Appendix 5 - Coastal Hazard Risk Identification Report

Cottesloe Foreshore Redevelopment

Coastal Hazard Risk Identification

CW933000

Prepared for
Town of Cottesloe

31 October 2016

Cardno
Shaping the Future

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Executive Summary

The Town of Cottesloe has a vision to develop the public spaces along the Cottesloe Foreshore, while conserving the area's environmental, recreational and historical values, which have made Cottesloe Beach an iconic Australian destination. To pursue this vision The Town has created a broad level concept plan for the foreshore, which it intends to advance through the concept and detailed design phases.

Cardno has been engaged to undertake concept design for the foreshore zone from Forrest Street to Eric Street and subsequent detailed design for the zone from Forrest Street to Napier Street. Cardno will manage all aspects of the design process, including community consultation, liaising with relevant government departments to ensure approvals are in place and undertaking contract administration for Stage 1 of the works. The project will involve the coordination of input from various disciplines, including landscape architecture, coastal engineering, civil engineering, traffic engineering / transport planning, public art consultants, electrical engineering and irrigation.

Documentation following the Coastal Hazard Risk Management and Adaptation Plan (CHRMAP) guidelines (WAPC, 2014) will be developed alongside the design process, to demonstrate to the Western Australian Planning Commission that current and potential future coastal hazards have been considered. This report addresses the initial steps in the CHRMAP process; namely establishing the context and identifying risks through a coastal vulnerability assessment.

The context for coastal management has been established through assessment of previous investigations, initial stakeholder consultation and the review of environmental conditions and processes at the site. This has allowed the determination of success criteria, against which identified risks will be evaluated. These criteria are:

> Environment and sustainability;

> Maintain and protect public safety;

> Protect and enhance the local economy and growth; and

> Protect community and lifestyle.

A site investigation was undertaken to assess the environmental setting of the study area and the layout of existing infrastructure at the site. This site visit, in conjunction with a review of existing coastal investigations in the area, allowed a preliminary assessment of coastal hazards and their associated risks.

Coastal hazards within the study area have been quantified and mapped through a coastal vulnerability assessment. This assessment follows the guidelines set out the State Planning Policy No 2.6 - State Coastal Planning Policy (SPP2.6) (WAPC, 2013). The coastal vulnerability of the study area now and for the future planning horizons 2040 and 2070 has been considered. Overall planning setbacks for erosion were developed by combining the potential for short-term (storm induced) erosion with potential long term erosion; comprising historical shoreline movement trends and that due to predicted sea level rise. Coastal inundation due to water level variations and wave setup has also been considered for current and future sea level rise scenarios.

In the next phase of the project, accompanying the finalisation of the concept design, risks will be evaluated in detail by analysing the likelihood and consequence of impacts due to the determined coastal hazards. This evaluation will draw on the success criteria to assess the acceptability of each risk. Advice will then be provided as to the most appropriate locations for various land-use proposals, and any adaptation options required to mitigate the risks of these hazards. Adaptation options will follow the SPP2.6 'Avoid, Retreat, Accommodate and Protect' hierarchy.

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1 Introduction

Cottesloe Beach is an ingrained Western Australian icon; it is recognised as the most popular beach in Perth, and a "must-visit" destination for visitors to Western Australia. It is home to the landmark Indiana Restaurant, the trendy Cottesloe Beach Hotel, and plays host to the annual Sculpture by the Sea exhibition.

As a result of recent changes to Town Planning rules, there is new interest in private redevelopment of buildings around Cottesloe Beach, with an initial redevelopment already approved. Additionally, the Town is in negotiations with the leaseholder of the Indiana Restaurant to consider opportunities to redevelop the landmark building.

Responding to this private redevelopment potential, and to ensure the iconic status of Cottesloe Beach is retained, the Town of Cottesloe (herein referred to as 'the Town') intends to redevelop the public spaces of the Cottesloe Foreshore. In combination with the private redevelopment, the Town desires to ensure the retention of the iconic status of Cottesloe Beach. Central to this objective, the Town desires to create a safe and vibrant public space that is sympathetic to its heritage values whilst confirming its important and special place in the social history and fabric of Perth and its surrounds.

In order to progress the redevelopment of the Cottesloe Foreshore, the Town has created a broad level concept plan depicting the community vision. The Town now intends to advance this plan and ultimately to commence the redevelopment of the public spaces of the Cottesloe Foreshore. The Town also seeks to resolve pedestrian and cyclist road safety problems, as part of the redevelopment.

1.1 Scope of Work

Cardno were engaged to assist the Town with the Cottesloe Foreshore Redevelopment Project described above ('the Redevelopment'). The extent of the study area is displayed in Figure 1-1. The scope of the project includes:

> Concept Design for Forrest Street to Eric Street; and
> Detailed Design and Contract Administration for Forrest Street to Napier Street.

Cardno's role in the Redevelopment involves managing all aspects of the design process, including:

> The preparation of a well refined concept plan for the complete foreshore area;
> Community and stakeholder engagement, to allow relevant parties to inform the design, and gain community support and buy-in to the design;
> Liaising with relevant departments such as the State Heritage Council and the Western Australian Planning Commission (WAPC) to gain the necessary approvals so that the project can be implemented;
> Progressing the first stage of works (between Napier and Forrest Streets) through to detailed design, to facilitate tendering and construction;
> Contract administration of the Stage 1 works; and
> Overarching the above will be coordinating the inputs from all relevant disciplines, including landscape architecture, coastal engineering, civil engineering, traffic engineering / transport planning, public art consultants, electrical engineering and irrigation.

Measures to protect, conserve and enhance the Cottesloe Foreshore's coastal values will be inherent in all aspects of the design. This is particularly important given the substantial recreational infrastructure proposed to be included directly on the coast, such as beach-side promenades, an extension to the existing terraces and changes to the car parks. These measures are important not only to ensure the long term sustainability of the foreshore development, but are also required to gain any required approval from the WAPC.

Figure 1-1 Study area – yellow box: concept design area, red box: detailed design area

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The coastal component of the overall project will follow the recommended CHRMAP methodology outlined in the CHRMAP Guidelines (WAPC, 2014). As such, Cardno will develop CHRMAP documentation that will demonstrate both to the WAPC, and the Town of Cottesloe that the proposed design includes suitable allowance for coastal processes, including present day erosion, historical shoreline movement, sea level rise and storm surge inundation. The steps involved in the risk management and adaptation process are presented in Figure 1-2. This report addresses the first two steps of this process by establishing the context of the CHRMAP and identifying areas at risk from coastal hazards within the study area.

The identified risks will be assessed in a risk assessment framework as part of the next phase of work, in conjunction with detailed design. Ongoing stakeholder consultation will ensure that appropriate success criteria are maintained, against which risks will be assessed. Outlined at the conclusion of this report are the next steps required in the process towards completing the CHRMAP for the Redevelopment.

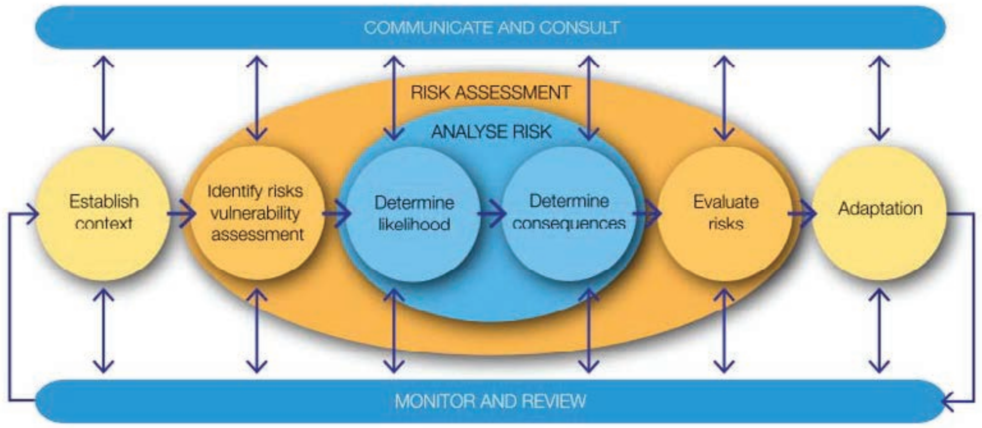

Figure 1-2 Risk management and adaptation process flowchart (WAPC, 2014)

1.2 Qualifications

Any potential impacts due to climate change, other than sea level rise, 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 redevelopment.

2 Establishing the Context

2.1 Legislative Context

Cardno and the Town of Cottesloe have committed to including measures to protect, conserve and enhance the Cottesloe Foreshore's coastal values in the Developed Concept Plan, particularly given the substantial recreational infrastructure proposed to be included directly on the coast, such as beach-side promenades, an extension to the existing terraces and adjustment to the car parks. These measures are important not only to ensure the long term sustainability of the foreshore development, but are also required to gain approval from the WAPC.

The Western Australian Planning Commission's most recent amendment to the State Coastal Planning Policy 2.6 recommends that management authorities develop a Coastal Hazard Risk Management Adaptation Plan (CHRMAP). This forms the basis of a risk mitigation approach to planning that identifies the hazards associated with existing and future development in the coastal zone. A critical stage of this process is establishing the context of the adaptation plan, through investigation and community consultation, by identifying the key built and natural assets, their value to the community and the success criteria for the adaptation plan.

This study will utilise the State Planning Policy No 2.6 - State Coastal Planning Policy (WAPC, 2013, herein referred to as 'SPP2.6'), WAPC's CHRMAP guidelines, and other relevant documentation to develop comprehensive CHRMAP documentation for the study area. This CHRMAP will guide the ongoing redevelopment of the Cottesloe Foreshore.

2.2 Proposed Redevelopment

This is described in Section 1. The proposed conceptual redevelopment layout, in its present form, is presented in Appendix 1.

2.3 Existing Studies

A number of studies and plans have been undertaken for the Cottesloe area to date. These include:

> Damara & CZM (2008)

> GBGMaps (2010 & 2011)

> MP Rogers (2005)

> BMT Oceanica (2015)

> Cardno (2016)

The results and analysis of these studies are incorporated into the relevant sections within this report.

2.4 Stakeholder Consultation

Stakeholder consultation is an important component of identifying assets of importance that are at risk of coastal hazards. Consultation is being undertaken as part of the greater Foreshore Redevelopment study. Cardno worked with the Town of Cottesloe to engage the key stakeholders involved in this study, all of which

are listed in Table 2-1 below. These are the main stakeholders whose values and development requirements shall form the success criteria developed specifically for this study. These criteria shall be assessed against each coastal hazard to ensure the development remains successful throughout the proposed design life.

Table 2-1 Government groups, stakeholders and community engaged in the study

Group	Department/Organisation
Government	WAPC
	State Heritage Council
	Department of Aboriginal Affairs
	Main Roads WA
Community & Stakeholders	Cottesloe Business Association
	Cottesloe Surf Life Saving Club (SLSC)
	North Cottesloe SLSC
	Cottesloe Coastcare Association
	Sculpture by the Sea
	Local Indigenous Groups
	Linley Lutton/Urbanix
	General Community (by way of forums)

2.4.1 Workshop 1 – Visioning

The first workshop was held with the Town of Cottesloe on the 9th February 2016. The aim of this workshop was to provide the design team with a clear understanding of the qualities, themes and vision that Council aspire to for the foreshore. From here, Cardno could begin the concept design in line with the Town of Cottesloe's requirements.

At the workshop, Cardno provided a brief photographic tour of other coastal developments throughout Western Australia and nationally to provide a point of reference for proposals at Cottesloe, and presented some initial options and ideas about how to best treat the key zones in the study area. It was agreed that the development should be low key, with high quality finishes; incorporate a lot of vegetation and 'nature', keep its general feeling and sense of place, have universal access and include environmentally sustainable principles.

Additional suggestions were provided, and feedback acquired, about how to best integrate Public Art within the landscape, with the primary focus recognising the Indigenous and European heritage of the site.

2.4.2 Stakeholder Meetings

Meetings with stakeholders commenced in February and March of 2016. The general consensus was in support of the redevelopment with positive and constructive suggestions from the various groups noted. There was cohesion between stakeholder expectations and the proposed design/vision for the areas, such as keeping/increasing vegetation in the study site and enhancing its natural value; minimising infrastructure (existing and proposed) that is visually obtrusive (car parks, signage); increasing accessibility to the site in a sustainable way (increased awareness of public transport options and bicycle use) and so on.

2.4.3 Additional Consultation

A number of stakeholder consultation events for the project are yet to be held as follows:

> Workshop 2 – Site Arrangement

> Workshop 3 – Present Draft Concept Plan

> Community Forum 1

> Community Forum 2

These are scheduled to occur later in the redevelopment design process.

2.5 Success Criteria

Success criteria are defined to evaluate the significance of identified risks. They determine if the objectives of the development will be achievable on an ongoing basis. In other words, they are the minimum benchmark performance indicators. The criteria below are previously defined success criteria as discussed in Damara & CZM (2008). They also reflect the views of the stakeholders as expressed in the consultation to date, and the objectives and values of the development. Whilst the criteria here are broad, they can be applied to specific consequences:

> Environment and sustainability;

> Maintain and protect public safety;

> Protect and enhance the local economy and growth; and

> Protect community and lifestyle.

Each risk identified in the risk assessment process shall be evaluated against these criteria. For those risks that are identified to be unacceptable through the consequence-likelihood matrix and vulnerability analysis, adaptation options must be investigated. It is important to note that consequence alone does not constitute failure of the success criteria. For example, minor loss of adaptive capacity to beach access may fail some of the above criteria, but if deemed to be unlikely, may be acceptable overall.

Ultimately, the CHRMAP aims to identify unacceptable risks and provide monitoring or adaptation solutions, whereby the development may continue to provide its services using a sustainable economic budget.

3 Environmental Setting

3.1 Site Visit

Cottesloe Beach is located 12 km west of Perth's city centre in Western Australia. Cottesloe's main beach is classified as a reef-protected, reflective sandy beach, while North Cottesloe is a reflective (sandy) beach (BMT Oceanica 2015). The area is made up primarily of calcium carbonate sediment from offshore biogenic sources and eroded Tamala Limestone cliffs from adjacent coastline (CZM & Damara 2008). A site visit was conducted on the 9th November 2015. Key observations from the visit are summarised in the text and images below.

The beach face is wide (at time of aerial and photographic surveys) (Figure 3-1a), with aeolian ripples in the back beach (Figure 3-1b). A steep scarp in the swash zone was present in the beach immediately north of the groyne, at the time of site visit (Figure 3-1c). This feature was noted by BMT Oceanica (2015) in their December 2014 survey. There was no sediment atop the intertidal platform immediately south of the groyne (Figure 3-1d).

Due to the presence of infrastructure, dunes within the study area begin from John St and extend north. They range from 3 to 13 m AHD and are up to 40 m wide in some places (from beach face up to footpath running adjacent to Marine Parade). They are moderately covered by low lying coastal vegetation (Figure 3-2a), with grass beginning as the dune gradient flattens out. Some areas of the dunes are under rehabilitation, and blow outs are also present in areas (Figure 3-2b and c). Limestone cliffs/outcrop in the south of the study area associated with Mudurup Rocks (Figure 3-2). Dense grass and the majority of the public amenity and infrastructure lies atop or immediately behind the primary dune system (Figure 3-3a).

The sea walls/amphitheatre extends to the beach face at main beach in the southern extent of the study area (Figure 3-3b). This extends north to John St. The sea walls will limit erosion of the shoreline landward, but may have the potential for a scarp to form immediately seaward following storm activity. There are numerous beach access paths constructed of various materials (paved or wooden), and varying in condition (some have been overgrown with grass or sediment has built up on top) (Figure 3-3c). Fencing surrounds the dunes to restrict access; these vary in their condition. Some erosion/undercutting has occurred at the base of some the staircases providing access to the beach (Figure 3-3d).

Figure 3-1 **Cottesloe beach (a) wide sandy beach face, facing south (b) aeolian ripples (c) steep swash zone (d) no sediment south of groyne**

Figure 3-2 **Cottesloe beach dune system (a) vegetation covering dunes (b) dune rehabilitation areas (d) dune blow outs (d) limestone outcrop in southern study area**

Figure 3-3 **Infrastructure at Cottesloe Beach (a) majority of infrastructure/public amenity atop primary dune system (b) sea wall/amphitheatre extended to beach face (c) beach access paths both paved (background) and wooden (foreground) (d) undercutting of sediment under staircase to beach**

3.2 Oceanographic Conditions

3.2.1 Wind

Cottesloe is located within the greater Perth coastline and experiences typical oceanographic conditions of the area. 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}.

3.2.2 Water Levels

Cottesloe, like the rest of the Perth coast, experiences low tidal range from mixed but mainly diurnal tides. The tidal range varies from 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 Fremantle have been included in Table 3-1. The full tidal range between LAT and HAT is quite small at 1.2 m.

Table 3-1 Fremantle Tide Level (Australian Hydrographic Service, 2012)

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

3.2.3 Wave Climate

The wave climate in the study area is seasonal. The wave energy is on average higher during the winter months of May to October. Analysis of the offshore waverider buoy at Rottnest from 1994-2006 indicated the annual wave energy peak occurred between June and September (Damara & CZM 2008).

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 study area's latitude, but have been recorded in the area and can cause significant damage to coastal infrastructure.

Cottesloe is afforded protection from offshore wave conditions by Rottnest Island to the west and fringing limestone reef structures scattered adjacent to the coastline. Cottesloe groyne can provide local sheltering from inshore waves, depending on the wave-direction.

3.3 Coastal Processes

3.3.1 Sediment Transport

Under the Department of Transport's (DoT's) sediment cell hierarchy (Stul et al 2012), the study site lies within Primary Sediment Cell F - South Mole Fremantle to Pinaroo Point. Within this primary cell the study area is covered by sediment cell 26, tertiary cell 26a – Mudurup Rocks to north Swanbourne pipe. This means the mechanisms of coastal change are expected to be similar throughout the study area over the short to medium term (i.e. inter-annual to decadal timescales).

Longshore sediment transport within the study area 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 (CZM & Damara 2008). Nearshore structures can obstruct this sediment movement. The most notable example of this is the Cottesloe groyne which exhibits accretion of sediment at its northern side in winter and alternatively erosion at the same site during summer.

Cross-shore sediment movement 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 can cause.

3.3.2 Shoreline Movement

Typically the shoreline shifts as a result of seasonal weather patterns and associated sediment transport regimes. In summer the Cottesloe main beach is relatively receded. This is due to strong northward currents associated with the south-westerly sea breeze, combined with water level fluctuations moving sediment northward alongshore. The Cottesloe groyne traps the material to the south of the groyne or diverts its transport offshore away from the main beach face; thus sediment is not deposited north of the groyne.

In winter, the shoreline advances as material accretes on the main beach. Winter wave conditions with significant offshore swell move sediment shoreward, feeding material to the nearshore zone and depositing it on the beach face at times. Storm events can drive erosion and accretion and lead to reshaping of beach form. The shift in longshore currents southward during this period means the Cottesloe groyne can now act as a sediment trap to its northern side, aiding retention of material.

North Cottesloe beach at the north of the study area, while exposed to the same hydrological conditions is less affected by the Cottesloe groyne. The beach is relatively open and exposed and its sedimentation is also influenced by a stunted headland at its northern end. Thus more subtle shoreline movements occur.

3.3.3 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. The existing controls at Cottesloe include the main groyne at Mudurup Rocks adjacent to the Surf Life Saving Club; the reef just offshore of the shoreline both adjacent to the study area and further south; Garden, Carnac and Rottnest Islands. Concrete sea walls that have been constructed between Warnham Road and Cottesloe Surf Life Club. These will affect the extent of landward erosion in the future.

The Town commissioned GPGMAPS to undertake geophysical investigations in 2010 and 2011 to address the key knowledge gap in understanding the study area's local geology. Based on testing of a longshore segment between Curtin Avenue and North Street, the depth between ground level and bedrock ranged between approximately 5 metres and greater than 10 metres. The compaction of beach sediment was found to be variable with depth along the tested segment, with generally poor compaction in the first 5 metres below the surface. Testing along a transect perpendicular to the shoreline revealed high variability in the depth from surface to bedrock; ranging from 2 metres to greater than 10 metres. These results indicated the bedrock on its own will not provide a suitable defence against erosion as it is too far below the surface.

Another existing control is the Town of Cottesloe's long-term beach monitoring program that commenced in 2014. The aim of the program is to gain knowledge of the patterns in beach changes along the Town's coastline, and potentially identify longer-term trends in erosions and/or accretion. The program involves shoreline surveys undertaken approximately every 6 months, spread along the span of the Town's shoreline. Complementary to this, monitoring by remote camera units provide images every hour of two key sections of the Town's coastline; Cottesloe Main Beach and North Cottesloe Beach

The monitoring program at present is relatively comprehensive given the Town's available resources. It is recommended the program is continued, in at least its current format, to gather a total dataset of 5-10 years before confident conclusions around trends in shoreline movement can be drawn.

Following completion of year 5 of monitoring, the data should be analysed for medium term trends, as well as for input into coastal management. For example, if medium term erosion trends were observed at a specific location, investigations could assist with management measures at that site. Data collection should still be ongoing, during and following this analysis. This dataset should be used in conjunction with the outcomes of this CHRMAP for optimal planning of the study area coastline.

3.4 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 mean sea level, 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 sea level rise are considered. It was noted in Section 1.2 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. This should be included in the monitoring and review process of this CHRMAP.

This study will consider the present timeframe, as well as the years 2040 and 2070. The period to 2070 has been included in the analysis to highlight the potential impacts and vulnerabilities beyond the 30 year design life. The purpose of performing risk assessments at different timeframes is to highlight the non-linear impacts of climate change over the design life of the assessment. It is recommended that the adaptation plan be reviewed in light of observed shoreline changes near to the end of the design life.

3.4.1 Sea-Level Rise

The International Panel for Climate Change's (IPCC) report AR4* (2007) has provided projections for sea level rise based on historical sea level rise and future emission scenarios. Based on the IPCC's projections, the DoT have recommended a vertical sea level rise of 0.9 m to be adopted when considering the impact of coastal processes over the next 100 years (2010 to 2110) (DoT 2010). Hunter's (2009) decadal representation of the recommended sea level rise scenario is presented in Figure 3-4, extended to 2110. These recommendations were formally adopted by the WAPC and form the basis of this project's sea level rise cases, presented in Table 3-2.

The more recently updated IPCC AR5 Report (2013) provided updated predictions of sea level rise due to a range of global emissions scenarios and the DoT (2010) recommendation remains consistent with these updated estimates.

For this study, only the sea level rise values up to 2070 have been used.

*The IPCC has released report AR5 (2014) however local projections for sea level rise relevant to this plan have not been significantly altered.

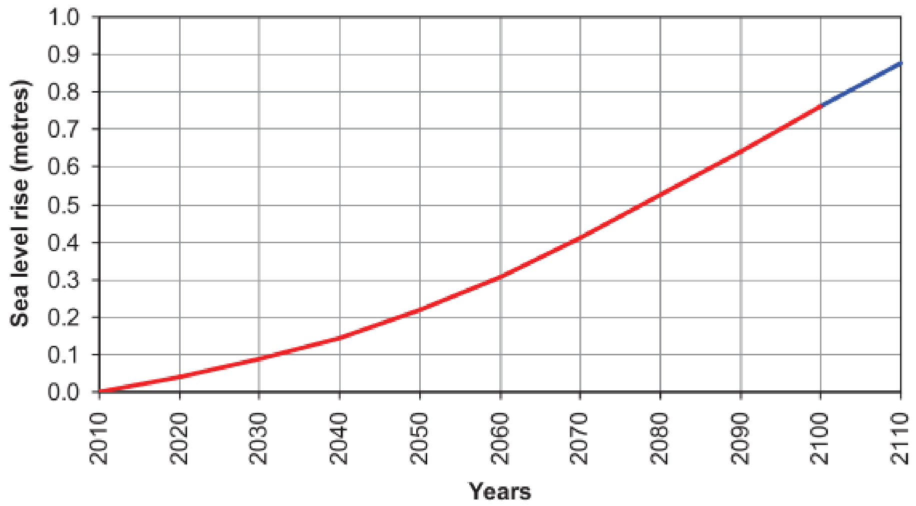

Figure 3-4 DoT's recommended allowance for sea level rise in coastal planning for WA (DoT 2010)

Table 3-2 Climate change simulations modelled sea level rise

Simulation	2040	2070	2110
Sea Level Rise	0.15 m	0.4 m	0.9 m

4 Coastal Hazard Risk Identification

4.1 Coastal Foreshore Reserve

Schedule One of SPP 2.6 provides guidance for calculating the coastal foreshore reserve to allow for coastal processes including present day erosion, historical shoreline movement, sea-level rise and storm surge inundation. The coastal foreshore reserve should be determined on a case by case basis and 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.

4.2 Erosion

The natural coastline is in general very responsive to the climate and any changes that occur. At any time, a development such as this is at risk of exposure to several forms of erosion. Allowances for these risks are categorised 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.

These three factors, plus an uncertainty allowance of 0.2 m per year, combine to form the predicted total erosion during the design life of the development. Included in SPP 2.6 is the current policy relating to the Sea Level Rise (SLR) projection for the 100-years planning period up to 2110. These revisions are:

> +0.15m for a 30-years (2040) planning period

> +0.4m for 60 years (2070) planning period

The predicted erosion values shall be calculated for the present day, and these timeframes, as presented in Table 3-2.

The coastal foreshore reserve is 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.

4.2.1 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 inundation and erosion. The Cottesloe region 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, 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 4-1 by the white dot). 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).

The SWAN model bathymetry is presented in Figure 4-1. This was generated using a combination of Two Rocks to Cape Naturaliste LiDAR data collected in 2009, and Navigational Charts AUS754 and AUS112 where the LiDAR was missing.

The synthetic storm was applied across the western model boundary, and part of the northern and southern boundaries, to bring the storm inshore. Cardno used SWAN model parameters consistent with Cardno (2015), for which good calibration was achieved. Data was extracted at 5 locations 2.5 km offshore for use in the coastal erosion model. The bathymetry and output locations are shown in more detail in Figure 4-2, a zoomed in presentation of the model bathymetry.

The output information at these 5 locations was analysed, and the maximum selected for input into the coastal erosion model to allow conservative results. The resultant design storm to be applied in the coastal erosion models is presented in Figure 4-3.

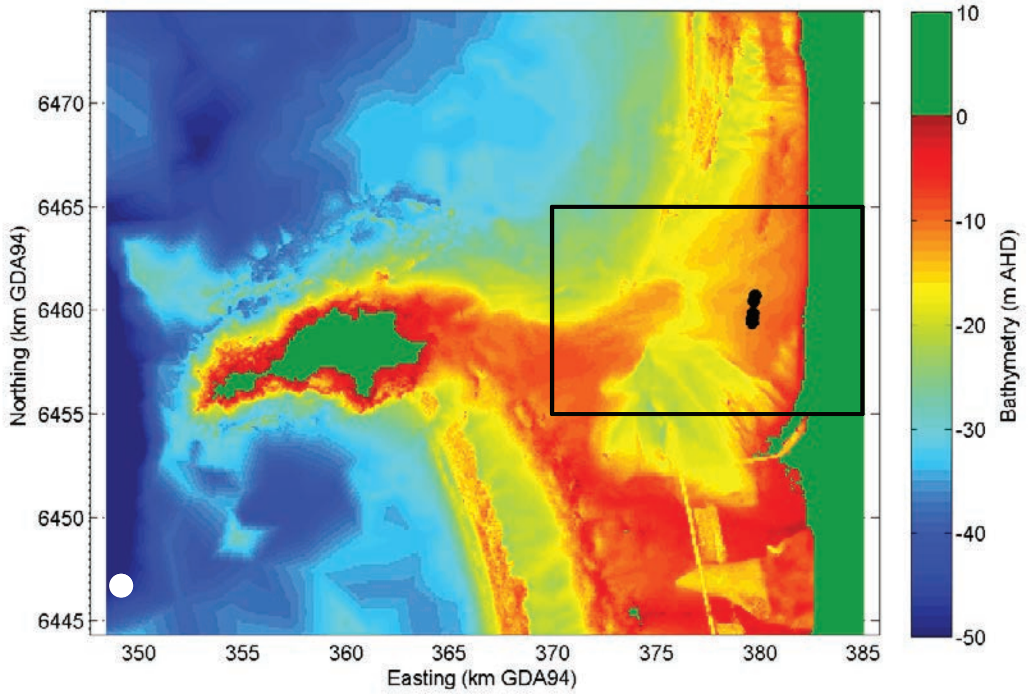

Figure 4-1 SWAN model bathymetry (m AHD). Rottnest Wave Buoy location shown by white dot; SBEACH output points indicated by black dots. Zoomed area presented below

Cottesloe Foreshore Redevelopment
Coastal Hazard Risk Identification

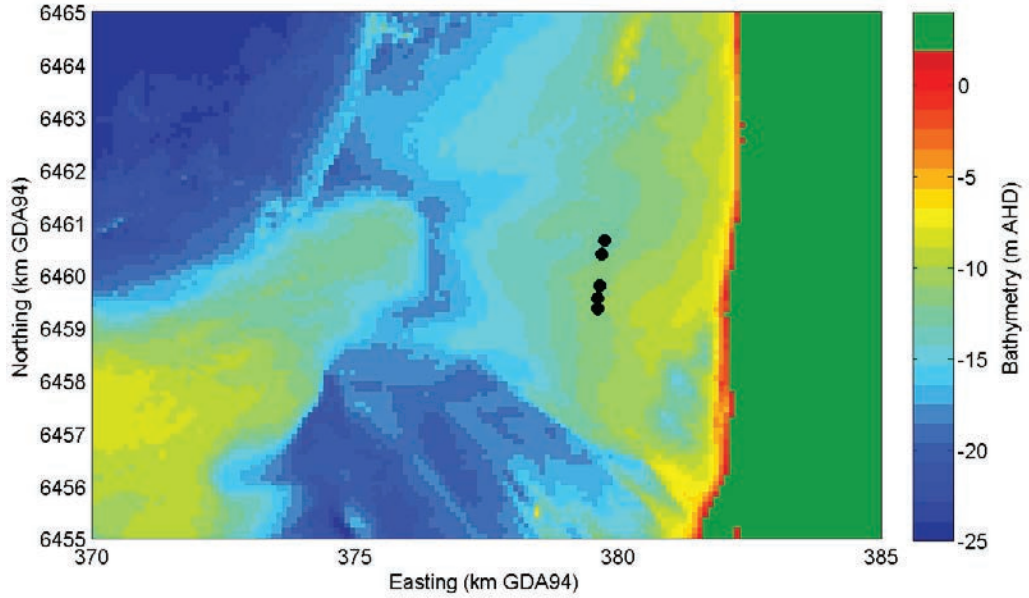

Figure 4-2 SWAN model bathymetry (m AHD) zoomed in on black rectangle area; SBEACH output points indicated by black dots

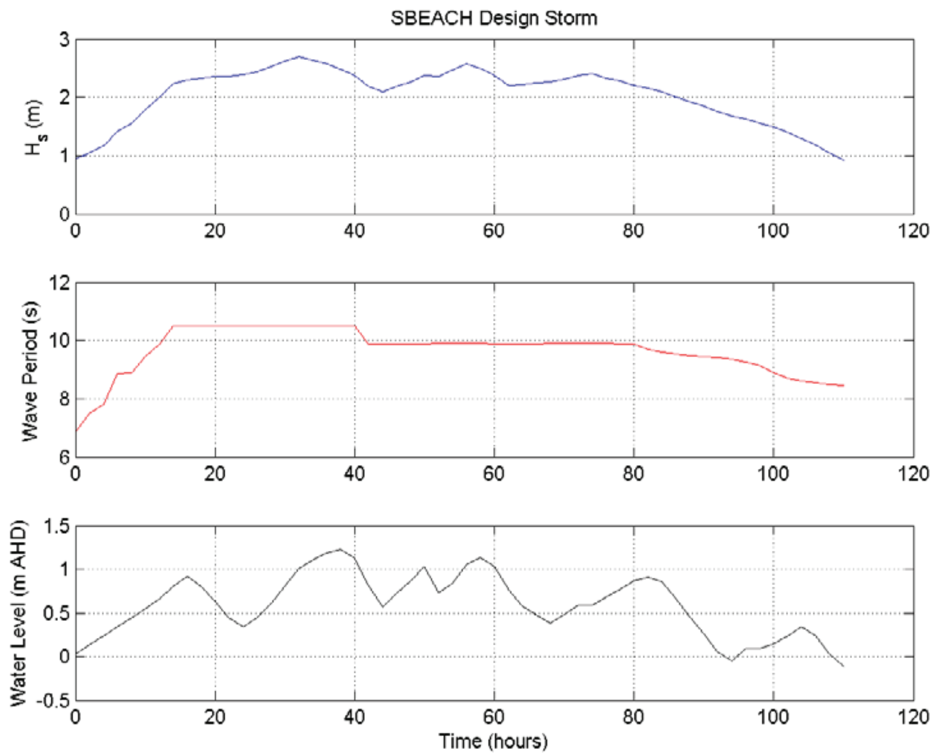

Figure 4-3 Design storm applied in SBEACH

4.2.2 S1 Acute Erosion

Short-term acute (storm-induced) erosion across the study site was investigated using the SBEACH numerical model as recommended in SPP2.6 for calculation of coastal processes allowance component S1. SBEACH was developed to calculate beach and dune erosion under storm wave action as described in Wise et al (1995).

Locations to be assessed were selected to be in line with the Town's beach monitoring program (Cardno 2016). These correspond to survey profiles 11, 13, 15 16 and 17, as displayed in Figure 4-4 (preceded by 'S' for survey location). The data from the September 2015 surveys was utilised for values above the 0 m AHD contour. From the 0 m AHD contour to 2.5 km offshore, the SWAN bathymetry was utilised. The SBEACH profile resolution is displayed in Table 4-1. Profiles were extended perpendicular to the coastline for 2.5 km to approximately -10 m AHD.

Table 4-1 SBEACH model resolution

Distance offshore from dune crest (m)	SBEACH grid resolution (m)
0 – 150	0.5
150 – 200	1
200 – 250	5
250 – 400	10
400 – 600	25
600 – 1000	50
1000 – 2500	500

The sediment size applied in the SBEACH model was 370 μm. This was based on a study undertaken by MP Rogers (MP Rogers, 2005) across the northern metropolitan coastline which involved collecting sediment samples for use in coastal modelling.

The presence of coastal structures and paths were applied in the model as follows:

> S11: Coastal footpath

> S13: Coastal footpath and limestone retaining wall

> S15: Car park retaining wall

> S16: Vertical seawall at base of amphitheatre

> S17: Vertical seawall seaward of the Cottesloe Surf Life Saving Club

The model was set up such that these structures would prevent erosion, subject to wave heights and relative water levels.

As discussed, the design storm output from the SWAN modelling was applied in SBEACH, three times in succession in line with SPP2.6. The model results are presented for each profile (S11 to S17) in Figure 4-5 to Figure 4-9. The plots show the intermediate profiles for simulations 1 and 2, as well as the initial and final profile.

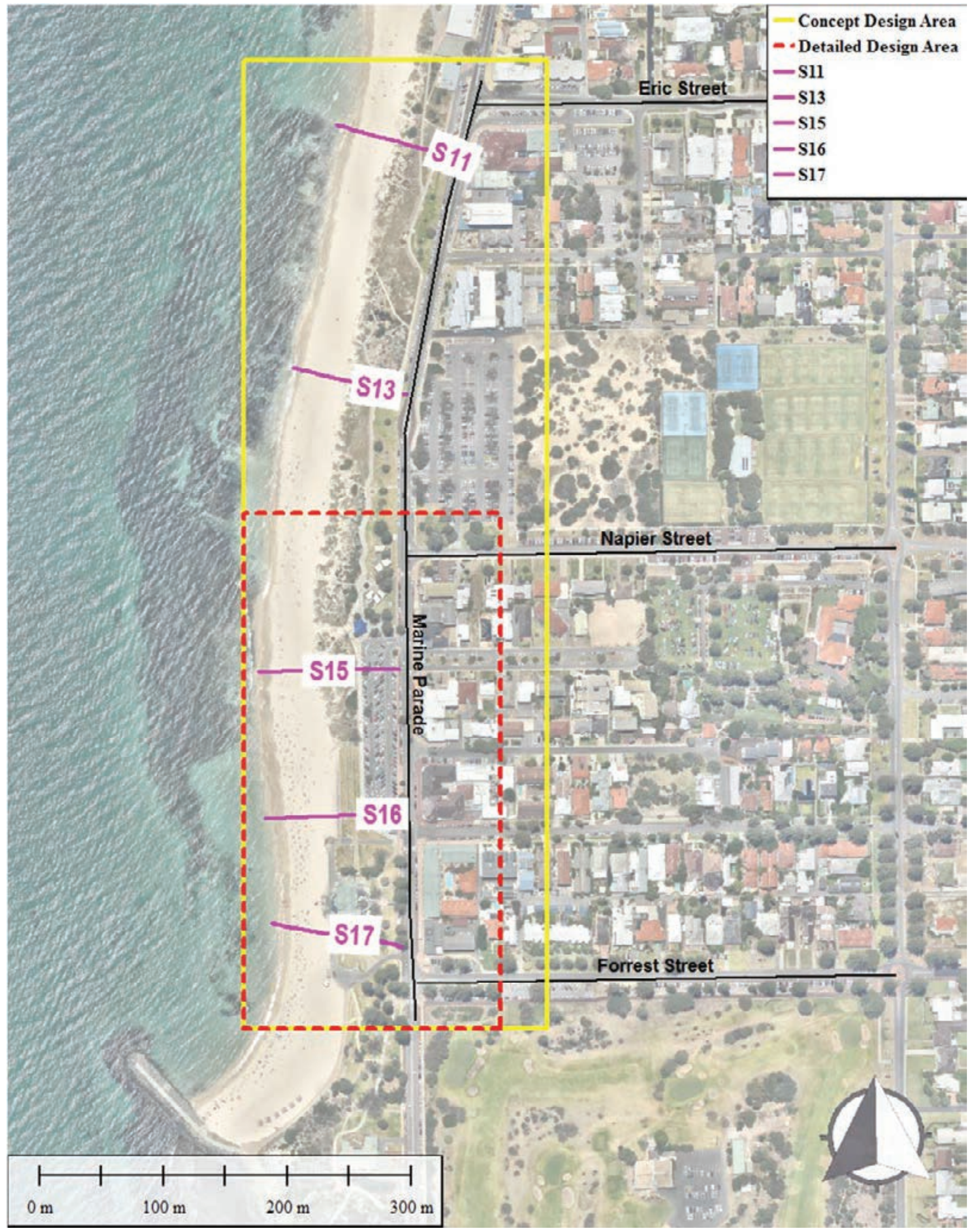

Figure 4-4 SBEACH profile locations

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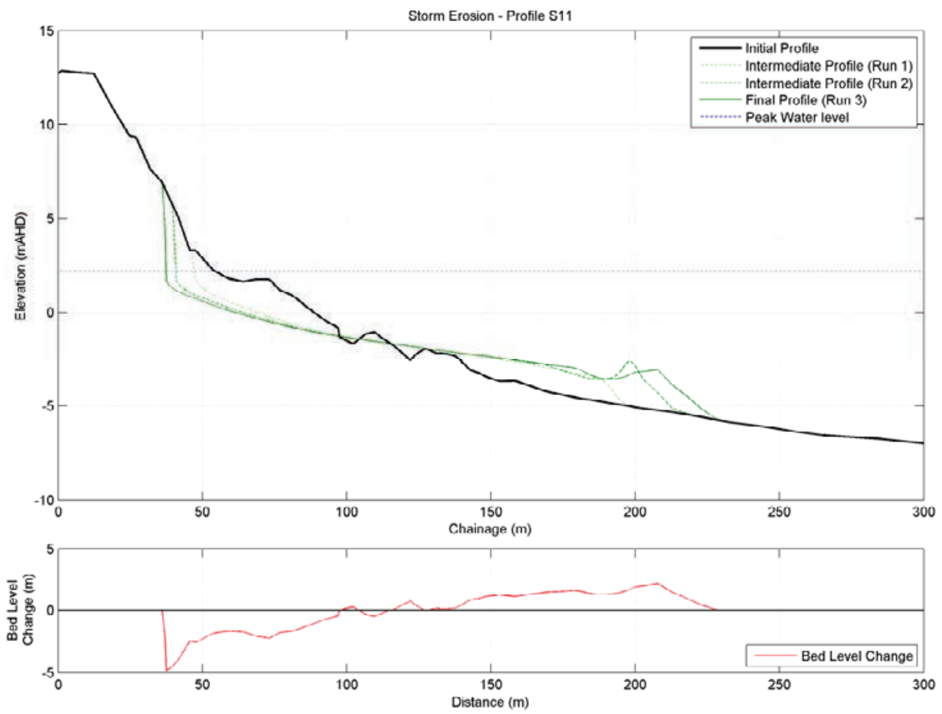

Figure 4-5 SBEACH results for Profile S11

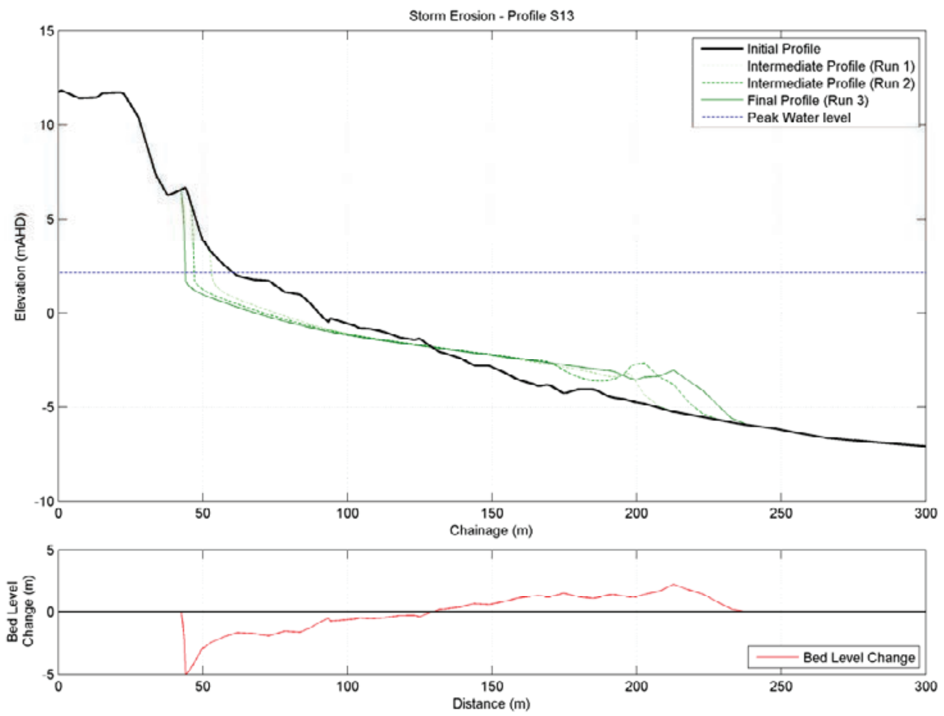

Figure 4-6 SBEACH results for Profile S13

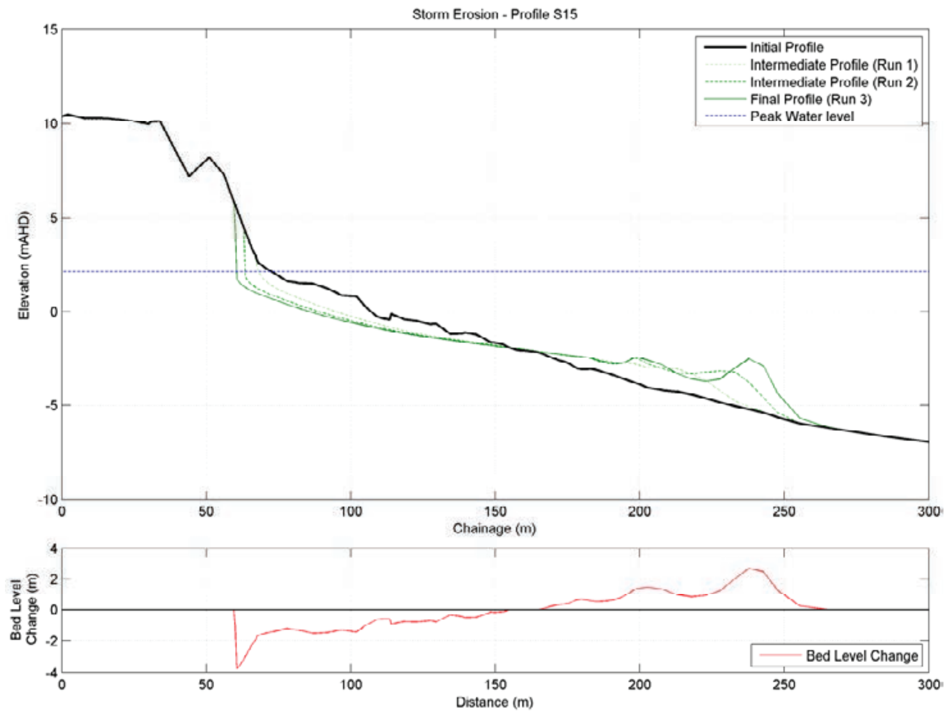

Figure 4-7 SBEACH results for Profile S15

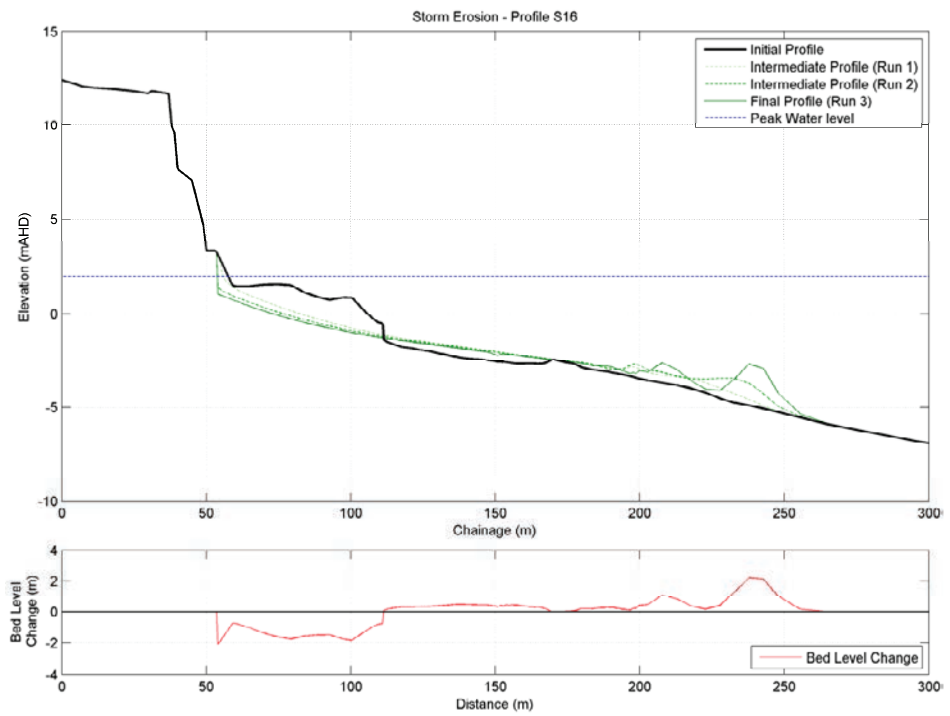

Figure 4-8 SBEACH results for Profile S16

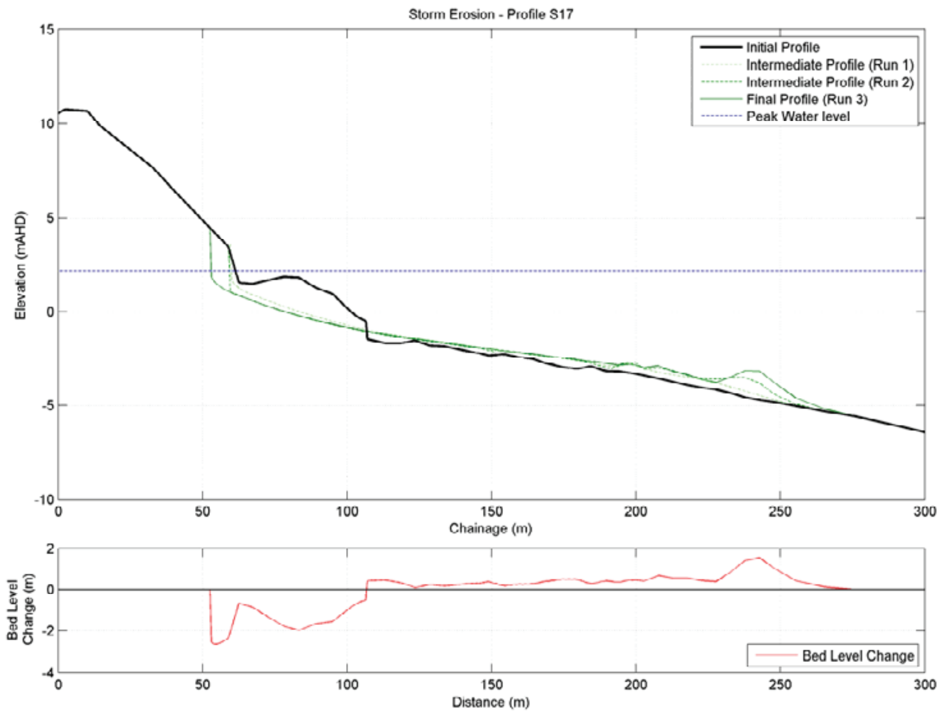

Figure 4-9 SBEACH results for Profile S17

A single S1 horizontal erosion distance is calculated for each profile based on the maximum horizontal erosion for that profile. This is taken as the maximum erosion calculated across all beach profiles within each section, to the nearest whole metre. Table 4-2 summarises the storm erosion values derived for each profile.

The SBEACH results also indicate the peak water level, which is used to derive the Horizontal Setback Datum (HSD) (blue horizontal line in Figure 4-5 to Figure 4-9). This corresponds to 2.1 m AHD. This value represents the one in 100 year water level plus an allowance for wave setup.

Table 4-2 Acute storm erosion allowance

Section	S1
S11	18
S13	17
S15	13
S16	4
S17	9

4.2.3 S2 Historic (Chronic) Erosion

Damara & CZM (2008) assessed historical coastal change. Within the project study area, they found that there was no history of exposed beach rock.

S2 was calculated by MP Rogers (2005) using aerial photographs from 1942 to 2004. To bring this analysis up to date, Cardno examined the 2004 image, and two additional images, 2012 and 2015, to establish further historical shoreline changes. The February 2012 and February 2015 aerial photographs were obtained from the Town of Cottesloe, and the 2004 image from the Department of Transport.

The most seaward vegetation line was traced for all three images. These lines are presented in Figure 4-10. In the detailed design area the main observation is the blowouts observed in the dune system since 2004. There has been accretion in the concept design area. All vegetation in the foredune is patchy; a dune revegetation program would assist with the stability of the dune going forward.

MP Rogers (2005) indicated the shoreline receded 15 m between 1942 and 2004. The vegetation line movement at each profile was measured between 2004 and 2015. The resultant total rate of change over the 74 year period was approximately 0.27 m per year at S11 and S13, and 0.23 m at S15. There was no change at S16 and S17 due to the presence of the seawall. In accordance with SPP2.6, this rate of recession is applied to the 2040 and 2070 scenario. The setback allowance is displayed in Table 4-3 for each profile location.

Table 4-3 Historic setback allowance S2 (m)

Profile	Existing	2040	2070
S11	0	8	16
S13	0	8	16
S15	0	7	14
S16	0	0	0
S17	0	0	0

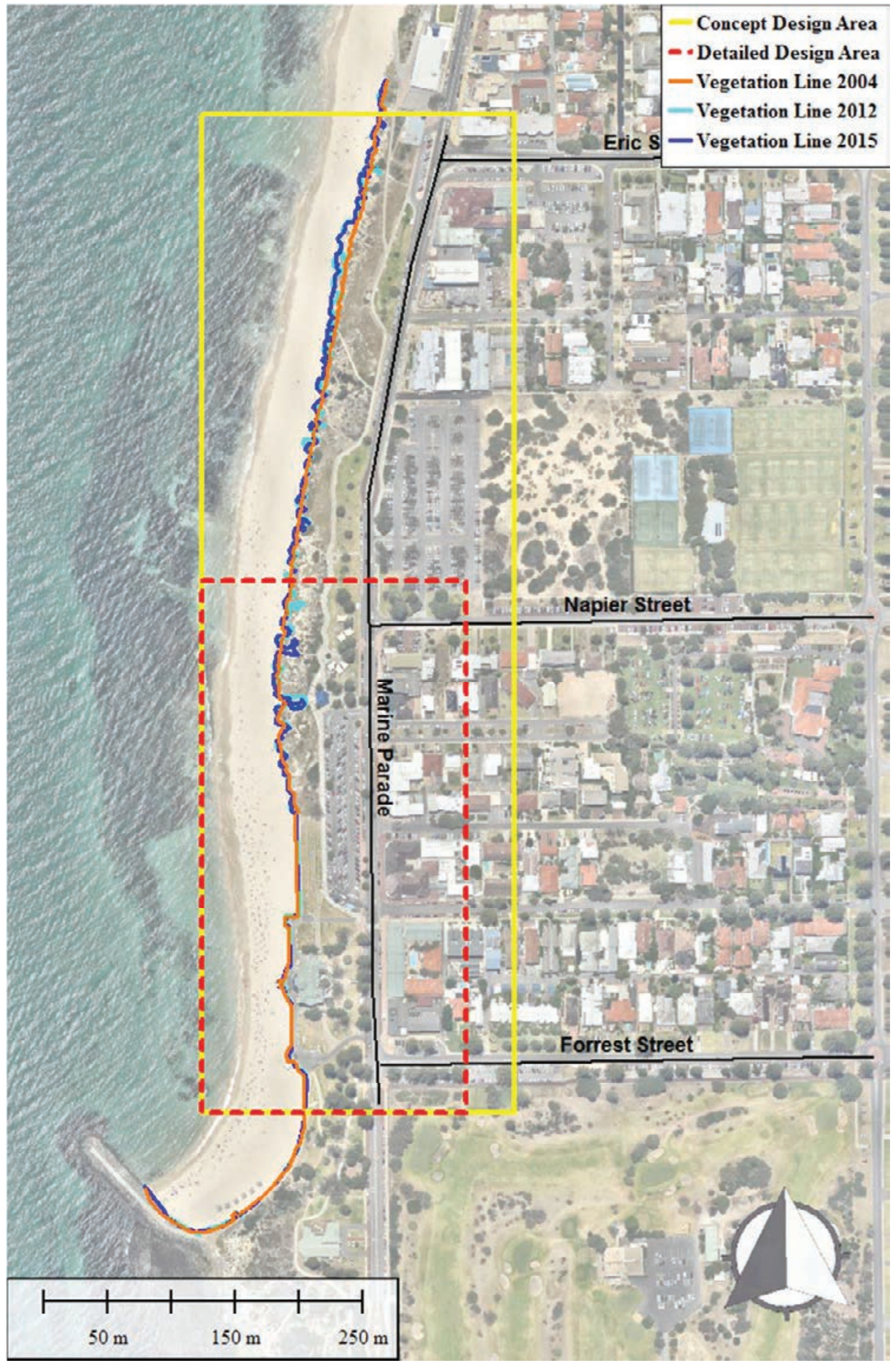

Figure 4-10 Vegetation lines from 2004, 2012 and 2015 aerial photographs

4.2.4 S3 Erosion due to Sea Level Rise

SPP2.6 stipulates an allowance of 90 m of shoreline recession should be made, based on a vertical sea level rise (SLR) of 0.90 m over the 100 years planning horizon to 2110. The planning horizons to be assessed for this study, as discussed in Section 3.4.1, are present day, 2040 and 2070. The values for each planning timeframe are presented in Table 4-4.

Table 4-4 Erosion due to SLR, S3 (m).

Profile	Existing	2040	2070
S11	0	27	54
S13	0	27	54
S15	0	27	54
S16	0	27	54
S17	0	27	54

4.3 Coastal Hazard Lines

The coastal foreshore reserve allowance for coastal processes for 2040 and 2070 are presented by profile location in Table 4-5 and Table 4-6. The present day coastal foreshore reserve allowance is the S1 column in Table 4-6. The stipulated uncertainty allowance of 0.2 m/year is included in the fifth column.

These coastal foreshore reserve allowances were applied to the HSD line and are plotted for the full study area in Figure 4-11. Also displayed in this figure are the study area sections demarcations.

Table 4-5 Coastal foreshore reserve allowance for coastal processes for 2040

Section	S1	S2	S3	Uncertainty Allowance	Total 2040 (m)
S11	18	8	27	6	59
S13	17	8	27	6	58
S15	13	7	27	6	53
S16	4	0	27	6	37
S17	9	0	27	6	42

Table 4-6 Coastal foreshore reserve allowance for coastal processes for 2070

Section	S1	S2	S3	Uncertainty Allowance	Total 2070 (m)
S11	18	16	54	12	100
S13	17	16	54	12	99
S15	13	14	54	12	93
S16	4	0	54	12	70
S17	9	0	54	12	75

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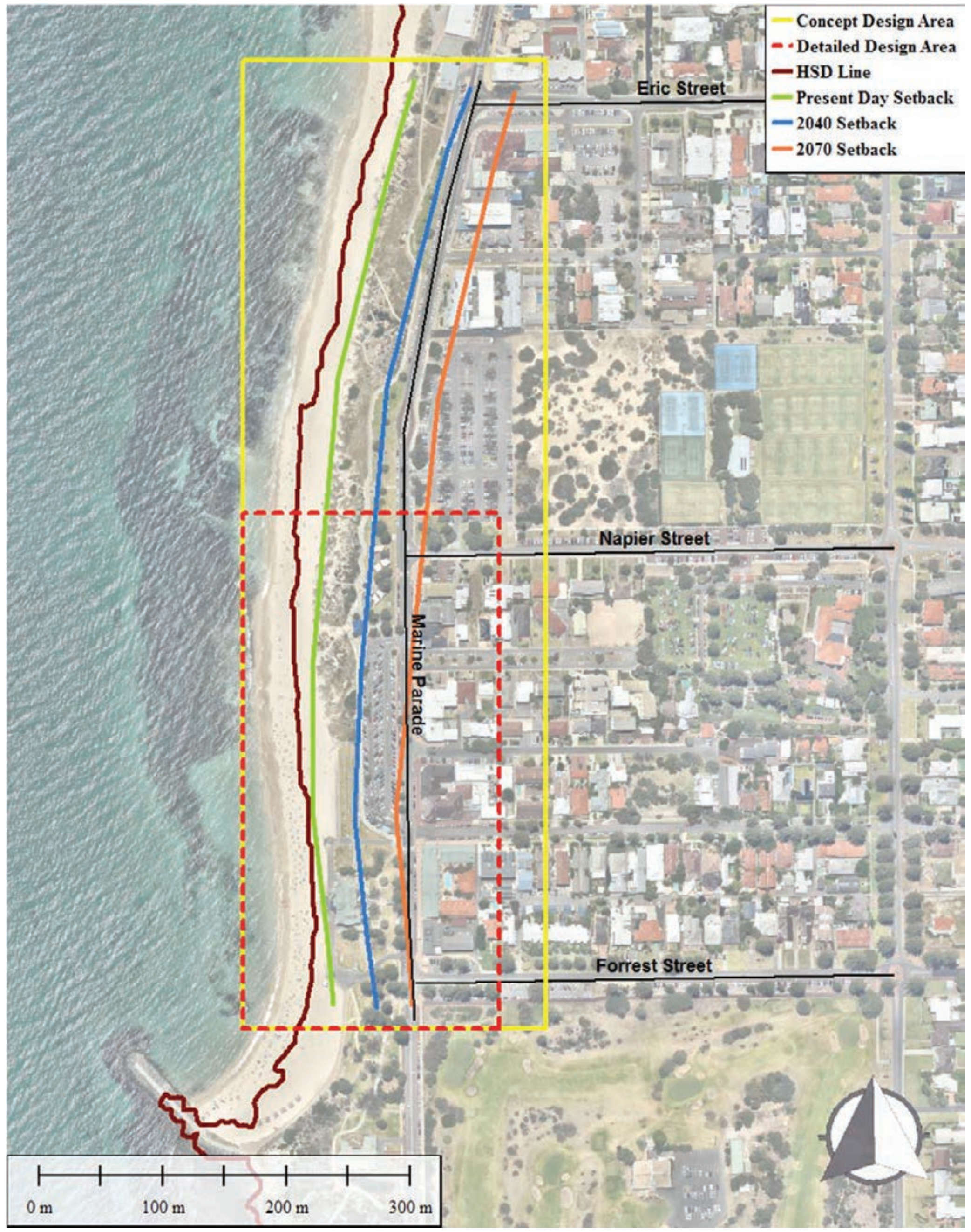

Figure 4-11 Coastal foreshore reserve allowances across the Cottesloe study area for all planning horizons.

4.4 S4 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 (1966-2015) at Fremantle from the DoT. An extreme value analysis was carried out on the dataset to estimate a 500 year ARI water level at Cottesloe (see Table 4-7).

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.

To include the effects of wave setup, Cardno undertook SBEACH modelling with the 500 year ARI water level and the peak wave heights taken from the SWAN wave model output locations (corresponding to a 100 year ARI event at Rottnest). The combination of a 500 year ARI water level with a 100 year ARI wave event would be considered to be a very conservative approach. Overall inundation levels, including the effects of sea-level rise, for present and future scenarios are shown in Table 4-7.

Table 4-7 Inundation level, S4

Component	Existing	2040	2070
500yr ARI water level (mAHD)	1.43	1.43	1.43
Allowance for nearshore setup (m)	1.37	1.37	1.37
Allowance for Sea Level Rise (m)	-	0.15	0.4
Total (mAHD)	**2.8**	**2.95**	**3.2**

The horizontal extent of the inundation for each level was approximated and mapped for the study area (Figure 4-12). These extents were estimated by interpolating between the perpendicular shoreline profiles undertaken by the Town in September 2015, also utilised in the SBEACH modelling. Survey data from the Town's April 2015 surveys was also incorporated where the September surveys were insufficient (i.e. landward of the beach face).

Due to the steep dune profile and substantial topographical relief landward of the foredune within the study area, the extent of inundation under future scenarios does not vary significantly to that for the present day scenario. It should be noted that erosion of the fordune, as assessed in Sections 4.1-4.3, is likely to allow inundation under future storm surge scenarios.

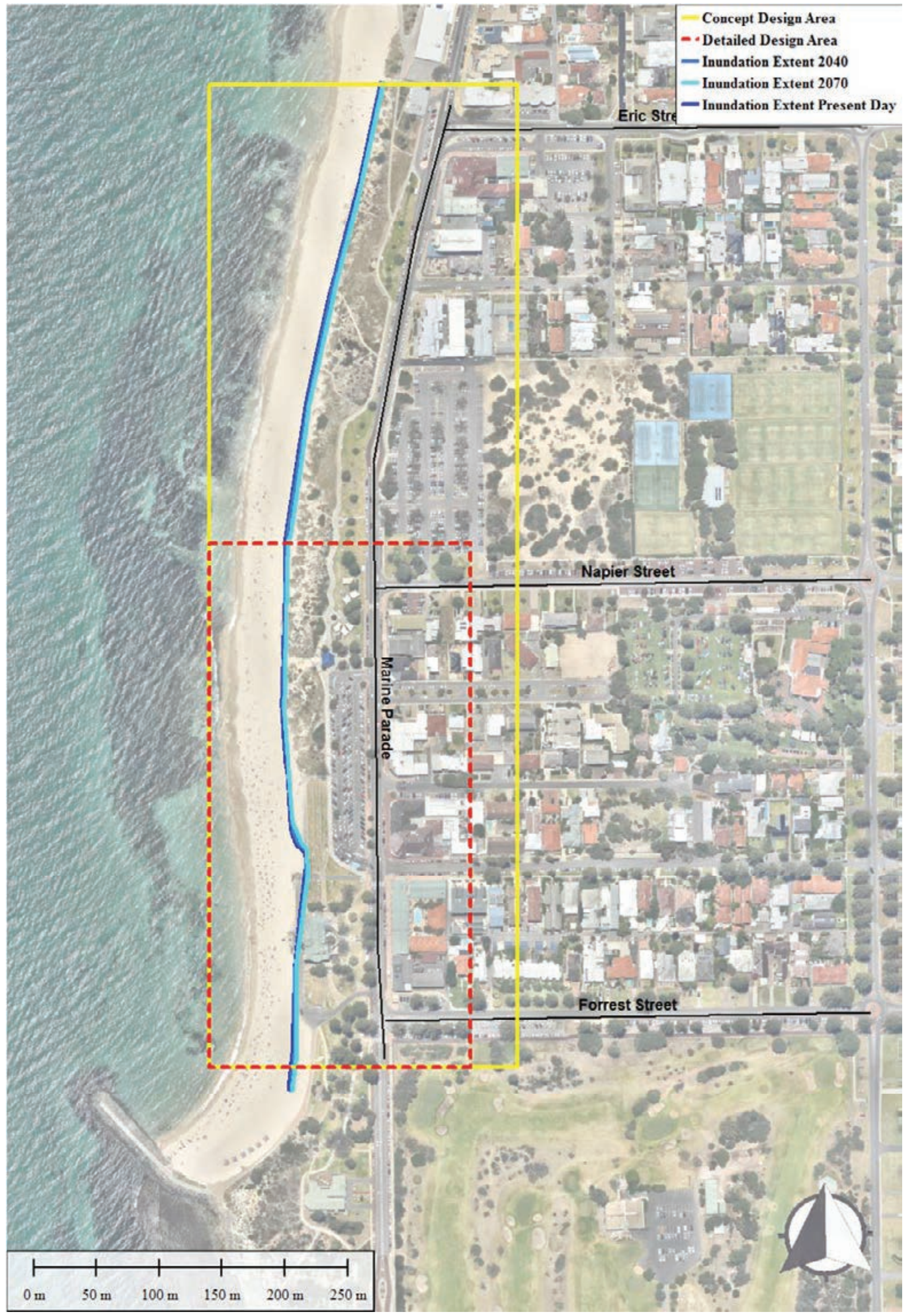

Figure 4-12 Inundation extents across the Cottesloe study area for all planning horizons

5 Conclusions & Further Study

This report addresses the initial steps in developing the CHRMAP that will accompany design of the Cottesloe Foreshore Redevelopment. The context has been established through assessment of previous investigations, initial stakeholder consultation and review of environmental conditions and processes at the site. Establishing the context has allowed the determination of success criteria, against which identified risks will be evaluated. These criteria reflect the key values associated with the study area and are as follows:

> Environment and sustainability;

> Maintain and protect public safety;

> Protect and enhance the local economy and growth; and

> Protect community and lifestyle.

Coastal hazards have been identified within the study area through a coastal vulnerability assessment, guided by SPP2.6. This assessment has provided estimates of erosion and coastal inundation, now and into the future for the 2040 and 2070 planning horizons.

5.1 Input into Concept Foreshore Redevelopment

The context establishment and coastal hazard risk identification undertaken within this report have allowed definition of the coastal foreshore reserve and associated coastal hazards for the Foreshore Redevelopment design life. It is noted that the coastal hazards likely to be encountered are coastal erosion (storm-induced and long-term), coastal inundation, and erosion due to wind and human interaction with the site(s).

In the next phase of the project risks will be evaluated in detail by analysing the likelihood and consequence of impacts due to coastal hazards. We will also provide advice as to the most appropriate locations for various land-use proposals, and any adaptation options required to mitigate the risks of these hazards. Adaptation options will follow the SPP2.6 'Avoid, Retreat, Accommodate and Protect' hierarchy.

A rough cost for adaptation options will be provided for input into the concept level cost estimate. The results of Phase 1 will be provided in a brief summary report.

Any gaps in knowledge or information will be highlighted in the summary report to allow time for collection or generation of this information during Phase 2 of the project.

5.2 Phase 2: Detailed Design

Following receipt of the stakeholder comments from Phase 1, Cardno will complete the CHRMAP process whilst concurrently upgrading the Concept Design to Detailed Design. Any necessary revision to the context establishment and coastal hazard risk identification will be carried out prior to moving to the next step in the CHRMAP process.

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Appendix 1: Proposed Conceptual Redevelopment