m p rogers & associates pl ABN 14 062 681 252
creating better coasts and ports

R771 Rev 1

June 2016

City of Joondalup

Joondalup Coastal Hazard Assessment

marinas
boat harbours
canals
breakwaters
jetties
seawalls
dredging
reclamation
climate change
waves
currents
tides
flood levels
water quality
siltation
erosion
rivers
beaches
estuaries

www.coastsandports.com.au

m p rogers & associates pl
creating better coasts and ports

Suite 1, 128 Main Street, Osborne Park, WA 6017
p: +618 9254 6600
e: admin@coastsandports.com.au
w: www.coastsandports.com.au

K1331, Report R771 Rev 1
Record of Document Revisions

Rev	Purpose of Document	Prepared	Reviewed	Approved	Date
A	Draft for MRA review	T Hunt	C Doak	T Hunt	31/05/2016
0	Issued for Client use	T Hunt	C Doak	T Hunt	2/06/2016
1	Updated with City comments and re-issued for use	T Hunt	C Doak	T Hunt	13/06/2016

Form 035 18/06/2013

Limitations of this Document

Executive Summary

MRA has previously completed assessments of the coastal hazards and vulnerability for the City of Joondalup's shoreline. These assessments were completed at different times and to varying baselines. Following the implementation of the City's coastal monitoring program, the City engaged MRA to complete a revised Coastal Hazard Assessment for the entire City coastline, to the requirements of the State Coastal Planning Policy (SPP2.6; WAPC 2013). This will provide a consistent assessment across the whole City.

Specifically, this Coastal Hazard Assessment included the following:

- Assessment of areas of rocky and sandy shoreline.
- Using updated shoreline movement plans from the City's coastal monitoring program to update the shoreline movement analysis for the whole City shoreline.
- Modelling the potential severe storm erosion across the City shoreline to the requirements of SPP2.6, using beach profiles from the City's coastal monitoring program.
- Assessment of the potential impacts of sea level rise.
- Modelling of the water levels at the shoreline for a 500 year ARI water level event.
- Assessment of the total coastal erosion and coastal inundation hazard allowances.
- Mapping the coastal hazards for the City shoreline.

The study area was broken into a number of different cells and chainages for the assessment, to ensure that variations in the shoreline were accounted for. These consisted of a number of sandy and rocky shorelines. The assessment focussed predominantly on the sandy shoreline sections.

Storm erosion modelling was completed for 11 profile across the City, to account for the varying shoreline forms and orientations. Measured beach profiles from the City's coastal monitoring program were used as input to the modelling, along with representative sediment sizes taken from site. Input wave and water levels were taken from recommended storm details provided by the Department of Transport, representing a 100 year ARI beach erosion event in south Western Australia. The storm erosion modelling suggested up to 46 m erosion could be experienced on the shoreline in the 100 year ARI event.

Shoreline movement plans for the City have recently been updated to 2015 in the City's coastal monitoring program. For this assessment the updated shoreline movement plans were used to update the shoreline movement assessment for the City.

The shoreline movement assessment showed similar trends in sediment movement to those previously observed. The following were noted from the shoreline movement assessment:

- There has been significant accretion south of Hillarys Boat Harbour, with the shoreline accreting up to 60 m since 1987.
- For the 2km north of Hillarys Boat Harbour, the shoreline has generally eroded since its construction.

- At Pinnaroo Point the shoreline initially accreted but has eroded rapidly in recent years.
- Mullaloo Beach has generally accreted since 1996.
- From the Burns Beach groyne north to the City's boundary, the shoreline has generally eroded.

Shoreline movement allowances were determined based on the historic and predicted future trends in movement.

An allowance for sea level rise has been made based on the recommendations of SPP2.6 and the Department of Transport. Allowances for sea level rise of 0.32 m for the coming 50 years and 0.90 m for the coming 100 years have been used. Based on these timeframes and the recommendations of SPP2.6, this may result in shoreline recession of 32 and 90 m respectively.

The total coastal erosion hazard allowance was estimated and mapped for the City shoreline. Allowances of between 85 and 256 m were estimated for the sandy shorelines in the coming 100 years. For the rocky shoreline a 5 m hazard allowance was estimated for low value public infrastructure (eg paths) and minimum 30 m for leasehold and freehold development.

The coastal inundation hazard was determined based on the 500 year ARI water level at the shoreline. This was determined using results from detailed cyclone modelling of the Western Australian coastline which were input into a shoreline change model to estimate water levels at the shoreline. This allowed accurate calculation of the wave setup on the shoreline. The 500 year ARI water levels at the shoreline in 2115 were estimated at between 3.50 and 4.0 mAHD across the study area.

Coastal hazard maps have been prepared for the City shoreline, presenting the coastal hazards at 2015, 2065 and 2115. Infrastructure located seaward of these coastal hazard lines may be considered vulnerable to coastal hazards in the relevant timeframe.

The maps indicate that there is minimal infrastructure vulnerable to coastal hazards in the present day. This is generally limited to dune fencing and beach access paths which have a functional need to be close to the active shoreline. The City should consider the need for maintenance of these items following storm events.

In the longer term, existing infrastructure has been identified within coastal hazard areas at a number of locations. To address this risk it is recommended the following are completed.

- The City continue the coastal monitoring program to identify changes to the shoreline.
- The coastal hazard assessment is reviewed and updated at approximately 10 year intervals or if large shoreline changes are identified from the monitoring.
- Proposed development within the coastal hazard areas should be supported by appropriate Coastal Hazard Risk Management and Planning.
- Geotechnical investigations be considered in key locations.

This assessment provides a consistent baseline for the entire present day City coast.

Table of Contents

Table of Figures

Table of Tables

1. Introduction

1.1 General

The City of Joondalup (City) manages over 15 km of shoreline in the northern Perth Metropolitan area (Figure 1.1). As part of their ongoing planning and management of the coast, the City is completing coastal hazard assessments supported by coastal monitoring.

Figure 1.1 City Coastline & Key Features or Landmarks

The City has engaged M P Rogers & Associates Pty Ltd (MRA) to update previous coastal hazard and vulnerability assessments to make use of the most recent coastal monitoring data.

1.2 Previous Studies

MRA has previously completed coastal hazard and vulnerability assessments for different sections of the City's shoreline. These are covered in the following three reports:

- Marmion to Sorrento Coastal Vulnerability Assessment (MRA 2015a).
- Hillarys to Ocean Reef Coastal Vulnerability (MRA 2012a).
- Iluka to Burns Beach Coastal Vulnerability Assessment (MRA 2014).

These assessments cover the entire City shoreline, but were completed in stages. As a result of this staging, the assessments were completed at different times and were therefore completed in line with the appropriate planning policies applicable at those times.

This assessment will therefore update the previous assessments to provide a consistent coastal hazard assessment for the whole City coastline, in line with the current State Planning Policy 2.6: State Coastal Planning Policy (SPP2.6; WAPC 2013).

It is noted that previous studies which pre-empted the updated SPP2.6 referred to *coastal vulnerability* lines and the vulnerability of the shoreline. The updated SPP2.6 defines *coastal vulnerability* as the susceptibility of a system to climate change or coastal hazards. *Coastal hazards* are defined as the consequence of coastal processes and are what are generally determined as part of a coastal assessment. For consistency with the updated SPP2.6, *coastal hazards* will be referred to in this report and the potential extent of influence will be determined and mapped from this assessment.

1.3 State Planning Policy 2.6

This coastal hazard assessment will be completed in line with the recommendations of SPP2.6. SPP2.6 provides the methodology for completing an assessment of the potential impacts of coastal processes on development in Western Australia. For sandy coasts, this methodology requires calculation of the following erosion allowances to accommodate the impacts of coastal processes on the development.

- S1 Erosion – allowance for storm erosion.
- S2 Erosion – allowance for historic shoreline movement trends.
- S3 Erosion – allowance for erosion caused by future sea level rise.
- S4 Inundation – allowance for storm surge inundation.

For rocky coasts, allowance for the current and future risk of erosion should generally be based on a geotechnical assessment of the shoreline stability and assessment of wave overtopping.

Coastal hazard maps will be prepared using the SPP2.6 methodology for 50 and 100 year planning horizons. This report presents the data, methods and findings of the coastal hazard assessment.

2. Site Setting

2.1 General

The coastal hazard assessment covers the entire City shoreline. For ease of reference and consistency, chainages have been determined for the shoreline and are presented in Figure 2.1.

Figure 2.1 Hazard Mapping Study Area Chainages

The chainages extend past the northern boundary of the City for the shoreline movement analysis.

The City coastline includes the Hillarys and Ocean Reef Boat Harbours, sections of rocky and sandy shorelines, various seawalls and a number of groynes at Sorrento and Burns Beach. Each of these structures and landforms will be discussed further in following sections of this report.

2.2 Sediment Cells

The study area extends from the northern end of Watermans Bay to Burns Beach. The study area includes a range of shoreline types, from rocky cliffs in the south to sandy beach and dune systems at the northern end.

Investigations by Searle & Semeniuk (1985) and Eliot et al (2005) have classified the Mandurah to Two Rocks coastline in terms of primary and secondary sediment cells. More recently, Damara WA (2012) classified the coastline between Cape Naturaliste and Moore River in terms of primary, secondary and tertiary level sediment cells. Damara WA (2012) define sediment cells as "*sections of the coast within which sediment transport processes are strongly related*" and proposed that the cells could provide a platform for the review and management of coastal processes over varying temporal and spatial scales.

The differences in cell hierarchy reflect the varying timescales for assessment of each sediment cell level. Characteristics of each cell level are described below (Damara WA 2012).

- Primary cells relate to geological processes and trends that may alter over geological timescales, but exchange of sediment between primary cells are considered to be relatively constant in the shorter developmental planning timeframes.
- Secondary cells describe the contemporary sediment movement and inter-decadal trends and landform response.
- Tertiary cells generally cover the reworking and movement of sediment in the nearshore area with shoreline responses of the seasonal to inter-annual timescales.

SPP2.6 makes reference to coastal sediment cells and notes that coastal hazard assessments should consider the entire sediment cell. The extent of the sediment cells defined by Damara WA (2012) around the City shoreline are presented in Figure 2.2.

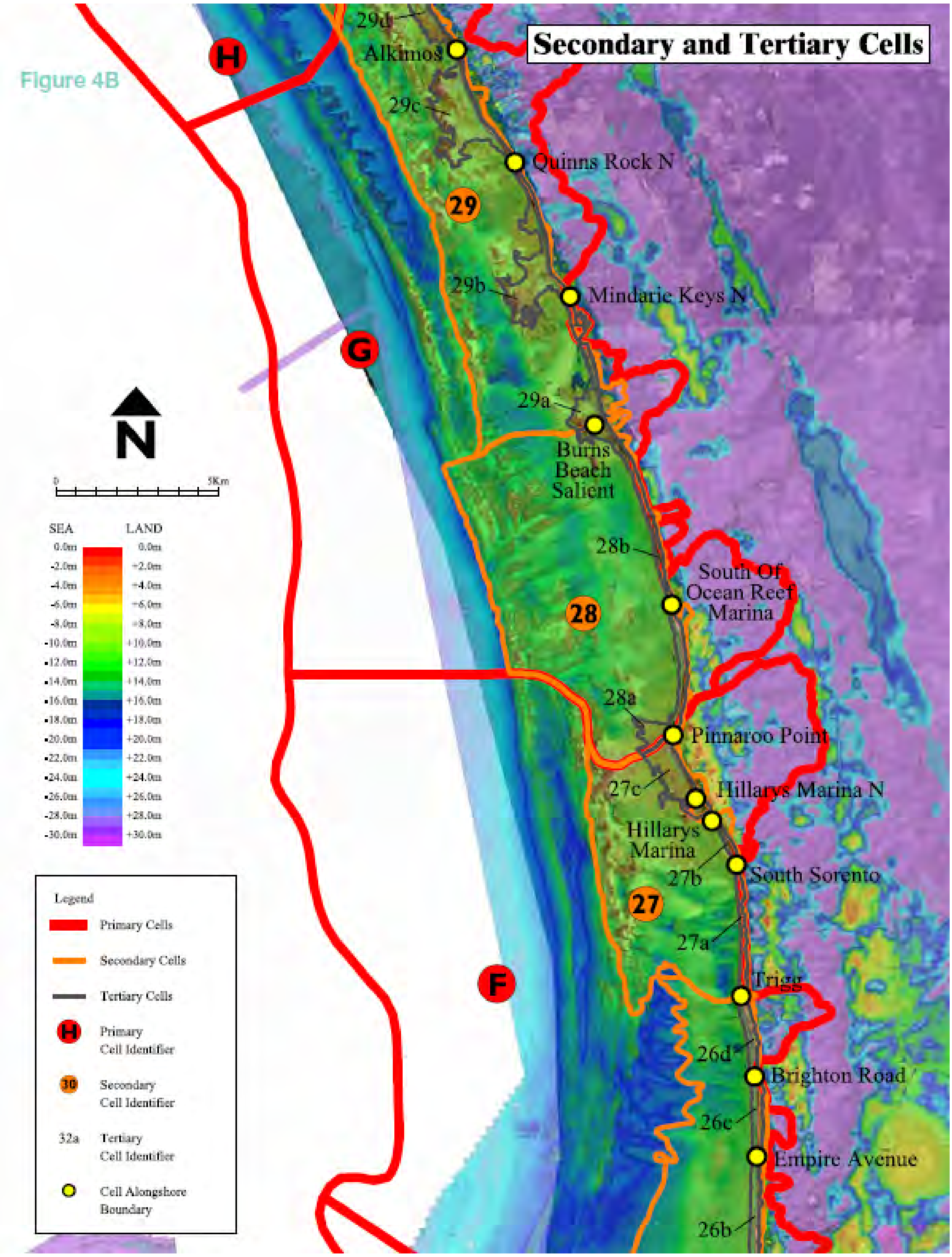

Figure 2.2 Sediment Cell Boundaries (Damara WA 2012)

The study area for this report falls covers the primary sediment cells F (Fremantle to Pinnaroo Point) and G (Pinnaroo Point to Yanchep). It primarily covers the secondary cells 27 (Trigg to

Pinnaroo) and 28 (Pinnaroo Point to Burns Beach Salient). These secondary cells will primarily be the focus of the assessment.

Within these secondary cells, there are 5 tertiary cells, outlined below:

- Trigg to South Sorrento (27a).
- South Sorrento to Hillarys Boat Harbour (27b).
- Hillarys Boat Harbour to Pinnaroo Point (27c).
- Pinnaroo Point to south of Ocean Reef Boat Harbour (28a).
- Ocean Reef Boat Harbour to Burns Beach salient (28b).

The southern-most of these (Trigg to South Sorrento) is largely outside the City boundaries but will be considered in the shoreline movement assessment. In addition, the next tertiary cell north (Burns Beach salient to Mindarie Marina) will also be considered in the shoreline movement assessment.

2.3 Geology & Geomorphology

The geology and geomorphology of the study area and greater Perth Metropolitan coastline is described in detail by Searle & Semeniuk (1985). The current shoreline lies on the Swan Coastal Plain, and generally comprises Holocene beach and dune sediment deposits overlying late Pleistocene, calcarenite limestone. These formations are the dominant landforms along the coast (Searle & Semeniuk 1985).

Searle & Semeniuk (1985) broadly classified the coast into a number of sectors. The City's shoreline lies at the southern end of the Whitfords to Lancelin sector, which the authors describe as a dominantly straight rocky shore with isolated accretionary cusps. The coast in this sector is generally characterised by rocky coasts and pocket beaches interspersed with straight sandy beaches (Searle & Semeniuk 1985).

This general characterisation of the sector is represented across the study area, with limestone cliffs, headlands and nearshore reef platforms to the south and sandy beach and dune systems to the north.

Individual descriptions of the geology and geomorphology of the City's shoreline have been described in more detail in the previous coastal hazard assessments (MRA 2012a, 2014 and 2015a). For the purposes of this updated assessment, it is important to note the general landforms that exist along the various sections of shoreline as well as areas of rocky and sandy shoreline within the City boundaries. A brief description of the landforms, features and shoreline types within the sectors is presented below.

2.3.1 Marmion

The sections of coast from the City's southern boundary to approximately the Marmion Angling & Aquatic Club (MAAC) largely consists of rock cliffs, interspersed with small sandy embayments. These embayments and pocket beaches likely consist of thin layers of sand overlying rock, which is exposed seasonally. A typical photograph of an embayment along this section of shoreline is presented in Figure 2.3. Recent geotechnical investigations have confirmed the presence of buried rock in the dunes in this area.

Figure 2.3 Marmion Shoreline

2.3.2 Sorrento

Between the MAAC and Hillarys Boat Harbour, the shoreline is generally sandy with noticeably less rock present on the shoreline and inshore areas. Recent geotechnical investigations north of the MAAC suggests that rock in the dunes is only present at lower elevations and further east for this sector compared to Marmion.

At the southern end of this sector the MAAC is protected by a limestone armour seawall. The car park immediately north of the MAAC is largely unprotected, although there is some informal rock armour placed at the toe of the dunes and understood to be some natural rock underneath the structure. The position of the bank under the car park is monitored by a fixed camera.

The shoreline in the north of this sector is compartmentalised with three groynes, installed in the early 1980's to protect the Sorrento foreshore and West Coast Drive. They are approximately 60 m in length and constructed from a mix of limestone and granite armour. They control the position and alignment of the shoreline through this section of coast. Between the first and second groynes a limestone block seawall at the rear of the beach also protects the Sorrento Surf Lifesaving Club (SLSC). The beach in front of the Sorrento SLSC is shown in Figure 2.4.

Figure 2.4 Sorrento Shoreline

The Hillarys Boat Harbour is protected from coastal hazards by breakwaters and controlled by the Department of Transport (DoT) and is therefore excluded from this assessment.

2.3.3 Hillarys to Pinnaroo Point

The shoreline north of Hillarys Boat Harbour is sandy and, except for the area immediately north of Hillarys which is somewhat protected by a wave shadow from the breakwaters, consists of a narrow beach and high dunes. The general shoreline is presented in Figure 2.5.

Figure 2.5 Beach North of Hillarys Boat Harbour

2.3.4 Pinnaroo Point

Pinnaroo Point is a sandy cuspate foreland with lower foredunes than the adjacent sections of coast. While the shoreline in the area has experienced long-term accretion over a number of decades, this trend may have reversed in recent years. The general shoreline at Pinnaroo is presented in Figure 2.6.

Figure 2.6 Shoreline at Pinnaroo Point

2.3.5 Pinnaroo Point to Mullaloo

The shoreline from Pinnaroo Point to Mullaloo is consistently sandy, with coastal dunes of varying elevations. The Mullaloo SLSC is located approximately halfway along this section of shoreline, where a section of dunes have been removed. There is a retaining wall in front of the SLSC, which may offer some protection to the club.

There are signs of accretion along this shoreline, with a wide beach, foredune forming along sections of the shoreline and indications of wind-blown sand accretion. Figure 2.7 presents the shoreline looking south from the northern extent of Mullaloo Beach.

Figure 2.7 Shoreline South of Mullaloo

2.3.6 Mullaloo to Ocean Reef Boat Harbour

From the northern end of Mullaloo Beach to the Ocean Reef Boat Harbour, the shoreline is characterised by limestone cliffs, with sand coming and going seasonally in front of the cliffs. For the purposes of the coastal hazard assessment, this entire section of shoreline will be assessed as rock. The general shoreline is presented in Figure 2.8.

Figure 2.8 Rock Shoreline South of Ocean Reef Boat Harbour

The Ocean Reef Boat Harbour is protected from coastal hazards by rock breakwaters and has therefore not been included in this assessment.

2.3.7 Ocean Reef Boat Harbour to Burns Beach Groyne

North of the Ocean Reef Boat Harbour the shoreline is characterised by limestone cliffs interspersed with small sandy embayments. The sandy embayments generally consist of thin layers of sand overlaying rock platform and pavement. There is likely to be rock buried in the dunes in these embayments. The general shoreline through this section is presented in Figure 2.9.

Figure 2.9 Shoreline North of Ocean Reef Boat Harbour

At Burns Beach a limestone groyne holds a sandy beach on its southern side. The beach south of the groyne has recently been the subject of a geotechnical investigation which showed consistent rock through this area.

2.3.8 Burns Beach

North of the Burns Beach groyne to the City's boundary, the shoreline is generally sandy, with high coastal dunes. For large parts of this section of coast the beach is narrow and there is nearshore rock and reef present. The extent of this rock on the shoreline is unclear and the shoreline will be assessed as sandy (Figure 2.10).

Figure 2.10 Shoreline at Burns Beach

2.3.9 Classification of Rock & Sand Shorelines

Previous coastal hazard assessments for the City's shoreline have classified the shoreline as either sandy or rocky, based on available information, assessments, site inspections and observations. The rock present on sections of shoreline is Tamala limestone, which can offer significant protection from coastal erosion. This is the same material present on the rocky shorelines of Cottesloe and Halls Head, Mandurah. In Mandurah, surveys of the rocky cliffs from early last century indicate there has been less than 5 m movement of the cliffs in over 100 years. This shows that competent limestone can provide protection and withstand the erosive effects of the ocean.

Following recommendations from the previous coastal hazard assessments, the City has recently completed some targeted geotechnical investigations at Marmion and Burns Beach (MRA 2016a). These investigations mapped the presence and continuity of the rock in the dunes in these areas. The assessment of areas of rock and sand shorelines have been updated with the results of these investigations.

The assessment of sections of rock and sandy shoreline will be considered in determination of the coastal hazards and shown clearly on prepared coastal hazard maps presented later in this report.

3. Storm Erosion (S1 Allowance)

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.

If the initial width of the surf zone is insufficient to dissipate the increased wave energy, this energy is often spent eroding the beach face, beach berm and sometimes the dunes. The eroded sand is transported offshore with the return water flow to form offshore bars. As these bars grow, they can cause incoming waves to break further offshore, decreasing the wave energy available to attack the beach. This is shown diagrammatically in Figure 3.1 for a sandy coastline.

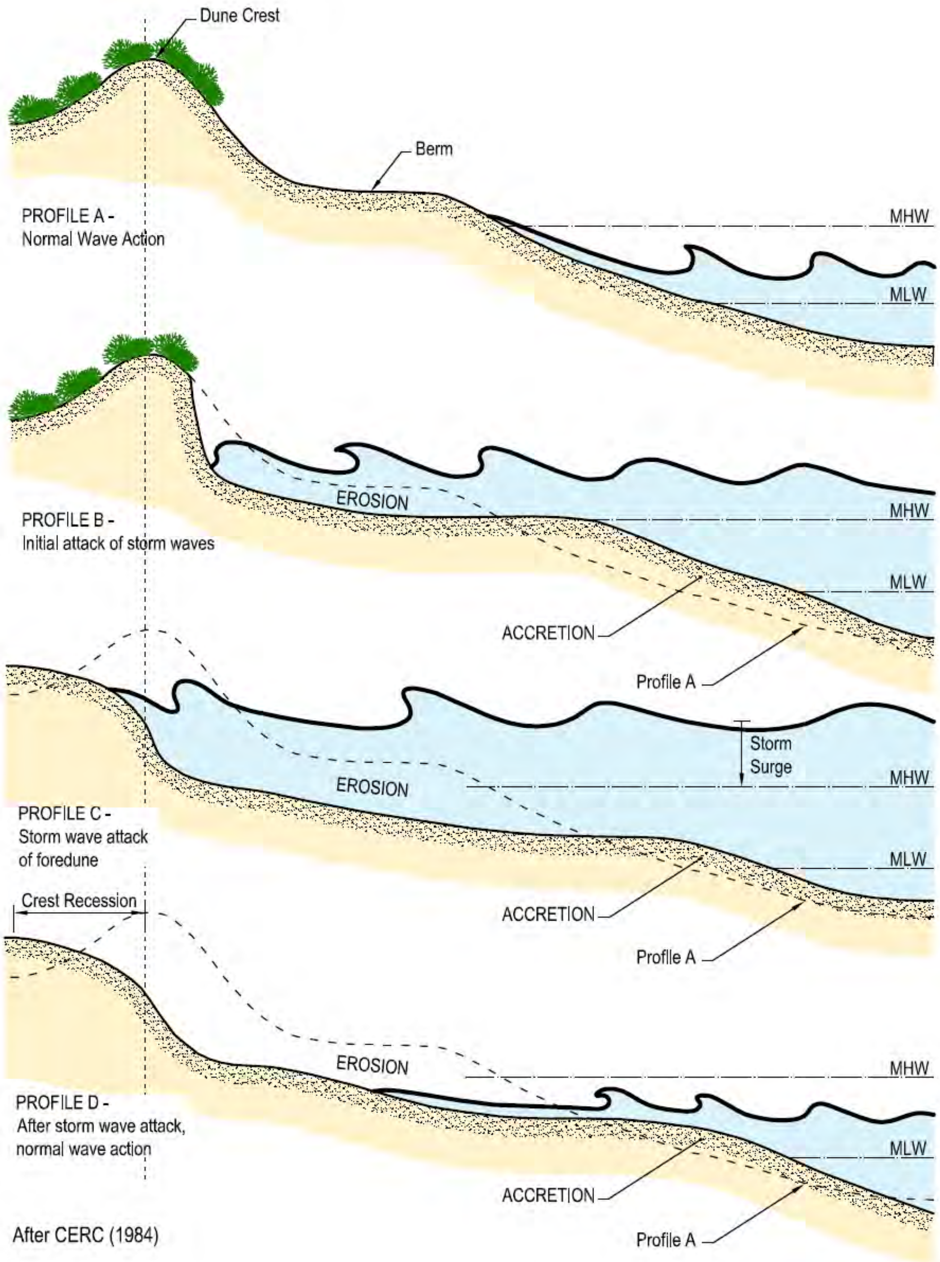

Figure 3.1 Storm Wave Attack

SPP2.6 recommends that the potential cross shore erosion be determined by modelling the impact of an appropriate storm sequence using acceptable models such as SBEACH (WAPC 2013). 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 ARI of 100 years.

3.1 SBEACH Model Setup

The SBEACH computer model was developed by the Coastal Engineering Research Centre 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).

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. Care should also be taken to ensure that the model is accurately reproducing the recorded wave heights and water levels.

Eleven beach profiles have been used to represent the City's shoreline, extending from the shoreline to approximately 10 m water depth. These profiles have been taken from the City's monitoring program and represent the various sandy shoreline sectors within the City. The location of the modelled beach profiles are indicated on Figure 3.2.

Note that the Profile numbering in this report *does not match* the beach monitoring profile numbering. This is due to ease of reference in this report and the removal of some of the monitoring profiles. Some care should be taken when comparing profile numbers from this report to the monitoring profiles.

Individual outputs for each of the beach profiles will be discussed further in following sections of this report.

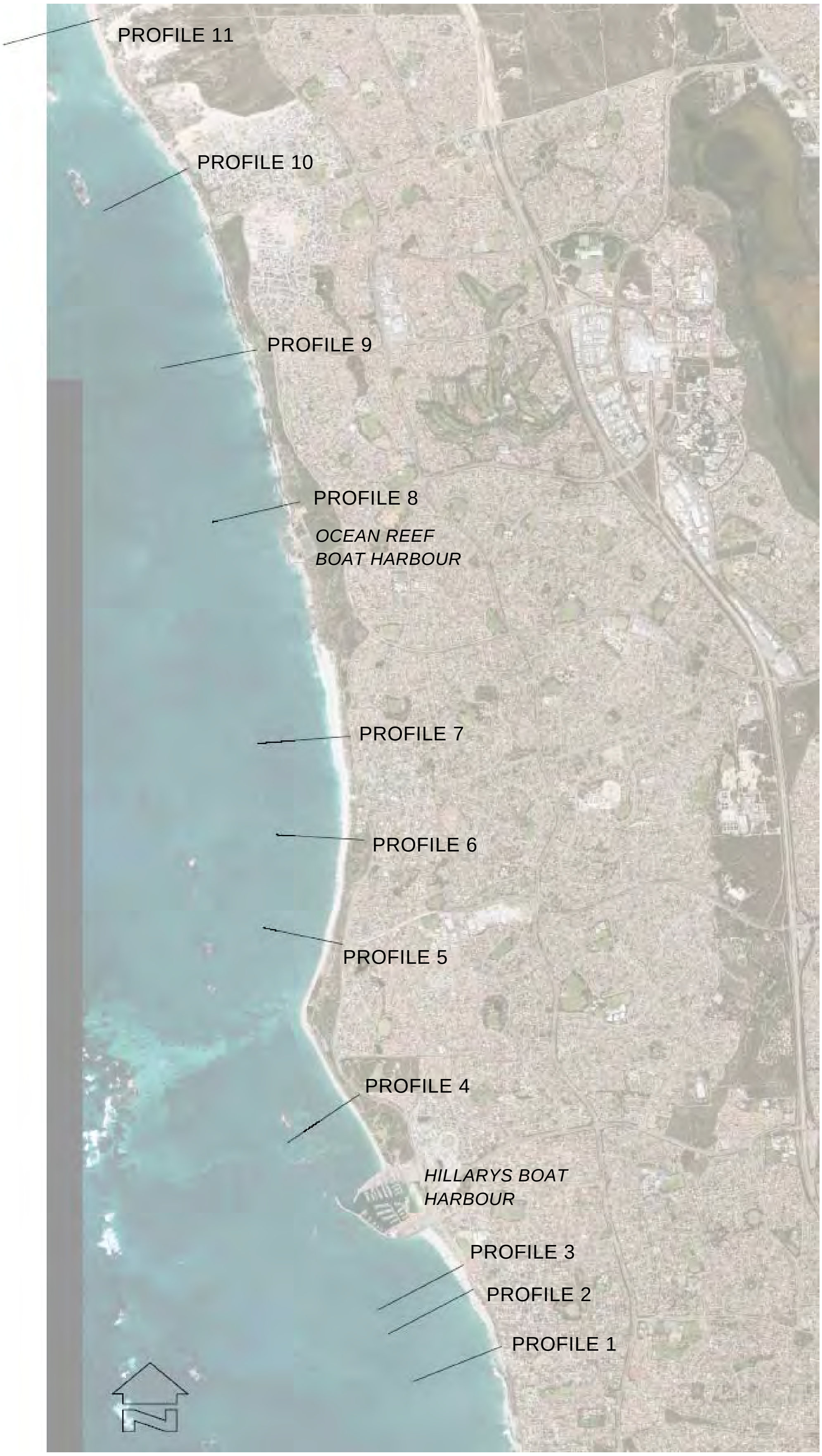

Figure 3.2 Location of Modelled Beach Profiles

3.2 SPP2.6 Storm Inputs

It is widely accepted that simulating 3 repeats of a severe storm sequence that affected south west Western Australia in July 1996 provides a conservative representation of the 100 year beach erosion event. This storm sequence had elevated water levels for a period of approximately 110 hours and caused significant 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 significant wave height (Hs) during this event peaked at 7.8 m at the South-West Rottnest wave-rider buoy. This corresponds to approximately the 5 year ARI wave height at South-West Rottnest and is applicable to the Perth Metropolitan coast.

MRA has previously completed detailed wave modelling for the Perth Metropolitan coastline using the SWAN model (MRA 2015b). The set-up, calibration and validation of this wave model is outlined in MRA (2015b) and a comparison of the measured and modelled wave conditions reproduced in Figure 3.3.

Figure 3.3 Measured & Modelled Wave Comparison Offshore from Ocean Reef

The comparison shows that the wave model can adequately simulate nearshore wave conditions in the study area. Using the validated wave model, MRA has modelled the recommended SPP2.6 storm for the Joondalup coastline. The input wave conditions to the model are presented in Figure 3.4.

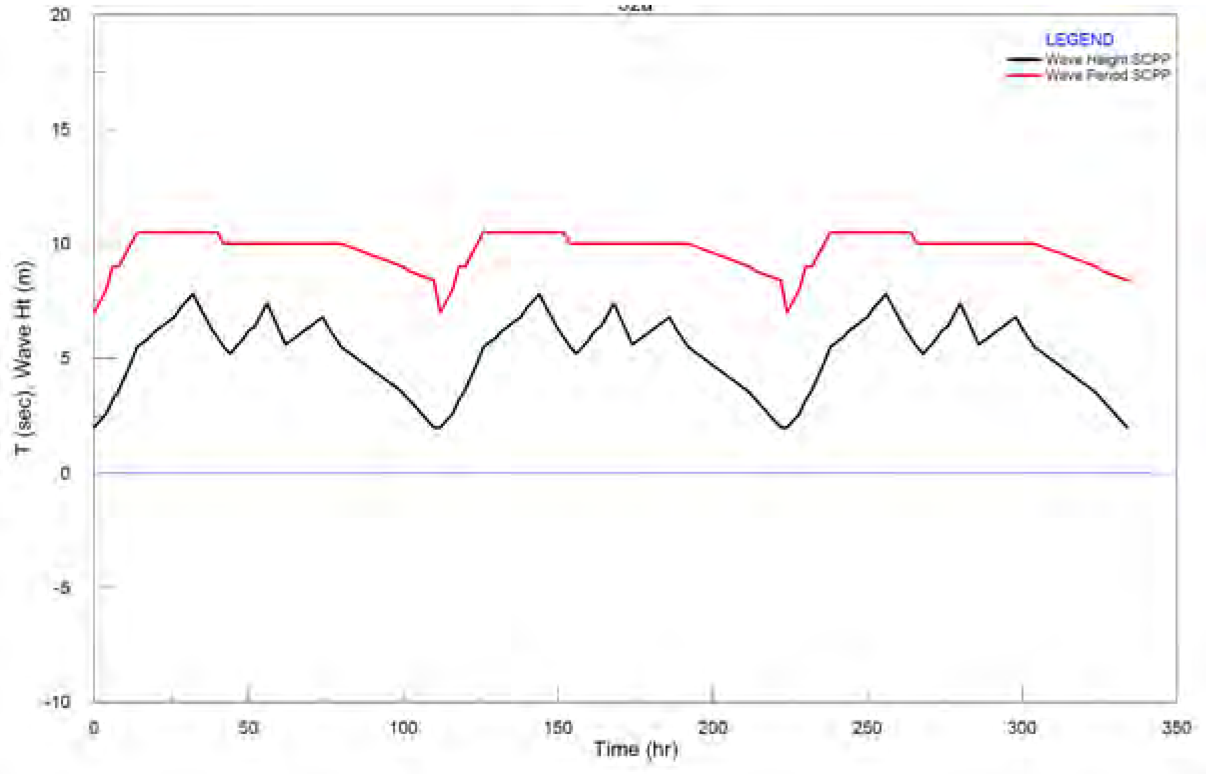

Figure 3.4 Offshore Wave Conditions for SPP2.6 Storm

A spatial plot of the wave conditions at the peak of this storm across the Perth Metropolitan area is presented in Figure 3.5.

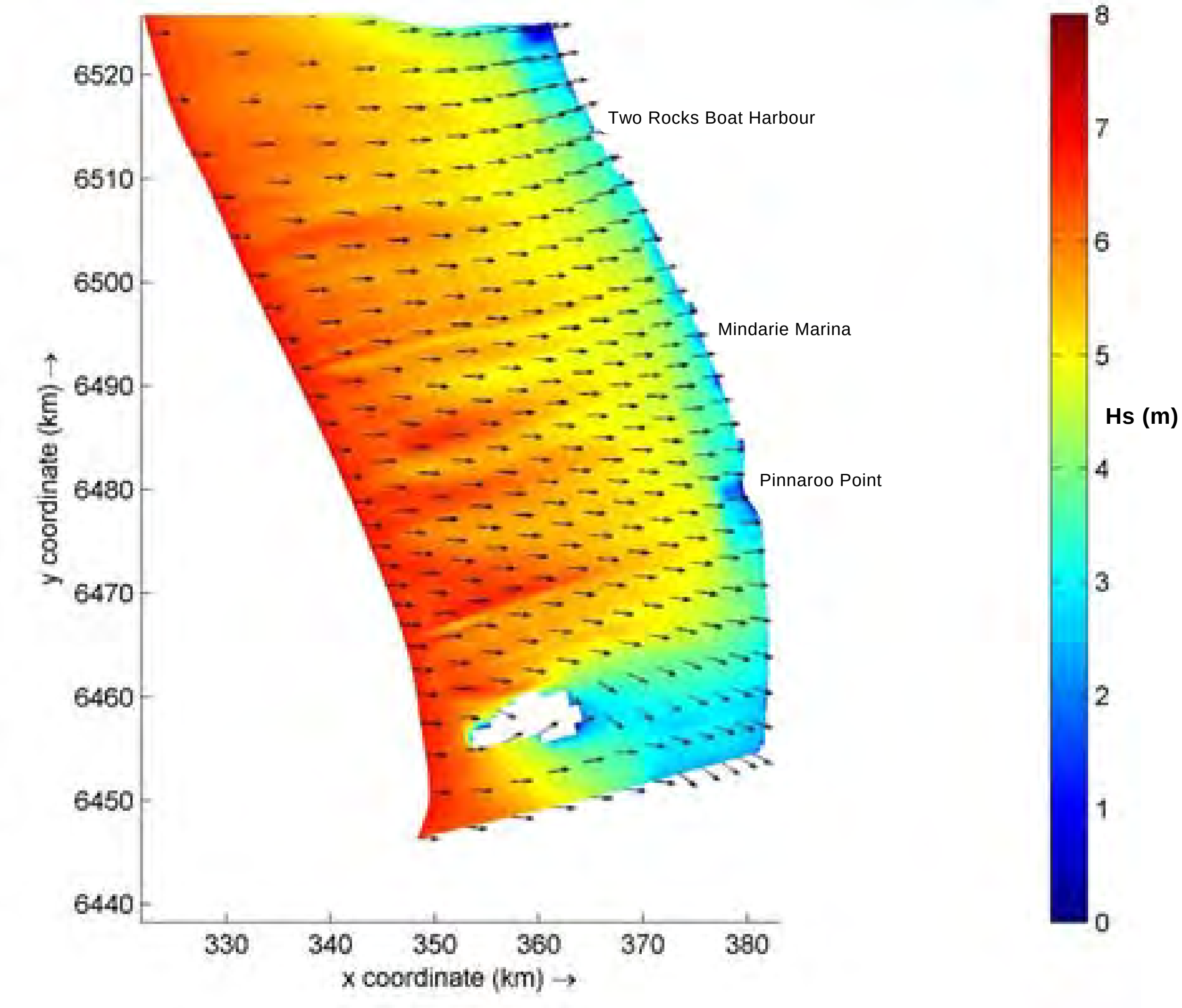

Figure 3.5 Spatial Plot of Wave Conditions in SPP2.6 Storm

Nearshore wave conditions have been extracted individually from the outputs of this modelling for each of the beach profiles and used as an input to the SBEACH model.

The water level recommended for use in this storm in the south-west of Western Australia has previously been provided by the Department of Transport (DoT). This water level peaks at approximately 1.0 mAHD and is applicable to approximately 5 m water depth. This has been used as an input to the SBEACH modelling for all profiles.

3.3 SBEACH Modelling

The SBEACH modelling of each of the beach profiles is outlined in the following sections.

3.3.1 Profile 1

Profile 1 is located immediately north of the Marmion Angling & Aquatic Club (MAAC). Nearshore reef platform is evident in the area and from the beach profiles and has been included in the modelling.

The peak significant wave height used in the modelling was 2.8 m in around 7 m of water. Sediment samples from the area suggest the representative sediment size D_{50} = 0.45 mm and this has been used in the modelling.

The results of the SBEACH modelling at Profile 1 are presented in Figure 3.6. The figure shows the pre- and post-storm beach profiles, peak water levels and wave heights during the storm event.

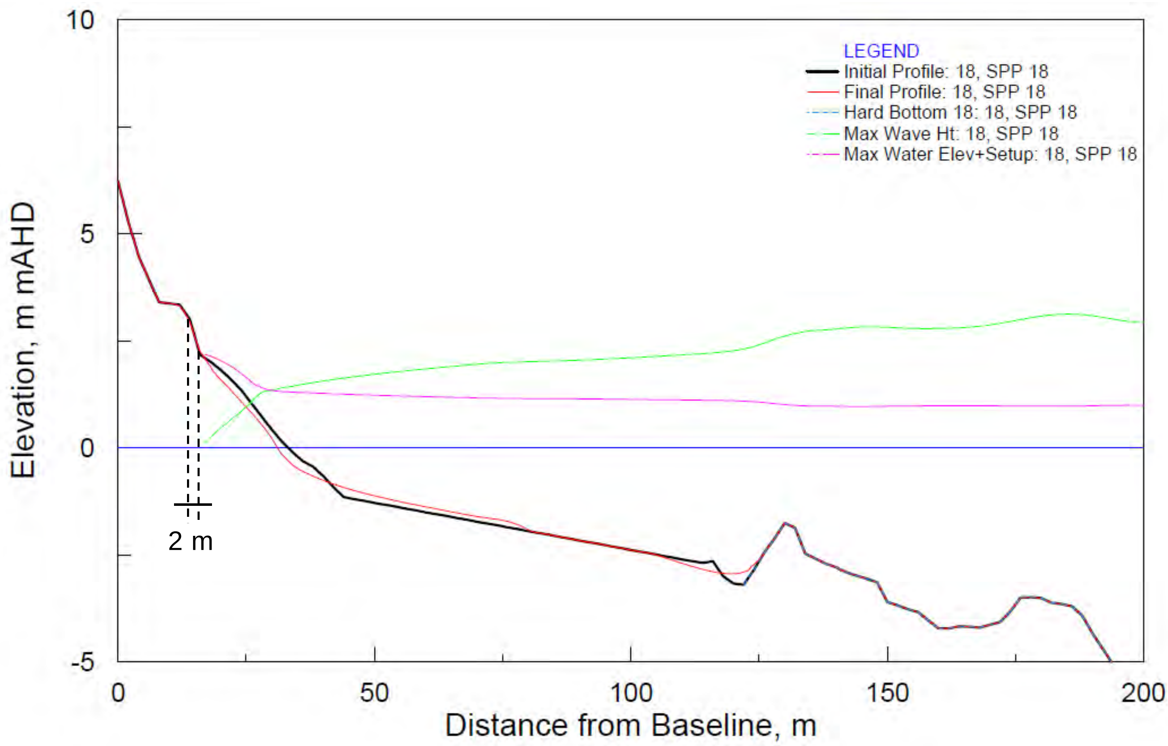

Figure 3.6 SBEACH Output from Profile 1

SPP2.6 requires the allowance for severe storm erosion is taken as the extent of erosion behind the Horizontal Shoreline Datum (HSD). The HSD is defined as the active limit of the shoreline under storm activity. The modelling shows that for Profile 1 the HSD is approximately 2.2 mAHD.

SPP2.6 requires that to ensure a stable post-storm shoreline slope, the slope of the final profile should be flatter than 30°. The SBEACH output for each profile was therefore reviewed to ensure the slope was flatter than 30°. For any profiles where the post-storm slope was greater than 30° a slope correction allowance was added. For Profile 1 the post-storm slope was flatter than 30°.

The figure shows that the modelled recession extended approximately 2 m behind the HSD. This has been increased slightly for a factor of safety (FOS) and the S1 erosion allowance recommended as 5 m.

3.3.2 Profile 2

Profile 2 is located between the southern and middle groynes at Sorrento. The peak significant wave height used in the modelling was 2.7 m in around 7 m of water. Sediment samples from the area suggest the representative sediment size D_{50} = 0.45 mm and this has been used in the modelling.

The results of the SBEACH modelling at Profile 2 are presented in Figure 3.7.

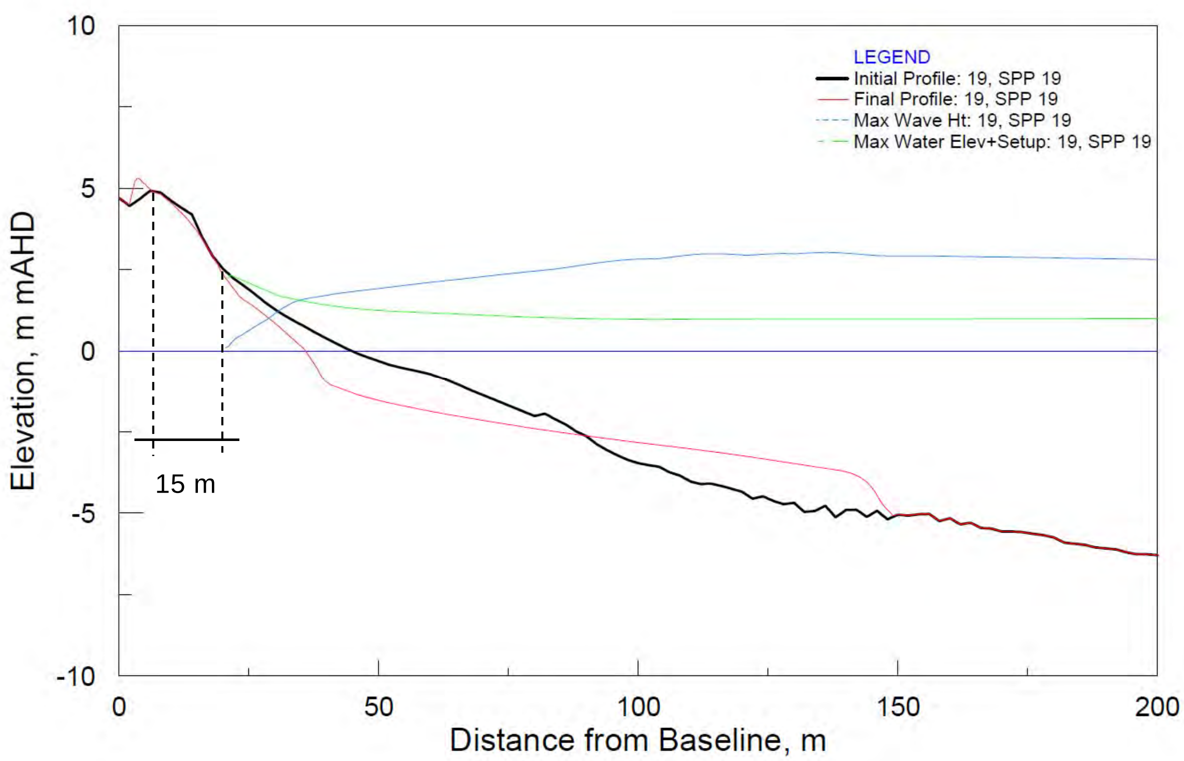

Figure 3.7 SBEACH Output from Profile 2

The modelling shows that for Profile 2 the HSD is approximately 2.3 mAHD. The modelled recession extended approximately 15 m behind the HSD and the S1 erosion allowance is recommended as 15 m.

3.3.3 Profile 3

Profile 3 is located in front of the Surf Lifesaving Club at Sorrento. This profile includes a seawall at the rear of the beach. The peak significant wave height used in the modelling was 2.7 m in around 8 m of water. Sediment samples from the area suggest the representative sediment size D_{50} = 0.45 mm and this has been used in the modelling.

The results of the SBEACH modelling at Profile 3 are presented in Figure 3.8.

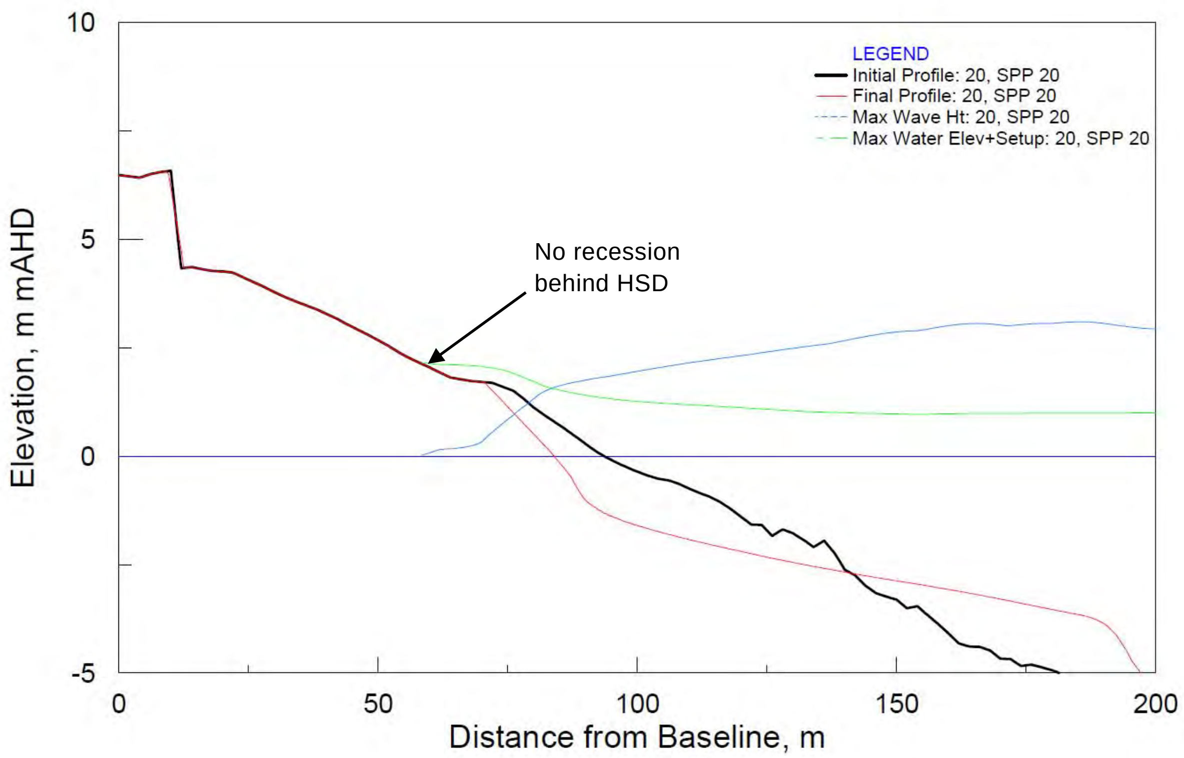

Figure 3.8 SBEACH Output from Profile 3

The modelling shows that for Profile 3 the HSD is approximately 2.2 mAHD. Due to the wide sandy beach and the beach grade, no recession was modelled behind the HSD. This is noted to be in part due to the elevated level of the HSD, as erosion is experienced at lower elevations on the beach profile. A FOS of 5 m has been included and the S1 erosion allowance is recommended as 5 m.

3.3.4 Profile 4

Profile 4 is located on the northern side of Hillarys Boat Harbour, south of Pinnaroo Point. The peak significant wave height used in the modelling was 2.4 m in around 6 m of water. Sediment samples from the area suggest the representative sediment size D_{50} = 0.29 mm and this has been used in the modelling.

The results of the SBEACH modelling at Profile 4 are presented in Figure 3.9.

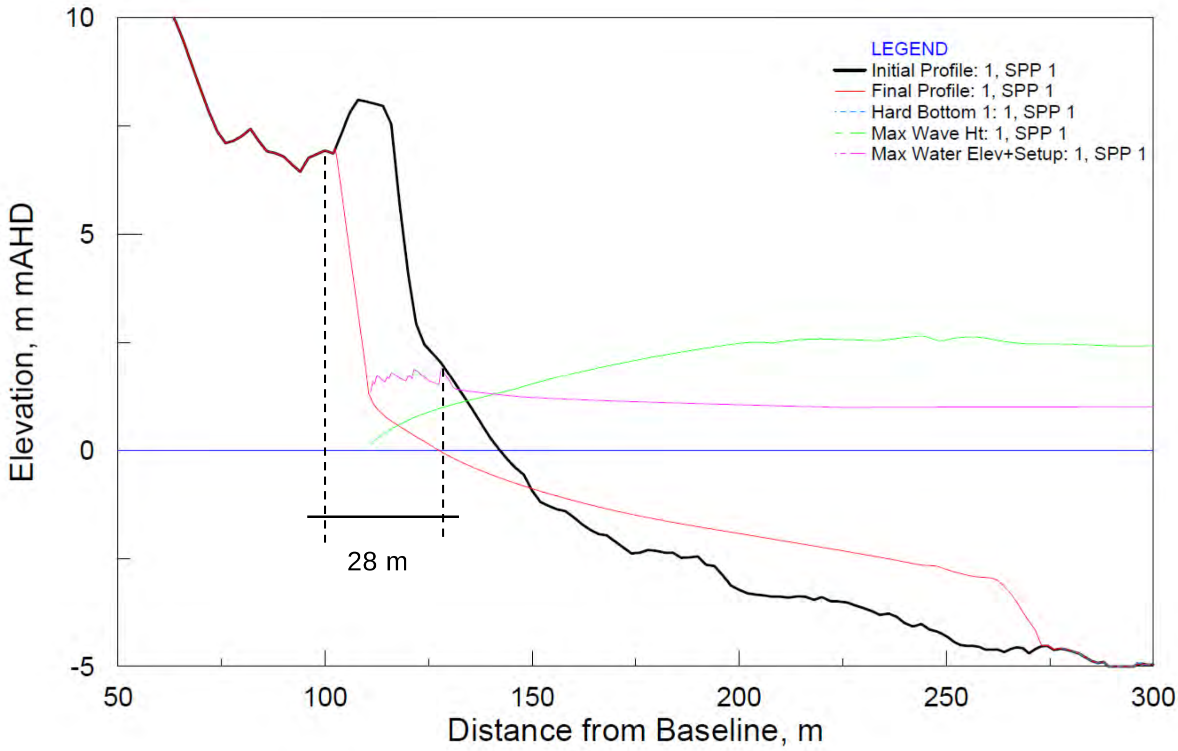

Figure 3.9 SBEACH Output from Profile 4

The modelling shows that for Profile 4 the HSD is approximately 1.7 mAHD. The modelled recession extended approximately 26 m behind the HSD. In this case the post-storm profile was steeper than 30° and a slope correction factor was therefore applied. The recommended S1 erosion allowance is 28 m.

3.3.5 Profile 5

Profile 5 is located on the northern side of Pinnaroo Point, near Whitfords Avenue. The peak significant wave height used in the modelling was 3.2 m in around 8 m of water. Sediment samples from the area suggest the representative sediment size D_{50} = 0.28 mm and this has been used in the modelling.

The results of the SBEACH modelling at Profile 5 are presented in Figure 3.10.

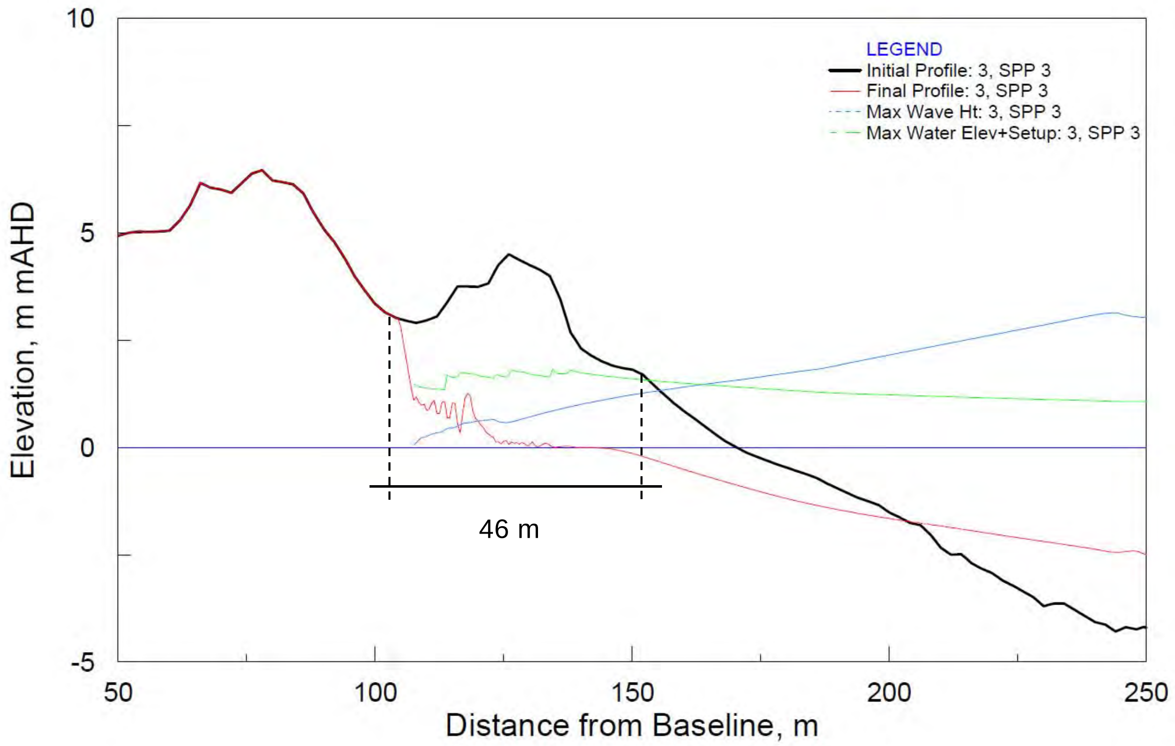

Figure 3.10 SBEACH Output from Profile 5

The modelling shows that for Profile 5 the HSD is approximately 1.8 mAHD. The modelled recession extended approximately 46 m behind the HSD and the S1 erosion allowance is recommended as 46 m.

3.3.6 Profile 6

Profile 6 is located in the middle of the sandy beach between Pinnaroo Point and Mullaloo. It is located south of the Mullaloo Surf Lifesaving Club. The peak significant wave height used in the modelling was 3.2 m in around 9 m of water. Sediment samples from the area suggest the representative sediment size D_{50} = 0.28 mm and this has been used in the modelling.

The results of the SBEACH modelling at Profile 6 are presented in Figure 3.11.

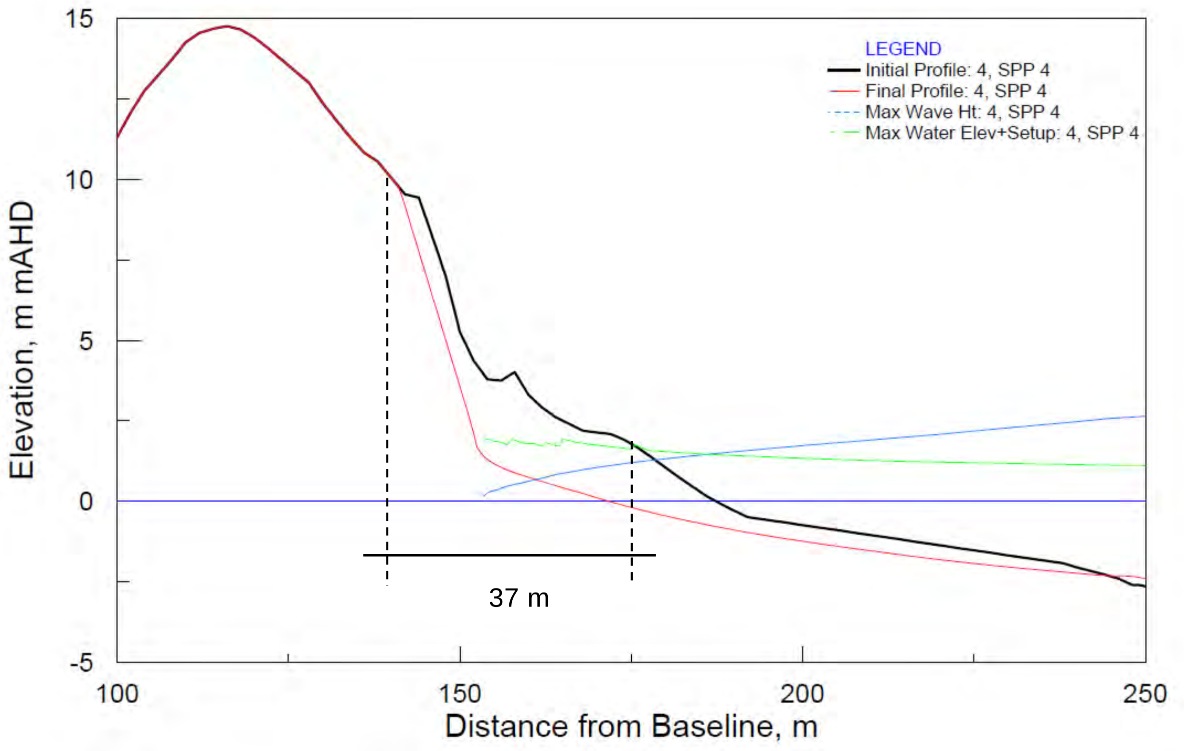

Figure 3.11 SBEACH Output from Profile 6

The modelling shows that for Profile 6 the HSD is approximately 2.0 mAHD. The modelled recession extended approximately 33 m behind the HSD. In this case the post-storm profile was steeper than 30° and a slope correction factor was applied. The recommended S1 erosion allowance is 37 m.

3.3.7 Profile 7

Profile 7 is located on Mullaloo Beach. The peak significant wave height used in the modelling was 3.4 m in around 10 m of water. Sediment samples from the area suggest the representative sediment size D_{50} = 0.28 mm and this has been used in the modelling.

The results of the SBEACH modelling at Profile 7 are presented in Figure 3.12.

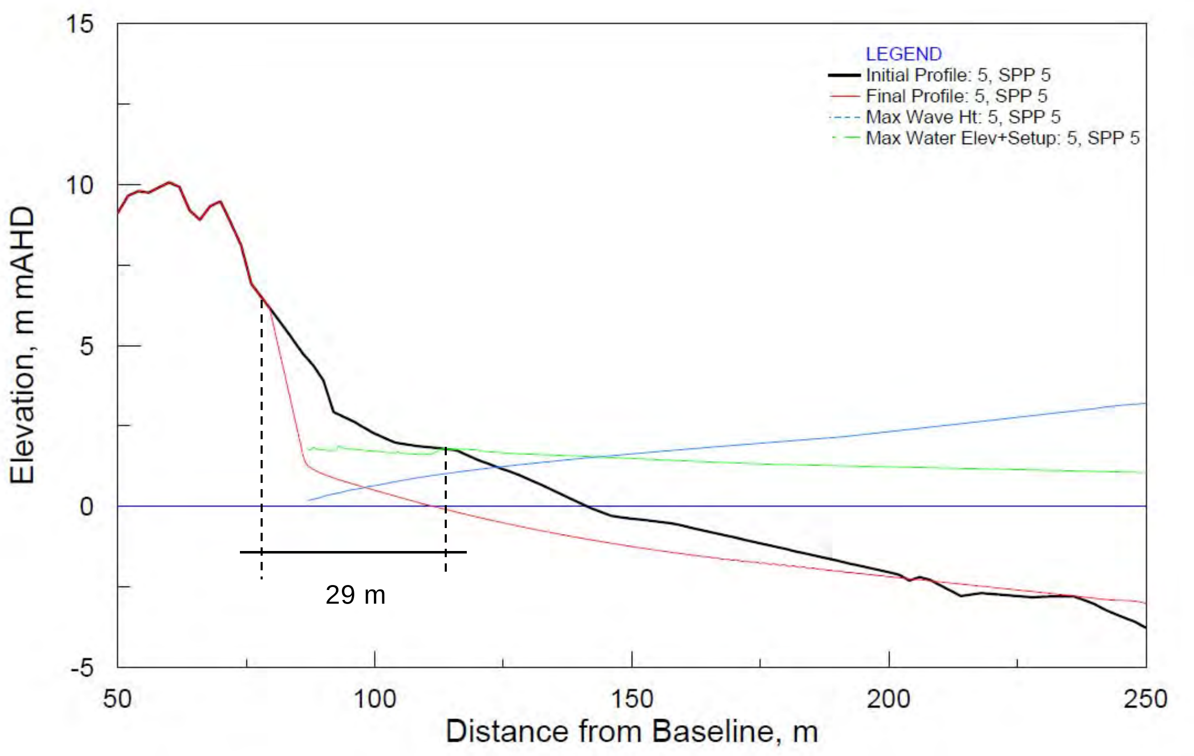

Figure 3.12 SBEACH Output from Profile 7

The modelling shows that for Profile 7 the HSD is approximately 1.9 mAHD. The modelled recession extended approximately 27 m behind the HSD. In this case the post-storm profile was steeper than 30° and a slope correction factor was applied. The recommended S1 erosion allowance is 29 m.

3.3.8 Profile 8

Profile 8 is located on a pocket beach on the northern side of Ocean Reef Boat Harbour. The peak significant wave height used in the modelling was 3.6 m in around 11 m of water. Sediment samples from the area suggest the representative sediment size D_{50} = 0.31 mm and this has been used in the modelling.

The results of the SBEACH modelling at Profile 8 are presented in Figure 3.13.

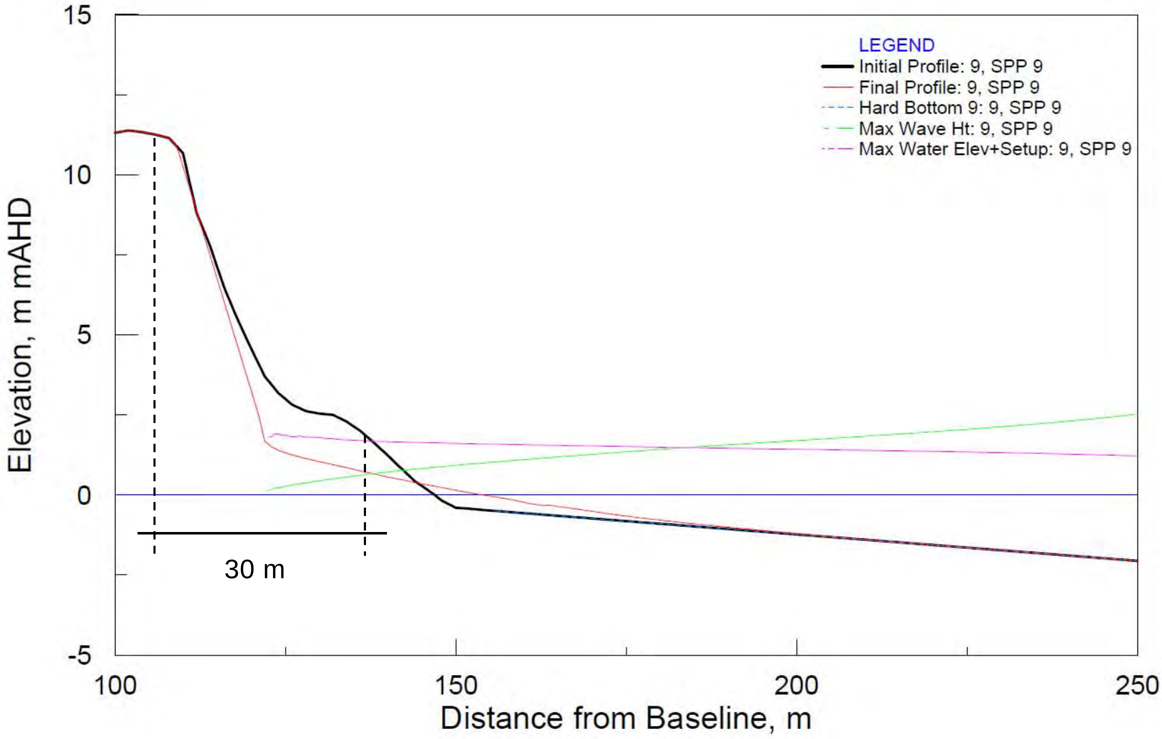

Figure 3.13 SBEACH Output from Profile 8

The modelling shows that for Profile 8 the HSD is approximately 1.9 mAHD. The modelled recession extended approximately 27 m behind the HSD. In this case the post-storm profile was steeper than 30° and a slope correction factor was applied. The recommended S1 erosion allowance is 30 m.

3.3.9 Profile 9

Profile 9 is located on a pocket sandy beach in Iluka, near Shenton Avenue. The peak significant wave height used in the modelling was 3.6 m in around 12 m of water. Sediment samples from the area suggest the representative sediment size D_{50} = 0.31 mm and this has been used in the modelling.

The results of the SBEACH modelling at Profile 9 are presented in Figure 3.14.

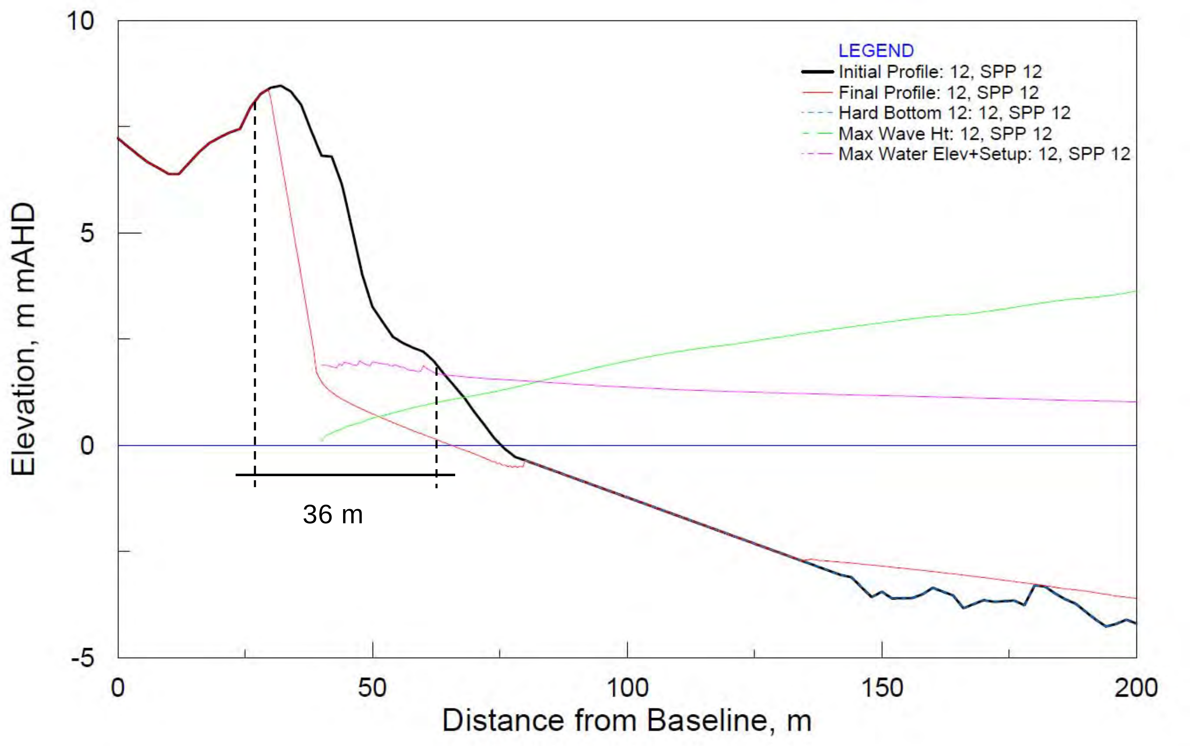

Figure 3.14 SBEACH Output from Profile 9

The modelling shows that for Profile 9 the HSD is approximately 2.0 mAHD. The modelled recession extended approximately 33 m behind the HSD. In this case the post-storm profile was steeper than 30° and a slope correction factor was applied. The recommended S1 erosion allowance is 36 m.

3.3.10 Profile 10

Profile 10 is located north of the Burns Beach groyne, in front of the recent Burns Beach subdivision. The peak significant wave height used in the modelling was 3.3 m in around 9 m of water. Sediment samples from the area suggest the representative sediment size D_{50} = 0.35 mm and this has been used in the modelling.

The results of the SBEACH modelling at Profile 10 are presented in Figure 3.15.

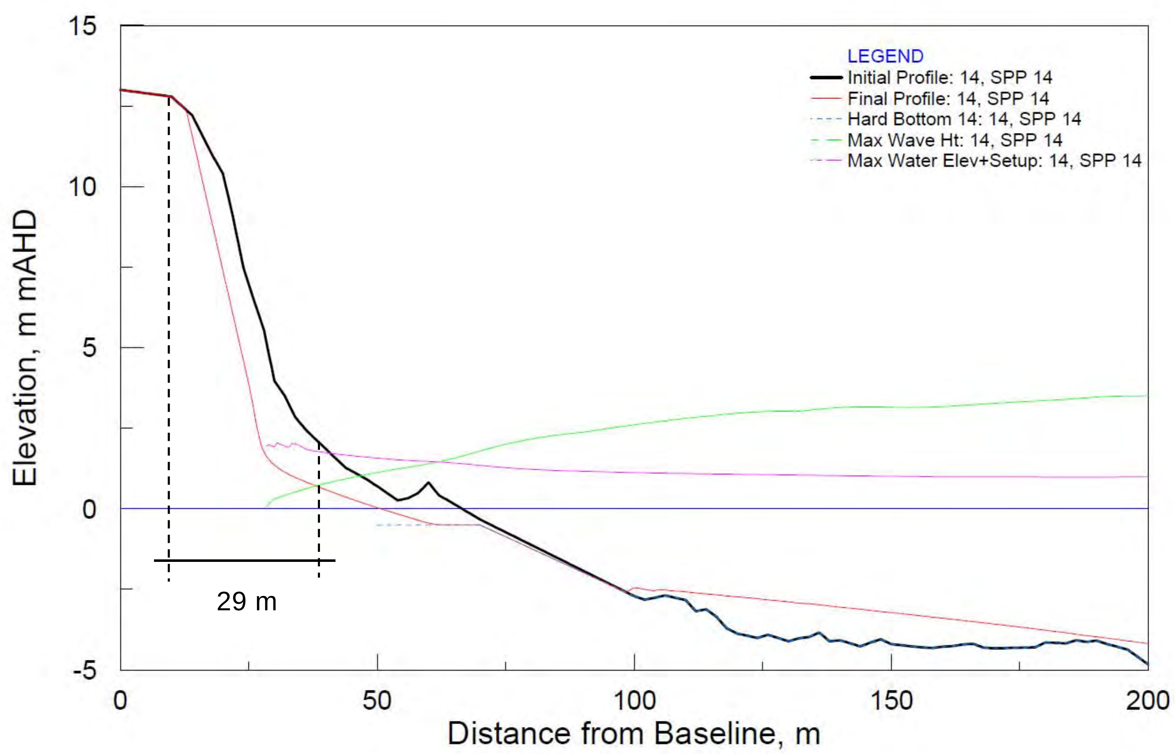

Figure 3.15 SBEACH Output from Profile 10

The modelling shows that for Profile 10 the HSD is approximately 2.1 mAHD. The modelled recession extended approximately 26 m behind the HSD. In this case the post-storm profile was steeper than 30° and a slope correction factor was applied. The recommended S1 erosion allowance is 29 m.

3.3.11 Profile 11

Profile 11 is located on the sandy shoreline at Burns Beach, near the northern boundary of the City. The peak significant wave height used in the modelling was 3.7 m in around 11 m of water. Sediment samples from the area suggest the representative sediment size D_{50} = 0.35 mm and this has been used in the modelling.

The results of the SBEACH modelling at Profile 11 are presented in Figure 3.16.

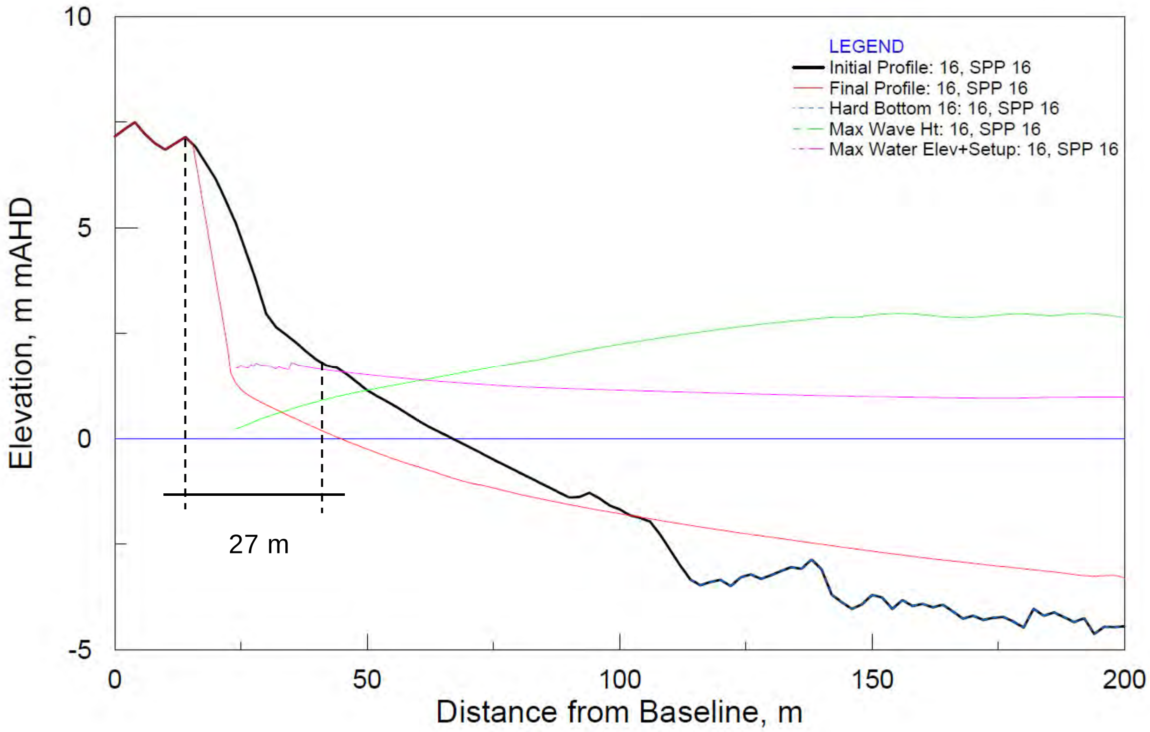

Figure 3.16 SBEACH Output from Profile 11

The modelling shows that for Profile 11 the HSD is approximately 1.8 mAHD. The modelled recession extended approximately 26 m behind the HSD. In this case the post-storm profile was steeper than 30° and a slope correction factor was applied. The recommended S1 erosion allowance is 27 m.

3.4 Summary of S1 Erosion Allowances

The previous sections have outlined the modelling and the recommended S1 allowances for the 11 profiles selected to represent the City's shoreline. The recommended allowances are summarised in Table 3.1.

Table 3.1 Summary of Recommended S1 Allowances

Profile	Location	HSD (mAHD)	S1 Allowance (m)
1	MAAC	2.2	5
2	Sorrento (south)	2.3	15
3	Sorrento SLSC	2.2	5
4	Pinnaroo Point (south)	1.7	28
5	Pinnaroo Point (north)	1.8	46
6	Kallaroo	2.0	37
7	Mullaloo	1.9	29
8	Ocean Reef (north)	1.9	30
9	Iluka	2.0	36
10	Burns Beach (south)	2.1	29
11	Burns Beach (north)	1.8	27

The allowances recommended in Table 3.1 include results of the SBEACH modelling, slope correction allowances, assessment of longshore gradients in storm events and appropriate FOS in the storm erosion assessment.

To determine the coastal erosion hazard allowances, the allowances in Table 3.1 will be applied to the relevant sections of shoreline adjacent to the beach profiles.

4. Shoreline Movement (S2 Allowance)

Historically, changes in shorelines occur on varying timescales from storm to post storm, seasonal and longer term (Short 1999). The S1 Allowance accounts for the short term storm timescale of beach change. The S2 Allowance is intended to account for the longer term movement of the shoreline that may occur within the planning horizon. To determine the S2 Allowance, historical shoreline movement trends are examined and likely future shoreline movements predicted.

4.1.1 Shoreline Movement Analysis

SPP2.6 recommends that shoreline movement trends be based on the review of available shoreline records. MRA has previously completed shoreline mapping and analysis within the City, based on available coastal vegetation lines from DoT and coastal vegetation lines mapped by MRA (MRA 2012a, 2014, 2015a). As part of the City's coastal monitoring program MRA has recently updated this mapping to include the coastal vegetation line from 2015. The coastal vegetation line was extracted from aerial photography using the methodology outlined in DoT (2009). The resultant Shoreline Movement Plans are contained in Appendix A. The estimated accuracy of the photogrammetry technique is expected to be in the order of ± 5m.

The Shoreline Movement Plans include vegetation lines between 1942 and 2015, covering over 70 years of shoreline movement. However, not all of the historical lines cover the whole study area. In addition, the construction of a number of coastal structures in the period has altered coastal processes and dynamics during that time. The relative shoreline movement has therefore been estimated relative to 1987/1996 – where available – when most of these changes had occurred. The relative shoreline movement was estimated at each of the 100 m chainages and is presented in Figure 4.1. Note that the City boundary is at approximately Chainage 16,200 m.

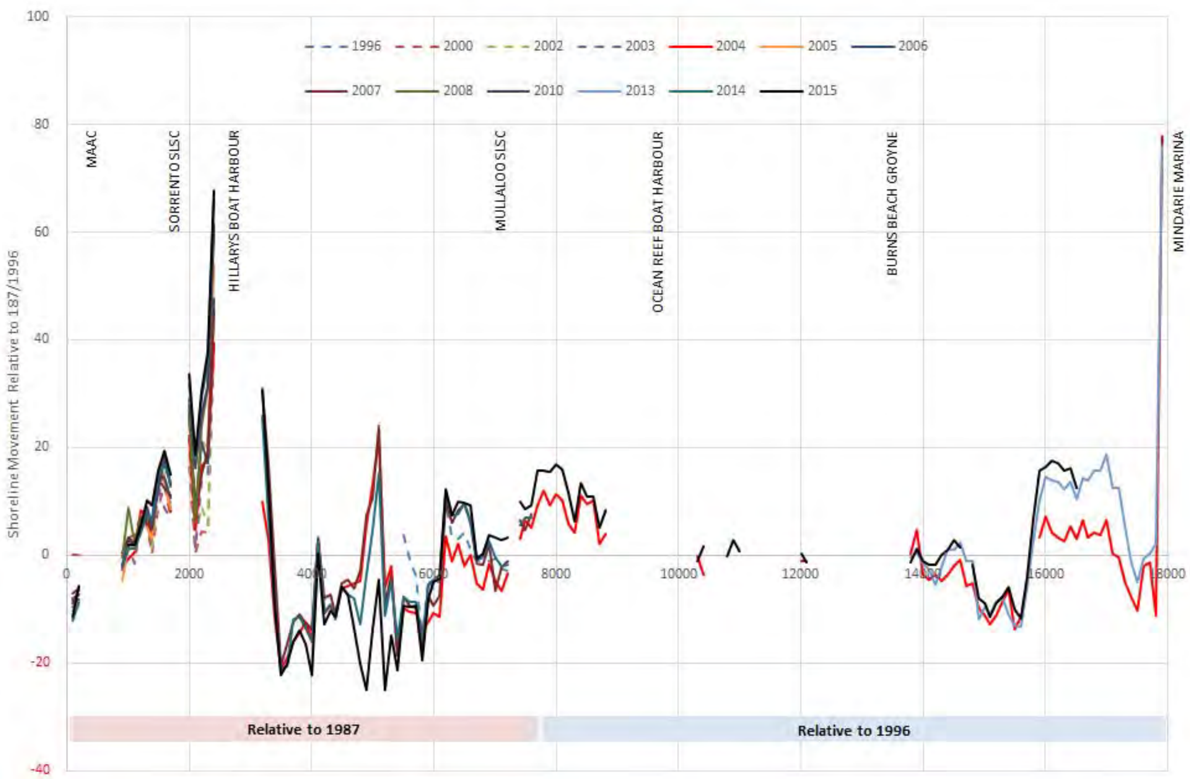

Figure 4.1 Shoreline Movement Relative to 1987/1996

The figure shows the following clear features from the shoreline movement analysis.

- There has been significant accretion south of Hillarys Boat Harbour, with the shoreline accreting up to 60 m since 1987.
- For the 2km north of Hillarys Boat Harbour, the shoreline has generally eroded since construction.
- At Pinnaroo Point the shoreline initially accreted but has eroded rapidly in recent years.
- Mullaloo Beach has generally accreted since 1996.
- From the Burns Beach groyne north to the City's boundary, the shoreline has generally eroded.

In addition to the general changes, the rates of movement at various times can also influence the projected shoreline movement. Time history plots have been extracted at the following key locations and are presented in Figures 4.2 to 4.10.

- Chainage 2,300 m – south of Hillarys Boat Harbour.
- Chainage 3,500 m – north of Hillarys Boat Harbour.
- Chainage 4,800 m – southern side of Pinnaroo Point.
- Chainage 5,300 m – northern side of Pinnaroo Point.
- Chainage 7,000 m – Kallaroo.
- Chainage 8,200 m – Mullaloo Beach.
- Chainage 14,200 m – north of Burns Beach Groyne.
- Chainage 15,500 m – Burns Beach Salient.
- Chainage 16,400 m – northern extent of the City.

The time history plots will be used to assist in determining the appropriate shoreline movement allowances for the study area. The figures present the position of the shoreline at measured intervals, relative to the reference year (1987 where available or 1996).

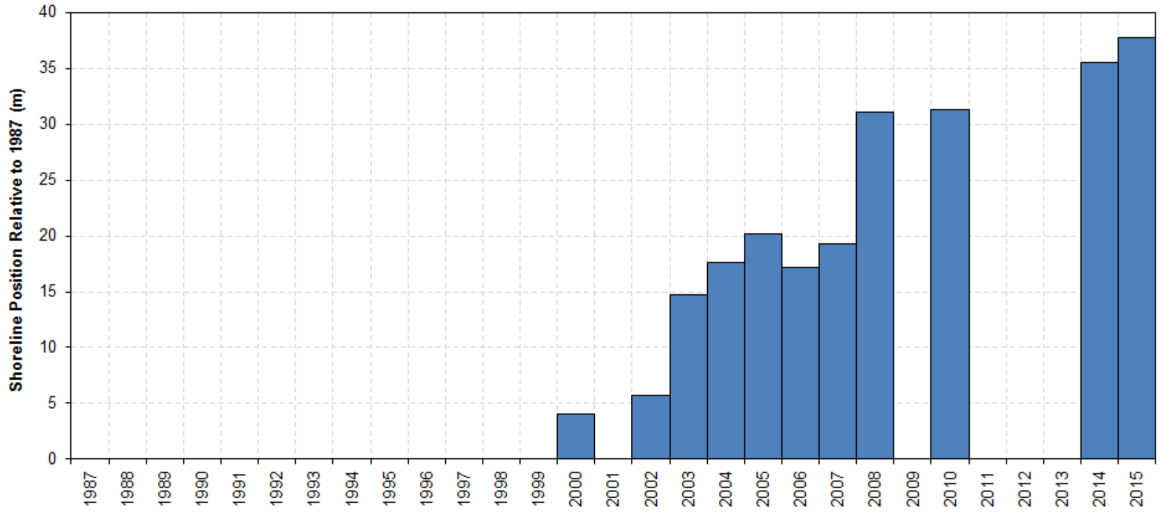

Figure 4.2 Time History of Shoreline Position at Chainage 2,300 m

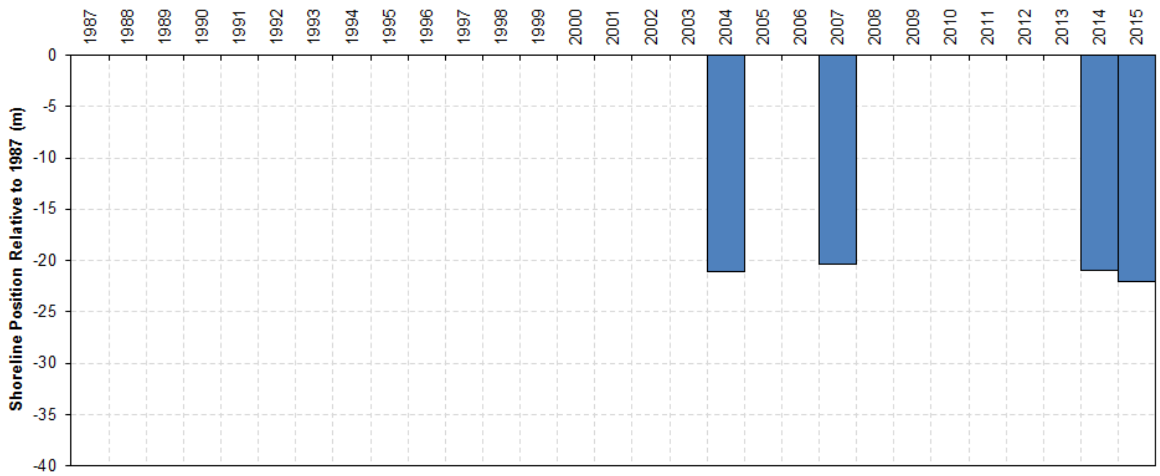

Figure 4.3 Time History of Shoreline Position at Chainage 3,500 m

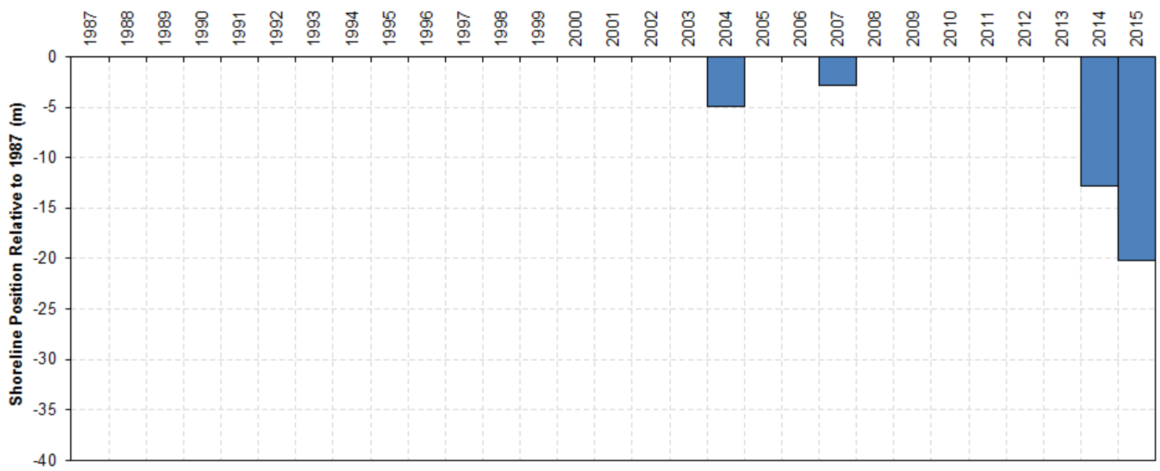

Figure 4.4 Time History of Shoreline Position at Chainage 4,800 m

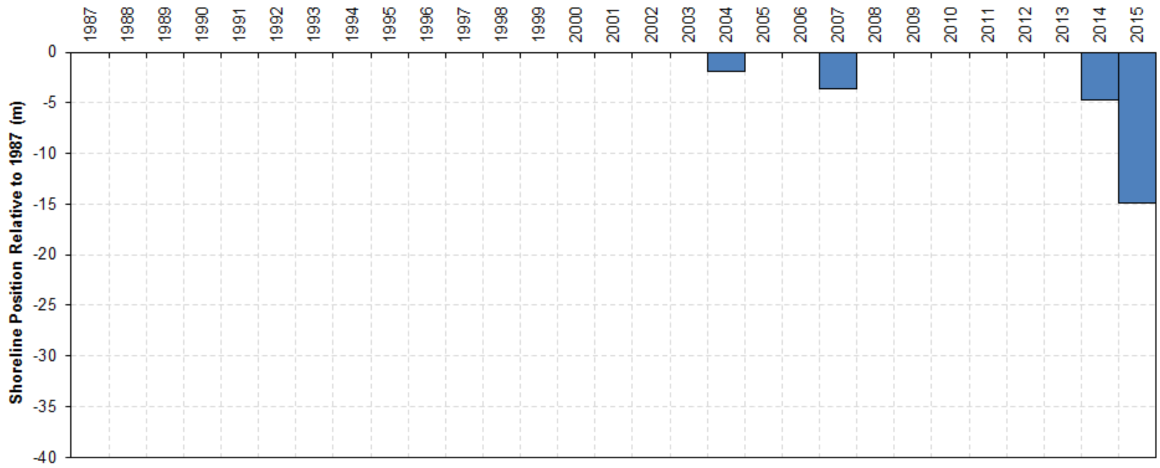

Figure 4.5 Time History of Shoreline Position at Chainage 5,300 m

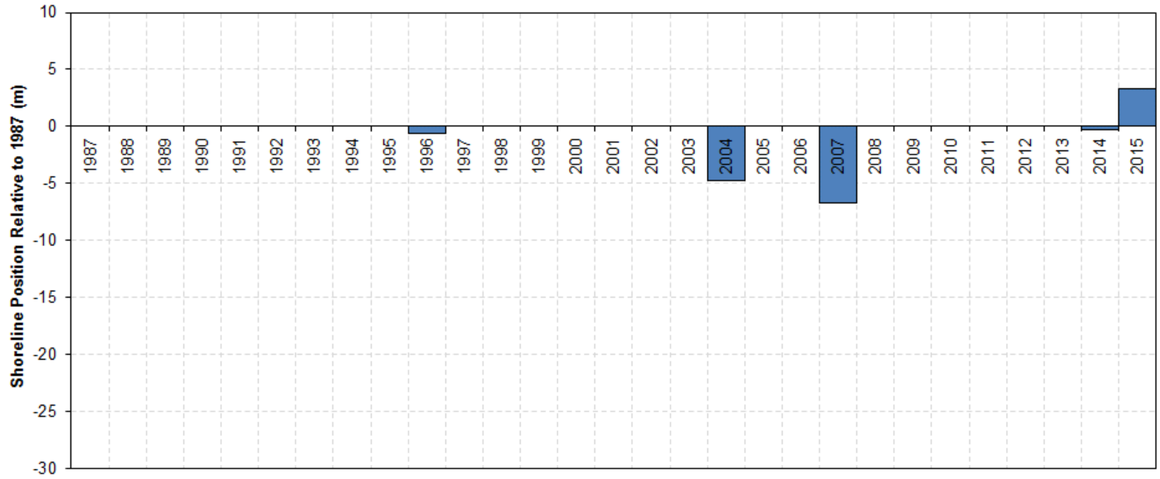

Figure 4.6 Time History of Shoreline Position at Chainage 7,000 m

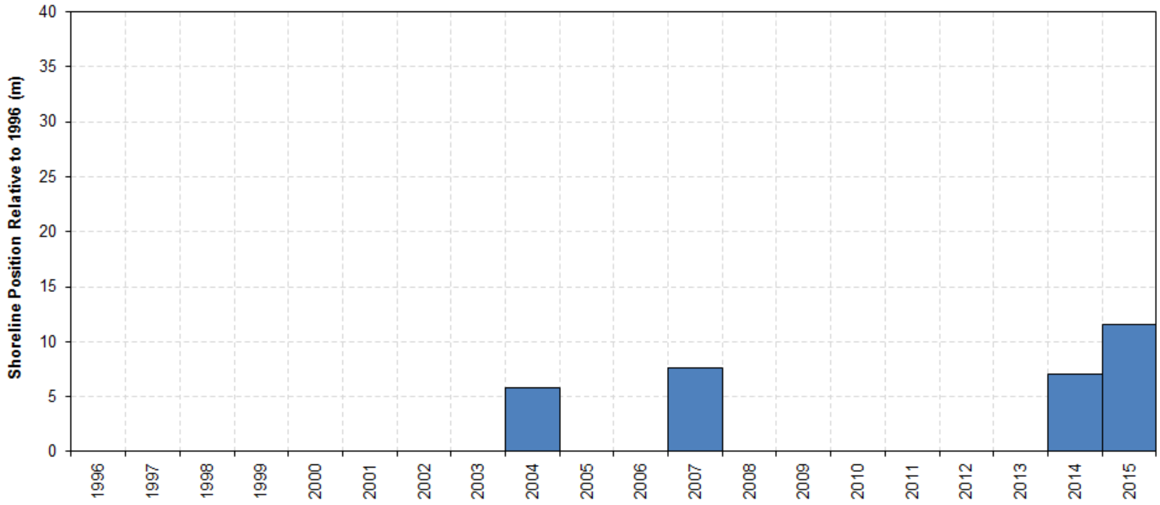

Figure 4.7 Time History of Shoreline Position at Chainage 8,200 m

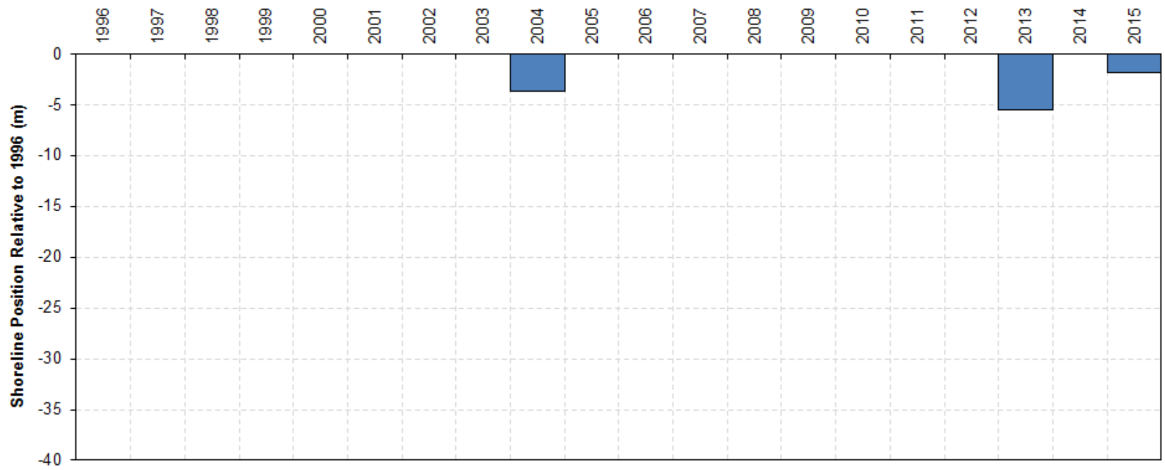

Figure 4.8 Time History of Shoreline Position at Chainage 14,200 m

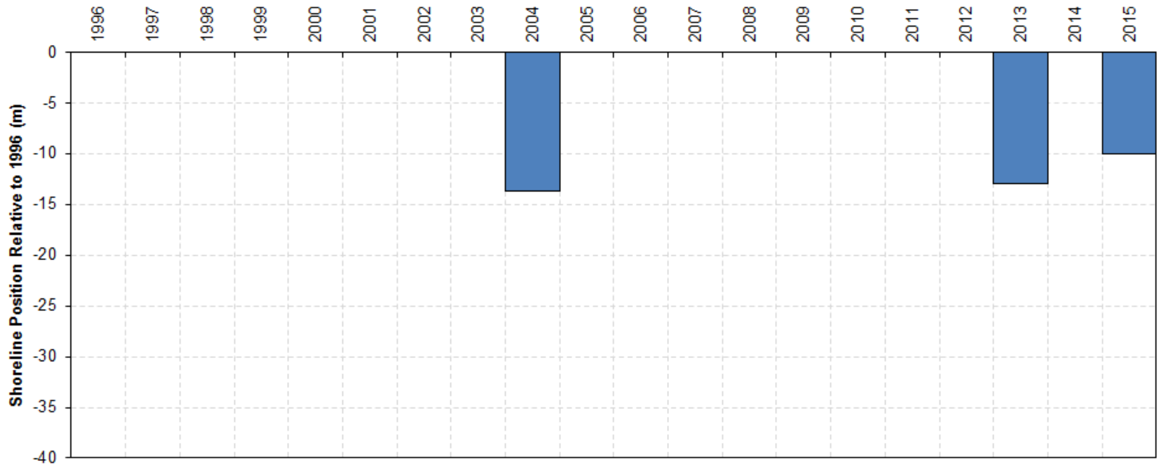

Figure 4.9 Time History of Shoreline Position at Chainage 15,500 m

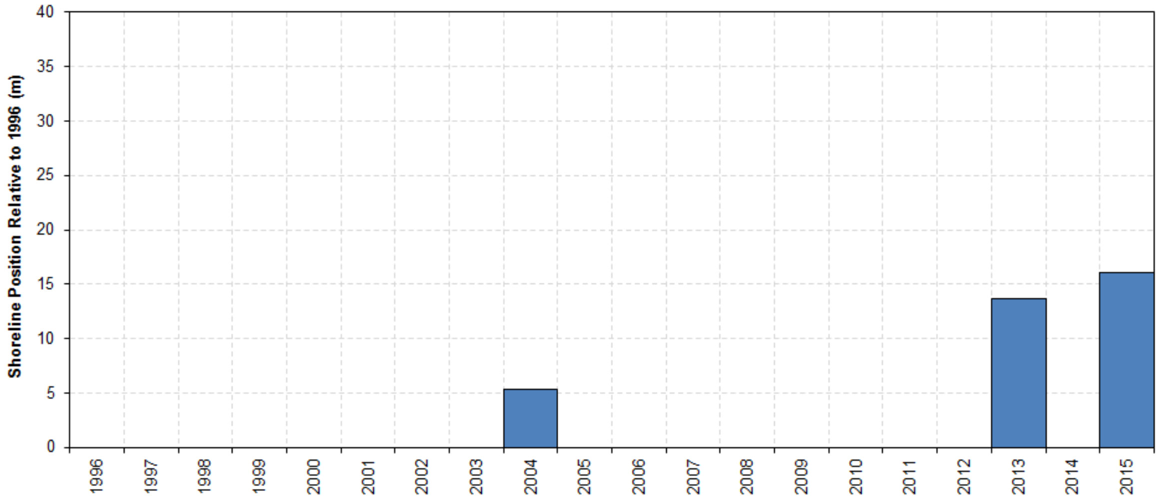

Figure 4.10 Time History of Shoreline Position at Chainage 16,400 m

4.1.2 Recommended S2 Erosion Allowance

The longer term rate of shoreline movement for the study area is presented in Figure 4.11.

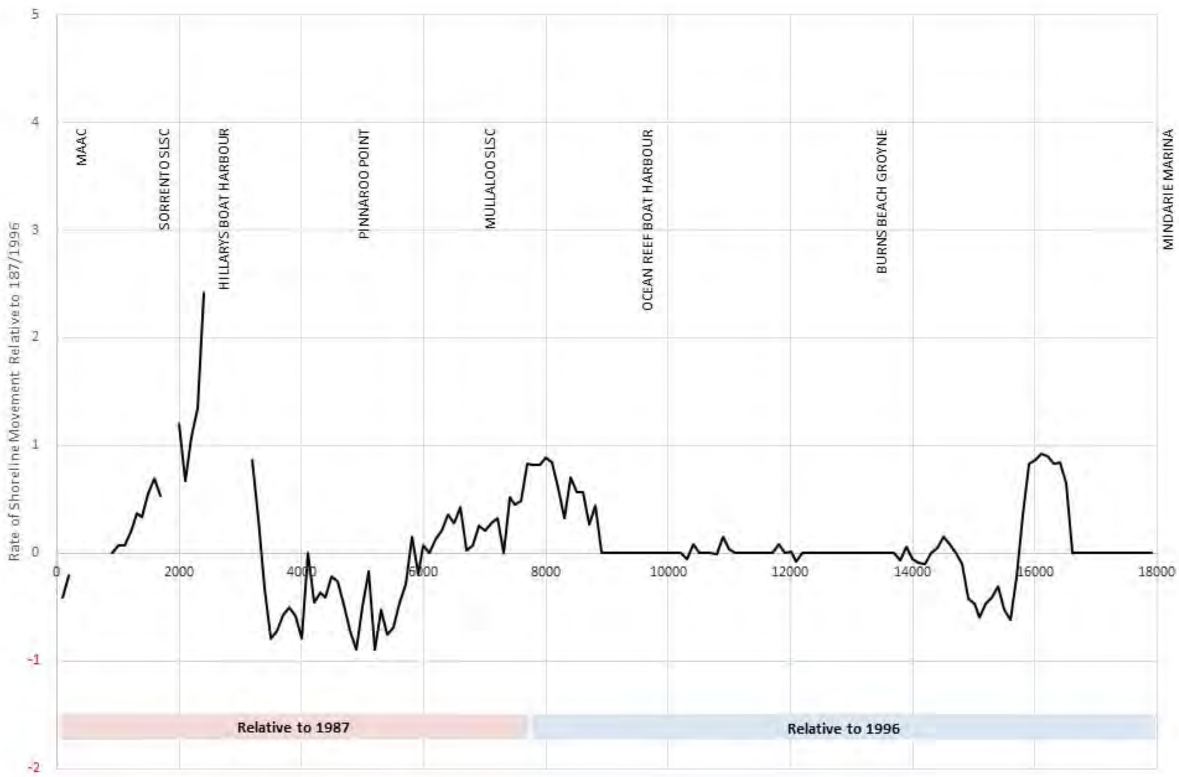

Figure 4.11 Rate of Shoreline Movement Relative to 1987/1996

From the rates of shoreline movement and time histories, the trends in shoreline movement and recommended allowances for future shoreline movement were estimated. The following were accounted for in the assessment.

- The area south of the Hillarys Boat Harbour has generally been accreting in the longer term. It is expected that this accretion will continue into the future, likely at slightly reduced rates.
- Excepting the area immediately north of Hillarys Boat Harbour – which falls within the wave shadow of the breakwaters and has accreted – the shoreline north to Pinnaroo Point has generally been eroding. This is expected to continue into the future.
- There has been some rapid recent erosion at Pinnaroo Point, with up to 10 m lost in the last year. This observed erosion is expected to be a combination of storm erosion (S1) and an erosion trend (S2). The rapid rate of erosion is not expected to continue in the longer term, but the shoreline is expected to continue to erode at a slower rate and an allowance for uncertainty in this area is recommended.
- Mullaloo Beach has been accreting in the long term and this is expected to continue, albeit at a reduced rate.
- The southern side of the Burns Beach salient has been eroding and the northern side accreting in the longer term. This is reasonably consistent with a large number of similar formations on the lower and mid-west coast of Western Australia.

SPP2.6 notes the following for calculation of the S2 Erosion allowance on sandy coasts.

The allowance for historic shoreline movement trends should generally be calculated as 100 times the historic annual rate of erosion.

On the basis of this and the above assessment, Table 4.1 presents the appropriate shoreline movement allowances for the study area.

Table 4.1 Summary of Recommended S2 Allowances

Chainage	Location	S2 Allowance (m/yr)
1,300 - 1,700	Marmion	0.0
2,000 – 2,400	Sorrento	0.3
3,200 – 3,400	Hillarys Boat Harbour (north)	0.0
3,500 – 4,600	Whitfords Nodes	-0.8
4,700 – 5,300	Pinnaroo Point	-1.1
5,400 – 5,500	Pinnaroo Point (north)	-0.8
5,600 – 6,100	Kallaroo	-0.5
6,200 – 8,800	Mullaloo	0.0
10,300 – 10,400	Ocean Reef Boat Harbour	-0.1
10,800 – 11,000	Resolute Way, Ocean Reef	0.0
11,800 – 12,100	Shenton Ave, Ocean Reef	-0.1
13,800 – 14,700	Burns Beach	-0.1
14,800 – 15,700	Burns Beach Salient (south)	-0.5
15,800 – 16,100	Burns Beach Salient (north)	0.0

Notes
1. Positive allowances are for accretion of the shoreline and result in a reduced overall allowance.
2. Negative allowances are for erosion and result in an increased overall allowance.
3. Allowances for future accretion are based on half the historic long term rate of accretion.

Due to the rapid erosion observed at Pinnaroo Point in recent years, some factor of safety has been included in the S2 allowance for the area. The S2 allowance has been increased by 0.2 m/yr to account for episodes of increased erosion.

These allowances are suitable for sandy shorelines and should be applied for the relevant planning timeframe. They do not apply to the rocky shorelines which have been assessed separately.

5. Sea Level Rise (S3 Allowance)

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 5.1 (IPCC 2013).

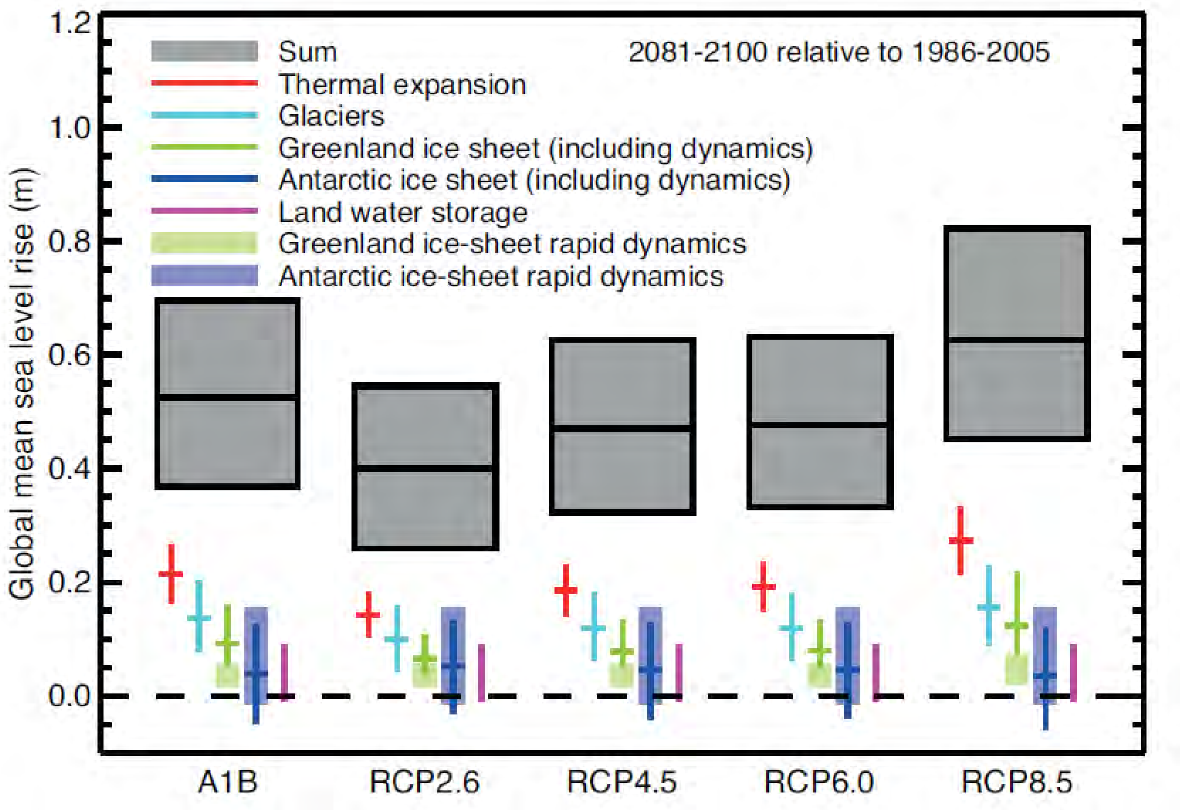

Figure 5.1 IPCC Scenarios for Sea Level Rise (IPCC 2013)

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).

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 SPP2.6 for use in coastal planning along the Western Australian coast. This is the sea level rise scenario adopted for this assessment and is presented in Figure 5.2.

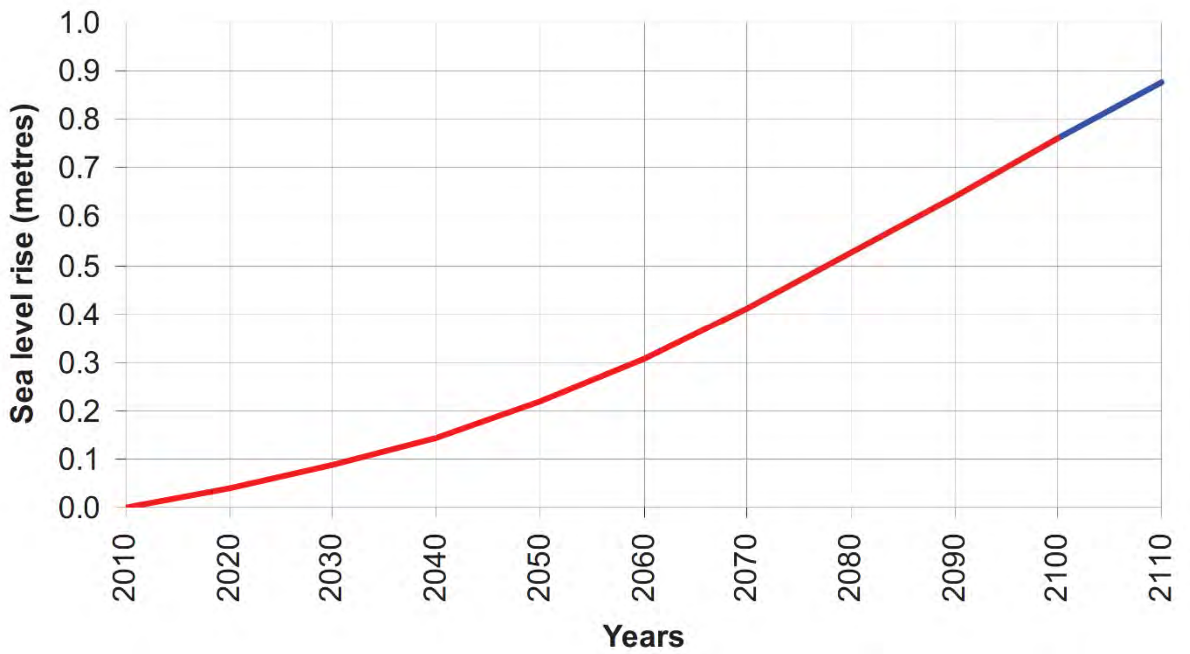

Figure 5.2 Recommended Sea Level Rise Allowances (DoT 2010)

SPP2.6 notes 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 of 0.9 m over a 100-year planning horizon or 90 m.

Table 5.1 summarises the sea level rise values and S3 Erosion allowances for the planning horizons. A base year of 2015 was used to determine the sea level rise values and used in this assessment, consistent with the shoreline movement mapping.

Table 5.1 Sea Level Rise Allowances

Planning Horizon	Potential Sea Level Rise (m)	S3 Erosion Allowance (m)
2065	0.32	32
2115	0.90	90

Notes: 1. Based on recommendations in DoT (2010) with a 2015 base year.

6. Inundation (S4 Allowance)

With respect to coastal inundation, SPP2.6 requires that development consider the potential effects of an event with an AEP of 0.2% per year. This is equivalent to an inundation event with an Average Recurrence Interval (ARI) of 500 years.

Accurate and statistically relevant predictions of the 500 year ARI event cannot be made solely using the available historical water level measurements along the Western Australian coastline due to the relatively short durations of the records. This is due to the fact that a continual water level record of about a third (167 years) of the recurrence interval in question (500 years) is required to ensure statistical relevance of the prediction. Even the longest water level record within Western Australia at Fremantle is limited to a little over 60 years of reliable record (records extend to before 1900 but are not reliable). Therefore, in the absence of sufficient water level data other methodologies must be considered to provide meaningful predictions of the 500 year ARI event.

The most widely accepted methodology for the estimation of the 500 year ARI water level event is to use available information on the frequency and characteristics of key meteorological events and, through modelling, generate a long term synthetic database of events and corresponding water levels. Though this process is still only based on a limited period of available data, the modelling seeks to capture the apparent randomness of the critical components of the meteorological effects through simulation of these events over extended periods of time. This methodology is particularly relevant in cyclone regions, where extremely localised effects on water levels can be observed. Modelling an extended time period therefore helps to ensure that the apparent randomness in cyclone track and severity is accounted for in any estimation of events with long recurrence intervals.

Given the complexity of the process and the requirement to understand the potential inundation levels associated with a 500 year ARI inundation event for future planning, MRA has recently completed an assessment of the 500 year ARI storm surge inundation event for the City. The detailed methodology and results of this assessment are provided in MRA (2016b).

The model was validated against measured cyclone tracks from the Bureau of Meteorology (BOM – refer Figure 6.1) and key parameters of measured cyclones. The validation showed a high level of agreement between the measured and modelled data.

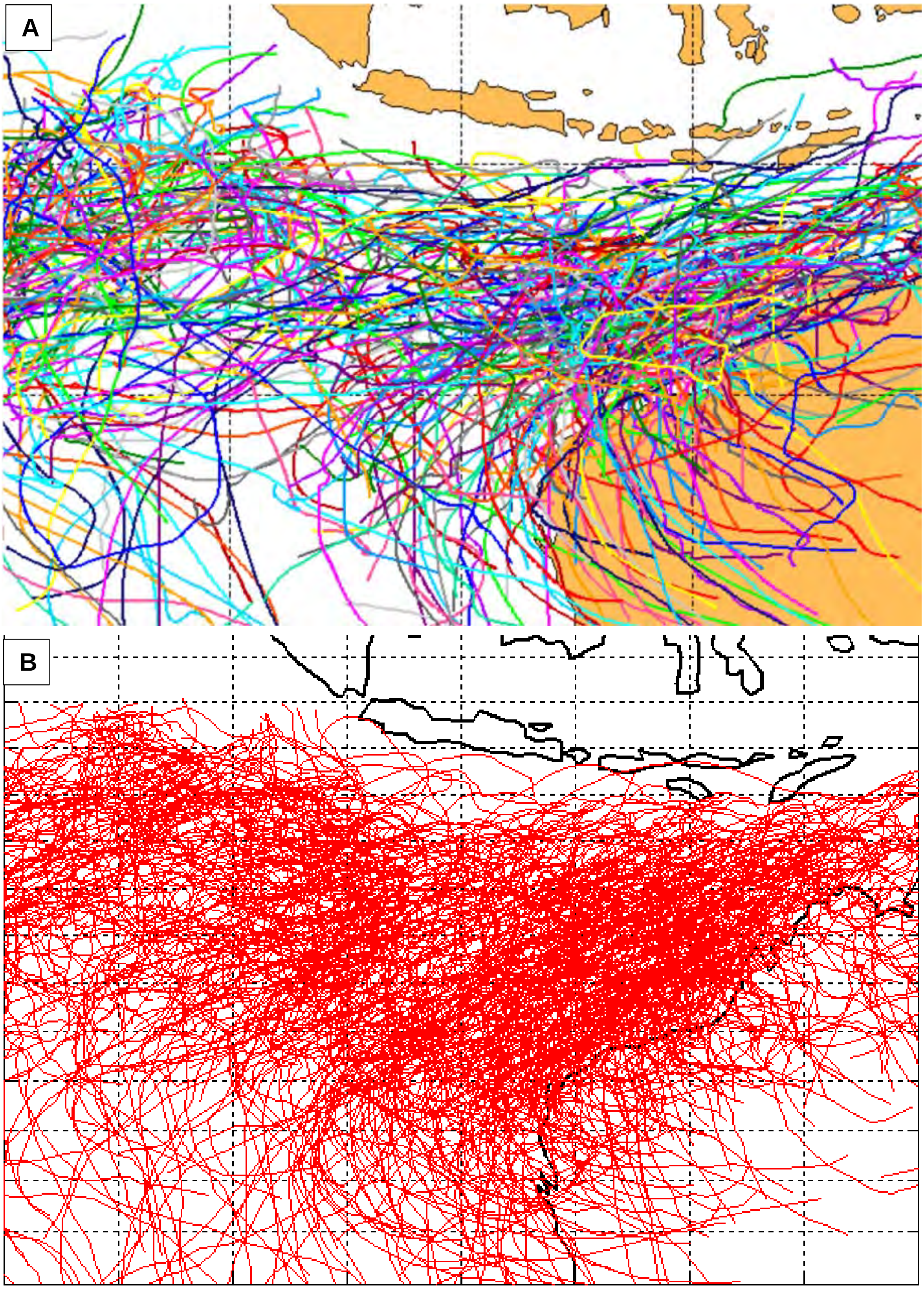

Figure 6.1 (A) Historical Cyclone Tracks since 1960; &
(B) Modelled Cyclone Tracks for the same period

From the synthesised record, MRA identified and modelled a 500 year ARI event. Spatial plots from the modelled event are presented in Figure 6.2, showing the passage of the event past the City shoreline.

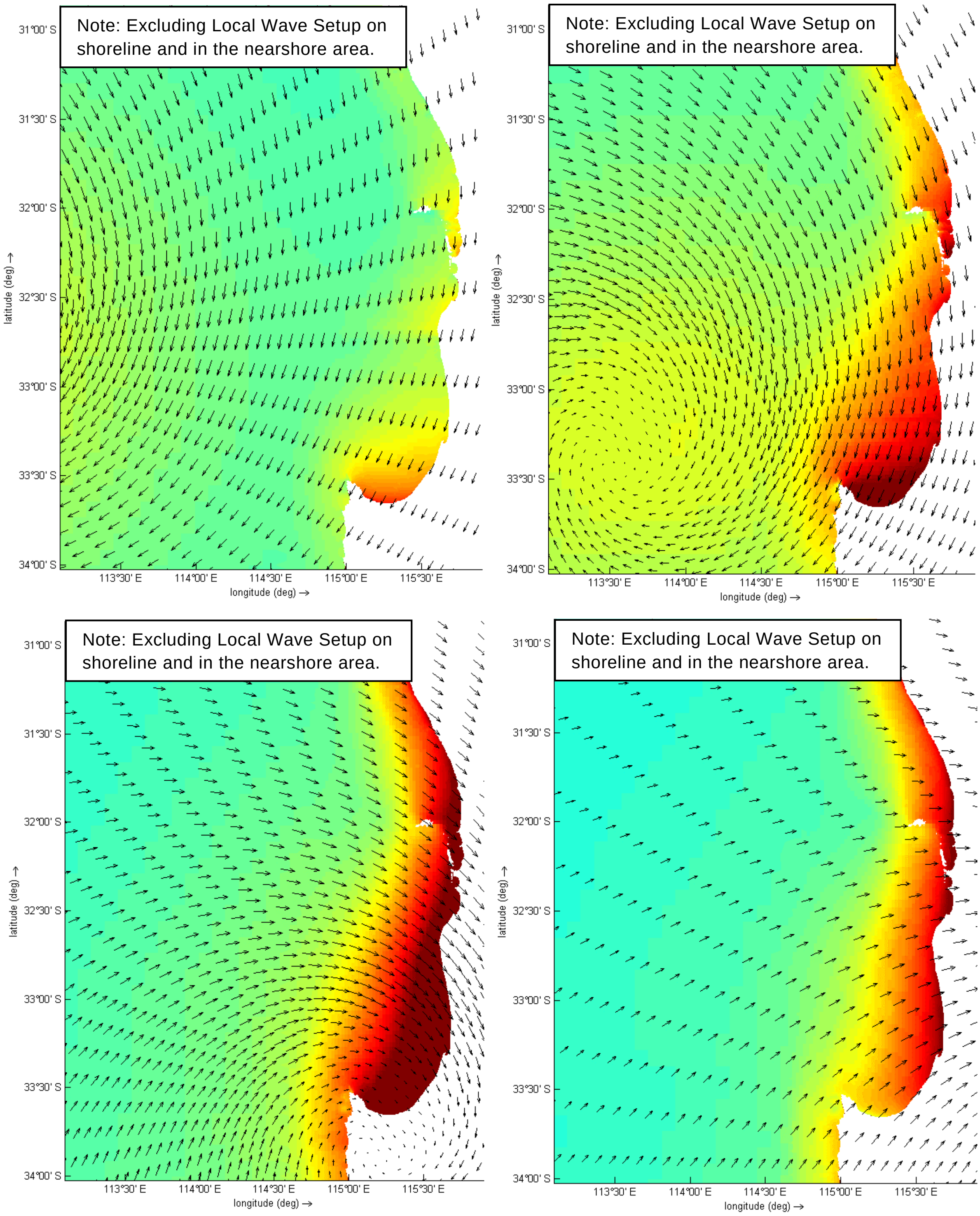

Figure 6.2 Delft3D Output Plots showing the Passage of the Synthesised 500 year ARI Event for the City Coastline (MRA 2016b)

MRA recommended that the following levels were appropriate for use as the 500 year ARI water level in the nearshore area.

Table 6.1 Cyclonic Storm Surge Inundation Levels for the City (MRA 2016b)

ARI (years)	Inundation Level [1] Present Day (mAHD)
500	1.60 [1]

Note: 1. The values in this table do not include inshore wave setup.

These values represent the 500 year ARI peak steady water level in a water depth of around 5 m. Closer to the shoreline, wave setup can result in an increased water level, which will vary based on the local bathymetry and incident waves. This is illustrated in Figure 6.3.

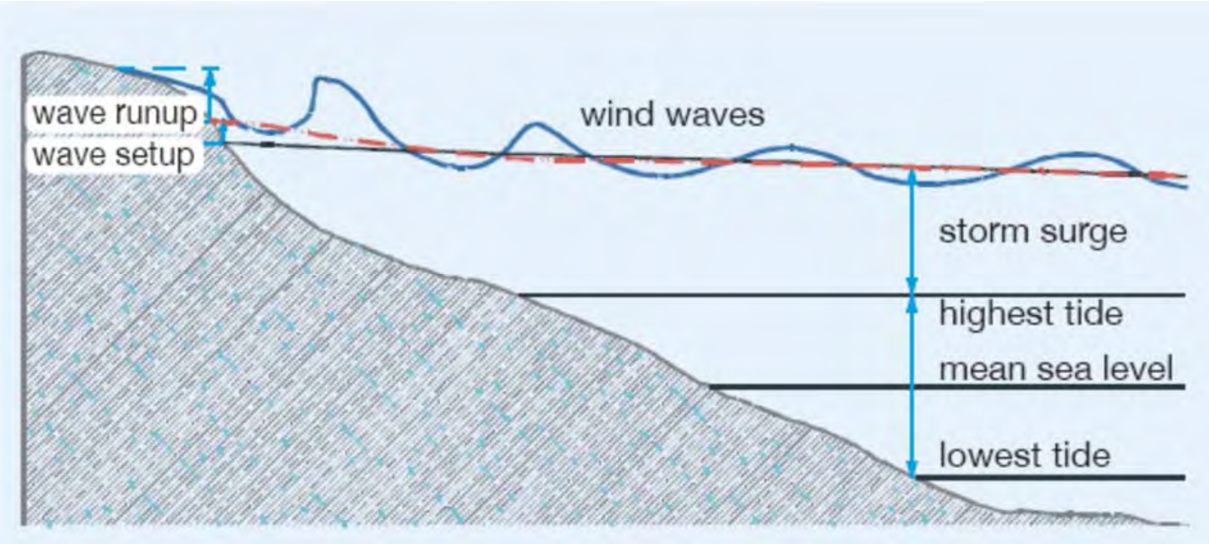

Figure 6.3 Components of Inshore Water Levels

Inshore wave setup is described by Dean and Walton (2008), which provides a comprehensive review of investigations into the extent of wave setup on beaches. Dean & Walton (2008) outline that wave setup is the additional water level that is due to the transfer of wave related momentum to the water column during the wave breaking process. The extent of the inshore wave setup can be substantial depending on the incident wave conditions and local bathymetry.

As a result, site specific assessment of the inshore wave setup has been completed for this study to translate the estimated water levels from the cyclone modelling to the shoreline.

The SBEACH model was setup and run at each of the 11 profiles previously used to translate the water levels from the nearshore area to the shoreline. It was estimated that additional wave setup in the order of 1.0 to 1.5 m could be expected along the shoreline. An example of the output at Profile 9 is presented in Figure 6.4.

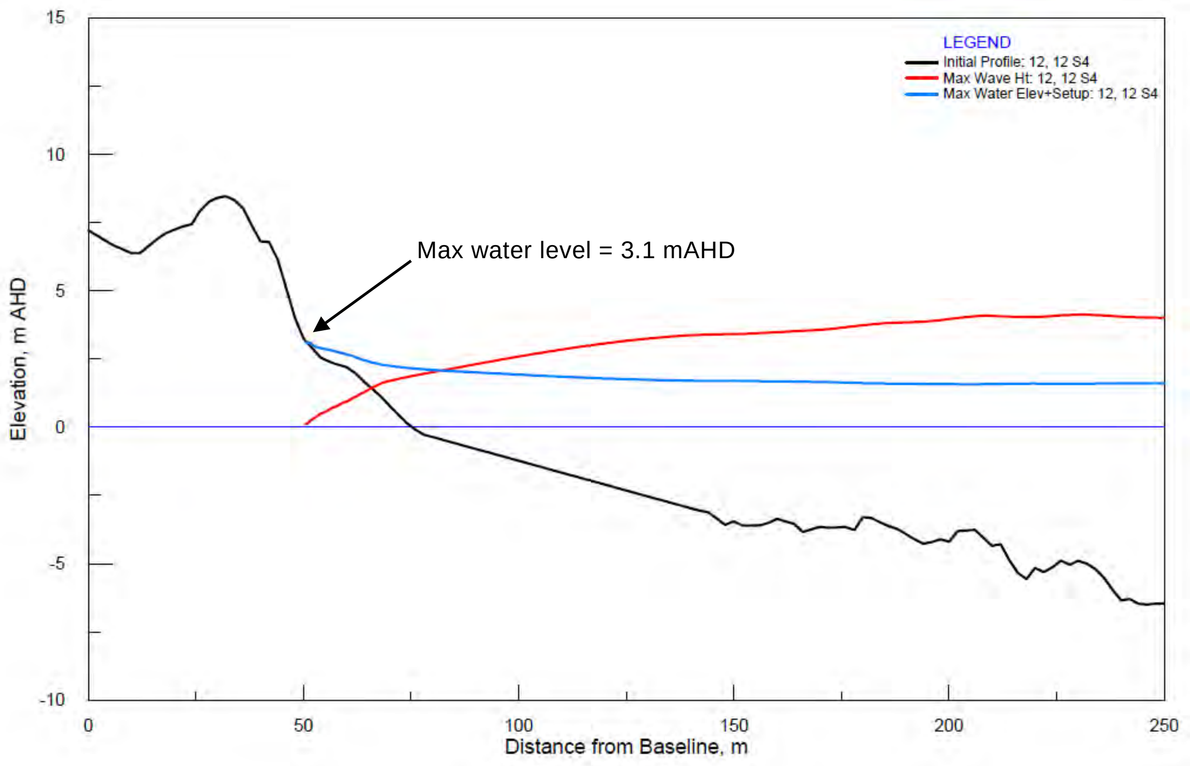

Figure 6.4 Estimated 500 year ARI Water Level at Shoreline

Figure 6.4 shows that the total water level at the shoreline is 3.1 mAHD, a setup of 1.5 m from the nearshore water level.

This has been included in estimates of the appropriate inundation levels for the various planning timeframes, presented in Table 6.2.

Table 6.2 Recommended S4 Inundation Levels

Component	Planning Timeframe		
	2015	**2065**	**2115**
500 year ARI nearshore peak steady water level (mAHD)	1.6	1.6	1.6
Allowance for nearshore wave setup (m)	1.0 – 1.5	1.0 – 1.5	1.0 – 1.5
Allowance for sea level rise (m)	0.0	0.32	0.90
Total Inundation Level (mAHD)	**2.60 – 3.10**	**2.92 – 3.42**	**3.50 – 4.00**

The levels presented in Table 6.2 have been used to prepare the coastal inundation hazard maps. These levels don't include any potential wave run-up or overtopping, which may need to be considered for infrastructure located close to the shoreline.

7. Assessment of Coastal Hazards

7.1 Coastal Erosion Hazards

The allowances for coastal erosion determined in the previous sections are summed to provide the total coastal erosion allowance. As required by SPP2.6, a 0.2 m/year allowance for uncertainty has also been included. Due to the uncertainties around ongoing shoreline movement in some areas, this is recommended as appropriate. The total coastal erosion hazard allowances are presented in Table 7.1 and should be measured from the HSD.

The table presents the coastal erosion hazard allowances for both the sandy and rocky sections of shoreline. For the rocky shoreline, an allowance of 5 m is used to assess risk to existing public and recreational infrastructure with relatively short design lives. This is comparable to measured erosion rates on coastlines with similar Tamala limestone, and consistent with MRA (2012). Leasehold and freehold development would need to be assessed on a case by case basis and is recommended to be setback at least 30 m from the rocky shoreline.

Table 7.1 Summary of Coastal Erosion Hazard Allowances

Chainage	Timeframe	S1 (m)	S2 (m)	S3 (m)	Uncertainty (0.2 m/yr)	Total Allowance (m)
0-900	2115	Rock				**5 (public) >30 (leasehold)**
900-1200	2015	5	0	0	0	**5**
	2065-2115	Rock				**5 (public) >30 (leasehold)**
1300-1700	2015	15	0	0	0	**15**
	2065	15	0	32	10	**57**
	2115	15	0	90	20	**125**
1800-2400	2015	5	0	0	0	**5**
	2065	5	-15	32	10	**32**
	2115	5	-30	90	20	**85**
2500-3100	Hillarys Boat Harbour					**na**
3200-3400	2015	28	0	0	0	**28**
	2065	28	0	32	10	**70**
	2115	28	0	90	20	**138**

Chainage	Timeframe	S1 (m)	S2 (m)	S3 (m)	Uncertainty (0.2 m/yr)	Total Allowance (m)
3500-4600	2015	28	0	0	0	**28**
	2065	28	40	32	10	**110**
	2115	28	80	90	20	**218**
4700-5000	2015	28	0	0	0	**28**
	2065	28	55	32	10	**125**
	2115	28	110	90	20	**248**
5100-5300	2015	46	0	0	0	**46**
	2065	46	55	32	10	**143**
	2115	46	110	90	20	**266**
5400-5500	2015	46	0	0	0	**46**
	2065	46	40	32	10	**128**
	2115	46	80	90	20	**236**
5600-6100	2015	46	0	0	0	**46**
	2065	46	25	32	10	**113**
	2115	46	50	90	20	**206**
6200-7600	2015	37	0	0	0	**37**
	2065	37	0	32	10	**79**
	2115	37	0	90	20	**147**
7700-8800	2015	29	0	0	0	**29**
	2065	29	0	32	10	**71**
	2115	29	0	90	20	**139**
8900-9700	2115	Rock				**5 (public) >30 (leasehold)**
9800-10100	Ocean Reef Boat Harbour					**na**
10200	2115	Rock				**5 (public) >30 (leasehold)**

Chainage	Timeframe	S1 (m)	S2 (m)	S3 (m)	Uncertainty (0.2 m/yr)	Total Allowance (m)
10300-10400	2015	30	0	0	0	**30**
	2065	30	5	32	10	**77**
	2115	30	10	90	20	**150**
10500-10700	2115	Rock				**5 (public) >30 (leasehold)**
10800-11000	2015	30	0	0	0	**30**
	2065	30	0	32	10	**72**
	2115	30	0	90	20	**140**
11100-11700	2115	Rock				**5 (public) >30 (leasehold)**
11800	2015	36	0	0	0	**36**
	2065	36	5	32	10	**83**
	2115	36	10	90	20	**156**
11900	2115	Rock				**5 (public) >30 (leasehold)**
12000-12100	2015	36	0	0	0	**36**
	2065	36	5	32	10	**83**
	2115	36	10	90	20	**156**
12200-13700	2115	Rock				**5 (public) >30 (leasehold)**
13800-14700	2015	29	0	0	0	**29**
	2065	29	5	32	10	**76**
	2115	29	10	90	20	**149**
14800-15400	2015	29	0	0	0	**29**
	2065	29	25	32	10	**96**
	2115	29	50	90	20	**189**

Chainage	Timeframe	S1 (m)	S2 (m)	S3 (m)	Uncertainty (0.2 m/yr)	Total Allowance (m)
15500-15700	2015	27	0	0	0	**27**
	2065	27	25	32	10	**94**
	2115	27	50	90	20	**187**
15800-16100	2015	27	0	0	0	**27**
	2065	27	0	32	10	**69**
	2115	27	0	90	20	**137**

These allowances have been used to prepare the Coastal Hazard Maps, presented in Appendix B.

7.2 Coastal Inundation Hazards

An assessment of the appropriate coastal inundation level for the study area was presented in Section 6 for the 500 year ARI water level. These levels have been used to prepare the Coastal Hazard Maps, presented in Appendix B. Due to the small differences in plan location for the various levels, only the 2115 inundation lines have been mapped.

Analysis of the coastal inundation hazard map shows that the shoreline generally has a low risk of inundation as a result of the combined impact of sea level rise and storm surge to 2116. The low risk is due to the generally high dunes and rocky cliffs in the study area. This presents a high elevation barrier to potential storm surge and inundation.

7.3 Summary of Coastal Hazards

The coastal hazard maps presented in Appendix B show areas of existing infrastructure which may be under threat from coastal erosion or inundation in the present day to coming 100 years. The maps generally show that there is minimal existing infrastructure at risk in the present day, limited to dune fencing and beach access paths. This infrastructure has a functional need to be close to the active beach and is appropriate.

In the coming 50 to 100 years there are a number of areas which may be at risk, outlined below.

- Sorrento.
- Around Pinnaroo Point.
- Kallaroo and Mullaloo.
- North of Ocean Reef Boat Harbour.
- Burns Beach.

Some of these areas (eg north of Ocean Reef Boat Harbour and Burns Beach groyne) may have rock buried in the dunes which could provide additional protection from coastal hazards. If the City wished to refine the coastal hazard assessment further this could be investigated at key areas as has recently been completed at Marmion. MRA do not believe there are any critical areas that need to be refined in the short term.

In most of the identified vulnerable areas, City infrastructure or assets (eg roads or car parks) would be at risk prior to private assets. The exceptions to this are the following:

- The residential properties on Merrifield Place, Mullaloo.
- The Mullaloo SLSC.
- The Whitfords Volunteer Sea Rescue Group building.

The City has commenced a coastal monitoring program for its shoreline, which will collect key beach profiles and estimate changes to the shoreline over time. It is recommended this program is continued, which will allow periodic updates to the coastal hazard assessments. It is recommended that the assessments are updated at approximately 10 yearly intervals, or if significant changes to the shoreline are identified in the monitoring.

The coastal erosion hazard around noted seawalls assumes that these structures are monitored and maintained into the future. Should these structures be allowed to fail, they may not protect the assets and infrastructure on the landward side.

The only area of coastal infrastructure shown to have some risk of coastal inundation was the lower lying section of the existing Ocean Reef Boat Harbour. This includes the boat launching area. The proposed Ocean Reef Marina redevelopment would include new breakwaters and development at increased elevations to reduce the coastal inundation risk in these areas to acceptable levels.

This coastal hazard assessment identifies the coastal erosion and inundation hazard areas for the current City shoreline. New development proposed on the City's coastline may fall within these coastal hazard areas and will need to address the coastal hazard risks. This includes the proposed Ocean Reef Marina.

It is recommended that any proposed development within these coastal hazard areas undergo Coastal Hazard Risk Management & Adaptation Planning to identify adaptation strategies for the identified hazards. A CHRMAP process is underway for the proposed Ocean Reef Marina redevelopment (MRA 2016c).

Key Recommendations

- Allow for maintenance of identified areas of dune fencing and access paths within current day hazard areas.
- Continue coastal monitoring program to identify changes to shoreline.
- Update coastal hazard assessment at approximately 10 year intervals or if large shoreline changes are identified from the monitoring.
- Proposed development within the coastal hazard areas should undergo CHRMAP.
- Consider geotechnical investigations to refine estimates in the longer term.

8. Summary & Conclusions

MRA has previously completed assessments of the coastal hazards and vulnerability for the City of Joondalup's shoreline. These assessments were completed at different times, using varying data and were completed to the planning policies of the time. Following the implementation of the City's coastal monitoring program, the City engaged MRA to complete a revised Coastal Hazard Assessment for the entire City coastline, to the requirements of the State Coastal Planning Policy (SPP2.6; WAPC 2013).

The coastal erosion hazards were assessed in line with SPP2.6, considering allowances for the following:

- Severe storm erosion (100 year ARI beach erosion event).
- Long term trends in shoreline movement.
- Erosion due to sea level rise.

An uncertainty allowance was included in line with the recommendations of SPP2.6. This is believed to be appropriate due to the rapid changes in shoreline position seen in several areas. These factors were used to determine a total coastal erosion hazard allowance and coastal hazard maps prepared for the City.

The coastal inundation hazard for the City shoreline was assessed using the predicted 500 year ARI water level from detailed cyclone modelling completed by MRA. These nearshore water levels were transformed to the shoreline and assessed across the study area. Coastal inundation maps were prepared for the City from this assessment.

The prepared coastal hazard maps show there is minimal existing infrastructure at risk from coastal hazards. This generally includes dune fencing and beach access paths which have a functional need to be close to the active shoreline. The City should consider the need for maintenance of these items following storm events.

In the longer term existing infrastructure has been identified within coastal hazard areas at a number of locations. To address this risk it is recommended the following are completed.

- The City continue the coastal monitoring program to identify changes to shoreline.
- The coastal hazard assessment is reviewed and updated at approximately 10 year intervals or if large shoreline changes are identified from the monitoring.
- Proposed development within the coastal hazard areas should undergo CHRMAP.
- Geotechnical investigations in key locations are considered.

9. References

Bird, E., 2000. *Coastal Geomorphology*. John Wiley & Sons, West Sussex, England.

Bruun, P. 1962, *Sea level rise as a cause of shore erosion*, Journal Waterways and Harbours Division, American Society of Civil Engineers. WWI, 88, pp. 117-130.

Damara WA, 2012. *Coastal Sediment Cells between Cape Naturaliste and the Moore River, Western Australia.* Report prepared by Damara WA Pty Ltd and Geological Survey of Western Australia for the Western Australian Department of Transport, Fremantle.

Dean, R G & Walton T L, 2008. *Wave Setup – a State of Art Review*. Beaches and Shores Research Centre, Institute of Science and Public Affairs, Florida State University.

Department of Transport. 2010. *Sea Level Change in Western Australia – Application to Coastal Planning,* Prepared by the Department of Transport, Coastal Infrastructure, Coastal Engineering Group, Western Australia.

Eliot, I., Gozzard, JR., Eliot, M., Stul, T. and McCormack G., 2012. *The coast of the Shires of Gingin and Dandaragan, Western Australia: Geology, Geomorphology and Vulnerability.* Prepared for the Department of Planning.

Eliot, I., Tonts, M., Eliot, M., Walsh, G. & Collins J. 2005. *Recreational Beach Users in Perth Metropolitan Area, March 2005 in Summer 2004 -2005,* The Institute of Regional Development, School of Earth and Geographical Sciences, Faculty of Natural and Agricultural Sciences, University of Western Australia, Crawley, WA.

IPCC 2001. *Summary for Policy Makers, Climate Change 2001: Impacts, Adaptation and Vulnerability*. Published by the Intergovernmental Panel on Climate Change and approved by the IPCC Working Group II in Geneva, February 2001.

IPCC. 2007. *Fourth Assessment Report - Climate Change 2007*. Published by the IPCC.

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

Jones T, Middelmann M & Corby N, comps. 2005. *Natural hazard risk in Perth, Western Australia: comprehensive report*. Geoscience Australia; 225–67.

Komar, P D. 1998. *Beach Processes and Sedimentation (2nd Edition).* Prentice Hall Inc, New Jersey, USA.

Landform Research 2009. *Assessment of Risk from Coastal Tamala Limestone in the City of Joondalup*. Prepared by Landform Research for the City of Joondalup.

Larson, M., Kraus, N. C. 1989. *SBEACH: Numerical Model for Simulating Storm-Induced Change*. US Army Corps of Engineers, Washington, USA.

MRA 2012a. *Hillarys to Ocean Reef Coastal Vulnerability Assessment, R316 Rev 1*. Prepared for the City of Joondalup, Perth.

MRA 2012b. *Marmion – Sorrento Coastal Protection Study, R284 Rev 2*. Prepared for the City of Joondalup, Perth.

MRA 2014. *Iluka to Burns Beach Coastal Vulnerability Assessment, R487 Rev 2*. Prepared for the City of Joondalup, Perth.

MRA 2015a. *Marmion to Sorrento Coastal Vulnerability Assessment, R574 Rev 1*. Prepared for the City of Joondalup, Perth.

MRA 2015b. *Ocean Reef Marina Coastal Processes Assessment, R519 Rev 2*. Prepared for City of Joondalup, Perth.

MRA 2016a. *Joondalup Coastal Vulnerability Geotechnical Study & Update, R727 Rev 0*. Prepared for the City of Joondalup, Perth.

MRA 2016b. *Cyclone Modelling, R774 Rev 0*. Prepared for the City of Joondalup, Perth.

MRA 2016c. *Ocean Reef Marina CHRMAP, R608 Rev 1*. Prepared for the City of Joondalup, Perth.

Sanderson, P. G. & Eliot, I. 1999, Compartmentalization of beachface sediments along the southwestern coast of Australia, *Marine Geology*, vol. 162, no. 1, pp. 145-164.

Searle, D. J. & Semeniuk, V. 1985. The natural sectors of the inner Rottnest Shelf coast adjoining the Swan Coastal Plain, *Journal of the Royal Society of Western Australia*, vol 67; p 116:136.

Short, A. D. 1999, *Handbook of Beach and Shoreline Morphodynamics*. John Wiley & Sons Ltd. England.

WAPC 2013. *State Planning Policy No. 2.6 - State Coastal Planning Policy*. Western Australian State Government, Perth.

Wise, R. A., Smith, S. J. & Larson, M. 1996. *SBEACH: Numerical Model for Simulating Storm-Induced Beach Change; Report 4, Cross shore transport under random waves and model validation with SUPERTANK and field data. Technical Report CERC-89-9 rept. 4*. Coastal Engineering Research Centre, Vicksburg, MS.

10. Appendices

Appendix A Shoreline Movement Plans

Appendix B Coastal Hazard Maps