APPENDIX

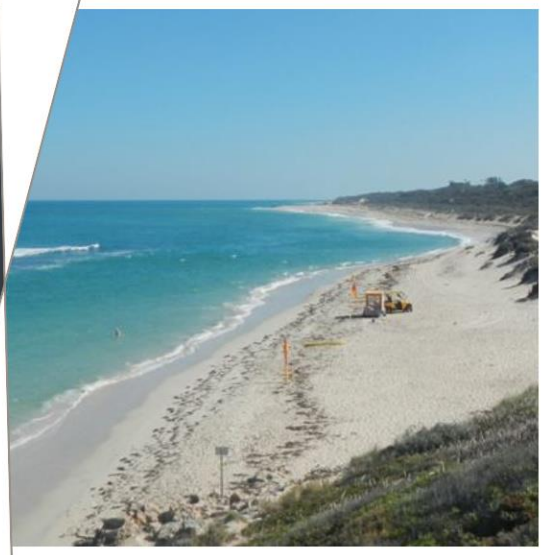
C

QUINNS BEACH COASTAL HAZARD IDENTIFICATION REPORT

City of Wanneroo

Quinns Coastal Hazard Identification

59916812



Prepared for
City of Wanneroo

6 June 2018

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1 Introduction

1.1 Background

Globally, mean sea level (MSL) has risen since the nineteenth century and is predicted to continue to rise, at an increasing rate, through the twenty first century (Intergovernmental Panel on Climate Change [IPCC], 2014), bringing changes to the Western Australian (WA) coastline over the coming decades. To prepare for sea level rise (SLR) induced coastal hazards, such as coastal erosion and inundation, all levels of government are putting processes in place to ensure that communities understand the risks to values and assets on the coast, and to plan to adapt over time.

Changes to MSL over the past century have been observed for the coastline adjacent to the Perth Metropolitan Area. *Sea Level Change in Western Australia – Application to Coastal Planning* (Department of Transport [DoT], 2010) reviewed information relating to SLR at a local scale and recommended an allowance for SLR be adopted for planning purposes. The WA State Government revised the State Coastal Planning Policy in 2013 to incorporate a projected SLR for WA of 0.9 m between 2010 and 2110 (**Figure 1-1**).

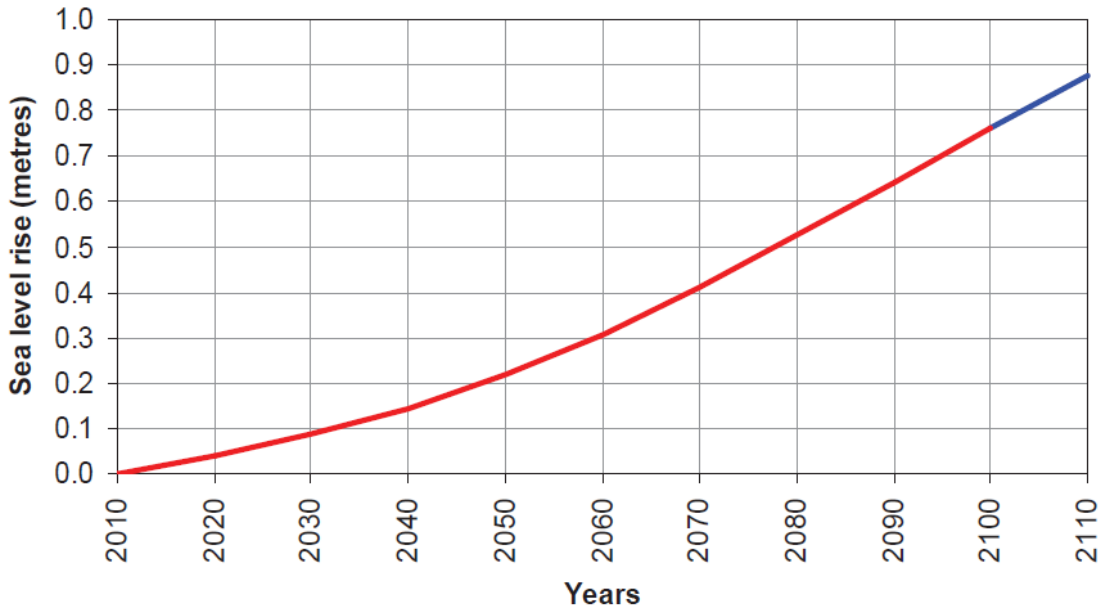


Figure 1-1 Recommended allowance for sea level rise in coastal planning in Western Australia (DoT, 2010).

The Wanneroo Local Government Area (LGA) coastline is generally sandy with intermittent limestone outcrops, featuring coastal dunes, nearshore reefs, islands and seagrass meadows. For sandy coastlines, increases in local MSL generally result in shoreline recession, with a “rule of thumb” often used, that a 1 cm rise will result in 1 m of landward recession of the shoreline. It should be noted that this is based on the “Bruun Rule” which is generally considered a conservative approach (Rosati et al, 2013; Cooper & Pilkey, 2004).

1.2 Purpose of this Study

The Tertiary Sediment Cell 29b (Stul et al, 2015), containing Quinns Beach, was not included in the coastal hazard assessment undertaken in Part 1 of the City of Wanneroo’s (‘the City’) Coastal Hazard Risk Management and Adaptation Plan (CHRMAP) (MRA, 2015). The area was excluded due to ongoing management works at Quinns, including the addition and extension of groynes to manage erosion in the area. These works will change the behaviour of the shoreline within the sediment cell into the future. As the layout and confirmation of these works was not finalised at the time of the project, it was not considered appropriate to make future hazard predictions.

During Part 2 of the CHRMAP, greater certainty on the management approach for Quinns Beach has been confirmed. The CHRMAP project has also identified the importance of implementing planning controls to reduce future risk, and these controls are guided by hazard extents. As such, the City commissioned Cardno to develop coastal hazard extents for the coastline comprising Tertiary Sediment Cell 29b (the 'Study Area'), as part of the CHRMAP Part 2 project. Given the significant controls placed along the shoreline over past decades (see **Section 2.3.2**), as well as those to be implemented in the near future, traditional techniques for determining erosion allowances, as outlined in SPP2.6, required some modification for application to this area. Cardno has used numerical modelling that incorporates the protection structures, to predict the behaviour of the shoreline during storm conditions, as well as over the next 50 years. Beyond this period, the structures have been considered to no longer exist, as management pathways beyond their design life cannot be committed to at this stage.

It must be noted that a risk and vulnerability assessment has not been undertaken for assets along the coast in the Study Area. This was not considered appropriate at this stage, given an interim *protect* strategy for the area has already been committed to by the City. The hazard lines, however, should be used by the City to implement appropriate planning controls. It should also be noted that a separate CHRMAP has been undertaken for Lot 211 Quinns Road, Mindarie (Cardno, 2018), which required the calculation of hazard extents at the southern part of Sediment Cell 29b. Although different modelling techniques were used for that assessment, the hazard extents are consistent between studies in that portion of the Study Area. The lines presented in this study should now supersede those calculated for the Lot 211 Quinns Road, Mindarie CHRMAP, as they are based on more recent information.

The Study Area for this project is the same as that for the Quinns Beach Long Term Coastal Management Study (see Cardno, 2015). The Long Term Coastal Management Study has been built upon and referred to heavily for this hazard assessment and 'sections', defined for analysis of the shoreline, have also been incorporated into this study. The Study Area, defined sections and other coastal features are depicted in **Figure 1-1**, below.

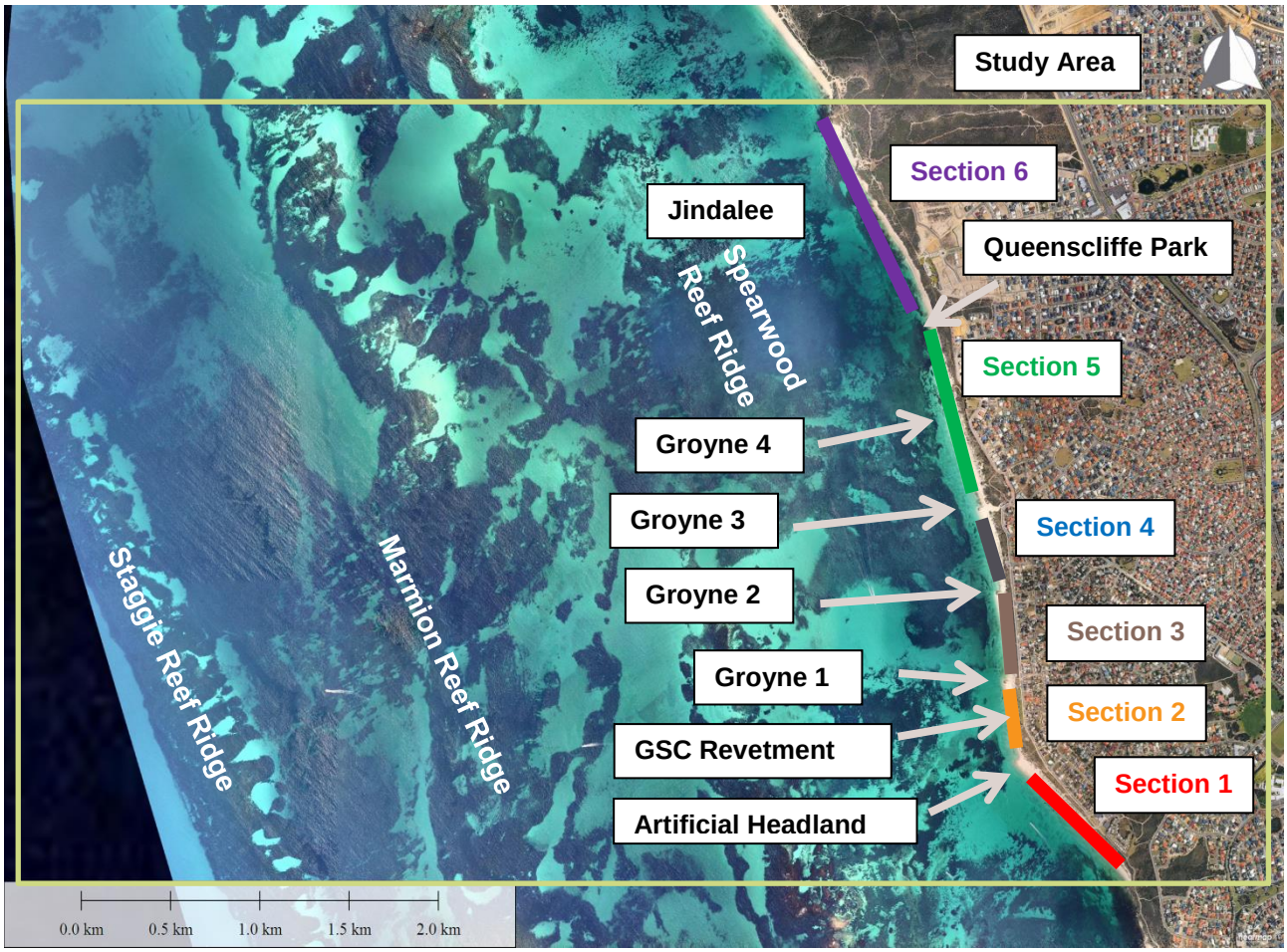


Figure 1-1 Study area compartmentalised into sections

1.3 Qualifications

Any potential impacts due to climate change, other than SLR, have not been considered in detail in this study, as they were not part of the scope. Any changes to the dominant storm direction due to climate change will have an impact on longshore sediment transport processes at the site.

Any potential effects due to salt water intrusion, changes in the water table, and other groundwater related effects have not been considered as part of this CHRMAP. Inundation and flash flood impacts arising from stormwater are assumed to be appropriately managed and have no significant impact on the study site.

2 Environmental Setting

2.1 Coastal Geomorphology

Sediment transport at Quinns Beach has a complex response to the spatially variable nearshore wave climate. Waves arriving from offshore are modified considerably through processes including shoaling, breaking, refraction and diffraction across the system of three reefs. Wave shoaling and breaking results in wave set-up over the shallower reef areas, which forces complex nearshore circulation and drives sediment transport pathways within the reef system. At the beach face, the variation in nearshore wave angle caused by the reefs results in complex littoral drift to both the north and south.

These processes occur and interact over a range of nested temporal and spatial scales. A beneficial conceptual framework for understanding the geomorphological outcomes of the interactions involves coastal compartments (commonly referred to as sediment cells). Coastal compartments have been mapped in Western Australia at three scales: Primary, Secondary and Tertiary (see Stul et al, 2015).

At the Primary Cell scale (100's kilometres, 1000's years) Quinns Beach is situated leeward of a number of remnant dune and reef ridges formed along temporary shorelines as sea levels rose and fell. The present day Spearwood, Marmion and Staggie limestone reef ridges are the highly weathered remains of those dunes. Consequently, at the Secondary Cell scale (10's kilometres, 100's of years) the City of Wanneroo coast has numerous salients and cuspate forelands associated with prominent sections of reef. Quinns Beach is a cuspate foreland that has formed as a result of the presence of Quinns Rocks in combination with shallower sections of the Staggie and Marmion Reef Ridges. At the nearshore Tertiary Cell scale (the scale of an individual beach) Quinns Beach is bounded by cliffs and Mindarie Keys to the south, and a series of nearshore reefs and cliffs to the north. A more detailed description of coastal geomorphology and sediment cell processes for the Quinns area is provided in Cardno (2015).

2.2 Oceanographic Conditions

2.2.1 Wind

The Study Area is located within the greater Perth coastline and experiences the typical oceanographic conditions of the region. It is influenced by two dominant seasonal weather patterns. The summer period is characterised by south to south-westerly sea breezes that generally increase through the afternoon and can be very strong at times. The winter period is characterised by intermittent storms attributed to mid latitude low pressure systems, shifting the dominant wind direction to north-westerly; these winds can exceed 20 ms^{-1}.

2.2.2 Water Level and Currents

The Study Area, like the rest of the Perth coast, experiences low tidal range from mixed but mainly diurnal tides. The tidal range varies from approximately 0.3 m during neap tides to 0.7 m during springs. This small tidal movement allows wind to be the major driver of currents, particularly within the nearshore zone. Longshore currents correspond to seasonal wind and wave conditions, predominantly propagating northward during summer and to the south during winter. The interaction of these currents with shoreline features can form local eddy and rip currents, particularly when swell is present driving substantial water movement perpendicular to the shore.

The present-day astronomical tidal planes at Two Rocks Marina have been included in **Table 2-1**. The full tidal range between LAT and HAT is relatively small at 1.2 m.

Table 2-1 Two Rocks tide level (NTC, 2014)

AHD (m)	Tide	Chart Datum (m)
0.6	Highest Astronomical Tide (HAT)	1.4
0.3	Mean Higher High Water (MHHW)	1.1
0.2	Mean Lower High Water (LMHW)	1.0
0	Australian Height Datum	0.8
-0.3	Mean Higher Low Water (MHLW)	0.5
-0.4	Mean Lower Low Water (MLLW)	0.4
-0.6	Lowest Astronomical Tide (LAT)	0.2

2.2.3 Wave Climate

The wave climate in the Study Area is seasonal with wave energy higher, on average, during the winter months of May to October. Analysis of the offshore waverider buoy data at Rottnest from 2005-2017 (DoT, 2018) indicates that the annual wave energy peak occurs between June and September.

The two seasonal weather modes dominate the local wave climate with locally generated seas from the south, south-west interrupting generally calm conditions during summer. Storms during winter lead to higher energy wave conditions and a greater presence of offshore derived swell, which generally propagates from the south-west. Tropical cyclones that develop during the summer months off WA's north-west coast rarely track down to the latitude of the Study Area, but have been recorded in the region and can cause significant damage to coastal infrastructure. Quinns is afforded some protection from offshore wave conditions by various fringing limestone reef structures scattered adjacent and at varied distance offshore.

2.3 Coastal Processes

2.3.1 Sediment Transport

Under the DoT's sediment cell hierarchy (Stul et al, 2015), the Study Area lies within Primary Sediment Cell G - Pinaroo Point to Yanchep. Within this primary cell the Study Area is covered by secondary sediment cell 29 and tertiary cell 29b – Mindarie Keys North to Quinns Rock North. The confinement of the Study Area to a single tertiary sediment cell means the mechanisms of coastal change are expected to be similar throughout the area over the short to medium term (i.e. inter-annual to decadal timescales).

Along the Perth coastline, longshore sediment transport has been shown to be mainly northward from September to April, associated with prevailing currents over the summer period. A southward movement of sediment is usually observed during the winter months of June and July. The result is a net northward movement of material annually. Nearshore structures and natural shoreline features can direct and obstruct the movement of suspended sediment.

Cross-shore sediment movement in the Perth region is also seasonal with sporadic periods of swell pushing sediment onto the shore, steepening the beach profile. Mid-year the beach is reformed by the energy of winter storms eroding the beach face and redepositing sediment to form sandbars just offshore. These formations become stable towards the end of winter and act as a buffer, preventing wave breaking at the shore and the substantial shifting of sediment that it can cause.

Nearshore flow structures are complex in the vicinity of the Study Area, due to the presence of nearshore reefs and other shoreline features; natural and man-made. A detailed analysis of sediment cell processes in the area is provided in Cardno (2015).

2.3.2 Existing Controls

Existing controls can refer to any structure, natural or artificial, that interacts or may interact in the future with the oceanographic conditions and coastal processes described above. Controls also include ongoing management such as nourishment programs and dune care. Significant existing controls for the Study Area (see also **Figure 1-1**) are:

- Groyne 4 located at approximate Chainage 26,500: Construction of this groyne was completed in 2018 and it is considered to be in excellent condition;
- Groyne 3 located at approximate Chainage 27,075: This was constructed in 2003 and maintenance works were carried out on the structure in 2014. The groyne is considered to be in good condition at present. The groyne will be extended during summer 2019-20 to improve its effectiveness;
- Groyne 2 located at approximate Chainage 27,550: This was constructed in 2002 and maintenance works were carried out on the structure in 2014. The groyne is considered to be in good condition at present. The groyne will be extended during summer 2018-19 to improve its effectiveness;
- Groyne 1 located at approximate Chainage 28,000: This was constructed in 2002 and maintenance works were carried out on the structure in 2014. The groyne is considered to be in good condition at present;
- The Geotextile Sand Container (GSC) revetment spanning from approximate Chainage 28,000 to 28,250: This was constructed in 2014 and is considered to be in excellent condition;
- The artificial headland located at approximate Chainage 28,450: This was constructed in 1977 (City of Wanneroo, 2014) and is considered to be in poor condition, with considerable displacement of armour rocks from their original configuration;
- Considerable natural, limestone rock is known to exist and has been identified along the shoreline in the Study Area, most notably at its northern and southern boundaries. Where this rock has been assessed through visual inspection or geophysical investigation, and confirmed to form a continuous barrier against coastal erosion, it has been factored into the calculation of coastal erosion hazard lines (see **Appendix A**);
- Considerable limestone reef structures are present offshore of the Study Area, as discussed in **Section 2.1** and described in detail in Cardno (2015). Wave modelling has accounted for these offshore reefs, as outlined in **Section 3.3.1**;
- The City applies regular sand nourishment to beaches within the Study Area, which varies but has recently involved the placement of approximately 10,000 to 20,000 cubic metres of sand per year. The City plans to continue nourishment to help maintain the shoreline position (in conjunction with the effects of the groynes) in front of key infrastructure within the Study Area; and
- Dune rehabilitation programs have been undertaken adjacent to the Quinns Dog Beach and ongoing dune maintenance (infill matting and planting) is undertaken by the City at Quinns, as required.

Based on the significant current and planned controls within the Study Area, it has been deemed appropriate for these controls to be factored into assessment of coastal erosion hazards, where applicable. The effect of these controls on hazard extents is detailed in **Sections 3.3.3** and **3.3.4**.

2.4 Climate Change Parameters

It is widely recognised in the scientific community that climate change is occurring and, as a result, possible effects must be considered when planning for the future. For this study the projected effects will most likely be an increase in MSL, as well as changes to storm frequency, direction and intensity, changes to precipitation patterns and increased temperatures. For the purpose of this CHRMAP only potential effects due to SLR are considered. It was noted in **Section 1.3** that there is the potential for changes in the dominant storm direction to impact the site by affecting the longshore sediment transport regime. This has not been considered in this study. Assessing these potential effects should be incorporated into ongoing monitoring and future CHRMAP revisions.

This study will consider the present timeframe, as well as the years 2030, 2050, 2070 2090 and 2120. This is consistent with the timeframes assessed in the overall CHRMAP and adheres to the SPP2.6 requirement for consideration of a 100 year planning period.

2.4.1 Sea Level Rise

The IPCC (2014) has provided projections for SLR based on historical SLR and future emission scenarios. Based on the IPCC's projections, the DoT have recommended a vertical SLR of 0.9 m to be adopted when considering the impact of coastal processes over the next 100 years (2010 to 2110) (DoT 2010). The

recommendations were formally adopted by the WAPC and form the basis of this project's SLR cases, presented in **Table 2-2**.

For this study, the prediction has been extrapolated linearly to 2120 to account for the full range of planning timeframes to be assessed.

Table 2-2 Recommended allowances for sea level rise

Simulation	Present day	2030	2050	2070	2090	2120
Sea Level Rise (m)	0	0.07	0.20	0.39	0.62	0.97
S3 Erosion allowance (m)	0	7	20	39	62	97

3 Coastal Hazard Identification

3.1 Coastal Foreshore Reserve

Schedule One of SPP 2.6 provides guidance for calculating the coastal foreshore reserve component to allow for coastal processes including present day erosion, historical shoreline movement, sea-level rise and storm surge inundation. This calculation does not account for the entire coastal foreshore reserve width. The overall coastal foreshore reserve width should be determined on a case by case basis. This should include allowance for additional functions provided by the coastal foreshore associated with environmental, social and indigenous values.

The component of the coastal foreshore reserve to allow for coastal processes should be sufficient to mitigate the risks of coastal hazards by allowing for landform stability, natural variability and climate change. The coastal foreshore reserve is a critical input into the coastal hazard risk management and adaptation planning framework outlined in SPP 2.6. The assessment considers allowances for coastal erosion and storm surge inundation in parallel.

3.2 Erosion Allowances

The natural coastline is, in general, very responsive to the climate and any changes that occur. At any time, coastal land such as that in the Study Area is at risk of exposure to several forms of erosion. Allowances for these risks are categorised in SPP2.6 as:

- (S1 Erosion) Allowance for the current risk of erosion;
- (S2 Erosion) Allowance for historic shoreline movement trends; and
- (S3 Erosion) Allowance for erosion caused by future sea level rise (see **Table 2-2**).

These three factors, plus an uncertainty allowance of 0.2 m per year, combine to form the required setback allowance for coastal erosion, for each of the planning timeframes being considered.

The setback distances are applied from a horizontal shoreline datum (HSD), a fixed line that is defined on the basis of the type of coastline being assessed. The HSD defines the active limit of the shoreline under storm activity, and should be determined against the physical and biological features of the coast. In most cases it should be defined as the seaward shoreline contour representing the peak steady water-level under storm activity.

3.3 S1 Erosion

The S1 erosion rate is defined as the current risk of shoreline erosion due to short term (acute) storm erosion. S1 erosion is estimated on sandy shorelines by first determining a suitable nearshore wave event and then modelling the response of the shoreline in a numerical storm erosion model such as SBEACH or XBEACH.

3.3.1 Wave Modelling

Design Storm

Schedule One of SPP2.6 describes different geographical areas for the definition of the storm event for use as the defined storm event in the assessment of coastal erosion. The study site lies in an area that requires the application of a mid-latitude depression or extra-tropical low storm event. Policy guidance for coastal erosion is that an event corresponding to the 100-years ARI ocean forces and coastal processes should be selected.

For this purpose, the DoT has generated a synthetic storm based on analysis of actual events for use in the application of SPP2.6. However, this storm was generated for offshore conditions, specifically at the Rottnest Wave Buoy location (location shown in **Figure 3-1**). It is not appropriate to apply this storm as forcing to coastal erosion models, due to the inability to resolve wave shoaling and frictional losses. As such, Cardno created a wave model using SWAN (Simulating WAves Nearshore).

Wave Model Description

The SWAN wave model system applied in this investigation was developed at the Delft University of Technology (Booij et al., 1999). The model can provide third generation full spectral solutions and includes wind input, refraction, diffraction, shoaling, bed friction, white capping, wave breaking, the effect of currents and non-linear wave-wave interaction.

It can be applied as a steady-state model for local sea, developed from spatially and temporally variable winds which provides a very reliable basis for generating local sea. The model has been well verified by its authors and is considered to be one of the most reliable systems available at present.

Wave Model Setup

Model Grid

A nested grid approach was adopted in order to enable the transition from ocean scales to coastal scales. A coarse grid, with 1000m x 1000m grid cells, extended from Lancelin to Preston Beach and from the coastline out to the -50m AHD contour line, with the offshore boundary located co-incident with the Rottnest Waverider buoy.

An intermediate grid (medium grid), with 200m grid cells, extended from Two Rocks to Hillarys and from the coastline out to the -30m AHD contour line. This medium grid used boundary conditions that were generated by the coarse grid model area. A fine grid area, with 40m grid cells, extended from 2 kilometres north to 4 kilometres south of the study area and from the coastline out to the -26m AHD contour line. The resolution of the fine grid was sufficient to resolve the complex series of barrier reefs present at Quinns Beach. **Figure 3-1** and **Figure 3-2** depict the grid nesting set up and bathymetry of the fine grid, respectively.

Bathymetry

The following bathymetric data were used in the nearshore wave modelling:

- Lancelin to Cape Peron Navigational Chart (AUS0754)
  - Source: Department for Planning and Infrastructure
- Bouvard Navigational Chart (AUS0755)
  - Source: Department for Planning and Infrastructure
- Two Rocks to Cape Naturaliste LiDAR data
  - Source: Department of Transport
  - Survey date: April 2009 to May 2009
- Quinns Beach Dynascan Survey
  - Source: Department of Transport
  - Survey date: October 2014
- Quinns Hydrographic Survey
  - Source: Department of Transport
  - Survey date: October 2014

The navigational charts were used for the coarse wave modelling grid, in the offshore area where LiDAR data was not available. The LiDAR data was used in the finer model domains, from the +5m AHD contour line to the offshore boundaries.

Boundary Conditions

The offshore open boundary of the coarse grid was forced with the CHRMAP storm time series provided by the DoT and modelled with a JONSWAP spectral shape.

The synthetic storm was applied across the western model boundary to bring the storm inshore. Cardno used SWAN model parameters consistent with Cardno (2015), for which good calibration was achieved. Data was

extracted at the boundary locations of the coastal erosion model. The bathymetry is shown in more detail in **Figure 3-2**, a zoomed in presentation of the model bathymetry.

The resultant design storm on the western boundary of the model to be applied in the coastal erosion model is presented in **Figure 3-3**.

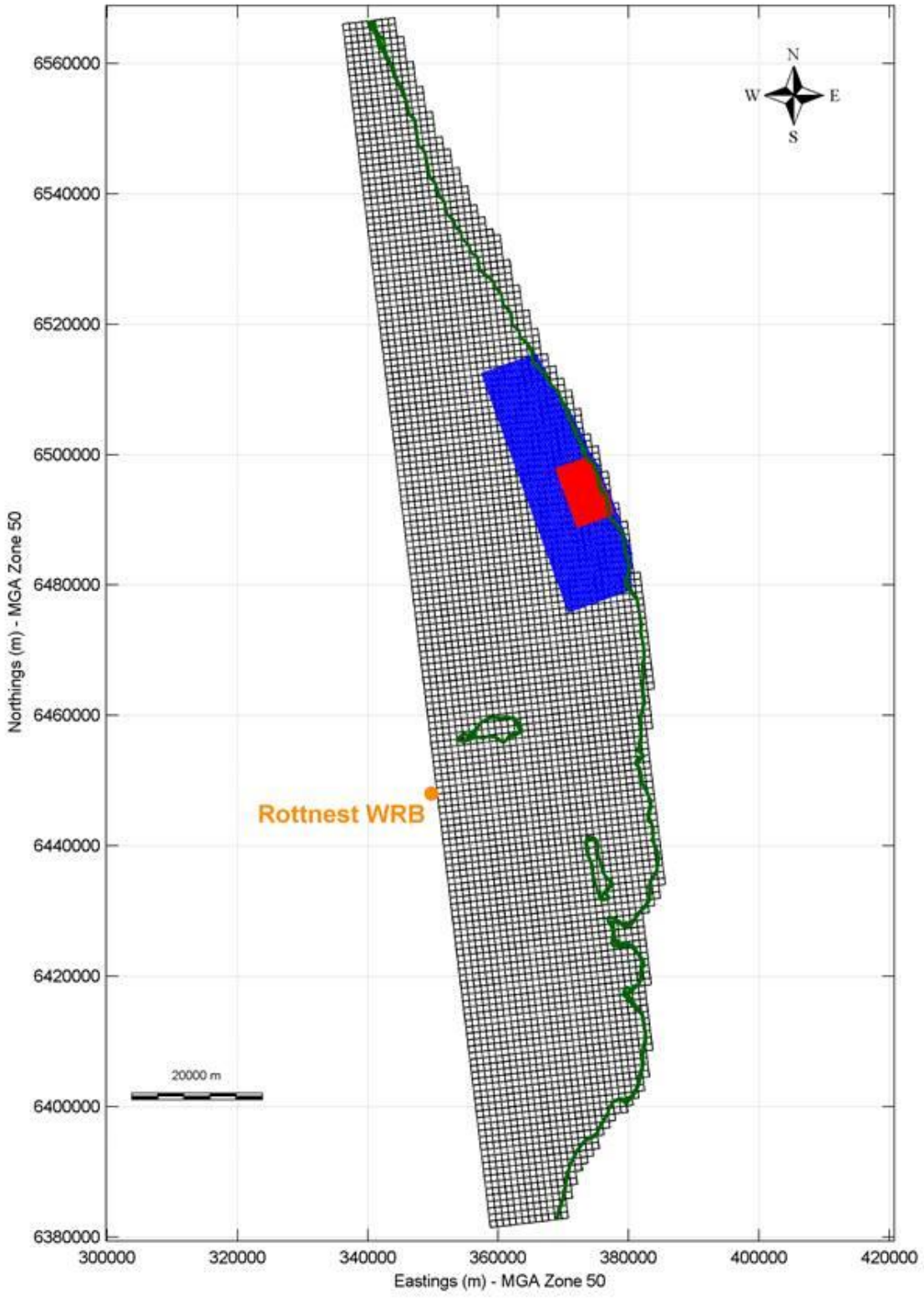


Figure 3-1 Nesting of SWAN grids: Coarse grid (black), medium grid (blue), fine grid (red)

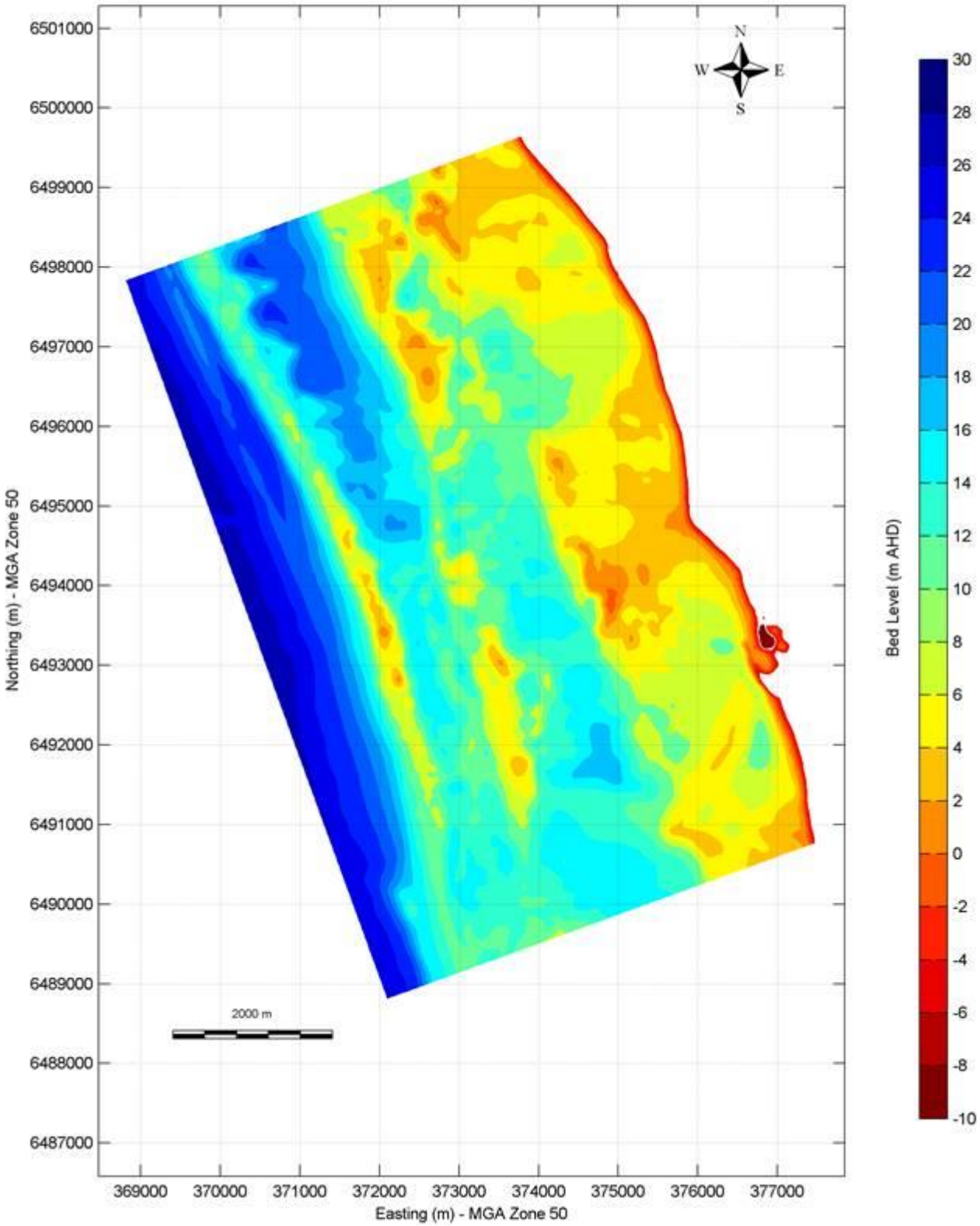


Figure 3-2 Bathymetry used in nearshore wave model

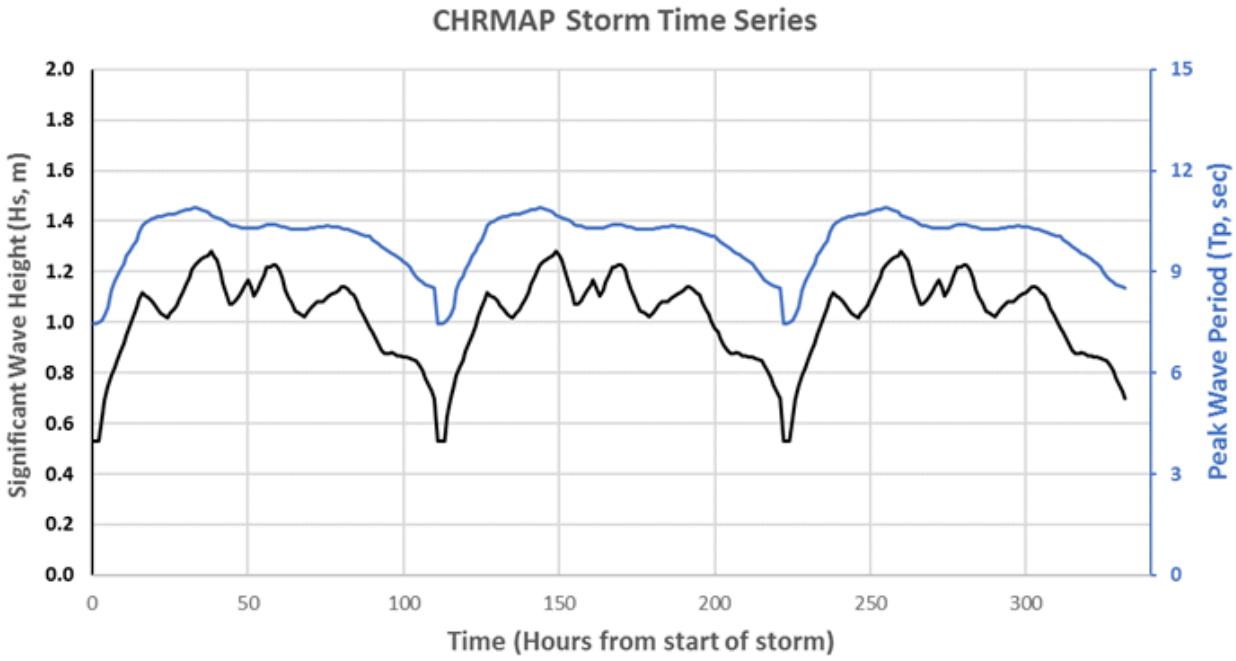


Figure 3-3 Storm time series applied to SBEACH modelling

3.3.2 Storm Erosion Modelling (S1)

Model description

XBeach is a 2D morphological model developed specifically to assess the time varying response of coastlines to storm and tropical cyclone conditions. It has specific formulations for dune erosion, overwash and breaching. XBeach does not model the short waves directly, rather it uses the results of SWAN to calculate and apply a non-stationary (time varying) long wave boundary condition to the model and then solves the propagation of the short wave envelope, non-stationary shallow water equations, sediment transport and morphology (Roelvink et al, 2009). Avalanching is used to model dune erosion and cross-shore transport is calculated specifically from a balance of onshore transport by wave skewness and asymmetry and offshore transport by return flow. Whilst XBeach includes the influence of wind on the hydrodynamics, it does not include the processes associated with wave growth within the model domain.

Model grid and bathymetry

A curvilinear grid was designed to follow the coastline, with local grid refinement through the study area and adjacent to the shoreline. The grid extended offshore to a depth of -27 m AHD approximately 6km offshore. The grid covered approximately 13 kilometres in the longshore direction with the model domain extended 3.8 kilometres north and 4.8 kilometres south of the study area.

The grid had a fine resolution along the beach and within the nearshore area in order to resolve the morphological processes along the beaches in the study area. The grid resolution of 4 metre cross-shore and 15 metres alongshore enabled a reasonable representation of the non-erodible structures which impact on the sediment transport: the groynes, the revetment, the headland and the limestone cliffs. Resolution gradually diminished to approximately 140 metres at the model boundaries.

Model bathymetry was developed from the following datasets: LiDAR was used from the 5mAHD depth to the offshore boundary, October 2014 Hydrographic survey was used in the nearshore area and beach profiles from the April and December 2017 Beach Profile Survey's.

Simulation period and timestep

The simulation period covered three iterations of the design Storm, as shown in **Figure 3-3**.

The time step in XBeach is determined automatically based on a Courant number criterion. For all XBeach simulations a Courant Number of 0.7 was specified. The Courant Number is given by the following equation (Deltares 2011):

$$\text{Courant Number} = (\Delta t \sqrt{gH})/(\{\Delta x, \Delta y\})$$

Where Δt is the time step, g is the acceleration of gravity, H is the water depth and $\{\Delta x, \Delta y\}$ is the minimal value of the grid spacing in either direction.

Boundary conditions

Flow Boundary Conditions

The model was bound by 3 open boundaries: West, North and South boundary.

The West offshore boundary consisted of time series of water level data from the design storm plus the wave setup calculated at the boundary of the XBEACH model from SWAN. A Neumann boundary condition was applied on the North and South boundaries. This boundary condition allows the specification of a 'zero gradient' boundary condition, allowing wind and wave driven currents to flow freely into or out of the domain.

Wave Boundary Conditions

Spatially and temporally varying 2D spectral boundary conditions from the SWAN model were applied to the XBeach model at the model boundaries (offshore and lateral).

Flow bed friction

The bed friction was defined by the constant Chezy coefficient of 55 $m^{1/2}/s$.

Wave breaking and dissipation

The wave breaking model of Roelvink, (1993) (*break=roelvink1*) was utilised in the model with a gamma factor of 0.55. Wave dissipation by bottom friction is modelled using a friction coefficient and model calibration resulted in a friction coefficient of 0.15.

Sediment description

The Van Thiel-Van Rijn sediment transport equations were applied in XBeach (van Rijn, 2007; van Thiel de Vries, 2009). The XBeach model used an initial sediment thickness map shown in **Figure 3-5**. No initial sediment was applied offshore of approximately the -5 mAHD contour level. Sediment transport in the offshore region is not relevant at the time scale of an individual storm; the sediment transport models were therefore limited to changes on the beach and out to the depth of closure. The non-erodible limestone cliffs along Sections 5 and 6, the groynes, the headland, the GSC revetment and the Mindarie Marina did not contribute to the sediment budget and therefore had zero metres of sediment. For the area from the beach to the closure depth (about -5mAHD), a constant thickness of 5 metres was added to the bed level so as to mimic the equilibrium beach profile; there was no sediment at closure depth (-5mAHD + 5 metres) while the beach, at an elevation of 3mAHD for example, had 8 metres of sediment. It should be noted that the nearshore reefs of Sections 5 and 6 were not schematised in the model. That is whilst the bed level included the reefs, their spatial description in the sediment thickness map was not able to be included due to limited detailed information on their location, extent and depth above (and below) the seabed.

A D_{50} grain size of 340 µm and D_{90} grain size of 500 µm was used in the XBeach model. This is based on sediment sampling undertaken on the site during previous studies.

Morphological parameter sensitivity analysis

A sensitivity analysis was performed on numerous parameters in the XBeach model that control the sediment transport and morphology. The greatest sensitivity was demonstrated by the facSk and facAs parameters which are calibration parameters that control the magnitude of onshore transport due to wave skewness and asymmetry respectively. Whilst these parameters can be adjusted independently in this study both were adjusted simultaneously with a final value of 0.3 selected for each. A summary of model parameters adjusted from their default values are:

- Onshore transport due to wave skewness (facSk) = 0.3
- Onshore transport due to wave asymmetry (facAs) = 0.3
- Wet area critical slope for avalanching (wetslp) = 0.2
- Wave bed friction coefficient (fw) = 0.15

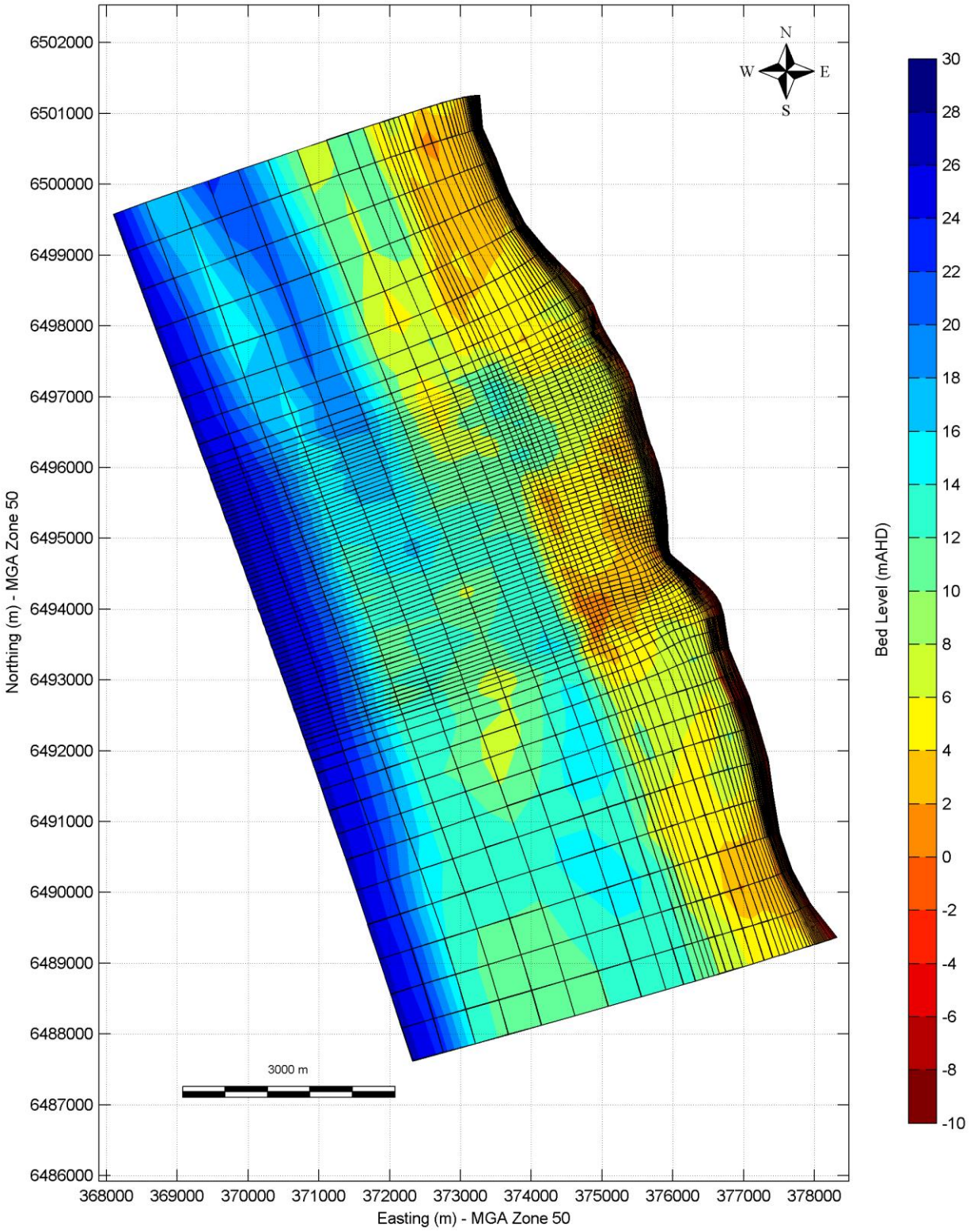


Figure 3-4 The grid set up and bathymetry used in the XBeach model. Note that for display purposes the grid has been de-refined by a factor of 4, i.e. 4 grid cells are represented by 1 grid cell.

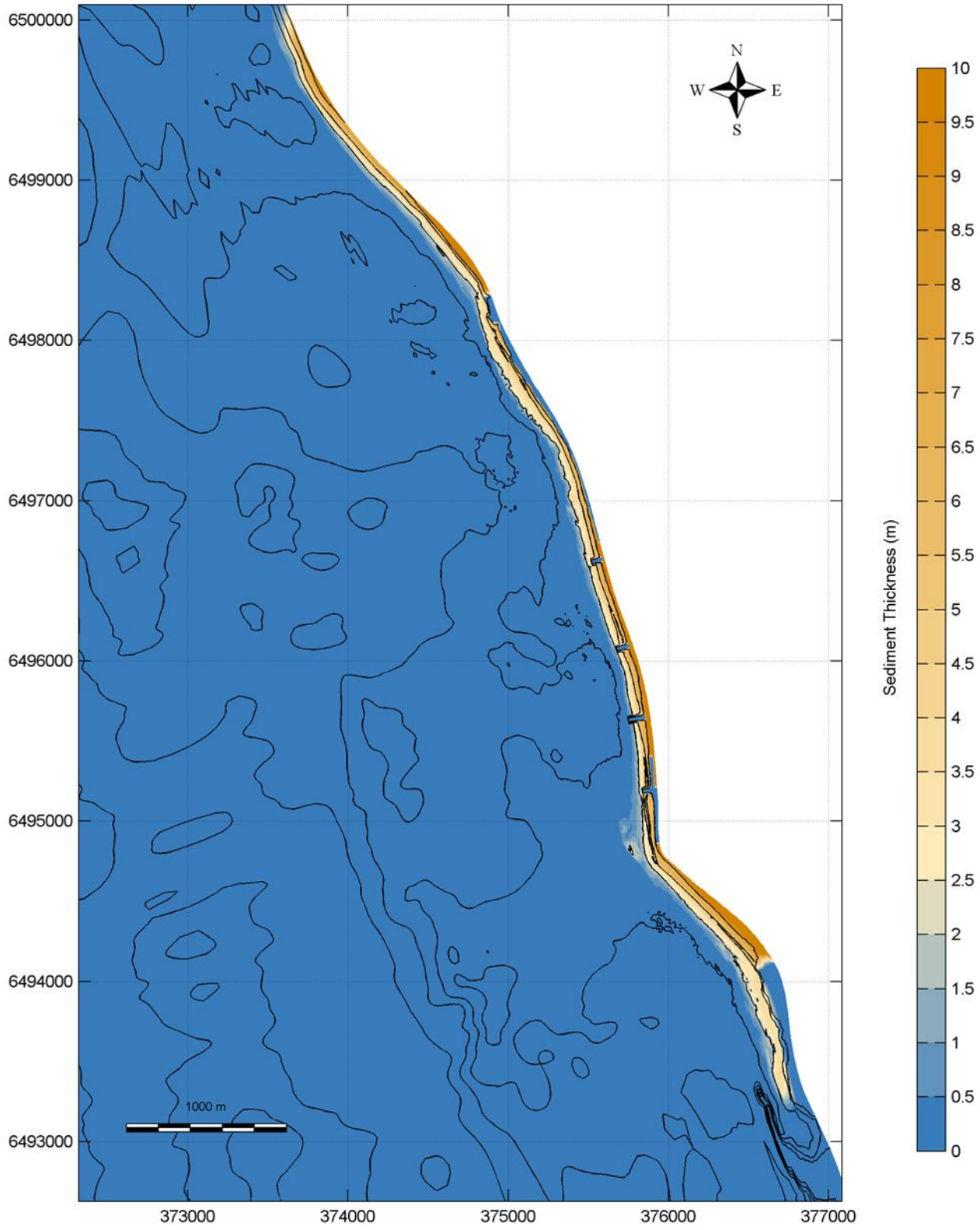


Figure 3-5 Initial sediment thickness used in the XBeach model.

Simulation Results

The XBEACH model results provide detailed information on the cross shore and longshore movement of sediment under storm conditions. This section outlines the model results for the storm erosion modelling using the XBEACH modelling system that was developed and validated as part of the Quinns Beach Long Term Coastal Management Study (Cardno, 2015).

Two outputs relevant to the erosion hazard assessment are:

1. The determination of the horizontal shoreline datum line (HSD); and
2. Determining the S1 erosion allowance.

The HSD line is the landward extent of the still water level (tide+surge+wave setup) during the design storm. To determine the location of the HSD, the maximum still water elevation from each XBEACH simulation was exported from the model and the maximum water surface drawn in GIS. The HSD line was created as the landward limit of this surface.

The S1 erosion allowance is defined as the landward limit of erosion. **Figure 3-6** presents the erosion and sedimentation that the model predicts at the end of the CHRMAP storm.

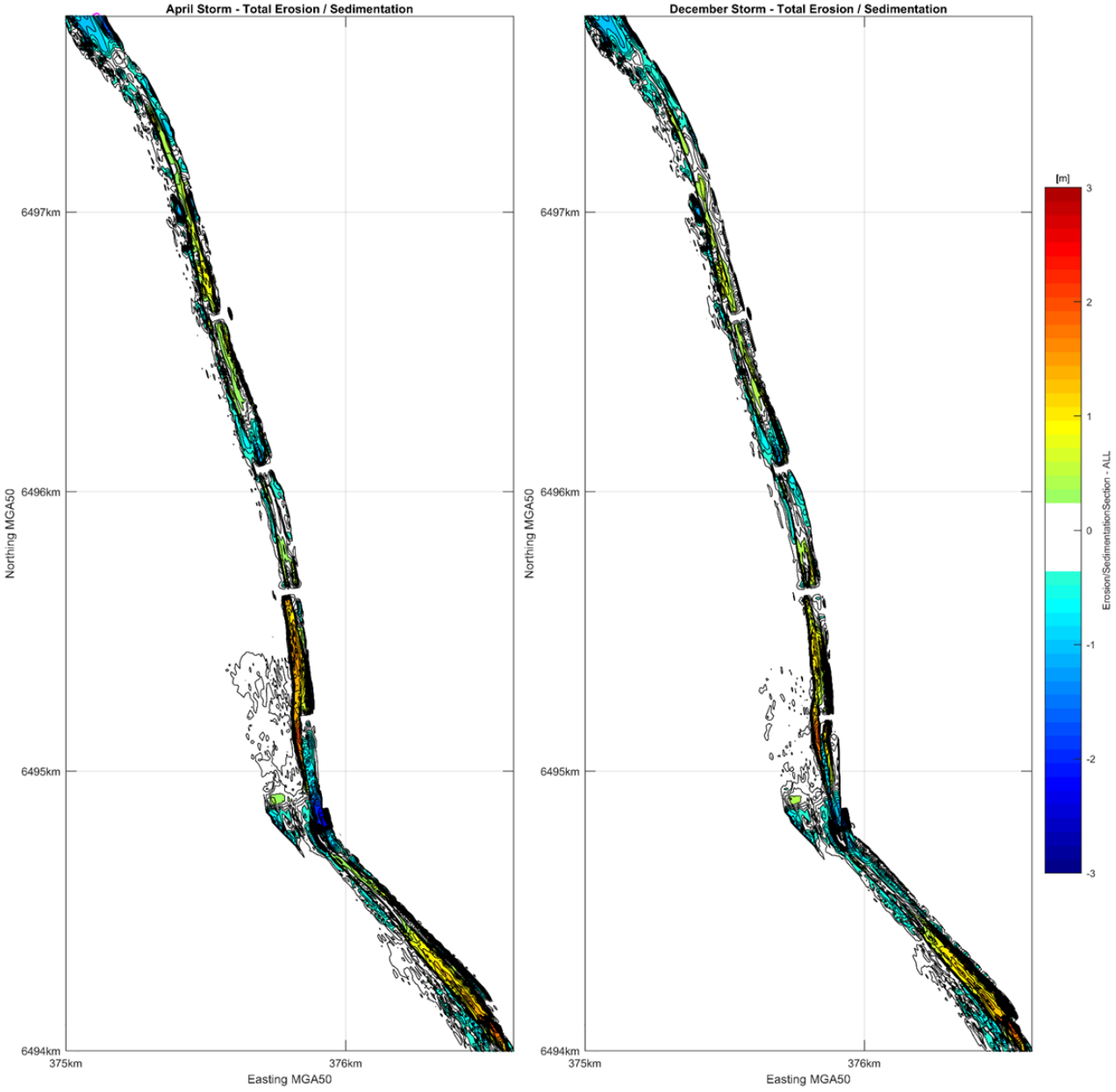


Figure 3-6 Cumulative erosion (blues) and sedimentation (yellow and red) at the end of the CHRMAP storms

Modelling results for XBEACH beach profiles are provided in **Appendix A**.

To determine the position of the S1 erosion line, the cumulative bed level change data was imported into GIS and the 0 bed level change contour was plotted. The S1 line was plotted as the landward limit of erosion during the storm event.

3.4 S2 Historic (Chronic) Erosion

Cardno assessed coastal vegetation lines from available aerial imagery from 1969 to 2017. Where possible, aerial images captured at a similar time of year were selected, to account for potential seasonal variability in vegetation. The overall timeframes of aerial images included in the assessment were separated for Section 1 and the remaining sectors (collectively) due to the influence of shoreline controls.

For Section 1, vegetation lines from aerial images were assessed for the full record, from 1969 to 2017. **Figure 3-7** shows vegetation line positions for the section, relative to 2017, with positive shoreline position values indicating that the 2017 vegetation line is further seaward than for that time period. Values for vegetation line positions are tabulated in **Table 3-1**.

On average, the shoreline has advanced slightly in Section 1 over the time period. This advance is likely to be (at least partly) attributed to the placement of the artificial headland in 1977, which is likely to have trapped predominantly northward moving sediment. This effect is likely to eventually cease (if it has not already done so) and, as such, a positive S3 value (accreting) has not been applied in the Section. A neutral S2 value of 0 m/year has been applied (see **Table 3-1**).

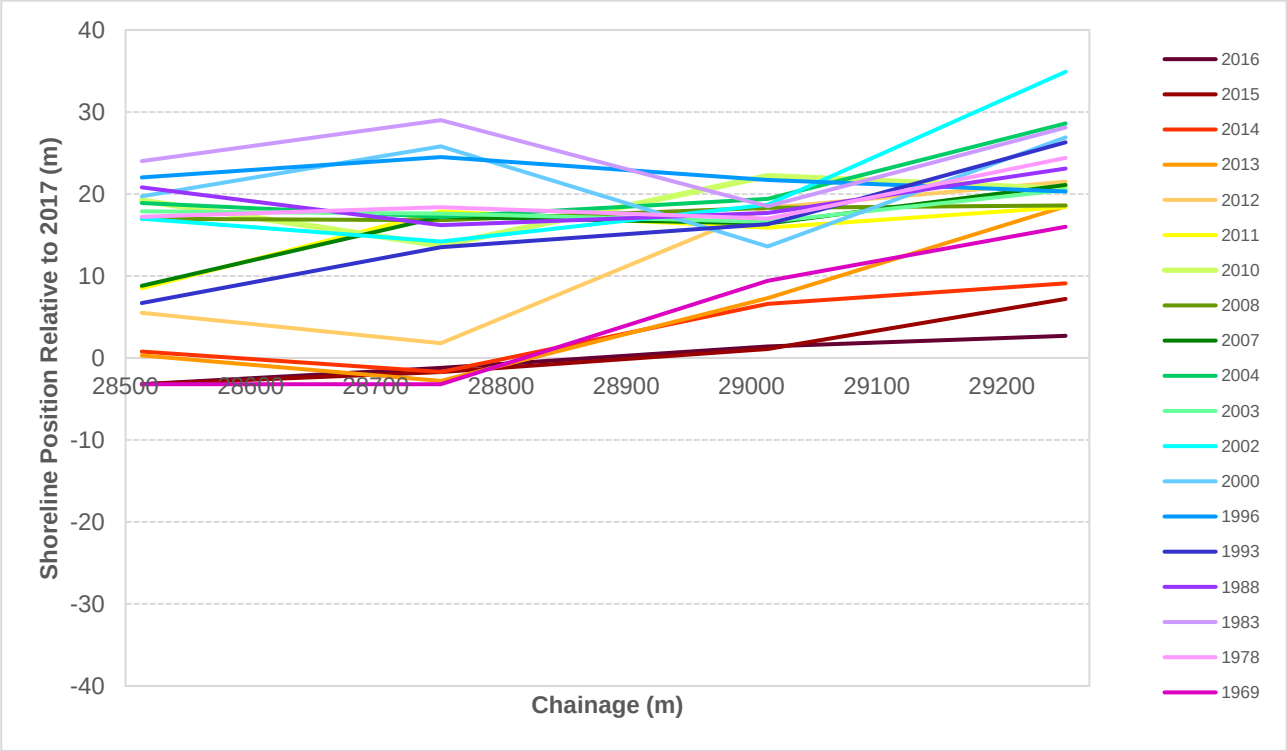


Figure 3-7 Section 1 historical vegetation line positions, relative to October 2017.

For Sections 2 to 6, vegetation lines from aerial images were only included between 1969 and 2000. The installation of groynes 1 to 3 commencing in 2002 will have significantly altered shoreline behaviour in these Sections. Considerable nourishment has also been placed during and following groyne construction. These factors will confound any analysis of natural shoreline variability between the construction period and present day. It is noted that the construction of the artificial headland is also likely to have altered natural shoreline movement. Any such effect would be difficult to isolate due to very few available aerial images and is likely to be of a much lower magnitude than that associated with the groyne field. As such, analysis has not sought to exclude any possible effects.

Figure 3-8 shows vegetation line positions for the sections relative to 2000, with positive shoreline position values indicating that the 2000 vegetation line is further seaward than for that time period. Values for vegetation line positions are tabulated in **Table 3-1**. The results show that the shoreline has generally eroded in Sections 2 and 3 and been stable in Sections 4 to 6.

For this hazard assessment, S2 historical shoreline erosion values have been applied from 2060. Prior to 2060 it has been assessed that the effects of the City's protect approach, including groynes, beach nourishment and the GSC revetment will counteract any historical shoreline movement trends.

This notion is supported by longshore sediment transport and shoreline modelling carried out by Cardno (2017) for the Study Area. The modelling estimated relative shoreline change over 50 years, based on the groyne design currently being implemented (with completion planned for 2020). Modelled shoreline change associated with the new groyne layout, as well as for the previous layout, is presented in **Figure 3-9**. The model results predict that the design will lead to accretion in Section 3, as opposed to erosion for the previous layout. Although there is slightly greater recession predicted for Section 2 (approximately 1m over 50 years), it is noted that the revetment in this Section will act as a barrier to erosion.

Overall, the modelling predicts greater retention of sediment within the planned groyne field, compared to the previous 3 groyne layout. This suggests that nourishment activities will be more efficient and that the City should be able to employ sand management techniques (such as sand bypassing and back passing) to maintain shoreline position in much of the Study Area until 2060. This management is still likely to require significant resources, and the City should review its ability to maintain the protection strategy on an ongoing basis, particularly at each future CHRMAP revision.

Beyond 2060, conservative allowances of 0.7 m/year and 0.4 m/year have been assumed for Sections 2 and 3, respectively. These values correspond to transects with maximum vegetation line recession, within these sections. Conservative values have been assumed due to uncertainty beyond this timeframe. There is also the potential for rapid shoreline adjustment once protection structures/techniques are no longer implemented or lose functionality. An allowance for historical shoreline erosion has not been included for areas assessed to have continuous rock barriers at the shoreline.

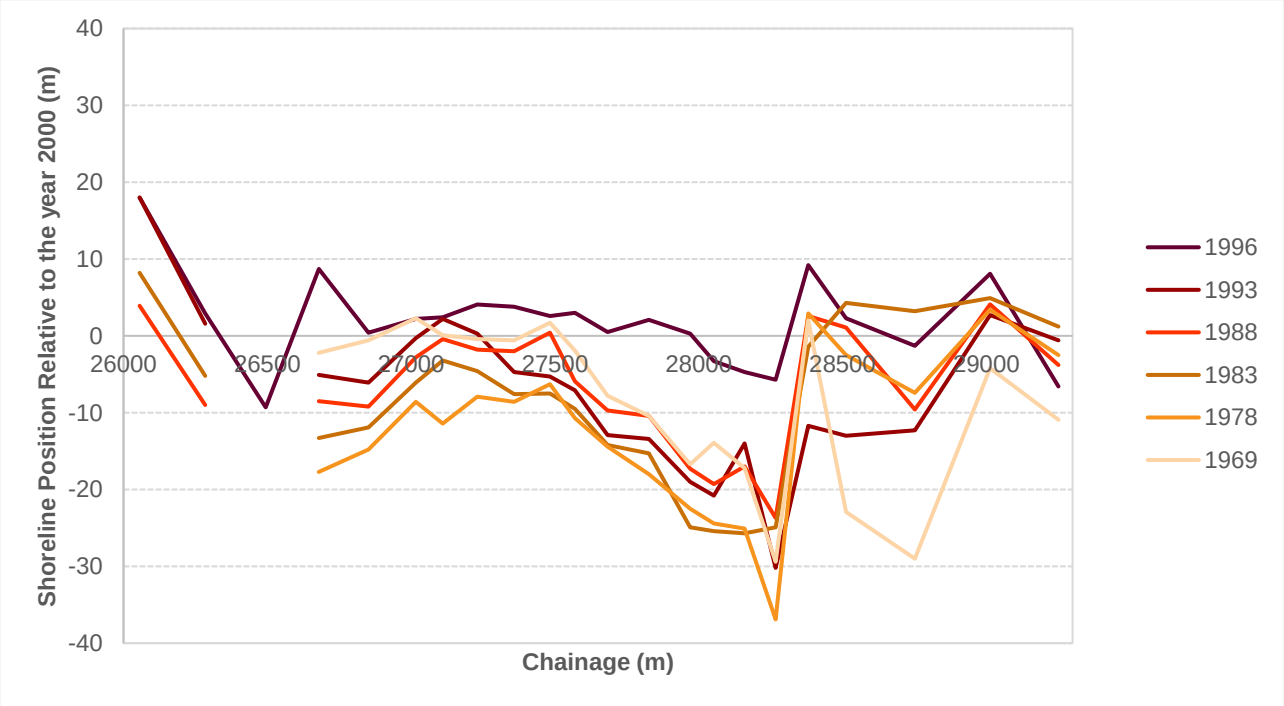


Figure 3-8 Section 2 to 6 historical vegetation line position, relative to January 2000.

Table 3-1 Historical vegetation line positions relative to the most recent suitable vegetation line (2017 for Section 1 and 2000 for elsewhere)

	Section 1				Section 2				Section 3				Section 4				Section 5				Section 6	
Chainage (m)	29251	29013	28752	28513	28381	28268	28160	28053	27970	27827	27683	27570	27483	27358	27230	27110	27017	26852	26679	26495	26284	26056
Year	Vegetation line relative to October 2017 (+ve = landward, -ve = seaward)				Vegetation line relative to January 2000 (+ve = landward, -ve = seaward)																	
Oct 1969	16.0	9.4	-3.2	-3.2	-10.9	-4.2	-29.0	-22.9	2.0	-29.4	-17.2	-13.9	-16.7	-10.4	-7.8	-1.9	1.7	-0.6	-0.4	0.1	2.3	-0.6
Jan 1978	24.4	17.0	18.4	17.2	-2.5	3.4	-7.4	-2.5	2.9	-36.9	-25.1	-24.4	-22.5	-18.0	-14.4	-10.7	-6.3	-8.6	-7.9	-11.4	-8.6	-14.8
Dec 1983	28.1	18.5	29.0	24.0	1.2	4.9	3.2	4.3	-1.4	-24.9	-25.7	-25.4	-24.9	-15.3	-14.2	-9.5	-7.5	-7.6	-4.6	-3.2	-6.1	-11.9
Nov 1988	23.1	17.7	16.2	20.8	-3.8	4.1	-9.6	1.1	2.6	-23.7	-17.0	-19.3	-17.3	-10.4	-9.7	-5.9	0.4	-2.0	-1.8	-0.4	-2.8	-9.2
Dec 1993	26.3	16.3	13.5	6.7	-0.6	2.7	-12.3	-13.0	-11.7	-30.2	-14.0	-20.8	-19.0	-13.4	-12.9	-7.1	-5.3	-4.7	0.3	2.2	-0.3	-6.1
Dec 1996	20.3	21.7	24.5	22.0	-6.6	8.1	-1.3	2.3	9.2	-5.7	-4.7	-3.3	0.3	2.1	0.5	3.0	2.6	3.8	4.1	2.4	2.2	0.4
Jan 2000	26.9	13.6	25.8	19.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jan 2002	34.9	18.7	14.2	17.0																		
Jan 2003	20.5	16.6	17.6	17.9																		
Dec 2004	28.6	19.4	17.2	18.9																		
Dec 2007	21.1	16.4	17.2	8.8																		
Dec 2008	18.6	18.3	16.8	17.0																		
Feb 2010	20.6	22.2	13.7	19.2																		
Feb 2011	18.4	15.9	17.9	8.5																		
Feb 2012	20.9	12.8	0.6	10.5																		
Oct 2012	21.5	18.3	1.8	5.5																		

Oct 2013	18.5	7.3	-2.8	0.3																	
Nov 2014	9.1	6.6	-1.7	0.8																	
Nov 2015	7.2	1.1	-1.7	-3.2																	
Oct 2016	2.7	1.4	-1.2	-3.2																	
Oct 2017	0	0	0	0																	
Average annual change (m)	0.4	0.2	-0.1	-0.1	0.0	-0.7	-0.4	-0.3	-0.4	-0.2	-0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	-0.2	0.0	0.2
Adopted S2 (pre-2060)	0.0 m/year				0.0 m/year				0.0 m/year				0.0 m/year				0.0 m/year				0.0 m/year	
Adopted S2 (post-2060)	0.0 m/year				-0.7 m/year				-0.4 m/year				0.0 m/year				0.0 m/year				0.0 m/year	

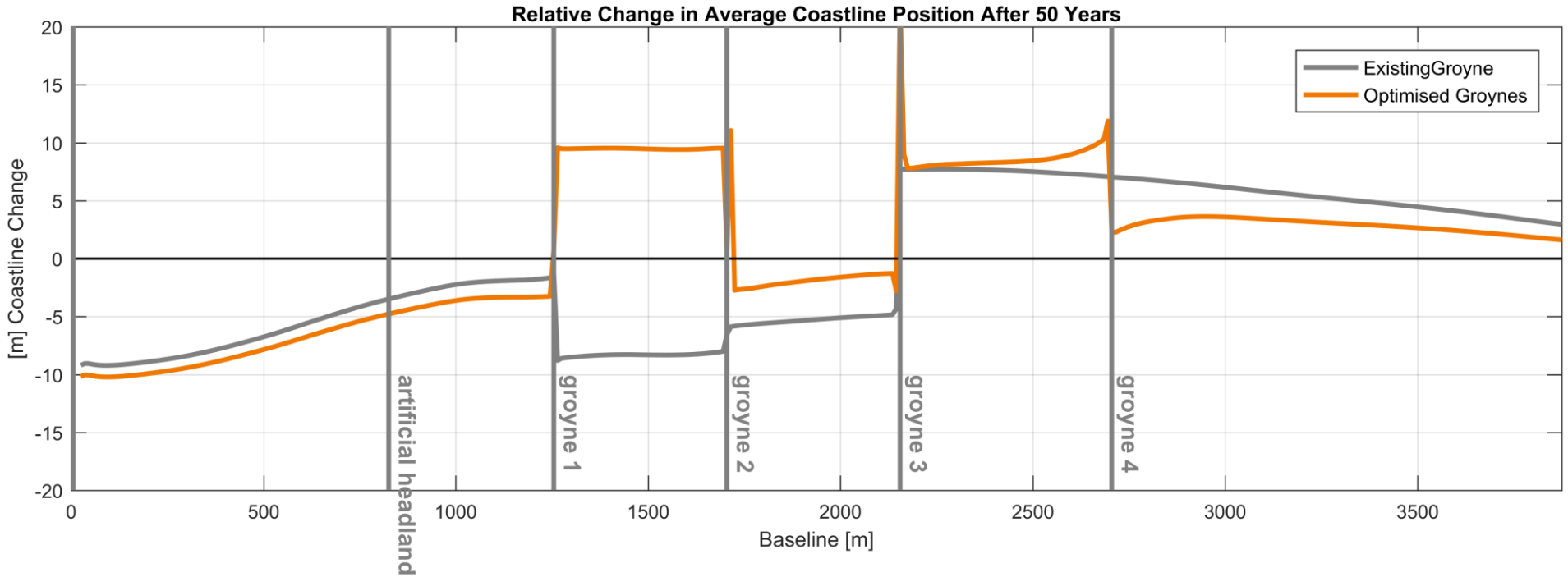


Figure 3-9 Longshore sediment transport and shoreline (LITPACK) model results for 50 years of shoreline change, based on the planned groyne design for the Study Area.

3.5 S3 Erosion due to SLR

The recommended erosion allowances for SLR were described in **Section 2.4.1** and are presented again in **Table 3-2**, below. Between Chainages 26,100 (the northern end of Waterland Point) and 28,300 (the southern extent of the GSC revetment) the S3 allowance has been excluded until the year 2060. This is due to the City's plan to continue sand nourishment to maintain the shoreline in these areas. The effect of this nourishment will be optimised by the function of the groynes, which will help retain sediment in the area (see also **Section 3.4** above). Beyond 2060, a shoreline recession rate of 1.1 m/year has been assumed, consistent with the recommended SLR allowance of 1.1 cm/year for this time period (see **Figure 1-1**).

Table 3-2 Recommended allowances for sea level rise

Simulation	Present day	2030	2050	2070	2090	2120
Sea Level Rise (m)	0	0.07	0.20	0.39	0.62	0.97
S3 Erosion allowance (m)	0	7	20	39	62	97

3.6 Coastal Erosion Hazard Lines

Coastal erosion hazard lines for each planning timeframe have been calculated and mapped from the HSD, by combining the S1, S2, S3 components where applicable, as well as an allowance for uncertainty of 0.2 m/year. For areas where continuous rock barriers are present at the shoreline, Cardno has incorporated the allowance for uncertainty only. The components used to derive the hazard lines at each chainage are tabulated in **Appendix B**. The hazard lines have been mapped over recent aerial imagery for the Study Area, presented in **Appendix C**.

3.7 S4 Storm Surge Inundation

According to SPP2.6, the allowance for storm surge inundation (S4) should be calculated based on a level with a 0.2% chance of exceedance annually, equivalent to a 500 year ARI event. The most reliable, long-term water level dataset in the area has been collected at Fremantle Fishing Boat Harbour. Cardno obtained 50 years of water level data (1966-2017) at Fremantle from the DoT. An extreme value analysis was carried out on the dataset to estimate a 500 year ARI water level in the region.

The water level record at Fremantle Boat Harbour comprises data collected within a protected marina and, as such, is unlikely to capture processes that can affect water level for an exposed shoreline; specifically setup caused by wind and wave processes. Investigations of setup suggest it is a considerable water level phenomenon in the nearshore zone and that the majority of wave setup generally occurs on the beach face (Dean & Walton, 2008). This supports the notion that the Fremantle dataset will not have properly captured water level increases due to setup in the area.

MRA (2015) undertook SBEACH modelling throughout the CoW coastline for Part 1 of the CHRMAP. They concluded that an allowance of 1.36 m for wind and wave setup was suitable for the area. The same value has been applied in this study for consistency.

Overall inundation levels, including the effects of SLR, for present day and future planning timeframes are shown in **Table 3-3**.

Table 3-3 Inundation level, S4

Component	Present day	2030	2050	2070	2090	2120
500yr ARI water level (mAHD)	1.43	1.43	1.43	1.43	1.43	1.43
Allowance for nearshore setup (m)	1.36	1.36	1.36	1.36	1.36	1.36
Allowance for Sea Level Rise (m)	0	0.07	0.20	0.39	0.62	0.97

Total (mAHD)	**2.79**	**2.86**	**2.99**	**3.18**	**3.41**	**3.76**

The horizontal extent of the inundation for the 2120 planning timeframe was approximated and mapped for the Study Area (**Appendix D**). The extent was estimated by interpolating between the perpendicular shoreline profiles undertaken for the City in April 2017. Due to the generally steep dune profile and substantial topographical relief landward of the foredune throughout the Study Area, the extent of inundation under future scenarios does not vary significantly to that for the present day scenario. The predicted inundation extent indicates that coastal erosion is a much greater coastal hazard in the Study Area and should be the key driver for any future risk and vulnerability assessment.

4 Discussion

The hazard lines derived through this assessment represent potential extents of coastal erosion and inundation hazards, at various timeframes up to 2120. They have been calculated following the methodology outlined in SPP2.6, with the addition of more detailed modelling and assessment, considered appropriate because much of the shoreline is, or will be, heavily controlled in the Study Area. The hazard lines are not supposed to represent accurate predictions of future shoreline positions. As such, they should not be used to assess the risk and vulnerability to coastal assets without interpretation.

The significant assumption that interim protection measures will be maintained by the City within the Study Area, up to the year 2060, should be carefully reviewed during each CHRMAP revision. Ongoing expenditure associated with protection, the effectiveness of protection measures and the functionality of protection structures should all be assessed during any such review.

The hazard extents derived in this study should be used to define areas for the implementation of planning controls within the Study Area, consistent with those recommended for implementation in the City's overall CHRMAP. Hazard extents should also be used to identify risk to coastal assets and inform the requirements for inspection of such assets and responses should they be damaged.

5 References

Booij, N., R. C. Ris and L. H. Holthuijsen (1999). A Third-Generation Wave Model for Coastal Regions, Part I, Model Description and Validation. J. Geophys. Res., 104, 7649-7666.

Cooper, J. A. G & Pilkey, O. H (2004) *Sea-level rise and shoreline retreat: time to abandon the Bruun Rule.* Global and Planetary Change 43 (2004) 157 – 171

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.* Department of Transport, Perth, Western Australia.

Cardno (2018) *Lot 211 Quinns Road, Mindarie Coastal Hazard Risk Management and Adaptation Plan*. Prepared for the City of Wanneroo.

Cardno (2017) *Quinns Beach Long Term Coastal Management Study: Detailed Design Report (Stage 3)*. Prepared for the City of Wanneroo.

Cardno (2015) *Quinns Beach Long Term Coastal Management Report Stage 1*. Prepared for the City of Wanneroo.

City of Wanneroo (2014). *Tender document for provision of consultancy services (AS4122-2010)- Quinns Beach Long Term Coastal Management (Tender Number: 01440)*

IPCC (2014) *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

MP Rogers & Associates (2015) *CHRMAP Part 1: Coastal Vulnerability Study & Hazard Mapping*. Prepared for the City of Wanneroo

Rosati, J. D, Dean, R. G. & Walton, T. L (2013) *The modified Bruun Rule extended for landward transport.* Marine Geology 340 (2013) 71-81

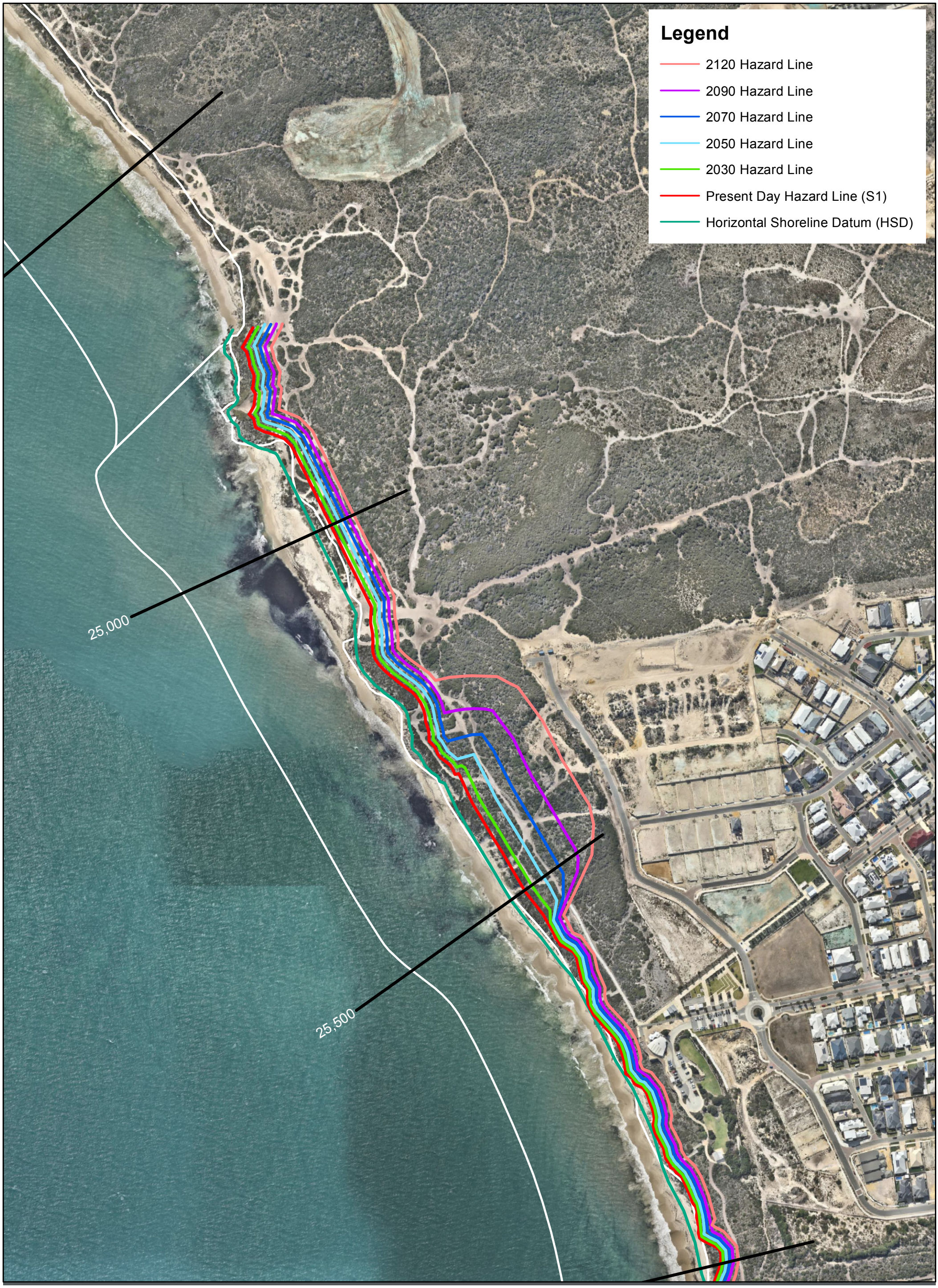
Stul T, Gozzard JR, Eliot IG and Eliot MJ (2015) *Coastal Sediment Cells for the Vlamingh Region between Cape Naturaliste and Moore River, Western Australia.* Report prepared by Seashore Engineering Pty Ltd and Geological Survey of Western Australia for the Western Australian Department of Transport, Fremantle.

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

APPENDIX

D

QUINNS BEACH COASTAL HAZARD MAPPING



COASTAL EROSION HAZARD MAP

QUINNS ROCKS

59916812 - WANNEROO CHRMAP

FIGURE 1

WANNEROO_CHRMAP_FIGURE_1 <REVB>

Date
6/06/2018

Size
A3

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11 Harvest Terrace
West Perth WA 6005
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Fax: 08 9486 8664

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COASTAL EROSION HAZARD MAP

QUINNS ROCKS

59916812 - WANNEROO CHRMAP

FIGURE 2

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6/06/2018

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Cardno
11 Harvest Terrace
West Perth WA 6005
Tel: 08 9273 3888
Fax: 08 9486 8664

Date
6/06/2018

Size
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COASTAL EROSION HAZARD MAPPING

QUINNS ROCKS

59916812 - WANNEROO CHRMAP

FIGURE 3

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Cardno
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West Perth WA 6005
Tel: 08 9273 3888
Fax: 08 9486 8664

Date
17/05/2018

Size
A3

2120 COASTAL INUNDATION HAZARD MAP

QUINNS ROCKS

59916812 - WANNEROO CHRMAP

FIGURE 1

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2120 COASTAL INUNDATION HAZARD MAP

QUINNS ROCKS

59916812 - WANNEROO CHRMAP

FIGURE 2

WANNEROO_CHRMAP_FIGURE_2_INUNDATION <REVA>

Date
17/05/2018

Size
A3

Cardno
11 Harvest Terrace
West Perth WA 6005
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West Perth WA 6005
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Fax: 08 9486 8664

Date
17/05/2018

Size
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2120 COASTAL INUNDATION HAZARD MAP

QUINNS ROCKS

59916812 - WANNEROO CHRMAP

FIGURE 3

WANNEROO_CHRMAP_FIGURE_3_INUNDATION <REVA>

APPENDIX

E

RISK ASSESSMENT CHAPTER REPORT

Risk Assessment Chapter Report

City of Wanneroo CHRMAP Part 2

59916812

Prepared for
The City of Wanneroo

30 November 2016

Cardno
Shaping the Future

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Date	30 November 2016
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Author(s):

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Approved By:

David van Senden
Senior Principal

Document History

Version	Effective Date	Description of Revision	Prepared by:	Reviewed by:
RevA	17/08/2016	DRAFT FOR DISCUSSION	JRB/DRS	DvS
V1	05/09/2016	INTERNAL DRAFT	JRB	DRS
RevB	09/09/2016	PRELIMINARY DRAFT	JRB/DRS	DvS
RevC	14/11/2016	FINAL DRAFT	DRS/JB	DvS
Rev0	30/11/2016	FINAL	DRS	DvS

Executive Summary

This document, the Risk Assessment Chapter Report, presents the results of the 'Risk Analysis' and 'Risk Evaluation' components of the CHRMAP process. The assessment has evaluated the risk to each identified asset (and adjacent assets) by combining the likelihood of an impact, such as coastal erosion, with its predicted consequence. This risk level has then been combined with the adaptive capacity for each asset to derive its vulnerability rating. The process is consistent with that outlined in the State Coastal Planning Policy Guidelines (WAPC 2013), and the CHRMAP guidelines (WAPC, 2014).

Although this risk assessment has been carried out for all planning timeframes, up to 2120, the focus in discussing the results has been on the vulnerability of assets in the present day and at the 2030 and 2050 timeframes. The results and prioritisation generally shows the beach at each identified site to be the first asset to have vulnerability raised above low, as you move through the planning timeframes. This has come about partly because the beach naturally has the closest proximity to the ocean and impacts of coastal hazards. It is also because of the substantial social value attributed to beaches, defined in the success criteria, as part of initial community and stakeholder consultation. Traditionally only built assets such as buildings and roads, with easily definable economic value, may have been considered in such an assessment. The beach and dune system are often the first line of defence for built infrastructure against the impacts of coastal hazards, so it is also appropriate in that regard that their urgency for treatment has been highlighted through this process.

The risk prioritisation has identified three sites (effectively two areas) with some immediate urgency. Residential lots, Brazier Road and its carparks in the vicinity of Yanchep lagoon were assessed as two sites for the risk assessment, but should be assessed together in determining adaptation options and any monitoring program. This area was found to be of the highest priority, due to the immediate vulnerability of a highly valued beach and the proximity of expensive infrastructure behind it. It has been recommended that monitoring and management options for this area be considered immediately. Sovereign Drive, its residential lots and associated assets were also prioritised for action in the immediate term. This is due to the value of infrastructure assets and the perceived vulnerability of the affronting beach to erosion. It has been recommended that existing information be better applied to refine the extent of hazards in the area and that monitoring and management options be considered as soon as possible. Prioritisation and preliminary timeframes for action for all sites are presented in the Conclusions section of the report.

The results and the risk prioritisation will now guide the next phases in the CHRMAP process. The vulnerability ratings, specific to assets, will be used to guide the development of suitable adaptation options for each site. Through identification of the assets most at risk, adaptation options can be tailored to account for the protection of these assets. The current vulnerability ratings will also be used for comparison, to predict a residual risk rating after a preferred, potential adaptation option has been implemented. The urgency for treatment will guide the final management plan, helping to develop monitoring programs and appropriate triggers, which call for intervention once detected. Some initial suggestions for monitoring have been made in the Conclusions section of this report. These will be expanded on in the Adaptation Options Chapter Report and final CHRMAP.

For all communication regarding this project, the City of Wanneroo is to please contact:

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Study Terminology

Abbreviation	Description
AEP	Annual Exceedance Probability
ARI	Average Recurrence Interval
AS	Australian Standard
BFS	Bush Forever Site
CHRMAP	Coastal Hazard Risk Management and Adaptation Plan
LGA	Local Government Area
MSL	Mean sea level
PEC	Priority Ecological Community
SPP2.6	State Planning Policy No 2.6
WAPC	Western Australian Planning Commission

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Appendices

Tables

Figures

1 Introduction

In 2015, the City of Wanneroo ('the City') commissioned a coastal vulnerability assessment to determine the extent of coastal hazards for its Local Government Area (LGA). This involved identifying the exposure of coastal assets (both built and natural) to hazards such as long and short term erosion and coastal inundation over several planning timeframes, accounting for the effects of climate change. That assessment formed Part 1 of the City's LGA-wide Coastal Hazard Risk Management and Adaptation Plan (CHRMAP).

The CHRMAP is to be completed in three parts:

> Part 1: Undertake a Coastal Vulnerability and Hazard Mapping study of the City's coastline in its entirety;

> Part 2: Complete Hazard Risk Assessment and Adaptation Planning for vulnerable areas of the City's coastline based on the findings of Part 1; and

> Part 3: Internal Review & Application.

Cardno is currently working with the City to undertake Part 2 of the CHRMAP. The objectives of Part 2 are to:

> Develop a Coastal Adaptation Plan to be implemented by the City. This plan will define adaptation measures for each of the prioritised sites. The plan will include relevant information so that coastal managers, land use planners and community groups can act accordingly. Any further investigation into the design of adaptation will be recommended as part of the plan; and

> Build understanding of climate science, coastal processes, hazards and risks across the community through the development of the CHRMAP.

Part 1 of the CHRMAP (MP Rogers, 2015) made a preliminary assessment of assets that are likely to be vulnerable at various planning timeframes, up to 2120, along the City's coastline. The City has selected the assets identified as vulnerable over the next 35 years (up to the 2050 planning timeframe) for further risk assessment and determination of adaptation options.

This document, the Risk Assessment Chapter Report, presents the results of the 'Risk Analysis' and 'Risk Evaluation' components of the CHRMAP process (see **Figure 1-1**). The assessment has evaluated the risk to each identified asset (and adjacent assets) by combining the likelihood of an impact, such as coastal erosion, with its predicted consequence. This risk level has then been combined with the adaptive capacity for each asset to derive its vulnerability rating. The process is consistent with that outlined in the State Coastal Planning Policy Guidelines (WAPC 2013), and the CHRMAP guidelines (WAPC, 2014).

The vulnerability ratings for each asset, at each planning timeframe, have been compared among areas to identify those most vulnerable in the short term. This will inform the adaptation options component of the CHRMAP by indicating which risks should be treated first and what level of urgency should be associated with the treatment. The current vulnerability ratings will also be used for comparison, to predict a residual risk rating after a preferred, potential adaptation option has been implemented.

The risk assessment has been carried out with respect to the defined success criteria. These criteria have been formed by the stakeholder engagement process; specifically, through the Community Values Survey. In this assessment the success criteria have been incorporated to guide the consequence scales, particularly for the social aspect. Subsequently, the success criteria will also guide the selection of preferred adaptation options as part of the next step in the CHRMAP process.

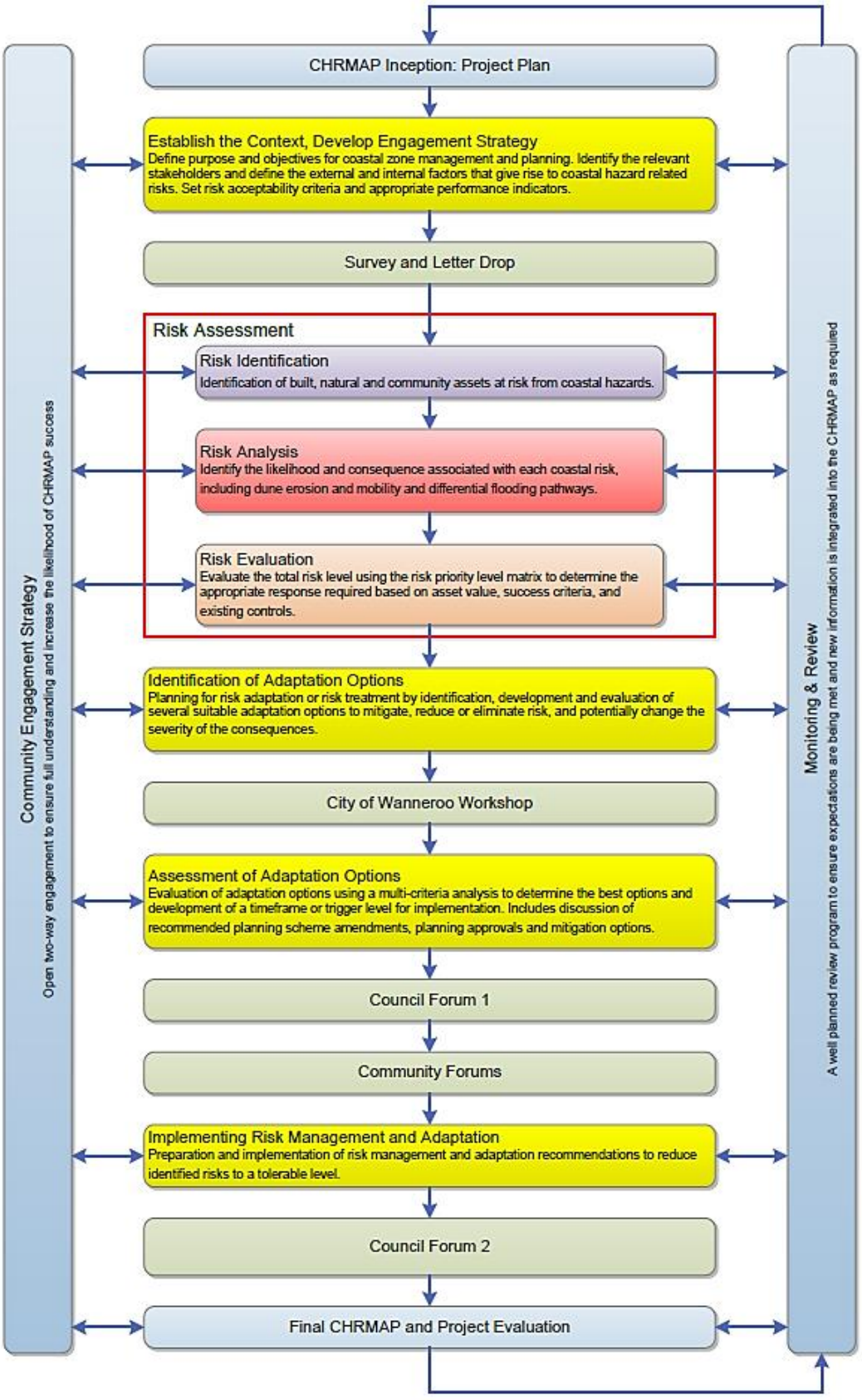


Figure 1-1 CHRMAP methodology flow chart for the City of Wanneroo (adapted from WAPC CHRMAP Guidelines, 2014)

2 Coastal Hazard Risk Identification

The Risk Identification (**Figure 1-1**) was conducted by MP Rogers in Part 1 of the CHRMAP (2015) and incorporates the S1, S2 and S3 erosion allowances and the S4 inundation allowance (WAPC, 2013).

2.1 Erosion

The natural coastline is constantly susceptible to erosion through short term processes, such as storm surge, and long term processes, such as rising sea levels and changes to alongshore sediment transport. The various forms of erosion are defined in the SPP2.6 as:

> (S1 Erosion) Allowance for the current risk of erosion;

> (S2 Erosion) Allowance for historic shoreline movement trends; and

> (S3 Erosion) Allowance for erosion caused by future sea level rise.

The overall risk posed by these processes is calculated by the summation of the above allowances plus an additional allowance for uncertainty.

The SPP2.6 requires consideration of the one-in-one hundred probability (or 1% AEP) storm event to assess potential impacts of the S1 component of erosion.

2.2 Inundation

Coastal inundation is flooding of water from the ocean, usually due to the combined effects of storm surge and wave run-up during severe weather events. All coastlines are exposed to this hazard and low lying areas can be particularly vulnerable. The SPP2.6 requires consideration of the 0.2% AEP water level to assess potential impacts of coastal inundation.

2.3 Exposure

Exposure relates to the hazards (erosion and inundation) and their sources, pathways, and controls. For example, an asset may be exposed to a severe storm event, causing a storm surge which results in coastal inundation up to a certain level. The terms event, stimuli, or climatic environment may all relate to exposure. Exposure to coastal hazards will likely increase with time if no adaptation planning occurs.

2.4 Assets at Risk from Coastal Erosion and Inundation (Coastal Hazards)

MP Rogers (2015) produced hazard maps to define the extents of coastal hazards at various planning timeframes. A number of areas (study sites) were identified that contained assets which were deemed vulnerable over timeframe's up to 2120. For this CHRMAP the City has elected to focus on those that contain assets which are vulnerable prior to 2050 (**Table 2-1**). As such, Cardno has undertaken the risk assessment and will carry out adaptation planning with a focus on these study sites.

For each of the study sites, a number of different assets have been identified to encompass the social, environmental and economic aspects to be considered in the planning process. These typically include the beach, natural foreshore reserve (with a particular focus on conservation areas), public infrastructure (for example carparks and roads), commercial and residential properties

Table 2-1 Key Vulnerable Areas (study sites) and their location (derived from MP Rogers, 2015)

Description	Suburb	Span of coastline assessed (Northings in MGA zone 50)	Estimated vulnerability timeframe
Priority Ecological Community	Two Rocks	6518012 m S to 6517304 m S	2030
Sovereign Drive and residential lots	Two Rocks	6515735 m S to 6514908 m S	From 2050
Beach access road and carpark 'The Spot'	Two Rocks	6512303 m S to 6511583 m S	2050
Capricorn Groyne carpark	Yanchep	6510151 m S to 6509517 m S	2050
Brazier Road carpark	Yanchep	6508882 m S to 6508431 m S	2030
Residential lots	Yanchep	6508418 m S to 6507918 m S	From 2030
Heritage site Karli Springs	Alkimos/Jindalee	6500433 m S to 6499585 m S	2050
Jindalee Boulevard carpark*	Jindalee	6497539 m S to 6497155 m S	Present day
Residential lots	Mindarie	6493848 m S to 6493217 m S	2050
Priority Ecological Community	Mindarie	6492655 m S to 6490505 m S	Present day

*The vulnerability of the study site containing the Jindalee Boulevard carpark and adjacent assets will be affected by the coastal protection works being planned for Quinn's Beach. As such, the City has agreed that the coastal hazard lines should be revised to incorporate these works. Cardno has, therefore, not carried out a detailed risk assessment for this area as part of this project.

3 Stakeholder and Community Engagement

A stakeholder engagement strategy has been developed to accompany Part 2 of the CHRMAP (Cardno, 2016), with the intention of engaging the local community and other relevant stakeholders. The strategy aims to ensure transparency in the CHRMAP process and create a sense of ownership over the project's outcomes for the community. The results of Part 1 of the CHRMAP, in particular the identified coastal hazards and key vulnerable areas, were presented to the community by the City in May of 2016.

3.1 Community Values Survey

The first phase of community engagement in Part 2 of the CHRMAP development was through the Coastal Values Survey. The survey was designed to determine the important values that stakeholders hold with respect to the coastline. Additional information was also collected to assess the demographic of respondents; including the proximity to the coast that they live and work, how frequently they use the coast and for what purpose. The survey was available online for a period of one month during July and August (2016), and could also be completed in paper form at local community centres and libraries. The community was informed about the survey through a letter drop to those residents within approximately 500 m of the identified vulnerable areas and through various forms of traditional and social media. A summary of the project and relevant background information was provided by the City through a dedicated web page with a link to the survey.

There was a generally good response to the survey with 79 surveys completed and a good distribution of respondents in terms of their perceived attachment to the coast (i.e. not all lived near the beach or necessarily were regular beach users). One question was designed specifically to guide the development of the success criteria for the CHRMAP. The question asked respondent to rank the various values they associated with the coast and describe any values they held, which they believed were not covered by the available options.

3.2 Success Criteria

Based on the results of the Coastal Values Survey, the following success criteria have been developed to guide the CHRMAP development:

SC1. Preservation and protection of important environmental sites and plant and animal communities;
SC2. Prioritisation of public safety at beaches and in foreshore areas;
SC3. Encouragement of coastal use through the provision and maintenance of public access and facilities at beaches and foreshore areas;
SC4. Protection and preservation of beaches and foreshore areas for recreational and passive use;
SC5. Provision and protection of foreshore areas for housing;
SC6. Use and protection of foreshore areas for local economic benefit;
SC7. Provision and protection of beach and foreshore access infrastructure (e.g. roads, carparks, paths); and
SC8. Maintenance and protection of indigenous and archaeological heritage sites within the beach and foreshore areas.

The success criteria have been shaped based on the options available for ranking in the coastal values question. All available options received sufficient support to be retained as success criteria. Comments provided in regards to additional values held by respondents did not lead to the consideration of any additional success criteria.

The success criteria are used in the risk assessment to inform the consequence ratings by adding value to assets whose economic value is difficult to define without detailed analysis. For example, the economic value of a beach is more difficult to define than that of a house or road. The consequence rating for the loss or degradation of the beach should, therefore, be guided by the value attributed to beaches by the community. This value is reflected in the success criteria and has been incorporated into the consequences ratings (**Table 4-3**), described in **Section 4.2.3**.

4 Risk Assessment Methodology

4.1 Overview

The risk assessment process uses the outcomes of Part 1 of the CHRMAP to characterise the risk and vulnerability of assets over the planning time frame. An overview of the framework adopted in this assessment is presented in **Figure 4-1.**

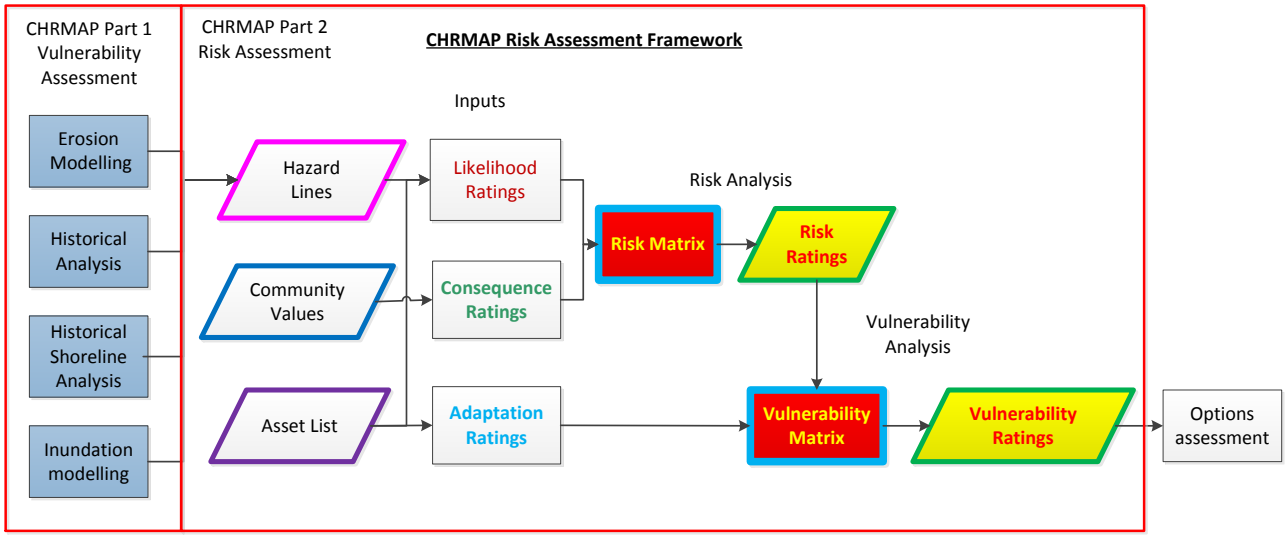


Figure 4-1 Schematic representation of the risk assessment process

There are a number of steps involved in the risk assessment process:

1. Define likelihood categories (ratings)
2. Allocate the likelihood of the risk occurring to specific assets for a particular planning timeframe based on the results of the hazard assessment;
3. Define consequence categories (ratings)
4. Allocate the consequence of the risk occurring to specific assets for a particular planning timeframe based on CHRMAP guidance, AS 5334-2013 and the project specific Success Criteria;
5. Define risk categories (ratings) based on the acceptability (or tolerability); and
6. Allocate the risk ratings for combinations of likelihood and consequence.

The process aims to be objective, logical and transparent. All steps call for interpretation, and allocation of consequence in particular may be based on subjective judgement. However, once the framework has been adopted, specific outcomes can be clearly traced to inputs. The inputs can be updated in response to new information or stakeholder input, and the risk assessment outcomes will be revised accordingly. Additional details on how the input parameters were derived, and the ratings were developed is provided below.

4.2 Risk Analysis

To assess the level of risk, or potential impact, posed to the assets by the identified coastal hazards, this CHRMAP has employed risk analysis techniques outlined in AS 5334-2013. The risk assessment entails the combination of likelihood and consequence of exposure to coastal hazard to produce the risk level, or potential impact, for each asset, as presented in **Figure 4-2** below.

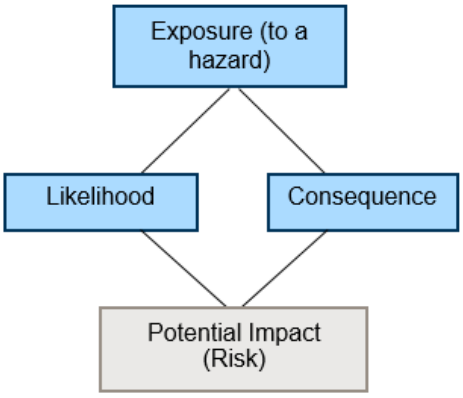


Figure 4-2 Risk analysis structure

The potential impact (risk) has been assessed for each asset at each of the planning timeframes:

- 2015
- 2030
- 2050
- 2070
- 2090
- 2120

This allows risk prioritisation and assessment of each asset's risk level over the 100 year planning horizon as required by SPP2.6.

For the purposes of this report 'short-term' refers to the period between 2015 and 2030, 'medium-term' refers to the period between 2030 and 2050, and long-term refers to the period beyond 2050. The 'immediate-term' or 'immediately' may also be used, generally referring to within the next 5 years.

4.2.2 Likelihood

According to WAPC (2014) and for the purposes of this study, likelihood is defined as the chance of erosion and storm surge inundation impacting on existing and future assets and their values. The likelihood scale that has been applied at each timeframe is presented in Error! Reference source not found.

Table 4-1 CHRMAP likelihood ratings

Rating	Description
Almost Certain	High possibility of impact to asset shoreline for a given planning timeframe
Likely	Impact to asset shoreline for a given planning timeframe is likely
Possible	Impact to asset shoreline for a given planning timeframe is possible
Unlikely	Impact to asset shoreline for a given planning timeframe is unlikely
Rare	May occur in exceptional circumstances

As outlined in **Section 2.1**, the erosion risk is made up of a number of components. Each of these is based on a suite of assumptions and each has a degree of uncertainty which may influence the likelihood of the predicted level of erosion occurring at each planning horizon. For instance, S1 assumes that the probability of a coastal hazard event occurring is the same each year, which is not necessarily the case when considering the effects of climate change and the rise in sea level over time, which underpins the future planning scenarios assessed in this study.

There is considerable scope for confusion in defining and allocating likelihood in terms of recurrence frequency / probability (as per AS 5334) for the purposes of risk assessment, since this terminology has specific meaning in the coastal context. Cardno has therefore adopted the approach presented in **Figure 4-**

3, which is generally consistent with guidance in WAPC (2014). This method assumes that in any given timeframe the likelihood of erosion occurring up to the calculated hazard line for that timeframe is at least "possible". For example, in **Figure 4-3**, in 2070 it is considered "likely" that asset A1 will be impacted, "possible" that asset A2 will be impacted and "unlikely" that asset A3 will be impacted by erosion. An example of the likelihood rating input format for assets in a particular study site is provided in **Table 4-2.**

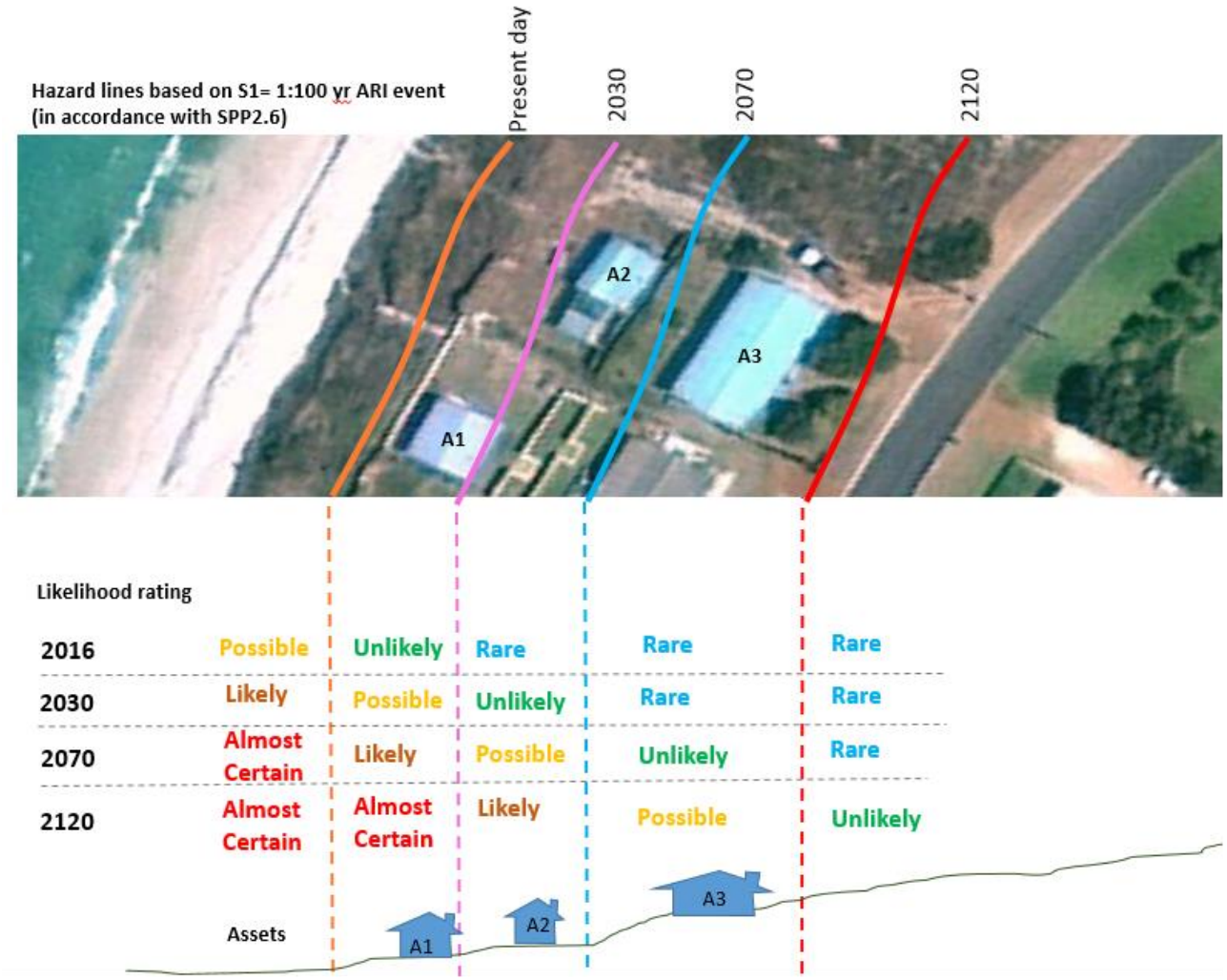


Figure 4-3 Representation of method used to assign likelihood ratings to individual assets for each planning timeframe

Table 4-2 Example likelihood rating inputs table

Planning timeframe						
-	2015	2030	2050	2070	2090	2120
Asset	Likelihood					
Beach	Unlikely	Possible	Likely	Almost Certain	Almost Certain	Almost Certain
Bush Forever Site	Rare	Unlikely	Possible	Likely	Likely	Almost Certain
Car Park	Rare	Rare	Unlikely	Possible	Likely	Almost Certain
Road	Rare	Rare	Unlikely	Possible	Likely	Almost Certain
Residential Lots	Rare	Rare	Unlikely	Unlikely	Possible	Likely

4.2.3 Consequence

Consequence is the result of a hazard impacting an area or asset. For this analysis, consequence has been divided into five ratings ranging from catastrophic to insignificant (**Table 4-3**). The consequence ratings for this risk assessment have been adapted from those presented in AS 5334-2013, and WAPC (2014), which focus on the social, economic and environmental consequences.

The ratings have been worded to include reference to the success criteria as cross referenced in **Table 4-4**. A heritage component has been incorporated alongside environmental impacts to ensure impacts to heritage sites are accounted for in the risk assessment process. The consequence descriptions have also been scaled to be applicable to the local context in which this study is being undertaken, where as previously their higher ratings were associated with consequences on a global scale. Generally, the consequence categories incorporate all of the values outlined by the success criteria and align comparatively between categories with the level of response to these success criteria.

Unless otherwise stated, the consequence ratings are generally associated with the impact of coastal erosion. Generally coastal inundation and coastal erosion will occur at the same time during a storm event. In the majority of circumstances and locations for the City's coastline, the impacts of coastal erosion on infrastructure will be more severe and long-lasting than the impacts of coastal inundation. There are circumstances where coastal erosion will not occur (e.g. where the shoreline is rock) and in these instances only the consequences of coastal inundation are considered. An example of this is for the residential lots at the north of Mindarie Marina.

Table 4-3 Consequence ratings (adapted from AS 5334-2013)

Rating	Safety and Social	Economic	Environment and Heritage
Catastrophic	Loss of life and serious injury. Large long-term or permanent loss of services, public access/amenity, employment, wellbeing or culture. No suitable alternative sites exist within the LGA.	Permanent and/or entire loss or damage to property, plant and equipment, finances >$5 million	Permanent and entire loss of flora, fauna conservation or heritage area (no chance of recovery)
Major	Serious injury. Medium term disruption to services, public access/amenity, employment, wellbeing or culture. Very limited suitable alternative sites exist within the LGA.	Permanent and/or large scale loss or damage to property, plant and equipment, finances > $2 - $5 million	Long-term and/or large scale loss of flora, fauna or heritage area (limited chance of recovery) with local impact.
Moderate	Minor injury. Major short term or minor long-term disruption to services, public access/amenity, employment, wellbeing, or culture. Limited suitable alternative sites exist within the LGA.	Permanent and/or medium scale loss or damage to property, plant and equipment, finances > $100,000 - $2 million	Medium-term and/or medium scale loss of flora, fauna or heritage area (recovery likely) with local impact.
Minor	Small to medium disruption to services, public access/amenity, employment, wellbeing, or culture. Many suitable alternative sites exist within the LGA.	Permanent and/or small scale loss or damage to property, plant and equipment, finances > $10,000 - $100,000	Short-term and/or small scale loss of flora, fauna or heritage area (strong recovery) with local impact.
Insignificant	Minimal short-term inconveniences to services, public access/amenity, employment, wellbeing, or culture. Many suitable alternative sites exist within the LGA.	Permanent loss or damage to property, plant and equipment, finances < $10,000	Negligible to no loss of flora, fauna or heritage area (strong recovery) with local impact.

Table 4-4 Relationship between consequence categories and success criteria

Criteria	Description	Consequence category
SC1	Preservation and protection of important environmental sites and plant and animal communities;	Environment and heritage
SC2	Prioritisation of public safety at beaches and in foreshore areas;	Safety and social
SC3	Encouragement of coastal use through the provision and maintenance of public access and facilities at beaches and foreshore areas;	Safety and social
SC4	Protection and preservation of beaches and foreshore areas for recreational and passive use;	Safety and social
SC5	Provision and protection of foreshore areas for housing;	Economic
SC6	Use and protection of foreshore areas for local economic benefit;	Economic
SC7	Provision and protection of beach and foreshore access infrastructure (e.g. roads, carparks, paths); and	Safety and social Economic
SC8	Maintenance and protection of indigenous and archaeological heritage sites within the beach and foreshore areas.	Environment and heritage

Consequence was allocated for each asset within a vulnerable area, and for each of the planning timeframes. It was possible for the severity of consequence to increase over time, assuming that impacts could be greater as well as more likely to occur. An example of the format of consequence rating inputs is provided in **Table 4-5**.

Table 4-5 Example consequence ratings applied to a vulnerable area

	Planning timeframe					
-	2015	2030	2050	2070	2090	2120
Impact on Beach	Major	Major	Major	Catastrophic	Catastrophic	Catastrophic
Impact on Bush Forever Site	Insignificant	Minor	Minor	Moderate	Moderate	Moderate
Impact on Car Park	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Impact on Road	Moderate	Moderate	Moderate	Major	Major	Major
Impact on Residential Lots	Minor	Minor	Minor	Minor	Moderate	Major

4.3 Risk Evaluation

4.3.1 Potential Impact (Risk Rating)

The CHRMAP uses a risk assessment matrix which is based on that provided in AS5334-2013 (**Table 4-6**). Risk ratings are defined by risk acceptability / tolerance and the urgency of required action (**Table 4-7**). This will help to prioritise multiple identified risks within the study area. It also provides a mechanism to compare the level of risk after a preferred adaptation option is determined, for example, at present a risk may be "extreme" in the short term, after the implementation of adaption option 'X' the risk level is re-evaluated and reduces to "medium".

Table 4-6 Risk matrix (Based on AS5334-2013)

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

Table 4-7 Risk levels and tolerances

Risk Level	Action Required	Acceptance/Tolerance
Extreme (E)	Immediate action required to eliminate or reduce risk to acceptable levels.	Unacceptable
High (H)	Immediate to short-term action required to eliminate or reduce risk to acceptable levels.	Tolerable / Unacceptable
Medium (M)	Short to medium term action to reduce risk to acceptable levels, or accept risk.	Tolerable
Low (L)	Accept risk.	Acceptable

The risk evaluation process utilises the outcomes of the risk analysis as inputs. Likelihood and consequence allocated for assets, under each scenario, are combined to derive a risk rating for each asset within each of vulnerable areas. Examples of the derived risk ratings for a particular study site are provided in **Table 4-8**.

Table 4-8 Example of risk rating results by asset and planning timeframe

-	Planning Timeframe					
	2015	2030	2050	2070	2090	2120
Beach	Medium	Medium	High	Extreme	Extreme	Extreme
Bush Forever Site	Low	Low	Low	Medium	Medium	High
Car Park	Low	Low	Medium	Medium	Medium	High
Road	Low	Low	Medium	High	High	Extreme
Residential Lots	Low	Low	Low	Medium	High	High

4.4 Vulnerability Analysis

As per AS 5334-2013, detailed risk analysis should include a vulnerability analysis to thoroughly examine how coastal hazards and climate change may affect the asset.

Vulnerability analysis involves assessing the asset's existing capacity to adapt to a potential impact; a flow chart for the process of establishing the vulnerability is presented in **Figure 4-4**. Adaptive capacity and vulnerability are detailed in the following sections

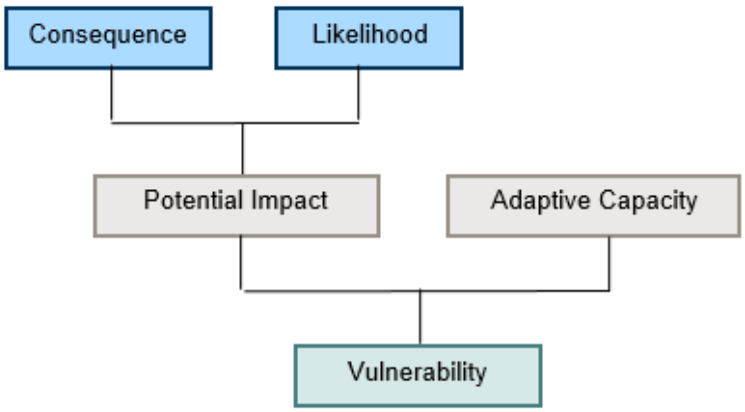


Figure 4-4 Vulnerability assessment structure

4.4.2 Adaptive Capacity

The adaptive capacity (**Table 4-9**) is based upon the potential for the system to be modified or acclimatise to cope with the impacts of identified hazards. The system of existing controls, such as the dune system and reef, all have an influence on the ability of hazards to affect a study site. The aim of the CHRMAP is to develop options that realise the potential adaptive capacity through techniques such as managed retreat, accommodation, and protection. An asset or group of assets with a high adaptive capacity is one that can easily (i.e. at low cost) be adapted or one that has some capacity to self-adapt with changing conditions (e.g. beaches and dune systems can migrate across shore as the mean sea level (MSL) changes). Assets with a high risk level and low adaptive capacity are deemed vulnerable and management options should be investigated. Examples of the adaptive capacity ratings allocated for a particular study site are provided in **Table 4-10**.

Table 4-9 CHRMAP adaptive capacity ratings

Rating	Adaptive Capacity
Low	Little or no adaptive capacity. Potential impact would destroy all functionality.
Moderate	Small amount of adaptive capacity. Difficult but possible to restore functionality through repair and redesign.
High	Decent adaptive capacity. Functionality can be restored, although additional adaptive measures should still be considered. Natural adaptive capacity restored slowly over time under average conditions.
Very High	Good adaptive capacity. Functionality restored easily. Adaptive systems restored at a relatively low cost or naturally over time.

Table 4-10 Example of adaptive capacity ratings applied to assets and timeframes

	Planning Time frame					
Asset	2015	2030	2050	2070	2090	2120
Beach	High	High	High	Moderate	Moderate	Low
Bush Forever Site	High	High	High	Moderate	Moderate	Low
Car Park	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Road	Moderate	Low	Low	Low	Low	Low
Residential Lots	Low	Low	Low	Low	Low	Low

4.4.3 Vulnerability

Vulnerability is the potential for a system to suffer damage or ill effects as a result of coastal hazards or climate change. Vulnerability is a function of the likelihood of an event occurring, the consequences of the event and the capacity to adapt and change. In a similar fashion to the risk methodology, potential impact and adaptive capacity can be combined using a customised matrix (**Table 4-11**) with the significance of the vulnerability rating listed in relation to acceptability and tolerances provided in **Table 4-12**. An example outcome from the analysis is provided in **Table 4-13**.

Table 4-11 Vulnerability Analysis Matrix

Risk Level (Potential Impact)	Adaptive Capacity			
	Very High	High	Moderate	Low
Extreme	H	H	VH	VH
High	M	H	H	VH
Medium	M	M	M	H
Low	L	L	L	L

Table 4-12 Vulnerability levels and tolerances

Vulnerability Level	Action Required	Acceptance/Tolerance
Very High (VH)	Significant further adaption required to ensure asset is not lost. Reconsideration of design if vulnerability cannot be reduced.	Unacceptable
High (H)	Further adaption required. All stakeholders should be fully aware of risks if vulnerability cannot be reduced.	Tolerable / Unacceptable
Medium (M)	Further adaption should be investigated, acceptable in certain circumstances. Monitoring programs recommended.	Tolerable
Low (L)	Acceptable; adaption and monitoring may be required over the asset's lifetime.	Tolerable / Acceptable

Table 4-13 Example of outcome from vulnerability analysis

Asset	Planning Timeframe					
-	2015	2030	2050	2070	2090	2120
Beach	Low	Low	Medium	Medium	High	High
Bush Forever Site	Low	Low	Low	Medium	High	Very High
Car Park	Low	Low	Low	Medium	Medium	High
Road	Low	Low	Low	Low	Low	Medium
Residential Lots	Low	Low	Low	Low	Low	High

4.4.4 Existing Controls

It is important to identify any existing (or committed) controls as part of the asset's system. These may include natural defences, natural structures, existing artificial structures, or any control that has already been committed to be installed. Any control, be it natural or man-made, that shall not be definitely in place, must be considered in the adaption planning section as a possible mechanism for protection from coastal hazards. Degradation of natural or existing controls that may occur over the lifetime of an asset will be considered as part of the management and adaptation planning process, where applicable.

5 Risk Assessment Results

For each asset initially identified as vulnerable by 2050 (**Table 2-1**), the section of coastline adjacent and relevant to that asset has been assessed. All assets within the section of coastline that might be affected have been assessed in their own right. For example, while a road may be the main asset identified in Part 1 of the CHRMAP (MP Rogers, 2015), the beach and bushland in front of this road have also been assessed. This is important because future treatment options are likely to affect all assets in the area. For example, the option could involve the use of hard protection (e.g. a rock wall) to reduce the risk of damage to the road. This will lower the road's vulnerability rating, but likely increase the beach and bushland's vulnerability as they are unable to migrate inland with rising sea levels.

5.1 Priority Ecological Community, Two Rocks

The section of coastline containing the Priority Ecological Community (PEC) lies within Tertiary Sediment Cell 31a (Stul et al, 2012) and extends approximately 750 m (see also **Figure A1** of **Appendix A**). The PEC (29b) consists of *Acacia* shrublands on taller dunes (Eco Logical 2015). The area also contains a Bush Forever Site (BFS 397).

It lies adjacent to a sandy coastline that is interrupted by small patches of beach rock and was, therefore, treated as a sandy coast for hazard assessment in Part 1 of this CHRMAP (MP Rogers, 2015). Historical shoreline analysis and an inspection of the beach in front of the PER suggest that the beach is prone to long and short-term erosion (MP Rogers, 2015).

5.1.1 Risk Analysis

5.1.1.1 Likelihood

The horizontal shoreline datum (HSD) for the northern portion of the coastline section (fronting the majority of the PEC) has been placed at +1.8 m AHD, which is approximately 16 m seaward of the coastal vegetation line. The section was allocated a short term erosion allowance (S1) of 10 m and a long term erosion allowance (S2) of 0.51 m/year, which was combined with the allowance for erosion caused by future sea level rise (S3) of 0.9 m/year (MP Rogers, 2015).

The assets identified that may be impacted within the coastline section are the beach, the PEC and the Bush Forever Site (BFS) 397. The relatively high exposure of the coastline to coastal processes means that the likelihood of impact to each of these assets generally increases over the planning timeframes. The likelihood ratings are presented in **Table 5-1**. The likelihood of significant impact (e.g. due to a 1% AEP storm) to assets within the study site has been assessed as rare for the present day. By 2030 the likelihood of such a storm having altered the assets as they currently exist has been deemed unlikely. At 2050, it has been considered likely that the beach will have been impacted and altered from its present state by major storms and changes to the local hydrodynamic and sediment transport regime, due to a higher MSL. Impact to dune vegetation assets behind this beach have subsequently been deemed possible at 2050, as the erosion of the beach could lead to some permanent loss of a portion of this habitat.

5.1.1.2 Consequence

The PEC has a priority rating of P3 which is described as a poorly known ecological community (Eco Logical 2015). While it has local significance, the PEC is known to occur between Seabird to south of Mandurah. By 2120, approximately one third of the PEC is predicted to be under threat, and therefore has been allocated a consequence rating of major once a significant proportion of the community becomes affected.

Bush Forever Site (BFS 397) is present in the study area, but extends well beyond the area as well, with a total area of 436 5 ha within the LGA and 552.2 ha overall.

The consequence ratings in **Table 5-1** below reflect the increasing loss of vegetation comprising the PEC and BFS, over the planning timeframes. The loss of larger portions of vegetation into the future, as suggested by the hazard lines, has been assessed as being of increasing consequence. At present the consequence has been deemed insignificant as any impacts are unlikely to be major, relative to the area of

coverage, or permanent. At 2030 and 2050 the consequence has been defined as minor and moderate, respectively, for the PEC and BFS due to the proportion of the local community predicted to be lost, according to the hazard lines.

The consequence of erosion for the beach has been considered minor across all planning timeframes as it is likely to maintain its form as an actively eroding beach. It is expected to be 'fed' by sediment from the dune system behind it, so is not predicted to be lost or substantially degraded from its present form into the future.

5.1.2 Risk Evaluation – Risk Level

The risk level (**Table 5-1**) has been determined by combining the likelihood and consequence for each asset, at each planning timeframe. The general increase in likelihood and consequence for each asset results in a similar increasing risk level over the planning timeframes, with the risk to all assets initially low.

5.1.3 Vulnerability Analysis

5.1.3.1 Adaptive Capacity

The PEC was assessed by Eco Logical (2015) as having a high vulnerability since the community is restricted to coastal dune habitat and is likely to have limited adaptive capacity due to specific habitat requirements being associated with coastal areas.

Adaptive capacity ratings are presented in **Table 5-1**. In general, beaches have a good adaptive capacity if they are unbounded by hard geological formations or infrastructure. The beach has been assigned a high adaptive capacity due to its ability to migrate landward with rising MSL. Dune vegetation has some adaptive capacity through its ability to grow and spread, effectively repairing itself after erosion. As disruptions such as scarping and dune blowouts potentially become more frequent or severe into the future, this adaptive capacity will likely be diminished. If an ecological community, such as this PEC, exists in an isolated or confined habitat it may have a lower adaptive capacity, due to its inability to spread as that habitat is removed or encroached upon.

5.1.3.2 Vulnerability Rating

The vulnerability ratings suggest the assets are generally not vulnerable in the short term (up to 2030), with vulnerability increasing gradually across planning time frames after this. The vulnerability of the PEC becomes very high towards the end of the century. The derived vulnerability ratings for the coastline section are presented in **Table 5-1**. The potential effects on this shoreline section over time, without the implementation of management options, would be:

> The beach will probably transform into a more actively eroding beach, which may have less useable beach width and a scarped back beach; and

> More frequent and a greater reach of erosion will likely cause dune blowouts and reduction in dune area, reducing overall coastal vegetation and more frequently interrupting its habitat.

Given the strong weighting for the success criteria relating to the preservation of environmental assets, treatment of the risk to the PEC should be considered in the medium term (prior to 2050).

5.1.3.3 Existing controls

The existing features in the vicinity of the PEC, likely to be exerting some control over coastal processes in the area, include:

> The nearshore reef systems adjacent to the northern and southern portions of the PEC, likely to be dissipating incident wave energy and helping to retain sediment at the shoreline section;

> The natural headland adjacent to the northern extent of the site, which probably helps retain sediment to its south but may be less effective at this as MSL rises; and

> Established dune vegetation which helps consolidate the dune system and provides minor defence against wind and wave driven erosion.

It is also understood that the area is currently used by four wheel drives with minimal existing control over this activity.

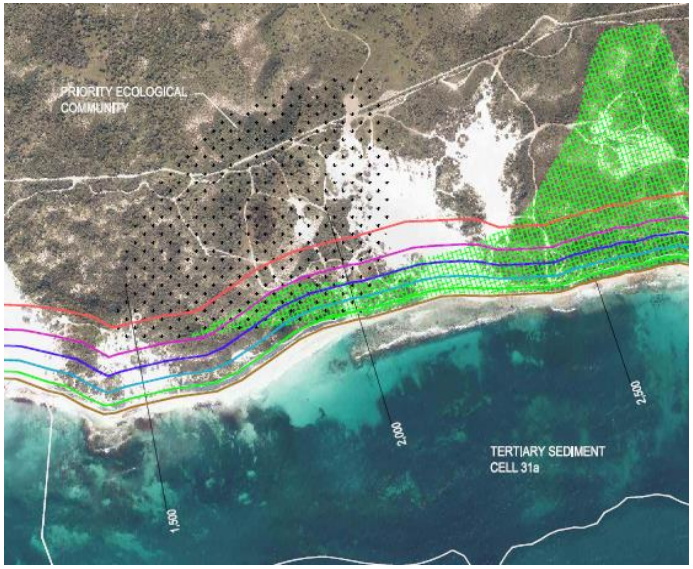
Table 5-1 Ratings for PEC, Two Rocks

Priority Ecological Community

Chainage 1,500 to 2,100

Estimated Vulnerability Time Frame: 2030

Asset Type	Function/Service	Value	Asset
Environmental	recreation, habitat, tourism, buffer	Environmental/Recreational	**Beach**
Environmental	habitat, ecosystem integrity, buffer	Environmental	**BFS 397**
Environmental	conservation value for threatened species, habitat, ecosystem integrity	Environmental	**PEC**



Assessment Inputs	2015	2030	2050	2070	2090	2120
Asset	**Likelihood**					
Beach	Rare	Unlikely	Likely	Almost Certain	Almost Certain	Almost Certain
BFS 397	Rare	Unlikely	Possible	Likely	Likely	Almost Certain
PEC	Rare	Unlikely	Possible	Likely	Likely	Almost Certain

Asset	Consequence of Erosion					
Impact on beach amenity	Minor	Minor	Minor	Minor	Minor	Minor
Impact on ecological buffer (BFS 397)	Insignificant	Minor	Moderate	Moderate	Moderate	Moderate
Impact on Priority Ecological Community	Insignificant	Minor	Moderate	Moderate	Major	Major

Asset	Adaptive capacity					
Beach	Very High	Very High	Very High	Very High	High	Moderate
BFS 397	High	High	Moderate	Moderate	Low	Low
PEC	Low	Low	Low	Low	Low	Low

Risk Assessment	2015	2030	2050	2070	2090	2120
	Risk					
Beach	Low	Low	Medium	Medium	Medium	Medium
BFS 397	Low	Low	Medium	Medium	Medium	High
PEC	Low	Low	Medium	Medium	High	Extreme

	Vulnerability					
Beach	Low	Low	Medium	Medium	Medium	Medium
BFS 397	Low	Low	Medium	Medium	High	Very High
PEC	Low	Low	High	High	Very High	Very High

5.2 Sovereign Drive and Adjacent Residential Lots, Two Rocks

The section of coastline containing the residential lots at Two Rocks lies within Tertiary Sediment Cell 31a (Stul et al, 2012) and extends approximately 800 m northward from the northern edge of the Two Rocks Marina (see also **Figure A2** of **Appendix A**). The section of coastline between Sovereign Drive and the ocean was subjected to a geotechnical investigation and, although subsurface rock is present, a continuous barrier of competent rock was not found to exist. The section was, therefore, treated as a sandy coast for its vulnerability assessment (MP Rogers, 2015). Historical shoreline analysis and an inspection of the beach in front of Sovereign Drive suggest the beach is prone to long and short term erosion (MP Rogers, 2015).

5.2.1 Risk Analysis

5.2.1.1 Likelihood

The HSD for this section of coastline has been placed at +1.8 m AHD, which is approximately 3 m landward of the coastal vegetation line. The section of shoreline in front of Sovereign Drive was allocated an S1 erosion allowance of 18 m and an S2 erosion allowance of 0.7 m/year in addition to the S3 allowance of 0.9 m/year (MP Rogers, 2015).

The assets identified that may be impacted within the coastline section are the beach, the BFS 397, Sovereign Drive and its residential lots and Tenggara Avenue and its residential lots. The likelihood of impact for the infrastructure assets is initially rare and increases over the planning timeframes depending on their proximity to the shoreline and position relative to the hazard lines (as outlined previously in **Figure 4-3**). The likelihood ratings are presented in **Table 5-2.** This table shows that it has been considered possible that Sovereign Drive will be affected by erosion by 2050, and its residential lots by 2070.

The likelihood of impact to all assets is considered rare at present. The likelihood of impact to the beach and BFS increases to unlikely by 2030 as the possibility of storm surge and an elevated MSL having altered their present state increases. By 2050 the likelihoods for the BFS and beach are possible and likely, respectively. The beaches exposure means the expected raised MSL and accompanying increase in coastal impact expected by 2050 is likely to cause shoreline recession and loss of sediment. It is possible this migration of the shoreline will also allow substantial impact to the vegetation behind the beach by 2050.

5.2.1.2 Consequence

The consequence ratings in **Table 5-2** below reflect the increasing loss of beach and vegetation comprising the BFS, over the planning timeframes, as the shoreline migrates landward. The increasing consequences for infrastructure relate to the greater economic loss associated with potential damage. For example, damage to one property is of lower consequence than damage to a line of houses, or the undermining of a small section of road will be less expensive to repair than if a large section of road is impacted. The results show that the consequences of erosion are considered to be “catastrophic” (i.e. permanent and/or entire loss or damage to property, plant and equipment, finances >$5 million) for a number of assets after 2090 unless mitigation measures are implemented.

The consequence ratings for the beach and BFS are insignificant and minor, respectively, for the present day. Both these assets increase in rating to the 2030 and 2050 timeframes as the hazard lines predict increasing portions of these assets will be permanently affected.

For hard infrastructure assets at present and at the 2030 timeframe the consequence of an erosion event impacting these assets has been considered moderate, as the extent of such an impact would likely be small. This consequence increases to major for all assets except Sovereign Drive at the 2050 timeframe, as the extent of such an impact would likely be greater than at the previous timeframes. This is primarily due to a more receded initial shoreline position.

5.2.2 Risk Evaluation – Risk Level

The general increase in likelihood and consequence for each asset results in similarly increasing risk ratings over the planning timeframes (**Table 5-2**), with all assets being assessed as being at extreme risk by the end of the century.

5.2.3 Vulnerability Analysis

5.2.3.1 Adaptive Capacity

While beaches and vegetation generally have good adaptive capacity, in this instance their ability to adapt is restricted because they are confined by hard infrastructure inland. Their adaptive capacity therefore diminishes into the future. Permanent infrastructure such as a road or house has inherently low adaptive capacity as it is generally not practical for it to be moved or raised to avoid damage. The adaptive capacity ratings are presented in **Table 5-2**.

5.2.3.2 Vulnerability Rating

All assets have low vulnerability at present and up to 2030, except for the BFS which has medium vulnerability at 2030. The vulnerability ratings suggest that built assets have high vulnerability in the medium term (2050) with medium and high vulnerability for the beach and BFS, respectively, at this timeframe. From 2050 all infrastructure assets have a high or very high vulnerability rating. The derived vulnerability ratings for the coastline section are presented in **Table 5-2**. The potential effects on this shoreline section over time, without the implementation of management options, would be:

> A more actively eroding beach, which may have less useable beach width and will likely lead to the exposure of a more rocky shoreline; and

> More frequent and a greater reach of erosion will likely cause dune degradation, reducing overall coastal vegetation and leading to the greater exposure of and damage to hard infrastructure.

Given the significant economic value of built assets in the coastline section, it is recommended further investigation and implementation of management options is implemented in the short term (by 2030).

5.2.3.3 Existing Controls

The existing features in the vicinity of Sovereign Drive, likely to be exerting some control over coastal processes in the area, include:

> Two Rocks Marina directly to the south, likely to be depriving the beach of natural renourishment;

> The nearshore reef system spanning the majority of the coastline adjacent to Sovereign Drive that would dissipate incident wave energy;

> Limestone formations underlying the beach and dunes, which will likely provide some protection for built infrastructure against coastal erosion and inundation;

> A natural headland approximately half way along the section of coast adjacent to Sovereign Drive which may help retain sediment in the area; and

> Established coastal vegetation that consolidates the dune system and provides minor defence against wind and wave driven erosion.

Table 5-2 Ratings for Sovereign Drive and Residential Lots, Two Rocks

Sovereign Drive and Residential Lots

Chainage 4,300 to 5,050 (Zone 3)

Estimated Vulnerability Time Frame: 2050

Asset Type	Function/Service	Value	Asset	Assessment Inputs: Likelihood 2015	2030	2050	2070	2090	2120
Environmental	recreation, habitat, tourism, buffer	Environmental/Recreational	Beach	Rare	Unlikely	Likely	Almost Certain	Almost Certain	Almost Certain
Environmental	habitat, ecosystem integrity, buffer	Environmental	BFS 397	Rare	Unlikely	Possible	Likely	Likely	Almost Certain
Economic	transport services, access to residential areas	Public Infrastructure	Sovereign Dve	Rare	Rare	Possible	Possible	Likely	Almost Certain
Economic	housing for current and future population	Residential	Residential (SD)	Rare	Rare	Rare	Possible	Likely	Almost Certain
Economic	housing for current and future population	Residential	Residential (TA)	Rare	Rare	Rare	Rare	Unlikely	Possible
Economic	transport services, access to residential areas	Public Infrastructure	Tenggara Ave	Rare	Rare	Rare	Rare	Unlikely	Possible

Asset	Consequence of Erosion 2015	2030	2050	2070	2090	2120
Impact on beach amenity	Insignificant	Minor	Moderate	Moderate	Major	Major
Impact on ecological buffer (BFS 397)	Minor	Moderate	Major	Major	Catastrophic	Catastrophic
Sovereign Drive becomes impacted	Moderate	Moderate	Moderate	Major	Catastrophic	Catastrophic
Residential Lots on Sov Dve become impacted	Moderate	Moderate	Major	Major	Catastrophic	Catastrophic
Residential Lots on Tengarra Ave become impacted	Moderate	Moderate	Major	Major	Catastrophic	Catastrophic
Tengarra Dve becomes impacted	Moderate	Moderate	Major	Major	Catastrophic	Catastrophic

Asset	Adaptive capacity 2015	2030	2050	2070	2090	2120
Beach	Very High	Very High	High	Moderate	Moderate	Low
BFS 397	High	High	Moderate	Moderate	Low	Low
Sovereign Dve	Low	Low	Low	Low	Low	Low
Residential (SD)	Low	Low	Low	Low	Low	Low
Residential (TA)	Low	Low	Low	Low	Low	Low
Tenggara Ave	Low	Low	Low	Low	Low	Low

	Risk Assessment 2015	2030	2050	2070	2090	2120
	Risk					
Beach	Low	Low	Medium	High	Extreme	Extreme
BFS 397	Low	Medium	High	High	Extreme	Extreme
Sovereign Dve	Low	Low	Medium	High	Extreme	Extreme
Residential (SD)	Low	Low	Medium	High	Extreme	Extreme
Residential (TA)	Low	Low	Medium	Medium	High	Extreme
Tenggara Ave	Low	Low	Medium	Medium	High	Extreme

	Vulnerability 2015	2030	2050	2070	2090	2120
Beach	Low	Low	Medium	High	Very High	Very High
BFS 397	Low	Medium	High	High	Very High	Very High
Sovereign Dve	Low	Low	High	Very High	Very High	Very High
Residential (SD)	Low	Low	High	Very High	Very High	Very High
Residential (TA)	Low	Low	High	High	Very High	Very High
Tenggara Ave	Low	Low	High	High	Very High	Very High

5.3 Beach Access Road and Carpark 'The Spot', Two Rocks

The section of coastline in front of the access road and carpark at 'The Spot' lies within Tertiary Sediment Cell 30b (Stul et al, 2012) and has been assessed for approximately 400 m, northward from the southern edge of the rocky headland in front of the carpark, for this risk assessment (see also **Figure A3** of **Appendix A**). The section is a mixture of sandy and rocky coastline, with a limestone headland between the carpark and the ocean (MP Rogers, 2015).

5.3.1 Risk Analysis

5.3.1.1 Likelihood

The carpark is afforded good protection due to the rock headland between it and the ocean. An S1, S2 or S3 erosion allowance was not applied to this section of coastline (MP Rogers, 2015). Sandy shoreline is present either side of this headland, including in front of the access road, and some allowance for erosion has been made there (MP Rogers, 2015).

The identified assets that may be impacted within the coastline section are the beach, the BFS 397, the carpark and the access road. The likelihood of impact to the beach and BFS increases over the planning timeframes. Impact to infrastructure assets is seen as unlikely until towards the end of the century. The likelihood ratings are presented in **Table 5-3**.

The likelihood of significant impact to assets within the study site has been assessed as rare for the present day. By 2030 the likelihood of storm impacts having altered the natural assets as they currently exist has been deemed unlikely. At 2050, it has been considered likely that the beach will have been impacted and altered from its present state by major storms and changes to the local hydrodynamic and sediment transport regime, due to a higher MSL. Impact to dune vegetation behind this beach has subsequently been deemed possible at 2050, as the erosion of the beach could lead to some permanent loss of a portion of this habitat.

Due to the protection of the rocky headland, impact to the carpark and access road has been deemed rare to 2030 and unlikely by 2050.

5.3.1.2 Consequence

The access road and car park are relatively minor pieces of infrastructure from an economic value viewpoint and, therefore, the consequences of damage to these have been considered minor. An initially minor consequence rating is seen over the time frames to 2050 for the Beach and BFS. In the later part of the century, as a greater portion of them is affected, this consequence is increased to moderate. The consequence ratings are presented in **Table 5-3**.

5.3.2 Risk Evaluation – Risk Level

Generally low risk has been predicted for assets in the area, early in the century. This increases in the second part of the century, particularly for natural assets. The derived risk levels are presented in **Table 5-3**.

5.3.3 Vulnerability Analysis

5.3.3.1 Adaptive Capacity

The beach and BFS have been allocated generally high adaptive capacity at present due to their ability to adjust to a changing shoreline. The adaptive capacity of the vegetation will diminish into the future as a portion of the BFS will likely be lost and unable to regenerate. Hard infrastructure generally has a low adaptive capacity, however, the costs of redirecting the road and moving the car park are not viewed as prohibitively expensive in this case, so some adaptive capacity is present. The adaptive capacity ratings are presented in **Table 5-3**.

5.3.3.2 Vulnerability Rating

The derived vulnerability ratings for the coastline section are presented in **Table 5-3**. The vulnerability of all assets is low to 2050, except for the beach which is medium at 2050. The natural assets have increasing

vulnerability beyond 2050 with the BFS scoring a very high vulnerability rating by 2120. The potential effects on this shoreline section over time, without the implementation of management options, would be:

> The beach is likely to recede either side of the rocky headland, possibly exposing more of the rock formation;

> The coastal vegetation could be reduced due to a greater reach of storm surge events; and

> The carpark and access road may be impacted via the sandy sections either side of the headland in the medium to long term (beyond 2050).

Given the low economic value of built assets at this site and a good adaptive capacity of natural assets at present, the implementation of adaptations options is not recommended prior to 2050. This recommendation should, however, be revised with the revision of the CHRMAP and assessment of coastal impacts at the site in the future.

5.3.3.3 Existing Controls

The existing features in the vicinity of the carpark and access road, likely to be exerting some control over coastal processes in the area, include:

> The natural rocky headland in front of the carpark protecting the asset and likely to be retaining sediment in the area;

> The scattered nearshore reef system, dissipating incident wave energy; and

> Coastal vegetation consolidating the dune system and providing minor defence against wind and wave driven erosion.

Table 5-3 Ratings for the Beach Access to 'The Spot', Two Rocks

Beach Access Road (to 'The Spot') (Unsealed)

Chainage 8,900 to 9,000 (Zone 2)

Estimated Vulnerability Time Frame: 2050

Asset Type	Function/Service	Value	Asset	Assessment Inputs 2015	2030	2050	2070	2090	2120
				Likelihood					
Environmental	recreation, habitat, tourism, buffer	Environmental/Recreational	Beach	Rare	Unlikely	Likely	Almost Certain	Almost Certain	Almost Certain
Environmental	habitat, ecosystem integrity, buffer	Environmental	BFS 397	Rare	Unlikely	Possible	Likely	Likely	Almost Certain
Economic	beach access, lookout	Public Infrastructure	Beach Carpark (unsealed)	Rare	Rare	Unlikely	Possible	Likely	Almost Certain
Economic	beach access, transportation service	Public Infrastructure	Beach Access Rd (unsealed)	Rare	Rare	Unlikely	Possible	Likely	Almost Certain

Asset	Consequence of Erosion 2015	2030	2050	2070	2090	2120
Impact on beach amenity	Minor	Minor	Minor	Minor	Moderate	Moderate
Impact on ecological buffer (BFS 397)	Insignificant	Minor	Minor	Moderate	Moderate	Moderate
Impact on carpark	Minor	Minor	Minor	Minor	Minor	Minor
Impact on beach access road	Minor	Minor	Minor	Minor	Minor	Minor

Asset	Adaptive capacity 2015	2030	2050	2070	2090	2120
Beach	Very High	Very High	Very High	High	High	Moderate
BFS 397	High	High	Moderate	Moderate	Low	Low
Beach Carpark (unsealed)	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Beach Access Rd (unsealed)	High	High	High	High	High	High

	Risk Assessment 2015	2030	2050	2070	2090	2120
	Risk					
Beach	Low	Low	Medium	Medium	High	High
BFS 397	Low	Low	Low	Medium	Medium	High
Beach Carpark (unsealed)	Low	Low	Low	Low	Medium	Medium
Beach Access Rd (unsealed)	Low	Low	Low	Low	Medium	Medium

	Vulnerability					
Beach	Low	Low	Medium	Medium	High	High
BFS 397	Low	Low	Low	Medium	High	Very High
Beach Carpark (unsealed)	Low	Low	Low	Low	Medium	Medium
Beach Access Rd (unsealed)	Low	Low	Low	Low	Medium	Medium

5.4 Carpark South of Capricorn Groyne, Yanchep

The section of coastline containing the carpark at Capricorn Groyne lies within Tertiary Sediment Cell 30a (Stul et al, 2012) and has been assessed for approximately 400 m to the north of the groyne and 100 m to the south, for this risk assessment (see also **Figure A4** of **Appendix A**). The section of coastline in front of the carpark, and containing the Capricorn Beach Groyne, has been treated as sandy for coastal vulnerability assessment (Cardno, 2014). The groyne was constructed in 1971 and, based on a review of aerial photography, is believed to have become saturated (with sediment to its south) around 1996 (MP Rogers, 2015). The groyne appears to have maintained a relatively stable shoreline position to its south.

5.4.1 Risk Analysis

5.4.1.1 Likelihood

The section of shoreline in front of the carpark was allocated an S1 erosion allowance of 21 m but found to be stable long-term with an S2 allowance of 0 m/year, likely due to the influence of the groyne that was constructed in 1971. The S3 allowance of -0.9 m/year was also applied (MP Rogers, 2015).

The assets identified that may be impacted within the coastline section are the beach, the BFS 397, the groyne carpark and adjoining road, Capricorn Village carpark and the residential lots in Capricorn Village. The likelihood of impact to the beach and BFS increases over the planning timeframes. Impact to infrastructure assets is seen as unlikely until towards the end of the century, if at all, depending on proximity to the shoreline.

The likelihood ratings are presented in **Table 5-4**. The likelihood of impact to the carpark has been considered rare to 2030 and unlikely in 2050 based on its location relative to the hazard line extents. The likelihood of significant impact to the beach and BFS within the study site has been assessed as rare for the present day. By 2030 the likelihood of storm surge having significantly altered the natural assets, as they currently exist, has been deemed unlikely. At 2050 it has been considered likely that the beach will have been impacted and altered from its present state by storm surge and changes to the local hydrodynamic and sediment transport regime, due to a higher MSL. Impact to dune vegetation behind this beach has subsequently been deemed possible at 2050, as the erosion of the beach could lead to some permanent loss of a portion of this habitat.

5.4.2 Consequence

A gradually increasing consequence rating is seen over the timeframes for the BFS as a greater portion of it is eroded. The consequence of impact to the beach has been deemed minor to 2070 as it would be actively eroding but not altered considerably compared to its current state. For hard infrastructure, minor consequence ratings are seen in the first half of the century as the result of erosion is likely to be partial damage. Later in the century more substantial or total damage has been predicted. The consequences of damage to residential housing increases as more properties would be impacted by a greater extent of storm erosion. The consequence ratings are presented in **Table 5-4**.

5.4.3 Risk Evaluation – Risk Level

Generally low risk has been predicted for assets in the area, early in the century. This increases from 2050, particularly for the natural assets and those located closest to the existing shoreline. The derived risk levels are presented in **Table 5-4**.

5.4.4 Vulnerability Analysis

5.4.4.1 Adaptive Capacity

The beach and BFS have been allocated generally high adaptive capacity, initially, due to their ability to adjust to a changing shoreline. The groyne should maintain a wide and useable beach face to its south over the planning timeframes. The adaptive capacity of the vegetation will diminish into the future as a portion of the BFS will likely be lost and unable to regenerate. Hard infrastructure has been allocated generally low adaptive capacity as it would have to be relocated, which would be an expensive exercise. The adaptive capacity ratings are presented in **Table 5-4**.

5.4.4.2 Vulnerability Rating

The vulnerability in the near future planning timeframes is low for all assets, partly due to the groyne's influence in maintaining the beach in front of the car park. The vulnerability of assets in the area increases in the second half of the century. The derived vulnerability ratings for the coastline section are presented in **Table 5-3**. The potential effects on this shoreline section over time, without the implementation of management options, would be:

> Receded shoreline due to higher MSL and, therefore, lower effectiveness of the groyne; and

> More frequent and a greater reach of erosion will likely reduce overall coastal vegetation areas and increasingly threaten infrastructure.

The vulnerability and requirement for management in this section should be reassessed in the short to medium term (2030 to 2050).

5.4.4.3 Existing Controls

The existing features in the shoreline section, likely to be exerting some control over coastal processes in the area, include:

> Capricorn Beach Groyne stabilising the shoreline position, particularly in front of the groyne car park;

> Nearshore reef system, directly offshore from the position of the carpark, dissipating incident wave energy;

> Established dune vegetation consolidating the dune system and providing minor defence against wind and wave driven erosion; and

> Yanchep Lagoon to the south which may have a small effect on sediment transport to the area.

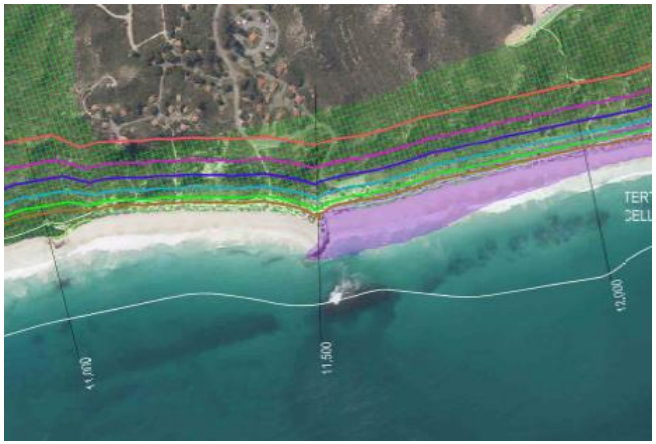
Table 5-4 Ratings for the Carpark South of Capricorn Groyne, Yanchep

Capricorn Groyne Carpark

Chainage11,500 to 11,600 (Zone 2)

Estimated Vulnerability Time Frame: 2050

Asset Type	Function/Service	Value	Asset	Assessment Inputs: Likelihood 2015	2030	2050	2070	2090	2120
Environmental	recreation, habitat, tourism, buffer	Environmental/Recreational	Beach	Rare	Unlikely	Likely	Almost Certain	Almost Certain	Almost Certain
Environmental	habitat, ecosystem integrity, buffer	Environmental	BFS 397	Rare	Unlikely	Possible	Likely	Likely	Almost Certain
Economic	beach access, lookout,	Public Infrastructure	Groyne Carpark	Rare	Rare	Unlikely	Possible	Almost Certain	Almost Certain
Economic	beach access, transportation service, residential	Public Infrastructure	Road	Rare	Rare	Rare	Unlikely	Possible	Almost Certain
Economic	residential access, beach access	Public Infrastructure	Car park (Cap Vill)	Rare	Rare	Rare	Rare	Rare	Unlikely
Economic	housing for current and future population	Residential	Residential (Cap Vill)	Rare	Rare	Rare	Rare	Rare	Rare



Asset	Consequence of Erosion 2015	2030	2050	2070	2090	2120
Impact on beach amenity	Minor	Minor	Minor	Minor	Moderate	Moderate
Impact on ecological buffer (BFS 397)	Insignificant	Insignificant	Minor	Minor	Moderate	Major
Impact on carpark south of Capricorn Groyne	Minor	Minor	Minor	Moderate	Moderate	Moderate
Impact on road to carpark	Minor	Minor	Minor	Moderate	Moderate	Moderate
Impact on carpark west of Capricorn Village	Minor	Minor	Minor	Moderate	Moderate	Moderate
Threat to Capricorn Village	Minor	Minor	Minor	Moderate	Moderate	Major

Asset	Adaptive capacity 2015	2030	2050	2070	2090	2120
Beach	Very High	Very High	Very High	High	High	Moderate
BFS 397	High	High	Moderate	Moderate	Low	Low
Groyne Carpark	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Road	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Car park (Cap Vill)	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Residential (Cap Vill)	Low	Low	Low	Low	Low	Low

	Risk Assessment 2015	2030	2050	2070	2090	2120
	Risk					
Beach	Low	Low	Medium	Medium	High	High
BFS 397	Low	Low	Low	Medium	Medium	Extreme
Groyne Carpark	Low	Low	Low	Medium	High	High
Road	Low	Low	Low	Medium	Medium	High
Car park (Cap Vill)	Low	Low	Low	Low	Low	Medium
Residential (Cap Vill)	Low	Low	Low	Low	Low	Medium

	Vulnerability					
Beach	Low	Low	Medium	Medium	High	High
BFS 397	Low	Low	Low	Medium	High	Very High
Groyne Carpark	Low	Low	Low	Medium	High	High
Road	Low	Low	Low	Medium	Medium	High
Car park (Cap Vill)	Low	Low	Low	Low	Low	Medium
Residential (Cap Vill)	Low	Low	Low	Low	Low	High

5.5 Carpark Adjacent to Brazier Road, Yanchep

The section of coastline in front of Brazier Road and its carparks lies within Tertiary Sediment Cell 30a (Stul et al, 2012) and has been assessed for approximately 350 m, northward from in line with the Brazier Road roundabout, for this risk assessment (see also **Figure A4** of **Appendix A**). The coastline in front of the road and carparks is primarily rocky, with some portions of sandy coastline to the north and south. The section of coastline is fronted entirely by Yanchep Lagoon, formed by a nearshore reef, open at the north and attached to the shore at the south.

5.5.1 Risk Analysis

5.5.1.1 Likelihood

The HSD for this section of coastline has been placed at +1.9 m AHD, which is approximately 3 m seaward of the coastal vegetation line. As the majority of the shoreline in front of Brazier Road is rocky, no S1 or S3 erosion has been allowed for. The sand shoreline sections to the north and south have been allocated S1 erosion allowances of 10 m and 24 m, respectively, as well as the standard S3 allowance of 0.9 m/year. The S2 allowance was 0 m/year for the section.

The identified assets that may be impacted within the coastline section are the beach, the BFS 397, Brazier Road and its carparks and the parkland behind the road. The likelihood of impact to the road and its carparks has been considered rare to 2030 and unlikely in 2050 based on their high relief and location relative to the hazard line extents.

The likelihood of significant impact to the beach and BFS within the study site has been assessed as rare for the present day. By 2030 the likelihood of storm surge having altered the natural assets as they currently exist has been deemed unlikely. At 2050, it has been considered likely that the beach will have been impacted and altered from its present state by major storms and changes to the local hydrodynamic and sediment transport regime, due to a higher MSL. Impact to dune vegetation behind this beach has subsequently been deemed possible at 2050, as the erosion of the beach could lead to some permanent loss of a portion of this habitat. The likelihood ratings are presented in **Table 5-5**.

5.5.1.2 Consequence

The consequence of substantial impact for the beach has been deemed major to 2050 and catastrophic beyond this. This is due to its significant value to the community for recreation and relative uniqueness within the LGA. The consequence of impact to the BFS is insignificant at present and minor for 2030 and 2050 as a higher portion of the vegetation would likely be affected.

The car parks and road have been assigned a moderate consequence up to 2050 due to economic value. The road has a more major consequence later in the planning timeframes, due to an expected greater extent of damage. The impact of any inundation to the parkland behind the road would likely be minor. The consequence ratings are presented in **Table 5-5**.

5.5.2 Risk Evaluation – Risk Level

The risk levels show generally low risk for all assets, except the beach, up to 2030. The beach has medium risk at 2015 and 2030 and high risk by 2050. Hard infrastructure is at medium risk at 2050. The derived risk levels are presented in **Table 5-5**.

5.5.3 Vulnerability Analysis

5.5.3.1 Adaptive Capacity

As the beach is backed by hard rock and vegetation is confined by the existing road, both of these assets have been allocated high adaptive capacity in the first half of the century, then moderate to low adaptive capacity for later planning timeframes. The road has low adaptive capacity, as relocating it would be expensive. Relocating the carparks is not seen to be prohibitively expensive, so moderate adaptive capacity has been allocated to these. The adaptive capacity ratings are presented in **Table 5-5**.

5.5.4 Vulnerability Rating

The vulnerability ratings suggest that all assets, except the beach, are generally not vulnerable in the short term (up to 2030), with vulnerability generally increasing at planning time frames after this. The vulnerability of the beach was found to be medium at present and high by 2050. The vulnerability of the car parks and roads have been derived as medium and high, respectively at 2050. The derived vulnerability ratings for the coastline section are presented in **Table 5-5**. The potential effects on this shoreline section over time, without the implementation of management options, would be:

> The useable beach width is likely to be reduced over time, potentially exposing a more rocky coastline;

> The coastal vegetation could be reduced substantially due to a greater reach of storm surge events; and

> Infrastructure will be at greater risk of coastal erosion and inundation due to a rising MSL and receding shoreline position.

Given the substantial economic value of hard infrastructure and high value of the beach at this site, it is recommended that the threat of coastal erosion is investigated further immediately and that adaptation options be considered in the short term (2016-2030) for this site.

5.5.4.1 Existing Controls

The existing features at or near the site, likely to be exerting some control over coastal processes in the area, include:

> The nearshore rock/reef formations providing protection from incident waves;

> The natural rocky headland in front of the road that would be a protective barrier against coastal erosion;

> The natural headland at the southern end of the section and change in shoreline orientation; and

> Established coastal vegetation consolidating the dune system and providing minor defence against wind and wave driven erosion.

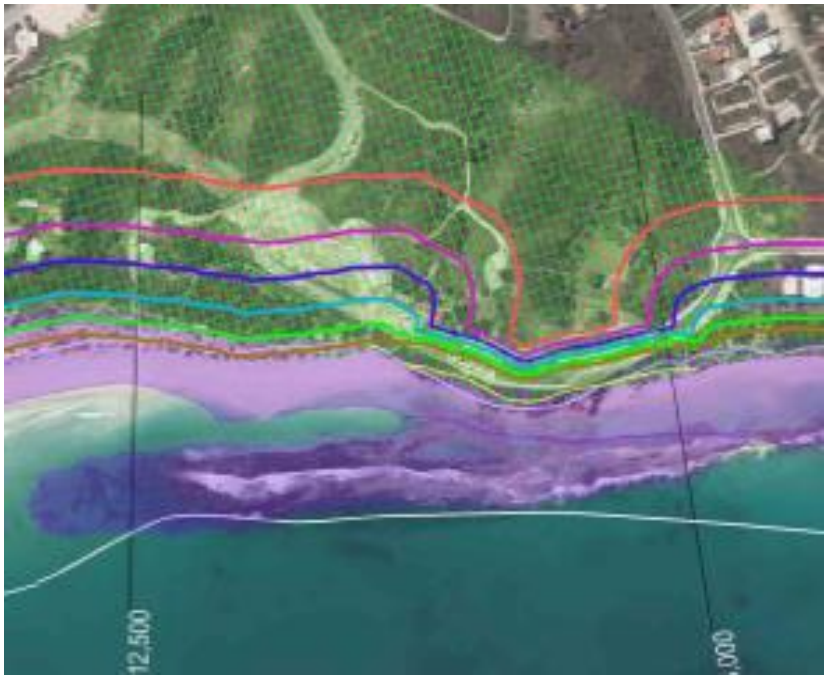
Table 5-5 Ratings for the Carpark Adjacent to Brazier Road, Yanchep

Brazier Road Carpark

Chainage 12,700 to 13,000 (Zone 3)

Estimated Vulnerability Time Frame: 2030

Asset Type	Function/Service	Value	Asset	Assessment Inputs: Likelihood 2015	2030	2050	2070	2090	2120
Environmental	recreation, habitat, tourism, buffer	Environmental/Recreational	Beach	Rare	Unlikely	Likely	Almost Certain	Almost Certain	Almost Certain
Environmental	habitat, ecosystem integrity, buffer	Environmental	BFS 397	Rare	Unlikely	Possible	Likely	Likely	Almost Certain
Economic	beach access, park access	Public Infrastructure	Car Park (Brazier Rd)	Rare	Rare	Unlikely	Possible	Likely	Almost Certain
Economic	thoroughfare, transportation services, access to beach, park, residential	Public Infrastructure	Road (Brazier)	Rare	Rare	Unlikely	Possible	Likely	Almost Certain
Economic	recreational, tourism	Recreational	Parkland (Fisherman's Hollow)	Rare	Rare	Unlikely	Unlikely	Possible	Likely



Asset	Consequence of Erosion 2015	2030	2050	2070	2090	2120
Impact on beach amenity	Major	Major	Major	Catastrophic	Catastrophic	Catastrophic
Impact on ecological buffer (BFS 397)	Insignificant	Minor	Minor	Moderate	Moderate	Moderate
Impact on carpark and Brazier Rd	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Impact on Brazier Rd itself	Moderate	Moderate	Moderate	Major	Major	Major
Impact on Fisherman's Hollow	Minor	Minor	Minor	Minor	Minor	Minor

Asset	Adaptive capacity 2015	2030	2050	2070	2090	2120
Beach	High	High	High	Moderate	Moderate	Low
BFS 397	High	High	High	Moderate	Moderate	Low
Car Park (Brazier Rd)	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Road (Brazier)	Low	Low	Low	Low	Low	Low
Parkland (Fisherman's Hollow)	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate

	Risk Assessment 2015	2030	2050	2070	2090	2120
	Risk					
Beach	Medium	Medium	High	Extreme	Extreme	Extreme
BFS 397	Low	Low	Low	Medium	Medium	High
Car Park (Brazier Rd)	Low	Low	Medium	Medium	Medium	High
Road (Brazier)	Low	Low	Medium	High	High	Extreme
Parkland (Fisherman's Hollow)	Low	Low	Low	Low	Low	Medium

	Vulnerability 2015	2030	2050	2070	2090	2120
Beach	Medium	Medium	High	Very High	Very High	Very High
BFS 397	Low	Low	Low	Medium	Medium	Very High
Car Park (Brazier Rd)	Low	Low	Medium	Medium	Medium	High
Road (Brazier)	Low	Low	High	Very High	Very High	Very High
Parkland (Fisherman's Hollow)	Low	Low	Low	Low	Low	Medium

5.6 Residential Lots, Yanchep

The section of coastline containing the Yanchep residential lots lies within Tertiary Sediment Cell 30a (Stul et al, 2012) and has been assessed for approximately 400 m; from in line with the Brazier Road roundabout at the north to the natural headland feature at the south, for this risk assessment (see also **Figure A4** of **Appendix A**). The section of shoreline in front of the residential lots has a generally consistent orientation. It has been classified as rocky in the southern portion of the beach section and sandy for the northern portion for coastal vulnerability assessment and the calculation of hazard lines (M P Rogers, 2015). The nearshore reef that forms Yanchep Lagoon intersects the shoreline in front of the residential lots.

5.6.1 Risk Analysis

5.6.1.1 Likelihood

The HSD for this section of coastline has been placed at +1.9 m AHD, which is approximately 3 m seaward of the coastal vegetation line. For the rocky section in front of the residential lots, no S1 or S3 allowance has been made. The sandy shoreline section has been allocated an S1 erosion allowance of 24 m. The S2 allowance was 0 m/year for the section with historical photography showing a relatively stable vegetation line. The standard 0.9 m/year S3 allowance was also applied to the sandy coastline section (MP Rogers, 2015).

The identified assets that may be impacted within the coastline section are the beach, the BFS 397, the residential lots and a small section of Brazier Road. The likelihood of impact to the road and residential lots has been considered rare to 2030 and unlikely at 2050, based on their high relief and location relative to the hazard line extents.

The likelihood of significant impact to the beach and BFS within the study site has been assessed as rare for the present day. By 2030 the likelihood of storm surge having altered the natural assets, as they currently exist, has been deemed unlikely. At 2050, it has been considered likely that the beach will have been impacted and altered from its present state by major storms and changes to the local hydrodynamic and sediment transport regime, due to a higher MSL. Impact to dune vegetation behind this beach has subsequently been deemed possible at 2050, as the erosion of the beach could lead to some permanent loss of a portion of this habitat. The likelihood ratings are presented in **Table 5-6**.

5.6.1.2 Consequence

The consequence of substantial impact for the beach has been deemed major to 2050 and catastrophic beyond this. This is due to its significant value to the community for recreation and relative uniqueness within the LGA. The consequence of impact to the BFS is insignificant at present and minor for 2030 and 2050 as a higher portion of the vegetation would likely be affected.

The road has been assigned a moderate consequence up to 2050 and residential lots have been assigned a moderate consequence up to 2030 and major consequence at 2050, due to economic value. Both built asset types have a more major consequence later in the planning timeframes, due to an expected greater extent of damage. The consequence ratings are presented in **Table 5-6.**

5.6.2 Risk Evaluation – Risk Level

The risk levels show generally low risk for all assets, except the beach, up to 2030. The beach has medium risk at 2015 and 2030 and high risk by 2050. Hard infrastructure is at medium risk at 2050. The derived risk levels are presented in **Table 5-6**.

5.6.3 Vulnerability Analysis

5.6.3.1 Adaptive Capacity

The adaptive capacity for the beach and vegetation forming the BFS 397 has been allocated high at the present day and 2030 planning timeframes and diminishing beyond this over the planning period as both are confined by hard infrastructure on their landward side. The adaptive capacity of the beach at this site is seen to be generally better than other confined beach sections within the LGA due to existing natural controls in the area. The natural headland and rock formations at the shore should help retain beach compartments

and, therefore, the amount of useable beach at the site as sea level rises. Hard infrastructure assets have been allocated low adaptive capacity as they would be expensive to redesign or relocate. The adaptive capacity ratings are presented in **Table 5-6**.

5.6.3.2 Vulnerability Rating

The vulnerability ratings suggest that assets are generally not vulnerable in the short term (up to 2030), with vulnerability increasing considerably at each planning time frame after this. The exception to this is the beach which has a vulnerability rating of medium up to 2030 and high at 2050. The vulnerability of hard infrastructure has also been derived as high at the 2050 planning timeframe. The derived vulnerability ratings for the coastline section are presented in **Table 5-6**. The potential effects on this shoreline section over time, without the implementation of management options, would be:

> The useable beach width is likely to be reduced over time, potentially exposing a more rocky coastline;

> The coastal vegetation could be reduced substantially due to a greater reach of storm surge events; and

> Infrastructure will be at greater risk of coastal erosion and inundation due to an increasing MSL and receding shoreline position.

Given the substantial economic value of residential housing at the site and high value of the beach itself, it is recommended that the threat of coastal erosion is investigated further immediately and that adaptation options be considered in the short term (2016-2030) for this site.

5.6.3.3 Existing Controls

The existing features in the vicinity of the residential lots, likely to be exerting some control over coastal processes in the area, include:

> The nearshore rock/reef formations providing protection from incident waves;

> A continuous line of rock directly in front of the southern portion of the section, which would reduce the impact of shoreward propagating waves and provide a partial barrier to coastal storm surge and inundation;

> The natural rocky headland just to the north of the coastline section and fronting alongshore reef, likely to be helping retain sediment that forms the beach in front of the residential lots;

> The natural headland at the southern end of the section and change in shoreline orientation, caused by the nearshore reef; and

> Established coastal vegetation consolidating the dune system and providing minor defence against wind and wave driven erosion.

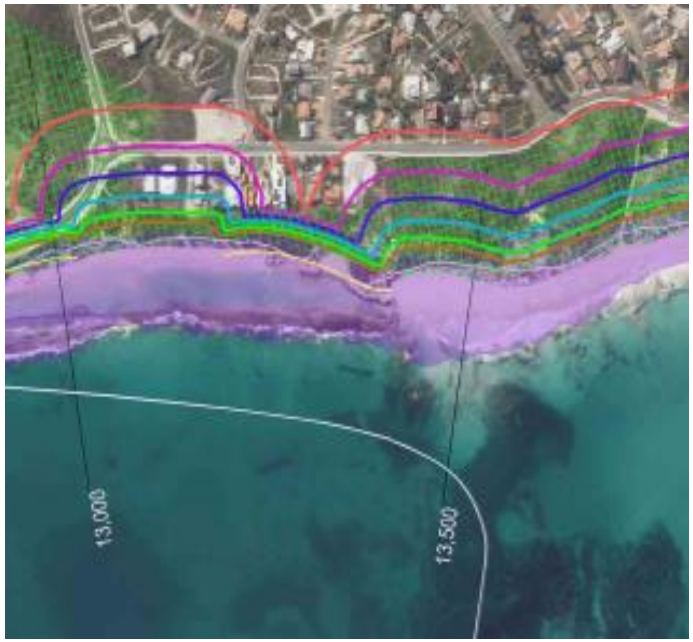
Table 5-6 Ratings for Residential Lots, Yanchep

Residential Lots Adjacent to Yanchep Lagoon

Chainage 13,000 to 13,400 (Zone 3)

Estimated Vulnerability Time Frame: 2030

Asset Type	Function/Service	Value	Asset	Assessment Inputs: 2015	2030	2050	2070	2090	2120
				Likelihood					
Environmental	recreation, habitat, tourism, buffer	Environmental/Recreational	Beach	Rare	Unlikely	Likely	Almost Certain	Almost Certain	Almost Certain
Environmental	habitat, ecosystem integrity, buffer	Environmental	BFS 397	Rare	Unlikely	Possible	Likely	Likely	Almost Certain
Economic	housing for current and future population	Residential	Residential	Rare	Rare	Unlikely	Possible	Likely	Almost Certain
Economic	transportation services, thoroughfare, access	Public Infrastructure	Road (Brazier)	Rare	Rare	Unlikely	Possible	Likely	Almost Certain



Asset	Consequence of Erosion					
Impact on beach amenity	Major	Major	Major	Catastrophic	Catastrophic	Catastrophic
Impact on ecological buffer (BFS 397)	Insignificant	Minor	Minor	Moderate	Moderate	Moderate
Impact on Residentail area	Moderate	Moderate	Major	Major	Major	Catastrophic
Impact on Brazier Rd itself	Moderate	Moderate	Moderate	Major	Major	Major

Asset	Adaptive capacity					
Beach	High	High	Moderate	Moderate	Low	Low
BFS 397	High	High	Moderate	Low	Low	Low
Residential	Low	Low	Low	Low	Low	Low
Road (Brazier)	Low	Low	Low	Low	Low	Low

Risk Assessment	2015	2030	2050	2070	2090	2120
	Risk					
Beach	Medium	Medium	High	Extreme	Extreme	Extreme
BFS 397	Low	Low	Low	Medium	Medium	High
Residential	Low	Low	Medium	High	High	Extreme
Road (Brazier)	Low	Low	Medium	High	High	Extreme

	Vulnerability					
Beach	Medium	Medium	High	Very High	Very High	Very High
BFS 397	Low	Low	Low	High	High	Very High
Residential	Low	Low	High	Very High	Very High	Very High
Road (Brazier)	Low	Low	High	Very High	Very High	Very High

5.7 Heritage Site Karli Spring, Alkimos

The section of coastline containing Karli Spring lies within Tertiary Sediment Cell 29c (Stul et al, 2012) and has been assessed for approximately 400m of coastline to the north and south (800 m total) of the spring, for this risk assessment (see also **Figure A5** of **Appendix A**). The section of shoreline in front of the spring has a generally consistent orientation and is relatively exposed to incident waves. The coastline was classified as sandy for coastal vulnerability assessment and the calculation of the hazard lines (M P Rogers, 2015).

5.7.1 Risk Analysis

5.7.1.1 Likelihood

The S1 erosion allowance has been applied as 42 m and the S2 erosion allowance has been calculated as 0.5 m/year (M P Rogers, 2015). The combination of the S2 allowance with the S3 erosion allowance of 0.9 m/year leads to a relatively large predicted shoreline recession over the planning timeframes.

The assets identified that may be impacted within the coastline section are the beach, the BFS 397 and Karli Spring. The relatively high exposure of the coastline to coastal processes means the likelihood of impact to each of these assets generally increases over the planning timeframes.

The likelihood of significant impact to the beach and BFS within the study site has been assessed as rare for the present day. By 2030 the likelihood of storm surge having altered the natural assets as they currently exist has been deemed unlikely. At 2050, it has been considered likely that the beach will have been impacted and altered from its present state by major storms and changes to the local hydrodynamic and sediment transport regime, due to a higher MSL. Impact to dune vegetation behind this beach has subsequently been deemed possible at 2050, as the erosion of the beach could lead to some permanent loss of a portion of this habitat.

The distance of Karli Spring from the coast and the substantial dune system in front of it (M P Rogers, 2015) suggest it is not likely to be impacted until towards the end of the century. It has been allocated a likelihood rating of rare up to 2050. The likelihood ratings are presented in **Table 5-7**.

5.7.1.2 Consequence

For all assets there is a general increase in consequence over time. The beach is predicted to change in comparison to its present state. An increasing portion of the BFS 397 is predicted to be lost over the planning timeframes. The consequence ratings reflect the increasing portion predicted to be lost by the extent of the hazard lines. The beach is also likely to be impacted and its shoreline position is likely to migrate inland. As the spring is linked to the water table and relies on the dune formations, it will likely experience the consequences of changes to these later in the century. All assets have consequence ratings of insignificant or minor up to 2050. The consequence ratings are presented in **Table 5-7**

5.7.2 Risk Evaluation – Risk Level

The initial risk levels show generally low risk for assets within the coastal section in the short term (up to 2030 and 2050) and generally increasing risk levels over the planning timeframes beyond this, due to increasing likelihood and consequence ratings. The derived risk levels are presented in **Table 5-7**.

5.7.3 Vulnerability Analysis

5.7.3.1 Adaptive Capacity

The beach has been allocated a generally good adaptive capacity due to its ability to migrate landward with changing sea level. The Bush Forever site has some adaptive capacity but this is seen to diminish over time with reduction in its habitat due to the landward migration of the shoreline and a greater reach of coastal erosion events. Karli Spring has been allocated low adaptive capacity as it is unlikely to adapt naturally and cannot be relocated. The adaptive capacity ratings are presented in **Table 5-7**.

5.7.3.2 Vulnerability Rating

The vulnerability ratings suggest the assets are generally not vulnerable up to 2050 (although the beach has medium vulnerability at 2050), with vulnerability increasing over the planning time frames thereafter. The

vulnerability of Karli Spring and vegetation comprising the BFS 397 becomes high and very high towards the end of the century. The derived vulnerability ratings for the coastline section are presented in **Table 5-7**. The potential effects on this shoreline section over time, without the implementation of management options, would be:

> The beach will probably transform from a dynamically stable, flat beach profile to an actively eroding beach, which may have less useable beach width; and

> More frequent and a greater reach of erosion will likely cause dune blowouts etc., reducing overall coastal vegetation and eventually influencing Karli Spring.

It should be noted that inspection of the beach (M P Rogers, 2015) suggested heavy use by vehicles is likely to be having a substantial effect on dune vegetation and the beach itself at the site.

Given the lack of hard infrastructure assets at this site and a good adaptive capacity of natural assets at present, the implementation of adaptations options is not recommended prior to 2050. This recommendation should, however, be revised with the revision of the CHRMAP and assessment of coastal impacts at the site in the future.

5.7.3.3 Existing Controls

The existing features in the vicinity of Karli Spring, likely to be exerting some control over coastal processes in the area, include:

> Substantial reef structures within 1 to 2 km of the shoreline, likely to be dissipating some incident wave energy prior to interaction with the shoreline. This effect will lessen over time as the MSL increases; and

> Established dune vegetation consolidating the dune system and providing minor defence against wind and wave driven erosion.

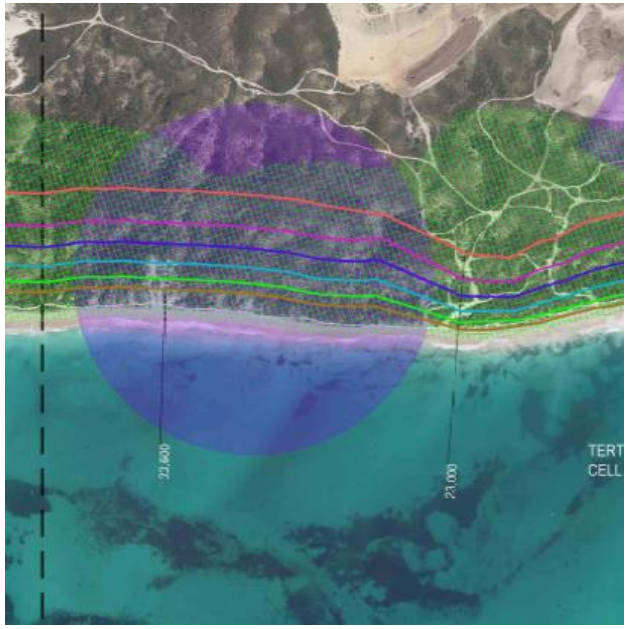
Table 5-7 Ratings for Karli Springs

Karli Springs

Chainage 22,700 (Zone 2)

Estimated Vulnerability Time Frame: 2050

Asset Type	Function/Service	Value
Environmental	recreation, habitat, tourism, buffer	Environmental/Recreational
Environmental	habitat, ecosystem integrity, buffer	Environmental
Environmental/Social	cultural significance, habitat, ecosystem integrity, buffer	Environmental/Cultural/Heritage



Assessment Inputs						
	2015	2030	2050	2070	2090	2120
Asset	**Likelihood**					
Beach	Rare	Unlikely	Likely	Almost Certain	Almost Certain	Almost Certain
BFS 397	Rare	Unlikely	Possible	Likely	Likely	Almost Certain
Karli Spring	Rare	Rare	Rare	Unlikely	Possible	Likely

Asset	Consequence of Erosion					
Impact on beach amenity	Minor	Minor	Minor	Minor	Minor	Minor
Impact on ecological buffer (BFS 397)	Insignificant	Minor	Minor	Moderate	Moderate	Moderate
Impact on Karli Springs	Insignificant	Insignificant	Minor	Moderate	Moderate	Major

Asset	Adaptive capacity					
Beach	Very High	Very High	Very High	High	High	High
BFS 397	High	High	Moderate	Moderate	Low	Low
Karli Spring	Low	Low	Low	Low	Low	Low

Risk Assessment						
	2015	2030	2050	2070	2090	2120
	Risk					
Beach	Low	Low	Medium	Medium	Medium	Medium
BFS 397	Low	Low	Low	Medium	Medium	High
Karli Spring	Low	Low	Low	Medium	Medium	High

	Vulnerability					
Beach	Low	Low	Medium	Medium	Medium	Medium
BFS 397	Low	Low	Low	Medium	High	Very High
Karli Spring	Low	Low	Low	High	High	Very High

5.8 Carpark Adjacent to Jindalee Boulevard, Jindalee

The section of coastline containing the coastal carpark off Jindalee Boulevard lies within Tertiary Sediment Cell 29b (Stul et al, 2012) and comprises approximately 200m of coastline to the north and south (450 m total) of the carpark (see also **Figure A6** of **Appendix A**). The section of shoreline in front of the carpark has a generally consistent orientation and is relatively exposed to incident waves. The carpark appears to be fronted by considerable rock formations but was classified as sandy for coastal vulnerability assessment and the calculation of hazard lines (M P Rogers, 2015).

The CoW is planning to implement coastal protection works at Quinns Beach, to the south of this site, based on investigations carried out as part of the Quinns Long-Term management Plan (Cardno, 2013 & 2015). The proposed works at Quinns Beach will have a considerable influence on the vulnerability of this coastal section. As such, Cardno and the City have agreed that a risk assessment for the site should be carried out considering the designed coastal protection, at a later stage.

5.9 Residential Lots, Mindarie

The section of coastline fronting the residential lots at Mindarie lies within Tertiary Sediment Cell 29a (Stul et al, 2012) and extends approximately 400 m northward from the northern side of the Mindarie Marina entrance (see also **Figure A7** of **Appendix A**). The section of shoreline in front of the residential lots is rocky throughout with intermittent sections of beach and substantial nearshore reef formations. The coastline was classified as rocky for coastal vulnerability assessment and the calculation of hazard lines (M P Rogers, 2015).

5.9.1 Risk Analysis

5.9.1.1 Likelihood

As this section was classified as a rocky coastline, no S1, S2 or S3 allowance has been incorporated into the hazard lines. The HSD appears to have been set approximately 20 m landward of the coastal vegetation line for this section, but this has not been stated in M P Rogers (2015).

The primary hazard for infrastructure assets in this section is likely to be damage due to coastal inundation. Because of the high relief of such infrastructure, likelihood has been assigned as rare for major infrastructure up to 2050.

The likelihood of impacts to the small beach sections and coastal vegetation increases over time with greater exposure to the impact of storms likely. The beach is likely to have been significantly impacted by 2050 due to a rising MSL and greater exposure to coastal impact. It is possible the vegetation forming the BFS will also have been impacted due to greater exposure by 2050. The likelihood ratings are presented in **Table 5-8**.

5.9.1.2 Consequence

The consequence for all assets at the site has been deemed minor up to 2050. For built infrastructure, this is because the impacts of inundation are generally less severe than for coastal erosion. The extent of any inundation event is also likely to be limited up to 2050. The majority of the BFS in the area appears to also have high relief, so is unlikely to be impacted severely by stand-alone inundation events. Although the beach is likely to experience erosion and be impacted across the planning timeframes to 2050, it has not been assessed to have as much value as other more frequently used beaches within the LGA. The consequence ratings are presented in **Table 5-8**.

5.9.2 Risk Evaluation – Risk Level

The initial risk levels show generally low risk for all assets at the site up to the 2050 planning timeframe, with the exception of the beach, which has a risk level of medium at 2050. The derived risk levels are presented in **Table 5-8**.

5.9.3 Vulnerability Analysis

5.9.3.1 Adaptive Capacity

For this section the intermittent beach sections are seen to have low adaptive capacity as they are confined by rock and will not be able to migrate landward with rising sea levels. The vegetation in the BFS is seen to have moderate adaptive capacity initially through its ability to regenerate following impact. This diminishes later in the century with more frequent coastal impact. Hard infrastructure has been allocated low adaptive capacity as it would be expensive to redesign or relocate. The adaptive capacity ratings are presented in **Table 5-8**.

5.9.3.2 Vulnerability Rating

All assets have a low vulnerability until 2050, except for the beach which has a vulnerability of low at 2030 and high at 2050. Beyond 2050 all assets have high vulnerability, or very high for the beach. For built assets, this jump in vulnerability is largely associated with uncertainty around the amount of protection that will be provided by existing rock and the elevation of assets above MSL. It is possible that these vulnerability ratings are highly conservative and further investigation should be carried out to assess the risk of inundation with a higher MSL. A survey of the elevation of the rock and geotechnical survey to determine its strength and continuity would determine its suitability as a protective barrier to storm surge. The high and very high

vulnerability ratings for the beach suggest this asset will be severely degraded and possibly lost with rising MSL.

The derived vulnerability ratings for the coastline section are presented in **Table 5-8**. The potential effects on this shoreline section over time, without the implementation of management options, would be:

> Areas of sandy beach are likely to be reduced and eventually removed over time, leaving an entirely rocky coastline;

> The coastal vegetation line will recede due to a greater reach of storm surge and wave run-up events; and

> Increasing frequency of coastal inundation to the parkland, walkway, road and residential properties due to a higher MSL.

Given the substantial economic value of residential housing in the section, it is recommended that the threat of coastal inundation is more thoroughly assessed at this site.

5.9.3.3 Existing Controls

The existing features in the vicinity of the site, likely to be exerting some control over coastal processes in the area, include:

> The marina directly to the south which blocks northward alongshore sediment transport;

> The marina breakwater directly offshore of the section, preventing the direct impact of predominantly south, south-westerly swell and sea waves;

> The nearshore reef system, connecting to the land in several places, which will dissipate incident wave energy, particularly from the more uncommon west, north-westerly direction. This dissipation is likely to be lessened into the future with rising sea level ;

> Established dune vegetation that is likely to provide a minor buffer against storm surge and inundation; and

> Naturally high relief and rock coastline which could be a substantial coastal barrier and should be better characterised (as suggested in **section 5.9.3.2**).

Table 5-8 Ratings for Residential Lots, Mindarie

Residential Lots, Mindarie

Chainage 29,900 to 30,200 (Zone 1/2)

Estimated Vulnerability Time Frame: 2050

Asset Type	Function/Service	Value	Asset	Assessment Inputs 2015	2030	2050	2070	2090	2120
				Likelihood					
Environmental	recreation, habitat, tourism, buffer	Environmental/Recreational	Beach	Rare	Unlikely	Likely	Almost Certain	Almost Certain	Almost Certain
Environmental	habitat, ecosystem integrity, buffer	Environmental	BFS 397	Rare	Unlikely	Possible	Likely	Likely	Almost Certain
Economic/Social/Environmental	recreation, access to beach/groyne/residential	Environmental/Recreational	Parkland & Walkway	Rare	Rare	Possible	Possible	Possible	Possible
Economic	housing for current or future population	Residential	Residential	Rare	Rare	Rare	Possible	Possible	Possible
Economic	tranportation services, access to residential	Public Infrastructure	Road (Clarecastle)	Rare	Rare	Rare	Possible	Possible	Possible

Asset	Consequence of Erosion					
Impact on beach amenity	Minor	Minor	Minor	Moderate	Moderate	Moderate
Impact on ecological buffer (BFS 397)	Minor	Minor	Minor	Moderate	Moderate	Moderate
Impact walkway and parkland	Minor	Minor	Minor	Moderate	Moderate	Moderate
Impact on residential lots	Minor	Minor	Minor	Moderate	Moderate	Moderate
Impact on Clarecastle Retreat (road)	Minor	Minor	Minor	Moderate	Moderate	Moderate

Asset	Adaptive capacity					
Beach	Moderate	Low	Low	Low	Low	Low
BFS 397	Moderate	Moderate	Moderate	Low	Low	Low
Parkland & Walkway	Low	Low	Low	Low	Low	Low
Residential	Low	Low	Low	Low	Low	Low
Road (Clarecastle)	Low	Low	Low	Low	Low	Low

	Risk Assessment 2015	2030	2050	2070	2090	2120
	Risk					
Beach	Low	Low	Medium	High	High	High
BFS 397	Low	Low	Low	Medium	Medium	High
Parkland & Walkway	Low	Low	Low	Medium	Medium	Medium
Residential	Low	Low	Low	Medium	Medium	Medium
Road (Clarecastle)	Low	Low	Low	Medium	Medium	Medium

	Vulnerability					
Beach	Low	Low	High	Very High	Very High	Very High
BFS 397	Low	Low	Low	High	High	Very High
Parkland & Walkway	Low	Low	Low	High	High	High
Residential	Low	Low	Low	High	High	High
Road (Clarecastle)	Low	Low	Low	High	High	High

5.10 Priority Ecological Community, Mindarie

The section of coastline containing the PEC lies within Tertiary Sediment Cell 29a (Stul et al, 2012) and extends approximately 2.5 km, from the southern edge of Mindarie Marina to the CoW LGA boundary at the south (see also **Figure A8** of **Appendix A**). The section of shoreline in front of the PEC has a generally consistent orientation and is relatively exposed to incident waves. The coastline was classified as sandy for coastal vulnerability assessment and for the calculation hazard lines (M P Rogers, 2015).

5.10.1 Risk Analysis

5.10.1.1 Likelihood

The HSD for this section of coastline has been placed at +1.8 m AHD, which is approximately 9 m seaward of the coastal vegetation line. The S1 allowance has been calculated as 52 m. For approximately the first 600 m of coastline to the south of Mindarie Marina the S2 erosion allowance has been calculated as 0.15 m/year. The remainder and majority of the coastline section was shown to be accreting slightly in recent decades and, as such, has been allocated an S2 allowance of 0 m/year (M P Rogers, 2015). The majority of the recession observed for the hazard lines is, therefore, attributed to the S3 erosion allowance of 0.9 m/year.

The assets identified that may be impacted within the coastline section are the beach and the PEC, which also forms part of the BFS. The relatively high exposure of the coastline to coastal processes means the likelihood of impact to each of these assets generally increases over the planning timeframes. The beach has a likelihood of rare at present, unlikely by 2030 and likely at 2050. This is due to its exposure to coastal erosion which should increase steadily with rising MSL. The dune vegetation has been allocated a rating of unlikely at 2030 and possible at 2050, as the recession of the shoreline allows degradation of a greater portion of the asset. The likelihood ratings are presented in **Table 5-9**.

5.10.1.2 Consequence

For all assets there is a general increase in consequence over time. The beach is predicted to change considerably in comparison to its present state. An increasing portion of the PEC and BFS 397 is predicted to be lost over the planning timeframes. For the PEC, the hazard lines suggest 30 to 40% of the ecological community will be lost over the coming century (M P Rogers, 2015). This has been classified as a major consequence due to its permanence. The consequence ratings are presented in **Table 5-9**.

The loss of larger portions of vegetation into the future, as suggested by the hazard lines, has been assessed as being of increasing consequence. At present and at 2030 the consequence has been deemed minor and insignificant for the PEC and BFS, respectively, as any impacts are unlikely to be permanent or severe, relative to the area of coverage. At 2050 the consequence has been defined as minor and moderate, respectively, for the PEC and BFS due to the proportion of the community predicted to be lost by the hazard lines.

The consequence of erosion for the beach has been considered minor across all planning timeframes as it is likely to maintain its form as an actively eroding beach. It is expected to be 'fed' by sediment from the dune system behind it, so is not predicted to be lost or substantially degraded from its present form into the future.

5.10.2 Risk Evaluation – Risk Level

The present day and 2030 risk levels show low risk for assets at the site, increasing to medium for the beach and PEC at 2050. The derived risk levels are presented in **Table 5-9**.

5.10.3 Vulnerability Analysis

5.10.3.1 Adaptive Capacity

The beach has been allocated a very high to high adaptive capacity, as it is not confined and is likely to be able to retreat with rising sea level, generally maintaining its form. The PEC was considered to have limited adaptive capacity by Eco Logical (2015). The PEC has been allocated moderate adaptive capacity up to 2030, due to the natural ability of coastal vegetation to regrow following erosion events. Beyond this its adaptive capacity is considered to be low, as the habitat of the PEC is expected to be reduced more

dramatically. The BFS 397 has been allocated moderate adaptive capacity, given ample land is available (landward of the BFS 397) for reallocation. Given the PEC and BFS 397 cover the same area in this section, the vulnerability of the BFS will be somewhat superseded by that for the PEC. The adaptive capacity ratings are presented in **Table 5-9**.

5.10.3.2 Vulnerability Rating

The vulnerability ratings suggest the assets are generally not vulnerable in the short term (up to 2030), with vulnerability increasing to medium for the beach and high for the PEC at 2050. The vulnerability of the PEC becomes very high towards the end of the century. The derived vulnerability ratings for the coastline section are presented in **Table 5-9**. The potential effects on this shoreline section over time, without the implementation of management options, would be:

> The beach will probably transform from a steady flat beach profile to an actively eroding beach, which may have less useable beach width and a scarped back beach; and

> More frequent and a greater reach of erosion will likely cause dune blowouts and reduction, reducing overall coastal vegetation and allowing more frequent impact to its habitat.

Given the strong weighting for the success criteria relating to the preservation of environmental assets, treatment of the risk to the PEC should be considered in the medium term (prior to 2050).

5.10.3.3 Existing Controls

The existing features in the vicinity of the PEC, likely to be exerting some control over coastal processes in the area, include:

> Interspersed nearshore reef areas that likely dissipate some wave energy prior to interaction with the beach. This dissipation is likely to reduce in the future with rising sea level;

> Mindarie Marina at the north of the study site which would trap sediment that is predominantly transported northward by nearshore currents. This is likely to stabilise the shoreline position directly to the south of the marina with a lesser influence by the marina as you move southward along the sites shoreline; and

> Established dune vegetation which consolidates the dune system and provides a minor buffer against wind and wave driven erosion.

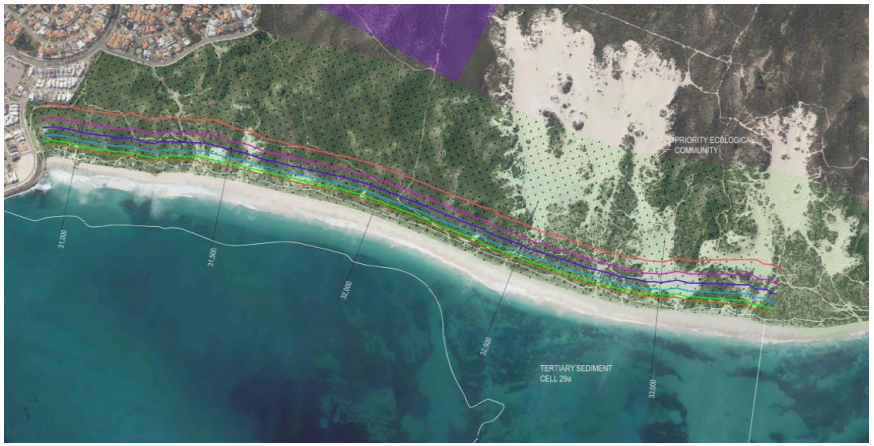
Table 5-9 Ratings for PEC, Mindarie

Priority Ecological Community

Chainage 30,800 to 33,300 (Zone 3)

Estimated Vulnerability Time Frame: Present Day

Asset Type	Function/Service	Value	Asset
Environmental	recreation, habitat, tourism, buffer	Environmental/Recreational	**Beach**
Environmental	habitat, ecosystem integrity, buffer	Environmental	**BFS 397**
Environmental	conservation value for threatened species, habitat, ecosystem integrity	Environmental	**PEC**



Assessment Inputs	2015	2030	2050	2070	2090	2120
Asset	**Likelihood**					
Beach	Rare	Unlikely	Likely	Almost Certain	Almost Certain	Almost Certain
BFS 397	Rare	Unlikely	Possible	Likely	Likely	Almost Certain
PEC	Rare	Unlikely	Possible	Likely	Likely	Almost Certain

Asset	Consequence of Erosion					
Impact on beach amenity	Minor	Minor	Minor	Minor	Minor	Minor
Impact on ecological buffer (BFS 397)	Insignificant	Insignificant	Minor	Minor	Moderate	Moderate
Impact on Priority Ecological Community	Minor	Minor	Moderate	Moderate	Major	Major

Asset	Adaptive capacity					
Beach	Very High	Very High	Very High	High	High	High
BFS 397	High	High	Moderate	Moderate	Low	Low
PEC	Moderate	Moderate	Low	Low	Low	Low

Risk Assessment	2015	2030	2050	2070	2090	2120
	Risk					
Beach	Low	Low	Medium	Medium	Medium	Medium
BFS 397	Low	Low	Low	Medium	Medium	High
PEC	Low	Low	Medium	Medium	High	Extreme

	Vulnerability					
Beach	Low	Low	Medium	Medium	Medium	Medium
BFS 397	Low	Low	Low	Medium	High	Very High
PEC	Low	Low	High	High	Very High	Very High

6 Conclusions

Analysis and discussion of the outcomes of the risk assessment, within the results section (**Section 5**), has focused on the present day, 2030 and 2050 planning scenarios. This aligns with the City's desire to plan for and manage the risks of coastal hazards within the first half of the 21st century. The risk assessment has been undertaken for all planning timeframes, up to 2120. However, considerable and increasing uncertainty accompanies the vulnerability ratings derived for later planning timeframes.

6.1 Risk Prioritisation

A preliminary risk prioritisation has been made for each of the sites assessed, based on the derived vulnerability ratings of assets within them. The prioritisation should guide which sites need further investigation and/or treatment most urgently. This ranking is based on the level of vulnerability (for any asset at a site) and the planning timeframe at which it occurs. The site(s) with the highest vulnerability rating(s) for any asset at the present day planning timeframe is/are prioritised highest, followed by the site(s) with the highest vulnerability rating(s) for any asset at the 2030 planning timeframe and so on. This prioritisation might be adjusted by a variety of factors, as the project progresses. These factors might include: the desires of the City and its council, the outcomes of a multi-criteria and cost-benefit analysis and further feedback gained through community and stakeholder consultation. Each site analysed in the risk assessment is presented in the following subsections (**6.1.1** to **6.1.9**) in order of priority, with **6.1.1** being of the highest priority and **6.1.9** being of the lowest priority.

6.1.1 Carpark adjacent to Brazier Road, Yanchep

This site has been prioritised based on the vulnerability of the beach, which is an asset of considerable value to the City. It has a medium vulnerability at present and this vulnerability becomes high by 2050 (**Table 6-1**). Loss of the beach or reduced beach amenity, due to coastal erosion, would have significant social, environmental and economic impact for the City. The beach and dunes also act as buffers against potential impacts to built assets behind them, which hold significant economic value and are expected to have increased vulnerability from 2050.

It is recommended an effective monitoring program be implemented to assess long and short term coastal erosion at the site as soon as possible, and help refine trigger levels for the implementation of adaptation measures. Adaptation options for the site should also be prepared and assessed as soon as possible.

Table 6-1 Final vulnerability ratings

	Risk Assessment					
	2015	2030	2050	2070	2090	2120
	Vulnerability					
Beach	Medium	Medium	High	Very High	Very High	Very High
BFS 397	Low	Low	Low	Medium	Medium	Very High
Car Park (Brazier Rd)	Low	Low	Medium	Medium	Medium	High
Road (Brazier)	Low	Low	High	Very High	Very High	Very High
Parkland (Fisherman's Hollow)	Low	Low	Low	Low	Low	Medium

6.1.2 Residential lots, Yanchep

This site is adjacent to the study site discussed in **Section 6.1.1** and is considered to have equivalent vulnerability and urgency for assessment and, potentially, treatment (see also **Table 6-2**). This site and that discussed in **6.1.1** should be combined for the purpose of developing a monitoring program, trigger levels and assessing adaptation options.

Table 6-2 Final vulnerability ratings

	Risk Assessment					
	2015	2030	2050	2070	2090	2120
	Vulnerability					
Beach	Medium	Medium	High	Very High	Very High	Very High
BFS 397	Low	Low	Low	High	High	Very High
Residential	Low	Low	High	Very High	Very High	Very High
Road (Brazier)	Low	Low	High	Very High	Very High	Very High

6.1.3 Sovereign Drive and adjacent residential lots, Two Rocks

This site has been prioritised based on a medium vulnerability of the BFS by 2030, as well as high vulnerability calculated for the majority of assets by 2050 (**Table 6-3**). The built assets, including residential houses and roads hold significant economic value. Considerable geophysical investigation has already been undertaken for this site, to determine if subsurface rock could provide protection for assets behind the beach, from the impacts of coastal erosion. It would be recommended that the information gathered is further analysed to determine the ability of the sites geology to provide protection. For this study the site was assessed as entirely sand (MP Rogers, 2015), which is likely to be very conservative.

It would also be recommended that an effective monitoring program be implemented within 5-10 years (or earlier if feasible) and that adaptation options are properly assessed, and triggers for implementation of preferred options properly defined prior to 2030.

Table 6-3 Final vulnerability ratings

	Risk Assessment					
	2015	2030	2050	2070	2090	2120
	Vulnerability					
Beach	Low	Low	Medium	High	Very High	Very High
BFS 397	Low	Medium	High	High	Very High	Very High
Sovereign Dve	Low	Low	High	Very High	Very High	Very High
Residential (SD)	Low	Low	High	Very High	Very High	Very High
Residential (TA)	Low	Low	High	High	Very High	Very High
Tenggara Ave	Low	Low	High	High	Very High	Very High

6.1.4 Priority Ecological Community, Two Rocks

The PEC at Two Rocks has been prioritised based on a high vulnerability for the ecological community at the 2050 planning timeframe (**Table 6-4**). The PEC is considered to have considerable environmental value.

It is recommended that a monitoring program be established for the PEC by 2030, to accurately quantify any loss of the overall PEC. Options should be developed to mitigate or offset the loss of the community once a trigger point is reached. This trigger point may be the loss of a certain percentage of the original coverage of the PEC, for example.

Table 6-4 Final vulnerability ratings

	Risk Assessment					
	2015	2030	2050	2070	2090	2120
	Vulnerability					
Beach	Low	Low	Medium	Medium	Medium	Medium
BFS 397	Low	Low	Medium	Medium	Medium	Very High
PEC	Low	Low	High	High	Very High	Very High

6.1.5 Residential lots, Mindarie

The site containing the residential lots at Mindarie has been prioritised due to the high vulnerability of the beach at the 2050 planning timeframe and the step from low vulnerability at 2050 to high at 2070 for all other assets (**Table 6-5**).

It is recommended that a suitable monitoring program be established for the beach and vegetation by 2030. Prior to this it would be recommended that the cost of maintaining the beach, as MSL rises, be assessed against the benefit of maintaining the asset. Determining the benefit of maintaining the beach would likely require gaining a better understanding of this particular beaches value to the community.

It is also recommended that rock located between the ocean and hard infrastructure assets be assessed in more detail to determine its suitability as a barrier against coastal storm surge and inundation. This might involve assessing the elevation of the rock and its strength and stability. This information alongside observations of changes in MSL over the coming decades would help reduce the uncertainty around the vulnerability of assets at the site beyond 2050.

Table 6-5 Final vulnerability ratings

	Risk Assessment					
	2015	2030	2050	2070	2090	2120
	Vulnerability					
Beach	Low	Low	High	Very High	Very High	Very High
BFS 397	Low	Low	Low	High	High	Very High
Parkland & Walkway	Low	Low	Low	High	High	High
Residential	Low	Low	Low	High	High	High
Road (Clarecastle)	Low	Low	Low	High	High	High

6.1.6 Priority Ecological Community, Mindarie

The PEC at Mindarie has been prioritised based on a high vulnerability for the ecological community at the 2050 planning timeframe (**Table 6-6**). The PEC is considered to have considerable environmental value.

It is recommended that a monitoring program be established for the PEC by 2030, to accurately quantify any loss of the overall PEC. Options should be developed to mitigate or offset the loss of the community once a trigger point is reached. This trigger point may be the loss of a certain percentage of the original coverage of the PEC.

Table 6-6 Final vulnerability ratings

	Risk Assessment					
	2015	2030	2050	2070	2090	2120
	Vulnerability					
Beach	Low	Low	Medium	Medium	Medium	Medium
BFS 397	Low	Low	Low	Medium	High	Very High
PEC	Low	Low	High	High	Very High	Very High

6.1.7 Heritage Site Karli Spring, Alkimos

The Karli Spring heritage site has been prioritised based on a medium vulnerability of the beach in front of it at 2050 and a step up to high vulnerability at 2070 for the spring itself (**Table 6-7**). There is uncertainty about how the spring will be affected with rising MSL. It is recommended that further investigation of the spring's link to coastal processes and a suitable monitoring program be developed for the site prior to 2050.

Table 6-7 Final vulnerability ratings

	Risk Assessment					
	2015	2030	2050	2070	2090	2120
	Vulnerability					
Beach	Low	Low	Medium	Medium	Medium	High
BFS 397	Low	Low	Low	Medium	High	Very High
Karli Spring	Low	Low	Low	High	High	Very High

6.1.8 Beach access road and carpark 'The Spot', Two Rocks

This site has been prioritised based on a medium vulnerability rating for the beach at 2050. The physical infrastructure at the site has a low vulnerability until the 2070 planning timeframe (**Table 6-8**). With the low economic value of infrastructure at this site and the social value seen to lie more within the surf break than the shoreline itself, no immediate action is recommended. A monitoring program should be considered for this site between the 2030 and 2050 timeframes. This recommendation, however, may be revised with future revisions of the CHRMAP or based on observations at the site over the coming decade.

Table 6-8 Final vulnerability ratings

	Risk Assessment					
	2015	2030	2050	2070	2090	2120
	Vulnerability					
Beach	Low	Low	Medium	Medium	High	High
BFS 397	Low	Low	Low	Medium	High	Very High
Beach Carpark (unsealed)	Low	Low	Low	Low	Medium	Medium
Beach Access Rd (unsealed)	Low	Low	Low	Low	Medium	Medium

6.1.9 Carpark south of Capricorn Groyne, Yanchep

This site has been prioritised based on a medium vulnerability of the beach at 2050 and a medium vulnerability for other assets, such as the BFS, carpark and adjoining road, at 2070 (**Table 6-9**). The site is already managed to an extent by the existing groyne, which is likely to lose effectiveness with rising MSL. A monitoring program should be considered for this site between the 2030 and 2050 timeframes. This recommendation, however, may be revised with future revisions of the CHRMAP or based on observations at the site over the coming decade.

Table 6-9 Final vulnerability ratings

	Risk Assessment					
	2015	2030	2050	2070	2090	2120
	Vulnerability					
Beach	Low	Low	Medium	Medium	High	High
BFS 397	Low	Low	Low	Medium	High	Very High
Groyne Carpark	Low	Low	Low	Medium	High	High
Road	Low	Low	Low	Medium	Medium	High
Car park (Cap Vill)	Low	Low	Low	Low	Low	Medium
Residential (Cap Vill)	Low	Low	Low	Low	Low	High

7 Discussion

This risk assessment has provided a timeframe for the vulnerabilities of key coastal assets within the City's LGA. It is reiterated that the uncertainty around the vulnerability levels of assets increases significantly moving forward across each planning timeframe. Although this risk assessment has been carried out for all planning timeframes, up to 2120, the focus in discussing the results has been on the vulnerability of assets in the present day and at the 2030 and 2050 timeframes.

The results and prioritisation generally shows the beach at each identified site to be the first asset to have vulnerability raised above low, as you move through the planning timeframes. This has come about partly because the beach naturally has the closest proximity to the ocean and impacts of coastal hazards. It is also because of the substantial social value attributed to beaches, defined in the success criteria, as part of initial community and stakeholder consultation. Traditionally only built assets such as buildings and roads, with easily definable economic value, may have been considered in such an assessment. The beach and dune system are often the first line of defence for built infrastructure against the impacts of coastal hazards, so it is also appropriate in that regard that their urgency for treatment has been highlighted through this process.

The results and the risk prioritisation will now guide the next phases in the CHRMAP project. The vulnerability ratings, specific to assets, will be used to guide the development of suitable adaptation options for each site. Through identification of the assets most at risk, adaptation options can be tailored to account for the protection of these assets. The current vulnerability ratings will also be used for comparison, to predict a residual risk rating after a preferred, potential adaptation option has been implemented. The urgency for treatment will guide the final management plan, helping to develop monitoring programs and appropriate triggers, which call for intervention once detected. Some initial suggestions for monitoring have been made in the conclusions section (**Section 6**) of this report. These will be expanded on in the Adaptation Options Chapter Report and final CHRMAP. With all environmental monitoring, commencing the collection of data as soon as possible leads to more comprehensive data sets and better informed decision making. Although it may be recommended that monitoring commence by 2030, for example, for a particular site, ideally this monitoring should be commenced immediately.

8 References

Cardno, 2013, *Quinns Beach Long Term Coastal Management Study Stage 1*. Prepared for the City of Wanneroo

Cardno, 2014, *Yanchep Surf Life Saving Club – Coastal Hazard Risk Management and Adaptation Plan*, Prepared for the City of Wanneroo

Cardno, 2015, *Quinns Beach Long Term Coastal Management Study Stage 2*. Prepared for the City of Wanneroo

Cardno, 2016, *Stakeholder Engagement Strategy – City of Wanneroo CHRMAP Part 2*. Prepared for the City of Wanneroo

MP Rogers & Associates, 2015, *CHRMAP Part 1: Coastal Vulnerability Study & Hazard Mapping*. Prepared for the City of Wanneroo.

Standards Australia Ltd, 2013, *Climate change adaptation for settlements and infrastructure – A risk based approach*, AS 5334-2013. Sydney, Australia

Stul, T., Gozzard, J. R., Eliot, I. G. & Eliot, M. J., 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.

WAPC, 2013, *State Planning Policy No. 2.6: State Coastal Planning Policy*. Under the Planning and Development Act 2005. Western Australia

WAPC, 2014, *Coastal Hazard Risk Management and Adaptation Planning Guidelines*. Perth, Australia

APPENDIX

F

ADAPTATION PLANNING CHAPTER REPORT

Adaptation Planning Chapter Report

City of Wanneroo CHRMAP Part 2

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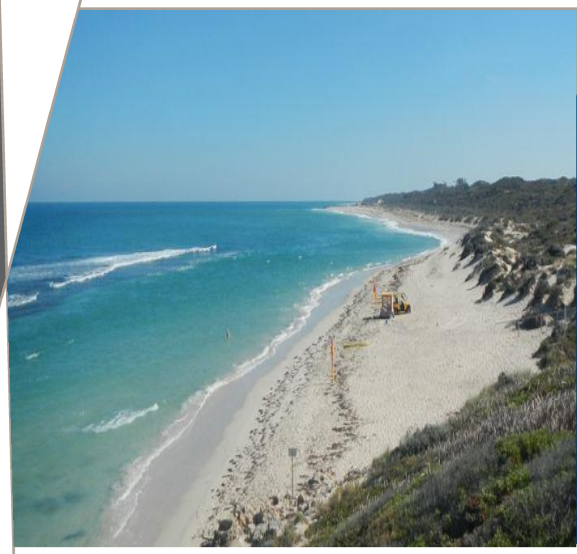

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11 May 2017

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Rev0	11/05/2017	Final	DRS	DvS

Executive Summary

This Adaptation Planning Chapter Report uses the results of the previous risk assessment process to identify and assess adaptation options. It is a component of the second part of the CHRMAP process (City of Wanneroo [CoW], 2016).

The Adaptation Planning Chapter Report aims to identify potential responses to the coastal hazard risks for each of the study sites and to provide a preliminary evaluation of the options to inform stakeholder and community engagement. The objectives of the adaptation options assessment are:

- To define a range of adaptation measures for each of the prioritised sites;
- To carry out a preliminary multi-criteria analysis (MCA) as a framework and starting point for stakeholder and community consultation, and to identify options for more detailed assessment in the future;
- To supply relevant information to inform preliminary options assessments for individual sites;
- To provide preliminary recommendations for the implementation of adaptation options and planning responses, with consideration of equity implications of the proposed options; and
- To identify further investigations that may be required.

Adaptation options have been focused on those assets deemed most 'at risk' of coastal hazard impact as determined in the CHRMAP Part 1 analysis (MP Rogers, 2015a) and described in the Risk Assessment Chapter Report (Cardno, 2016).

The adaptation options assessment has been guided by the success criteria defined by the stakeholder engagement process; specifically, through the Community Values Survey, and these success criteria have been used to undertake a preliminary assessment of the acceptability of potential adaptation options.

Multi-criteria analysis is used to assess options for each identified site with the "recommended" and "further investigation required" options implementation implications discussed.

In general the proposed adaptation options effectively describe technical mitigation measures for adapting to the effects of landward migration of the shoreline due to future sea level rise and coastal erosion. These options are further assessed in the context of the range planning instruments currently either in place, under review or subject to update prior to 2025 that the State and Local Government may utilise to effect changes in the character and use of the coastal zone.

In general options recommend that:

- Where there is currently no existing development seaward of the predicted 2120 hazard line, planning controls and coastal zone boundaries be adjusted to preclude development within the zone;
- Where high value natural assets exist seaward of the 2120 hazard line, dune care and sand management options be considered;
- Where public built assets exist seaward of the 2120 hazard line, retreat options should be considered; and/or
- Where private land and dwellings are located seaward of the 2120 hazard line, options to retreat, accommodate or protect should be considered.

A set of guiding principles (discussed in **Section 5-1**) is provided to support deliberations during the next round of community forums and feedback sessions, where the aim is to elicit community consensus on the priorities and content of the CHRMAP plan.

The key vulnerability timeframes for the selected sites, listed in **Table 1-1,** show that the earliest key vulnerability is the 2050 timeframe and hence a number of long term implementation plans may be reviewed in the future CHRMAP updates to occur every 5 to 10 years.

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Appendices

1 Introduction

1.1 Overview of CHRMAP Process

In 2015, the City of Wanneroo ('the City') commissioned a coastal vulnerability assessment to determine the extent of coastal hazards for its Local Government Area (LGA). This involved identifying the exposure of coastal assets (both built and natural) to hazards such as long- and short-term erosion and coastal inundation over several planning timeframes, accounting for the effects of climate change. That assessment formed Part 1 of the City's LGA-wide Coastal Hazard Risk Management and Adaptation Plan (CHRMAP).

The CHRMAP is to be completed in three parts:

> Part 1: Undertake a Coastal Vulnerability and Hazard Mapping study of the City's coastline in its entirety;

> Part 2: Complete Hazard Risk Assessment and Adaptation Planning for vulnerable areas of the City's coastline based on the findings of Part 1; and

> Part 3: Internal Review & Application.

Cardno is currently working with the City to undertake Part 2 of the CHRMAP. The objectives of Part 2 are to:

> Develop a Coastal Adaptation Plan to be implemented by the City. This plan will define adaptation measures for each of the prioritised sites. The plan will include relevant information so that coastal managers, land use planners and community groups can act accordingly. Any further investigation into the design of adaptation will be recommended as part of the plan; and

> Build understanding of climate science, coastal processes, hazards and risks across the community through the development of the CHRMAP.

Part 1 of the CHRMAP (MP Rogers, 2015a) made a preliminary assessment of assets that are likely to be vulnerable at various planning timeframes, up to 2120, along the City's coastline. The City has selected the assets identified as vulnerable over the next 35 years (up to the 2050 planning timeframe) for further risk assessment and determination of adaptation options.

Focusing on the sites identified in Part 1 of the CHRMAP, Cardno has undertaken the 'Risk Analysis' and 'Risk Evaluation' components of the process (Cardno, 2016). This assessment has evaluated the risk to each identified asset (and adjacent assets) by combining the likelihood of an impact, such as coastal erosion, with its predicted consequence. This risk level has then been combined with the adaptive capacity for each asset to derive its vulnerability rating. The process is consistent with that outlined in the State Coastal Planning Policy Guidelines (WAPC 2013), and the CHRMAP guidelines (WAPC, 2014).

This Adaptation Planning Chapter Report, uses the results of the risk assessment process to identify and assess adaptation options (see **Figure 1-1**).

The adaptation options assessment was carried out with respect to the success criteria defined by the stakeholder engagement process; specifically, through the Community Values Survey. These have been used to undertake a preliminary assessment of the acceptability of potential adaptation options.

This document is a component of the second part of the CHRMAP process, the Chapter Report on Identification and Assessment of Adaptation Options (City of Wanneroo, 2016). This involves deriving a number of suitable adaptation options for the coastal hazards predicted to impact the City's coastline (**Figure 1-2**). Adaptation options will cater to those assets deemed most 'at risk' of coastal hazard impact as determined by MP Rogers (2015a) and in the Risk Assessment Chapter Report (Cardno, 2016).

The adaptation planning process will adopt steps developed by the Western Australian Planning Commission (2014).

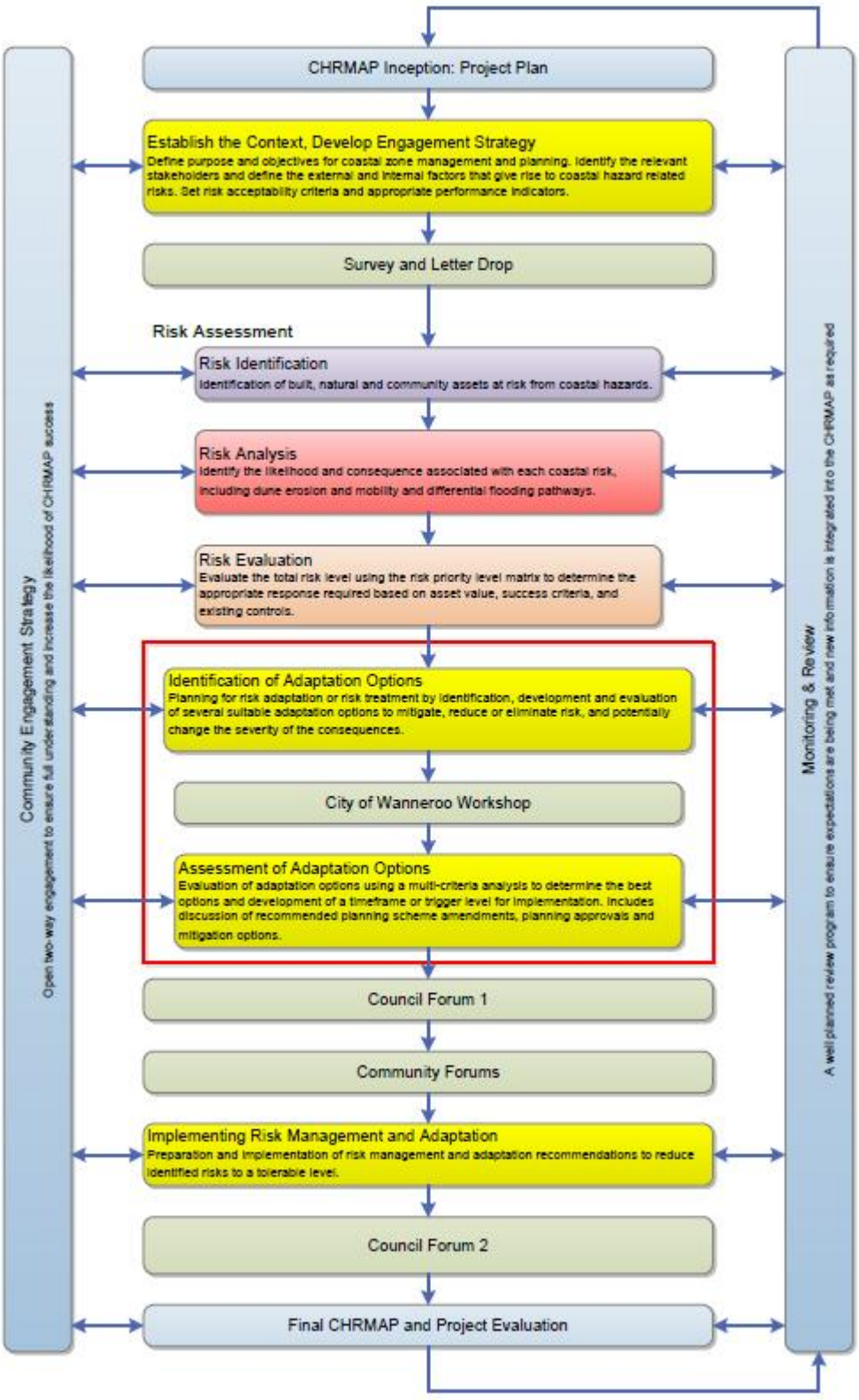


Figure 1-1 CHRMAP methodology flow chart for the City of Wanneroo (adapted from WAPC CHRMAP Guidelines, 2014) with red box showing focus of the current report

Figure 1-2 Key areas within the City of Wanneroo addressed by the current CHRMAP

1.2 Risk Assessment Outcomes

The risk assessment process has further refined the estimated vulnerability timeframes for each of the study sites (**Table 1-1**). For reference, the City's mapping of the coastal erosion hazard lines at each site are included as **Appendix A**. At each of the study sites, a number of different assets have been identified to encompass the social, environmental and economic aspects to be considered in the planning process. These typically include the beach, natural foreshore reserve (with a particular focus on conservation areas), public infrastructure (for example carparks and roads), and commercial and residential properties. A summary of the risk assessment for each study site is presented in **Appendix B.**

Table 1-1 Key Vulnerable Areas (study sites), their locations and estimated vulnerability timeframes (updated following the risk assessment)

Description	Suburb	Span of coastline assessed (Northings in MGA zone 50)	Estimated vulnerability timeframe
Priority Ecological Community	Two Rocks	6518012 m S to 6517304 m S	2050
Sovereign Drive and residential lots	Two Rocks	6515735 m S to 6514908 m S	2050
Beach access road and carpark 'The Spot'	Two Rocks	6512303 m S to 6511583 m S	2070-2090
Capricorn Groyne carpark	Yanchep	6510151 m S to 6509517 m S	2070-2090
Brazier Road carpark	Yanchep	6508882 m S to 6508431 m S	2050
Residential lots	Yanchep	6508418 m S to 6507918 m S	2050
Heritage site Karli Springs	Alkimos/Jindalee	6500433 m S to 6499585 m S	2070
Residential lots	Mindarie	6493848 m S to 6493217 m S	2050-2070
Priority Ecological Community	Mindarie	6492655 m S to 6490505 m S	2050-2070

1.3 Objectives and Structure of This Report

This chapter of the CHRMAP aims to identify potential responses to the coastal hazard risks for each of the study sites and provide a preliminary evaluation of the options in advance of stakeholder and community engagement. The adaptation options assessment has the following objectives:

- To define a range of adaptation measures for each of the prioritised sites;
- To carry out a preliminary multi-criteria analysis (MCA) as a framework and starting point for stakeholder and community consultation, and to identify options for more detailed assessment in the future;
- To supply relevant information to inform preliminary options assessments for individual sites;
- To provide preliminary recommendations for the implementation of adaptation options and planning responses, with consideration of equity implications of the proposed options; and
- To identify further investigations that may be required.

The chapter report is structured as follows:

- **Section 1** provides an introduction to the stand-alone chapter report.
- **Section 2** introduces relevant aspects of the statutory planning framework, CHRMAP guidelines and consultation derived community values;
- **Section 3** provides a description of the methods used in the preliminary MCA, options assessment and consideration of planning controls;
- **Section 4** provides the outcomes of the adaptation options assessment process, and is structured to present the preliminary MCA, discussion of the adaptation options (avoid, accommodate, managed retreat and protect), implications for equity and statutory planning considerations.
- **Section 5** provides discussion and proposes overarching approaches to coastal adaption planning on the City's consideration, and
- **Section 6** summarises the findings of the report.

1.4 The Next Steps

The next step in the CHRMAP process is to present the findings of the adaptation planning process to the City's council, through a council forum, and to the community, through community information sessions. This consultation will be used to inform these stakeholders and obtain their feedback on the acceptability of the

various adaptation options presented. This feedback will be used to further inform and finalise the MCA. The final MCA will then be used to develop adaptation and management pathways for each site. These pathways will span the full 100 year planning timeframe, noting the increasing uncertainty into the future and potential for new information to alter the pathways. The CHRMAP will be focused around these pathways, outlining further investigation and monitoring programs required to help guide and refine the pathways into the future. Specific triggers for the implementation of adaptation options will also accompany each pathway.

2 Adaptation Planning Framework

2.1 Statutory Planning Framework

The State Planning Framework is summarised in **Figure 2-1**. The key statutory planning document for the City of Wanneroo (the City) is District Planning Scheme No. 2 (DPS2). This applies zones and reserves to land within the City and outlines the permissibility of land uses, the requirements for development and the processes for seeking approval for proposed development. DPS2 was gazetted on 6 July 2001.

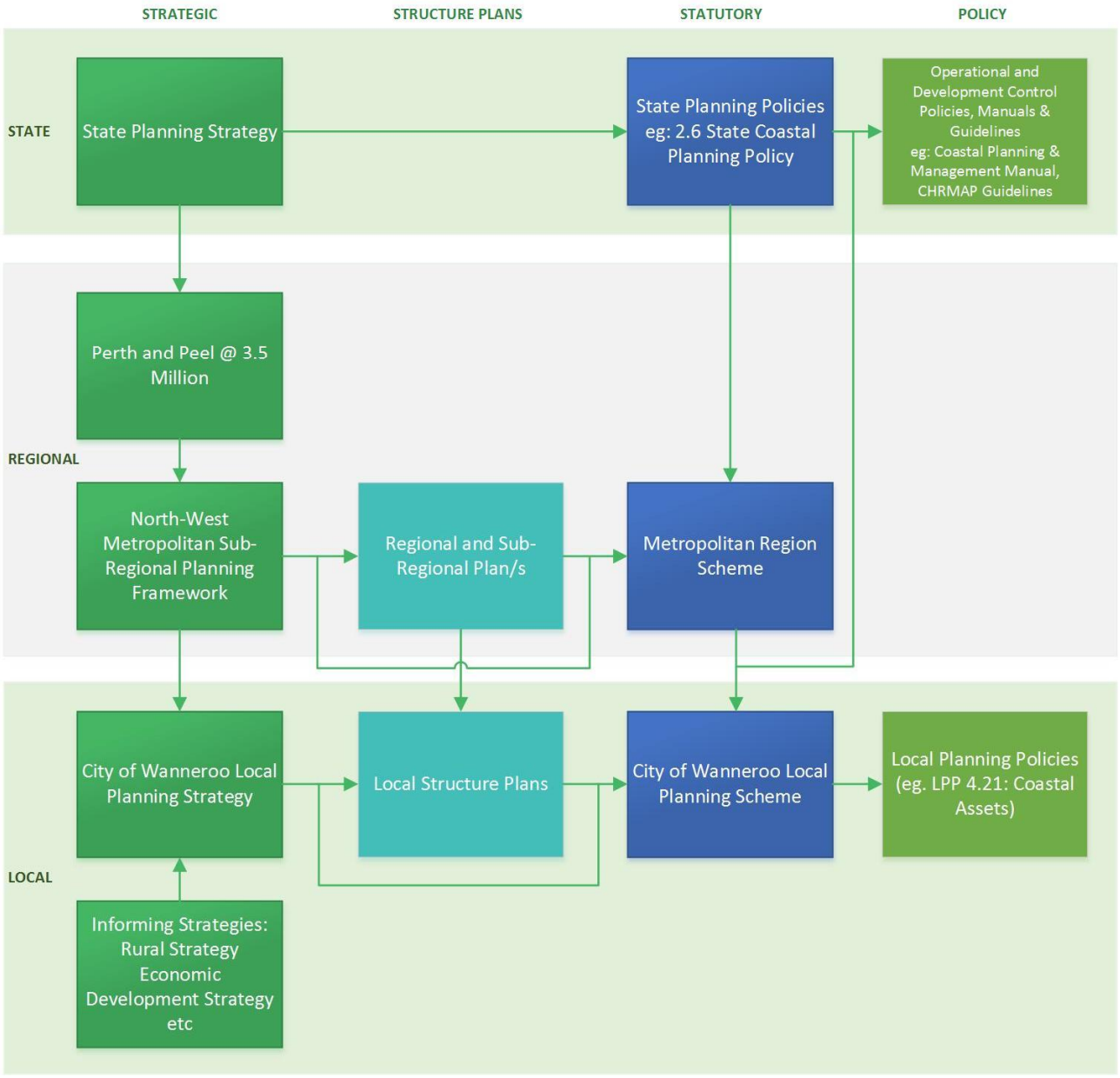
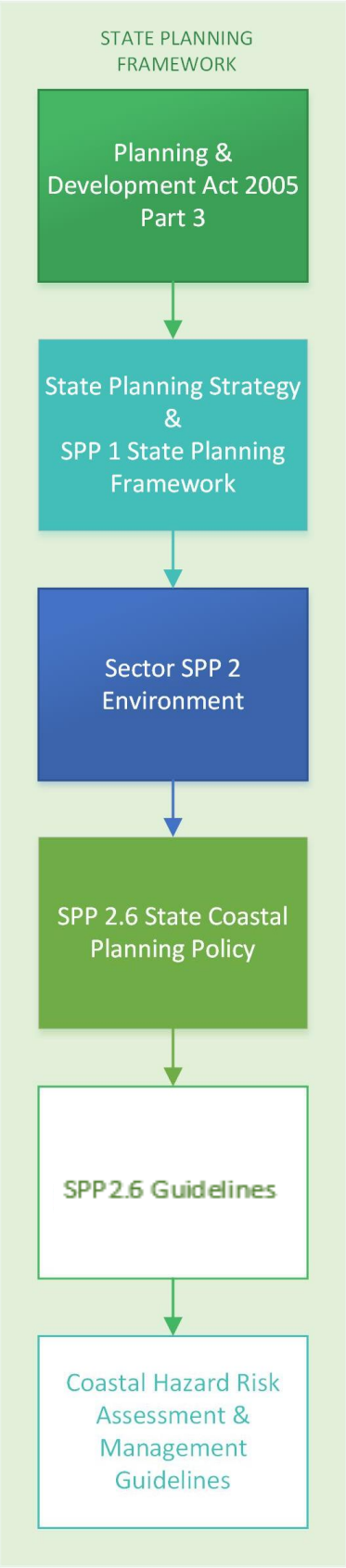


Figure 2-1 Planning context overview

Clause 1.6 of DPS2 lists the scheme aims and objectives, including the following that directly addresses the City's coastal planning responsibilities (emphasis added):

"(f) To encourage development which will (inter alia) ensure permanent and easy access by the public to the ocean shore and recreation reserves."



As required by the *Planning and Development (Local Planning Scheme) Regulations 2015* (the Regulations), DPS2 must be reviewed by October 2017. The review must consider whether DPS2 is up-to-date and complies with the Regulations. This review has commenced, as has the preparation of a new local planning strategy.

As part of the review of DPS2 the City will identify any aspects of the current document that are inconsistent with the intent of regional and state strategies, policies, and statutory requirements, including *State Planning Policy 2.6 – State Coastal Planning Policy* (SPP2.6).

State Planning Policies provide the highest level of planning policy control and guidance in Western Australia and are prepared under Part 3 of the *Planning and Development Act 2005*. SPP2.6 is an environmental sector policy consistent with the higher order *SPP 2 Environmental and Natural Resources Policy.* This relationship is illustrated in the diagram at left, which also shows how the CHRMAP process fits into the hierarchy.

City of Wanneroo *Local Planning Policy 4.21 Coastal Assets Policy* (LPP 21) was adopted in August 2016 under the deemed provisions of DPS2. It is intended to complement SPP2.6, the WAPC *Coastal Planning and Management Manual* and the WAPC *Coastal Hazard Risk Management and Adaptation Planning Guidelines* and is to be considered in conjunction with those documents as well as other local planning policies. Its purpose is to provide guidance to land developers, consultants, the community and contractors as to the type of permanent and temporary assets that the City will consider within the foreshore reserve; and to guide the location of proposed assets relative to the projected onset of coastal processes and landward migration of the shoreline, as calculated in accordance with SPP2.6.

The objectives of the policy are complementary to the objectives of DPS2 and SPP2.6 and are:

1. Maintain a high level of coastal foreshore amenity for current and future residents;
2. Provide coastal foreshore and access points at safe swimming beaches;
3. Encourage innovative asset designs through a combination of permanent facilities and temporary, relocatable structures that fulfil a short term purpose;
4. Conservation of natural assets and ecological values;
5. Allow for the natural movement of sediment and beach restructuring over the 100 year planning timeframe;
6. Provide for a range of coastal foreshore uses that encourage physical activity and connectivity with the natural environment;
7. Recognise the impacts of climate change through informed planning; and
8. Provide sustainable coastal infrastructure that is designed and located with consideration to sea level rise projections.

These policy provisions are appropriate for development within the coastal foreshore reserve, which, consistent with SPP2.6, is defined as "*the area in the coast set aside in public ownership to allow for likely*

impacts of coastal hazards and provide protection of public access, recreation and safety, biodiversity and ecosystem integrity, landscape, visual landscape, indigenous and cultural heritage".

2.2 CHRMAP Framework

Planning for risk management and/or adaptation involves the identification, development and evaluation of several suitable options to mitigate or allow for the potential impacts of a coastal hazard, as determined in the risk assessment process.

While cost-benefit criteria will be important to assess the viability of particular options, some criteria are difficult to quantify, so all criteria are included in the overall analysis; often referred to as multi-criteria analysis (MCA) (see **Section 4**).

Risk management options should also be assessed in terms of their restriction on future planning and risk management opportunities. Options that allow for a wide range of future strategies are considered more favourably. SPP2.6 utilises this philosophy, recommending adaption planning on the preferential basis of avoid, managed retreat, accommodate, protect (**Figure 2-2**).

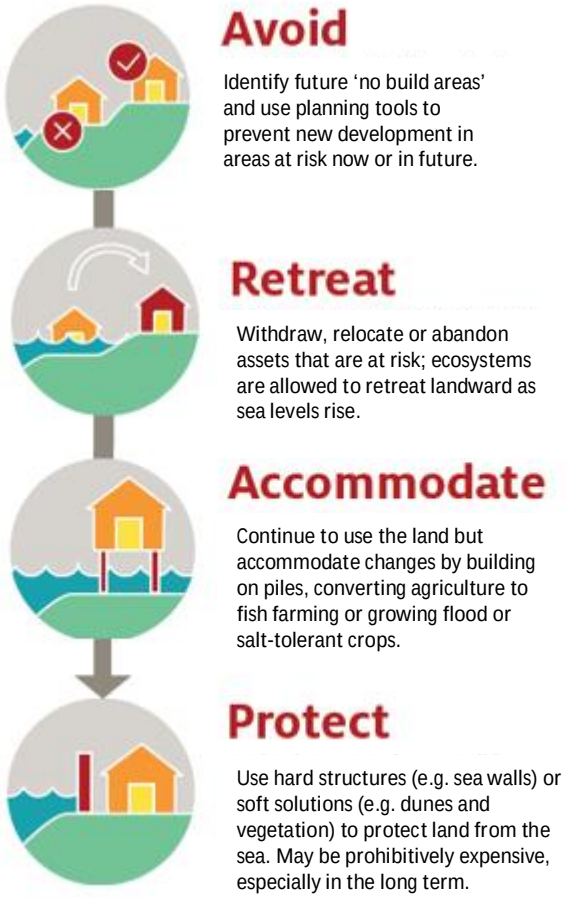


Figure 2-2 WAPC preferential planning hierarchy (CoastAdapt, 2016)

Adaption planning is a somewhat cyclical process, moving through the preferred options until suitable mitigation is achieved. The CHRMAP management and adaption plan employs the following steps:

> Selecting several adaptation options;

> Evaluating under which selection or selections of adaptations and controls the risk becomes tolerable;

> Planning new adaptation options if previously selected ones are not tolerable; and

> Assessing the effectiveness of the new adaptation options compared with the success criteria determined through consultation.

Table 2-1 provides an overview of the possible risk management options. The options have been separated into the WAPC planning philosophy classifications. The risk management and adaption options aim to mitigate risk and vulnerability through one or more of the following:

> Avoiding the risk;

> Removing the risk;

> Changing the likelihood;

> Changing the consequences;

> Increasing adaptability; and/or

> Transferring or accepting the risk.

All of these methods to reduce risk fall within the categories presented in **Figure 2-2**. 'Avoid' and 'managed retreat' options are generally the preferred options for any new or existing developments. 'Accommodate' options aim to re-design existing infrastructure to mitigate potential impacts as they occur. 'Accommodate' options may also be employed for existing developments, when there is no practical option to avoid or retreat from coastal hazards. 'Protect' options are often considered the last line of defence and are the least favourable options. These options aim to protect an asset from coastal hazards by preventing the hazard from reaching the asset. They range from 'soft' options such as beach nourishment to hard structures such as seawalls.

In accordance with the CHRMAP guidelines, equity implications also need to be considered. In particular, the assessment is to identify who may benefit and who may be disadvantaged by proposed options and raise the question of who would be expected to bear the cost of implementation.

Table 2-1 Adaptation and Management Options (adapted from WAPC, 2014)

Option Category	Option Name	Option Code	Description
Avoid	Avoid development	**AV**	New residential or commercial development within the coastal foreshore reserve is not allowed.
Managed Retreat	Leave unprotected / repair	**MR1**	Assets are left unprotected and loss is accepted following hazard event. Repairs may be implemented for public safety, and asset is retreated outside hazard zone, or in the case of beaches/vegetation, as natural recession occurs.
	Remove / relocate	**MR2**	Assets located in the hazard zone are relocated or destroyed. Applied to assets of low value where it is impractical to re-design to withstand hazard impacts.
	Prohibit further development / redevelopment	**MR3**	Allows continued use of the current infrastructure until such time that impacts arise, but prohibits the development of further infrastructure (densification) as the area/asset is known to be vulnerable.
Accommodate	Notification on title	**AC1**	Indicates to current and future landholders that an asset is likely to be affected by coastal hazards over the planning timeframe. Helps owners to make informed decisions about level of risk they are/may be willing to accept and that risk management and adaptation is likely to be required at some stage.
	Emergency plans and controls	**AC2**	Implement plans for assets/areas that are at risk of coastal erosion. Have procedures in place for before, during and after the events for safety. E.g. signage/barriers to prevent access.
	Re-design to withstand impact	**AC3**	Where avoiding or relocating is not an option, re-design to withstand impacts. E.g. raising houses and roads.
Protect	Dune care program	**PR1**	Development of a long term program for revegetation and rehabilitation of the dune system.
	Sand management	**PR2**	Involves the use of machinery to perform beach scraping or reshaping, which is the movement of sand along or up the beach face to optimise retention of material. Can also be in the form of sand bypassing or backpassing, which involves moving sand along a beach where it has been restricted by a structure. Sand fencing to manage wind-blown erosion also falls under this category.
	Beach nourishment	**PR3**	Replacement of sand on upper beach face and dunes to re-establish the sandy beach and provide additional buffer and sediment supply. Generally utilised in conjunction with other methods for sand retention (such as groynes).
	Groyne	**PR4**	Construct shore normal groynes along the beach to compartmentalise sediment and stabilise sections of shoreline.
	Nearshore reef / breakwater	**PR5**	Construct artificial reef or raise existing natural nearshore reef structure to maintain level of protection as sea level rises.
	Seawall	**PR5**	Construct seawall in front of asset or along length of coastline to protect it from coastal hazards. This may need to be accompanied by beach replenishment/renourishment.
Do nothing	Do nothing	**DN**	No limitations on development or controls on adaptation planning. Accept risk.

2.3 Success Criteria

The success criteria have been developed based on the results of the Coastal Values Survey, to underpin the CHRMAP process. These criteria were incorporated to determine consequence ratings during the risk assessment process. They have also been considered and referred to during the identification and assessment of adaptation options. The criteria are as follows:

SC1. Preservation and protection of important environmental sites and plant and animal communities;
SC2. Prioritisation of public safety at beaches and in foreshore areas;
SC3. Encouragement of coastal use through the provision and maintenance of public access and facilities at beaches and foreshore areas;
SC4. Protection and preservation of beaches and foreshore areas for recreational and passive use;
SC5. Provision and protection of foreshore areas for housing*;
SC6. Use and protection of foreshore areas for local economic benefit;
SC7. Provision and protection of beach and foreshore access infrastructure (e.g. roads, carparks, paths); and
SC8. Maintenance and protection of indigenous and archaeological heritage sites within the beach and foreshore areas.

*It should be noted that while this success criteria (SC5) received substantial response from the community, it is not compliant with SPP2.6 with respect to new development (assuming 'foreshore areas' are within the coastal foreshore reserve). Selecting the 'Protect' approach is considered least desirable, in general, under the risk management and adaptation hierarchy, as outlined in the CHRMAP guidelines (WAPC, 2014) (see also **Section 2.2** and **Figure 2-2**). All other success criteria have implications that are generally equitable to all community members, now and into the future, with respect to the use of coastal and foreshore areas. Alternatively, the implications of SC5 are likely to be beneficial to a select group of community members (i.e. protected landowners) and potentially detrimental to other members of the community, such as beach users and ratepayers contributing to the protection measures.

It is also noted that legally there is no obligation of the State or Local governments to either protect public and private assets within the coastal erosion zone, nor to compensate for any losses incurred due to erosion. While SC5 was considered a community aspiration it must be recognised that assets currently located in future potential impact zones are subject to a rigorous procedure for determining there suitability to attract state or local government funding for mitigation works.

3 Adaptation Planning Process

3.1 Multi-criteria Analysis Methods

This section details the selection and evaluation of possible adaption options to reduce risk levels and vulnerability. The CHRMAP has employed an overview style evaluation system to identify practical adaption options for each identified risk. Once a suitable adaption option, or combination of options, is recommended the residual risk is evaluated by assessing the option against the project's success criteria.

This evaluation style is qualitative and is designed to provide an overall indication of an option's suitability. Options are colour coded according to the traffic light method, displayed in **Table 3-1**. Red lights are not always intended to completely disregard the option, but more to provide an indication of when reassessment may be required or that the option is not feasible. An example of a completed, preliminary MCA is provided in **Table 3-2**. The process involves consideration of the following aspects.

Preliminary feasibility:

- Effectiveness;
- Legal / approval risk; and
- Reversibility / adaptability.

Preliminary acceptability:

- Environmental and social impact; and
- Community acceptability.

Preliminary financial implication:

- Financial gain / avoidance of cost;
- Capital cost; and
- Ongoing cost.

The MCA is considered to be preliminary at this stage, as the options have not yet been presented to the community or the City's council. Community acceptability is a key criteria of the MCA and the ratings for each option will be updated following community and council consultation.

Table 3-1 Multi-Criteria 'Traffic Light' Assessment Framework

	Preliminary Feasibility			Preliminary Acceptability		Preliminary Financial Implication		
	Effectiveness	Legal / Approval Risk	Reversibility / Adaptability	Environmental / Social Impact	Community Acceptability	Financial Gain / Avoidance of Cost	Capital Cost	Ongoing Cost
Unlikely to be acceptable	Likely to be ineffective	Not likely to be approved / likely to result in legal risk	Not likely to be reversible. Limits future options once implemented	Likely to have unacceptable negative impacts	Unlikely to meet most success criteria	No financial gain or avoidance of cost	Very expensive	Very expensive
May be acceptable	May be effective	May not be approved / may present legal risk	Likely to be reversible / adaptable at high costs	Some impacts that could be managed to an acceptable level	Mixed response, may meet some success criteria but not others	Some financial gain / some avoidance of cost	Moderately expensive	Moderately expensive
Likely to be acceptable or "No regrets"	Likely to be effective	Likely to be approved / minimal legal risk	Easily reversible or adaptable for the future. No negative impacts in the future	Not likely to have negative impacts / may have positive impacts	Likely to meet most success criteria	Large financial gain / avoidance of cost	Low cost	Low cost
Not Applicable								

Table 3-2 Example of preliminary multi-criteria analysis

Option Category	Option Code	Option Name	Preliminary Feasibility			Preliminary Acceptability		Preliminary Financial Implication			Recommendation
			Effectiveness	Legal / Approval Risk	Reversibility / Adaptability	Environmental / Social Impact	Community Acceptability	Economic gain / Avoidance of Cost	Capital Cost	Ongoing Cost	
Avoid	AV	Avoid development									Recommend
Managed Retreat	MR1	Leave unprotected / repair									Do not recommend
	MR2	Remove / relocate									Further assessment
	MR3	Prohibit further development / redevelopment									Recommend
Accommodate	AC1	Notification on title									Recommend
	AC2	Emergency plans and controls									Recommend
	AC3	Re-design to withstand impact	N/A								
Protect	PR1	Dune care program									Recommend
	PR2	Sand Management									Further assessment
	PR3	Beach Nourishment									Further assessment
	PR4	Groyne									Further assessment
	PR5	Nearshore Reef / Breakwater									Do not recommend
	PR6	Seawall									Further assessment
Do Nothing	DN	Do Nothing									Do not recommend

3.2 Adaptation and Management Options Assessment

Following the preliminary MCA, all options classified as 'recommended' or requiring 'further investigation' have been further assessed and are discussed for each study site in **Section 4** of this report. The options assessment is based on existing site specific or regional information and general coastal engineering knowledge. Many of the sites require further investigation to determine the suitability of certain adaptation and management options and are also discussed below.

3.3 Statutory Planning Considerations

The provisions of District Planning Scheme No. 2 (DPS2), relevant local planning policies and structure plans, where applicable, were examined to identify the existing controls relating to each site. This included the extent of current zones and reserves in relation to the plotted coastal process lines.

Planning related options that have been recommended for implementation or further investigation following the MCA have been considered with respect to DPS2. Recommendations have been made in regard to the modification, where appropriate, of existing planning controls to align them with these adaptation/management options.

4 Outcomes

4.1 Priority Ecological Community, Two Rocks

4.1.1 Preliminary Multi-criteria Analysis

A summary of the preliminary multi-criteria analysis for the PEC, Two Rocks is presented in **Table 4-1**. At present, there is no existing development, public infrastructure or access to this site. As such, the Managed Retreat (MR3) and Accommodate (AC1, AC2 and AC3) options have been deemed 'not applicable' for this site. Relocation of the PEC (MR2) has not been recommended due to the significant relative expense this would involve and likely ineffectiveness. Beach nourishment (PR3) and hard engineering protection options (PR4, PR5 and PR6) have not been recommended primarily due to the relatively large capital and ongoing costs involved in implementing these options. It is also likely to be seen as unacceptable or inappropriate to install engineered structures to control a section of coastline in its natural state. Taking no action (DN) is not recommended – as a minimum, planning controls should be implemented based on the coastal hazard extents defined in Part 1 of this CHRMAP (M P Rogers, 2015a), in accordance with SPP2.6 requirements.

4.1.2 Avoid Option

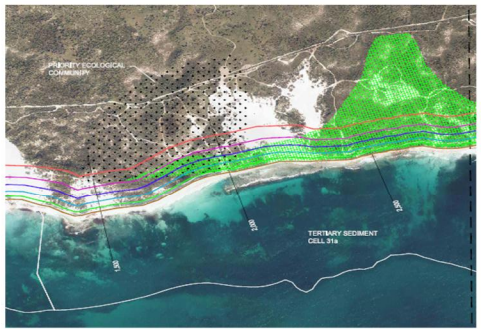
In accordance with SPP2.6, it is recommended that new development is avoided (AV) seaward of the 2120 coastal erosion hazard line, plus an additional allowance for foreshore reserve. Recommendations around the specific mechanisms for implementing this control are detailed below in **Section 4.1.6**.

4.1.3 Managed Retreat Option

Leaving the PEC unprotected against coastal hazards (MR1) is likely to lead to a gradual recession of the vegetation line over time with an expected rising mean sea level (MSL) and, therefore, greater inland reach of coastal erosion events. Coastal vegetation assemblages have the capacity to repair themselves following erosion events, depending on the frequency of impact. Dune vegetation is important in helping to consolidate the dune system and provides some protection against wind-blown erosion. It provides minimal protection against coastal storm surge due to its shallow rooted nature. Replanting vegetation in areas prone to frequent coastal impact, without implementing additional protective measures, would ultimately be a waste of resources. The gradual loss of a portion of the PEC at the shoreline over time may be deemed acceptable (given that rising MSL is a quasi-natural phenomenon) provided monitoring and management is undertaken to ensure undue pressure is not being placed on the overall PEC. If this option is adopted it would be recommended that a dune care program, involving the repair of inland areas damaged by four wheel driving activities, be implemented to reduce the overall pressure on the PEC and compensate for habitat loss adjacent to the beach.

Table 4-1 Preliminary Multi-criteria Analysis for PEC, Two Rocks

1: Priority Ecological Community, Two Rocks



Main asset type Environmental

Long term pathway TBD

Vulnerability timeframe 2050

	2015	2030	2050	2070	2090	2120
	Vulnerability					
Beach	Low	Low	Medium	Medium	Medium	Medium
BFS 397	Low	Low	Medium	Medium	High	Very High
PEC	Low	Low	High	High	Very High	Very High

Option Category	Option Code	Option Name	Preliminary Feasibility			Preliminary Acceptability		Preliminary Financial Implication			Recommendation
			Effectiveness	Legal / Approval Risk	Reversibility / Adaptability	Environmental / Social Impact	Community Acceptability	Economic gain / Avoidance of Cost	Capital Cost	Ongoing Cost	
Avoid	AV	Avoid development									Recommend
Managed Retreat	MR1	Leave unprotected / repair									Further assessment
	MR2	Remove / relocate									Do not recommend
	MR3	Prohibit further development / redevelopment	N/A								
Accommodate	AC1	Notification on title	N/A								
	AC2	Emergency plans and controls	N/A								
	AC3	Re-design to withstand impact	N/A								
Protect	PR1	Dune care program									Recommend
	PR2	Sand Management									Further assessment
	PR3	Beach Nourishment									Do not recommend
	PR4	Groyne									Do not recommend
	PR5	Nearshore Reef / Breakwater									Do not recommend
	PR6	Seawall									Do not recommend
Do Nothing	DN	Do Nothing									Do not recommend

4.1.4 Protect Options

Dune care program

It is recommended that a dune care/revegetation program (PR1) be implemented for the PEC which involves preventing four wheel drive access and revegetating tracks and other areas that have been degraded due to anthropogenic impacts. A concept design showing the areas recommended for revegetation is presented in **Figure 4.1** of **Appendix C**. Dune care programs along the Western Australia coastline are generally undertaken by volunteer groups (primarily community groups working under Coastcare) and, as such, their cost of implementation is difficult to quantify. The City should liaise with Coastcare to determine the best methods of implementing a dune care program at this site and the resources likely to be required. Preventing four wheel drive access to coastal areas in the City's LGA is an ongoing issue and is likely to require significant resources to implement and police.

Sand Management

Sand management techniques, such sand scraping and sand fencing, are generally seen as small scale and short-term solutions to coastal erosion issues. The large scale of this site and limited access at present is likely to mean such techniques will have a high relative expense for minimal protective impact over the long-term. It is understood that there are plans to develop land in the vicinity of the PEC and that the beach areas may become more accessible and frequented in the future. In this case, sand management techniques could be implemented to control small portions of the site for beach amenity. Dune blowouts at the south of the site suggest wind-blown erosion is an issue in the area. Sand-fencing could be implemented to control the impact of wind-blown erosion on the beach and inland areas. Sand scraping may also be considered in the future as a method of maintaining useable beach areas and providing additional protection in front of beach dunes and access infrastructure. A detailed sediment budget and geotechnical assessment of the foreshore and coastal dunes zone would be required to develop a cost estimate for the optimal sand management technique.

4.1.5 Equity Implications

Dune care is generally considered a socially equitable and environmentally positive option which is broadly applicable to most coastal sites. Small scale sand management is also aimed to improve public amenity and environmental protection, therefore, the beneficiaries of the selected options are the conservation estate and the general public. No coastal engineering protection works are proposed that could result in increased erosion at other locations adjacent to the site, and therefore there are limited equity implications in adopting the recommended management options.

4.1.6 Statutory Planning Considerations

Preparation of a proposed local structure plan for North Two Rocks is well advanced at this location (CLE 2014).

The Priority Ecological Community (PEC) appears to be located largely within land indicated for R80 - R60 and R30 – R60 residential development. It is not the purpose of this study to recommend on the appropriate mechanisms for conserving this PEC within the structure plan beyond the limits of the modelled 2120 hazard line, however if development entails removal or damage to the PEC then combined with the threat posed by coastal processes there is a high probability that most if not all of it will disappear as there will be no opportunity for it to progressively recolonise eastwards as the coast recedes.

The coastal parts of the PEC are located within the current MRS Parks and Recreation reserve. This reserve boundary broadly aligns with the 2070 hazard line in this location, although in some parts the 2070 hazard line encroaches beyond the reserve into the Urban zone. However, a significant portion of the urban zone is impacted by the 2090 and 2120 hazard lines. This means that the entire Parks and Recreation Reserve and a considerable portion of the Urban zone may have a high vulnerability beyond 2070.

The draft local structure plan proposes a Special Use (Coastal) zone over land affected by the physical processes within the structure plan boundary.

> It will be necessary to overlay the physical processes setbacks identified in the CHRMAP with those in the draft structure plan, which was prepared in 2014, prior to completion of the work by MP Rogers in late 2015. It is probable that the setbacks applied in the draft structure plan are less than those now

identified, meaning that the PEC and land identified for future development in the structure plan will be more exposed to risk than originally anticipated.

> The draft structure plan contemplates subdivision and development within the Special Use (Coastal) zone that would not be permitted within the coastal foreshore reserve, as outlined in LPP 4.21. The City should carefully consider the proposed provisions relating to this proposed zone, including the legal effectiveness of any indemnity relating to effects of coastal processes on development and the potential impacts on the objective of maintaining public access to the coast of any protection measure that might be put in place by a private owner to protect their land.

> The City should give consideration to ways in which zoned land at risk of impact from coastal processes could be included in an expanded foreshore reserve, including possible incentives.

Avoidance of development would require amendment of the structure plan so that land within the area exposed to coastal processes plus an allowance for future foreshore access and amenity is designated for foreshore reserve. Application of LPP 2.41 over that land would then be appropriate.

Designating the land as a Special Use (Coastal) zone as presently proposed would have the effect of the land being an extension of the adjacent future Coastal Centre and would not protect it from being further subdivided.

Planning for the future Coastal Centre, which may also be affected by coastal processes (subject to detailed overlay to be determined), would need to accommodate managed retreat and preservation of a coastal foreshore reserve.

As development has not yet occurred, one option would be to amend DPS2 to introduce a local reserve over the affected land, pending future extension of the MRS Parks and Recreation reserve. The local reserve and zone boundaries would then have to be reflected in any structure plan pertaining to this site. It should be noted, however, that applying a reserve over privately owned land would trigger a claim for injurious affection under the Planning and Development Act (2005). Alternatively, DPS2 could be amended to apply a Special Control Area (SCA) over affected land to restrict its use to temporary development. The SCA might incorporate other controls that would allow retreat of development and commensurate expansion of the publicly accessible foreshore as defined trigger events (which would have to be identified) were reached. Linking retreat to trigger events would allow development to remain for a longer or lesser time depending on the speed with which predicted coastal recession progresses.

It is recommended that the City carefully consider the implications of the current proposed structure plan provisions with respect to the identified 2120 hazard line, plus the requirements for additional foreshore reserve width. Mechanisms available to limit future liabilities should be fully investigated.

Protection via a dune care programme would not require planning intervention per se, however the ability to protect the PEC in the longer term presupposes that there remain dunes to care for.

4.2 Sovereign Drive and Adjacent Residential Lots, Two Rocks

4.2.1 Preliminary multi-criteria analysis

A summary of the preliminary multi-criteria analysis for Sovereign Drive and Adjacent Residential Lots, Two Rocks is presented in **Table 4-2**. Due to the significant public and private infrastructure that is vulnerable at this site, leaving unprotected (MR1) has not been recommended. The redesigning of infrastructure, such as roads and houses, to withstand coastal erosion impacts (AC3) has been deemed not applicable in this setting. Taking no action (DN) has not been recommended due to the significant infrastructure present and, therefore, risk to the City.

4.2.2 Previous Assessment

Department of Transport (DoT)

As Two Rocks Marina is managed by the DoT they have a vested interest in the Marina any coastal erosion issues that may be associated with the Marina. The City should continue to liaise closely with the DoT regarding the monitoring and management of coastal erosion at this site. It should be noted that the Septre Court staircase was damaged by coastal erosion and removed in October 2016. The City is currently looking to undertake design and construction of a replacement structure, incorporating the findings of the options assessment (M P Rogers, 2015b) (see below) and the CHRMAP. The City is looking to the State Government to fund this and potential future adaptation and management measures, as it appear that the Marina is exacerbating coastal erosion at this site.

Management options assessment

A detailed assessment of management options for this site, over a 25 year planning timeframe, has been undertaken by M P Rogers (2015b) and is presented in the *Two Rocks Coastal Management Report*. The assessment of management options for the site is more extensive and detailed than the assessment that would generally be undertaken as part of this CHRMAP. As such, the results of the report are referred to for many of the management options below, with some additional commentary around the longer term (beyond 25 years) implications of each management option.

Geophysical information

Considerable geophysical information has been collected at this site and is summarised in the *Two Rocks Geophysical Infill Survey* (GBGMaps, 2016). The investigations show a significant presence of underlying limestone at the site. This information has not, however, been sufficient to suggest there is a continuous barrier that would prevent coastal erosion. The coast has, therefore, been treated as entirely sandy for the development of the coastal erosion hazard lines (M P Rogers, 2015a). Prior to the implementation of any major management option, it is recommended that an investigation of the influence that this geology would have on predicted shoreline recession and loss of beach, under future climate change scenarios. Field observations are scant on the influence of underlying rock for perched beaches experiencing erosion, in comparison to unbounded sandy beaches (Gallop et al, 2011).

4.2.3 Avoid Option

In accordance with SPP2.6, it is recommended that new residential development is avoided (AV) seaward of the 2120 coastal erosion hazard line, plus an additional allowance for foreshore reserve. Recommendations around the specific mechanisms for implementing this control are detailed below in **Section 4.2.8**.

4.2.4 Managed Retreat Options

Remove/relocate

MP Rogers (2015b) investigated adopting a ‘managed retreat’ option (MR2) at this site and the potential requirements and implications over a 25 years planning timeframe (**Appendix D**). This option involved the relocation of a navigation marker and the Sceptre Court Stairs and Platform. The option also incorporated an 80m extension alongshore of the northern marina seawall, as a protective measure. The estimated cost for adopting this option was approximately $980,000. In addition to this, a shoreline monitoring program is recommended with a present day cost of approximately $10,000 per annum. Beyond a 25 year planning timeframe, considerably more public and private infrastructure is predicted to be vulnerable to coastal

erosion. The implications of adopting a managed retreat approach for this site, beyond a 25 year planning timeframe should be considered and reviewed before adopting this option.

Prohibit further development or redevelopment

It is recommended that the City consider prohibiting any further development or redevelopment (MR3) seaward of the 2120 coastal erosion hazard line, plus an additional allowance for foreshore reserve, except where it complies with SPP2.6 (e.g. infill development). The appropriateness of this prohibition should also be assessed in the future, once a clear adaptation pathway has been developed for the site. The specific mechanisms available for implementing this control are discussed below in **Section 5.3.2**.

4.2.5 Accommodate Options

Notification on title

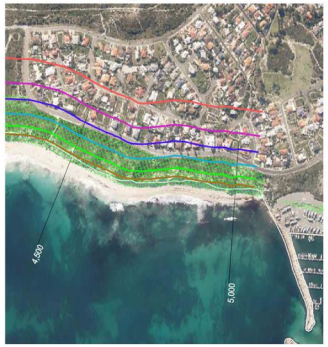
It is recommended that notifications be placed on the titles of all properties lying seaward of the 2120 hazard line, as required under SPP2.6. How this is achieved should be determined by the City in consultation with the Department of Planning. A recommendation for applying this control is provided in **Section 5.3**.

Emergency plans and controls

As various infrastructure at this site is projected to become vulnerable to coastal hazards over future planning timeframes, it is recommended that emergency plans and controls are prepared and put in place (AC2) so that they can be actioned when this infrastructure is threatened or damaged by coastal erosion events. This option is particularly pertinent if protect options are not implemented at the site. Preparing emergency plans and controls before the infrastructure becomes vulnerable will ensure there is a clear plan of action which can be implemented by the City in the event of a hazardous coastal erosion event. This plan may include, for example, closing the relevant public infrastructure and/or otherwise restricting access, putting up signage informing the public of implemented changes and recommended alternative usage areas, and informing any other relevant authorities of implemented changes and restrictions. The trigger for implementation of the emergency plan and controls should be based on ongoing monitoring of the site.

Table 4-2 Preliminary Multi-criteria Analysis for Sovereign Drive and Adjacent Residential Lots, Two Rocks

2: Sovereign Drive and Residential Lots



Main asset type Economic / Social
Long term pathway TBD
Vulnerability timeframe 2050

	2015	2030	2050	2070	2090	2120
	Vulnerability					
Beach	Low	Low	Medium	High	Very High	Very High
BFS 397	Low	Medium	High	High	Very High	Very High
Sovereign Dve	Low	Low	High	Very High	Very High	Very High
Residential (SD)	Low	Low	High	Very High	Very High	Very High
Residential (TA)	Low	Low	High	High	Very High	Very High
Tenggara Ave	Low	Low	High	High	Very High	Very High

Option Category	Option Code	Option Name	Preliminary Feasibility			Preliminary Acceptability		Preliminary Financial Implication			Recommendation
			Effectiveness	Legal / Approval Risk	Reversibility / Adaptability	Environmental / Social Impact	Community Acceptability	Economic gain / Avoidance of Cost	Capital Cost	Ongoing Cost	
Avoid	AV	Avoid development									Recommend
Managed Retreat	MR1	Leave unprotected / repair									Do not recommend
	MR2	Remove / relocate									Further assessment
	MR3	Prohibit further development / redevelopment									Recommend
Accommodate	AC1	Notification on title									Recommend
	AC2	Emergency plans and controls									Recommend
	AC3	Re-design to withstand impact	N/A								
Protect	PR1	Dune care program									Recommend
	PR2	Sand Management									Further assessment
	PR3	Beach Nourishment									Further assessment
	PR4	Groyne									Further assessment
	PR5	Nearshore Reef / Breakwater									Further assessment
	PR6	Seawall									Further assessment
Do Nothing	DN	Do Nothing									Do not recommend

4.2.6 Protect Options

Dune care program

It is recommended that a dune care/revegetation program (PR1) be implemented for the dune system fronting Sovereign Drive. This program would help to consolidate the dune system and maintain its function as a protective buffer. It would also help to reduce wind-blown erosion and retain sand within the beach system. The program might involve revegetating or enhancing vegetation in degraded areas and preventing dune access outside of the provided access ways. The program would not be a protective measure against coastal storm surge. A concept design showing the area recommended for dune care is presented in **Figure 4.2** of **Appendix C**. Dune care programs along the Western Australia coastline are generally undertaken by volunteer groups (primarily community groups working under Coastcare) and, as such, their cost of implementation is difficult to quantify. The City should liaise with Coastcare to determine the best methods of implementing a dune care program at this site and the resources likely to be required.

Beach nourishment

M P Rogers (2015b) assessed the option of applying sand nourishment to the beach at the study site, as a management technique over a 25 years planning timeframe (**Appendix D**). Their assessment was accompanied by a 50 m extension alongshore of the existing marina seawall, relocating the Sceptre Court Stairs and Platform and an ongoing shoreline monitoring campaign. It was estimated that on average 25,000 m^3 of sand would be required to be placed each year at a cost of approximately $900,000 per annum. Shoreline monitoring would also be required to ensure the proper and timely placement of sand, to optimise the effect of placement. Beyond the 25 year timeframe assessed by M P Rogers (2015b), the required volume of material and subsequent cost to maintain the shoreline position would increase and eventually become unviable, based on MSL rise and shoreline recession predictions. This option may be useful as a short-term measure to mitigate risk but it is unlikely to be a long-term (beyond 50 years) solution if predicted rises in MSL are realised.

Sand management

Sand management, in the form of sand bypassing, would involve taking material from the southern side of Two Rocks Marina, where it currently accumulates, and depositing it on the beach in front of the study site, to the north of the marina. This is effectively assisting the natural process of longshore sediment transport northward. The effect of sand bypassing is the same as described above for beach nourishment, however, the source is readily available to the City, leading to reduced cost. M P Rogers (2015b) have estimated the bypassing of, on average, 25,000 m^3 of sand each year at a cost of approximately $390,000 per annum. A shoreline monitoring program estimated at around $10,000 per year would also be required to help optimise the effectiveness of bypassing activities. M P Rogers (2015b) have concluded the most effective bypassing method would be by using a mobile pumping plant system (**Appendix D**). Based on this, sand bypassing is likely to be a more economical method of renourishment, compared to importing sand from an outside source. Again, beyond the 25 years planning timeframe, the volume of material required to maintain the shoreline position is likely to increase. Available sediment to the south of the marina is also likely to diminish into the future with predicted rise in MSL. These factors are likely to make this option unviable in the long-term (beyond 50 years).

Groyne(s)

M P Rogers (2015b) investigated the staged implementation of two groynes (PR4) in front of the study site to stabilise the shoreline and help retain sediment on the beach in front of the infrastructure (**Appendix D**). This option also involves a 50 m extension of the northern marina seawall. The estimated overall cost to implement this option was $4.7 million (at 2015 prices), including contingencies. Due to the staged approach, this cost would be spread over several years. An annual shoreline monitoring program, at a cost of $10,000 per annum, has also been recommended. No provision has been made for sand nourishment or back passing over the 25 year planning timeframe. Although the groynes will stabilise the shoreline by restricting alongshore sediment transport, the addition of sediment is still likely to be required to replace material lost due to the combination of storm events and predicted MSL rise. This may not be required within the 25 years planning timeframe but will likely be a significant cost to consider over the lifespan of the protective structures. The impacts to areas of the coast to the north of the groynes, due to changes to the alongshore sediment transport regime, should also be considered prior to selecting this option. Detailed sediment

transport modelling, incorporating sea level rise scenarios, would be recommended to further assess the long-term implications of adopting this option.

Offshore breakwaters

The construction of offshore breakwaters (PR5) as a protective measure was investigated by M P Rogers (2015b) (**Appendix D**). This also included a 50 m extension of the northern marina seawall and the relocation of the Sceptre Court Stairs and Platform. The total estimated cost of implementing this option was $7.2 million (at 2015 prices). It is recommended that further modelling and investigation of the interaction these offshore breakwaters would have on the local sediment transport regime is undertaken, including an assessment of potential impacts to other area along the coastline. The cost of maintenance, upgrade and refurbishment of the breakwaters, beyond the 25 years planning timeframe should also be considered.

Seawall

M P Rogers (2015b) investigated the construction of an 860 m long seawall (PR6) in a staged approach, as a protective measure for the site (**Appendix D**). The seawall has been proposed to provide approximately 40 m of buffer seaward from the edge of Sovereign Drive. This would allow the protection of a large portion of the dune vegetation, however, ultimately the beach would be degraded and potentially lost over time, without intervention. The estimated overall cost of constructing the seawall, including contingencies, was approximately $5.9 million (M P Rogers, 2015b). It was also recommended that the first stage of construction be completed in approximately 5 years time, to maintain an adequate buffer between the seawall and Sovereign drive. The cost to maintain the seawall beyond a 25 year planning timeframe, and the source of funding for this maintenance, should be fully investigated prior to selecting this option.

4.2.7 Equity Implications

The selection of adaptation options for this site has significant equity implications. Residents in this area would be the main beneficiaries of protection measures along with beach users, where protection options incorporate retaining the beach. Costly protection works may reduce budget availability for alternative public works or programs in other areas of the LGA / State. Protective structures also have the potential for shifting and exacerbating erosion impacts to other areas of the coastline, and/or reducing public amenity of the beach.

Residents would also bear much of the disadvantage from managed retreat options, since there is no legal requirement for compensation in the event of eviction (voluntary or forced) and /or loss of property.

The avoid option would result in loss of revenue to land owners, the state and/or the City if previously valuable land cannot be developed.

Dune care is generally a socially equitable and environmentally positive option which is broadly applicable to most coastal sites.

4.2.8 Statutory Planning Considerations

Currently there is an MRS Parks and Recreation reserve between Sovereign Drive and the ocean, whilst the residential lots are zoned Residential R20 in DPS2. The Local Housing Strategy implementation is guided by LPP 3.1 Local Housing Strategy Implementation, which proposes increased density from R20 to R40 and R60 to promote redevelopment/infill of this older, established part of Two Rocks.

A significant number of lots and all of Sovereign Drive, plus all or part of several local access roads are modelled to be affected by coastal processes by 2120.

The proposed rezoning is only likely to see more intensive development of existing lots, or minor land assembly to achieve larger development sites, with the result that ownership will be further fragmented through subdivision (including strata subdivision). Redevelopment of existing lots may result in more defensive construction if appropriate requirements are inserted into the planning scheme. Whether this would be sufficient to prevent long term impacts on assets, however, would require further investigation and probably an overall scheme to ensure a consistent, adequate defence.

A developer contribution scheme imposed on redevelopment might be appropriate to fund design and construction of an adequate defence in the long term.

Avoidance of any new development on the foreshore reserve is possible, or limited development in accordance with LPP 2.21. It is too late to avoid development on the zoned land, as it has already occurred.

Removal or relocation of existing development would require acquisition of affected properties. Relocation would require identification and appropriate zoning of an alternative location. The highly fragmented land ownership is a significant impediment.

Comprehensive redevelopment of this area to relocate development beyond the 2120 line would be highly unlikely without significant incentive through rezoning and/or much higher density development being possible on the unaffected land, and even then would require a long lead time and appropriate market conditions. Rezoning in the short term to encourage long term comprehensive redevelopment would be likely to result in blight and/or artificially inflated property prices on the 'up-zoned' land which would make land assembly by a motivated developer more difficult. Such a course of action may have long term merit but would need careful management and a considerable amount of further investigation.

Prohibition of further development or redevelopment

Rezoning of affected land or another scheme amendment (such as introducing an SCA) would be required to prevent further development. Depending upon the option selected it may open up the right to claim for injurious affection for affected landowners, and could result in progressive deterioration of housing stock if owners have no incentive to invest in maintenance of properties. LPP 3.1 and the proposed increase in residential density for this area should be carefully reviewed by the City, in light of the information presented in this report and the overall CHRMAP.

4.3 Beach Access Road and Carpark 'The Spot', Two Rocks

4.3.1 Preliminary Multi-criteria Analysis

A summary of the preliminary MCA for the Beach Access Road and Carpark 'The Spot', Two Rocks is presented in **Table 4-3**. At present, the only public access and infrastructure at this location is an unsealed road and both upper and lower carparks. The lower carpark in particular is located close to the current shoreline. As such, some of the Managed Retreat (MR3) and Accommodate (AC1 and AC3) options have been deemed 'not applicable' for this site. Beach nourishment (PR3) and hard engineering protection options (PR4, PR5 and PR6) have not been recommended primarily due to the relatively large capital and ongoing costs involved in implementing these options. It is also likely to be seen as unacceptable or inappropriate to install engineered structures to control a section of coastline in a relatively natural state. Taking no action (DN) is not recommended – as a minimum, planning controls should be implemented based on the coastal hazard extents defined in Part 1 of this CHRMAP (M P Rogers, 2015a), in accordance with SPP2.6 requirements.

4.3.2 Avoid Options

In accordance with SPP2.6, it is recommended that new residential development is avoided (AV) seaward of the 2120 coastal erosion hazard line, plus an additional allowance for foreshore reserve. Recommendations around the specific mechanisms for implementing this control are detailed below in **Section 4.3.7**.

4.3.3 Managed Retreat Options

Leave unprotected/repair

Leaving the lower carpark and the section of the beach access road between the upper and lower carparks unprotected (MR1) would mean that they may be damaged by coastal erosion at some point in the future, which would require subsequent repairs to make them safe and functional again. Both the frequency and extent of damage to these elements of infrastructure from coastal erosion events would generally increase over time from that point, as would the associated repair requirements and costs. Although the hazard lines suggest the assets are vulnerable over the planning timeframe, there is some uncertainty around this, given the high relief of the assets and the considerable rock formations in the area. Monitoring and further investigation (such as a geophysical survey) should be undertaken to assess the need for any action at this site.

Remove/relocate

Another option for managed retreat would be to remove and relocate the carpark (MR2) to an area further from the shoreline where it is no longer vulnerable to coastal hazards. This is particularly applicable for the lower carpark and the section of the access road between the upper and lower carparks, though it should be noted that the hazard lines also start to encroach on the current upper carpark by the 2120 timeframe. The lower carpark could be removed and relocated to the area adjacent to the upper carpark as shown in **Figure 4.3** of **Appendix C**. It is recommended that the removal and relocation of the lower carpark and the section of beach access road between the upper and lower carparks be undertaken before or when they become vulnerable to coastal hazards, for safety and functionality reasons. The trigger to undertake this action should be based on ongoing monitoring of the shoreline in front of the assets.

Table 4-3 Preliminary Multi-criteria Analysis for 'The Spot'

3: Beach Access Road (to 'The Spot') (Unsealed)

Main asset type Economic / Social

Long term pathway TBD

Vulnerability timeframe 2070-2090

	2015	2030	2050	2070	2090	2120
	Vulnerability					
Beach	Low	Low	Medium	Medium	High	High
BFS 397	Low	Low	Low	Medium	High	Very High
Beach Carpark (unsealed)	Low	Low	Low	Low	Medium	Medium
Beach Access Rd (unsealed)	Low	Low	Low	Low	Medium	Medium

Option Category	Option Code	Option Name	Preliminary Feasibility			Preliminary Acceptability		Preliminary Financial Implication			Recommendation
			Effectiveness	Legal / Approval Risk	Reversibility / Adaptability	Environmental / Social Impact	Community Acceptability	Economic gain / Avoidance of Cost	Capital Cost	Ongoing Cost	
Avoid	AV	Avoid development									Recommend
Managed Retreat	MR1	Leave unprotected / repair									Recommend
	MR2	Remove / relocate									Recommend
	MR3	Prohibit further development / redevelopment	N/A								
Accommodate	AC1	Notification on title	N/A								
	AC2	Emergency plans and controls									Recommend
	AC3	Re-design to withstand impact	N/A								
Protect	PR1	Dune care program									Further assessment
	PR2	Sand Management									Further assessment
	PR3	Beach Nourishment									Do not recommend
	PR4	Groyne									Do not recommend
	PR5	Nearshore Reef / Breakwater									Do not recommend
	PR6	Seawall									Do not recommend
Do Nothing	DN	Do Nothing									Do not recommend

4.3.4 Accommodate Options

Emergency plans and controls

As the lower carpark and the associated section of the beach access road are predicted to become vulnerable over future planning timeframes, it is recommended that emergency plans and controls are prepared and put in place (AC2) so that they can be actioned if and when this infrastructure is threatened or damaged by coastal erosion. These plans would be particularly pertinent for this site if managed retreat options are adopted. Preparing emergency plans and controls before the infrastructure becomes vulnerable will ensure there is a clear plan of action which can be implemented by the City in the event of a threat/damage by coastal erosion. This plan may include, for example, closing the relevant infrastructure and/or otherwise restricting access, putting up signage informing the public of implemented changes and recommended alternative usage areas, and informing any other relevant authorities of implemented changes and restrictions. The trigger for implementation of the emergency plan and controls should be based on ongoing monitoring of the site.

4.3.5 Protect Options

Dune Care Program

It is currently considered that undertaking a dune care program (PR1) at this site is unnecessary as the public appears to be generally accessing the beach via the established access ways and the coastal vegetation appears to be in good health. Resources for this form of protection could be better allocated to other sections of coast within the LGA. However, this option could be considered in the future should monitoring suggest it is required. Dune care programs along the Western Australia coastline are generally undertaken by volunteer groups (primarily community groups working under Coastcare) and, as such, their potential cost of implementation is difficult to quantify. The City could liaise with Coastcare to determine the best methods of implementing a dune care program at this site and the resources likely to be required if this option is to be pursued.

Sand Management

Sand management techniques (PR2), such as sand scraping and sand fencing, are generally seen as small scale and short-term solutions to coastal erosion issues and would not be recommended, at present, for this site. The area is generally accessed as a surf break which means the focus of the public is on the surf conditions rather than the beach amenity. Sand management techniques could be implemented to control small portions of the site for beach amenity, however the public appears to be generally accessing the beach via the established access ways, meaning the benefit of sand management in this area is likely to be relatively low compared to other sites. Sand-fencing could be implemented in the future to control the impact of wind-blown erosion on the beach and inland areas. Sand scraping may also be considered in the future as a method of maintaining useable beach areas and providing additional protection in front of beach dunes and access infrastructure. A detailed sediment budget and geotechnical assessment of the foreshore and coastal dunes zone would be required to develop a cost estimate for the optimal sand management technique.

4.3.6 Equity Implications

Based on the small scale of infrastructure at this site and the nature of management options, there are minimal equity implications in managing this site at this point in time.

4.3.7 Statutory Planning Considerations

This site is fully contained within an MRS Parks and Recreation reservation and relocation of the car park and access road as and when required would be technically achievable. The lower car park is at risk although it is situated on a rocky section of coastline. It is noted that the upper car park has recently been extended although this too may be partly at risk of impact in the longer term.

Of possible greater concern but beyond the scope of this work, however, is that the coastal processes lines encroach into zoned land to the south of this site, within the Yanchep Two Rocks District Structure Plan. This will require further investigation with a view to potentially reserving any affected land for an extension of the coastal foreshore reserve.

Avoidance of any new development on the foreshore reserve is possible, or limited development in accordance with LPP 2.21 can be contemplated.

4.4 Carpark South of Capricorn Groyne, Yanchep

4.4.1 Preliminary Multi-criteria Analysis

A summary of the preliminary multi-criteria analysis for the Carpark South of Capricorn Groyne, Yanchep is presented in **Table 4-4**. At present, the infrastructure in this area consists of a groyne (which is in a degraded state), a carpark behind the groyne, the access road to the groyne carpark, a second carpark adjacent to the Capricorn Village site and the Capricorn Village site itself. The redesigning of infrastructure to withstand coastal impact (AC3) has been deemed 'not applicable' in this setting. Hard engineering protection options (PR5 and PR6) have not been recommended primarily due to the relatively large capital and ongoing costs involved in implementing these options. Taking no action (DN) is not recommended – as a minimum, planning controls should be implemented based on the coastal hazard extents defined in Part 1 of this CHRMAP (M P Rogers, 2015a), in accordance with SPP2.6 requirements.

4.4.2 Avoid Options

In accordance with SPP2.6, it is recommended that new residential development is avoided (AV) seaward of the 2120 coastal erosion hazard line, plus an additional allowance for foreshore reserve. Recommendations around the specific mechanisms for implementing this control are detailed below in **Section 4.4.7**.

4.4.3 Managed Retreat Options

Leave unprotected/repair

Leaving the groyne carpark and the beach access road unprotected (MR1) would mean that they will potentially be damaged by coastal erosion at some point in the future, which would require subsequent repairs to make them safe and functional again. Both the frequency and extent of damage to these elements of infrastructure from subsequent coastal erosion events would generally increase over time from that point, as would the associated repair requirements and costs. Due in part to the presence of the existing groyne near the lower carpark, the future erosion in front of the lower carpark is less certain and so leaving the carpark unprotected and repairing in the event of damage could be adopted at present while the changes in this area are monitored.

Remove/Relocate

Another option for managed retreat of the lower carpark and beach access road is to remove and relocate them (MR2) to an area further from the coast where they are no longer vulnerable and to do this at or before the time where they become vulnerable to coastal erosion. This is particularly applicable for the lower carpark and the section of the beach access road between the upper and lower carparks, though it should be noted that the hazard lines start to encroach on the current upper carpark by the 2120 timeframe. The lower carpark could be removed and relocated to the area adjacent to the upper carpark as shown in **Figure 4.4** of **Appendix C**. It would be recommended that the removal and relocation of the lower carpark and the section of beach access road between the upper and lower carparks be further assessed, due in large part to the presence of the existing groyne which makes the future erosion in front of the lower carpark less certain. The option to remove\relocate the lower carpark and beach access road can be implemented at a future point once it has become likely that this infrastructure will be impacted by coastal hazards. The trigger to undertake this action should be based on ongoing monitoring of the area in front of the lower carpark.

Prohibit Further Development/Redevelopment

In accordance with SPP2.6, it is recommended that any further development or redevelopment (MR3) is not permitted seaward of the 2120 coastal erosion hazard line, plus an additional allowance for foreshore reserve. Recommendations around the specific mechanisms for implementing this control are detailed below in **Section 4.4.7**.

Table 4-4 Preliminary Multi-criteria Analysis for Capricorn Groyne Carpark

4: Capricorn Groyne Carpark

Main asset type Economic / Social

Long term pathway TBD

Vulnerability timeframe 2070-2090

	2015	2030	2050	2070	2090	2120
	Vulnerability					
Beach	Low	Low	Medium	Medium	High	High
BFS 397	Low	Low	Low	Medium	High	Very High
Groyne Carpark	Low	Low	Low	Medium	High	High
Road	Low	Low	Low	Medium	Medium	High
Car park (Cap Vill)	Low	Low	Low	Low	Low	Medium
Residential (Cap Vill)	Low	Low	Low	Low	Low	High

Option Category	Option Code	Option Name	Preliminary Feasibility			Preliminary Acceptability		Preliminary Financial Implication			Recommendation
			Effectiveness	Legal / Approval Risk	Reversibility / Adaptability	Environmental / Social Impact	Community Acceptability	Economic gain / Avoidance of Cost	Capital Cost	Ongoing Cost	
Avoid	AV	Avoid development									Recommend
Managed Retreat	MR1	Leave unprotected / repair									Further assessment
	MR2	Remove / relocate									Further assessment
	MR3	Prohibit further development / redevelopment									Recommend
Accommodate	AC1	Notification on title									Recommend
	AC2	Emergency plans and controls									Recommend
	AC3	Re-design to withstand impact	N/A								
Protect	PR1	Dune care program									Recommend
	PR2	Sand Management									Further assessment
	PR3	Beach Nourishment									Further assessment
	PR4	Groyne									Further assessment
	PR5	Nearshore Reef / Breakwater									Do not recommend
	PR6	Seawall									Do not recommend
Do Nothing	DN	Do Nothing									Do not recommend

4.4.4 Accommodate Options

Notification on Title

It is recommended that notifications be placed on the titles of all properties lying seaward of the 2120 hazard line, as required under SPP2.6. How this is achieved should be determined by the City in consultation with the Department of Planning. A recommendation for applying this control is provided in **Section 5.3**.

Emergency Plans and Controls

As multiple elements of infrastructure at this site, particularly the lower carpark and associated beach access road, are predicted to become vulnerable to coastal erosion over future planning timeframes, it is recommended that emergency plans and controls are prepared and put in place (AC2) so that they can be actioned when this infrastructure is threatened or damaged by coastal erosion. This will be particularly pertinent if managed retreat options are adopted at this site. Preparing emergency plans and controls before the infrastructure becomes vulnerable will ensure there is a clear plan of action which can be implemented by the City in the event of a threat/damage by coastal erosion. This plan may include, for example, closing the relevant infrastructure and/or otherwise restricting access, putting up signage informing the public of implemented changes and recommended alternative usage areas, and informing any other relevant authorities of implemented changes and restrictions. The trigger for implementation of the emergency plan and controls should be based on ongoing monitoring of the site.

4.4.5 Protect Options

Dune Care Program

It is recommended that a dune care/revegetation program (PR1) be implemented for the dune system on both sides of the existing groyne. This program would help to consolidate the dune system and maintain its function as a protective buffer. It would also help to reduce wind-blown erosion and retain sand within the beach system. The program might involve revegetating or enhancing vegetation in degraded areas and preventing dune access outside of the provided access ways. The program would not be a protective measure against coastal storm surge. A concept design showing the area recommended for dune care is presented in **Figure 4.4** of **Appendix C**. Dune care programs along the Western Australia coastline are generally undertaken by volunteer groups (primarily community groups working under Coastcare) and, as such, their cost of implementation is difficult to quantify. The City should liaise with Coastcare to determine the best methods of implementing a dune care program at this site and the resources likely to be required.

Sand Management

Sand management (PR2), in the form of sand bypassing, would involve taking material from the southern side of the existing groyne, where it currently accumulates during summer, and depositing it on the beach to the north of the existing groyne (**Figure 4.4** of **Appendix C**). This is effectively assisting the natural process of alongshore sediment transport northward. The effect of sand bypassing is the same as described below for beach nourishment, however, the source is owned by and available to the City, leading to reduced cost compared with importing sand from an outside source. It is recommended that the potential need for and feasibility of sand bypassing around the groyne be further assessed. Recent aerial photos clearly show that the sand accumulation against the groyne is seasonal with sand accumulating against the south side of the groyne over summer and the north side of groyne over winter. The net transport of sand around the groyne should be estimated based on multiple years of measured beach data to inform whether sand bypassing is necessary and, if so, estimate the volume which should be backpassed.

Beach Nourishment

Beach nourishment (PR3), in the form of placing sand from an outside source onto the beach, would involve placement of appropriate sand material on the beach around the existing groyne (**Figure 4.4** of **Appendix C**). The effect would be similar to the sand bypassing option described above but with the sand coming from an external source and thus increasing the total sediment volume in the system. One potential downside of beach nourishment compared to sand bypassing is that the sand must be purchased from an external supplier if the City cannot source appropriate sand from a source which the City owns and is available for use; generally resulting in a higher unit cost. Similar to the recommendations for sand management above, it is recommended that the potential need for and feasibility of beach nourishment around the groyne be

further assessed. Recent aerial photos clearly show that the sand accumulation against the groyne is seasonal with sand accumulating against the south side of the groyne over summer and the north side of groyne over winter. The net transport of sand around the groyne should be estimated based on multiple years of measured beach data to inform whether beach nourishment is necessary and, if so, estimate the volume which should be nourished.

Groyne

The existing Capricorn Groyne was constructed in 1971 and was estimated to have become saturated around 1996 by M P Rogers (2015a). From recent aerial photographs it appears the groyne is in poor condition and, if so, its functionality in terms of interrupting alongshore sediment transport may be reduced compared to its original design. One protection option for the infrastructure located around the groyne is to refurbish, repair or even extend the groyne (PR4) (seaward or landward) such that it provides protection to the infrastructure behind the groyne (**Figure 4.4** of **Appendix C**). This option is particularly relevant if future sea level rise and associated shoreline recession results in the shoreline flanking behind the existing groyne which would significantly change the groyne's effect on the coastline around it. Over the long-term the continuation of sea level rise and associated shoreline recession may result in the existing groyne behaving like an offshore breakwater rather than a groyne. A large scale repair, refurbishment or extension of the existing groyne would have a significant capital cost (millions of dollars) and so the justification of modifying the existing groyne would require significant further assessment before it could be confirmed as an effective, cost-efficient option.

4.4.6 Equity Implications

Implementation of adaptation options for this site has equity implications. Current and future potential residents in this area will be the main beneficiaries, along with other beach users to a lesser extent. Costly protection works may reduce budget availability for alternative public works or programs in other areas of the City or state. Protective structures also have the potential for shifting and exacerbating erosional impacts further north. Development immediately adjacent to the 2120 hazard line has the potential to restrict land availability for foreshore reserve and limit public access to the beach.

Renourishment activities are generally beneficial for beach users and residents residing behind the beach, however these activities can incur significant ongoing cost. It may be seen that the funding for these activities could be better allocated elsewhere in the community.

Dune care is a generally socially equitable and environmentally positive option which is broadly applicable to most coastal sites.

4.4.7 Statutory Planning Considerations

The public car park is located fully within the MRS Parks and Recreation reserve, however the reserve itself does not fully encompass the extent of currently predicted coastal processes. The lower car park is estimated to be impacted by 2050; the upper car park by around 2120.

There is a section of Urban zoned land affected by the 2120 coastal processes line. Approved Local Structure Plan 75 (LSP75, Capricorn Coastal Node) applies over the land zoned Urban, and recognises the future coastal hazards by nominating the land seaward of the 2120 extent as 'future parks and recreation foreshore reserve'. Adjacent land is designated as Residential R40, with an overlay stating 'permanent residential development excluded'. The actual extent of this exclusion zone is not defined in LSP75. It must be noted that the definition of Permanent Residential Development in the LSP75 refers to the type of occupancy of the development rather than the permanency of the buildings.

Should erosion of the coast to the extent predicted by 2120 occur, there will be no remaining land within which to locate assets such as car parking or other public amenities. Consideration should be given to including provision for extension of the foreshore reserve in the long term, by preventing establishment of permanent development within a distance that would have to be determined. The exclusion zone in the structure plan needs further definition and possible extension to provide for this long term eventuality.

Avoidance of any new development on the foreshore reserve is possible, or limited development in accordance with LPP 2.21 can be considered.

Prohibition of further development or redevelopment

As the land is currently undeveloped, one option would be to amend DPS2 to introduce a local reserve over the affected land, pending future extension of the MRS Parks and Recreation reserve. The local reserve and zone boundaries would then have to be reflected in any structure plan pertaining to this site. It should be noted, however, that applying a reserve over privately owned land would trigger a claim for injurious affection under the Planning and Development Act (2005). Alternatively, DPS2 could be amended to apply a Special Control Area (SCA) over affected land to restrict its use to temporary development. The SCA might incorporate other controls that would allow retreat of development and commensurate expansion of the publicly accessible foreshore as defined trigger events (which would have to be identified) were reached. Linking retreat to trigger events would allow development to remain for a longer or lesser time depending on the speed with which predicted coastal recession progresses.

It is recommended that the City carefully consider the implications of the current proposed structure plan provisions with respect to the identified 2120 hazard line, plus the requirements for additional foreshore reserve width. Mechanisms available to limit future liabilities should be fully investigated.

4.5 Carpark Adjacent to Brazier Road and Residential Lots, Yanchep

4.5.1 Preliminary Multi-criteria Analysis

The sites containing the carpark adjacent to Brazier Road and the Residential Lots, Yanchep have been combined for the purposes of assessing management and adaptation options, due to their proximity. The results of the MCA's for the two sites are presented in **Tables 4-5** and **4-6**, respectively, the outcomes of which are generally consistent. Due to the significant value of public and private infrastructure adjacent to the coastline, leaving unprotected (MR1) has not been recommended. The redesigning of infrastructure, such as roads and houses, to withstand coastal erosion impacts (AC3) has been deemed not applicable in this setting. The construction of a groyne or groynes (PR4) has not been recommended due to the existing nearshore reef at the site and the complexity this adds for alongshore sediment transport. Taking no action (DN) has not been recommended due to the significant infrastructure present and, therefore, risk to the City.

4.5.2 Avoid Option

In accordance with SPP2.6, it is recommended that new residential development is avoided (AV) seaward of the 2120 coastal erosion hazard line, plus an additional allowance for foreshore reserve. Recommendations around the specific mechanisms for implementing this control are detailed below in **Section 4.5.7**.

4.5.3 Managed Retreat Options

Remove/relocate

The option of removing or relocating infrastructure (MR2) would involve the realignment of Brazier Road away from the shoreline, the removal of residential properties on the seaward side of Brazier Road at the south of the site and the removal of infrastructure along the existing Brazier Road at the north of the site (see **Figure 4.5a** in **Appendix C**). This option allows the beach, which is considered to be a highly valuable asset, to be retained in a useable state. The implications of adopting this option are significant and likely to cost the city in the order of tens of millions of dollars. The full cost implications of this option, in comparison to other options for the site, should be considered over the full 100 years planning timeframe.

Prohibit further development or redevelopment

It is recommended that the City consider prohibiting any further development or redevelopment (MR3) seaward of the 2120 coastal erosion hazard line, plus an additional allowance for foreshore reserve, except where it complies with SPP2.6 (e.g. infill development). The appropriateness of this prohibition should also be assessed in the future, once a clear adaptation pathway has been developed for the site. The specific mechanisms available for implementing this control are discussed below in **Section 5.3.2**.

4.5.4 Accommodate Options

Notification on Title

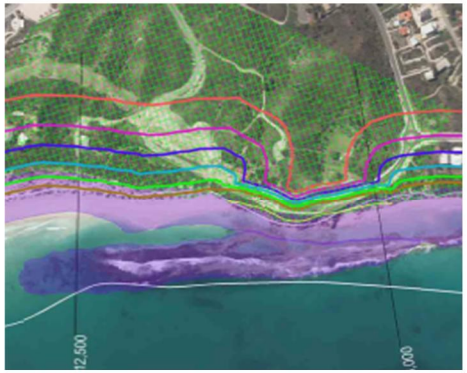
It is recommended that notifications be placed on the titles of all properties lying seaward of the 2120 hazard line, as required under SPP2.6. How this is achieved should be determined by the City in consultation with the Department of Planning. A recommendation for applying this control is provided in **Section 5.3**.

Emergency Plans and Controls

As various infrastructure at this site is predicted to become vulnerable to coastal erosion over future planning timeframes, it is recommended that emergency plans and controls are prepared and put in place (AC2) so that they can be actioned if and when this infrastructure is threatened or damaged by coastal erosion. This will be particularly pertinent if managed retreat options are adopted at this site. Preparing emergency plans and controls before the infrastructure becomes vulnerable will ensure there is a clear plan of action which can be implemented by the City in the event of a threat/damage by coastal erosion. This plan may include, for example, closing the relevant infrastructure and/or otherwise restricting access, putting up signage informing the public of implemented changes and recommended alternative usage areas, and informing any other relevant authorities of implemented changes and restrictions. The trigger for implementation of the emergency plan and controls should be based on ongoing monitoring of the site.

Table 4-5 Preliminary Multi-criteria Analysis for Brazier Road Carpark

5: Brazier Road Carpark



Main asset type Economic / Social

Long term pathway TBD

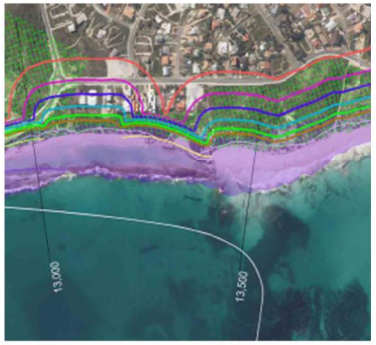
Vulnerability timeframe 2050

	2015	2030	2050	2070	2090	2120
	Vulnerability					
Beach	Medium	Medium	High	Very High	Very High	Very High
BFS 397	Low	Low	Low	Medium	Medium	Very High
Car Park (Brazier Rd)	Low	Low	Medium	Medium	Medium	High
Road (Brazier)	Low	Low	High	Very High	Very High	Very High
Parkland (Fisherman's Hollow)	Low	Low	Low	Low	Low	Medium

Option Category	Option Code	Option Name	Preliminary Feasibility			Preliminary Acceptability		Preliminary Financial Implication			Recommendation
			Effectiveness	Legal / Approval Risk	Reversibility / Adaptability	Environmental / Social Impact	Community Acceptability	Economic gain / Avoidance of Cost	Capital Cost	Ongoing Cost	
Avoid	AV	Avoid development									Recommend
Managed Retreat	MR1	Leave unprotected / repair									Do not recommend
	MR2	Remove / relocate									Further assessment
	MR3	Prohibit further development / redevelopment									Recommend
Accommodate	AC1	Notification on title									Recommend
	AC2	Emergency plans and controls									Recommend
	AC3	Re-design to withstand impact	N/A								
Protect	PR1	Dune care program									Recommend
	PR2	Sand Management									Recommend
	PR3	Beach Nourishment									Further assessment
	PR4	Groyne									Do not recommend
	PR5	Nearshore Reef / Breakwater									Further assessment
	PR6	Seawall									Further assessment
Do Nothing	DN	Do Nothing									Do not recommend

Table 4-6 Preliminary Multi-criteria Analysis for Residential Lots, Yanchep

6: Residential Lots Adjacent to Yanchep Lagoon



Main asset type Economic / Social

Long term pathway TBD

Vulnerability timeframe 2050

	2015	2030	2050	2070	2090	2120
	Vulnerability					
Beach	Medium	Medium	High	Very High	Very High	Very High
BFS 397	Low	Low	Low	High	High	Very High
Residential	Low	Low	High	Very High	Very High	Very High
Road (Brazier)	Low	Low	High	Very High	Very High	Very High

Option Category	Option Code	Option Name	Preliminary Feasibility			Preliminary Acceptability		Preliminary Financial Implication			Recommendation
			Effectiveness	Legal / Approval Risk	Reversibility / Adaptability	Environmental / Social Impact	Community Acceptability	Economic gain / Avoidance of Cost	Capital Cost	Ongoing Cost	
Avoid	AV	Avoid development									Recommend
Managed Retreat	MR1	Leave unprotected / repair									Do not recommend
	MR2	Remove / relocate									Further assessment
	MR3	Prohibit further development / redevelopment									Recommend
Accommodate	AC1	Notification on title									Recommend
	AC2	Emergency plans and controls									Recommend
	AC3	Re-design to withstand impact	N/A								
Protect	PR1	Dune care program									Recommend
	PR2	Sand Management									Recommend
	PR3	Beach Nourishment									Further assessment
	PR4	Groyne									Do not recommend
	PR5	Nearshore Reef / Breakwater									Further assessment
	PR6	Seawall									Further assessment
Do Nothing	DN	Do Nothing									Do not recommend

4.5.5 Protect Options

Dune care program

It is recommended that a dune care/revegetation program (PR1) be implemented for the dune system along the length of the study site. This program would help to consolidate the dune system and maintain its function as a protective buffer. It would also help to reduce wind-blown erosion and retain sand within the beach system. The program might involve revegetating or enhancing vegetation in degraded areas and preventing dune access outside of the provided access ways. The program would not be a protective measure against coastal storm surge.

Sand management

Minor sand management techniques (PR2) such as sand scraping and sand fencing could be considered at this site to maintain beach and dune amenity, respectively. Given the complex nearshore reef structure, the appropriateness of sand scraping would need to be assessed in light of changes in beach morphology over time and local sediment transport regimes. This would require further investigation of the sites hydrodynamic and sediment transport regime. This has been assessed to a limited extent by Gallop et al. (2011). Sand fencing can help limit wind-blown sediment transport and retain sediment on the beach face, preventing loss of material inland. A detailed sediment budget and geotechnical assessment of the foreshore and coastal dunes zone would be required to develop a cost estimate for the optimal sand management technique.

Beach nourishment

Beach nourishment could be undertaken at this site, to the north and south of the rocky headland fronting Brazier Road (**Figure 4.5a** in **Appendix C**). The presence of the nearshore reef is likely to help retain sediment on the beach face for a longer period, in comparison to an exposed beach. It would be recommended that a shoreline monitoring program, involving regular beach profile surveys and photographs be first implemented to determine the nature of changes in beach morphology and estimate volumes and the seasonality of erosion and accretion. This would allow the optimal timing and volume of sediment placement to be achieved. There does not appear to be a readily available source of sediment in the vicinity of the site, and any removal of material from the north of the site is likely to have an effect elsewhere along the coastline, due to the nature of longshore sediment transport in the region. Sediment would probably, therefore, have to be imported, making renourishment more expensive. Sand renourishment will help to remedy loss of beach in the short term, but with rising MSL over longer timeframes (e.g. beyond 50 years) this management technique is likely to become increasingly expensive and eventually unviable.

Nearshore reef

A large natural nearshore reef exists along the length of this study site. This reef provides protection for the coastline against coastal storm surge but it may also slow the regeneration of the beach behind it, following coastal erosion events (Gallop et al, 2011). The hydrodynamics and sediment transport processes in the vicinity of this nearshore reef are complex and not fully understood (Gallop et al, 2011). As MSL rises into the future, the influence of this reef as a protection for the beach is likely to diminish. A future management option could involve artificially enhancing the nearshore reef by raising its level. This option would require considerable site investigation and modelling to assess its viability. Due to the considerable further investigation required, a concept design has not been presented for this option at this stage.

Seawall

A seawall could be constructed to protect residential lots at the south of the site and Brazier Road itself, where it is not fronted and protected sufficiently by existing rock. The preliminary concept design for such a seawall would be in two sections: an approximately 550 m section to the south of the rocky headland fronting the residential lots, and a 200 m section to the north of the rocky headland (see **Figure 4.5b** in **Appendix C**). This assumes the rocky headland is a sufficient coastal barrier in itself. Further investigation of the height, strength and continuity of this rock should be carried out to refine the extents and footprint of any proposed seawall. Geophysical information would also be required along the proposed seawall alignment to determine the footing requirements. The construction of a seawall would allow the protection of a portion of coastal vegetation, but would ultimately lead to degradation and potential loss of the beach over time. Beach nourishment could help remedy the loss of beach but this will likely become increasingly expensive and

eventually unviable. The value of the beach itself and the potential cost of maintaining a seawall over the 100 year planning timeframe should be properly considered before selecting this protective option.

4.5.6 Equity Implications

Implementation of adaptation options for public assets (including roads) may generally be considered to be equitable.

Protection of the residential area has more significant equity implications. Although adjacent residents in this area will be the main beneficiaries, the beach in this area has been identified as a significant community asset, and therefore works may benefit many residents in the City as well as tourists and visitors to Yanchep. Costly protection works may reduce budget availability for alternative public works or programs in other areas of the LGA / State. Protective structures also have the potential for shifting and exacerbating erosional impacts elsewhere along the coastline. In the case of a seawall, this would likely be beneficial to residents and in protecting the City's infrastructure assets. It would however be detrimental to beach users and the community in that the beach is likely to degrade over time. Development immediately adjacent to the 2120 hazard line has the potential to restrict land availability for foreshore reserve and limit public access to the beach.

Renourishment activities are generally beneficial for beach users and residents residing behind the beach, however these activities can incur significant ongoing cost. It may be seen that the funding for these activities could be better allocated elsewhere in the community.

Residents would bear much of the disadvantage from avoid and managed retreat options, since there is no legal requirement for compensation in the event of eviction (voluntary or forced) and /or loss of property.

Dune care is generally a socially equitable and environmentally positive option which is broadly applicable to most coastal sites.

4.5.7 Statutory Planning Considerations

Car parking on both sides of Brazier Road, Brazier Road itself and various other assets including 'The Lagoon Café' and attached public toilets are all potentially affected by predicted coastal processes. The new Yanchep Surf Life Saving Club is under construction north of the car parks under investigation, within the Parks and Recreation reserve. This land is fully contained within the Parks and Recreation reserve and there is potential to relocate the assets if necessary, although to do so will require clearing of native vegetation.

Redirection of the road, if required, would likely be the most significant cost. There is no necessity to amend the scheme in this location, and LPP 4.21 will apply.

Notification on the City's asset management system to alert users of the risk and the application of LPP 4.21 is recommended.

Notification on any leases or management orders should be sought.

4.6 Heritage Site Karli Spring, Alkimos

4.6.1 Preliminary Multi-criteria Analysis

A summary of the preliminary multi-criteria analysis for the Heritage Site Karli Spring, Alkimos is presented in **Table 4-7**. At present, there is no existing development, public infrastructure or access to this site. As such, the Managed Retreat (MR2, MR3) and Accommodate (AC1, AC2 and AC3) options have been deemed 'not applicable' for this site. Beach nourishment (PR3) and hard engineering protection options (PR4, PR5 and PR6) have not been recommended primarily due to the relatively large capital and ongoing costs involved in implementing these options. It is also likely to be seen as unacceptable or inappropriate to install engineered structures to control a section of coastline in its natural state. Taking no action (DN) is not recommended – as a minimum, the requirement for additional planning controls should be investigated based on the coastal hazard extents defined in Part 1 of this CHRMAP (M P Rogers, 2015a), in accordance with SPP2.6 requirements.

4.6.2 Avoid Options

In accordance with SPP2.6, it is recommended that new residential development is avoided (AV) seaward of the 2120 coastal erosion hazard line, plus an additional allowance for foreshore reserve.

4.6.3 Managed Retreat Options

Leave Unprotected/Repair

Leaving the Heritage Site Karli Springs unprotected against coastal hazards (MR1) is likely to lead to a gradual recession of the vegetation line over time with an expected rising MSL and, therefore, greater inland reach of coastal erosion events. Dune vegetation forms an important component of the natural protection of the Heritage Site Karli Springs against coastal erosion. Coastal vegetation assemblages have the capacity to repair themselves following erosion events, depending on the frequency of impact. Dune vegetation is important in helping to consolidate the dune system and provides some protection against wind-blown erosion. It provides minimal protection against coastal storm surge due to its shallow rooted nature. Replanting vegetation in areas prone to frequent coastal impact, without implementing additional protective measures, would ultimately be a waste of resources. At present it is uncertain what the exact nature and extent of this heritage site is and what potential requirements for its protection may exist. It is thus recommended that the City further investigate the nature and extent of this heritage site and any potential requirements for its protection to inform future reviews of the CHRMAP.

4.6.4 Protect Options

Dune care program

It is recommended that a dune care/revegetation program (PR1) be implemented for the Heritage Site Karli Springs which involves preventing four wheel drive access and revegetating tracks and other areas that have been degraded due to anthropogenic impacts. A concept design showing the areas recommended for revegetation is presented in **Figure 4.6** of **Appendix C**. Dune care programs along the Western Australia coastline are generally undertaken by volunteer groups (primarily community groups working under Coastcare) and, as such, their cost of implementation is difficult to quantify. The City should liaise with Coastcare to determine the best methods of implementing a dune care program at this site and the resources likely to be required. Preventing four wheel drive access to coastal areas in the City's LGA is an ongoing issue and is likely to require significant resources to implement and police. This option may also be seen as unacceptable to some members of the community who use the access tracks and beach for recreation purposes.

Vegetation rehabilitation at the study site has been proposed within the Alkimos Beach Foreshore Management Plan ([FMP] RPS, 2015). The areas for rehabilitation are generally consistent with those suggested in the concept design (**Figure 4.6, Appendix C**). There are additional vegetation rehabilitation areas proposed in the FMP, required following the proposed construction of access infrastructure at the site. The City should review this FMP in light of the information presented in this report and the overall CHRMAP process.

Sand Management

Sand management techniques (PR2), such sand scraping and sand fencing, are generally seen as small scale and short-term solutions to coastal erosion issues. It is recommended that sand-fencing be implemented to control the impact of wind-blown erosion on the beach and inland areas to increase the natural protection of the site. Sand scraping may also be considered in the future as a method of maintaining useable beach areas and providing additional protection in front of beach dunes and access infrastructure.

4.6.5 Equity Implications

Dune care is a generally socially equitable and environmentally positive option which is broadly applicable to most coastal sites. Small scale sand management is also aimed to improve public amenity and environmental protection, therefore the beneficiaries of the selected options are the conservation estate and the general public. No coastal engineering protection works are proposed which may result in increased erosion at other locations adjacent to the site, and therefore there are limited equity implications for this site.

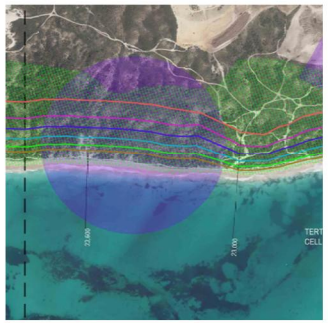
4.6.6 Statutory Planning Considerations

This heritage site is assessed as having high vulnerability from 2070, and very high vulnerability by 2120.

The heritage site and land seaward of the 2120 hazard line is contained entirely within the Parks and Recreation reserve, under the MRS. As such, planning responses may not be required for this study site. At present, the additional width for future public amenity that is required landward of the 2120 hazard line (Section 5.9 of SPP2.6) has not been determined. It is recommended that the City establish this required additional width and determine the implications for the South Alkimos Local Structure Plan No. 72 ([LSP 72] Roberts Day, 2016) and the Alkimos Beach Foreshore Management Plan (RPS, 2015). The LSP72 would require revision if this additional width extends landward beyond the boundary of the Parks and Recreation Reserve. It is also recommended that the City review the Alkimos Coastal Node Local Structure Plan (Creative Design + Planning, 2016), to the north of the study site, in light of the information presented in Section 5.3 of this report and the overall CHRMAP process.

Table 4-7 Preliminary Multi-criteria Analysis for Karli Springs

7: Karli Springs



Main asset type Heritage / Environmental

Long term pathway TBD

Vulnerability timeframe 2070

	2015	2030	2050	2070	2090	2120
	Vulnerability					
Beach	Low	Low	Medium	Medium	Medium	Medium
BFS 397	Low	Low	Low	Medium	High	Very High
Karli Spring	Low	Low	Low	High	High	Very High

Option Category	Option Code	Option Name	Preliminary Feasibility			Preliminary Acceptability		Preliminary Financial Implication			Recommendation
			Effectiveness	Legal / Approval Risk	Reversibility / Adaptability	Environmental / Social Impact	Community Acceptability	Economic gain / Avoidance of Cost	Capital Cost	Ongoing Cost	
Avoid	AV	Avoid development									Recommend
Managed Retreat	MR1	Leave unprotected / repair									Further assessment
	MR2	Remove / relocate	N/A								
	MR3	Prohibit further development / redevelopment	N/A								
Accommodate	AC1	Notification on title	N/A								
	AC2	Emergency plans and controls	N/A								
	AC3	Re-design to withstand impact	N/A								
Protect	PR1	Dune care program									Recommend
	PR2	Sand Management									Recommend
	PR3	Beach Nourishment									Do not recommend
	PR4	Groyne									Do not recommend
	PR5	Nearshore Reef / Breakwater									Do not recommend
	PR6	Seawall									Do not recommend
Do Nothing	DN	Do Nothing									Do not recommend

4.7 Residential Lots, Mindarie

4.7.1 Preliminary Multi-criteria Analysis

A summary of the preliminary multi-criteria analysis for the Residential Lots, Mindarie is presented in **Table 4-8**. There is some uncertainty regarding the vulnerability and requirement for management and adaptation options at this site. In part 1 of the CHRMAP (M P Rogers, 2015a) physical infrastructure at the site is considered to be fronted by a continuous rock barrier. As such, assets seaward of the rock barrier have been considered to be at risk of coastal erosion while those behind have only been considered to be at risk of inundation. Further assessment of the height, strength and continuity of this rock should be made to determine the requirement for adaptation and management of infrastructure assets behind it.

Given the nature of the inundation hazard at this site, at this stage removing or relocating infrastructure (MR2) has not been recommended as it seems unnecessary. The redesigning of infrastructure, such as roads and houses, to withstand coastal erosion impacts (AC3) has been deemed not applicable in this setting. Due to the small size of the beach fronting the site, sand management (PR2) has not been recommended. Due to the coastline being 'rocky', the construction of groynes (PR4) or nearshore breakwaters (PR5) has been deemed 'not applicable' for this site. Taking no action (DN) has not been recommended as at a minimum the true threat of coastal inundation to infrastructure at the site should be properly investigated and planning controls implemented where appropriate.

4.7.2 Avoid Option

In accordance with SPP2.6, it is recommended that any further residential development is avoided (AV) seaward of the 2120 coastal erosion hazard line. It must be noted that for this site, the hazard lines appear to have been drawn receding based on the mandatory safety factor of 0.2 m per year. If the natural rock at the site does form a continuous barrier, it may be inappropriate to implement planning controls on the land behind this rock. The avoid option should be re-assessed following more detailed investigation of the nature of the rock barrier and subsequent threat of coastal inundation specific to this site.

4.7.3 Managed Retreat Options

Leave unprotected

Dependant on the risk of coastal inundation to infrastructure at this site, leaving assets unprotected may be a valid option. For example, if more detailed analysis of the protection afforded by the rock barrier means a sufficiently low probability of inundation, it may be deemed an allowable risk. If the risk is present, emergency plans and controls should be in place to enact should flooding to public and private infrastructure occur.

Prohibit further development or redevelopment

As described in **Section 4.7.2** above, the actual hazard and accuracy of the 2120 hazard line should be reassessed following better investigation of the existing rock barrier.

It is recommended that the City consider prohibiting any further development or redevelopment (MR3) seaward of the 2120 coastal erosion hazard line, plus an additional allowance for foreshore reserve, except where it complies with SPP2.6 (e.g. infill development). The appropriateness of this prohibition should also be assessed in the future, once a clear adaptation pathway has been developed for the site. The specific mechanisms available for implementing this control are discussed below in **Section 5.3.2**.

4.7.4 Accommodate Options

Notification on Title

It is generally recommended that notifications be placed on the titles of all properties lying seaward of the 2120 hazard line, as required under SPP2.6. In this case the accuracy of the 2120 hazard should first be properly assessed before this option is enacted. A recommendation for applying this control, should it be necessary, is provided in **Section 5.3**.

Table 4-8 Preliminary Multi-criteria Analysis for Residential Lots, Mindarie

8: Residential Lots, Mindarie

Main asset type Economic / Social

Long term pathway TBD

Vulnerability timeframe 2050-2070

	2015	2030	2050	2070	2090	2120
	Vulnerability					
Beach	Low	Low	High	Very High	Very High	Very High
BFS 397	Low	Low	Low	High	High	Very High
Parkland & Walkway	Low	Low	Low	High	High	High
Residential	Low	Low	Low	High	High	High
Road (Clarecastle)	Low	Low	Low	High	High	High

Option Category	Option Code	Option Name	Preliminary Feasibility			Preliminary Acceptability		Preliminary Financial Implication			Recommendation
			Effectiveness	Legal / Approval Risk	Reversibility / Adaptability	Environmental / Social Impact	Community Acceptability	Economic gain / Avoidance of Cost	Capital Cost	Ongoing Cost	
Avoid	AV	Avoid development									Recommend
Managed Retreat	MR1	Leave unprotected / repair									Further assessment
	MR2	Remove / relocate									Do not recommend
	MR3	Prohibit further development / redevelopment									Recommend
Accommodate	AC1	Notification on title									Recommend
	AC2	Emergency plans and controls									Recommend
	AC3	Re-design to withstand impact	N/A								
Protect	PR1	Dune care program									Recommend
	PR2	Sand Management									Do not recommend
	PR3	Beach Nourishment									Further assessment
	PR4	Groyne	N/A								
	PR5	Nearshore Reef / Breakwater	N/A								
	PR6	Seawall									Further assessment
Do Nothing	DN	Do Nothing									Do not recommend

Emergency Plans and Controls

As infrastructure at this site may become vulnerable to coastal inundation over future planning timeframes, it is recommended that emergency plans and controls are prepared and put in place (AC2) so that they can be actioned if and when this infrastructure is threatened or affected by coastal storm surge. Preparing emergency plans and controls before the infrastructure becomes vulnerable will ensure there is a clear plan of action which can be implemented by the City in the event of a threat/damage by coastal inundation. This plan may include, for example, closing the relevant infrastructure and/or otherwise restricting access, putting up signage informing the public of implemented changes and recommended alternative usage areas, and informing any other relevant authorities of implemented changes and restrictions. The trigger for implementation of the emergency plan and controls should be based on ongoing monitoring of the site.

4.7.5 Protect Options

Dune care program

It is recommended that a dune care/revegetation program (PR1) be implemented for the dune system along the length of the study site (**Figure 4.7** in **Appendix C**). This program would help to consolidate the dune system and maintain its function as a protective buffer. It would also help to reduce wind-blown erosion and retain sand within the beach system. The program might involve revegetating or enhancing vegetation in degraded areas and preventing dune access outside of the provided access ways. The program would not be a protective measure against coastal storm surge and due to the small amount of coastal vegetation at this site it would be more for amenity purposes.

Beach nourishment

Beach nourishment (PR3) at this site could be implemented to maintain the beach amenity in front of the residential properties (**Figure 4.7** in **Appendix C**). Because of the geomorphology of the shoreline and the primary hazard to infrastructure being coastal inundation, beach nourishment would not necessarily be a protective measure for infrastructure assets. Also, due to the rocky nature of the shoreline, the longevity of placed material is likely to be less than might be expected at other sites. It would be recommended that sand nourishment is implemented only if the local community has a strong desire to maintain the beach amenity at this site and if residents with a vested interest are prepared to contribute to or bear the cost of a nourishment program.

Seawall

Dependant on the results of an assessment of the height, continuity and strength of the existing natural rock barrier at this site, a seawall could be implemented to enhance the natural barrier (**Figure 4.7** in **Appendix C**). This would provide protection to infrastructure such as the road and residential lots, but not the beaches and coastal vegetation. The necessity for any protective structure should be assessed before this option is further considered.

4.7.1 Equity Implications

The selection of adaptation options for this site has significant equity implications. Residents in this area would be the main beneficiaries of protection measures, along with beach users to a lesser extent. Costly protection works may reduce budget availability for alternative public works or programs in other areas of the LGA / State. Protective structures also have the potential for shifting and exacerbating erosional impacts further north, and/or reducing public amenity of the beach.

Residents would also bear much of the disadvantage from avoid and managed retreat options, since there is no legal requirement for compensation in the event of eviction (voluntary or forced) and /or loss of property.

Dune care is a generally socially equitable and environmentally positive option which is broadly applicable to most coastal sites.

4.7.2 Statutory Planning Considerations

These high value lots built on a narrow peninsula are largely already developed – remaining undeveloped lots will be infill. Without protection, several of the lots will become highly vulnerable by around 2070. By that

time, most of the houses will be well over 50 years old. In the meantime, there may have been modifications and improvements made to homes.

Road access to the lots will become vulnerable and there is no alternative possible due to the water (ocean and marina) on three sides.

Planning approval should be required for any development including extensions to existing houses. A special control area could be considered for affected land, to include special requirements relating to development of the land. Scheme provisions could require any redevelopment to incorporate protective measures of an appropriate nature (to be determined) or to comprise only removable/temporary structures, with a trigger identified (and noted on the title) for removal to be required. Indemnity against future claims on the City should be required if new development is sought, if such indemnity can be legally upheld. If not, consideration may have to be given to preventing redevelopment of lots through the inclusion of specific provisions in the planning scheme before the land becomes highly vulnerable (ie: before 2070 or such trigger event as might be identified).

Additional density is not advised. If not already present, any redevelopment should be conditional upon a notification being placed on the Title of the land.

4.8 Priority Ecological Community, Mindarie

4.8.1 Preliminary Multi-criteria Analysis

A summary of the preliminary multi-criteria analysis for the PEC, Mindarie is presented in **Table 4-9**. At present, there is no existing development, public infrastructure or access to this site. As such, the Managed Retreat (MR3) and Accommodate (AC1, AC2 and AC3) options have been deemed 'not applicable' for this site. Relocation of the PEC (MR2) has not been recommended due to the significant relative expense this would involve and likely ineffectiveness. Beach nourishment (PR3) and hard engineering protection options (PR4, PR5 and PR6) have not been recommended primarily due to the relatively large capital and ongoing costs involved in implementing these options. It is also likely to be seen as unacceptable or inappropriate to install engineered structures to control a section of coastline in its natural state. Taking no action (DN) is not recommended as, at least, ongoing monitoring should be implemented based on the coastal hazard information defined in Part 1 of this CHRMAP (M P Rogers, 2015a), in accordance with SPP2.6 requirements.

4.8.2 Avoid Options

In accordance with SPP2.6, it is recommended that new development is avoided (AV) seaward of the 2120 coastal erosion hazard line, plus an additional allowance for foreshore reserve.

4.8.3 Managed Retreat Options

Leave Unprotected/Repair

Leaving the PEC unprotected against coastal hazards (MR1) is likely to lead to a gradual recession of the vegetation line over time with an expected rising MSL and, therefore, greater inland reach of coastal erosion events. Coastal vegetation assemblages have the capacity to repair themselves following erosion events, depending on the frequency of impact. Dune vegetation is important in helping to consolidate the dune system and provides some protection against wind-blown erosion. It provides minimal protection against coastal storm surge due to its shallow rooted nature. Replanting vegetation in areas prone to frequent coastal impact, without implementing additional protective measures, would ultimately be a waste of resources. The gradual loss of a portion of the PEC at the shoreline over time may be deemed acceptable given that rising MSL is a quasi-natural phenomenon, provided monitoring and management is undertaken to ensure undue pressure is not being placed on the overall PEC. If this option is adopted it would be recommended that a dune care program, involving the repair of inland areas damaged by four wheel driving activities, be implemented to reduce the overall pressure on the PEC and compensate for habitat loss adjacent to the beach.

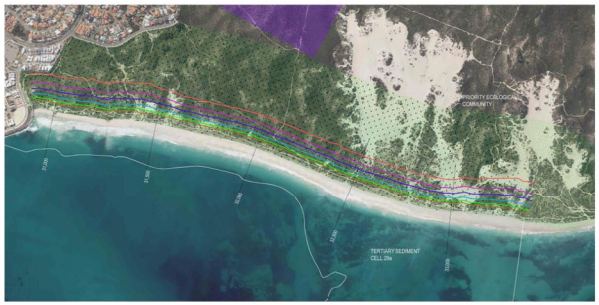
4.8.4 Protect Options

Dune care program

It is recommended that a dune care/revegetation program (PR1) be implemented for the PEC which involves preventing four wheel drive access and revegetating tracks and other areas that have been degraded due to anthropogenic impacts. A concept design showing the areas recommended for revegetation is presented in **Figure 4.8** of **Appendix C**. Dune care programs along the Western Australian coastline are generally undertaken by volunteer groups (primarily community groups working under Coastcare) and, as such, their cost of implementation is difficult to quantify. The City should liaise with Coastcare to determine the best methods of implementing a dune care program at this site and the resources likely to be required. Preventing four wheel drive access to coastal areas in the City's LGA is an ongoing issue and is likely to require significant resources to implement and police.

Table 4-9 Preliminary Multi-criteria Analysis for PEC, Mindarie

9: Priority Ecological Community, Mindarie



Main asset type Environmental

Long term pathway TBD

Vulnerability timeframe 2050-2070

	2015	2030	2050	2070	2090	2120
	Vulnerability					
Beach	Low	Low	Medium	Medium	Medium	Medium
BFS 397	Low	Low	Low	Medium	High	Very High
PEC	Low	Low	High	High	Very High	Very High

Option Category	Option Code	Option Name	Preliminary Feasibility			Preliminary Acceptability		Preliminary Financial Implication			Recommendation
			Effectiveness	Legal / Approval Risk	Reversibility / Adaptability	Environmental / Social Impact	Community Acceptability	Economic gain / Avoidance of Cost	Capital Cost	Ongoing Cost	
Avoid	AV	Avoid development									Recommend
Managed Retreat	MR1	Leave unprotected / repair									Further assessment
	MR2	Remove / relocate									Do not recommend
	MR3	Prohibit further development / redevelopment	N/A								
Accommodate	AC1	Notification on title	N/A								
	AC2	Emergency plans and controls	N/A								
	AC3	Re-design to withstand impact	N/A								
Protect	PR1	Dune care program									Recommend
	PR2	Sand Management									Further assessment
	PR3	Beach Nourishment									Do not recommend
	PR4	Groyne									Do not recommend
	PR5	Nearshore Reef / Breakwater									Do not recommend
	PR6	Seawall									Do not recommend
Do Nothing	DN	Do Nothing									Do not recommend

Sand management

Sand management techniques (PR2), such as sand scraping and sand fencing, are generally seen as small scale and short-term solutions to coastal erosion issues. The large scale of this site and limited access at present is likely to mean such techniques will have a high relative expense for minimal protective impact over the long-term. Dune blowouts at the south of the site suggest wind-blown erosion is an issue in the area. Sand-fencing could be implemented to control the impact of wind-blown erosion on the beach and inland areas. Sand scraping may also be considered in the future as a method of maintaining useable beach areas and providing additional protection in front of beach dunes.

4.8.5 Equity Implications

Dune care is a generally socially equitable and environmentally positive option which is broadly applicable to most coastal sites. Small scale sand management is also aimed to improve public amenity and environmental protection, therefore the beneficiaries of the selected options are the conservation estate and the general public. No coastal engineering protection works are proposed which may result in increased erosion at other locations adjacent to the site, and therefore there are limited equity implications for this site.

4.8.6 Statutory Planning Considerations

This PEC is fully contained within the Parks and Recreation reserve. No other planning control is necessary.

It is noted that developed, zoned land to the north may be affected by future coastal processes and this should be investigated

5 Discussion

5.1 General Observations

In reviewing the selected sites the subject of this study and considering the implications for land use planning, it has become obvious that some of the issues arising will also apply to areas outside of these focus areas. It is outside the scope of this study to examine other areas in detail, however it is strongly suggested that the City consider the recommendations of this study for applicability beyond the selected sites.

By way of example, there are many agreed and some draft local and district structure plans affecting coastal land in the City of Wanneroo, and each one will need to be reviewed to identify any content that may conflict with the principles of coastal adaptation planning and in particular the scheme objective of ensuring permanent and easy public access to the ocean shore (the beach) and recreation reserves. The City will need to consider the implications of any such conflicts, and what, if anything, can be done to avoid the exposure of more assets to risk from coastal processes where land remains undeveloped.

It is noted that in accordance with s.27 of the Deemed Provisions, set out in the Regulations and also in DPS2, the effect of a structure plan is that, where the WAPC has approved a structure plan for an area, the decision maker is to have due regard to, but is not bound by, the structure plan when deciding the application (emphasis added).

Local structure plans typically indicate future proposed zoning, and the expectation is that once the structure plan has been implemented to a stage that the boundaries of the proposed zoning are set and not going to be changed, then they be incorporated into the planning scheme as a standard amendment. Currently approved structure plans have a life of 10 years from the date of approval or until 19 October 2025, whichever is the later, unless they have been revoked earlier. The local government or the landowner is able to request the WAPC to revoke approval of a structure plan under a number of circumstances, including when implementation is complete, or if effective implementation is not possible due to change in legislation or a state planning policy.

The zoning of land is one of the key planning tools available to manage the use of land exposed to coastal hazards. Through the zoning of land in the local planning scheme, land uses and land use densities can be controlled. If a land use is considered to be strategically compatible with the risk then it should be zoned accordingly to provide certainty to the community and developers. However if the risk is not acceptable then the land use should not be permitted. Zoning creates expectations. Leaving the consideration of hazards to the development assessment stage makes the potential for competing interests to complicate the assessment and potentially result in outcomes contrary to the best interests of preventing avoidable risk arising from inappropriate development.

‘Down zoning’ or ‘back zoning’ to limit the type and/or density of development permissible prior to identification of the hazard may be politically unpalatable but may be the most responsible course of action in some cases.

It is recommended that the City amend DPS2 (or include as part of proposed Local Planning Scheme No. 3) to incorporate relevant aspects of SPP2.6 and ensure that the City has due regard to SPP2.6. This is consistent with Section 77 of the *Planning and Development Act 2005*. Further details are provided in **Section 5.3**.

5.2 Planning Scheme Horizon

The Regulations require local planning schemes to be reviewed every five years. This can be considered a “health check” to ensure the scheme remains current with respect to current issues, trends and policy and strategy context. Local planning strategies, which provide the broader planning direction within which the local planning scheme operates typically have a planning horizon of 10 to 15 years.

However determination of development proposals has a much longer horizon. It is only necessary to look back to the first land subdivisions created upon colonization to see that they continue to influence

development over one hundred years later. Buildings may be replaced over the decades, but the urban pattern remains largely unchanged. Similarly, development approved now will remain in place for many decades.

Comprehensive redevelopment of earlier subdivision to provide for contemporary needs and/or address issues arising from early land uses is complex and very expensive and usually requires the expenditure of public funds to carry out or facilitate.

There is land zoned but not yet developed for urban and other development that modelling indicates will be impacted by coastal processes within the next hundred years. Although the likelihood of that hazard having an impact may be beyond the horizon of key planning instruments including DPS2 and its successor (i.e. in the next 15 or even 50 years), it is predicted to be affected and responsibility to the future community development needs direct development away from coastal erosion risk areas.

5.3 DPS2 & LSP Recommendations

The following sections provide recommendations for incorporation into DPS2 or any new planning scheme and LSPs, based on the results of the CHRMAP to date. The current planning scenarios captured under DPS2 are shown schematically in **Figure 5-1**.

5.3.1 Undeveloped Land

Presently, much of the undeveloped land lying seaward of the 2120 hazard line is contained within the Parks & Recreation Reserve under the Metropolitan Region Scheme (MRS). It is recommended that this reserve be expanded, or added to at a local scale as an interim measure, to contain all undeveloped land lying seaward of the coastal foreshore reserve once identified, inclusive of the 2120 hazard line. Coastal foreshore reserve boundaries should be determined in accordance with SPP2.6 Section 5.9, and include an allowance for coastal processes as well as future public amenity at the end of the planning timeframe (2120). This recommendation is also consistent with Section 5.2(i) of SPP2.6 which encourages urban development around existing settlements and discourages continuous linear urban development along the coast.

The way in which the above recommendation should be implemented will depend upon whether the land concerned is currently subject to a Local Structure Plan (LSP) or not:

a) Where a LSP is still to be prepared:

It is recommended that the City develops a default minimum distance allowance for the public amenity allocation within the foreshore reserve. It is recommended that this minimum allowance for public amenity be added to the 2120 hazard line to delineate an indicative minimum distance from the coast for the landward boundary of the Metropolitan Region Scheme Reserves and that plans showing the resulting landward indicative reserve boundary be prepared and included in a Local Planning Policy (**Figure 5-1a**). This recommendation is based on the understanding that the reserve boundary will be properly assessed and incorporated at the local structure planning stage (as per b) below) and will be regularly updated alongside subsequent CHRMAP reviews.

The purpose of delineating the indicative minimum reserve boundary at this stage is mainly to assist in informing prospective purchasers of such land that, while the current zoning of the land under the MRS and DPS 2 might indicate urban or other development potential, such potential is in fact unlikely to exist due to allowances needing to be made for future coastal erosion.

Mechanisms for ensuring outcomes of the current and future CHRMAPs are included in MRS reviews and updates need to be investigated at each future review.

b) Where the land concerned is already subject to an approved or draft LSP, or LSP about to be prepared:

As for a) above, coastal foreshore reserve boundaries should be determined in accordance with SPP2.6 section 5.9, and include an allowance for coastal processes as well as future public amenity at the end of the planning timeframe (2120) (**Figure 5-1b**). This recommendation is also consistent with Section 5.2(i) of SPP2.6 which encourages urban development around existing settlements and discourages continuous linear urban development along the coast.

LSPs should be required to propose a foreshore reserve boundary that meets the requirements of SPP2.6 section 5.9:

(ii) The required coastal foreshore reserve will vary according to the circumstances of any particular proposal. Each proposal must be assessed on its merits having regard to this policy, including the principles and guidelines of Schedule One and the Coastal Planning Policy Guidelines.

(iii) Ensure that the identification of land to be set aside for public ownership for management, public access, recreation, and conservation is undertaken during the planning process. Generally this land should be given up free of cost at the time of development, subdivision or strata subdivision, over and above the required provision of public open space.

It is recommended that a detailed investigation into the implications of the CHRMAP for existing and draft Structure Plans be carried out to determine a proposed foreshore reserve boundary, in accordance with the above. New LSPs being prepared should also be required to similarly determine proposed foreshore reserve boundaries.

Once these boundaries have been determined the LSPs should be amended in accordance with clause 29 of the deemed provisions of DPS2. Such an amendment could show the current zoned land coastward of these boundaries as proposed to be reserved Parks and Recreation under the MRS (i.e. not actually reserved under the LSP or the local planning scheme). The LSPs should also advise that upon a subdivision application being submitted for land adjacent to the future reserve land, the WAPC should consider including a subdivision condition requiring that the future reserve land be ceded free-of cost (to either the WAPC or the Crown). (Noting that under current WAPC policies, this land is not to be credited as local POS provision). Following ceding, the intention is that the MRS be amended to reserve the land as Parks and Recreation Reserve under that scheme. (Under the Planning Act, this land will then automatically also be shown as regional reserve on the local planning scheme).

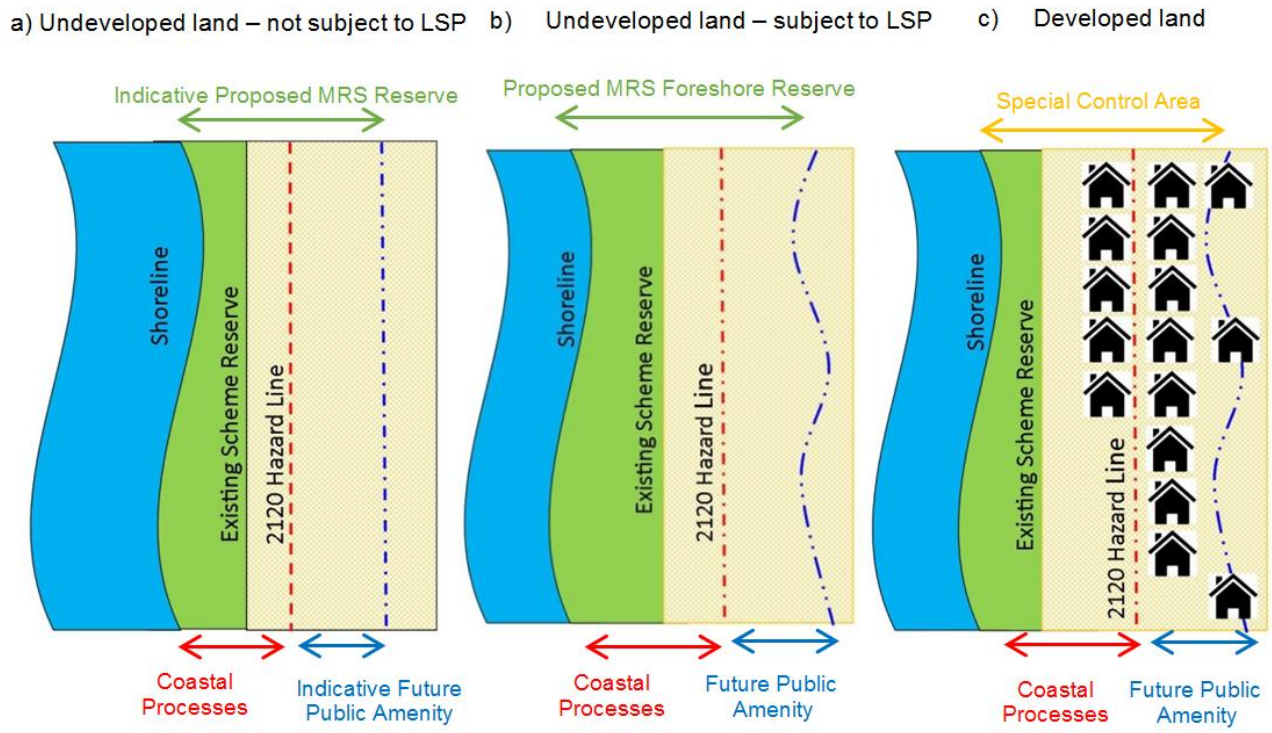


Figure 5-1 Schematic diagram indicating the recommended definition of the foreshore reserve boundary for three planning scenarios

5.3.2 Developed Land

It is recommended that a key mechanism for implementation of adaptation planning in developed areas is the use of a Special Control Area (SCA) (**Figure 5-1c**). SCAs are areas in which special scheme provisions apply, in addition to the actual requirements of the zone or reservation. It is a spatial overlay that could apply

to areas in which the risk of erosion requires special consideration. Special planning provisions in relation to these areas can then be developed to manage this risk.

The extent of the SCA needs to take into consideration the 2120 hazard line, and an allowance for future public amenity. It is therefore recommended that the landward extent of the SCA is determined in a manner consistent with the definition of the foreshore reserve (i.e. in accordance with SPP2.6, Section 5.9).

In SCA's the following recommendations are made:

a) Notification of Landowners as part of Subdivision/ Development proposals: As specified in section 5.5(ii) of SPP2.6, where a coastal hazard is identified it should be disclosed to those likely to be affected. Any approval for subdivision and/or development should include a condition that current and future lot owners be made aware of the coastal hazard risk by providing the following notification on the certificate of title: *VULNERABLE COASTAL AREA – This lot is located in an area likely to be subject to coastal erosion and/or inundation over the next 100 years.*

It is recommended that this notification be required in approving subdivision and development applications for all land within the SCA, and at a minimum include all land lying seaward of the 2120 (100 year planning timeframe) hazard line for coastal erosion, calculated in Part 1 of the CHRMAP (M P Rogers, 2015).

Informing potential purchasers of land within erosion hazard areas is important to allow people to make informed decisions about land they may look to purchase and develop. One mechanism for doing this is by incorporating the requirement that any planning approval issued for development within the 2120 hazard line include a condition requiring that the aforementioned notification be placed on the title. Such a notification would take the form of a Notification under section 70A of the Transfer of Land Act 1893. A Section 70A Notice, as it is commonly known, advises prospective purchasers of a potential hazard or factor that might impact the enjoyment of the property. Typically it is only acceptable to place such a notice on a certificate of title if the factor is relatively permanent and would not be evident at all, or would not necessarily be obvious on inspection of the land. Potential erosion is one such factor. The notification could also include the possibility that there may be limitations on the nature of development that may be permitted on the land. It would not be appropriate to detail those limitations, which might change over time.

b) Notification on Title outside of Subdivision/Development Approvals: Except when the notification is required as a condition of development or subdivision approval, the land owner's acceptance is required before application to place a notice on a title can be lodged with the Registrar of Titles. Therefore, whilst it is possible to apply to have a section 70A notice placed on the Title in other circumstances, it can only be with the agreement of the owner. Also, a fee is payable which might make the task cost prohibitive depending on the number of titles involved. Nevertheless, the apparent impractical nature of the process requires further consideration and possibly negotiation with the State Government to, for example, remove the associated fees, in the public interest or redraft the policy to facilitate the intent of this clause.

Development Approvals: Development of land within the SCA needs to be carefully considered based on the outcomes of the overall CHRMAP. In general the principles outlined in **Section 5.4** of this document should apply, and it is recommended that the City develop appropriate planning documents to control and guide development within the SCA. It is recommended that all development within the SCA be made to require approval. Approval should be time limited and the triggers for removal of assets should be identified and included as a condition of any approval (with possible memorial on the title to make this known to landowners for as long as necessary).

The State Coastal Planning Policy Guidelines (Section 5) provides for consideration of infill development where the parcel of land lies in between existing development and does not extend seaward past the line of existing development. In considering development proposals or subdivision of land within the SCA, the City would need to consider the adaptation and management measures to be adopted for the area. If the recommended option is one of 'Managed Retreat' or 'Do Nothing', development or subdivision may only be considered in accordance with The State Coastal Planning Policy Guidelines. For example: locating development on the least hazardous portion of the site, not permitting an increase in development density, or favouring low cost and temporary developments. If a 'Protect' approach has been adopted, and appropriately planned and allowed for, development approval would need to consider whether appropriate arrangements for sharing the responsibility for future management of the coastal hazard risk are in place.

Retreat Planning: Before any implementation of CHRMAP recommendations, it is recommended that a retreat options plan be prepared that includes information on the regulatory framework, landowner right and responsibilities and a strategy for the City and State to support the process. The City and State would need to investigate their potential liabilities, for example should injurious affection arise due to adversely affecting people's development rights by making changes to planning policies or schemes. The financial implications and responsibilities for compulsory acquisition of land in the future should also be assessed, and funding allocated by responsible authorities for this where necessary.

5.3.3 Development within the Foreshore Reserve

Development of the foreshore reserve should only be undertaken in accordance with Local Planning Policy 4.21 and SPP2.6 policy and guidelines.

- Coastal roads: SPP2.6 states that generally coastal roads should not be developed within the coastal foreshore reserve. Design of new subdivisions should be robust enough to allow for alternative routes to be taken in the event that a key access route is impacted by coastal processes.
- Coastal car parks: SPP2.6 states that coastal carparks should be located landwards of the likely impacts of coastal processes. However, the design life of the carpark and most up to date coastal hazard line, relevant to that timeframe, should also be considered in planning such facilities, along with the availability of suitable land to relocate them in the future, if necessary.
- Commercial and Tourist Related Infrastructure: Development of commercial and tourist related infrastructure within the coastal foreshore reserve may be considered as outlined in Section 7.4 of Schedule 1 of SPP2.6. Development plans for such infrastructure should properly allow for the risks of coastal hazards (as determined in the CHRMAP) over the full lifespan of the proposed development. This should also include an appropriate assessment of social, economic and environmental impacts of the proposed development, and allocation of financial responsibilities (for the whole of life of the development including its potential removal at end-of-life to, for example, allow for future retreat), prior to approval.
- Public recreation facilities: SPP2.6 is not intended to prevent the development of public recreation facilities such as minor carparks, amenities, pedestrian access, recreational equipment and infrastructure for public safety within the coastal foreshore reserve. Development approval for such infrastructure needs to consider their full lifespan with respect to the applicable hazard extents.
- Temporary development: where it is deemed acceptable for development of a temporary nature to be permitted in accordance with SPP2.6 Schedule 1, Section 7, conditions of approval for temporary development outlined in LPP 4.21 should also be considered. It is recommended that approval be time limited and that triggers for removal of the assets should be identified and included as a condition of any approval (with possible memorial on the title to make this known to landowners for as long as necessary).

5.3.4 Land Records System

It is recommended that the City introduce an easily recognisable alert into its land records system so that staff accessing information on any affected land – including road reserves and other Council controlled land within the City - for any reason can be made aware of the presence of the coastal hazard or any other factor requiring special attention or liaison with another part of the organisation or external agency. This will reduce the risk of works being undertaken by the City that are contrary to any adopted strategy for the land under consideration.

Information on relevant coastal hazards and the implications for property, now and into the future, should also be made available to potential buyers upon making a land purchase enquiry.

5.4 General Coastal Planning Principles

With a view to achieving the planning objective of ensuring permanent and easy public access to the beach and coastal recreation (foreshore) reserves, some guiding principles are proposed. These could form the basis for drafting scheme and/or policy provisions relating to the definition of coastal recreation reserves.

1. The coast and coastal recreation reserves are a public asset which should not, now or in the future, become the de facto exclusive domain of private landowners by virtue of the erosion of coastal reserves or other coastal processes.
2. Coastal reserves should be wide enough that they can still perform recreation and/or conservation functions (according to the reasons for their initial designation) even if they are affected by coastal erosion or diminution due to sea level rise.
3. Privatisation of coastal land at risk of erosion or long term inundation through freehold or long term leasehold subdivision should be avoided.
4. Permanent structures including buildings should not be permitted on land at risk of erosion or long term inundation.
5. Redevelopment of land at risk of erosion or long term inundation with permanent structures should not be permitted within the at-risk parts of the site.

5.5 Uncertainty and Adaptive Management

The coastal hazard lines derived in Part 1 of the CHRMAP process (M P Rogers, 2015a) (also see **Appendix A**) are subject to a number of assumptions that introduce a degree of uncertainty into the predicted location of each hazard line, at each planning time frame. The CHRMAP process recognises this and utilises adaptive management techniques to continually monitor, assess and revise plans as new information comes to light in the future. The confounding aspects of hazard line predictions for variable sea level rise and climate change scenarios and the complex coastal planning instruments will require a careful, balanced consideration when prioritising implementation of proposed adaptation options. The guiding principles discussed above and acceptance of the uncertainty in the hazard lines are intended to provide a reasonable overview to inform the community forum and feedback session that will be used to guide the content of the final CHRMAP.

Alongside the recommended adaptation pathways that will form the basis of the final CHRMAP, recommendations will be made for further investigation and monitoring programs specific to each site. This will help refine and guide the adaptation pathways into the future. The aim will be to make recommendations that will help reduce the uncertainty in the coastal process hazards, prior to subsequent updates of the City's CHRMAP.

6 Summary

The results of the preliminary MCA applied to each identified site (discussed in **Section 4**) are summarised in **Table 6-1**. The management options abbreviations in the **Table 6-1** were defined above in **Table 2-1**.

In general the proposed adaptation options effectively discuss technical mitigation options for adapting to the effects of landward migration of the shoreline, due to future sea level rise and coastal erosion. The preceding Section (**5**) provides a discussion of the range of planning instruments currently either in place, under review or subject to update prior to 2025, that the State and Local Government may utilise to effect changes in the character and use of the coastal zone.

The key vulnerability timeframes for the sites listed in **Table 1-1** show that the earliest key vulnerability is the 2050 time frame.

In general options recommend that:

- Where there is currently no existing development seaward of the predicted 2120 hazard line, planning controls and coastal zone boundaries be adjusted to preclude development within the zone;
- Where high value natural assets exist seaward of the 2120 hazard line, dune care and sand management options be considered;
- Where public built assets exist seaward of the 2120 hazard line, retreat options should be considered; and/or
- Where private land and dwellings are located seaward of the 2120 hazard line, options to retreat, accommodate or protect should be considered.

The guiding principles discussed in **Section 5-1** and acknowledgement of the uncertainty in the hazard lines will need to be considered during the next round of community forums and feedback session, , where the aim is to elicit community consensus on the priorities and content of the CHRMAP plan.

Table 6-1 Summary of preliminary MCA/CBA results showing recommended (R) options in green, not recommended (NR) options in red and adaptation planning options for further assessment (FA) in yellow. Not applicability (N/A) options shown in grey.

Description	Avoid	Managed Retreat			Accommodate			Protect							Preliminary long term pathway
	AV	MR1	MR2	MR3	AC1	AC2	AC3	PR1	PR2	PR3	PR4	PR5	PR6	DN	
Priority Ecological Community	R	FA	NR	N/A	N/A	N/A	N/A	R	FA	NR	NR	NR	NR	NR	No development permitted Managed retreat with low-level protection (dune care and possible sand management)
Sovereign Drive and residential lots	R	NR	FA	R	R	R	N/A	R	FA	FA	FA	FA	FA	NR	Avoidance of additional development Protection of private property and public assets and possible maintenance of beach amenity
Beach access road and carpark 'The Spot'	R	R	R	N/A	N/A	R	N/A	FA	FA	NR	NR	NR	NR	NR	No development permitted Managed retreat with possible low-level protection (dune care and sand management)
Capricorn Groyne carpark	R	FA	FA	R	R	R	N/A	R	FA	FA	FA	NR	NR	NR	Avoidance of additional development Low level protection of private property, possible managed retreat or protection
Brazier Road carpark	R	NR	FA	R	R	R	N/A	R	R	FA	NR	FA	FA	NR	Avoidance of additional development Protection of private property and public assets, maintenance of beach amenity
Residential lots, Yanchep	R	NR	FA	R	R	R	N/A	R	R	FA	NR	FA	FA	NR	Avoidance of additional development Protection of private property and public assets, possible maintenance of beach amenity
Heritage site Karli Springs	R	FA	N/A	N/A	N/A	N/A	N/A	R	R	NR	NR	NR	NR	NR	No development permitted Managed retreat with low-level protection (dune care and sand management)
Residential lots, Mindarie	R	FA	NR	R	R	R	N/A	R	NR	FA	N/A	N/A	FA	NR	Avoidance of additional development Protection of property by natural controls, possible sand nourishment to maintain public amenity
Priority Ecological Community	R	FA	NR	N/A	N/A	N/A	N/A	R	FA	NR	NR	NR	NR	NR	No development permitted Managed retreat with low-level protection (dune care and possible sand management)

AV	Avoid development	AC1	Notification on title	PR1	Dune care program	PR5	Nearshore Reef / Breakwater
MR1	Leave unprotected / repair	AC2	Emergency plans and controls	PR2	Sand Management	PR6	Seawall
MR2	Remove / relocate	AC3	Re-design to withstand impact	PR3	Beach Nourishment	DN	Do Nothing
MR3	Prohibit further development / redevelopment			PR4	Groyne		

7 References

Cardno, 2013, *Quinns Beach Long Term Coastal Management Study Stage 1*. Prepared for the City of Wanneroo.

Cardno, 2015, *Quinns Beach Long Term Coastal Management Study Stage 2*. Prepared for the City of Wanneroo.

Cardno, 2016, *City of Wanneroo CHRMAP Part 2 – Risk Assessment Chapter Report*. Prepared for the City of Wanneroo.

City of Wanneroo, 2016, *CHRMAP Part 2 – Coastal Adaptation Plan Project Brief & Scope of Works*. Perth, Western Australia.

CLE, 2014, North Two Rocks Local Structure Plan. Part One – Statutory Report . http://www.wanneroo.wa.gov.au/downloads/file/1040/draft_north_two_rocks_local_structure_plan_-_part_1

Creative Design + Planning, 2016, *Alkimos Coastal Node LSP No. 101*. Prepared for Landcorp

Darby, R., 2016, *South Alkimos Local Structure Plan*. prepared by Roberts Day Pty Ltd.

Gallop, S. L., Bosserelle, C., Pattiaratchi, C. B. & Eliot, I., 2011, *Hydrodynamic and morphological response of a perched beach during sea breeze activity*. Journal of Coastal Research, SI 64, pp. 75-79

GBGMaps, 2016, *Two Rocks Geophysical Infill Survey, Western Australia*. Prepared for the City of Wanneroo.

MP Rogers & Associates, 2015a, *CHRMAP Part 1: Coastal Vulnerability Study & Hazard Mapping*. Prepared for the City of Wanneroo.

MP Rogers & Associates, 2015b, *Two Rocks Coastal Management*. Prepared for the City of Wanneroo.

RPS, 2015, *Foreshore Management Plan: Alkimos Beach*. Prepared for Lend Lease

Standards Australia Ltd, 2013, *Climate change adaptation for settlements and infrastructure – A risk based approach*, AS 5334-2013. Sydney, Australia

WAPC, 2013, *State Planning Policy No. 2.6: State Coastal Planning Policy*. Under the Planning and Development Act 2005. Western Australia

WAPC, 2014, *Coastal Hazard Risk Management and Adaptation Planning Guidelines*. Perth, Australia

APPENDIX

G

ADAPTATION OPTIONS - CONCEPTS

RESTRICT ACCESS

PRIORITY ECOLOGICAL COMMUNITY

RESTRICT ACCESS

DUNE CARE / REVEGETATION

LEGEND

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

0 100 160m

SCALE 1:4000 @A3

PRELIMINARY

NOT TO BE USED FOR CONSTRUCTION PURPOSES

City of Wanneroo

Protect Option - Dune Care

Figure 4.1

Priority Ecological Community, Two Rocks

Date	Scale	Size
20.02.2017	1:4000	A3
59916812-001		####
Drawing Number		Revision

DATE PLOTTED: 20 February 2017 2:50 PM BY : VINCENT CHAN KUN WA
CAD File: \\AUPERCFS01\Coastal&Ocean$\Jobs\59916812_WanneroCHRMAP\Drawings\Landscape\59916812-WanneroCHRMAP-Figs-Aerials_.dwg

0 50 100m

SCALE 1:3000 @A3

PRELIMINARY

NOT TO BE USED FOR CONSTRUCTION PURPOSES

City of Wanneroo

Protect Option - Dune Care

Figure 4.2

Sovereign Drive & adjacent residential lots, Two Rocks

Date	Scale	Size
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59916812-002		####
Drawing Number		Revision

DATE PLOTTED: 20 February 2017 2:50 PM BY : VINCENT CHAN KUN WA
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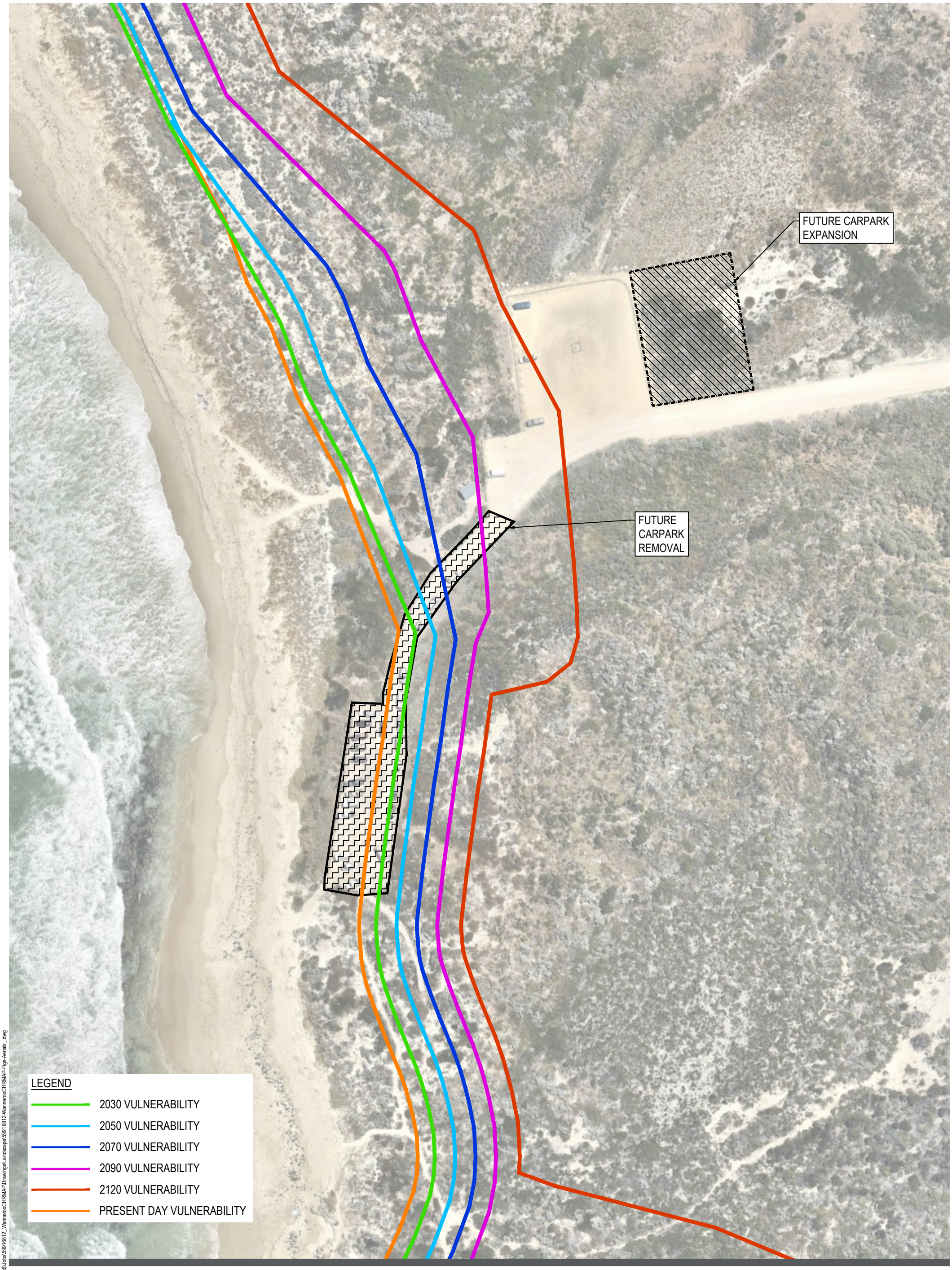

0 20 40m

SCALE 1:1000 @A3

PRELIMINARY

NOT TO BE USED FOR CONSTRUCTION PURPOSES

City of Wanneroo

Managed Retreat Option - Remove/Relocate

Figure 4.3

Beach Access Roads and Carpark 'The Spot', Two Rocks

Date	Scale	Size
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59916812-003 (Drawing Number) #### (Revision)

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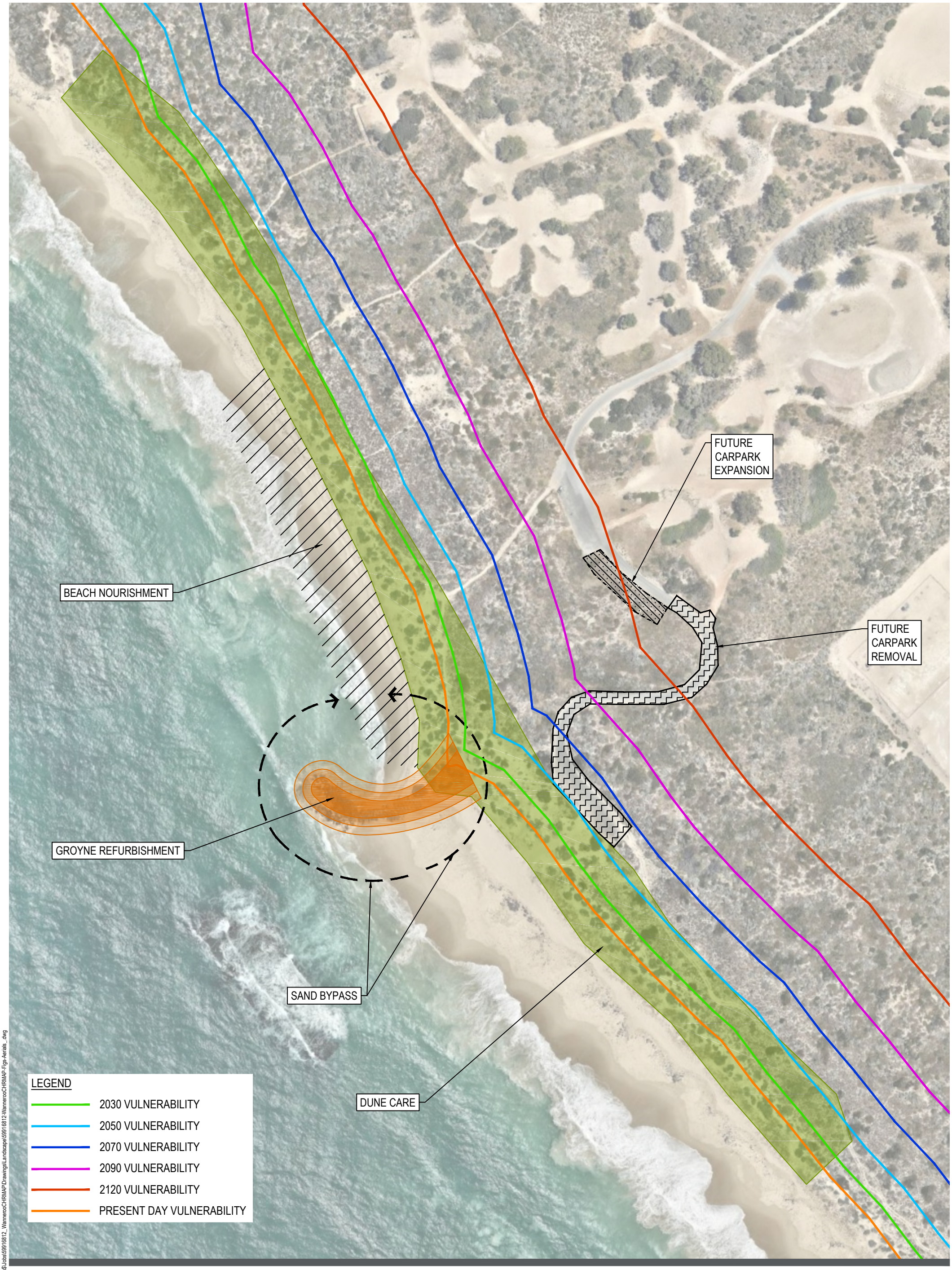

0 50m

SCALE 1:2000 @A3

PRELIMINARY

NOT TO BE USED FOR CONSTRUCTION PURPOSES

City of Wanneroo

Protect and Managed Retreat Options

Figure 4.4

Carpark South of Capricorn Groyne, Yanchep

Date	Scale	Size
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59916812-004		####
Drawing Number		Revision

DATE PLOTTED: 20 February 2017 2:50 PM BY : VINCENT CHAN KUN WA
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REALIGN ROAD

REMOVE

LEGEND

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

0 50 100m

SCALE 1:3000 @A3

PRELIMINARY

NOT TO BE USED FOR CONSTRUCTION PURPOSES

City of Wanneroo

Managed Retreat Option - Remove/Relocate

Figure 4.5a

Carpark adjacent to Brazier Road and residential lots, Yanchep

Date	Scale	Size
20.02.2017	1:3000	A3

59916812-005 Drawing Number

Revision

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BEACH NOURISHMENT

SEAWALL

BEACH NOURISHMENT

SEAWALL

LEGEND

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

0 50 100m

SCALE 1:3000 @A3

PRELIMINARY

NOT TO BE USED FOR CONSTRUCTION PURPOSES

City of Wanneroo

Protect Options

Figure 4.5b

Carpark adjacent to Brazier Road and residential lots, Yanchep

Date	Scale	Size
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59916812-006 (Drawing Number)

(Revision)

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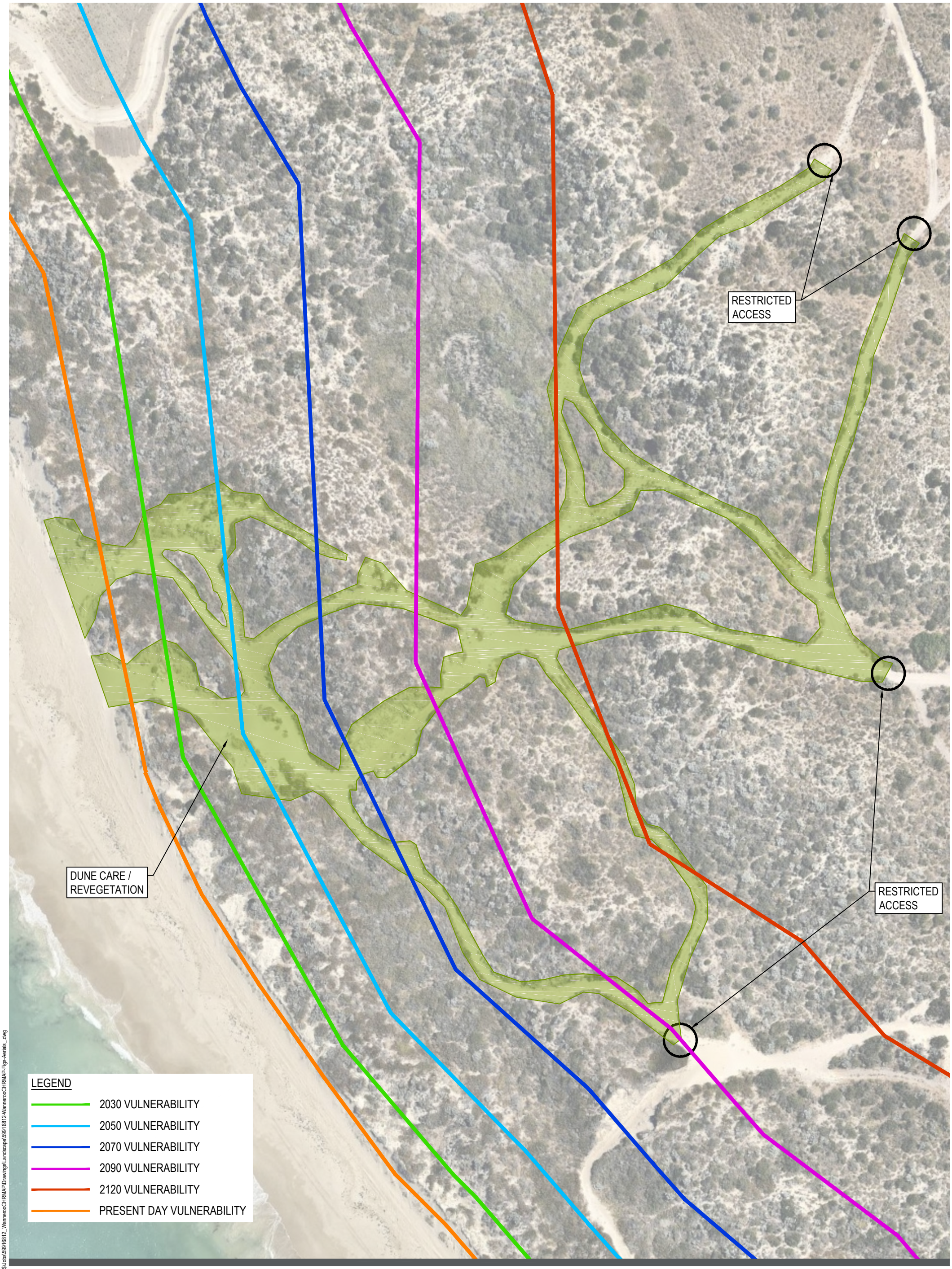

0 20 40m

SCALE 1:1000 @A3

PRELIMINARY

NOT TO BE USED FOR CONSTRUCTION PURPOSES

City of Wanneroo

Protect Option - Dune Care

Fig 4.6

Heritage Site,

Karli Springs, Alkimos

Date	Scale	Size
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Drawing Number		Revision

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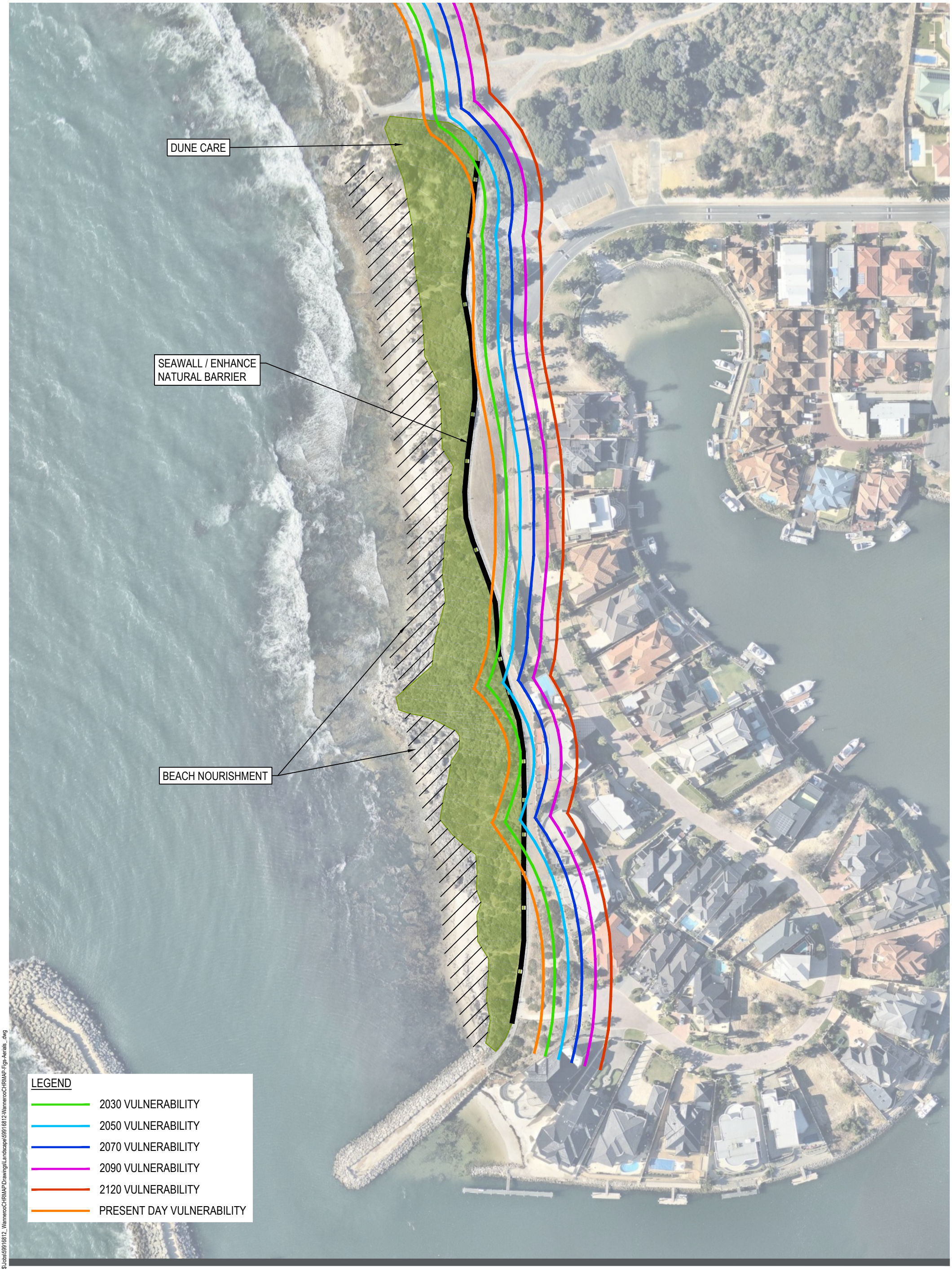

0 50m

SCALE 1:1500 @A3

PRELIMINARY

NOT TO BE USED FOR CONSTRUCTION PURPOSES

City of Wanneroo

Protect Options

Figure 4.7

Residential lots, Mindarie

Date	Scale	Size
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59916812-008 (Drawing Number)

(Revision)

DATE PLOTTED: 20 February 2017 2:50 PM BY : VINCENT CHAN KUN WA

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DUNE CARE

PRIORITY ECOLOGICAL COMMUNITY

LEGEND

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

0 100 100m

SCALE 1:7000 @A3

PRELIMINARY

NOT TO BE USED FOR CONSTRUCTION PURPOSES

City of Wanneroo

Protect Option - Dune Care

Figure 4.8

Priority Ecological Community, Mindarie

Date	Scale	Size
20.02.2017	1:7000	A3

59916812-009 Drawing Number

Revision

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APPENDIX

H

SOVEREIGN DRIVE, TWO ROCKS – MANAGEMENT CONCEPT DESIGNS (MRA, 2015B)

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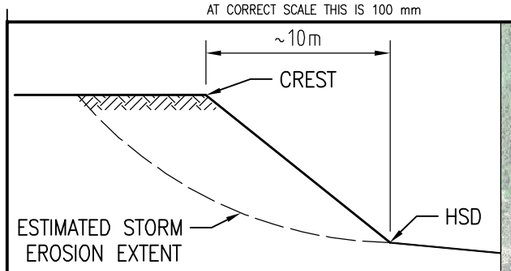

LINE RELATIONSHIP DIAGRAM
NTS

EXISTING SEAWALL AND
AD-HOC REPAIRS

PATH

EXISTING NAVIGATION MARKER

STAIRS AND PLATFORM

LEGEND:

- 2037 CREST LINE
- 2022 CREST LINE
- EXTENT OF STORM EROSION
- 2011 HSD (TOE OF SCARP)

NOTES:

1. MONITORING OF SHORELINE SHOULD BE UNDERTAKEN TO TRACK SHORELINE RECESSION
2. ESTIMATED CREST LINES ARE BASED ON RECESSIONS DUE TO STORM EROSION, SHORELINE MOVEMENT AND SEA LEVEL RISE

MANAGEMENT NOTES

① RELOCATE OR MODIFY STAIRS AND PLATFORM

② RELOCATE NAVIGATION MARKER

③ EXTEND SEAWALL BY APPROXIMATELY 80m

AT CORRECT SCALE THIS IS 100 mm

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MANAGED RETREAT OPTION

CITY OF WANNEROO – TWO ROCKS COASTAL REVIEW

SCALE AT A3 1:5,000

FEBRUARY 2013

SK1030-25/07/2013-1

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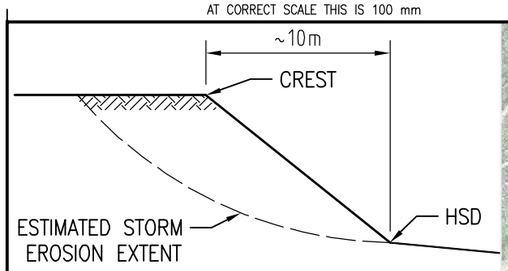

LINE RELATIONSHIP DIAGRAM
NTS

EXISTING SEAWALL AND
AD-HOC REPAIRS

② POTENTIAL ACCESS

EXISTING
NAVIGATION
MARKER

PATH

STAIRS AND PLATFORM

① APPROX 500m

PLACE 25,000 m3/yr

LEGEND:

- 2037 CREST LINE
- 2022 CREST LINE
- EXTENT OF STORM EROSION
- 2011 HSD (TOE OF SCARP)

NOTES:

1. 2022, 2037 LINES DO NOT INCLUDE AN ALLOWANCE FOR SHORELINE RECESSION DUE TO LONGSHORE TRANSPORT
2. POTENTIAL SEDIMENT SOURCES INCLUDE ROCLA GIN GIN QUARRY AND CARRAMAR RESOURCE INDUSTRIES
3. A MONITORING PROGRAM SHOULD BE CONDUCTED WITH SAND NOURISHMENT PROGRAM
4. ESTIMATED CREST LINES ARE BASED ON RECESSIONS DUE TO STORM EROSION AND SEA LEVEL RISE

MANAGEMENT NOTES

① RELOCATE OR MODIFY STAIRS AND PLATFORM

② EXTEND SEAWALL BY APPROXIMATELY 50m

③ SAND NOURISHMENT OF 25,000 m3/yr TO BE CONDUCTED ANNUALLY

AT CORRECT SCALE THIS IS 100 mm

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SAND NOURISHMENT OPTION

CITY OF WANNEROO – TWO ROCKS COASTAL EROSION REVIEW

FEBRUARY 2013

SCALE AT A3 1:5,000

SK1030-25/07/2013-2

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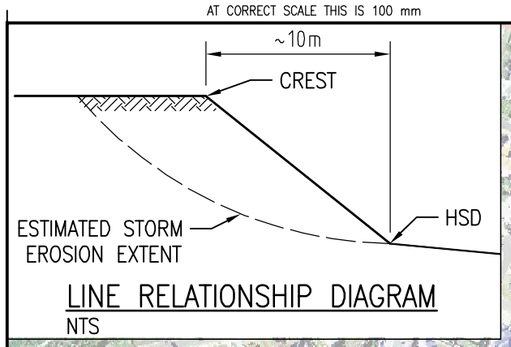

LINE RELATIONSHIP DIAGRAM
NTS

EXISTING SEAWALL AND AD-HOC REPAIRS
POTENTIAL ACCESS
EXISTING NAVIGATION MARKER
POTENTIAL ACCESS TO BEACH
POTENTIAL SAND SOURCE
POTENTIAL PIPE ROUTES
SEAGRASS WRACK ACCUMULATES IN THIS AREA
PLACE 25,000 m3/yr
APPROX 500m
STAIRS AND PLATFORM

LEGEND:

- 2037 CREST LINE
- 2022 CREST LINE
- EXTENT OF STORM EROSION
- 2011 HSD (TOE OF SCARP)

NOTES:

1. 2022, 2037 LINES DO NOT INCLUDE AN ALLOWANCE FOR SHORELINE RECESSION DUE TO LONGSHORE TRANSPORT.
2. MONITORING OF SHORELINE SHOULD BE UNDERTAKEN TO TRACK SHORELINE RECESSION & EFFECTIVENESS OF BYPASSING.
3. ESTIMATED CREST LINES ARE BASED ON RECESSIONS DUE TO STORM EROSION AND SEA LEVEL RISE.

MANAGEMENT NOTES

① RELOCATE OR MODIFY STAIRS AND PLATFORM

② EXTEND SEAWALL BY APPROXIMATELY 50m

③ SAND BYPASSING OF 25,000 m3/yr TO BE COMPLETED ANNUALLY

AT CORRECT SCALE THIS IS 100 mm

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SAND BYPASSING OPTION

CITY OF WANNEROO – TWO ROCKS COASTAL EROSION REVIEW

SCALE AT A3 1:5,000

FEBRUARY 2013

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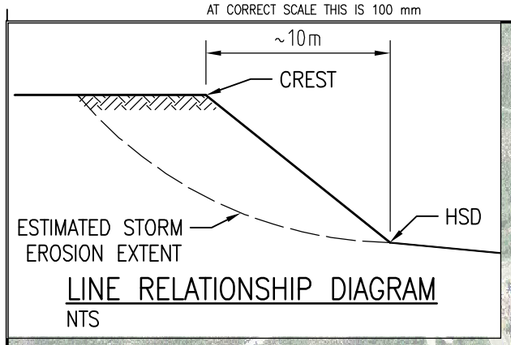

LINE RELATIONSHIP DIAGRAM
NTS

AT CORRECT SCALE THIS IS 100 mm

TYP SECTION
1:20

LEGEND:

- 2037 CREST LINE
- 2022 CREST LINE
- EXTENT OF STORM EROSION
- 2011 HSD (TOE OF SCARP)

NOTES:

1. ESTIMATED CREST LINES ARE BASED ON RECESSIONS DUE TO STORM EROSION, SHORELINE MOVEMENT AND SEA LEVEL RISE IF SEAWALL NOT CONSTRUCTED
2. MONITORING OF SHORELINE SHOULD BE UNDERTAKEN TO TRACK SHORELINE RECESSION

MANAGEMENT NOTES

① STAGE A IS PRIORITY FOR WORKS. SEAWALL IS CONSTRUCTED TO MAINTAIN MINIMUM BUFFER OF 40m FROM THE ROAD RESERVE TO ALLOW FOR DUNE SLOPE AND USEABLE FORESHORE RESERVE

② REMAINDER OF SEAWALL TO BE COMPLETED IN STAGES AS EROSION PROGRESSES

③ RELOCATE NAVIGATION MARKER TO BEHIND PROPOSED SEAWALL LOCATION AS NEEDED

④ RELOCATE OR MODIFY STAIRS AND PLATFORM

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SEAWALL OPTION

CITY OF WANNEROO – TWO ROCKS COASTAL EROSION REVIEW

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SK1030-25/07/2013-3

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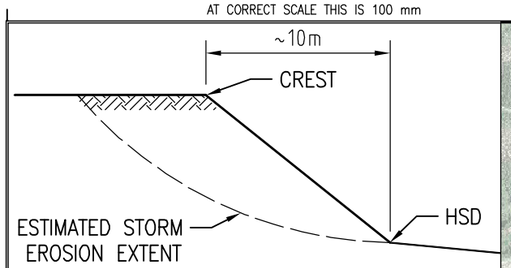


LINE RELATIONSHIP DIAGRAM
NTS

STAIRS AND PLATFORM ③

ESTIMATED FINAL SHORELINE

EXISTING NAVIGATION MARKER

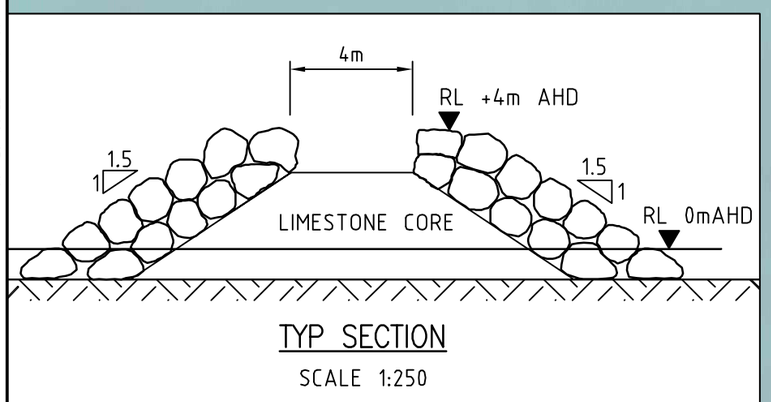
ESTIMATED FINAL SHORELINE

EXISTING SEAWALL AND AD-HOC REPAIRS ②

CONTINUED EROSION

① ④

AT CORRECT SCALE THIS IS 100 mm



TYP SECTION
SCALE 1:250

LEGEND:

- 2037 CREST LINE
- 2022 CREST LINE
- EXTENT OF STORM EROSION
- 2011 HSD (TOE OF SCARP)

NOTES:

1. TO MAINTAIN APPROPRIATE BUFFER, GROYNES HAVE TO BE BUILT WITHIN ~5 YEARS
2. IF CONSTRUCTION IS DELAYED, NOURISHMENT MAY BE REQUIRED
3. ESTIMATED CREST LINES ARE BASED ON RECESSIONS DUE TO STORM EROSION AND SEA LEVEL RISE
4. MONITORING OF SHORELINE SHOULD BE UNDERTAKEN TO TRACK SHORELINE RECESSION
5. 2022, 2037 LINES DO NOT INCLUDE AN ALLOWANCE FOR SHORELINE RECESSION DUE TO LONGSHORE TRANSPORT

MANAGEMENT NOTES

① CONSTRUCTION OF STAGE 1 GROYNES

② EXTEND SEAWALL BY APPROXIMATELY 50m

③ STAIRS AND PLATFORM TO BE RELOCATED OR MODIFIED

④ CONSTRUCT STAGE 2 GROYNES PRIOR TO 2037

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GROYNES OPTION

CITY OF WANNEROO – TWO ROCKS COASTAL EROSION REVIEW

FEBRUARY 2013

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SK1030-25/07/2013-4

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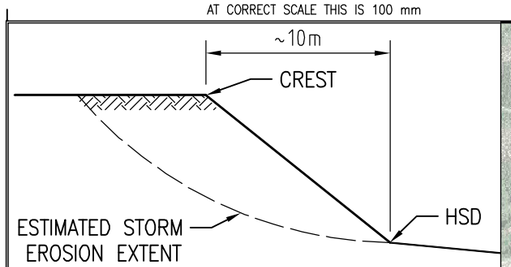

LINE RELATIONSHIP DIAGRAM
NTS

AT CORRECT SCALE THIS IS 100 mm

TYP SECTION
SCALE 1:250

LEGEND:

- 2037 CREST LINE
- 2022 CREST LINE
- EXTENT OF STORM EROSION
- 2011 HSD (TOE OF SCARP)

NOTES:

1. 2022, 2037 LINES DO NOT INCLUDE AN ALLOWANCE FOR SHORELINE RECESSION DUE TO LONGSHORE TRANSPORT.
2. MONITORING OF SHORELINE SHOULD BE UNDERTAKEN TO TRACK SHORELINE RECESSION
3. ESTIMATED CREST LINES ARE BASED ON RECESSIONS DUE TO STORM EROSION AND SEA LEVEL RISE.

MANAGEMENT NOTES

① RELOCATE OR MODIFY STAIRS DUE TO STORM EROSION RISK

② EXTEND SEAWALL LENGTH BY APPROXIMATELY 50m

③ CONSTRUCT OFFSHORE BREAKWATER, LEAVE SAND BUNDS AS NOURISHMENT FOR TOMBOLO FORMATION

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OFFSHORE BREAKWATERS OPTION

CITY OF WANNEROO – TWO ROCKS COASTAL EROSION REVIEW

SCALE AT A3 1:5,000

FEBRUARY 2013

SK1030-25/07/2013-5