever Site 397	Present Day
	4,300 m to 5,050 m	Infrastructure	Sovereign Drive & residential lots	From 2050
	5,300 m	Infrastructure	Two Rocks Marina sheds	Inundation timeframe unknown
30b (Wreck Point to Yanchep Headland North)	6,300 to 10,200 m	Environmental	Bush Forever Site 397	Present Day
	8,900 to 9,000 m	Infrastructure	Beach access road	2050[1]
30a (Yanchep Headland North to Yanchep)	10,300 to 14,400 m	Environmental	Bush Forever Site 397	Present Day
	11,000 to 11,500 m	Infrastructure	Capricorn Village car-park & building	2120
	11,500 to 11,600 m	Infrastructure	Car-park	2050
	12,400 m	Infrastructure	Buildings	2070

Notes: 1. Vulnerability dependent on extent, level & strength of rock at the rear of beach. Geotechnical investigations would be required to identify these factors.

Table 14.1B Assets Vulnerable to Coastal Erosion & Inundation

Sediment Cell	Chainage	Asset Type	Description	Potential Vulnerability Timeframe
30a (Yanchep Headland North to Yanchep)	12,500 m	Infrastructure	Existing Yanchep SLSC	2070
	12,700 m	Infrastructure	New Yanchep SLSC	Refer Cardno (2014)
	12,700 to 13,000 m	Infrastructure	Car-parks	2030[1]
	13,000 to 13,400 m	Infrastructure	Residential lots	From 2030[1]
	13,500 to 14,400 m	Infrastructure	Roads & residential lots	From 2070
29d (Yanchep to Alkimos)	14,500 to 20,700 m	Environmental	Bush Forever Site 397	Present Day
	14,500 to 15,000 m	Infrastructure	Roads & residential lots	From 2090
	20,100 to 20,300 m	Infrastructure	Roads	From 2090
29c (Alkimos to Quinns Rock North)	20,800 to 24,700 m	Environmental	Bush Forever Site 397	Present Day
	22,700 m	Aboriginal Heritage Site	"Karli Spring"	2050
29b (Quinns Rock North to Mindarie Keys North)	Sediment Cell 29b is not being assessed in this CHRMAP[2]			
29a (Mindarie Keys North to Burns Beach Salient)	29,400 to 33,300 m	Environmental	Bush Forever Site 397	Present Day
	29,900 to 30,200 m	Infrastructure	Residential lots	2050[1]
	30,800 to 33,300 m	Environmental	Priority Ecological Community	Present Day

Notes: 1. Vulnerability dependent on extent, level & strength of rock at the rear of beach. Geotechnical investigations would be required to identify these factors.
2. The Quinns Beach Long Term Coastal Management Study aims to develop a number of management options in this sediment cell, which will affect the results of any CHRMAP assessment.

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16. Appendices

Appendix A **Environmental Vulnerability Assessment (Eco Logical 2015)**

Appendix B **1909 HWM Survey**

Appendix C **Erosion Hazard Mapping**

Appendix D **Erosion Allowances**

Appendix E **1908 HWM Survey**

Appendix A Environmental Vulnerability Assessment (Eco Logical 2015)

City of Wanneroo Coastal Vulnerability Assessment Ecological Functions

Prepared for
M P Rogers and Associates

2 April 2015

DOCUMENT TRACKING

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Contents

List of figures

List of tables

Abbreviations

Abbreviation	Description
CoW	City of Wanneroo
DEC	Department of Environment and Conservation (now known as Department of Parks and Wildlife)
DoE	Department of the Environment
ELA	Eco Logical Australia
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999* (federal)
ESA	Environmentally Sensitive Area
km	Kilometres
MRA	M P Rogers and Associates
Parks and Wildlife	Department of Parks and Wildlife
PEC	Priority Ecological Community
SoW	Scope of Work
TEC	Threatened Ecological Community
WAH	Western Australian Herbarium
WC Act	*Wildlife Conservation Act 1950* (State)

1 Introduction

1.1 Project background

Eco Logical Australia Pty Ltd (ELA) was engaged by M P Rogers and Associates Pty Ltd (MRA) to undertake an assessment of ecological values that are considered conservation significant occurring along the City of Wanneroo (CoW) coastline. The study is to support the first phase of a Coastal Hazard Risk Management and Adaptation Plan which is being prepared by MRA for the CoW.

1.2 Scope and objectives

To fulfil the Scope of Works (SoW), MRA required a high level assessment to be undertaken of any ecological values that could be threatened by potential coastal erosion in the CoW. In order to fulfil the SoW the following was required:

- Undertake a desktop assessment to identify the type and location of ecological values that are considered conservation significant in the potential coastal erosion zone
- Conduct an assessment on the vulnerability of ecological values, including an assessment of the potential adaptive capacity of these values
- Provide a report summarising the above findings

2 Methods

2.1 Desktop assessment

A search of relevant databases and data sources was conducted to gain information about ecological values occurring or potentially occurring within the coastal erosion influence zone. Searches were conducted to identify any conservation listed flora and fauna species and vegetation communities as well as any conservation areas. The following data sources were queried to obtain this information:

- Department of Parks and Wildlife (Parks and Wildlife) and Western Australian Museum's NatureMap online database (Parks and Wildlife 2015)
- Western Australian Herbarium's (WAH) FloraBase (WAH 2015)
- Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) Protected Matters Search Tool (Department of the Environment [DoE] 2015a)
- Vegetation complex mapping (Heddle et al 1980)
- Landgate SLIP Public Web Map Service (State of Western Australia 2015)

For each ecological value identified, the following contextual information was also obtained through review of scientific papers and databases to assist with assessment of vulnerability and adaptive capacity:

- Key habitat requirements
- Current known distribution within CoW and across entire range
- Number of known records within CoW and across entire known range

Conservation codes, categories and criteria for flora and fauna protected under the EPBC Act and *Wildlife Conservation Act 1950* (WC Act) can be found in Appendix A.

2.2 Vulnerability assessment

The potential adaptive capacity and vulnerability/susceptibility to loss for each of the ecological values identified in the desktop assessment was determined through consideration of the following factors:

- Whether required habitat/s are restricted to the potential coastal erosion influence zone or occur inland
- Where majority of records occur i.e. within coastal zone or inland
- Whether records are restricted to CoW or occur/can occur (e.g. fauna) elsewhere
- Whether records occur outside of coastal zone (may indicate potential for adaptive capacity)
- Known range of occurrence of records
- Number of known records
- For fauna, the mobility of species

From this assessment a vulnerability score was determined for each ecological value to highlight values most susceptible to loss from coastal erosion. The scores and criteria used to determine each is presented in Table 1.

Table 1: Vulnerability scoring criteria

Susceptibility to loss criteria	Vulnerability Score
Ecological value has high adaptive capacity, is known to occur across a broad range not limited to the coastal environment and is known from numerous records	Low
Ecological value may potentially be affected as records are restricted to coastal environment and/or has scope for adaptive capacity	Moderate
Ecological value known only from potential coastal erosion zone in CoW, has few known records, and is unlikely to have adaptive capacity	High

3 Desktop review

3.1 Study area

The study area is approximately 30 km long, covering the full extent of the CoW coastline from Tamala Park to north of Two Rocks. The study area also extends approximately 500 m inland to capture the landward distance of potential coastal erosion influence.

3.2 Existing environmental overview

3.2.1 Vegetation

Vegetation within the Perth metropolitan area has been described by Heddle et al. (1980) as vegetation complexes. The study area comprises two vegetation complexes: The Quindalup Complex and the Cottesloe Complex – Central and South. The area of each complex that occurs within the study area is presented in Table 2 and the descriptions for each are as follows:

- Quindalup Complex – Coastal dune complex consisting mainly of two alliances – the strand and fore-dune alliance and the mobile and stable dune alliance. Local variations include the low closed forest of *Melaleuca lanceolata – Melaleuca preissii* and the closed scrub of *Acacia rostellifera* (Heddle 1980)
- Cottesloe Complex – Central and South – Mosaic of woodland of *Eucalyptus gomphocephala* and open forest of *E. gomphocephala – E. marginata – E. calophylla*; closed heath on the Limestone outcrops (Heddle 1980)

Table 2: Vegetation complexes within the study area

Complex	Extent overall (ha) (% within study area)	Extent in City of Wanneroo (ha) (% within study area)	Extent within study area (ha)
Quindalup Complex	21,322.64 (0.52 %)	5,989.69 (1.85 %)	110.92
Cottesloe Complex - Central and South	15,815.73 (9.34 %)	6,122.77 (21.13 %)	1477.34

3.2.2 Conservation listed flora

Ten conservation listed flora species were returned by the database search as occurring or having the potential to occur within the study area (Table 3). There was one species listed as Threatened (WC Act) and Vulnerable (EPBC Act), one species listed as Threatened (WC Act), one species listed as Priority 1, one as Priority 2, five species as Priority 3 and one species as Priority 4. Of these species, seven are currently known to occur within the study area.

3.2.3 Conservation listed fauna

Seven conservation listed fauna species were returned by the database searches as being recorded or having the potential to utilise habitat within the study area (Table 4). There was one species listed as Threatened (WC Act) and Endangered (EPBC Act), four species listed as Priority (included Priority 1,

Priority 3, Priority 4 and Priority 5), one species listed as Specially Protected (WC Act) and one species listed as Migratory.

3.2.4 Conservation significant vegetation

Threatened Ecological Communities (TECs) are described as biological flora or fauna assemblages occurring in a particular habitat, which are under threat of modification or destruction from various processes (Department of Environment and Conservation [DEC] 2010). TECs are significant at the State level and are listed as Environmentally Sensitive Areas (ESAs) under Schedule 5 of the EP Act (see Appendix A). Twenty-three of the 69 TECs listed in Western Australia are also nationally recognised under the EPBC Act.

Three TECs were identified from the database searches as occurring or having the potential to occur within the study area. Of these, two are listed as Critically Endangered under the WC Act and Endangered under the EPBC Act while the remaining community is listed under the WC Act only as Endangered (Table 5).

Priority Ecological Communities (PECs) are biological flora or fauna communities that are recognised to be of significance, but do not meet the criteria for a TEC. There are five categories of PECs, none of which are currently protected under legislation (see Appendix A).

Two PECs were identified as occurring or having the potential to occur, both of which are currently listed as Priority 3 (Table 5).

Table 3: Conservation listed flora species returned by the database searches and habitat and distribution information for each

Species	Conservation Status		Habitat	Distribution
	WC Act / Parks and Wildlife	EPBC Act		
Eucalyptus argutifolia (Wabling Hill Mallee)	T	Vu	Grows in shallow soils over limestone and on slopes or gullies of limestone ridges and outcrops.	Known from 63 records on NatureMap and 39 records in Florabase. Found on the Swan Coastal Plain over 275 km from Jurien Bay to Lake Clifton. Mostly occurs around the Perth metropolitan area. It is found along coast however there are also records up to 13 km inland. Most records occur from 3-13 km from coast. This species has been recorded at one location within the study area.
Marianthus paralius	T		Grows in dry white sand over limestone.	Known from 9 records on NatureMap and 6 records in Florabase. Found on the Swan Coastal Plain over a range of 65 km from Seabird in the north to Joondalup in the south. Most occurrences are around Seabird and almost all records are on the coast; one record does however occur 3 km inland. Currently there is only one known record of this species in the CoW; it is within Kinsale Park which is within the study area.
Leucopogon maritimus	P1		Grows on slopes/upper slopes of coastal dunes in dry sand.	Known from 17 records on NatureMap and 17 records in Florabase. Known only from the Swan Coastal Plain over a range of 70 km. Found in the Local Government Areas of Gingin, Joondalup and Wanneroo. Occurrences are mostly along the coast however there are some records which are up to 5 km inland. This species has been recorded at six locations within the study area.

Species	Conservation Status		Habitat	Distribution
	WC Act / Parks and Wildlife	EPBC Act		
Fabronia hampeana (A type of Moss)	P2		Grows on *Macrozamia.*	Known from 13 records on NatureMap and 6 records in Florabase. Found along the WA coast from Eneabba to Esperance however mostly occurs around Perth Metropolitan area. Most records occur 1 - 3.5 km from coast. Very few records occur within 500 m of coast.
Calandrinia oraria	P3		Grows on coastal sand dunes.	Known from 9 records on NatureMap and 9 records in Florabase. Occurs over a range of 280 km from Greens Head in the north to Singleton in the south. Most records are in the Shire of Gingin. Only one record occurs within the CoW and it is approximately 1 km from the coast. There is a record up to 8 km inland however most are in close proximity to the coast.
Hibbertia spicata subsp. *leptotheca*	P3		Grows in sand and near-coastal limestone ridges, outcrops & cliffs.	Known from 64 records on NatureMap and 35 records in Florabase. Occurs over a range of 600 km, from Kalbarri in the north to Mandurah in the south. Most records are located around the Perth metropolitan area. Records are scattered from the coast up to 15 km inland. This species has been recorded at one location within the study area.
Leucopogon sp. Yanchep (M. Hislop 1986)	P3		Grows in light grey-yellow sand, brown loam, limestone, laterite and granite on coastal plains, breakaways, valley slopes and low hills.	Known from 30 records on NatureMap and 30 records in Florabase. Occurs over a range of approximately 120 km from Dandaragan in the north to Wanneroo in the south. Most records are located in the CoW and Shire of Gingin. Mostly occurs inland rather than on the coast. Found up to 25 km inland from the coast. This species has been recorded at one location within the study area.

Species	Conservation Status		Habitat	Distribution
	WC Act / Parks and Wildlife	EPBC Act		
Sarcozona bicarinata	P3		Grows in white/grey sand over rocky limestone outcrops.	Known from 8 records on NatureMap and 5 records in Florabase. Occurs over a range of 50 km from Seabird in the north to Wanneroo in the south. There is one record in the City of Wanneroo, located approximately 1.5 km inland from the coast. All current known records occur from the coast up to 2.5 km inland.
Stylidium maritimum	P3		Grows in coastal heath and shrubland and open *Banksia* woodland.	Known from 82 records on NatureMap and 39 records in Florabase. Occurs over a range of 365 km from Eneabba in the north to Mandurah in the south. Records are scattered throughout the Swan Coastal Plain and occur from the coast and up to 20 km inland. This species occurs at two locations within the study area.
Conostylis pauciflora subsp. *euryrhipis*	P4		Grows in white, grey or yellow sand on consolidated dunes.	Known from 53 records on NatureMap and 25 records in Florabase. Occurs over a range of 145 km from Cervantes in the north to Wanneroo in the south. There is also an outlier record located near Northam. Most records are from Lancelin to Wanneroo and records are scattered from immediately adjacent to the coast to 10 km inland. This species occurs at two locations within the study area.

Table 4: Conservation listed fauna species returned by the database searches and habitat and distribution information for each

Species	Conservation Status		Habitat	Distribution
	WC Act / Parks and Wildlife	EPBC Act		
Calyptorhynchus latirostris (Carnaby's Cockatoo (short-billed black-cockatoo), Carnaby's Cockatoo)	T	En	Carnaby's Black-Cockatoo mainly occurs in uncleared or remnant native eucalypt woodlands, especially those that contain Salmon Gum (*Eucalyptus salmonophloia*) and Wandoo (*E. wandoo*), and in shrubland or kwongan heathland dominated by *Hakea*, *Dryandra*, *Banksia* and *Grevillea* species (DoE 2015b). It is a seasonal visitor to plantations of exotic pines (*Pinus spp*.), and sometimes occurs in forests containing Marri (*Corymbia calophylla*), Jarrah (*Eucalyptus marginata*) or Karri (*E. diversicolor;* DoE 2015b).	Carnaby's Black-Cockatoo is endemic to, and widespread in, the south-west of Western Australia.
Bothriembryon perobesus (land snail)	P1		Limited habitat information available for this species; however record which was found in CoW was found in sedgeland (Parks and Wildlife 2015)	Known from three locations across a range of 95 km; one of the locations is within the CoW. Even though there is a record of this species within CoW, this species is not recognised as occurring within the south-west on the most current Parks and Wildlife conservation listed fauna list. The record in the CoW is also of moderate certainty, so it is possible that it has been misidentified and does not occur in the area.

Species	Conservation Status		Habitat	Distribution
	WC Act / Parks and Wildlife	EPBC Act		
Neelaps calonotos (Black-striped Snake)	P3		Found in *Banksia* woodlands and sandy areas (Atlas of Living Australia 2015).	Known from 212 locations from Dongara in the north to Mandurah in the south. Locations are scattered throughout the Swan Coastal Plain.
Synemon gratiosa (Graceful Sunmoth)	P4		Found in open areas of herbland, heathland and shrubland on secondary Quindalup dunes containing *Lomandra maritima* and *Banksia* woodland with *L. hermaphrodita* (DoE 2015c)	Known from 956 records over 600 km from Kalbarri in the north to Binningup in the south
Isoodon obesulus subsp*. fusciventer* (Quenda, Southern Brown Bandicoot)	P5		Associated with wetlands on the Swan Coastal Plain (DEC 2012a)	Known to occur across the entire south-west of Western Australia
Morelia spilota subsp*. imbricata* (Carpet Python)	S		Known to occur in semi-arid coastal and inland habitats consisting of *Banksia* woodland, eucalypt woodlands, and grasslands (DEC 2012b).	Known from 423 records across the south-west of Western Australia
Merops ornatus (Rainbow Bee-eater)	IA	M	Occurs in a variety of habitats but mainly in open forests and woodlands, shrublands, and in various cleared or semi-cleared habitats, including farmland and areas of human habitation (DoE 2015c)	Distributed across much of mainland Australia.

Table 5: Conservation listed vegetation communities occurring within or in close proximity to the study area, their descriptions and known extent

Community	Status		Description	Extent
	WC ACT / Parks and Wildlife	EPBC Act		
Aquatic Root Mat Community Number 1 of Caves of the Swan Coastal Plain	T/Cr	En	At Yanchep and on the Leeuwin Naturaliste Ridge, permanent streams and pools occur in caves and some support dense growths of root mats (English et al 2000). The root mats provide a constant and abundant primary food source for some of the richest aquatic cave communities known (English et al 2000).	Only occur within the City of Wanneroo in caves at Yanchep National Park. Buffer of TEC occurs within the study area
Woodlands over sedgelands in Holocene dune swales of the southern Swan Coastal Plain (original description; Gibson et al. (1994).	T/Cr	En	Sedgelands in Holocene dune swales community occurs in linear damplands and occasionally sumplands, between Holocene dunes (DEC 2011). Typical and common native species are the shrubs *Acacia rostellifera, Acacia saligna, Xanthorrhoea preissii,* the sedges *Baumea juncea, Ficinia nodosa, Lepidosperma gladiatum*, and the grass *Poa porphyroclados* (DEC 2011).	The present known extent is approximately 193 ha mostly occurring between parallel sand ridges of the Rockingham-Becher Plain; there are also some small occurrences at Yanchep and Dalyellup. Occurrence in City of Wanneroo is approximately 4 km inland from coast. Buffer of TEC occurs within the study area (DEC 2011).

Community	Status		Description	Extent
	WC ACT / Parks and Wildlife	EPBC Act		
Melaleuca huegelii - Melaleuca acerosa (currently *M. systena*) shrublands on limestone ridges (Gibson et al. 1994 type 26a)	T/En		Occurs on skeletal soil on ridge slopes and ridge tops and is known from massive limestone ridges around Yanchep north of Perth and South of Perth near Lake Clifton (Luu and English 2005).	Currently known from a total of 164 ha. Of this, 8 ha from Parks and Wildlife reserves, 26 ha is in National Parks, 106 ha is in State forest (most of which is proposed to be changed to National Park or conservation reserves) and 8 ha is under the care, control and management of other authorities (mainly LGA's; Luu and English 2005). The study area does not contain a mapped occurrence or is within the buffer however, there are known occurrences in close proximity
Acacia shrublands on taller dunes (29b)	P3		Community is dominated by *Acacia* shrublands or mixed heaths on the larger dunes. No consistent dominant but species such as *Acacia rostellifera*, *Acacia lasiocarpa*, and *Melaleuca acerosa* were important (Parks and Wildlife 2014).	This community stretches from Seabird to south of Mandurah. Known to occur within the study area.
Coastal shrublands on shallow sands (29a)	P3		Mostly heaths on shallow sands over limestone close to the coast. No single dominant but important species include *Spyridium globulosum*, *Rhagodia baccata*, and *Olearia axillaris* (Parks and Wildlife 2014).	This community occurs along the coastal areas of the Swan Coastal Plain and is known to occur within the study area.

3.2.5 Environmentally Sensitive Areas

Environmentally Sensitive Areas are defined in the Environmental Protection (Environmentally Sensitive Areas) Notice 2005 under section 51B of the WA state EP Act. ESAs include areas declared as: World Heritage; included on the Register of the National Estate[1] ; defined wetlands; vegetation containing rare (Threatened) flora; TECs; and Bush Forever sites.

In addition to the TECs and Threatened flora discussed in previous sections, ESAs also occur within the study area for Bush Forever sites. Three Bush Forever sites occur within the study area; the extent of each within the study area and extent overall is presented in Table 6 below.

Table 6: Bush Forever sites occuring within the study area

Reserve/Conservation Area	Area (ha) within study area	Overall extent (ha)
Bush forever site 322	132	407.9
Bush forever site 397	436	552.2
Bush forever site 289	46	551.5

[1] Note the Register of National Estate was closed in 2007 and is no longer a statutory list. The Register of National Estate has been replaced by the National Heritage List under the EPBC Act.

4 Results and Discussion

4.1 Conservation listed flora

One conservation listed flora species, *Marianthus paralius*, was scored as having high vulnerability to potential coastal erosion (Table 7).

Marianthus paralius is a Threatened (WC Act) flora species known from nine records in NatureMap (Parks and Wildlife 2015). All of the current known records occur on the Swan Coastal Plain over a range of 65 km. In the CoW, one record is known to occur and it is located in the potential coastal erosion influence zone (Figure 1). Two records also occur to the south, 6 km and 9 km away; no further records occur within 50 km, with the remainder located around the town of Seabird. Key habitat for this species occurs along coastal areas and almost all of the known records are restricted to within 500 m of the beach zone. The high vulnerability score was assigned to this species on the basis that there is only one record within the CoW and there are few other records nearby and overall. Furthermore as this species is restricted to coastal areas, the majority of known records are likely to be impacted by coastal erosion which would likely affect the conservation status of this species. This species is also unlikely to have good adaptive capacity as its key habitat occurs in coastal environments which would be subject to coastal erosion.

Two conservation listed flora species, *Leucopogon maritimus* and *Calandrinia oraria*, were scored as having moderate vulnerability to coastal erosion (Table 7).

Leucopogon maritimus is a Priority 1 flora species known from 17 records in NatureMap (Parks and Wildlife 2015). All of the current known records of this species occur over a range of 40 km and all except three occur within the CoW. Key habitat for this species is coastal dunes; however it is not entirely restricted to coastal areas with some records occurring up to 5 km inland. As a third of the known records occur within the coastal erosion influence zone, impacts to these occurrences would likely affect the conservation status of this species. The vulnerability is however considered to be moderate as there is scope for this species to have good adaptive capacity given there are several occurrences beyond the coastal erosion influence zone.

Calandrinia oraria is listed as a Priority 3 flora species and is known from nine records in NatureMap (Parks and Wildlife 2015). The current known records of this species occur over a range of 280 km with records sparsely distributed over this distance. In the CoW, there is one record of this species and it is located in proximity to the coastal erosion influence zone. Many records of this species are located within areas which are likely to be subject to coastal erosion, and as there are so few current known records of this species, any impacts are likely to affect its conservation status. Vulnerability of this species is however deemed to be moderate as it may also have good adaptive capacity as some records occur inland, indicating it is not entirely restricted to coastal habitat. Furthermore, given this species' large range, it is also likely that further surveys would find additional records of this species.

All remaining conservation listed flora species identified in the desktop assessment were assessed as having low vulnerability to coastal erosion and were also likely to have good adaptive capacity (Table 7). Figure 2 displays areas where flora values have moderate vulnerability and Figure 3 shows the location of flora values with low vulnerability.

4.2 Conservation listed fauna

No conservation listed fauna species were assessed as having high vulnerability (Table 8).

Two species, Carnaby's Cockatoo (*Calyptorhynchus latirostris*) and Land Snail (*Bothriembryon perobesus*) were assessed as having moderate vulnerability (Table 8).

Carnaby's Cockatoo is a highly mobile species however if breeding habitat occurs nearby then the study area could provide potential foraging habitat. This species was assessed as having moderate vulnerability as foraging habitat near breeding areas are important food sources and any impacts may affect the survival of offspring of birds that utilise this area.

The Land Snail (*Bothriembryon perobesus*) is currently known from three records in NatureMap, one of which occurs within the coastal erosion influence zone in the CoW (Parks and Wildlife 2015). This species is not recognised as occurring within the south-west on the most current Parks and Wildlife conservation listed flora list. The record that occurs in CoW is also only of moderate certainty, so it is possible that it has been misidentified and does not occur in the area. There is also limited knowledge about its habitat requirements. If however the identification is correct and the species does occur in the area, it could potentially be impacted.

All remaining conservation listed fauna species are highly mobile and habitats are not restricted to coastal areas, they are therefore considered to have low vulnerability (Table 8). Figure 2 displays areas where fauna values have moderate vulnerability and Figure 3 shows the location of fauna values with low vulnerability.

4.3 Conservation significant vegetation

All of the TECs are considered to have low vulnerability (Table 9; Figure 3).

Both of the PECs identified in the desktop assessment were assessed as having high vulnerability (Table 9). Both the *Acacia* shrublands on taller dunes (29b) PEC and Coastal shrublands on shallow sands (29a) PEC (both Priority 3 communities), are restricted to habitat within the potential coastal erosion influence zone (Figure 1). Resultantly any impacts to this area will directly impact these PECs. These PECs are also likely to have limited adaptive capacity due to their specific habitat requirements being associated with coastal areas.

4.4 Environmentally Sensitive Areas

The ESA for Bush Forever Site 397 is considered to have high vulnerability as almost the entire area of this site is within the potential coastal erosion influence zone (Figure 1).

The remaining Bush Forever Sites (Site 322 and Site 289) are considered to have moderate vulnerability as both are partly within the potential coastal erosion influence zone (Figure 2). Approximately 32 % of Bush Forever Site 322 and 8 % of Bush Forever Site 289 is within the potential erosion influence zone.

Threatened flora and TECs, which are also considered to be ESAs, are discussed in the sections above.

Table 7: Conservation listed flora vulnerability assessment

Species	Conservation Status		Adaptive capacity	Sensitivity to loss	Vulnerability score
	WC Act / Parks and Wildlife	EPBC Act			
Eucalyptus argutifolia (Wabling Hill Mallee)	T	Vu	Likely to have good adaptive capacity as it is found frequently inland beyond 500 m from coastline.	While there is one record occurring within the coastal erosion influence zone, this species is unlikely to be sensitive to loss as it is not restricted to coastal habitats and frequently occurs inland. The species is also well represented in the CoW and loss of the location within the study area will not affect its occurrence in the area.	Low
Marianthus paralius	T		Unlikely to have good adaptive capacity as key habitat is restricted to coastal areas.	The record within the CoW is within the coastal erosion influence zone and is likely to be impacted. As this is currently the only known record in CoW and this species is not known from many records, it is likely to be sensitive to loss.	High
Leucopogon maritimus	P1		Could potentially have adaptive capacity as it is known to occur inland.	Of the current known records of this species, six occur within the coastal erosion influence zone; these constitute approximately a third of the current known records of this species. Impact to these six records could potentially affect the conservation status of this species if it could not be successfully established elsewhere and/or no further records are found inland.	Moderate

Species	Conservation Status		Adaptive capacity	Sensitivity to loss	Vulnerability score
	WC Act / Parks and Wildlife	EPBC Act			
Fabronia hampeana	P2		Likely to be successful as it is known to occur inland more than 500 m from the coast.	Unlikely to be impacted as not restricted to area adjacent to the coast, it occurs mostly inland.	Low
Calandrinia oraria	P3		It could potentially have good adaptive capacity as it is known to occur beyond 500 m inland from the coast	There is one record of this species in the CoW and it could potentially be impacted due to its proximity to the coastline. Although the species has a large range, almost all the records are in close proximity to the coast.	Moderate
Hibbertia spicata subsp. *leptotheca*	P3		Likely to have good adaptive capacity as it is found frequently inland beyond 500 m from coastline.	Unlikely to be impact as this species' has a large range, is not entirely restricted to coastal areas and is known from numerous records. In the CoW, while one record occurs within the study area, there are several other records outside occurring from 800 m to 4.5 km from the coast.	Low
Leucopogon sp. Yanchep (M. Hislop 1986)	P3		Likely to have good adaptive capacity as it is not restricted to coastal type habitats and occurs in a variety of habitats	Although there is one current record within the coastal erosional influence zone, any impacts to this record are unlikely to affect this species' conservation status as it is well represented in the CoW and most records occur outside the coastal zone. Furthermore this species is known from numerous records over a large range.	Low

Species	Conservation Status		Adaptive capacity	Sensitivity to loss	Vulnerability score
	WC Act / Parks and Wildlife	EPBC Act			
Sarcozona bicarinata	P3		Likely to have good adaptive capacity as it is found frequently inland beyond 500 m from coastline.	It is unlikely that the record in the CoW would be impacted given it is beyond 500 m from the coast. It is unlikely this species would be impacted as it is known to occur inland up to 2.5 km from the coastal area.	Low
Stylidium maritimum	P3		Likely to have good adaptive capacity as it is found frequently inland beyond 500 m from coastline.	It is unlikely that impacts to the two records of this species occurring within the study area would affect its conservation status as it is well known across its range and is not restricted to areas immediately adjacent to the coast, with some records occurring up to 20 km inland.	Low
Conostylis pauciflora subsp. *euryrhipis*	P4		Likely to have good adaptive capacity as it is found frequently inland beyond 500 m from coastline.	Although two records of this species are currently known to occur within the study area, it is unlikely the conservation status of this species would be impacted as it is known from numerous records over a large range; many of which are separated from the coastal area. This species also occurs frequently in the CoW.	Low

Table 8: Conservation listed fauna vulnerability assessment

Species	Conservation Status		Adaptive capacity	Sensitivity to loss	Vulnerability score
	WC Act / Parks and Wildlife	EPBC Act			
Calyptorhynchus latirostris (Carnaby's Cockatoo (short-billed black-cockatoo), Carnaby's Cockatoo)	T	En	This species is mobile and could use other areas nearby for foraging, however if there is breeding habitat nearby then this potential foraging habitat could be part of an important food source and any impacts may affect the survival of offspring of birds that utilise this area.	There is some potentially suitable foraging habitat for this species that may be impacted. Occurrence of birds that utilise are could potentially be sensitive to habitat loss	Moderate
Bothriembryon perobesus (land snail)	P1		Likely to have limited adaptive capacity.	If this species does occur in the area there is the potential for it to be impacted as there are very few known records and there is limited knowledge about its habitat requirements.	Moderate
Neelaps calonotus (Black-striped Snake)	P3		Likely to have high adaptive capacity as suitable habitat extends inland.	Unlikely to be impacted as has a large distribution and occurs in habitats that are not restricted to the area immediately adjacent to coast.	Low
Synemon gratiosa (Graceful Sunmoth)	P4		Likely to be high as habitat extends inland	Likely to impact some habitat however unlikely to significantly impact species as habitat also occurs inland	Low

Species	Conservation Status		Adaptive capacity	Sensitivity to loss	Vulnerability score
	WC Act / Parks and Wildlife	EPBC Act			
Isoodon obesulus subsp. *fusciventer* (Quenda, Southern Brown Bandicoot)	P5		Potentially high as is mobile and can utilise habitats elsewhere	Unlikely to be impacted, habitat is marginal along the coast and it is not restricted to coastal vegetation but rather occurs in a variety of habitat types across the south-west of Western Australia	Low
Morelia spilota subsp. *imbricata* (Carpet Python)	S		Potentially high as uses a variety of habitat types.	Unlikely to be impacted as has a large distribution and occurs in habitats that are not restricted to the coastal area.	Low
Merops ornatus (Rainbow Bee-eater)	IA	M	Highly adaptable as uses a variety of habitat types.	This species is unlikely to be impacted as it is highly mobile and utilises a variety of habitats	Low

Table 9: Conservation significant vegetation vulnerability assessment

Community	Status		Adaptive capacity	Sensitivity to loss	Vulnerability score
	WC ACT / Parks and Wildlife	EPBC Act			
Aquatic Root Mat Community Number 1 of Caves of the Swan Coastal Plain	T/Cr	En	Will have low adaptive capacity as this community occurs in a very specific habitat of which is highly restricted	Unlikely to be impacted as community is 5 km from coast; only buffer occurs within the study area	low
Woodlands over sedgelands in Holocene dune swales of the southern Swan Coastal Plain (original description; Gibson et al. (1994)	Cr	En	Potential adaptive capacity	Unlikely to be impacted as community is 4 km from coast; only buffer occurs within the study area	low
Melaleuca huegelii - Melaleuca acerosa (currently *M. systena*) shrublands on limestone ridges (Gibson et al. 1994 type 26a)	T/En		Likely to have adaptive capacity as habitat also occurs inland.	Currently there are no mapped occurrences of this TEC within the study area, however there is the potential for it to occur. This community is unlikely to be sensitive to loss as most occurrences are inland and its habitat is not restricted to the coastal area.	low
Acacia shrublands on taller dunes (29b)	P3		Could potentially have adaptive capacity if dune systems remain intact	Likely to be sensitive as this community is restricted to coastal dunes.	High
Coastal shrublands on shallow sands (29a)	P3		Unlikely to have adaptive capacity as habitat is specific to coastal area	Likely to be sensitive as this species is associated with coastal habitats	High

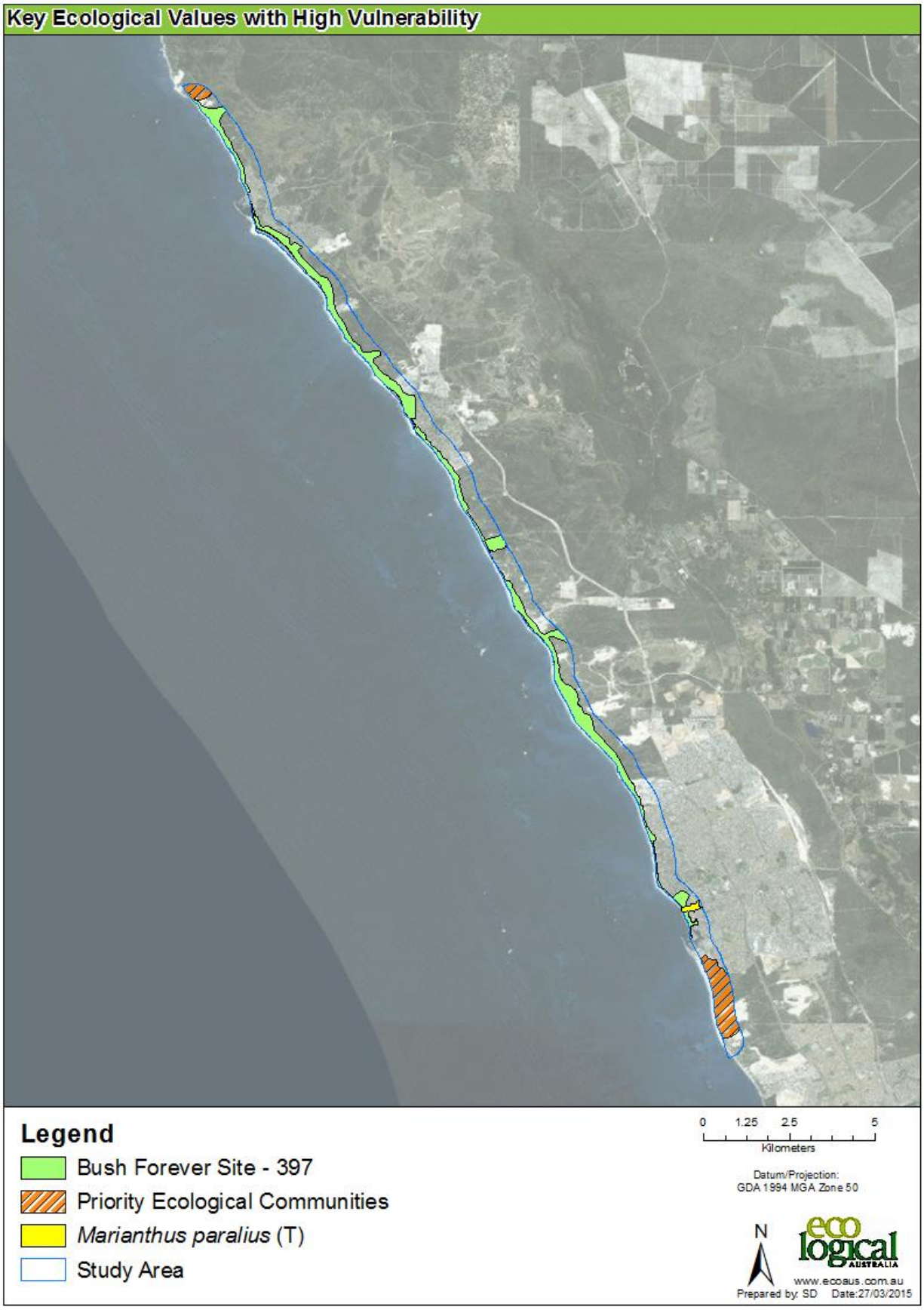

Figure 1: Key ecological values with high vulnerability

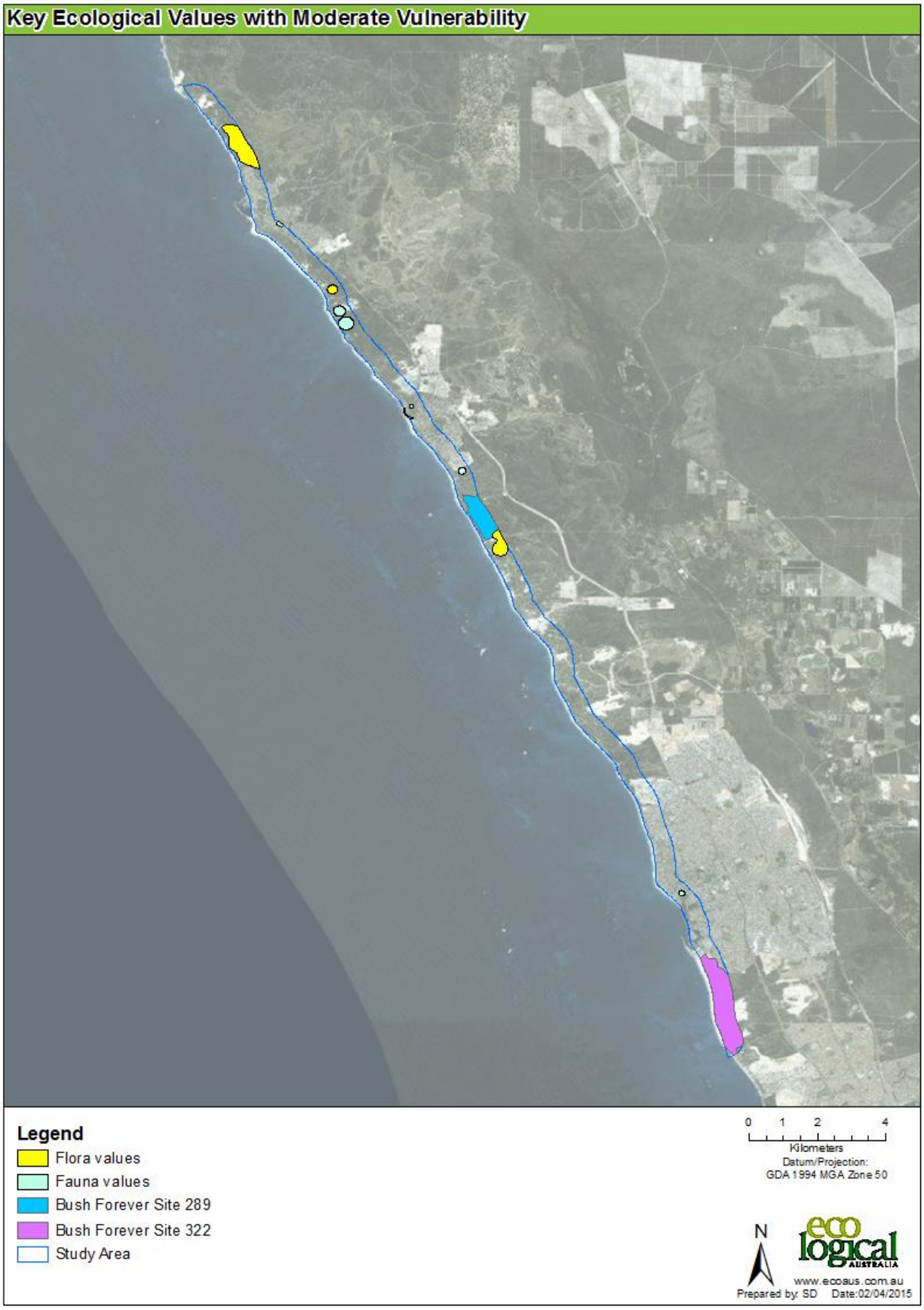

Figure 2: Key ecological values with moderate vulnerability

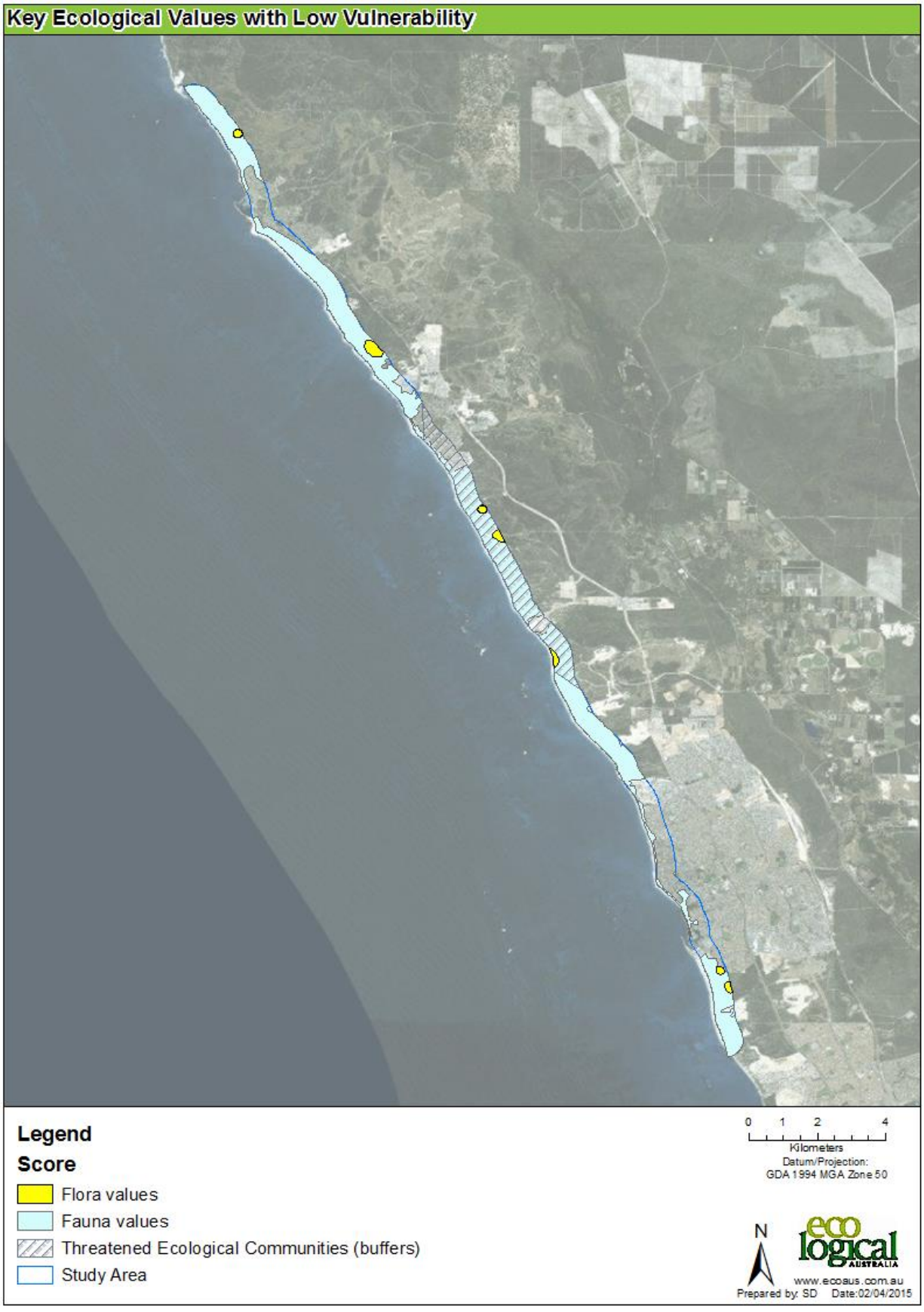

Figure 3: Key ecological values with low vulnerability

5 Summary

Of the ecological values identified in the potential coastal erosion influence zone, four values were identified as having high vulnerability due to reasons such as values having few known records and records being restricted to coastal areas likely to be impacted.

The values identified as having high vulnerability included the conservation listed flora species *Marianthus paralius*, the PECs *Acacia* shrublands on taller dunes (29b) and Coastal shrublands on shallow sands (29a) and the ESA Bush Forever Site 397.

Six values were identified as having moderate vulnerability as these values could potentially be impacted, but they have scope for adaptive capacity.

Values identified as having moderate vulnerability included the conservation listed flora species *Leucopogon maritimus* and *Calandrinia* oraria, the conservation listed fauna species Carnaby's Cockatoo (*Calyptorhynchus latirostris*) and Land Snail (*Bothriembryon perobesus*) and the ESAs Bush Forever Site 322 and Bush Forever Site 289.

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Appendix A Framework for conservation significance ranking for flora and fauna species

IUCN categories and criteria (IUCN 2012)

Categories and criteria are also used for the EPBC Act and the WC Act.

Category	Definition
Extinct (EX)	There is no reasonable doubt that the last member of the species has died.
Extinct in the Wild (EW)	Taxa known to survive only in captivity or as a naturalised population well outside its past range; or taxa has not been recorded in its known and/or expected habitat at appropriate seasons, anywhere in its past range, despite exhaustive surveys over a time frame appropriate to its life cycle and form.
Critically Endangered (CE)	Taxa considered to be facing an extremely high risk of extinction in the wild.
Endangered (EN)	Taxa considered to be facing a very high risk of extinction in the wild.
Vulnerable (VU)	Taxa considered to be facing a high risk of extinction in the wild.
Near Threatened (NT)	Taxa has been evaluated against the criteria but does not qualify for Critically Endangered, Endangered or Vulnerable now, but is close to qualifying for or is likely to qualify for a threatened category in the near future.
Least Concern (LC)	Taxa has been evaluated against the criteria and does not qualify for Critically Endangered, Endangered, Vulnerable or Near Threatened. Widespread and abundant taxa are included in this category.
Data Deficient (DD)	There is inadequate information to make a direct, or indirect, assessment of taxa's risk extinction based on its distribution and/or population status.
Not Evaluated (NE)	Taxa has not yet been evaluated against the criteria.
Migratory (M)	Not an IUCN category. Species are defined as migratory if they are listed in an international agreement approved by the Commonwealth Environment Minister, including: • the Bonn Convention (Convention on the Conservation of Migratory Species of Wild Animal) for which Australia is a range state; • the agreement between the Government of Australian and the Government of the People's Republic of China for the Protection of Migratory Birds and their environment (CAMBA); • the agreement between the Government of Japan and the Government of Australia for the Protection of Migratory Birds and Birds in Danger of Extinction and their Environment (JAMBA); or • the agreement between Australia and the Republic of Korea to develop a bilateral migratory bird agreement similar to the JAMBA and CAMBA in respect to migratory bird conservation and provides a basis for collaboration on the protection of migratory shorebirds and their habitat (ROKAMBA).

Categories of conservation significance for flora and fauna under the WC Act

Schedule	Code	Conservation Status	Description
Schedule 1 Taxa that have been adequately searched for and are deemed to be in the wild either rare, in danger of extinction, or otherwise in need of special protection, and have been gazetted as such. Schedule 1 flora and fauna are further ranked according to their level of threat using IUCN Red List criteria (CR, EN, and VU).	S1	Threatened Flora	Declared Rare Flora - Extant
		Threatened Fauna	Fauna that is rare or likely to become extinct
Schedule 2 Taxa which have been adequately searched for and there is no reasonable doubt that the last individual has died, and have been gazetted as such.	S2	Presumed Extinct Flora	Declared Rare Flora - Extinct
		Presumed Extinct Fauna	
Schedule 3 Birds that are subject to an agreement between governments of Australia and Japan relating to the protection of migratory birds and birds in danger of extinction.	S3	Migratory	Birds protected under an international agreement
Schedule 4 Fauna that is in need of special protection, otherwise than for the reasons mentioned in the above schedules.	S4	Specially Protected Fauna	Other specially protected fauna

Priority categories recognised by the Department of Parks and Wildlife for flora and fauna

Category	Definition
Priority 1 (P1)	Poorly-known taxa. Taxa that are known from one or a few collections or sight records (generally less than five), all on lands not managed for conservation, e.g. agricultural or pastoral lands, urban areas, Shire, Westrail and Main Roads WA road, gravel and soil reserves, and active mineral leases and under threat of habitat destruction or degradation. Taxa may be included if they are comparatively well known from one or more localities but do not meet adequacy of survey requirements and appear to be under immediate threat from known threatening processes.
Priority 2 (P2)	Poorly-known taxa. Taxa that are known from one or a few collections or sight records, some of which are on lands not under imminent threat of habitat destruction or degradation, e.g. national parks, conservation parks, nature reserves, State forest, vacant Crown land, water reserves, etc. Taxa may be included if they are comparatively well known from one or more localities but do not meet adequacy of survey requirements and appear to be under threat from known threatening processes.
Priority 3 (P3)	Poorly-known taxa. Taxa that are known from collections or sight records from several localities not under imminent threat, or from few but widespread localities with either large population size or significant remaining areas of apparently suitable habitat, much of it not under imminent threat. Taxa may be included if they are comparatively well known from several localities but do not meet adequacy of survey requirements and known threatening processes exist that could affect them.
Priority 4 (P4)	Rare, Near Threatened and other taxa in need of monitoring. (a) Rare. Taxa that are considered to have been adequately surveyed, or for which sufficient knowledge is available, and that are considered not currently threatened or in need of special protection, but could be if present circumstances change. These taxa are usually represented on conservation lands. (b) Near Threatened. Taxa that are considered to have been adequately surveyed and that do not qualify for Conservation Dependent, but that are close to qualifying for Vulnerable. (c) Taxa that have been removed from the list of threatened species during the past five years for reasons other than taxonomy.
Priority 5 (P5)	Conservation dependent taxa. Taxa that are not threatened but are subject to a specific conservation program, the cessation of which would result in the taxa becoming threatened within five years..

Definitions and criteria for threatened ecological communities under Schedule 5 of the state *Environmental Protection Act 1986*

Critically Endangered (CR)

An ecological community that has been adequately surveyed and found to have been subject to a major contraction in area and/or that was originally of limited distribution and is facing severe modification or destruction throughout its range in the immediate future, or is already severely degraded throughout its range but capable of being substantially restored or rehabilitated.

An ecological community will be listed as Critically Endangered when it has been adequately surveyed and is found to be facing an extremely high risk of total destruction in the immediate future. This will be determined on the basis of the best available information, by it meeting any one or more of the following criteria (A, B or C):

A) The estimated geographic range, and/or total area occupied, and/or number of discrete occurrences since European settlement have been reduced by at least 90% and either or both of the following apply (i or ii):

i. geographic range, and/or total area occupied and/or number of discrete occurrences are continuing to decline such that total destruction of the community is imminent (within approximately 10 years);
ii. modification throughout its range is continuing such that in the immediate future (within approximately 10 years) the c

B) Current distribution is limited, and one or more of the following apply (i, ii or iii):

i. geographic range and/or number of discrete occurrences, and/or area occupied is highly restricted and the community is currently subject to known threatening processes which are likely to result in total destruction throughout its range in the short term future (within approximately 20 years);
ii. there are few occurrences, each of which is small and/or isolated and all or most occurrences are very vulnerable to known threatening processes;
iii. there may be many occurrences but total area is small and all or most occurrences are small and/or isolated and very vulnerable to known threatening processes.

C) The ecological community exists only as very modified occurrences that may be capable of being substantially restored or rehabilitated if such work begins in the short-term future (within approximately 20 years).

Endangered (EN)

An ecological community that has been adequately surveyed and found to have been subject to a major contraction in area and/or was originally of limited distribution and is in danger of significant modification throughout its range or severe modification or destruction over most of its range in the near future.

An ecological community will be listed as Endangered when it has been adequately surveyed and is not Critically Endangered but is facing a very high risk of total destruction in the near future. This will be determined on the basis of the best available information by it meeting any one or more of the following criteria (A, B, or C):

A) The geographic range, and/or total area occupied, and/or number of discrete occurrences have been reduced by at least 70% since European settlement and either or both of the following apply (i or ii):

i. the estimated geographic range, and/or total area occupied and/or number of discrete occurrences are continuing to decline such that total destruction of the community is likely in the short term future (within approximately 20 years);
ii. modification throughout its range is continuing such that in the short term future (within approximately 20 years) the community is unlikely to be capable of being substantially restored or rehabilitated.

B) Current distribution is limited, and one or more of the following apply (i, ii or iii):

i. geographic range and/or number of discrete occurrences, and/or area occupied is highly restricted and the community is currently subject to known threatening processes which are likely to result in total destruction throughout its range in the short term future (within approximately 20 years);
ii. there are few occurrences, each of which is small and/or isolated and all or most occurrences are very vulnerable to known threatening processes;
iii. there may be many occurrences but total area is small and all or most occurrences are small and/or isolated and very vulnerable to known threatening processes.

C) The ecological community exists only as very modified occurrences that may be capable of being substantially restored or rehabilitated if such work begins in the short-term future (within approximately 20 years).

Vulnerable (VU)

An ecological community that has been adequately surveyed and is found to be declining and/or has declined in distribution and/or condition and whose ultimate security has not yet been assured and/or a community that is still widespread but is believed likely to move into a category of higher threat in the near future if threatening processes continue or begin operating throughout its range.

An ecological community will be listed as Vulnerable when it has been adequately surveyed and is not Critically Endangered or Endangered but is facing a high risk of total destruction or significant modification in the medium to long-term future. This will be determined on the basis of the best available information by it meeting any one or more of the following criteria (A, B or C):

A) The ecological community exists largely as modified occurrences that are likely to be capable of being substantially restored or rehabilitated.

B) The ecological community may already be modified and would be vulnerable to threatening processes, is restricted in area and/or range and/or is only found at a few locations.

C) The ecological community may be still widespread but is believed likely to move into a category of higher threat in the medium to long term future because of existing or impending threatening processes.

Definitions and criteria for priority ecological communities used by the Department of Parks and Wildlife

Possible threatened ecological communities that do not meet survey criteria or that are not adequately defined are added to the Priority Ecological Community List under priorities 1, 2 and 3. These three

categories are ranked in order of priority for survey and/or definition of the community, and evaluation of conservation status, so that consideration can be given to their declaration as threatened ecological communities. Ecological communities that are adequately known, and are rare but not threatened or meet criteria for Near Threatened, or that have been recently removed from the threatened list, are placed in Priority 4. These ecological communities require regular monitoring. Conservation Dependent ecological communities are placed in Priority 5.

Priority One: Poorly-known ecological communities

Ecological communities that are known from very few occurrences with a very restricted distribution (generally ≤5 occurrences or a total area of ≤ 100ha). Occurrences are believed to be under threat either due to limited extent, or being on lands under immediate threat (e.g. within agricultural or pastoral lands, urban areas, active mineral leases) or for which current threats exist. May include communities with occurrences on protected lands. Communities may be included if they are comparatively well-known from one or more localities but do not meet adequacy of survey requirements, and/or are not well defined, and appear to be under immediate threat from known threatening processes across their range.

Priority Two: Poorly-known ecological communities

Communities that are known from few occurrences with a restricted distribution (generally ≤10 occurrences or a total area of ≤200ha). At least some occurrences are not believed to be under immediate threat of destruction or degradation. Communities may be included if they are comparatively well known from one or more localities but do not meet adequacy of survey requirements, and/or are not well defined, and appear to be under threat from known threatening processes.

Priority Three: Poorly known ecological communities

i. Communities that are known from several to many occurrences, a significant number or area of which are not under threat of habitat destruction or degradation or:
ii. communities known from a few widespread occurrences, which are either large or with significant remaining areas of habitat in which other occurrences may occur, much of it not under imminent threat, or;
iii. communities made up of large, and/or widespread occurrences, that may or may not be represented in the reserve system, but are under threat of modification across much of their range from processes such as grazing by domestic and/or feral stock, and inappropriate fire regimes.

Communities may be included if they are comparatively well known from several localities but do not meet adequacy of survey requirements and/or are not well defined, and known threatening processes exist that could affect them.

Priority Four: Ecological communities that are adequately known, rare but not threatened or meet criteria for Near Threatened or that have been recently removed from the threatened list. These communities require regular monitoring.

i. Rare. Ecological communities known from few occurrences that are considered to have been adequately surveyed, or for which sufficient knowledge is available, and that are considered not currently threatened or in need of special protection, but could be if present circumstances change. These communities are usually represented on conservation lands.

ii. Near Threatened. Ecological communities that are considered to have been adequately surveyed and that do not qualify for Conservation Dependent, but that are close to qualifying for Vulnerable.
iii. Ecological communities that have been removed from the list of threatened communities during the past five years.

Priority Five: Conservation Dependent ecological communities

Ecological communities that are not threatened but are subject to a specific conservation program, the cessation of which would result in the community becoming threatened within five years.

ecological AUSTRALIA

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F 02 9264 0717

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F 02 4443 6655

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Canberra ACT 2601
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F 02 6103 0148

NEWCASTLE
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Newcastle NSW 2300
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F 02 4910 0126

NAROOMA
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Narooma NSW 2546
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F 02 4476 1161

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Coffs Harbour Jetty NSW 2450
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F 02 6651 6890

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Armidale NSW 2350
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F 02 6372 9230

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F 08 9322 1358

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Austinmer NSW 2515
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Gosford NSW 2250
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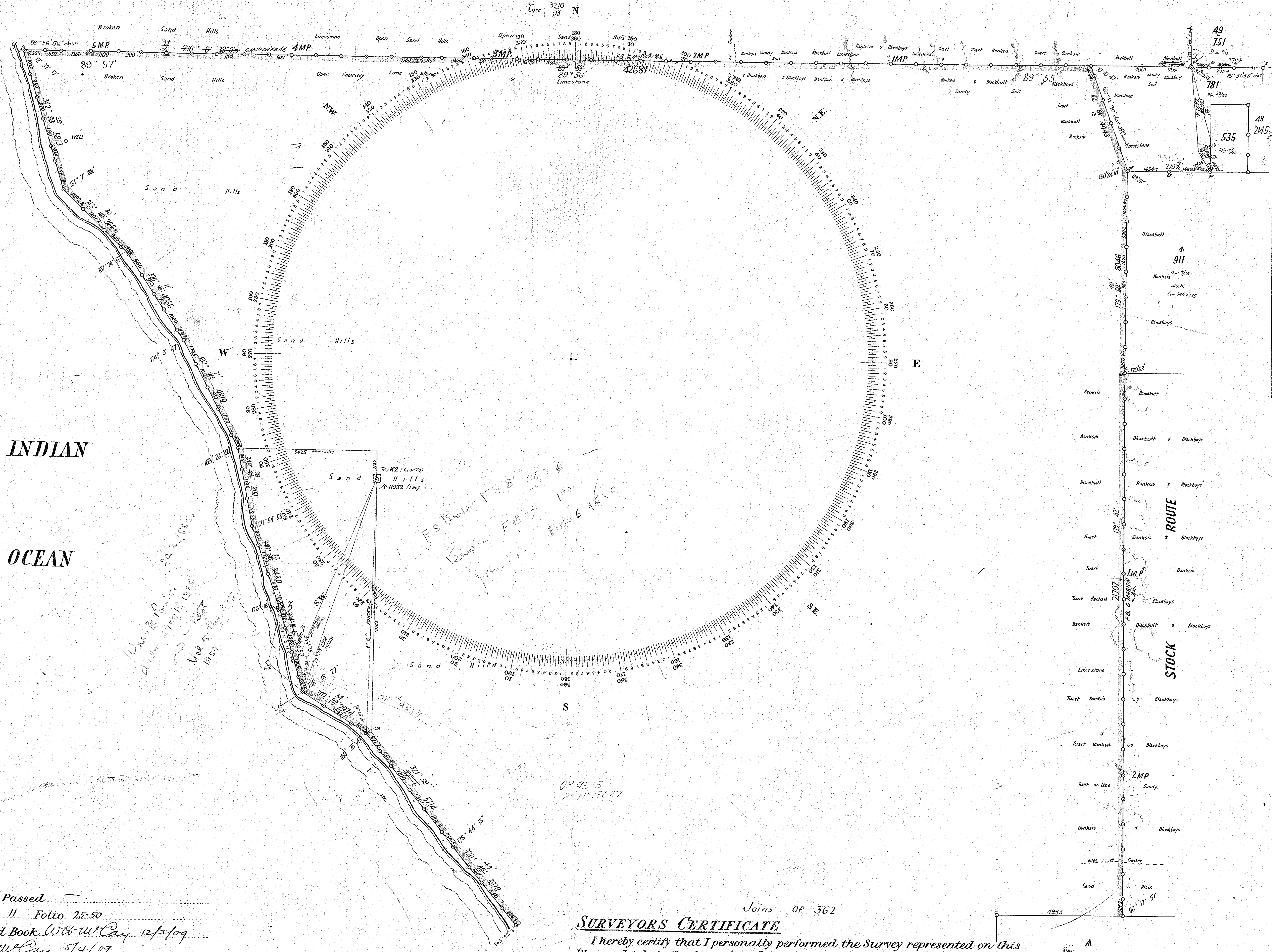
Appendix B 1909 HWM Survey

PLAN OF
SWAN LOCATION 1370
THE MIDLAND RAILWAY C^OY OF W.A.L^TD

47250 Acres
~~47,425 Acres.~~



Sheet 1.

Calculation for Area of

Nº & Page of Field Book	Bearing	Distance	Latitudes N +	Latitudes S −	Departures E +	Departures W −	Multipliers +	Multipliers −	Double +	Areas −
	Surround	Angles	−0′ 44″							
		Chainage	N+21·1	E+71						
	N. severance	Angles	+1′ 47″							
		Chainage	N-0·1	E+35·9						

DP 231390
PD SWAN 361

REFERENCE TO CORNERS

Corner	Bearing	Distance to	Description of Tree	Nº & Mark on Tree
A				
B				
C				
D				
E				
F				
G				
H				
I				
J				
K				
L				
M				
N				
O				
P				
Q				
R				
S				

Azimuth observed at x y & z
or assumed from
Date of Marking 17 1 1909
Field Book Nº 32 Page 1-10
Scale 20 Chains to an inch

Account Nº — Passed —
Calculation Book Nº 11 Folio 25-50
Compared with Field Book Wm McCay 12/3/09
Examined Wm McCay 5/4/09
Plan passed William Rowley Inspector of Plans. Date 7/1/10
Charted on Standard Plan 29/80 Date 25 1 10
" " Working " Date
" " Compilation " Swan 107, 108 & 106 Date 24/2/10
Registered A Cooper Date 13 2 09

Joins OP 362

SURVEYORS CERTIFICATE

I hereby certify that I personally performed the Survey represented on this Plan, which to the best of my belief is accurate, and the work has been executed in accordance with the Regulations for the guidance of Surveyors.

Licensed Surveyor
Date 9/2/9

Survey approved
Surveyor General
Date 2.2.10

Dept of Land Administration
U000 16997

SWAN 361

PLAN OF

SWAN LOCATION 1370

THE MIDLAND RAILWAY C^OY OF W.A. L^TD

INDIAN

OCEAN

Calculation for Area of

Nº & Page of Field Book	Bearing	Distance	Latitudes N +	Latitudes S −	Departures E +	Departures W −	Multipliers +	Multipliers −	Double +	Areas −
	Surround	Angles	−0'14"							
		Chainage	N+21.1	E+7.1						
	N. severance	Angles	+1'47"							
		Chainage	N−0.1	E+35.9						
	N central sev.	Angles	−1'20"							
		Chainage	N+13.9	E+2.1						

REFERENCE TO CORNERS

Corner	Bearing	Distance to	Description of Tree	Nº & Mark on Tree
A				
B				
C				
D				
E				
F				
G				
H				
I				
J				
K				
L				
M				
N				
O				
P				
Q				
R				
S				

Azimuth observed at West end of Road ⊥ at Loc 422
or assumed from
Date of Marking 17-12 - 17-1 - 1909
Field Book Nº 31/30 (J. Ewing 32) Page 10-11, 12-14, 17-23
Scale 20 Chains to an inch

Account Nº — Passed —
Calculation Book Nº 11 Folio 25-50
Compared with Field Book W.H. McCay 12/3/09
Examined W.H. McCay 5/4/09
Plan passed William Rowley per W.H.M. Inspector of Plans. Date 7/1/10
Charted on Standard Plan 29/80 A. A. McA. Date 24.1.13
" " Working " By Photolitho Date
" " Compilation " Swan 406 Date 24/2/10
Registered A. Cooper Date 13.2.9

SURVEYORS CERTIFICATE

I hereby certify that I personally performed the Survey represented on this Plan, which to the best of my belief is accurate, and the work has been executed in accordance with the Regulations for the guidance of Surveyors.

Wm Gemmell 19/1/09
Licensed Surveyor
Date 9/2/9

Survey approved. Harry F. Johnston
Surveyor General
Date 2.2.10

SWAN 362

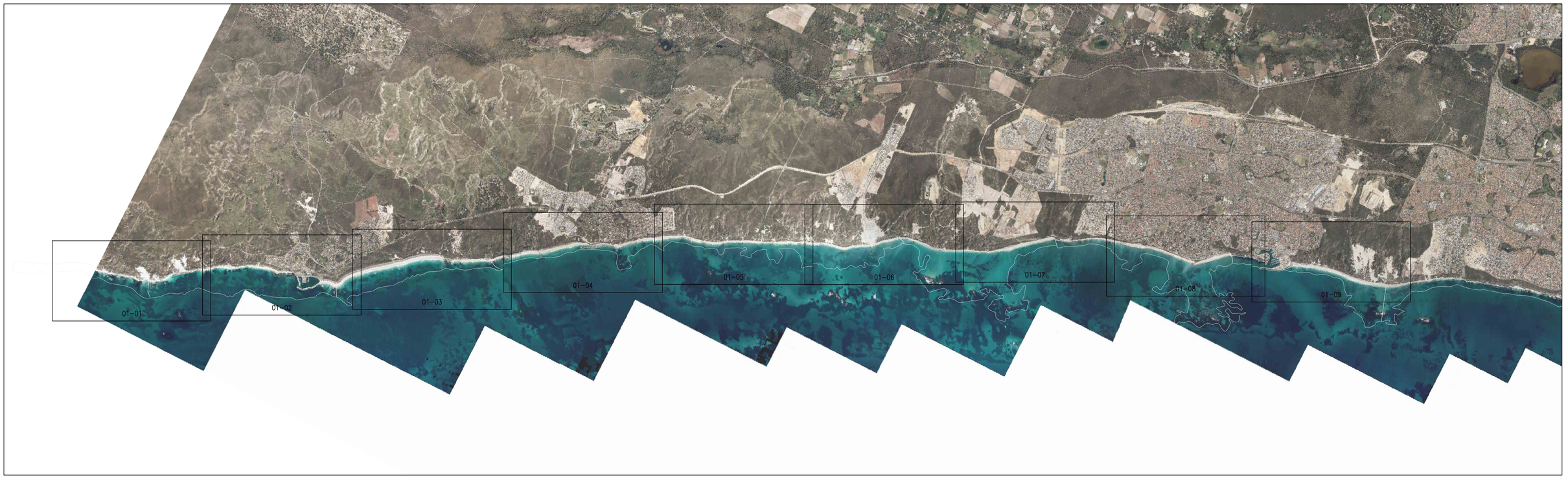
Appendix C Erosion Hazard Mapping

AT CORRECT SCALE THIS IS 100 mm

CITY OF WANNEROO

COASTAL HAZARD RISK MANAGEMENT & ADAPTATION PLAN

DRAWING No.	TITLE
D1212-01-01	COOK LUMP
D1212-01-02	TWO ROCKS NORTH
D1212-01-03	TWO ROCKS SOUTH
D1212-01-04	YANCHEP
D1212-01-05	EGLINTON
D1212-01-06	ALKIMOS
D1212-01-07	JINDALEE
D1212-01-08	QUINNS ROCKS
D1212-01-09	MINDARIE TO TAMALA PARK



AT CORRECT SCALE THIS IS 100 mm

CAD: D12120100B

REV	DATE	APPROVED	AMENDMENT
B	1.07.15	CRD	UPDATED AND REISSUED
A	8.01.15	CRD	PRELIMINARY ISSUE

This plan is not to be used for construction unless issued as Rev 0 and signed below

CLIENT: CITY OF WANNEROO

DESIGNED	CHECKED	APPROVED
B. SMITH	C. DOAK	
DRAWN	CHECKED	
T. VAN BEEM	B. SMITH	

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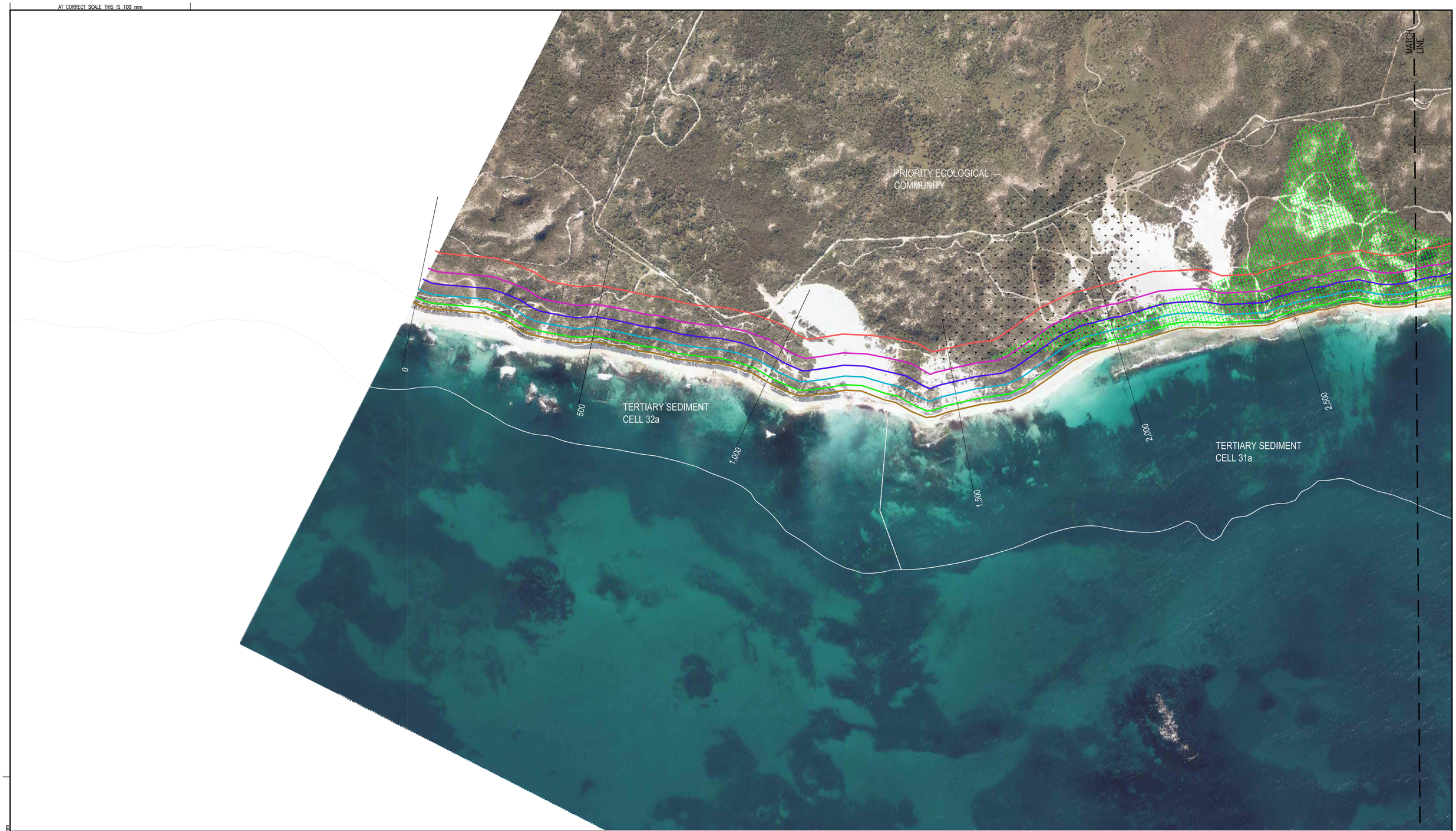
admin@coastsandports.com.au

PROJECT: COASTAL HAZARD RISK MANAGEMENT & ADAPTATION PLAN

TITLE: EROSION HAZARD MAPPING
DRAWING LIST AND SHEET LAYOUT

SCALE AT A1	DRAWING NUMBER	REV
1:40,000	D1212-01-00	B

AT CORRECT SCALE THIS IS 100 mm



AT CORRECT SCALE THIS IS 100 mm

LAYOUT 1

LEGEND:

- ROCKY COAST
- PRESENT DAY VULNERABILITY
- 2030 VULNERABILITY
- 2050 VULNERABILITY
- 2070 VULNERABILITY
- 2090 VULNERABILITY
- 2120 VULNERABILITY

ENVIRONMENT

- BUSH FOREVER SITE 397
- HIGH VULNERABILITY ECOLOGICAL SYSTEM

CULTURAL HERITAGE

- REGISTERED ABORIGINAL CULTURAL HERITAGE SITES

AERIAL PHOTOGRAPH TAKEN: 2014

CAD: D12120101B

REV	DATE	APPROVED	AMENDMENT	REV	DATE	APPROVED	AMENDMENT
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PROJECT: COASTAL HAZARD RISK MANAGEMENT & ADAPTATION PLAN

TITLE: EROSION HAZARD MAPPING
COOK LUMP

SCALE AT A1	DRAWING NUMBER	REV
1:5,000	D1212–01–01	B

AT CORRECT SCALE THIS IS 100 mm

AT CORRECT SCALE THIS IS 100 mm

LAYOUT 2

LEGEND:

- ROCKY COAST
- PRESENT DAY VULNERABILITY
- 2030 VULNERABILITY
- 2050 VULNERABILITY
- 2070 VULNERABILITY
- 2090 VULNERABILITY
- 2120 VULNERABILITY

ENVIRONMENT

- BUSH FOREVER SITE 397
- HIGH VULNERABILITY ECOLOGICAL SYSTEM

CULTURAL HERITAGE

- REGISTERED ABORIGINAL CULTURAL HERITAGE SITES

AERIAL PHOTOGRAPH TAKEN: 2014

CAD: D12120102B

REV	DATE	APPROVED	AMENDMENT	REV	DATE	APPROVED	AMENDMENT
B	1.07.15	CRD	UPDATED AND REISSUED				
A	8.01.15	CRD	PRELIMINARY ISSUE				

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CLIENT: CITY OF WANNEROO

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DRAWN	CHECKED	
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PROJECT: COASTAL HAZARD RISK MANAGEMENT & ADAPTATION PLAN

TITLE: EROSION HAZARD MAPPING
TWO ROCKS NORTH

SCALE AT A1	DRAWING NUMBER	REV
1:5,000	D1212-01-02	B

AT CORRECT SCALE THIS IS 100 mm

MATCH LINE

MATCH LINE

TERTIARY SEDIMENT CELL 30b

TERTIARY SEDIMENT CELL 30a

"THE SPOT"

1,000

7,500

8000

8,500

9,000

9,500

10,000

10,500

AT CORRECT SCALE THIS IS 100 mm

LAYOUT 3

LEGEND:

- ROCKY COAST
- PRESENT DAY VULNERABILITY
- 2030 VULNERABILITY
- 2050 VULNERABILITY
- 2070 VULNERABILITY
- 2090 VULNERABILITY
- 2120 VULNERABILITY

ENVIRONMENT

- BUSH FOREVER SITE 397
- HIGH VULNERABILITY ECOLOGICAL SYSTEM

CULTURAL HERITAGE

- REGISTERED ABORIGINAL CULTURAL HERITAGE SITES

AERIAL PHOTOGRAPH TAKEN: 2014

CAD: D12120103B

REV	DATE	APPROVED	AMENDMENT	REV	DATE	APPROVED	AMENDMENT
B	1.07.15	CRD	UPDATED AND REISSUED				
A	8.01.15	CRD	PRELIMINARY ISSUE				

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DRAWN	CHECKED	
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PROJECT: COASTAL HAZARD RISK MANAGEMENT & ADAPTATION PLAN

TITLE: EROSION HAZARD MAPPING
TWO ROCKS SOUTH

SCALE AT A1	DRAWING NUMBER	REV
1:5,000	D1212-01-03	B

AT CORRECT SCALE THIS IS 100 mm

AT CORRECT SCALE THIS IS 100 mm

LAYOUT 4

LEGEND:

- ROCKY COAST
- PRESENT DAY VULNERABILITY
- 2030 VULNERABILITY
- 2050 VULNERABILITY
- 2070 VULNERABILITY
- 2090 VULNERABILITY
- 2120 VULNERABILITY

ENVIRONMENT

- BUSH FOREVER SITE 397
- HIGH VULNERABILITY ECOLOGICAL SYSTEM

CULTURAL HERITAGE

- REGISTERED ABORIGINAL CULTURAL HERITAGE SITES

AERIAL PHOTOGRAPH TAKEN: 2014

CAD: D12120104B

REV	DATE	APPROVED	AMENDMENT
B	1.07.15	CRD	UPDATED AND REISSUED
A	8.01.15	CRD	PRELIMINARY ISSUE

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CLIENT: CITY OF WANNEROO

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DRAWN: T. VAN BEEM | CHECKED: B. SMITH

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PROJECT: COASTAL HAZARD RISK MANAGEMENT & ADAPTATION PLAN

TITLE: EROSION HAZARD MAPPING YANCHEP

SCALE AT A1: 1:5,000 | DRAWING NUMBER: D1212–01–04 | REV: B

AT CORRECT SCALE THIS IS 100 mm

MATCH LINE

MATCH LINE

14,500

15,000

15,500

16,000

16,500

TERTIARY SEDIMENT
CELL 29d

17,000

17,500

18,000

AT CORRECT SCALE THIS IS 100 mm

LAYOUT 5

LEGEND:

ROCKY COAST

PRESENT DAY VULNERABILITY

2030 VULNERABILITY

2050 VULNERABILITY

2070 VULNERABILITY

2090 VULNERABILITY

2120 VULNERABILITY

ENVIRONMENT

BUSH FOREVER
SITE 397

HIGH VULNERABILITY
ECOLOGICAL SYSTEM

CULTURAL HERITAGE

REGISTERED ABORIGINAL
CULTURAL HERITAGE SITES

AERIAL PHOTOGRAPH TAKEN: 2014

CAD: D12120105B

REV	DATE	APPROVED	AMENDMENT	REV	DATE	APPROVED	AMENDMENT
B	1.07.15	CRD	UPDATED AND REISSUED				
A	8.01.15	CRD	PRELIMINARY ISSUE				

This plan is not to be used for construction unless issued as Rev 0 and signed below

CLIENT: CITY OF WANNEROO

DESIGNED	CHECKED	APPROVED
B. SMITH	C. DOAK	
DRAWN	CHECKED	
T. VAN BEEM	B. SMITH	

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coastal and port engineers

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PROJECT: COASTAL HAZARD RISK MANAGEMENT & ADAPTATION PLAN

TITLE: EROSION HAZARD MAPPING
EGLINTON

SCALE AT A1	DRAWING NUMBER	REV
1:5,000	D1212–01–05	B

AT CORRECT SCALE THIS IS 100 mm

LAYOUT 6

LEGEND:

- ROCKY COAST
- PRESENT DAY VULNERABILITY
- 2030 VULNERABILITY
- 2050 VULNERABILITY
- 2070 VULNERABILITY
- 2090 VULNERABILITY
- 2120 VULNERABILITY

ENVIRONMENT

- BUSH FOREVER SITE 397
- HIGH VULNERABILITY ECOLOGICAL SYSTEM

CULTURAL HERITAGE

- REGISTERED ABORIGINAL CULTURAL HERITAGE SITES

AERIAL PHOTOGRAPH TAKEN: 2014

CAD: D12120106B

REV	DATE	APPROVED	AMENDMENT
B	1.07.15	CRD	UPDATED AND REISSUED
A	8.01.15	CRD	PRELIMINARY ISSUE

This plan is not to be used for construction unless issued as Rev 0 and signed below

CLIENT: CITY OF WANNEROO

DESIGNED	CHECKED	APPROVED
B. SMITH	C. DOAK	
DRAWN	CHECKED	
T. VAN BEEM	B. SMITH	

m p rogers & associates pl
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admin@coastsandports.com.au

PROJECT: COASTAL HAZARD RISK MANAGEMENT & ADAPTATION PLAN

TITLE: EROSION HAZARD MAPPING ALKIMOS

SCALE AT A1	DRAWING NUMBER	REV
1:5,000	D1212-01-06	B

AT CORRECT SCALE THIS IS 100 mm

AT CORRECT SCALE THIS IS 100 mm

MATCH LINE

MATCH LINE

TERTIARY SEDIMENT
CELL 29b

TERTIARY SEDIMENT
CELL 29c

22,500

23,000

23,500

24,000

24,500

25,000

25,500

26,000

AT CORRECT SCALE THIS IS 100 mm

LAYOUT 7

LEGEND:

- ROCKY COAST
- PRESENT DAY VULNERABILITY
- 2030 VULNERABILITY
- 2050 VULNERABILITY
- 2070 VULNERABILITY
- 2090 VULNERABILITY
- 2120 VULNERABILITY

ENVIRONMENT

- BUSH FOREVER SITE 397
- HIGH VULNERABILITY ECOLOGICAL SYSTEM

CULTURAL HERITAGE

- REGISTERED ABORIGINAL CULTURAL HERITAGE SITES

AERIAL PHOTOGRAPH TAKEN: 2014

CAD: D12120107C

REV	DATE	APPROVED	AMENDMENT	REV	DATE	APPROVED	AMENDMENT
C	11.11.15	CRD	UPDATED WITH CITYS COMMENTS				
B	1.07.15	CRD	UPDATED AND REISSUED				
A	8.01.15	CRD	PRELIMINARY ISSUE				

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B. SMITH	C. DOAK	
DRAWN	CHECKED	
T. VAN BEEM	B. SMITH	

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PROJECT: COASTAL HAZARD RISK MANAGEMENT & ADAPTATION PLAN

TITLE: EROSION HAZARD MAPPING
JINDALEE

SCALE AT A1	DRAWING NUMBER	REV
1:5,000	D1212–01–07	C

AT CORRECT SCALE THIS IS 100 mm

LAYOUT 8

LEGEND:

- ROCKY COAST
- PRESENT DAY VULNERABILITY
- 2030 VULNERABILITY
- 2050 VULNERABILITY
- 2070 VULNERABILITY
- 2090 VULNERABILITY
- 2120 VULNERABILITY

AERIAL PHOTOGRAPH TAKEN: 2014

ENVIRONMENT

- BUSH FOREVER SITE 397
- HIGH VULNERABILITY ECOLOGICAL SYSTEM

CULTURAL HERITAGE

- REGISTERED ABORIGINAL CULTURAL HERITAGE SITES

CAD: D12120108C

AT CORRECT SCALE THIS IS 100 mm

REV	DATE	APPROVED	AMENDMENT	REV	DATE	APPROVED	AMENDMENT
C	11.11.15	CRD	UPDATED WITH CITYS COMMENTS				
B	1.07.15	CRD	UPDATED AND REISSUED				
A	8.01.15	CRD	PRELIMINARY ISSUE				

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CLIENT: CITY OF WANNEROO

DESIGNED	CHECKED	APPROVED
B. SMITH	C. DOAK	
DRAWN	CHECKED	
T. VAN BEEM	B. SMITH	

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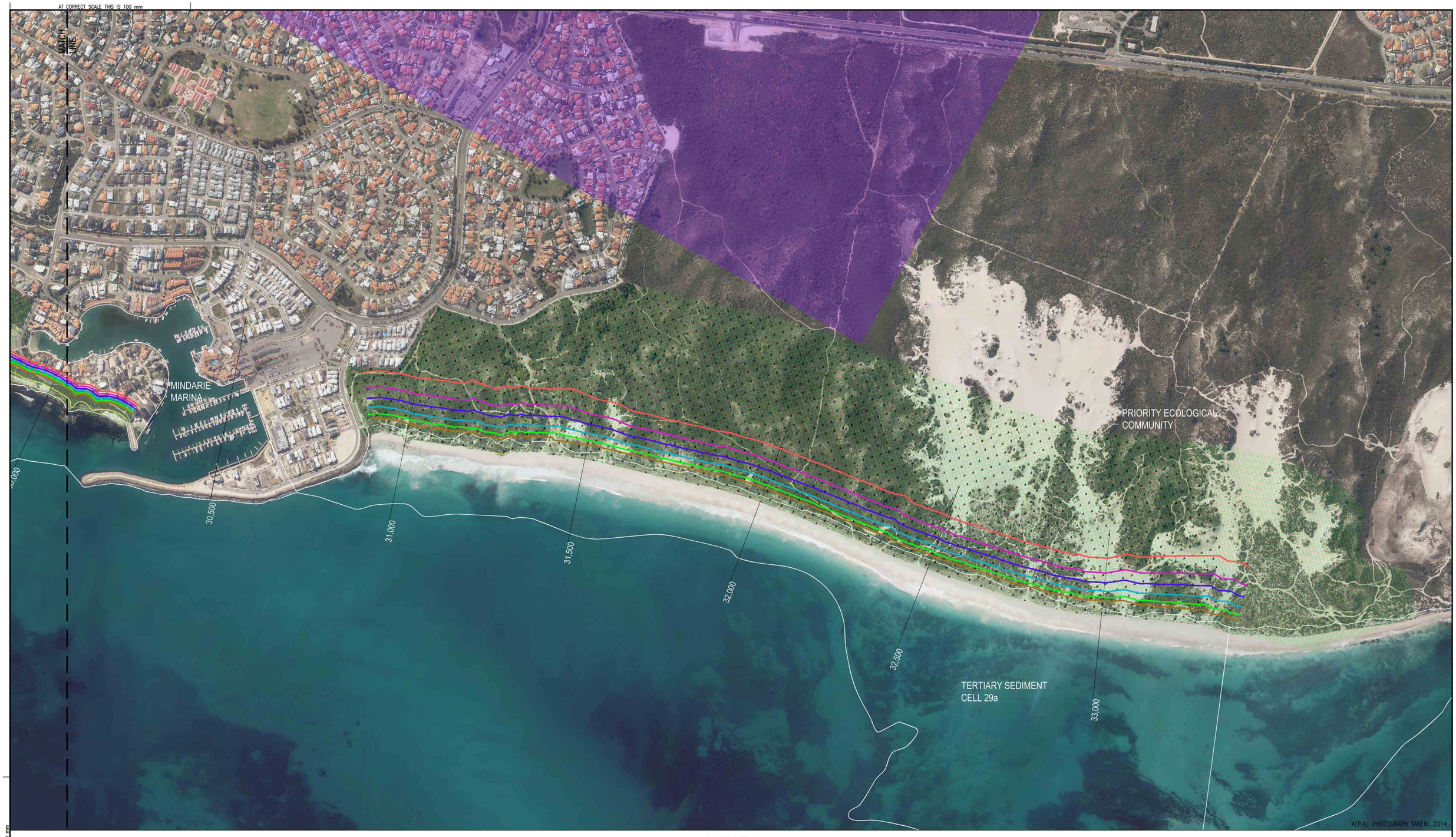
PROJECT: COASTAL HAZARD RISK MANAGEMENT & ADAPTATION PLAN

TITLE: EROSION HAZARD MAPPING
QUINNS ROCKS

SCALE AT A1	DRAWING NUMBER	REV
1:5,000	D1212-01-08	C

AT CORRECT SCALE THIS IS 100 mm



AT CORRECT SCALE THIS IS 100 mm

LAYOUT 9

LEGEND:

- ROCKY COAST
- PRESENT DAY VULNERABILITY
- 2030 VULNERABILITY
- 2050 VULNERABILITY
- 2070 VULNERABILITY
- 2090 VULNERABILITY
- 2120 VULNERABILITY

ENVIRONMENT

- BUSH FOREVER SITE 397
- HIGH VULNERABILITY ECOLOGICAL SYSTEM

CULTURAL HERITAGE

- REGISTERED ABORIGINAL CULTURAL HERITAGE SITES

AERIAL PHOTOGRAPH TAKEN: 2014

CAD: D12120109B

REV	DATE	APPROVED	AMENDMENT
B	1.07.15	CRD	UPDATED AND REISSUED
A	8.01.15	CRD	PRELIMINARY ISSUE

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CLIENT: CITY OF WANNEROO

DESIGNED	CHECKED	APPROVED
B. SMITH	C. DOAK	
DRAWN	CHECKED	
T. VAN BEEM	B. SMITH	

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PROJECT: COASTAL HAZARD RISK MANAGEMENT & ADAPTATION PLAN

TITLE: EROSION HAZARD MAPPING MINDARIE TO TAMALA PARK

SCALE AT A1	DRAWING NUMBER	REV
1:5,000	D1212–01–09	B

Appendix D Erosion Allowances

Chainage (m)	Tertiary Sediment Cell	Zone	Erosion Allowance (m)																			
			2015	2030				2050				2070				2090				2120			
			S1	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total
100	32a	1	20	5	7	3	35	12	20	7	59	19	39	11	89	26	62	15	123	37	97	21	175
200			20	5	7	3	35	12	20	7	59	19	39	11	89	26	62	15	123	37	97	21	175
300			20	5	7	3	35	12	20	7	59	19	39	11	89	26	62	15	123	37	97	21	175
400			20	5	7	3	35	12	20	7	59	19	39	11	89	26	62	15	123	37	97	21	175
500			20	5	7	3	35	12	20	7	59	19	39	11	89	26	62	15	123	37	97	21	175
600			20	5	7	3	35	12	20	7	59	19	39	11	89	26	62	15	123	37	97	21	175
700			20	5	7	3	35	12	20	7	59	19	39	11	89	26	62	15	123	37	97	21	175
800			20	5	7	3	35	12	20	7	59	19	39	11	89	26	62	15	123	37	97	21	175
900			20	5	7	3	35	12	20	7	59	19	39	11	89	26	62	15	123	37	97	21	175
1,000			20	5	7	3	35	12	20	7	59	19	39	11	89	26	62	15	123	37	97	21	175
1,100			20	5	7	3	35	12	20	7	59	19	39	11	89	26	62	15	123	37	97	21	175
1,200			20	5	7	3	35	12	20	7	59	19	39	11	89	26	62	15	123	37	97	21	175
1,300	31a	1	10	8	7	3	28	18	20	7	55	28	39	11	88	38	62	15	125	54	97	21	182
1,400			10	8	7	3	28	18	20	7	55	28	39	11	88	38	62	15	125	54	97	21	182
1,500			10	8	7	3	28	18	20	7	55	28	39	11	88	38	62	15	125	54	97	21	182
1,600			10	8	7	3	28	18	20	7	55	28	39	11	88	38	62	15	125	54	97	21	182
1,700			10	8	7	3	28	18	20	7	55	28	39	11	88	38	62	15	125	54	97	21	182
1,800			10	8	7	3	28	18	20	7	55	28	39	11	88	38	62	15	125	54	97	21	182
1,900			10	8	7	3	28	18	20	7	55	28	39	11	88	38	62	15	125	54	97	21	182
2,000			10	8	7	3	28	18	20	7	55	28	39	11	88	38	62	15	125	54	97	21	182
2,100		2	11	8	7	3	29	18	20	7	56	28	39	11	89	38	62	15	126	54	97	21	183
2,200			11	6	7	3	27	14	20	7	52	22	39	11	83	30	62	15	118	42	97	21	171
2,300			11	4	7	3	25	8	20	7	46	13	39	11	74	18	62	15	106	25	97	21	154

Chainage (m)	Tertiary Sediment Cell	Zone	Erosion Allowance (m)																			
			2015	2030				2050				2070				2090				2120			
			S1	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total
2,400			11	4	7	3	25	8	20	7	46	13	39	11	74	18	62	15	106	25	97	21	154
2,500			11	4	7	3	25	8	20	7	46	13	39	11	74	18	62	15	106	25	97	21	154
2,600			11	4	7	3	25	8	20	7	46	13	39	11	74	18	62	15	106	25	97	21	154
2,700			11	4	7	3	25	8	20	7	46	13	39	11	74	18	62	15	106	25	97	21	154
2,800			11	4	7	3	25	8	20	7	46	13	39	11	74	18	62	15	106	25	97	21	154
2,900			11	4	7	3	25	8	20	7	46	13	39	11	74	18	62	15	106	25	97	21	154
3,000			11	4	7	3	25	8	20	7	46	13	39	11	74	18	62	15	106	25	97	21	154
3,100		2	11	4	7	3	25	8	20	7	46	13	39	11	74	18	62	15	106	25	97	21	154
3,200			11	4	7	3	25	8	20	7	46	13	39	11	74	18	62	15	106	25	97	21	154
3,300			11	4	7	3	25	8	20	7	46	13	39	11	74	18	62	15	106	25	97	21	154
3,400	31a		11	4	7	3	25	8	20	7	46	13	39	11	74	18	62	15	106	25	97	21	154
3,500			11	4	7	3	25	8	20	7	46	13	39	11	74	18	62	15	106	25	97	21	154
3,600			11	4	7	3	25	8	20	7	46	13	39	11	74	18	62	15	106	25	97	21	154
3,700			11	4	7	3	25	8	20	7	46	13	39	11	74	18	62	15	106	25	97	21	154
3,800			11	6	7	3	27	14	20	7	52	21	39	11	82	29	62	15	117	41	97	21	170
3,900			18	8	7	3	36	19	20	7	64	30	39	11	98	41	62	15	136	57	97	21	193
4,000			18	11	7	3	39	25	20	7	70	39	39	11	107	53	62	15	148	74	97	21	210
4,100			18	11	7	3	39	25	20	7	70	39	39	11	107	53	62	15	148	74	97	21	210
4,200		3	18	11	7	3	39	25	20	7	70	39	39	11	107	53	62	15	148	74	97	21	210
4,300			18	11	7	3	39	25	20	7	70	39	39	11	107	53	62	15	148	74	97	21	210
4,400			18	11	7	3	39	25	20	7	70	39	39	11	107	53	62	15	148	74	97	21	210
4,500			18	11	7	3	39	25	20	7	70	39	39	11	107	53	62	15	148	74	97	21	210
4,600			18	11	7	3	39	25	20	7	70	39	39	11	107	53	62	15	148	74	97	21	210

Chainage (m)	Tertiary Sediment Cell	Zone	Erosion Allowance (m)																			
			2015	2030				2050				2070				2090				2120			
			S1	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total
4,700		**3**	**18**	11	7	3	**39**	25	20	7	**70**	39	39	11	**107**	53	62	15	**148**	74	97	21	**210**
4,800			**18**	11	7	3	**39**	25	20	7	**70**	39	39	11	**107**	53	62	15	**148**	74	97	21	**210**
4,900			**18**	11	7	3	**39**	25	20	7	**70**	39	39	11	**107**	53	62	15	**148**	74	97	21	**210**
5,000			**18**	11	7	3	**39**	25	20	7	**70**	39	39	11	**107**	53	62	15	**148**	74	97	21	**210**
5,100	**31a**	**4**	**Rocky Coast**																			
5,200																						
5,300																						
5,400																						
5,500																						
5,600																						
5,700																						
5,800																						
5,900		**5**	**22**	-4	7	3	**28**	-9	20	7	**40**	-14	39	11	**58**	-19	62	15	**80**	-26	97	21	**114**
6,000			**22**	-4	7	3	**28**	-9	20	7	**40**	-14	39	11	**58**	-19	62	15	**80**	-26	97	21	**114**
6,100			**22**	-4	7	3	**28**	-9	20	7	**40**	-14	39	11	**58**	-19	62	15	**80**	-26	97	21	**114**
6,200			**22**	-12	7	3	**20**	-28	20	7	**21**	-44	39	11	**28**	-60	62	15	**39**	-84	97	21	**56**
6,300	**30b**	**1**	**22**	-12	7	3	**20**	-28	20	7	**21**	-44	39	11	**28**	-60	62	15	**39**	-84	97	21	**56**
6,400			**22**	-12	7	3	**20**	-28	20	7	**21**	-44	39	11	**28**	-60	62	15	**39**	-84	97	21	**56**
6,500			**22**	-12	7	3	**20**	-28	20	7	**21**	-44	39	11	**28**	-60	62	15	**39**	-84	97	21	**56**
6,600			**22**	-12	7	3	**20**	-28	20	7	**21**	-44	39	11	**28**	-60	62	15	**39**	-84	97	21	**56**
6,700			**22**	-12	7	3	**20**	-28	20	7	**21**	-44	39	11	**28**	-60	62	15	**39**	-84	97	21	**56**
6,800			**22**	-12	7	3	**20**	-28	20	7	**21**	-44	39	11	**28**	-60	62	15	**39**	-84	97	21	**56**
6,900			**22**	-12	7	3	**20**	-28	20	7	**21**	-44	39	11	**28**	-60	62	15	**39**	-84	97	21	**56**

Chainage (m)	Tertiary Sediment Cell	Zone	Erosion Allowance (m)																			
			2015	2030				2050				2070				2090				2120			
			S1	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total
7,000			22	-12	7	3	20	-28	20	7	21	-44	39	11	28	-60	62	15	39	-84	97	21	56
7,100			22	-12	7	3	20	-28	20	7	21	-44	39	11	28	-60	62	15	39	-84	97	21	56
7,200			22	-12	7	3	20	-28	20	7	21	-44	39	11	28	-60	62	15	39	-84	97	21	56
7,300			22	-12	7	3	20	-28	20	7	21	-44	39	11	28	-60	62	15	39	-84	97	21	56
7,400			22	-12	7	3	20	-28	20	7	21	-44	39	11	28	-60	62	15	39	-84	97	21	56
7,500			22	-12	7	3	20	-28	20	7	21	-44	39	11	28	-60	62	15	39	-84	97	21	56
7,600			22	-12	7	3	20	-28	20	7	21	-44	39	11	28	-60	62	15	39	-84	97	21	56
7,700			22	-12	7	3	20	-28	20	7	21	-44	39	11	28	-60	62	15	39	-84	97	21	56
7,800			22	-12	7	3	20	-28	20	7	21	-44	39	11	28	-60	62	15	39	-84	97	21	56
7,900			22	-12	7	3	20	-28	20	7	21	-44	39	11	28	-60	62	15	39	-84	97	21	56
8,000		1	22	-12	7	3	20	-28	20	7	21	-44	39	11	28	-60	62	15	39	-84	97	21	56
8,100	30b		22	-12	7	3	20	-28	20	7	21	-44	39	11	28	-60	62	15	39	-84	97	21	56
8,200			22	-12	7	3	20	-28	20	7	21	-44	39	11	28	-60	62	15	39	-84	97	21	56
8,300			22	-12	7	3	20	-28	20	7	21	-44	39	11	28	-60	62	15	39	-84	97	21	56
8,400			22	-12	7	3	20	-28	20	7	21	-44	39	11	28	-60	62	15	39	-84	97	21	56
8,500			22	-12	7	3	20	-28	20	7	21	-44	39	11	28	-60	62	15	39	-84	97	21	56
8,600			22	-12	7	3	20	-28	20	7	21	-44	39	11	28	-60	62	15	39	-84	97	21	56
8,700			22	-12	7	3	20	-28	20	7	21	-44	39	11	28	-60	62	15	39	-84	97	21	56
8,800			22	-12	7	3	20	-28	20	7	21	-44	39	11	28	-60	62	15	39	-84	97	21	56
8,900			22	-8	7	3	25	-18	20	7	32	-28	39	11	45	-38	62	15	62	-53	97	21	88
9,000																							
9,100		2	Rocky Coast																				
9,200																							

Chainage (m)	Tertiary Sediment Cell	Zone	Erosion Allowance (m)																			
			2015	2030				2050				2070				2090				2120			
			S1	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total
9,300	30b	3	28	2	7	3	40	4	20	7	59	6	39	11	84	8	62	15	113	11	97	21	157
9,400			28	2	7	3	40	4	20	7	59	6	39	11	84	8	62	15	113	11	97	21	157
9,500			28	2	7	3	40	4	20	7	59	6	39	11	84	8	62	15	113	11	97	21	157
9,600			28	2	7	3	40	4	20	7	59	6	39	11	84	8	62	15	113	11	97	21	157
9,700			28	2	7	3	40	4	20	7	59	6	39	11	84	8	62	15	113	11	97	21	157
9,800			28	2	7	3	40	4	20	7	59	6	39	11	84	8	62	15	113	11	97	21	157
9,900			28	2	7	3	40	4	20	7	59	6	39	11	84	8	62	15	113	11	97	21	157
10,000			28	2	7	3	40	4	20	7	59	6	39	11	84	8	62	15	113	11	97	21	157
10,100			28	2	7	3	40	4	20	7	59	6	39	11	84	8	62	15	113	11	97	21	157
10,200			28	2	7	3	40	4	20	7	59	6	39	11	84	8	62	15	113	11	97	21	157
10,300	30a	1	28	6	7	3	44	14	20	7	69	22	39	11	100	30	62	15	135	42	97	21	188
10,400			28	12	7	3	50	28	20	7	83	44	39	11	122	60	62	15	165	84	97	21	230
10,500			28	8	7	3	46	19	20	7	74	30	39	11	108	41	62	15	146	58	97	21	204
10,600			28	3	7	3	41	7	20	7	62	11	39	11	89	15	62	15	120	21	97	21	167
10,700			28	3	7	3	41	7	20	7	62	11	39	11	89	15	62	15	120	21	97	21	167
10,800			28	3	7	3	41	7	20	7	62	11	39	11	89	15	62	15	120	21	97	21	167
10,900			28	3	7	3	41	7	20	7	62	11	39	11	89	15	62	15	120	21	97	21	167
11,000			28	3	7	3	41	7	20	7	62	11	39	11	89	15	62	15	120	21	97	21	167
11,100		2	21	0	7	3	31	0	20	7	48	0	39	11	71	0	62	15	98	0	97	21	139
11,200			21	0	7	3	31	0	20	7	48	0	39	11	71	0	62	15	98	0	97	21	139
11,300			21	0	7	3	31	0	20	7	48	0	39	11	71	0	62	15	98	0	97	21	139
11,400			21	0	7	3	31	0	20	7	48	0	39	11	71	0	62	15	98	0	97	21	139
11,500			21	0	7	3	31	0	20	7	48	0	39	11	71	0	62	15	98	0	97	21	139

Chainage (m)	Tertiary Sediment Cell	Zone	Erosion Allowance (m)																			
			2015	2030				2050				2070				2090				2120			
			S1	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total
11,600	30a	2	21	0	7	3	31	0	20	7	48	0	39	11	71	0	62	15	98	0	97	21	139
11,700			21	0	7	3	31	0	20	7	48	0	39	11	71	0	62	15	98	0	97	21	139
11,800			21	0	7	3	31	0	20	7	48	0	39	11	71	0	62	15	98	0	97	21	139
11,900			21	0	7	3	31	0	20	7	48	0	39	11	71	0	62	15	98	0	97	21	139
12,000			21	0	7	3	31	0	20	7	48	0	39	11	71	0	62	15	98	0	97	21	139
12,100			21	0	7	3	31	0	20	7	48	0	39	11	71	0	62	15	98	0	97	21	139
12,200			21	2	7	3	33	4	20	7	52	6	39	11	77	8	62	15	106	11	97	21	150
12,300			21	3	7	3	34	7	20	7	55	11	39	11	82	15	62	15	113	21	97	21	160
12,400			21	5	7	3	36	11	20	7	59	17	39	11	88	23	62	15	121	32	97	21	171
12,500			10	5	7	3	25	11	20	7	48	17	39	11	77	23	62	15	110	32	97	21	160
12,600			10	5	7	3	25	11	20	7	48	17	39	11	77	23	62	15	110	32	97	21	160
12,700			10	5	7	3	25	11	20	7	48	17	39	11	77	23	62	15	110	32	97	21	160
12,800		3	Rocky Coast																			
12,900																						
13,000																						
13,100			24	0	7	3	34	0	20	7	51	0	39	11	74	0	62	15	101	0	97	21	142
13,200			Rocky Coast																			
13,300																						
13,400																						
13,500		4	24	0	7	3	34	0	20	7	51	0	39	11	74	0	62	15	101	0	97	21	142
13,600			24	0	7	3	34	0	20	7	51	0	39	11	74	0	62	15	101	0	97	21	142
13,700			24	0	7	3	34	0	20	7	51	0	39	11	74	0	62	15	101	0	97	21	142
13,800			24	0	7	3	34	0	20	7	51	0	39	11	74	0	62	15	101	0	97	21	142

Chainage (m)	Tertiary Sediment Cell	Zone	Erosion Allowance (m)																			
			2015	2030				2050				2070				2090				2120			
			S1	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total
13,900	30a	4	24	0	7	3	34	0	20	7	51	0	39	11	74	0	62	15	101	0	97	21	142
14,000			24	0	7	3	34	0	20	7	51	0	39	11	74	0	62	15	101	0	97	21	142
14,100			24	0	7	3	34	0	20	7	51	0	39	11	74	0	62	15	101	0	97	21	142
14,200			24	0	7	3	34	0	20	7	51	0	39	11	74	0	62	15	101	0	97	21	142
14,300			24	0	7	3	34	0	20	7	51	0	39	11	74	0	62	15	101	0	97	21	142
14,400			24	0	7	3	34	0	20	7	51	0	39	11	74	0	62	15	101	0	97	21	142
14,500	29d	1	24	0	7	3	34	0	20	7	51	0	39	11	74	0	62	15	101	0	97	21	142
14,600			24	0	7	3	34	0	20	7	51	0	39	11	74	0	62	15	101	0	97	21	142
14,700			24	0	7	3	34	0	20	7	51	0	39	11	74	0	62	15	101	0	97	21	142
14,800			24	0	7	3	34	0	20	7	51	0	39	11	74	0	62	15	101	0	97	21	142
14,900			24	0	7	3	34	0	20	7	51	0	39	11	74	0	62	15	101	0	97	21	142
15,000			24	0	7	3	34	0	20	7	51	0	39	11	74	0	62	15	101	0	97	21	142
15,100			24	1	7	3	35	3	20	7	54	5	39	11	79	7	62	15	108	9	97	21	151
15,200			24	3	7	3	37	6	20	7	57	10	39	11	84	14	62	15	115	19	97	21	161
15,300		2	27	4	7	3	41	10	20	7	64	15	39	11	92	21	62	15	125	29	97	21	174
15,400			27	4	7	3	41	10	20	7	64	15	39	11	92	21	62	15	125	29	97	21	174
15,500			27	4	7	3	41	10	20	7	64	15	39	11	92	21	62	15	125	29	97	21	174
15,600			27	4	7	3	41	10	20	7	64	15	39	11	92	21	62	15	125	29	97	21	174
15,700			27	4	7	3	41	10	20	7	64	15	39	11	92	21	62	15	125	29	97	21	174
15,800			27	4	7	3	41	10	20	7	64	15	39	11	92	21	62	15	125	29	97	21	174
15,900			27	4	7	3	41	10	20	7	64	15	39	11	92	21	62	15	125	29	97	21	174
16,000			27	4	7	3	41	10	20	7	64	15	39	11	92	21	62	15	125	29	97	21	174
16,100			27	4	7	3	41	10	20	7	64	15	39	11	92	21	62	15	125	29	97	21	174

Chainage (m)	Tertiary Sediment Cell	Zone	Erosion Allowance (m)																			
			2015	2030				2050				2070				2090				2120			
			S1	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total
16,200	29d	2	27	4	7	3	41	10	20	7	64	15	39	11	92	21	62	15	125	29	97	21	174
16,300			27	4	7	3	41	10	20	7	64	15	39	11	92	21	62	15	125	29	97	21	174
16,400			27	4	7	3	41	10	20	7	64	15	39	11	92	21	62	15	125	29	97	21	174
16,500			27	4	7	3	41	10	20	7	64	15	39	11	92	21	62	15	125	29	97	21	174
16,600			27	4	7	3	41	10	20	7	64	15	39	11	92	21	62	15	125	29	97	21	174
16,700			27	4	7	3	41	10	20	7	64	15	39	11	92	21	62	15	125	29	97	21	174
16,800			27	4	7	3	41	10	20	7	64	15	39	11	92	21	62	15	125	29	97	21	174
16,900			27	4	7	3	41	10	20	7	64	15	39	11	92	21	62	15	125	29	97	21	174
17,000			27	4	7	3	41	10	20	7	64	15	39	11	92	21	62	15	125	29	97	21	174
17,100		3	27	0	7	3	37	0	20	7	54	0	39	11	77	0	62	15	104	0	97	21	145
17,200			27	0	7	3	37	0	20	7	54	0	39	11	77	0	62	15	104	0	97	21	145
17,300			27	0	7	3	37	0	20	7	54	0	39	11	77	0	62	15	104	0	97	21	145
17,400			27	0	7	3	37	0	20	7	54	0	39	11	77	0	62	15	104	0	97	21	145
17,500			27	0	7	3	37	0	20	7	54	0	39	11	77	0	62	15	104	0	97	21	145
17,600			27	0	7	3	37	0	20	7	54	0	39	11	77	0	62	15	104	0	97	21	145
17,700			27	0	7	3	37	0	20	7	54	0	39	11	77	0	62	15	104	0	97	21	145
17,800			27	0	7	3	37	0	20	7	54	0	39	11	77	0	62	15	104	0	97	21	145
17,900			27	0	7	3	37	0	20	7	54	0	39	11	77	0	62	15	104	0	97	21	145
18,000			27	0	7	3	37	0	20	7	54	0	39	11	77	0	62	15	104	0	97	21	145
18,100		4	37	2	7	3	49	4	20	7	68	6	39	11	93	8	62	15	122	12	97	21	167
18,200			37	3	7	3	50	8	20	7	72	12	39	11	99	17	62	15	131	23	97	21	178
18,300			37	3	7	3	50	8	20	7	72	12	39	11	99	17	62	15	131	23	97	21	178
18,400			37	3	7	3	50	8	20	7	72	12	39	11	99	17	62	15	131	23	97	21	178

Chainage (m)	Tertiary Sediment Cell	Zone	Erosion Allowance (m)																			
			2015	2030				2050				2070				2090				2120			
			S1	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total
18,500		4	37	3	7	3	50	8	20	7	72	12	39	11	99	17	62	15	131	23	97	21	178
18,600			37	3	7	3	50	8	20	7	72	12	39	11	99	17	62	15	131	23	97	21	178
18,700			37	3	7	3	50	8	20	7	72	12	39	11	99	17	62	15	131	23	97	21	178
18,800			37	3	7	3	50	8	20	7	72	12	39	11	99	17	62	15	131	23	97	21	178
18,900			37	3	7	3	50	8	20	7	72	12	39	11	99	17	62	15	131	23	97	21	178
19,000			37	3	7	3	50	8	20	7	72	12	39	11	99	17	62	15	131	23	97	21	178
19,100			37	3	7	3	50	8	20	7	72	12	39	11	99	17	62	15	131	23	97	21	178
19,200			37	3	7	3	50	8	20	7	72	12	39	11	99	17	62	15	131	23	97	21	178
19,300			26	0	7	3	36	0	20	7	53	0	39	11	76	0	62	15	103	0	97	21	144
19,400			26	0	7	3	36	0	20	7	53	0	39	11	76	0	62	15	103	0	97	21	144
19,500			26	0	7	3	36	0	20	7	53	0	39	11	76	0	62	15	103	0	97	21	144
19,600	29d		26	0	7	3	36	0	20	7	53	0	39	11	76	0	62	15	103	0	97	21	144
19,700			26	0	7	3	36	0	20	7	53	0	39	11	76	0	62	15	103	0	97	21	144
19,800			26	0	7	3	36	0	20	7	53	0	39	11	76	0	62	15	103	0	97	21	144
19,900			26	0	7	3	36	0	20	7	53	0	39	11	76	0	62	15	103	0	97	21	144
20,000		5	26	0	7	3	36	0	20	7	53	0	39	11	76	0	62	15	103	0	97	21	144
20,100			26	0	7	3	36	0	20	7	53	0	39	11	76	0	62	15	103	0	97	21	144
20,200			26	0	7	3	36	0	20	7	53	0	39	11	76	0	62	15	103	0	97	21	144
20,300			26	0	7	3	36	0	20	7	53	0	39	11	76	0	62	15	103	0	97	21	144
20,400			26	0	7	3	36	0	20	7	53	0	39	11	76	0	62	15	103	0	97	21	144
20,500			26	0	7	3	36	0	20	7	53	0	39	11	76	0	62	15	103	0	97	21	144
20,600			26	0	7	3	36	0	20	7	53	0	39	11	76	0	62	15	103	0	97	21	144
20,700			26	0	7	3	36	0	20	7	53	0	39	11	76	0	62	15	103	0	97	21	144

Chainage (m)	Tertiary Sediment Cell	Zone	Erosion Allowance (m)																			
			2015	2030				2050				2070				2090				2120			
			S1	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total
20,800	29c	1	30	2	7	3	42	4	20	7	61	6	39	11	86	8	62	15	115	11	97	21	159
20,900			30	2	7	3	42	4	20	7	61	6	39	11	86	8	62	15	115	11	97	21	159
21,000			16	2	7	3	28	4	20	7	47	6	39	11	72	8	62	15	101	11	97	21	145
21,100			16	1	7	3	27	2	20	7	45	3	39	11	69	4	62	15	97	5	97	21	139
21,200			16	0	7	3	26	0	20	7	43	0	39	11	66	0	62	15	93	0	97	21	134
21,300			16	0	7	3	26	0	20	7	43	0	39	11	66	0	62	15	93	0	97	21	134
21,400			16	0	7	3	26	0	20	7	43	0	39	11	66	0	62	15	93	0	97	21	134
21,500			16	0	7	3	26	0	20	7	43	0	39	11	66	0	62	15	93	0	97	21	134
21,600			16	2	7	3	28	4	20	7	47	7	39	11	73	9	62	15	102	13	97	21	147
21,700			16	4	7	3	30	9	20	7	52	14	39	11	80	19	62	15	112	26	97	21	160
21,800			16	6	7	3	32	13	20	7	56	21	39	11	87	28	62	15	121	39	97	21	173
21,900		2	42	8	7	3	60	18	20	7	87	28	39	11	120	38	62	15	157	53	97	21	213
22,000			42	8	7	3	60	18	20	7	87	28	39	11	120	38	62	15	157	53	97	21	213
22,100			42	8	7	3	60	18	20	7	87	28	39	11	120	38	62	15	157	53	97	21	213
22,200			42	8	7	3	60	18	20	7	87	28	39	11	120	38	62	15	157	53	97	21	213
22,300			42	8	7	3	60	18	20	7	87	28	39	11	120	38	62	15	157	53	97	21	213
22,400			42	8	7	3	60	18	20	7	87	28	39	11	120	38	62	15	157	53	97	21	213
22,500			42	8	7	3	60	18	20	7	87	28	39	11	120	38	62	15	157	53	97	21	213
22,600			42	8	7	3	60	18	20	7	87	28	39	11	120	38	62	15	157	53	97	21	213
22,700			42	8	7	3	60	18	20	7	87	28	39	11	120	38	62	15	157	53	97	21	213
22,800			42	6	7	3	58	13	20	7	82	21	39	11	113	28	62	15	147	39	97	21	199
22,900			42	4	7	3	56	9	20	7	78	14	39	11	106	19	62	15	138	26	97	21	186
23,000			42	2	7	3	54	4	20	7	73	7	39	11	99	9	62	15	128	13	97	21	173
23,100			42	0	7	3	52	0	20	7	69	0	39	11	92	0	62	15	119	0	97	21	160

Chainage (m)	Tertiary Sediment Cell	Zone	Erosion Allowance (m)																			
			2015	2030				2050				2070				2090				2120			
			S1	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total
23,200	29c	3	**7**	2	7	3	**19**	5	20	7	**39**	8	39	11	**65**	11	62	15	**95**	16	97	21	**141**
23,300			**7**	5	7	3	**22**	11	20	7	**45**	18	39	11	**75**	24	62	15	**108**	34	97	21	**159**
23,400			**7**	5	7	3	**22**	11	20	7	**45**	18	39	11	**75**	24	62	15	**108**	34	97	21	**159**
23,500			**7**	5	7	3	**22**	11	20	7	**45**	18	39	11	**75**	24	62	15	**108**	34	97	21	**159**
23,600			**7**	5	7	3	**22**	11	20	7	**45**	18	39	11	**75**	24	62	15	**108**	34	97	21	**159**
23,700			**7**	5	7	3	**22**	11	20	7	**45**	18	39	11	**75**	24	62	15	**108**	34	97	21	**159**
23,800			**7**	5	7	3	**22**	11	20	7	**45**	18	39	11	**75**	24	62	15	**108**	34	97	21	**159**
23,900			**7**	7	7	3	**24**	16	20	7	**50**	25	39	11	**82**	35	62	15	**119**	48	97	21	**173**
24,000			**Rocky Coast**																			
24,100																						
24,200																						
24,300		4																				
24,400																						
24,500																						
24,600																						
24,700																						
24,800	29b		**Sediment Cell 29b is not being assessed in this CHRMAP.**																			
24,900																						
25,000																						
25,100																						
25,200																						
25,300																						
25,400																						

Chainage (m)	Tertiary Sediment Cell	Zone	Erosion Allowance (m)																			
			2015	2030				2050				2070				2090				2120			
			S1	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total
25,500																							
25,600																							
25,700																							
25,800																							
25,900																							
26,000																							
26,100																							
26,200																							
26,300																							
26,400																							
26,500																							
26,600	29b																						
26,700																							
26,800																							
26,900																							
27,000																							
27,100																							
27,200																							
27,300																							
27,400																							
27,500																							
27,600																							
27,700																							

Sediment Cell 29b is not being assessed in this CHRMAP.

Chainage (m)	Tertiary Sediment Cell	Zone	Erosion Allowance (m)																			
			2015	2030				2050				2070				2090				2120			
			S1	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total
27,800	29b		Sediment Cell 29b is not being assessed in this CHRMAP.																			
27,900																						
28,000																						
28,100																						
28,200																						
28,300																						
28,400																						
28,500																						
28,600																						
28,700																						
28,800																						
28,900																						
29,000																						
29,100																						
29,200																						
29,300																						
29,400	29a	1	Rock																			
29,500																						
29,600																						
29,700																						
29,800																						
29,900																						
30,000																						

Chainage (m)	Tertiary Sediment Cell	Zone	Erosion Allowance (m)																			
			2015	2030				2050				2070				2090				2120			
			S1	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total
30,100		1	Rock																			
30,200																						
30,300		2	Mindarie Marina																			
30,400																						
30,500																						
30,600																						
30,700																						
30,800																						
30,900																						
31,000			**52**	2	7	3	**64**	4	20	7	**83**	6	39	11	**108**	8	62	15	**137**	11	97	21	**181**
31,100			**52**	2	7	3	**64**	5	20	7	**84**	8	39	11	**110**	11	62	15	**140**	16	97	21	**186**
31,200	**29a**		**52**	2	7	3	**64**	5	20	7	**84**	8	39	11	**110**	11	62	15	**140**	16	97	21	**186**
31,300			**52**	2	7	3	**64**	5	20	7	**84**	8	39	11	**110**	11	62	15	**140**	16	97	21	**186**
31,400			**52**	2	7	3	**64**	5	20	7	**84**	8	39	11	**110**	11	62	15	**140**	16	97	21	**186**
31,500			**52**	2	7	3	**64**	4	20	7	**83**	6	39	11	**108**	8	62	15	**137**	11	97	21	**181**
31,600			**52**	0	7	3	**62**	0	20	7	**79**	0	39	11	**102**	0	62	15	**129**	0	97	21	**170**
31,700			**52**	0	7	3	**62**	0	20	7	**79**	0	39	11	**102**	0	62	15	**129**	0	97	21	**170**
31,800			**52**	0	7	3	**62**	0	20	7	**79**	0	39	11	**102**	0	62	15	**129**	0	97	21	**170**
31,900			**52**	0	7	3	**62**	0	20	7	**79**	0	39	11	**102**	0	62	15	**129**	0	97	21	**170**
32,000			**52**	0	7	3	**62**	0	20	7	**79**	0	39	11	**102**	0	62	15	**129**	0	97	21	**170**
32,100			**52**	0	7	3	**62**	0	20	7	**79**	0	39	11	**102**	0	62	15	**129**	0	97	21	**170**
32,200			**52**	0	7	3	**62**	0	20	7	**79**	0	39	11	**102**	0	62	15	**129**	0	97	21	**170**
32,300			**52**	0	7	3	**62**	0	20	7	**79**	0	39	11	**102**	0	62	15	**129**	0	97	21	**170**

Chainage (m)	Tertiary Sediment Cell	Zone	Erosion Allowance (m)																			
			2015	2030				2050				2070				2090				2120			
			S1	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total	S2	S3	FoS	Total
32,400	29a	3	52	0	7	3	62	0	20	7	79	0	39	11	102	0	62	15	129	0	97	21	170
32,500			52	0	7	3	62	0	20	7	79	0	39	11	102	0	62	15	129	0	97	21	170
32,600			52	0	7	3	62	0	20	7	79	0	39	11	102	0	62	15	129	0	97	21	170
32,700			52	0	7	3	62	0	20	7	79	0	39	11	102	0	62	15	129	0	97	21	170
32,800			52	0	7	3	62	0	20	7	79	0	39	11	102	0	62	15	129	0	97	21	170
32,900			52	0	7	3	62	0	20	7	79	0	39	11	102	0	62	15	129	0	97	21	170
33,000			52	0	7	3	62	0	20	7	79	0	39	11	102	0	62	15	129	0	97	21	170
33,100			52	2	7	3	64	4	20	7	83	6	39	11	108	8	62	15	137	11	97	21	181
33,200			52	3	7	3	65	7	20	7	86	11	39	11	113	15	62	15	144	21	97	21	191
33,300			52	5	7	3	67	11	20	7	90	17	39	11	119	23	62	15	152	32	97	21	202

Appendix E 1908 HWM Survey

J. EWNG 31

11

P17935

8

W.G. 3/12/08

Indian Ocean

Sandy Beach

Water Mark

Rocks

150 337 1' 30" 6° 184 21 35" 2302

173 38' 25"

334 33' 40" / 360 / 4694 33' 40" / 173 38' 25"

200 1840 Sand Hills

300 910

T.B. 343 28' / 343 23' 20 20 160 7' 50"

280 31' 20" / 360 / 4640 31' 20" / 160 7' 50"

300 7230

7100 Sand Hills

125 5990 1370

250 4990

400 3960

250 2800 Sand Hills

200 1850

200 1000 Sand Hills

323 35' 45" T.B / 323 31' 20 20 20.06 = 55 20.06 1890 E.J. HORLIN 49 p 10.

285 35' 40" / 360 / 4645 35' 40" / 161 23' 55"

161 23' 55

250

200 1230 1370

342 11' 30" T.B / 342 7' 20 20 Now 20.18

275

165 2' 50 4210 See E.J. HORLIN FB 49 P 10 3/3/16

300 11' 20" / 360 / 4660 11' 20" / 165 2' 50"

175 4000

200 2900 Sand Hills W.G. 3/12/08

3/12/08

W.G.
4/12/08

250 1240 ϕ

(obs) 344° 23' 30" T.B. 311° 24'
344° 17' 20 167' 51' 360
6605 4|671 24'
250 167 51'

Loose Sand Hills

350 5700 ϕ

300 5020 ϕ

200 3615 ϕ

300 2660 ϕ B70

300 1900 ϕ Sand Hills

250 930 ϕ

340° 26' 30"
332° 14' T.B 360
300, 332 8' 4|700° 26' 30
175 6' 37" 20 175 6' 37"

Sandy Beach with boulders of rock

High Water

Indian

8045

W.G.
4/12/08

~7515 links

APIDIANA

High Water Mark

400 6800 ϕ Sand Hills

225 5800 ϕ

250 5220 ϕ B70

175 4220 ϕ

200 3070 ϕ Sand Hills

250 2070 ϕ See p 23 for obs

300 900 ϕ

T.B. 337° 6' 45" obs

Rock

Ocean

4/12/08

11

P17935

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