City of Rockingham

Coastal Hazard Risk Management and Adaptation Plan - Technical Assessment

59918065

Prepared for
City of Rockingham

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Contact Information

Cardno (WA) Pty Ltd
ABN 77 009 119 000

11 Harvest Terrace
West Perth WA 6005
Australia

www.cardno.com
Phone +61 8 9273 3888
Fax +61 8 9486 8664

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Author(s):

Name: Daniel Strickland
Job title: Coastal Engineer

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Approved By:

Name: Chris Scraggs
Job title: Principal Coastal Engineer

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Executive Summary

The City of Rockingham is preparing for the threats of climate change and sea level rise to its coastal assets and values. This Coastal Hazard Risk Management and Adaptation Plan (CHRMAP) has been prepared to provide a long term view of the potential future coastal hazards for the City, and highlight possible strategies to adapt to the changing future oceanic and coastal conditions.

Development of the City's CHRMAP has followed the requirements of Western Australian State Planning Policy No. 2.6: State Coastal Planning Policy (SPP2.6) and supporting guideline documents. A coastal hazard assessment was undertaken to determine potential extents of coastal erosion and inundation hazards over future planning timeframes to 2110. The City's coastline was divided into 6 sectors for assessment. The risk and vulnerability assesment was applied to each sector and results highlighted the most vulnerable assets and areas along the City's coastline, for which more detailed assessment of adaptation options were investigated.

A range of options for addressing the challenges of coastal erosion and its effects on the coastal zone over the next century have been outlined. While it is natural that the community would prefer to protect and preserve the current features of the coastal zone, the reality is that unless some new and innovative protection methods are developed, the costs of maintaining current features will likely become prohibitively expensive at some point in the future, given current sea level rise projections. The interim nature of protection options needs to be recognised across the community and, the adaption options developed and solutions optimised for social, environmental and economic (affordability) drivers.

The recently released draft Planned and Managed Retreat Guidelines (WAPC, 2017) suggest the process for implementing future managed retreat should include compensation under provisions in the *Land Administration Act (1997)*. In reality, this is unlikely to be financially feasible in the immediate to short term in the City, unless the State or Commonwealth Governments provide the majority of funding to acquire property. It is important to note that while the eventual implementation of the managed retreat option is recommended in this CHRMAP, its future implementation will need further investigation of the implications for both Governments and Private stakeholders. Nevertheless, the City should engage with its community and begin preparations to adopt adaptation pathways involving eventual managed retreat of vulnerable assets, as this will be the most economically responsible and equitable approach over the long term.

Through further detailed economic and feasibility assessment, it is likely that the implementation of interim protection measures in some areas will be found to provide overall benefit to the City. Interim protection would also delay the expensive implementation of managed retreat. A number of options have been identified that aim to protect developed areas likely to become highly vulnerable to coastal erosion in the short term. The implementation of protection measures should be carried out under the user pays principle, and ensure that the provision of a beach and foreshore for the enjoyment of the wider community is not compromised. A key challenge for the City will be determining who the beneficiaries of coastal management are, and installing methods to apportion costs appropriately.

The CHRMAP process is designed to be ongoing, with regular updates associated with the emergence and collection of new information. This information could be collected by the City to refine the accuracy of predicted risk to its assets. It could also be based on environmental factors that are largely beyond the City's control, such as changes to mean sea level and the rate of sea level rise. Key recommendations have been made, based on the findings of this CHRMAP, for implementation before 2030 and in the lead up to the next CHRMAP revision. These are summarised in the table below.

ID	Recommendation
R1	Engage the community to present the results of this CHRMAP and collect their feedback on the acceptability of adaptation options and pathways.
R2	A detailed economic assessment should be undertaken to establish the economic value/contribution of natural assets in key vulnerable areas.
R3	Investigate and establish a fund for ongoing coastal adaptation and management, and allocate funding sources.
R4	Existing and proposed structure plans should be reviewed to ensure they adhere to SPP2.6 and account for the risks identified in this CHRMAP.
R5	TPS2 should be amended to incorporate SPP2.6 and include vulnerable areas as SCAs.
R6	Landholders that may be affected by coastal hazards by 2110 should be notified directly and by the application of notification on Certificates of Title, where possible.
R7	Initiate/continue targeted beach nourishment in vulnerable areas.
R8	Undertake a detailed options assessment for management of coastal vulnerability in Sector 3, with a particular focus on ongoing erosion issues at Mersey Point.
R9	Undertake a detailed options assessment for management of coastal vulnerability in Sector 2A.
R10	Set up a coastal asset inventory and emergency/damage response plan to respond to potential coastal impacts.
R11	Initiate a long-term coastal monitoring program, incorporating *ad hoc* storm and metocean monitoring, and coastal asset condition assessments.
R12	Undertake a local water level and SLR rise analysis.
R13	Undertake a detailed sediment transport analysis to establish a detailed sediment budget for the City, focusing on Sectors 2 and 3.
R14	Undertake an investigation to identify suitable sediment sources and determine available volumes for use in ongoing beach nourishment.
R15	Update the City’s Asset Management Plan to reflect adaptive measures selected by the City and develop a priority matrix to ensure assets nearer to the foreshore area are performing as expected.
R16	Stormwater and drainage system be reviewed for functional capacity should issues be reported.
R17	Continue to undertake environmental surveys and monitor TDS levels for Lake Richmond. .
R18	Undertake a full revision of the City’s CHRMAP, identifying and incorporating relevant new information.

Abbreviations and Acronyms

Abbreviation	Description
ARI	Average Recurrence Interval
AS	Australian Standard
BoM	Bureau of Meteorology
CHRMAP	Coastal Hazard Risk Management and Adaption Plan
DoP	Department of Planning (now part of DoPLH)
DoPLH	Department of Planning, Lands and Heritage
DoT	WA Department of Transport
GIS	Geographic Information System
HSD	Horizontal Shoreline Datum (see SPP2.6)
IPCC	International Panel on Climate Change
LAA	Land Administration Act (1997)
LGA	Local Government Area
MCA	Multi-criteria analysis
MSL	Mean sea level
SCA	Special Control Area
SLR	Sea Level Rise
SPP	State Planning Policy
SPP2.6	State Planning Policy No 2.6: State Coastal Planning Policy (WAPC, 2013)
The City	City of Rockingham
TPS2	Town Planning Scheme No. 2
WA	Western Australia
WAPC	Western Australian Planning Commission

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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**).

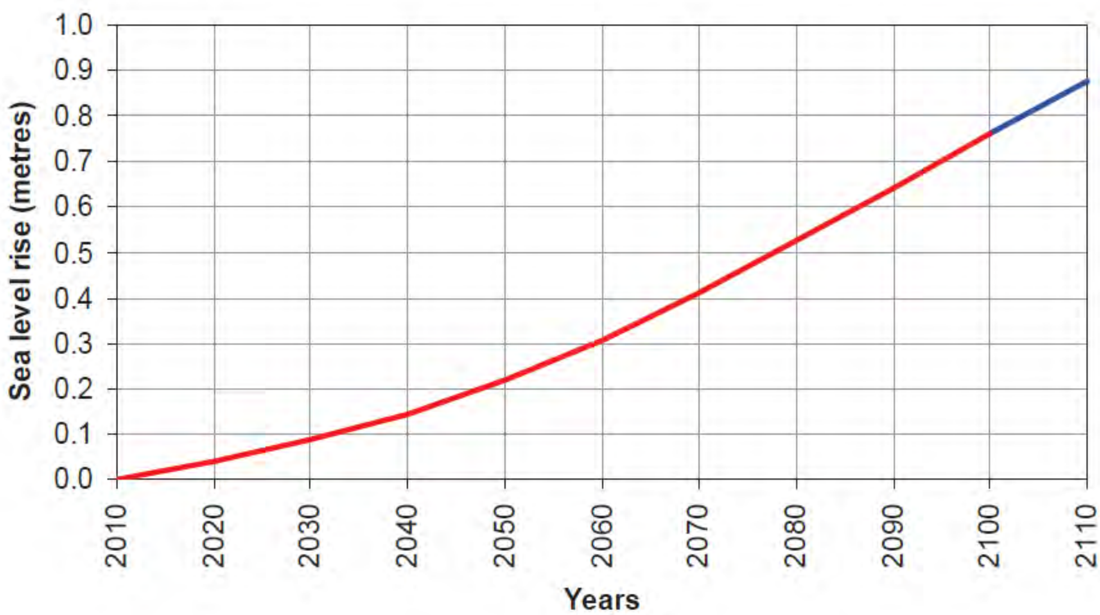


Figure 1-1 Recommended allowance for sea level rise in coastal planning in Western Australia (DoT, 2010).

The Rockingham Local Government Area (LGA) coastline is low lying and sandy, 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 (**Figure 1-2**; CoastAdapt, 2017).

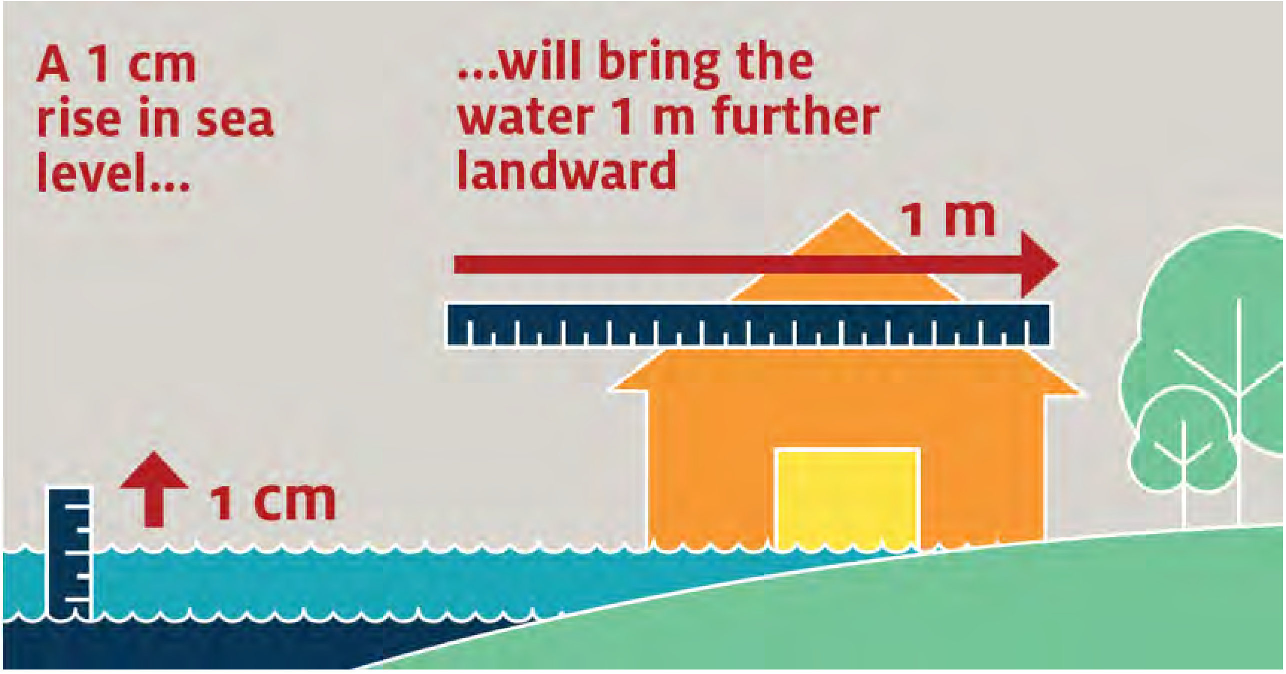


Figure 1-2 Simplified schematic of how sea level rise will impact shorelines (CoastAdapt, 2017).

The City of Rockingham (the City) is developing a Coastal Hazard Risk Management and Adaptation Plan (CHRMAP), with technical input from Cardno, to identify risks and plan to adapt to the potential impacts associated with predicted SLR along their coastline.

The purpose of the CHRMAP process is to:

> Ensure that development and the location of coastal facilities takes into account coastal processes, landform stability, coastal hazards, climate change and biophysical criteria;

> Guide the identification of appropriate areas for the sustainable use of the coast for housing, tourism, recreation, ocean access, maritime industry, commercial and other activities;

> Provide for public coastal foreshore reserves on the coast and ensure access to them; and

> Protect, conserve and enhance coastal zone values, particularly in areas of landscape, biodiversity and ecosystem integrity, indigenous and cultural significance.

1.2 Overview of the CHRMAP Process

The key policy governing coastal planning in WA is the *State Planning Policy No. 2.6: State Coastal Planning Policy* (Western Australian Planning Commission [WAPC], 2013a) (SPP2.6). SPP2.6 recommends that management authorities develop a CHRMAP, using a risk mitigation approach to planning, that identifies the hazards associated with existing and future development in the coastal zone. SPP2.6 and the *State Coastal Planning Policy Guidelines* (WAPC, 2013b) contain prescriptive details, for example in relation to scales of assessment, storm event types and SLR allowances.

The WAPC (2014) has also developed the *Coastal hazard risk management and adaptation planning guidelines* (the CHRMAP Guidelines) which are less prescriptive, but are aimed to ensure that planning is carried out using a risk based approach with due regard given to stakeholder engagement, community consultation and education, and that a full range of adaptation options is considered. An overview of the typical CHRMAP process is shown in **Figure 1-3**.

Coastal planning in accordance with SPP2.6 also needs to take into consideration the requirements of other planning policies, including *Statement of Planning Policy No. 2: Environment and Natural Resources Policy* (WAPC, 2003) and *Statement of Planning Policy No. 3: Urban Growth and Settlement* (WAPC, 2006).

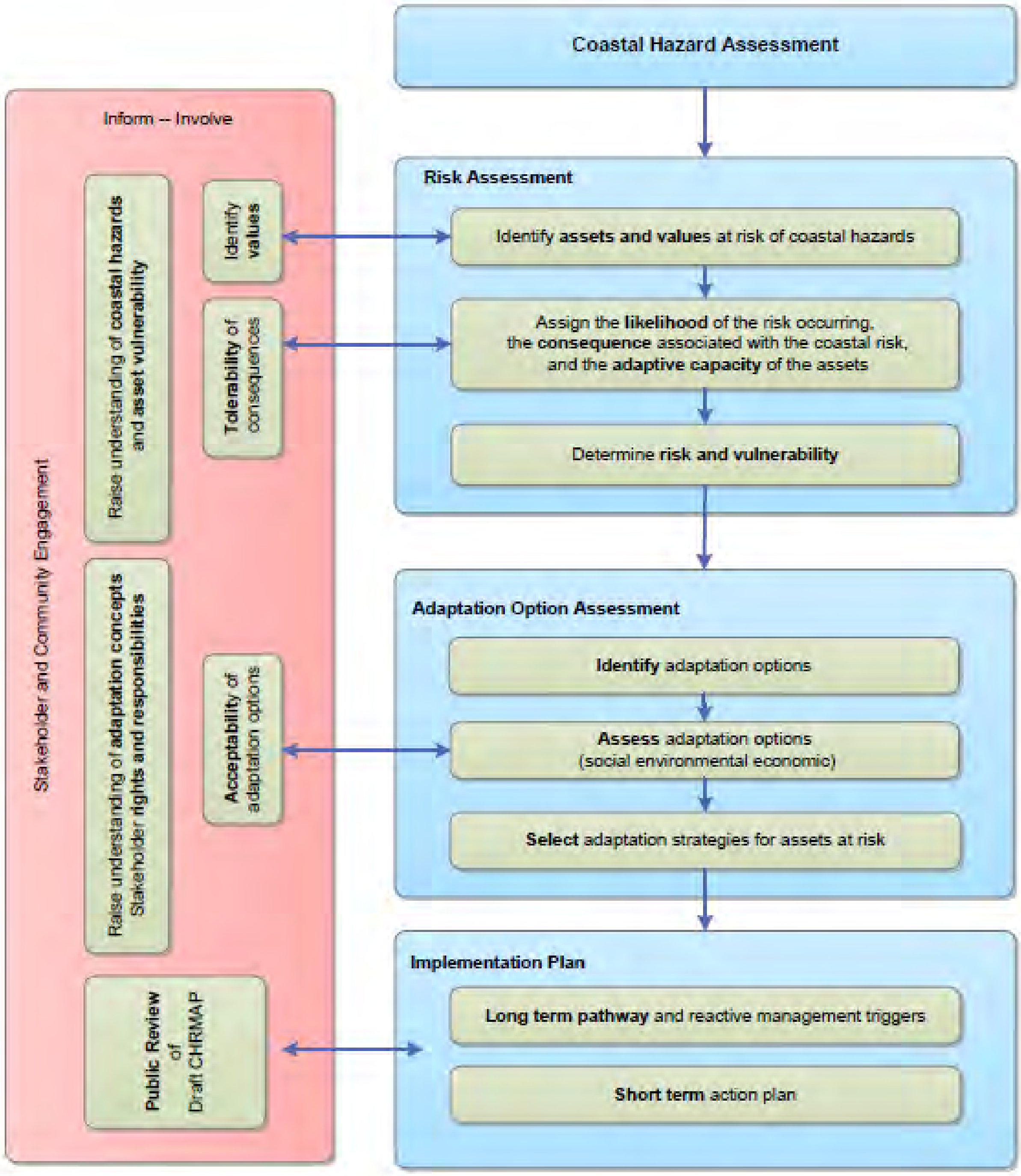


Figure 1-3 CHRMAP methodology flow chart (adapted from the CHRMAP Guidelines (WAPC, 2014)).

1.3 Success Criteria

Based on the results of the City's Coastal Values Survey, the following success criteria have been developed to guide the CHRMAP process:

SC1: Conserve natural attributes (e.g. clear water, vegetated dunes and sandy beaches);

SC2: Ensure public safety and access;

SC3: Minimise impacts on existing residential areas;

SC4: Provision and maintenance of public amenities;

SC5: Conserve areas for recreational and passive use;

SC6: Provision of foreshore areas for local economic benefit;

SC7: Provision of access infrastructure (e.g. roads, carparks, paths); and

SC8: Maintenance and preservation of indigenous and cultural heritage sites.

It is noted that legally there is no obligation of the State or Local Governments to either protect public and private assets within the coastal hazard zone, nor to compensate for any losses incurred due to coastal hazards. While SC3 is considered a community aspiration it must be recognised that assets currently located in present and future potential impact zones may not attract state or local government funding for mitigation works.

1.4 Guiding Principles and Concepts

Underlying the CHRMAP process are a number of guiding principles and concepts which are fundamental to understanding the purpose and outcomes of the process. These are outlined in the following subsections.

1.4.1 Equity

Equity is a concept central to the purpose of the CHRMAP process. Australia's coastline is highly valued by the community as a public asset, with stakeholders ranging from individual property owners in coastal areas, to all levels of government, ratepayers within the LGA, taxpayers in general and users both from within and outside of jurisdictional boundaries.

Responsibility for coastal planning lies with both State and Local Governments, and in making decisions these authorities need to consider equity of access, equity of enjoyment and equity in terms of who benefits, who is disadvantaged, who should pay and the subsequent allocation of public resources.

Equity is also relevant to considerations about how a protection structure (for example a groyne) might impact coastal processes. Protection structures may exacerbate erosion adjacent to the structure, and limit sediment availability for maintaining beaches and community values some distance from the protected area. Protection structures can also result in significant impacts to coastal ecosystems, well beyond the local area in which the structures are installed (Gittman et al., 2016). Coastal protection may create beneficiaries (those who are protected from hazards) and potentially disadvantage others who may be considered to be affected parties. In this regard, coastal management has similarities to the management of water rights, if one user takes all the water upstream and leaves none for downstream users then this is not considered fair and equitable. In a future of eroding coastlines due to SLR, sand can be a valuable commodity.

Intergenerational equity is also a key consideration of the CHRMAP process, underpinned by the 100-year planning timeframe considered. Continuing to develop the coast as it has been developed in the past will create further issues and expense for future generations. Similarly, protecting existing assets now may be delaying proper management of the issue to future generations, and may not be considered economically responsible from a long term perspective. The challenge is to ensure that planning and management is as transparent and equitable as possible.

1.4.2 Coastal Foreshore Reservation

The coastal foreshore provides beach access, public space for recreation and conservation, is a tourist attraction and provides habitat for native flora and fauna. Importantly, it can also provide a buffer to protect built assets, such as buildings and infrastructure, from coastal hazards.

SPP2.6 Schedule One provides guidance for calculating the component of the coastal foreshore reserve required to allow for coastal processes, to be contained in an appropriate coastal foreshore reserve (determined in accordance with SPP2.6 Clause 5.9) of greater width. This should ensure that, at the end of the planning timeframe, a coastal foreshore reserve is still present and not exposed to the adverse impacts of erosion and inundation. It is behind this reserve that additional development is able to be considered. Having said this, Schedule One also contains Clause 7 – Variations, which outlines specific instances where certain types of development may be considered appropriate within a coastal foreshore reserve, regardless of the allowance for physical coastal processes.

The allowance for physical processes is based on the 100-year coastal erosion hazard line (the 2110 planning timeframe in this CHRMAP), determined in accordance with SPP2.6. In addition to the allowance for physical processes, the foreshore reserve should include land allocation for maintaining the values, functions and equitable use of the coast over the 100-year planning timeframe (see **Figure 1-4**).

Providing easy public access to the beach and coastal foreshore reserves is a fundamental coastal planning objective. The coast and coastal foreshore reserves are public assets which should not, now or in the future, become the exclusive domain of private landholders by virtue of the erosion of coastal reserves or other coastal processes. Coastal reserves should be wide enough to perform recreation and/or conservation functions (according to the reasons for their initial designation) even if they are permanently affected by coastal erosion due to SLR. Where existing assets and/or infrastructure are located within the coastal hazard areas, the existing coastal foreshore reserve may not be sufficiently wide to ensure that the values, functions and equitable use of the coast can continue to be provided for over the 100-year planning timeframe without management intervention.

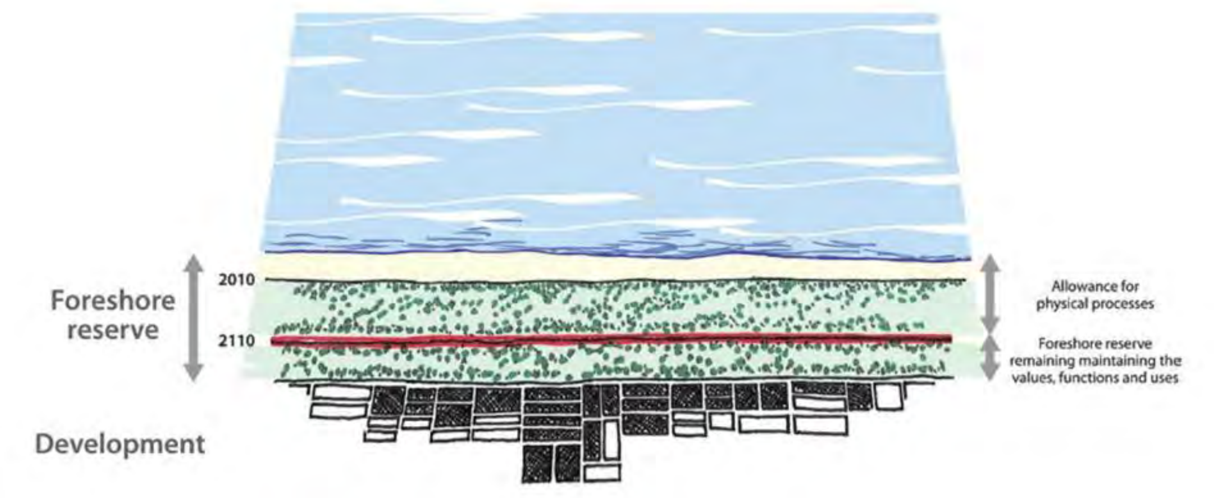


Figure 1-4 Coastal foreshore reserve – sandy coast example (WAPC, 2013b).

1.4.3 Rights and Responsibilities

In WA, landholders own the rights to develop and use land as granted by land use regulations; they do not own the land itself. There is no law requiring the government (at any level) to provide protection of private property from natural hazards, nor compensation when land is lost to the sea. There are, however, several laws that allow the intervention of governments to enforce eviction if private property becomes uninhabitable, or removal of property if it constitutes a public risk. In the event of coastal erosion causing a property to “fall into the sea”, and the land to disappear below the high water mark, the loss is to be borne by the property owner.

Nonetheless, it is the aim of all levels of government to protect the interests of all Australians, and the CHRMAP process ultimately intends to minimise risks and maximise beneficial use of the coast from an economic, social and environmental perspective. Mechanisms for managed retreat may require public expenditure and in some instances, where overall public good can also be demonstrated, protection may also be publicly funded. Where the benefits of a particular coastal protection measure are limited to private beneficiaries, there is an expectation that the cost will be borne by those beneficiaries under the “user pays” principle.

1.4.4 Hazards and Risks

A hazard is a potential source of harm or adverse impact. SLR is predicted to lead to an increase in hazardous erosion and coastal inundation along the Rockingham LGA coastline. Coastal erosion and inundation hazards have been calculated in accordance with SPP2.6 and have been interpreted to identify assets and values at risk from these hazards (**Figure 1-5**).

Risk is defined as a hazardous event or circumstance and the consequences that may arise from it. Risk is measured in terms of a combination of the likelihood of a hazard occurring and the consequence of that hazard occurring (likelihood and consequence) (**Figure 1-6**).

1.4.5 Assets and Values

An asset is defined as a useful or valuable entity. In the current CHRMAP, assets include:

> Natural features such as beaches and natural vegetation;

> Buildings and other structures (houses and commercial buildings);

> Infrastructure relating to drainage, water and sewerage;

> Roads, paths and walkways; and

> Coastal structures, such as jetties, boat ramps, seawalls and groynes.

As defined in *Climate change adaptation for settlements and infrastructure – A risk based approach* (AS 5334-2013) an asset’s value can be tangible or intangible, financial or non-financial. Examples of non-tangible assets include ecological function and coastal views. The value of an asset includes consideration of risks and liabilities, and can be positive or negative at different stages of the asset’s life. Economic assets can be further categorised as public or private.

Values in the context of the CHRMAP further encompass the economic, social (including heritage) and environmental values of the coastal area.

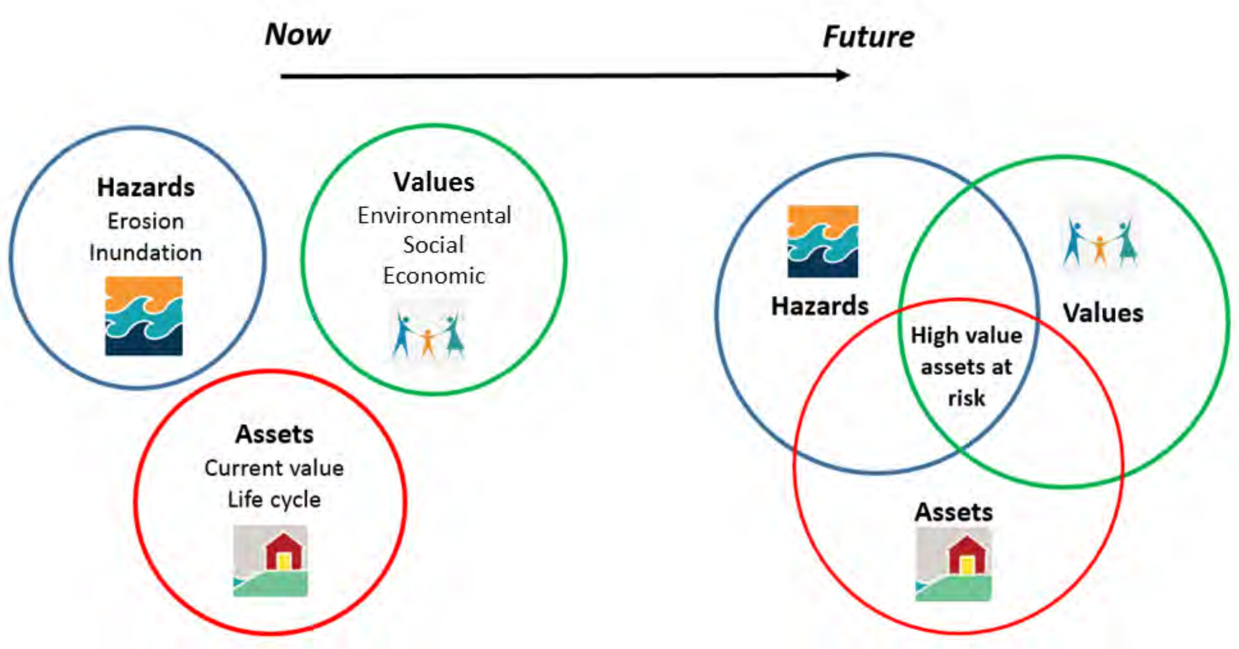


Figure 1-5 Conceptual relationship between key inputs to the coastal risk assessment process

1.4.6 Vulnerability

Vulnerability has a specific meaning in the context of risk-based approaches to climate change adaptations, in accordance with Australian Standards (AS 5334-2013) and SPP2.6, which defines vulnerability as:

> *"the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity. Systems that are highly exposed, sensitive and less able to adapt are vulnerable"*

This report uses vulnerability as the final outcome of the risk assessment process, combining likelihood and consequence of hazards with the adaptive capacity of assets in a stepwise process (**Figure 1-6**).

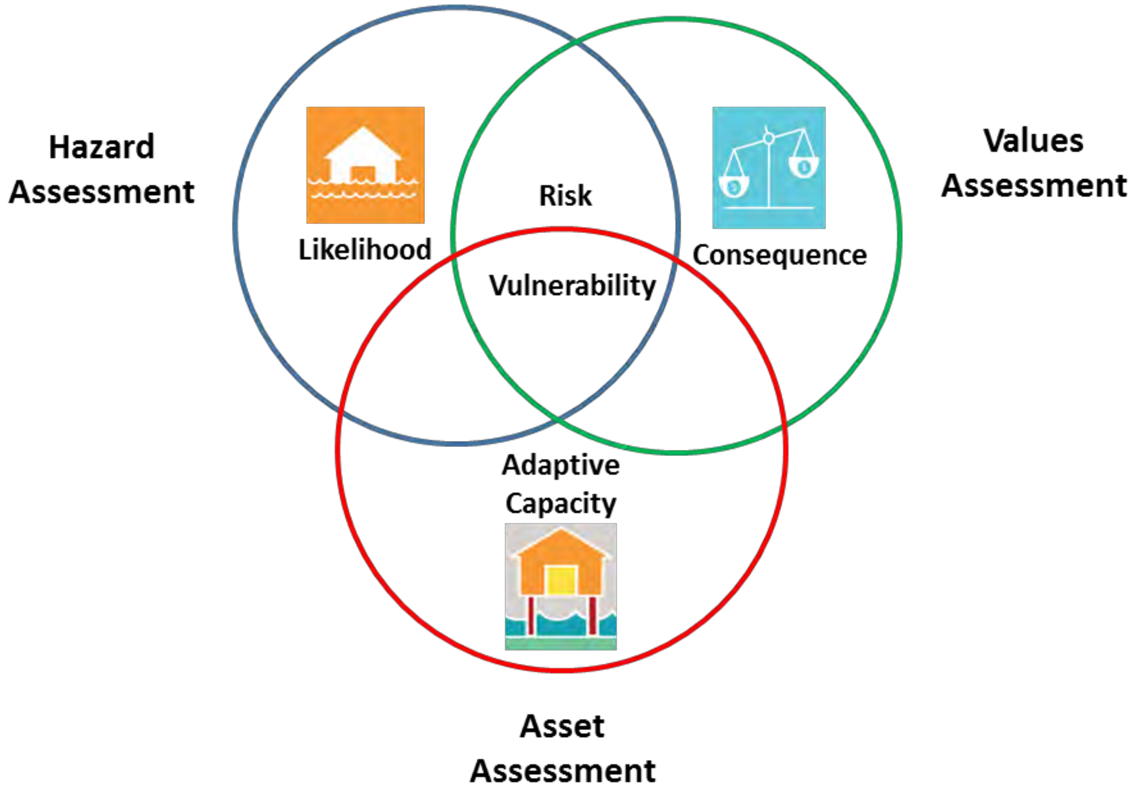


Figure 1-6 Conceptual relationship between risk assessment components.

1.4.7 Temporal Scales

Coastal hazard assessment and management needs to consider a number of different timeframes (**Figure 1-7**). SPP2.6 specifies the need for identifying risks and extending planning considerations out to a 100-year planning horizon (also described as 'long term' in this report). Practical planning for implementation, from the City's point of view, requires a focus on the 'short term' (up to the 2030 planning timeframe) and also 'medium term' referring to the period up to the 2070 planning timeframe.

The need for identifying potential long term risks is important to ensure that these risks are taken into consideration in the City's asset management strategy and statutory planning framework. The long term perspective is also important for management of community expectations and gives potentially impacted stakeholders prior notice of the potential hazards.

This CHRMAP includes an assessment of immediate (2017) to long term vulnerability of coastal assets associated with predicted SLR. Long term adaptation pathways have been developed for all areas of the coast being assessed, as required by SPP2.6. A short term implementation plan has also been developed, focusing on areas where assets have been assessed as highly vulnerable by the 2030 planning timeframe. This short term implementation plan is designed such that the actions do not prevent long term pathways from being realised.

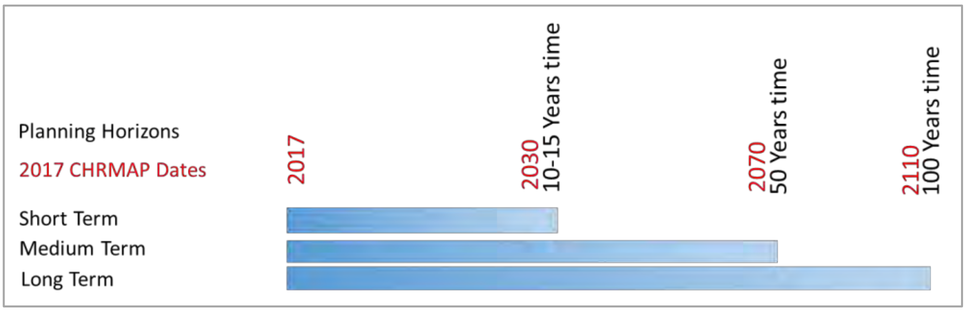


Figure 1-7 Coastal planning timeframes assessed in this study

1.4.8 Spatial Scales

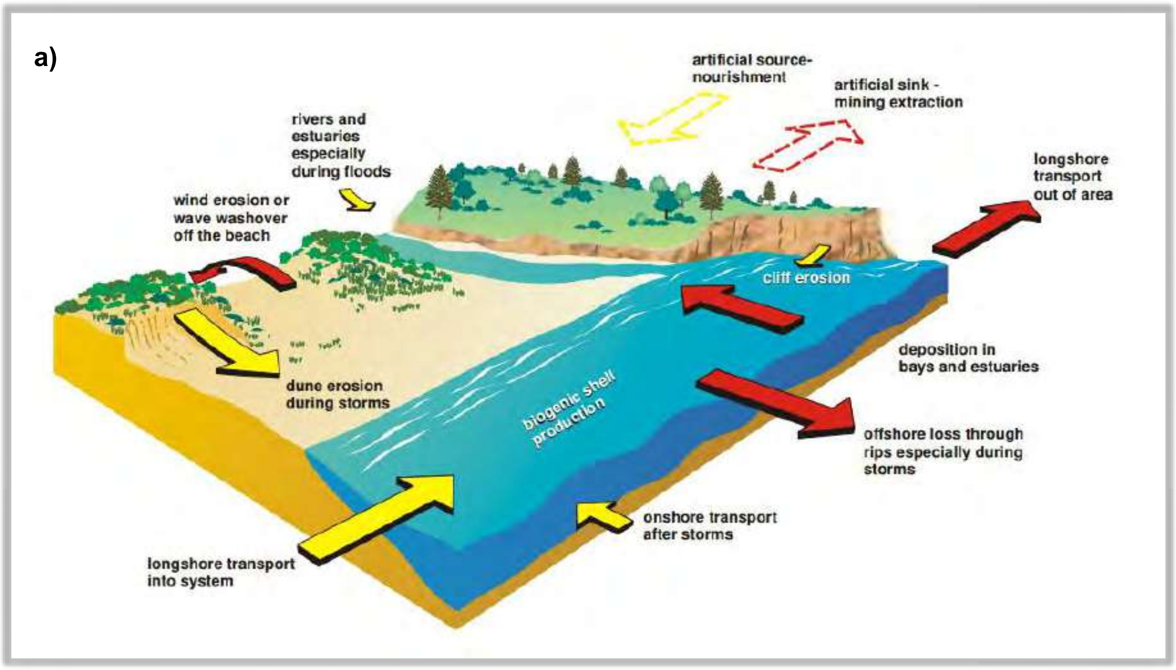
In accordance with SPP2.6, the coastal hazards along the City's coastal zone have been identified at a coastal sediment cell scale. The policy requires assessment at this scale to account for the impact of existing controls and future management techniques on areas of the coast that are away from the direct area of interest (a common example of this is erosion down-drift of a groyne or marina). For more information on the classification of coastal sediment cells and their function see Stul et al. (2015).

Using the hazard lines derived for the broader sediment cell scale this CHRMAP then looks at finer spatial scales, to assess the vulnerability of assets and to simplify management planning. Within each 'Sector' assigned by the City, assets are considered individually or grouped according to the type of asset and in consideration of current land use. The risks and vulnerability of individual or groups of assets within each sector have then been assessed.

1.5 Key Coastal Processes Concepts

A basic understanding of coastal processes is important for understanding the issues and constraints associated with managing the hazards of SLR and coastal erosion. **Figure 1-8a** illustrates the multiple processes involved in adding (accretion; yellow) and removing (erosion; red) sediment from the shoreline. The size of the arrows broadly represent the volume of sediment movement involved in each process. **Figure 1-8b** shows how a storm can remove sediment from the beach and reshape the shoreline profile, due to a combination of elevated water level and wave action. As MSL increases, storms can have a greater inland 'reach' and less of the removed sediment returns to the beach, leading to long term recession.

A key step in the coastal hazard identification is the definition of a horizontal shoreline datum (HSD) along the coastline, which "should define the active limit of the shoreline under storm activity" (WAPC, 2013a). Effectively, the HSD is the shoreline at a particular point in time that can then be used as a bench mark or reference for assessing historic and future potential shoreline movement. The HSD is the benchmark from which the extent of coastal hazards, at each planning timeframe, is measured. The HSD is constantly moving and its position, relative to the location of assets is one of the key triggers for implementing management responses. It must be noted that future revisions of this CHRMAP will be based on new information, and the HSD and hazard lines should be recalculated accordingly.



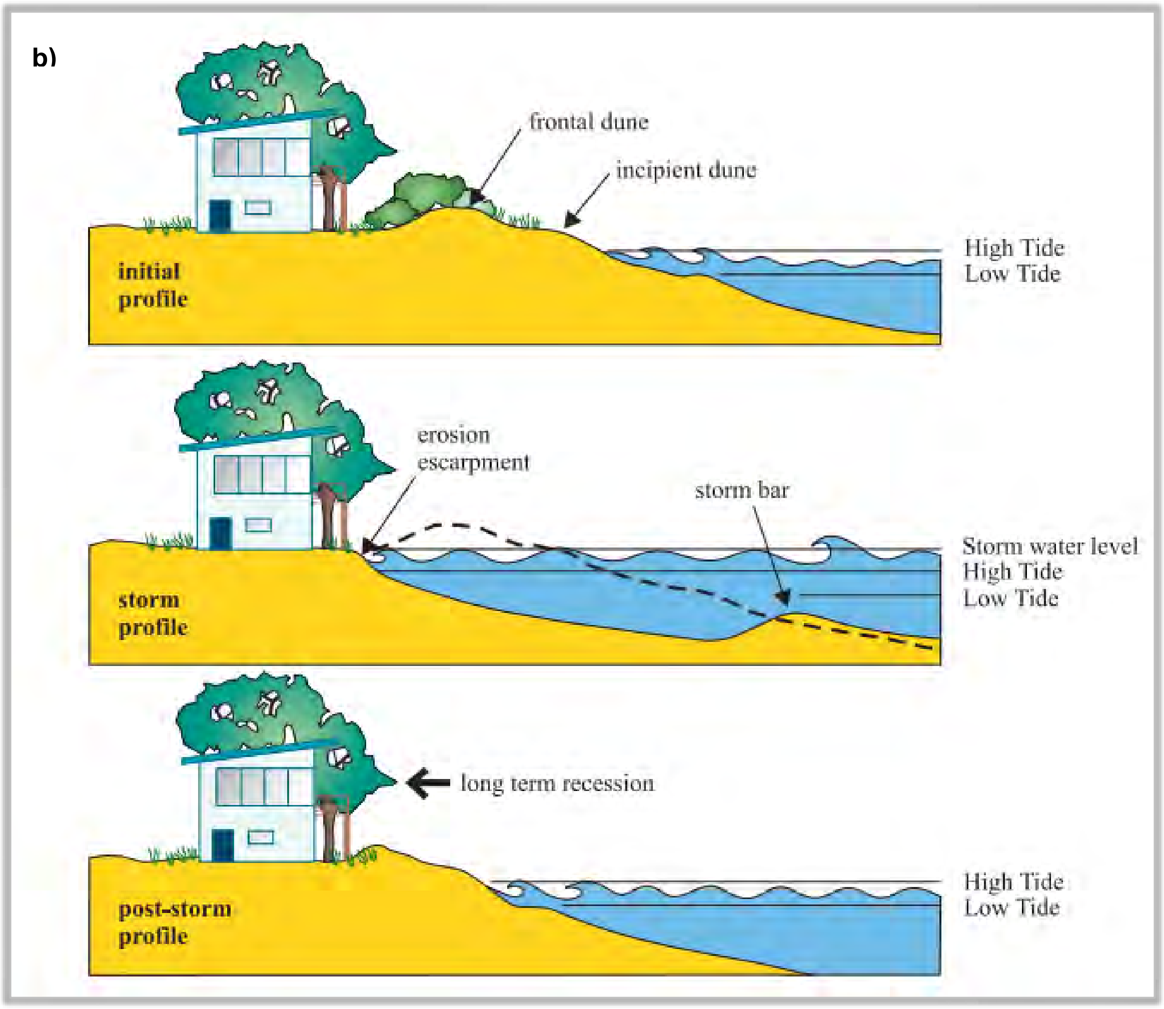


Figure 1-8 Conceptual representation of key coastal erosion concepts; a) sediment transport processes and b) long-term beach recession due to permanent sand loss (source: NSW Department of Land and Water Conservation, 2001)

1.6 Purpose and Structure of this Report

The purpose of this report is to describe the CHRMAP process and summarise the methodology and results of the process, in relation to the City's coastline. The CHRMAP also outlines long term adaptation and management pathways for the City. Key recommendations for implementation by the 2030 planning timeframe have been made, predominantly relating to the most vulnerable areas of the City's coastline. The report is broken down into the following sections:

> **Section 1** provides an introduction to the CHRMAP process and its purpose;
> **Section 2** summarises the coastal hazard risk modelling component of the CHRMAP;
> **Section 3** summarises the coastal hazard risk assessment component of the CHRMAP;
> **Section 4** summarises the risk management and adaptation options assessment;
> **Section 5** looks at long-term management and adaptation pathways for each of the coastal sectors;
> **Section 6** discuss key issues around implementation of the CHRMAP's recommendations;
> **Section 7** makes recommendations for monitoring and further investigations; and
> **Section 8** summarises the key recommendations of the CHRMAP and outlines the short term implementation plan.
> **Section 9** provides a general discussion on the CHRMAP process.

For ease of reading and to summarise key information at the front of this report, previous Chapter Reports that document the CHRMAP process have been included as appendices. The appendices are arranged as follows:

> **Appendix A** – Coastal Hazard Risk Modelling Chapter Report;
> **Appendix B** – Inundation Hazard Maps;
> **Appendix C** – SBEACH Result Figures;
> **Appendix D** – Chainage Figures;
> **Appendix E** – Coastal Erosion Allowances;
> **Appendix F** – Erosion Hazard Maps;
> **Appendix G** – Groundwater Rise and Drainage Infrastructure Hazard Map;
> **Appendix H** – Coastal Hazard Risk Assessment Chapter Report;
> **Appendix I** – Risk Assessment Methodology
> **Appendix J** – Vulnerable Asset Information & Risk Assessment Results;
> **Appendix K** – Risk Management and Adaptation Chapter Report;
> **Appendix L** – Multi-criteria Analysis Tables
> **Appendix M** – Adaptation Options Concept Designs

2 Coastal Hazard Risk Modelling

The coastal hazard risk modelling component of this CHRMAP involved the identification of coastal erosion and inundation hazard extents, comprising the first step in the CHRMAP process (see **Figure 1-3**). Analysis of measured data as well as numerical modelling was undertaken to estimate these extents for each planning timeframe (2017, 2030, 2070 and 2110), across the study area. It should be noted that the methods used to estimate the coastal inundation and erosion extents and allowances involve considerable uncertainty, and SPP2.6 thus specifies that a precautionary and conservative approach be adopted.

2.1 Storm Surge Inundation Assessment (S4)

Coastal inundation hazards have been estimated for a 1, 10, 50, 100 and 500-year average recurrence interval (ARI) water level, for each of the planning timeframes. This assessment involved the estimation of coastal inundation water levels based on a combination of estimated ARI water levels from tide gauge measurements, an estimate of wave setup along the City's coastline and an allowance for predicted SLR over the 100-year planning timeframe.

2.2 Shoreline Stability Assessment

Coastal erosion hazards have been estimated using the methodology specified in SPP2.6, which requires an allowance for the current risk of storm erosion based on a 100-year ARI storm event (S1 erosion), an allowance for future erosion based on historic shoreline movement trends (S2 erosion), an allowance for erosion associated with future SLR (S3 erosion) and an additional factor of uncertainty. These components were combined to derive coastal erosion hazard extents at each of the planning timeframes.

2.3 Hazard Maps

The estimated coastal inundation levels were applied to develop maps of coastal inundation hazard extents, depths and durations. The estimated coastal erosion allowances were applied to develop maps of erosion hazard lines. These hazard maps visually show the extent of the estimated hazard areas for communication to stakeholders and the community.

2.4 Groundwater Rise Assessment

A macro-scale estimate of the potential rise in groundwater due to SLR to 2110 was completed and mapped. Cardno utilised the Department of Water and Environmental Regulation's maximum groundwater level contours for the groundwater rise assessment. 2110 SLR was then added to the groundwater levels to provide groundwater elevations in 2110.

2.5 Stormwater Drainage Assessment

An assessment of the City's stormwater drainage infrastructure, which may be impacted by coastal erosion and inundation, was completed based on the estimated inundation and erosion hazard areas. Assets estimated to be affected by 2070 were physically surveyed. Maps of impacted stormwater drainage assets were also produced.

2.6 Outcomes

The results of the coastal hazard assessment indicate that the City's has assets at risk from both coastal inundation and coastal erosion at present, and that these hazards are forecast to increase into the future. The assessment has identified assets and areas which are potentially at risk from coastal inundation and/or erosion over the various planning timeframes. This identification has then been used to inform the risk assessment process. The hazards should be communicated to the community and stakeholders to stimulate discussion and elicit feedback with regards to future coastal management and adaptation for the City.

The **Coastal Hazard Risk Modelling Chapter Report** is presented in **Appendix A**, with **Appendices B** to **G** providing detail on the inputs and outcomes of the hazard assessment process. The mapping of coastal inundation hazards is presented in **Appendix B** and the mapping of coastal erosion hazards is presented in **Appendix F**.

3 Coastal Hazard Risk Assessment

The coastal hazard risk assessment has interpreted the results of coastal hazard risk modelling to estimate risk and vulnerability for the City's assets. The **Coastal Hazard Risk Assessment Chapter Report** is presented in **Appendix H** and further detail on the risk assessment methodology is presented in **Appendix I**. The assessment has been applied to identify risk and vulnerability separately for both coastal erosion and inundation, for the present day and over future planning timeframes to 2110. Determining risk for each asset or group of assets involves combining the likelihood of impact with the consequences should this impact occur. Vulnerability is then assessed by combining the risk to assets with their respective adaptive capacities (see also **Figure 1-6**). A brief description of these inputs is provided in the following sections.

3.1 Likelihood

According to WAPC (2014) and for the purposes of this study, likelihood is defined as the chance of erosion or storm surge inundation impacting on existing assets and their values. In this CHRMAP, likelihood has been assigned based on the mapping of coastal erosion and inundation extents with respect to the location of assets. The erosion and inundation hazard extents are 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 or inundation occurring at each planning horizon. SPP2.6 also requires the modelling of coastal hazard events with a very low probability of occurrence, which are difficult to translate to the actual likelihood of coastal impact over the specified planning timeframes. A methodology for consistently assigning likelihood to each asset (or asset group) across the planning timeframes has been developed by Cardno (see **Appendix I**) using professional judgement and coastal processes expertise.

3.2 Consequence

Consequence is the result of a hazard impacting an area, asset or group of assets. 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. A heritage component has also been incorporated alongside environmental impacts to ensure impacts to heritage sites are accounted for in the risk assessment process. Generally, the consequence categories incorporate all of the values outlined by the Success Criteria (see **Section 1.3**) and align comparatively between categories with the level of response to these Success Criteria.

3.3 Adaptive Capacity

The adaptive capacity is based upon the potential for an asset to be modified or acclimatise to cope with the impacts of identified hazards. 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 MSL changes). Assets with a high risk level and low adaptive capacity are deemed vulnerable and management options should be investigated.

3.4 Outcomes

The risk assessment has identified assets, groups of assets and areas potentially vulnerable to coastal erosion and inundation hazards at present and up to the 2110 planning timeframe. The full details of assets assessed, inputs and outcomes of the risk assessment are provided in **Appendix J**. Several assets or groups of assets were identified as being highly or very highly vulnerable by the 2030 planning timeframe, specifically in Coastal Sectors 2, 3 and 4. Areas containing these assets were prioritised for more detailed assessment with regards to adaptation.

In general, coastal erosion hazards lead to the highest vulnerability in the short term, due to their greater capacity to cause permanent changes to the shoreline and damage assets. The risk of coastal inundation, however, increases substantially over future planning timeframes and extends across large areas of low-lying land along the City's coastline. Although options for short-term implementation are generally focused on mitigating the threat of coastal erosion, they must consider and account for future hazards associated with coastal inundation.

4 Risk Management and Adaptation

An assessment of risk management and adaptation options has been undertaken based on the results of the completed risk and vulnerability assessment. The assessment identified potential responses to the coastal hazard risks for each of the coastal Sectors within the study area, and provided a preliminary evaluation of the available options, to inform future stakeholder and community engagement. The **Risk Management and Adaptation Chapter Report** is presented in **Appendix K**. The objectives of the adaptation options assessment were:

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

The adaptation options assessment has been guided by the Project's Success Criteria (see **Section 1.3**), defined through the City's community engagement process. These criteria have been used to undertake a preliminary assessment of the social acceptability of potential adaptation options.

As recommended in the CHRMAP Guidelines (WAPC, 2014), an MCA has been used as a preliminary step to identify potentially suitable adaptation options for each sector (or sub-sector), as well as to discount unviable options. The analysis uses a broad range of criteria and a simple 'traffic light' rating system to evaluate the acceptability of each option. The full results of the MCA are provided in **Appendix L**. Through the MCA, various options have been either recommended, not recommended or identified as requiring further investigation for each sector.

Avoid, Accommodate and some 'soft' *Protection* options have been discussed with respect to the City's entire coastline. *Managed Retreat* and *Protect* options have been outlined for priority sectors, where some implementation of the options may be required prior to 2030. Concept maps for protection options are provided in **Appendix M**.

In general, the proposed adaptation options provide technical mitigation approaches for adapting to the effects of landward migration of the shoreline, due to future SLR and associated coastal erosion and inundation. A summary of the range of planning instruments available to effect changes in the character and use of the coastal zone have also been outlined.

In general, options recommend that:

- Where there is currently no existing development seaward of the predicted 2110 coastal erosion hazard line, planning controls and coastal zone boundaries be adjusted to preclude development within the zone;
- Where high value natural and social assets exist seaward of the 2110 coastal erosion hazard line, adaptation options and pathways which maintain the present values of these assets should be favoured;
- Where public built assets exist seaward of the 2110 coastal erosion hazard line, managed retreat options should be considered; and/or
- Where private land and dwellings are located seaward of the 2110 coastal erosion hazard line, options to retreat or provide interim protection should be considered.

5 Long-term Management and Adaptation Pathways

5.1 Long-term Pathways

A key purpose of the CHRMAP is to plan for the responsible use of coastal areas up to the year 2110, and beyond. It is clear that planning decisions made decades and even centuries in the past, prior to understanding the implications of climate change and SLR, are a key contributor to the current situation where assets are becoming increasingly vulnerable to coastal hazards.

Recommended long-term pathways have been proposed for each of the City's coastal sectors in **Sections 5.3** to **5.10** below. These pathways should provide perspective and guidance for any short-term actions recommended for implementation. The long-term pathways presented should be viewed as flexible and likely to evolve. They should, however, have a focus on avoiding the creation of additional risk to be managed. They should also seek to move towards managing the retreat of valuable built assets, as this is generally the most economically responsible approach over the long term.

Long term pathways are presented in tables where columns represent planning timeframes from the short term (between now and 2030) into the future (beyond 2110). For each Sector, applicable asset types have been separated, given that different management options and triggers will be required for different asset types. These asset categories include:

> Undeveloped land;

> Minor public infrastructure and drainage infrastructure;

> Major public infrastructure and residential/commercial property; and

> Natural assets such as beaches and dunes.

For each of the asset categories, applicable management options are presented in rows beneath them. Management options and their codes are presented in **Table 5-1**, below, for reference. As is shown in the tables, multiple management options will be applicable for each asset category, as these options are not mutually exclusive. For example, while interim protection may be the appropriate option for a developed area, options that prepare for future managed retreat (*MR3*) and that accommodate risk (*AC1*, *AC2*) are also likely to be implemented in tandem.

It must also be noted that the display of a certain option at a certain planning timeframe does not necessarily indicate that the option should/will be implemented at that timeframe. The implementation of the option should occur based on the associated trigger(s) being reached. This comes back to the flexibility of management pathways. Further to this, future management options are not yet certain for all assets, particularly major infrastructure. For these cases the pathways split the available options (predominantly managed retreat vs protection) to identify that the pathway is yet to be determined. Further investigation and preparation will be required to confirm these future pathways, with decision points occurring beyond 2030.

The uncertainty around management pathways increases significantly as you advance across timeframes to 2110. Although pathways have been forecast based on the hazard and risk assessment outcomes for the CHRMAP, it is important to note that changes in management and adaptation approaches should be based on triggers (**Section 5.2**). Using triggers to guide management responses should ensure that they are appropriately timed. Implementing management to mitigate a level of risk that is not yet present would be an unnecessary use of resources. Conversely, if risks become present earlier than was predicted, there should be a prepared management response in place to react to the issue.

Long-term pathways contain a large amount of information in a simplified format and can seem confusing. This level of detail, however, is necessary given the broad range of assets types located in each Sector and the multiple adaptation options available to be implemented.

Table 5-1 Adaptation and management options (adapted from WAPC, 2014).

Option Category	Option Name	Option Code	Description
Avoid	Avoid development	**AV**	Avoidance of freehold residential or commercial development within the coastal foreshore reserve.
Managed Retreat	Leave unprotected / repair	**MR1**	Assets are left unprotected and loss is accepted following hazard event. Repairs may be implemented to extend life and for public safety in the short-term. In the case of natural assets, such as beaches and vegetation, allow the impacts of hazards to occur. Drainage infrastructure repaired to ensure operation for future rainfall events.
	Remove / relocate	**MR2**	Assets located in the hazard zone are permanently removed or relocated. For residential and commercial property, this option may require voluntary or compulsory acquisition of land. Drainage infrastructure relocated to an area which will not be impacted again within asset life. Drainage to be removed if no other assets are left to service.
	Planning controls for managed retreat	**MR3**	Use of planning controls to allow continued use of the current infrastructure until such time that impacts arise, but restrict the development of further infrastructure (densification) as the area/asset is known to be vulnerable. This option also includes mechanisms for ensuring that Local Government, land owners and prospective buyers are made aware of the risk.
Accommodate	Planning controls to accommodate/identify risk	**AC1**	Indicates to current and future landholders that an asset is at risk from coastal hazards over the planning timeframe. Helps owners to make informed decisions about the level of risk they are/may be willing to accept and that risk management and adaptation is likely to be required at some stage. For areas prone to inundation, planning controls such as minimum finished floor levels (FFL) may be applicable under this category.
	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.
	Redesign to withstand impact	**AC3**	Usually applicable to flood/inundation prone areas (e.g. flood plains) where an area may continue to be inhabited, despite elevated risk, by designing infrastructure to withstand flood events. This option is not generally applicable for coastal erosion hazards. In the context of Rockingham, this option may be applicable to drainage infrastructure, which might require redesign to better accommodate coastal inundation events. Lake Richmond could be redesigned (i.e. weir boards etc.) to limit impact to hydrology, flora and fauna, social criteria and economic benefits.

Protect	Dune care / sand management	**PR1**	Development of an ongoing program for revegetation and rehabilitation of the dune system. Sand fencing to manage wind-blown erosion also falls under this category.
	Beach nourishment / sand management	**PR2**	Addition of sand to the beach, dune and/or nearshore area to replace lost material and/or create additional buffer. This option is a temporary measure and can be more effective in association with hard protection options, such as groynes. The sand may be from an external source or from a nearby part of that coastal area (i.e. via sand bypassing or back passing).
	Groyne(s)	**PR3**	Construct groynes along the beach to restrict longshore sediment movement and stabilise sections of shoreline. This option is often accompanied by beach nourishment. Hard protection generally diverts erosion issues elsewhere, such as to the down drift side of a groyne, and can have significant impact on coastal ecosystems.
	Nearshore reef(s) / breakwater(s)	**PR4**	Construct offshore reef(s)/breakwater(s) or raise existing natural nearshore reef structure to maintain level of protection as sea level rises. Hard protection generally diverts erosion issues elsewhere, such as to beaches either side of the nearshore structures, and can have significant impact on coastal ecosystems.
	Seawall(s)	**PR5**	Construct seawall in front of assets or along length of coastline to protect them from coastal hazards. Hard protection generally diverts erosion issues elsewhere, such as to beaches either side of, and directly in front of, a seawall. They can also have significant impact on coastal ecosystems.
Do nothing	Do nothing	**DN**	Take no action. No limitations on development or implementation of adaptation planning. Accept risk.

5.2 Triggers

The Draft Guidelines for Planned or Managed Retreat (‘the Draft Guidelines’, DoPHL, 2017) provide guidance on the appropriate triggers or criteria to commence actioning the transfer of land to the public realm. The guidelines suggest the following:

> *Planned retreat allows development to remain and be safely used until the coastal hazard risk becomes unacceptable. Initiation of the process to remove at risk development can be controlled by triggers such as:*
>
> *Trigger 1. Where the most landward part of the Horizontal Shoreline Datum (HSD) is within 40 metres of the most seaward point of a development or structure.*
>
> *Trigger 2. Where a public road is no longer available or able to provide legal access to the property.*
>
> *Trigger 3. When water, sewage or electricity to the lot is no longer available as they have been removed/ decommissioned by the relevant authority due to coastal hazards.*

The Draft Guidelines state that *Trigger 1* can be varied where modelling has been undertaken in accordance with SPP2.6, to determine an S1 erosion distance. As this modelling has been undertaken as part of the CHRMAP, the nominal 40 metre distance has been replaced with the calculated S1 distance for this trigger. Calculated values for S1 vary along the City’s coastline due to coastal exposure, shoreline profile and sediment size. The value is, therefore, site-specific for use as a trigger value. Specific S1 values for each area of the coastline are presented in **Appendix E**.

The triggers defined in the Draft Guidelines are based on physical drivers and focus on triggering a managed retreat approach. For the purpose of guiding management pathways in this CHRMAP, various additional triggers have been defined (**Table 5-2**). These look at additional drivers for management actions, including social and economic drivers. The triggers also relate to the implementation of management responses other than managed retreat, such as the implementation of interim protection where this can be demonstrate to be appropriate. The triggers also help to define when preparatory actions should be undertaken, such as the implementation of planning controls. The triggers used to guide the long-term pathways for the CHRMAP are outlined in **Table 5-2**, below, and these are listed under related management options in the long-term pathway tables for each Sector.

Table 5-2 CHRMAP triggers, the method(s) for assessing when they are reached and some examples of responses.

Trigger name	Trigger	Method(s) of assessment	Example response(s)
T1	The HSD is within the S1 distance of an asset's most seaward extent.	> Ongoing shoreline monitoring (survey profiles) to determine present location of HSD; > S1 defined by modelling, with data collected during shoreline and storm monitoring used to validate/refine the S1 value.	> Remove major infrastructure (roads, carparks), residential and commercial buildings, and transfer land to public realm; > Provide interim protection for major infrastructure (roads, carparks), residential and commercial buildings; > Prepare response plans for minor infrastructure that could be impacted.
T2	A public road is no longer available or able to provide legal access to a property.	> Liaison with/notification by relevant State Government departments;	> Remove residential and commercial buildings, and transfer land to public realm;
T3	Water, sewage or electricity to a lot is no longer available as they have been removed/ decommissioned by the relevant authority due to coastal hazards.	> Liaison with/notification by utilities providers;	> Remove residential and commercial buildings, and transfer land to public realm;
T4	Residential or commercial property lies seaward of the most up to date 100-year coastal erosion hazard line.	> Definition of hazard extents through this CHRMAP; > CHRMAP and hazard extent updates due to the availability of more relevant/recent information (such as updated SLR predictions) and changes in environmental conditions (such as changes to MSL);	> Include all affected land in a SCA and ensure the hazard information is incorporated in structure planning; > Provide notification of potential hazards on certificates of title where possible and by direct contact with affected landholders.
T5	Residential or commercial property lies within the extent of the most up to date 100-year coastal inundation hazard extent.	> Definition of hazard extents through this CHRMAP; > CHRMAP and hazard extent updates due to the availability of more relevant/recent information (such as updated SLR predictions) and changes in environmental conditions (such as changes to MSL);	> Include all affected land in a SCA and ensure the hazard information is incorporated in structure planning; > Provide notification of potential hazards on certificates of title where possible and by direct contact with affected landholders.
T6	An asset is damaged, destroyed or becomes unsafe due to coastal erosion.	> Inspection of coastal assets following storm events or during times of increased longshore erosion (e.g. by works staff, Rangers); > Remote coastal monitoring cameras; > Notification by the public.	> Remove asset and relocate to less hazardous area if possible/appropriate;

T7	Assets are predicted to become highly or very highly vulnerable within the next planning timeframe (2030 in this CHRMAP) or within 15-20 years.	> Definition of hazard extents through this CHRMAP; > CHRMAP and hazard extent updates due to the availability of more relevant/recent information (such as updated SLR predictions) and changes in environmental conditions (such as changes to MSL);	> Undertake detailed cost-benefit analysis and assessment of community acceptance of interim protection vs managed retreat of the affected assets; > Identify sources and begin to allocate funding for management.
T8	The overall community and stakeholders are no longer supportive of a specific coastal management technique or approach.	> Ongoing community engagement.	> Investigate, identify and implement a change in the adaptation pathway.
T9	A specific coastal management technique is forecast to no longer be economically or physically feasible within 10 years.	> Ongoing shoreline and coastal asset monitoring; > Budget expenditure and forecasts.	> Investigate, identify and implement a change in the adaptation pathway.
T10	The beach and coastal foreshore reserve is significantly diminished with respect to its original state and function.	> Long-term coastal monitoring program; > Assessment of aerial imagery; > Feedback through ongoing community consultation.	> Investigate, identify and implement a change in the adaptation pathway.
T11	Undeveloped land is identified as lying within the hazard extents	> Definition of hazard extents through this CHRMAP; > CHRMAP and hazard extent updates due to the availability of more relevant/recent information (such as updated SLR predictions) and changes in environmental conditions (such as changes to MSL);	> Implement planning controls to avoid inappropriate development of the land.

5.3 Sector 1: Municipal Boundary (North) to Wanliss Street

The proposed long-term management and adaptation pathways for Sector 1, along with potential associated triggers, are presented in **Table 5-3**. The assets in the sector are not predicted to be highly vulnerable in the short term. The management pathway for the sector should look to avoid further permanent development in the coastal foreshore reserve.

When affected by coastal hazards and no longer safe or serviceable, minor infrastructure should be removed and relocated or replaced (if necessary) in a less vulnerable area.

Significant public infrastructure and residential and commercial property is likely to be highly vulnerable at some stage across the future planning timeframes, requiring managed retreat from the area. There may be overall benefit in using an interim protection measure for the sector, to delay the timing of this managed retreat. Such a protection measure should maintain the amenity of the coastal foreshore reserve and be funded under the beneficiary pays principal. Managed retreat is likely to be triggered when Rockingham Beach Road requires removal due to intolerable risk or to maintain a suitable foreshore reserve. This would also trigger the removal of the first row of houses along Rockingham Beach Road, due to loss of legal access.

The maintenance and enhancement of the beach and dune system, through dune care, sand management and beach nourishment, should be considered in the sector. These assets provide a valuable, natural protective function.

Table 5-3 Long-term management and adaptation pathways for Sector 1 and associated triggers.

Planning Timeframe	2017 -2030	2030 -2070	2070 - 2110	2110 - future
Assets	**Undeveloped Land**			
Pathway	*Avoid (AV)*			
Trigger(s)	T11			
Assets	**Minor Public Infrastructure and Drainage Infrastructure**			
Pathway	*Managed Retreat (MR1, MR2)*			
Trigger(s)	T6			
Pathway	*Accommodate (AC2)*			
Trigger(s)	T1			
Assets	**Major Public Infrastructure and Residential and Commercial Property**			
Pathway	*Accommodate (AC1, AC2)*			
Trigger(s)	T1, T4, T5			
Pathway	*Planning for Managed Retreat (MR3)*			
Trigger(s)	*T4, T7*			
Pathway	*Soft Protect (PR1, PR2)*	*Protect (PR1, PR2, PR3, PR4)* **and / or** *Managed Retreat (MR2)*		*Managed Retreat (MR2)*
Trigger(s)	T10	T1, T8, T9, T10 T1, T2, T3, T6, T8, T9, T10		T1, T2, T3, T6, T8, T9, T10
Assets	**Beach and Dunes**			
Pathway	*Soft Protect (PR1, PR2)*			
Trigger(s)	T10			

5.4 Sector 2A: Wanliss Street to Garden Island Causeway

The proposed long-term management and adaptation pathways for Sector 2A, along with potential associated triggers, are presented in **Table 5-4**. The assets in the sector have been assessed as highly vulnerable in the short term, which could require a significant change in the management approach for the area. The management pathway for the sector should look to avoid further permanent development in the coastal foreshore reserve.

When affected by coastal hazards and no longer safe or serviceable, minor infrastructure should be removed and relocated (or replaced if necessary) in a less vulnerable area. Significant public infrastructure and residential and commercial property is predicted to be highly vulnerable in the short term, requiring interim protection and/or managed retreat. Managed retreat is likely to be triggered when Esplanade and/or Rockingham Beach Road requires removal due to intolerable risk or to maintain a suitable foreshore reserve. This would also trigger the removal of the first row of houses along these roads, due to loss of legal access.

There is likely to be overall benefit in using an interim protection measure for the sector, particularly if it also mitigates coastal inundation hazards, which are predicted to increase risk levels significantly over future planning timeframes. Any protection measure should maintain the amenity of the coastal foreshore reserve, including key recreation areas such as parks, and be funded under the beneficiary pays principal.

The maintenance and enhancement of the beach and dune system, through dune care, sand management and beach nourishment, should be applied in the sector. These assets provide a valuable, natural protective function. Further investigation is required to determine how best to prepare for and accommodate risk for Lake Richmond, which is predicted to be affected by SLR and other climate change impacts across the planning timeframes.

Table 5-4 Long-term management and adaptation pathways for Sector 2A and associated triggers.

Planning Timeframe	2017 -2030	2030 -2070	2070 - 2110	2110 - future
Assets	**Undeveloped Land**			
Pathway	*Avoid (AV)*			
Trigger(s)	T11			
Assets	**Lake Richmond**			
Pathway	*Accommodate (AC3)*			
Trigger(s)	Further investigation required to define trigger(s)			
Assets	**Minor Public Infrastructure and Drainage Infrastructure**			
Pathway	*Managed Retreat (MR1, MR2)*			
Trigger(s)	T6			
Pathway	*Accommodate (AC2)*			
Trigger(s)	T1			
Assets	**Major Public Infrastructure and Residential and Commercial Property**			
Pathway	*Accommodate (AC1, AC2)*			
Trigger(s)	T1, T4, T5			
Pathway	*Planning for Managed Retreat (MR3)*			
Trigger(s)	*T4, T7*			
Pathway	*Soft Protect (PR1, PR2)*	*Protect (PR1, PR2, PR3, PR4, PR5)* ***and / or*** *Managed Retreat (MR2)*		
Trigger(s)	T10	T1, T8, T9, T10 T1, T2, T3, T6, T8, T9, T10		
Assets	**Beach and Dunes**			
Pathway	*Soft Protect (PR1, PR2)*			
Trigger(s)	T10			

5.5 Sector 2B: Garden Island Causeway to Boundary Road

The proposed long-term management and adaptation pathways for Sector 2B, along with potential associated triggers, are presented in **Table 5-5**. Some assets in the sector have been assessed as highly vulnerable in the short term, which could require a significant change in the management approach for the area. The management pathway for the sector should look to avoid further permanent development in the coastal foreshore reserve.

When affected by coastal hazards and no longer safe or serviceable, minor infrastructure should be removed and relocated (or replaced if necessary) to a less vulnerable area.

Due to the low concentration of vulnerable assets in the sector and their lower economic value compared to other key vulnerable assets in the City, a managed retreat approach should be adopted for all built assets in this sector. This should occur when assets are either damaged or their risk level becomes intolerable.

The maintenance and enhancement of the beach and dune system, through dune care and sand management should be applied in the sector. These assets provide a valuable, natural protective function.

Table 5-5 Long-term management and adaptation pathways for Sector 2B and associated triggers.

Planning Timeframe	2017 -2030	2030 -2070	2070 - 2110	2110 - future
Assets	**Undeveloped Land**			
Pathway	*Avoid (AV)*			
Trigger(s)	T11			
Assets	**Minor Public Infrastructure and Drainage Infrastructure**			
Pathway	*Managed Retreat (MR1, MR2)*			
Trigger(s)	T6			
Pathway	*Accommodate (AC2)*			
Trigger(s)	T1			
Assets	**Major Public Infrastructure and Residential and Commercial Property**			
Pathway	*Accommodate (AC1, AC2)*			
Trigger(s)	T1, T4, T5			
Pathway	*Planning for Managed Retreat (MR3)*			
Trigger(s)	*T4, T7*			
Pathway	*Soft Protect (PR1)*			
	and *Managed Retreat (MR2)*			
Trigger(s)	T10			
	T1, T2, T3, T6, T10			
Assets	**Beach and Dunes**			
Pathway	*Soft Protect (PR1)*			
Trigger(s)	T10			

5.6 Sector 3: Boundary Road to Shelton Street

The proposed long-term management and adaptation pathways for Sector 3, along with potential associated triggers, are presented in **Table 5-6**. The assets in the sector have been assessed as highly vulnerable in the short term, which could require a significant change in the management approach for the area.

When affected by coastal hazards and no longer safe or serviceable, minor infrastructure should be removed and relocated (or replaced if necessary) in a less vulnerable area.

Significant public infrastructure and residential and commercial property is predicted to be highly vulnerable in the short term, requiring interim protection and/or managed retreat. Managed retreat is likely to be triggered when Arcadia Drive or Warnbro Beach Road requires removal due to intolerable risk or to maintain a suitable foreshore reserve. This would also trigger the removal of the first row of houses along these roads, due to loss of legal access.

There is likely to be overall benefit in using interim protection measures for the sector, if it also mitigates the hazard of coastal inundation, which is predicted to increase risk levels significantly over future planning timeframes. Any protection measure should maintain the amenity of the coastal foreshore reserve and be funded under the beneficiary pays principal.

The maintenance and enhancement of the beach and dune system, through dune care, sand management and beach nourishment, should be applied in the sector. These assets provide a valuable, natural protective function.

Table 5-6 Long-term management and adaptation pathways for Sector 3 and associated triggers.

Planning Timeframe	2017 -2030	2030 -2070	2070 - 2110	2110 - future
Assets	**Minor Public Infrastructure and Drainage Infrastructure**			
Pathway	*Managed Retreat (MR1, MR2)*			
Trigger(s)	T6			
Pathway	*Accommodate (AC2)*			
Trigger(s)	T1			
Assets	**Major Public Infrastructure and Residential and Commercial Property**			
Pathway	*Accommodate (AC1, AC2)*			
Trigger(s)	T1, T4, T5			
Pathway	*Planning for Managed Retreat (MR3)*			
Trigger(s)	*T4, T7*			
Pathway	*Protect (PR1, PR2, PR5)*	*Protect (PR1, PR2, PR3, PR5)*		
		and / or *Managed Retreat (MR2)*		
Trigger(s)	T1, T10	T1, T8, T9, T10		
		T1, T2, T3, T6, T8, T9, T10		
Assets	**Beach and Dunes**			
Pathway	*Soft Protect (PR1, PR2)*			
Trigger(s)	T10			

5.7 Sector 4A: Shelton Street to Bayeux Avenue

The proposed long-term management and adaptation pathways for Sector 4A, along with potential associated triggers, are presented in **Table 5-7**. The assets in the sector are not predicted to be highly vulnerable until later in the century.

When affected by coastal hazards and no longer safe or serviceable, minor infrastructure should be removed and relocated or replaced (if necessary) to a less vulnerable area.

Public infrastructure and residential and commercial property may be highly vulnerable at some stage across the future planning timeframes, requiring managed retreat from the area. There may be overall benefit in using an interim protection measure in some parts of the sector, to delay the timing of this managed retreat. Such a protection measure should maintain the amenity of the coastal foreshore reserve and be funded under the beneficiary pays principal.

The maintenance and enhancement of the beach and dune system, through dune care, sand management and beach nourishment, should be considered in the sector. These assets provide a valuable, natural protective function.

Table 5-7 Long-term management and adaptation pathways for Sector 4A and associated triggers.

<table>
<tr><th>Planning Timeframe</th><th>2017 -2030</th><th>2030 -2070</th><th>2070 - 2110</th><th>2110 - future</th></tr>
<tr><td>Assets</td><td colspan="4">Minor Public Infrastructure and Drainage Infrastructure</td></tr>
<tr><td>Pathway</td><td colspan="4">Managed Retreat (MR1, MR2)</td></tr>
<tr><td>Trigger(s)</td><td colspan="4">T6</td></tr>
<tr><td>Pathway</td><td colspan="4">Accommodate (AC2)</td></tr>
<tr><td>Trigger(s)</td><td colspan="4">T1</td></tr>
<tr><td>Assets</td><td colspan="4">Major Public Infrastructure and Residential and Commercial Property</td></tr>
<tr><td>Pathway</td><td colspan="4">Accommodate (AC1, AC2)</td></tr>
<tr><td>Trigger(s)</td><td colspan="4">T1, T4, T5</td></tr>
<tr><td>Pathway</td><td colspan="4">Planning for Managed Retreat (MR3)</td></tr>
<tr><td>Trigger(s)</td><td colspan="4">T4, T7</td></tr>
<tr><td>Pathway</td><td colspan="2">Soft Protect (PR1, PR2)</td><td>Soft Protect (PR1, PR2)
and / or MR (MR2)</td><td>Managed Retreat (MR2)</td></tr>
<tr><td>Trigger(s)</td><td colspan="2">T1, T10</td><td>T1, T8, T9, T10
T1, T2, T3, T6, T8, T9, T10</td><td>T1, T2, T3, T6, T8, T9, T10</td></tr>
<tr><td>Assets</td><td colspan="4">Beach and Dunes</td></tr>
<tr><td>Pathway</td><td colspan="4">Soft Protect (PR1, PR2)</td></tr>
<tr><td>Trigger(s)</td><td colspan="4">T10</td></tr>
</table>

5.8 Sector 4B: Bayeux Avenue to Becher Point

The proposed long-term management and adaptation pathways for Sector 4B, along with potential associated triggers, are presented in **Table 5-8**. The assets in the sector are not predicted to be highly vulnerable in the short term. The management pathway for the sector should look to avoid further permanent development in the coastal foreshore reserve.

When affected by coastal hazards and no longer safe or serviceable, minor infrastructure should be removed and relocated or replaced (if necessary) to a less vulnerable area.

Major built infrastructure, including residential property at Port Kennedy is likely to be highly vulnerable at some stage across the future planning timeframes, requiring managed retreat from the area. There may be overall benefit in using a seawall to provide interim protection for built assets, to delay the timing of this managed retreat. Such a protection measure should maintain the amenity of the coastal foreshore reserve and be funded under the beneficiary pays principal.

The maintenance and enhancement of the beach and dune system, through dune care and sand management, should be considered in the sector. These assets provide a valuable, natural protective function.

Table 5-8 Long-term management and adaptation pathways for Sector 4B and associated triggers.

<table>
<tr><th>Planning Timeframe</th><th>2017 -2030</th><th>2030 -2070</th><th>2070 - 2110</th><th>2110 - future</th></tr>
<tr><td>Assets</td><td colspan="4">Undeveloped Land</td></tr>
<tr><td>Pathway</td><td colspan="4">Avoid (AV)</td></tr>
<tr><td>Trigger(s)</td><td colspan="4">T11</td></tr>
<tr><td>Assets</td><td colspan="4">Minor Public Infrastructure and Drainage Infrastructure</td></tr>
<tr><td>Pathway</td><td colspan="4">Managed Retreat (MR1, MR2)</td></tr>
<tr><td>Trigger(s)</td><td colspan="4">T6</td></tr>
<tr><td>Pathway</td><td colspan="4">Accommodate (AC2)</td></tr>
<tr><td>Trigger(s)</td><td colspan="4">T1</td></tr>
<tr><td>Assets</td><td colspan="4">Major Public Infrastructure and Residential and Commercial Property</td></tr>
<tr><td>Pathway</td><td colspan="4">Accommodate (AC1, AC2)</td></tr>
<tr><td>Trigger(s)</td><td colspan="4">T1, T4, T5</td></tr>
<tr><td>Pathway</td><td colspan="4">Planning for Managed Retreat (MR3)</td></tr>
<tr><td>Trigger(s)</td><td colspan="4">T4, T7</td></tr>
<tr><td rowspan="2">Pathway</td><td rowspan="2">Soft Protect (PR1)</td><td colspan="2">Protect (PR1, PR2, PR5)</td><td rowspan="2">Managed Retreat (MR2)</td></tr>
<tr><td colspan="2">and / or Managed Retreat (MR2)</td></tr>
<tr><td rowspan="2">Trigger(s)</td><td rowspan="2">T1, T10</td><td colspan="2">T1, T8, T9, T10</td><td rowspan="2">T1, T2, T3, T6, T8, T9, T10</td></tr>
<tr><td colspan="2">T1, T2, T3, T6, T8, T9, T10</td></tr>
<tr><td>Assets</td><td colspan="4">Beach and Dunes</td></tr>
<tr><td>Pathway</td><td colspan="4">Soft Protect (PR1)</td></tr>
<tr><td>Trigger(s)</td><td colspan="4">T10</td></tr>
</table>

5.9 Sector 5: Secret Harbour Foreshore Park to Turtles Bend

The proposed long-term management and adaptation pathways for Sector 5, along with potential associated triggers, are presented in **Table 5-9**. Some assets in the sector are predicted to be highly vulnerable in the second half of the century.

When affected by coastal hazards and no longer safe or serviceable, minor infrastructure should be removed and relocated or replaced (if necessary) to a less vulnerable area.

Public infrastructure such as carparks and the Secret Harbour Surf Life Saving Club may be highly vulnerable at some stage across the future planning timeframes, requiring managed retreat from the area.

The maintenance and enhancement of the beach and dune system, through dune care and sand management, should be considered in the sector. These assets provide a valuable, natural protective function.

Table 5-9 Long-term management and adaptation pathways for Sector 5 and associated triggers.

Planning Timeframe	2017 -2030	2030 -2070	2070 - 2110	2110 - future
Assets	**Undeveloped Land**			
Pathway	*Avoid (AV)*			
Trigger(s)	T11			
Assets	**Minor Public Infrastructure and Drainage Infrastructure**			
Pathway	*Managed Retreat (MR1, MR2)*			
Trigger(s)	T6			
Pathway	*Accommodate (AC2)*			
Trigger(s)	T1			
Assets	**Major Public Infrastructure**			
Pathway	*Accommodate (AC2)*			
Trigger(s)	T1			
Pathway	*Planning for Managed Retreat (MR3)*			
Trigger(s)	*T4, T7*			
Pathway	*Soft Protect (PR1)*			
	and *Managed Retreat (MR2)*			
Trigger(s)	T10			
	T1, T6, T10			
Assets	**Beach and Dunes**			
Pathway	*Soft Protect (PR1)*			
Trigger(s)	T10			

5.10 Sector 6: Turtles Bend to Municipal Boundary (South)

The proposed long-term management and adaptation pathways for Sector 6, along with potential associated triggers, are presented in **Table 5-10**. There are very few built assets predicted to become vulnerable before 2110.

When affected by coastal hazards and no longer safe or serviceable, minor infrastructure should be removed and relocated or replaced (if necessary) to a less vulnerable area.

The maintenance and enhancement of the beach and dune system, through dune care and sand management, should be considered in the sector. These assets provide a valuable, natural protective function.

Table 5-10 Long-term management and adaptation pathways for Sector 6 and associated triggers.

Planning Timeframe	2017 -2030	2030 -2070	2070 - 2110	2110 - future
Assets	**Undeveloped Land**			
Pathway	*Avoid (AV)*			
Trigger(s)	T11			
Assets	**Minor Public Infrastructure and Drainage Infrastructure**			
Pathway	*Managed Retreat (MR1, MR2)*			
Trigger(s)	T6			
Pathway	*Accommodate (AC2)*			
Trigger(s)	T1			
Assets	**Beach and Dunes**			
Pathway	*Soft Protect (PR1)*			
Trigger(s)	T10			

6 Implementation

A range of options for managing and adapting to the effects of coastal erosion and inundation on the coastal zone, over the next century, have been outlined in the **Risk Management and Adaptation Chapter Report** (**Appendix K**). While it is natural that the community would prefer to protect and preserve the current features of the coastal zone, the reality is that unless some new and innovative protection methods are developed, the cost of maintaining current features will likely become prohibitively expensive at some point in the future. The interim nature of protection options needs to be recognised across the community and, the adaption options developed and solutions optimised for social, environmental and economic (affordability) drivers. This section first discusses the issues around funding and equity, looks at planning mechanisms that should be incorporated as soon as possible, then discusses management priorities for the City.

The CHRMAP process recognises the difficult decisions that will need to be made in the near future and the CHRMAP is intended to be updated at least every 10 years, or as new information becomes available that may significantly alter the extent of hazards, such as new SLR predictions.

6.1 Funding and Equity

As detailed through economic analyses in the **Risk Management and Adaptation Chapter Report**, the cost to manage changes to the City's coastline in the future is predicted to be considerably greater than current expenditure on coastal management. Significant expenditure may be directed towards a combination of interim protection, to maintain the shoreline position, and compensation for affected landholders, to implement managed retreat and allow the shoreline to recede. Although part funding is likely to be received from the State Government, the City should prepare to take on a significant portion of the cost and take responsibility for ensuring the most responsible financial decisions are made.

When identifying funding sources for ongoing and future management, the City should carry out the appropriate investigations to ensure this funding is derived from the beneficiaries of the management measures. Those parties that would be disadvantaged by any management activities should also be identified and appropriately compensated. Equity, in the context of the CHRMAP process, was discussed in more detail in **Section 1.4.1**. Further investigation, beyond this CHRMAP, will be required to inform the most fair and equitable approach to managing the City's coastline. Key recommendations to investigate equity and establish funding sources are detailed below.

R1: Engage the community to present the results of this CHRMAP and collect their feedback on the acceptability of adaptation options and pathways.

Critical to the CHRMAP process is ongoing community engagement. The City should present the results of the CHRMAP to the community to ensure transparency, educate them on coastal processes and the hazards associated with SLR, and seek their feedback on the acceptability of the range of adaptation measures presented. It will be important to highlight protection and managed retreat as two distinct management approaches, and provide an informed account of the advantages and disadvantages of each. It should be emphasised that managed retreat is the preferred approach over the long term. Engagement activities should also be used to assess the communities and users willingness to contribute to the management of the coast, through a variety of methods including council rates, taxes, access fees etc.

R2: A detailed economic assessment should be undertaken to establish the economic value/contribution of natural assets in key vulnerable areas.

This assessment should look at the range of direct and indirect economic benefits provided by beaches and the coastal foreshore reserve (including parks). The assessment should focus on Sector's 2 and 3, where the highest vulnerability is present in the short term. The assessment should incorporate:

- Estimates of beach visitation and surveys of beach visitors to assist in estimating tourism, external and local visitor value;
- An assessment of the effect of proximity to the beach on property values as well as the identification of any links between beach quality (beach width, useability etc.) and local property value;

> Assessment of the beach's contribution to local business revenue, for example by assessing seasonal trends in turnover;

> Assessment of the economic value of the environmental functions of the beach and foreshore; and

> Identification of existing beneficiaries and the level to which they benefit from the natural assets.

A critical information gap existing at present, that is required to inform a proper cost-benefit analysis of future adaptation options, is an estimate of the economic value/productivity of beaches and other natural assets. This input is required to establish a 'base case' for economic analysis, against which costs and benefits can be assessed. This will be required to inform detailed options assessments, such as those recommended in **Section 6.3**.

R3: Investigate and establish a fund for ongoing coastal adaptation and management, and allocate funding sources.

Following a detailed economic assessment and the selection and refinement of long-term management pathways, the City should look to establish a fund for management of coastal hazards into the future. Levels of funding required should be informed by economic values presented in this CHRMAP and more detailed economic analyses performed through detailed options assessments.

A portion of council rates could be a key funding source, and the use of specified area rates should be considered. Specified area rates will help apportion funding contributions, aligning them with the level of benefit that certain rate payers will receive as a result of management.

The requirement for developer contributions should also be considered. Such contributions would be required where a development is set to benefit from its proximity to the coast and, therefore, the management of the coast in the area.

Sourcing funding from beach and foreshore users could also be considered. This might be in the form coastal car parking fees and marine park entry fees. Fees for use of boat launching facilities could also be incorporated, given that such facilities are likely to require additional maintenance and management as a result of SLR. Sourcing funding in this way would need to be carefully approached, given that the intent of the CHRMAP is to ensure the beach and coastal foreshore reserve is a public asset that should be available to all members of the community.

Future sources of State and Federal Government funding are unpredictable and somewhat beyond the control of Local Governments. The City should, however, demonstrate its preparedness and liaise closely with these levels of government to secure funding where available.

6.2 Planning Controls

A range of planning mechanisms and considerations were presented in the **Risk Management and Adaptation Chapter Report**. The City should look to implement appropriate planning controls as soon as possible, as many of these will help limit risk and liability for the City in the future. The following key recommendations are made with respect to planning controls.

R4: Existing and proposed structure plans should be reviewed to ensure they adhere to SPP2.6 and account for the risks identified in this CHRMAP.

All structure planning should account for the hazards identified in this CHRMAP and the requirements of SPP2.6. The primary mechanism for achieving this through structure planning, will be the allocation of a suitable portion of land as coastal foreshore reserve. This foreshore reserve should be of adequate width to account for the 2110 coastal erosion hazard line, and also ensure a functional foreshore area will remain should this hazard extent be realised in the future. In due course and as structure plans are implemented, it is expected that the zones and reserves they include will be reflected in the City's Town Planning Scheme No.2 (TPS2) via scheme amendments.

R5: TPS2 should be amended to incorporate SPP2.6 and include vulnerable areas as Special Control Areas (SCA).

It is recommended that the City amend TPS2 to directly reference SPP2.6 and ensure it is read as part of TPS2. Wording and placement of this reference is specified in the *Draft Planned or Managed Retreat*

Guidelines (WAPC, 2017). It is also recommended that TPS2 be amended to incorporate areas lying within the 2110 coastal erosion and inundation extents as SCAs. Two SCA's will be required, as different controls will be required in areas prone to erosion, compared to areas prone to inundation. The SCA for erosion is likely to exhibit a greater level of control and should, therefore, prevail in areas of both erosion and inundation hazard. The SCA classification should be used to facilitate land use changes and ensure development control over the identified areas. The nature of the SCA would be distinct for areas at risk of erosion, compared to those at risk from inundation. They should function as follows:

> The SCA for coastal erosion should be based on the 2110 hazard extent, plus an additional allowance for future foreshore amenity;
> The SCA for coastal erosion should establish the intent to eventually retreat from the identified area;
> Both SCA's should require that all development in the area requires approval, allowing the City to control development and ensure it aligns with the long-term pathways for the area;
> SCA's should not extend over areas zoned such that development is already prohibited, such as Parks and Recreation Reserve; and
> The details of how development might be controlled in these SCAs has been outlined in **Risk Management and Adaptation Chapter Report** – see **Appendix K.**

R6: Landholders that may be affected by coastal hazards by 2110 should be notified directly and by the application of notification on Certificates of Title, where possible.

It is important that the City notify the community and potentially affected landholders and stakeholders of the results of the CHRMAP and the extents of potential coastal hazards. It is recommended that the City notify holders of land lying with the 100 year erosion and inundation extents directly, via mail or email. There are also mechanisms to apply notification of the potential hazards to Certificates of Title (outlined in **Risk Management and Adaptation Chapter Report)**, and these should be implemented where possible.

6.3 Management Priorities

6.3.1 Ongoing protection

R7: Initiate/continue targeted beach nourishment in vulnerable areas.

In the short term, beach nourishment should continue to be employed to manage coastal erosion hazards along the City's coastline. With predicted SLR, the volume of sand required is likely to increase and it will be important to allocate nourishment effort as effectively as possible. Nourishment activities are often reactive and are in response to threats to individual assets or isolated areas. While this may seem necessary, it could be an inappropriate allocation of resources.

The City should review past nourishment activities and plan future activities in light of the results of hazard modelling undertaken as part of the CHRMAP. Nourishment should target areas with the highest overall vulnerability and also consider where the most value can be added through the activity, such as by improving beach amenity at popular beaches. Areas where nourishment should be considered/continued include:

> Along Rockingham Beach between Catalpa Park and The Cruising Yacht Club due to the vulnerability of landward assets, the potential for event based erosion and the opportunity to improve beach amenity;
> To the north of Shorewater Foreshore Park due to the vulnerability of landward assets, the potential for event based erosion and the opportunity to improve beach amenity;
> Along the southern side of Mersey Point due to the vulnerability of landward assets;
> To the west of Safety Bay Foreshore Park due to the vulnerability of landward assets, the potential for event based erosion and the opportunity to improve beach amenity; and
> In front of vulnerable infrastructure (predominantly carparks) due to the vulnerability of landward assets, the potential for event based erosion and the opportunity to improve beach amenity.

Effective beach nourishment programs should consider the various components that increase the activities success and the longevity of protection. These include:

> Selecting the appropriate location for placement;

> Using the most effective placement volume, footprint and profile;

> Selecting appropriate sand in terms of grain size and colour; and

> Timing nourishment for greatest effect.

Specific criteria for when and where nourishment should be placed can be developed and refined through data collected during ongoing shoreline monitoring (**R11**), as well as through other specialist investigations including sediment transport analysis (**R13**), detailed management options assessments (**R8**, **R9**) and even community engagement (**R1**) and economic assessment (**R2**) - to identify where nourishment would be most beneficial from a social perspective.

6.3.2 Sector 3 Vulnerability and Mersey Point

R8: Undertake a detailed options assessment for management of coastal vulnerability in Sector 3, with a particular focus on ongoing erosion issues at Mersey Point.

The City should undertake a detailed options assessment of potential mitigation measures for vulnerable areas in Sector 3. The study should consider the implementation of managed retreat, groynes, offshore breakwaters, seawall(s) and nourishment, in isolation or as a combination. Mersey Point is currently experiencing erosion issues and this should be an area of priority for the treatment options. A detailed options assessment should include the following:

> Detailed engineering feasibility of coastal protection structures;

> Sediment transport modelling to estimate the future changes to the shoreline, with the installation of structures or without management; and

> Detailed costings of the management options and a detailed cost-benefit analysis, assessing the full lifecycle of each prospective option and determining the value of natural assets involved.

It should be noted that to properly assess and implement major management options, other key recommendations will require implementation. These include **R1** and **R13**.

6.3.3 Sector 2A Vulnerability

R9: Undertake a detailed options assessment for management of coastal vulnerability in Sector 2A.

The City should undertake a detailed options assessment of potential mitigation measures for vulnerable areas in Sector 2A. The study should consider the implementation of managed retreat, groynes, offshore breakwaters, seawall(s) and nourishment, in isolation or as a combination. A detailed options assessment should include the following:

> Detailed engineering feasibility of coastal protection structures;

> Sediment transport modelling to estimate the future changes to the shoreline, with the installation of structures or without management; and

> Detailed costings of the management options and a detailed cost-benefit analysis, assessing the full lifecycle of each prospective option and determining the value of natural assets involved.

It should be noted that to properly assess and implement major management options, other key recommendations will require implementation. These include **R1** and **R13**.

6.3.4 Hazard Response

R10: Set up a coastal asset inventory and emergency/damage response plan to respond to potential coastal impacts.

With a changing climate and SLR, there is a greater likelihood of experiencing coastal hazard events that are more severe than those encountered in the past. Because of this, there may be a lack of preparation for severe coastal hazard (and other extreme weather) events. The City should use the hazard extents derived through the CHRMAP, specifically those for the present day (2017) and 2030 planning timeframes, to create an inventory of assets that could be impacted. If applicable, the City's existing asset management system could be updated to include these assets.

With the identification of vulnerable assets, the possible result of impacts should be assessed and any potential risks to public safety identified (flooding, unsafe/unstable infrastructure etc.). The City should develop a plan to respond to hazardous events, and the asset damage and scenarios that could be associated with them. This plan might involve the rapid installation of signage and access prevention, the timely removal of damaged assets and response plans for emergency situations.

7 Monitoring and Further Investigation

Monitoring and further investigation is recommended with respect to the CHRMAP process and has been defined to better inform future iterations of the City's CHRMAP. Further investigation that will refine estimated risk levels and inform management beyond the CHRMAP process has also been recommended.

7.1 Long-term coastal monitoring (S2, S3)

R11: Initiate a long-term coastal monitoring program, incorporating ad hoc storm and metocean monitoring, and coastal asset condition assessments.

Long term estimates of recession are typically derived using historic high resolution aerial imagery. This provides a useful indication of how the shoreline has moved in the past. Due to the difficulties in defining shoreline positions from aerial imagery, it is common practice to use the vegetation line as an indicator of shoreline movement. Whilst this is a useful analysis to estimate historic long term trends, it is emphasised that the vegetation line does not necessarily move at the same rate as the shoreline. For instance the vegetation could be smothered in sand due to high winds, could have been disturbed due to human interference (i.e. driving on the dunes, development, fire, pests etc.), or recent storm activity may have occurred where the beach is recovering faster than the vegetation.

This is further complicated in the assumption that the shoreline will erode due to rising sea levels. Noting that sea levels have risen in the past, the SLR component (S3) of historic erosion is typically (conservatively) assumed to be negligible. Moving forward, SLR is predicted to accelerate, so any future updates to the CHRMAP process may need to split historic erosion rates into an underlying erosion rate and a rate due to SLR.

To inform future revisions of the CHRMAP and to identify the current position of the HSD, it is recommended that the city implement regular monitoring, in addition to analysis of collected aerial imagery. It is understood that shoreline monitoring is already carried out along part of the City's coastline, through the Peron Naturaliste Partnership. That monitoring program should be assessed alongside the recommendations in this report, to achieve efficiencies, improvements and collaboration where possible, and avoid unnecessary repetition of monitoring activities. The City's program should include:

> Regular analysis of aerial images, vegetation lines, and creation of GIS layers to describe them. I.e. digital tracing of vegetation lines and shorelines (at least in key vulnerable areas) in a GIS format, to allow analysis and comparison over time;

> 6 monthly beach profile monitoring at set transect locations, spaced at 50 to 100 metre intervals, depending on the change in orientation of the shoreline (i.e. long straight beaches can have surveys wider apart). The surveying should prioritise areas with the highest vulnerability at present. Ideally all of Sector's 1, 2 and 3 should have surveying commence as soon as possible, to ensure the longest dataset possible is available to inform future management. These should be timed to occur in the intervals between the Perth seasonal summer and winter (approximately April and October/November, respectively);

> Nearshore bathymetric surveys on an annual basis (or 6 monthly in association with beach profiles if feasible);

> Sediment sampling at beach profile locations (6 monthly). Ideally, samples would be analysed for particle size distribution by a laboratory. Lab analysis can be expensive and other options are available, such as analysing with sediment sizing cards, and/or the collection and storage of sediment samples for future analysis if/when required;

> Installation of remote imagery cameras - As well as providing ongoing information on the state of beaches, cameras also capture a range of other data, including storm effects, beach visitation, coastal inundation extents and seasonal variations that could be missed by beach profile surveys;

> Storm monitoring and metocean data collection as described below (**Section 7.2**);

> Regular analysis of collected data (every 2-5 years as required) alongside wind data collected by the BoM, and water level and wave data collected by the DoT.

It would be recommended that the City engage a specialist coastal monitoring consultant to review and formalise the monitoring program for their overall coastline. This should involve the development of a monitoring manual, which also includes instruction around storm monitoring (**Section 7.2**).

7.2 Storm and metocean monitoring (S1)

The collection of data around storm events will be valuable in refining estimates of how vulnerable beaches within the City are to storm-based erosion. The collected data can be used to qualify and validate modelled S1 erosion extents. These extents are critical to adaptation planning because they are used as a trigger distance to initiate a change in the management pathway, such as a shift to managed retreat (see **Table 5-1** – T1). Considerable uncertainty exists around the application of storm erosion modelling techniques (Ranasinghe et al, 2013), such as SBEACH modelling commonly used in the CHRMAP process. Additionally, the lack of data available to confidently quantify what a 1 in 100-year storm event is, for a particular area, means that estimated storm erosion is generally conservative, and potentially unrealistic.

The City should incorporate *ad hoc* storm monitoring in key vulnerable areas into the recommended long-term coastal monitoring program (see **Section 7.1**). The key components of the program would be shoreline profiling and sediment sampling, targeting vulnerable sections of coastline before and after storm events. Sampling should target the most severe storm events, or those with the greatest potential to lead to shoreline impact. Predicting the duration and intensity of forecast storms is difficult and, furthermore, predicting their ability to impact the shoreline is impossible. Notwithstanding this, there are several key factors that should be assessed when selecting a storm to monitor. These are as follows:

> Predicted wave height, period and direction (forecast of these is available at websites such as seabreeze.com.au and Willy Weather). Higher wave height and longer wave period means higher wave energy and greater ability to erode the coastline. A wave direction that is less obstructed by offshore island and reefs is also preferred;

> Predicted tide/water level (available at the websites above or from the BoM website). Water level is highly important in a storms ability to impact the coastline. Storms should be chosen where the peak of the storm is predicted to occur at high tide, ideally during spring tides; and

> Predicted storm duration. Generally, storms with a longer duration will have higher impact on the coast. Longer duration also means there is the potential for storm peak(s) to occur during elevated water levels.

Once a storm has been selected for measurement, data should be collected as close to the start and finish of storm conditions as practicable.

Profiling is critical for assessing changes in the shoreline and estimating changes in volume of sand on the beach. It is important to note that the shoreline is constantly changing and profiling provides a 'snapshot' in time of the beach cross section. The dynamic nature of the shoreline means it is important to profile as close to before and after a storm as possible, to avoid detecting changes that might be associated with other processes. Profiling protocols for storm monitoring should be consistent with those outlined in Section 7.2, and the same profile locations as the overall monitoring program should be used where possible.

Sediment sampling is important to assess the change in composition of beach sand, associated with storm impact. Generally smaller grain sizes are taken away more easily, leaving large sand particles after a storm event. Sediment data will be useful for informing renourishment and shoreline protection activities, where the characteristics of imported sand are critical (see **Section 6.3.1**). Sediment sampling protocols for storm monitoring should be consistent with those outlined in **Section 7.1**, and the same sample locations as the overall monitoring program should be used where possible.

Ideally, metocean data such as water level, wave and current conditions should also be measured during storm monitoring. This data can help define the nature of the sampled storm event, including its severity and duration. This type of data collection is relatively expensive and would be difficult to implement alongside each storm sampling exercise. Targeted metocean data collection campaigns (during the winter period for example) should, however, be incorporated into the City's coastal monitoring program where feasible. Metocean data has significant value and provides information for a range of applications. These include: validating wave and hydrodynamic modelling, informing sediment transport analysis and modelling, informing detailed management options assessments and informing the design of coastal structures.

7.3 Coastal Asset Condition Assessment

Some built assets necessarily reside within coastal hazard areas because of their purpose. These assets include boat ramps, jetties, groynes, seawalls, breakwaters and associated access infrastructure, like carparks and access ways. An example is the Point Peron Boat Ramp and associated parking and access. Such assets are generally designed to be sufficiently strong to withstand coastal hazards in their own right, or accompanied by protection against coastal hazards. As MSL has already been rising and climate change is expected to bring further changes to water levels and storm intensity, it is possible that existing coastal assets have been under designed for present and/or future coastal conditions. Assets like boat ramps, protection structures and access ways can also lose functionality as conditions change and the shoreline is altered. This is always a challenge when placing fixed infrastructure at a dynamic shoreline.

As unprecedented changes and coastal conditions are predicted to occur, it is recommended that more regular condition assessment of coastal infrastructure be undertaken by the City. For significant infrastructure, assessments should be carried out by an experienced coastal or maritime structural engineer. Formal inspection frequency should be approximately every 5 to 10 years, but this should be flexible based on the outcomes of previous assessments and observations from informal assessments. There should also be the capacity to inspect infrastructure after major storm events, to identify any critical damage.

7.4 Water level/ inundation (S4)

R12: Undertake a local water level and SLR analysis.

A key component of this CHRMAP involved analysis of water level records to estimate peak water levels during extreme events. Due to the length and reliability of the data set, the tide record from Fremantle Fishing Boat Harbour was analysed to define design water levels for various ARI events. Water level can change considerably with location (even when nearby). To better inform risk levels prior to the next CHRMAP revision, it is recommended that the City undertake a local assessment of water levels, adjacent to its coastline. The assessment should include:

> Collection of water level data (during storm events if possible) for analysis/comparison through the deployment of instrumentation at a selected offshore location. A specialist consultant would be required to carry out this data collection;
> An analysis of water level records (including historical) at nearby locations, including Fremantle, Mangles Bay and Mandurah, to establish relationships between the datasets and identify historical SLR trends specific to Rockingham; and
> Visual inspections (or remote imagery capture) of inundation extents during storm activity, to assess against modelled hazard extents.

7.5 Further Investigation

7.5.1 Sediment Transport Analysis

R13: Undertake a detailed sediment transport analysis to establish a detailed sediment budget for the City, focusing on Sectors 2 and 3.

Coastal erosion hazards, as estimated through the CHRMAP process, are based on a number of simplified assumptions. One of the key assumptions made in defining hazard extents is that the historical rate of shoreline recession will continue at the same rate into the future. In reality, the rate of recession is governed by a number of factors including wave conditions, bathymetry, availability and size of sediment and the orientation of the shoreline.

This CHRMAP assessment has identified a number of assets which are potentially at risk of erosion hazards now, or in the future. To further qualify the risk levels, it is recommended that a detailed sediment transport analysis be undertaken to quantify expected erosion and accretion rates in the future. Key outcomes of the study should include:

> Development of a (or multiple) validated numerical sediment transport and shoreline response model(s) of the Rockingham shoreline;
> Quantification of gross and net transport rates along the Rockingham foreshore under current and future climatic conditions;

- Further quantification and refinement of future erosion hazards to be incorporated into the next CHRMAP revision; and
- Assessment and further development of any proposed shoreline protection options (such as groynes, breakwaters, seawalls, nourishment programs etc.), and their impacts on the shoreline.

The CHRMAP process has identified that the most vulnerable sections of coastline lie within Sectors 2 and 3, therefore the sediment transport assessment should focus on these areas.

7.5.2 Nourishment Sand Source Investigation

R14: Undertake an investigation to identify suitable sediment sources and determine available volumes for use in ongoing beach nourishment.

The preferred management scheme for vulnerable areas in the short term is to continue and enhance the City's beach nourishment activities. This management technique provides temporary protection, generally improves beach amenity and maintains a flexible adaptation pathway for the future. As sea levels rise, the volume of sand needed to be added to the beach will increase. In anticipation of the increased nourishment volumes it will be prudent to identify suitable sediment sources for use in the future. This could include identification of sources such as:

- Stripping sand from the City's beaches where accretion is occurring or in areas not considered to be vulnerable;
- Investigation of the existing sand trap, and investigating ways to increase the trapping efficiency of this operation;
- Sourcing sand from developments close to the coast where excavation in good quality sand (for example basement excavation) is proposed; and
- Identification of nearshore sand sources that could be sourced using dredging operations.

7.5.3 Geophysical Investigations

Geophysical investigations can be useful in identifying the depth of erodible material below the ground surface. Given the generally low lying nature of the City's coastal areas and the general lack of exposed hard rock in these areas, a geophysical investigation is not expected to add significant value to future revisions of the CHRMAP.

Noting that managed retreat is a potential adaptation option in the future, geophysical investigations may be more beneficial prior to major built infrastructure being removed. The geophysical investigation could inform the managed retreat decision, ensuring assets are not removed unnecessarily.

Geophysical investigation generally involve transect and point measurements to identify layers and hardness of material below the surface. For this purpose, they would be used to identify if there is a continuous, alongshore rock barrier located below the ground surface (e.g. within a sand dune), that has sufficient strength and height to prevent coastal hazards impacting assets on its landward side. Such investigations are carried out by geologists using specialised equipment.

7.5.4 Stormwater and Drainage Asset Management

R15: Update the City's Asset Management Plan to reflect adaptive measures selected by the City and develop a priority matrix to ensure assets nearer to the foreshore area are performing as expected.

Moving forward in consideration of expected SLR, the City's drainage maintenance plan will need to be developed in accordance with the adaptation options selected by the City. It will be important that maintenance is proactive as opposed to reactive. A proactive maintenance regime could substantially prolong the useful life of the stormwater and drainage assets.

It is suggested that a priority matrix be developed that assesses maintenance of assets nearer to the foreshore areas in line with the potential impacts of erosion and inundation. This is to ensure that the assets in these vulnerable locations are performing as expected and are not hindered by blockages, or other obstructions.

Operational and maintenance activities may be targeted to mitigate critical asset failure and maintain service levels. These activities may include increased inspection frequency and higher maintenance intervention levels.

Identification of critical stormwater assets and their failure modes will be necessary to minimise risk and inform the City's asset management plan. For example, critical stormwater assets are likely to include:

> Drainage structures under main roads;
> Drainage structures under roads with no nearby alternative routes;
> Drainage structures near schools, aged care and childcare facilities;
> Drainage structures protecting emergency services sites; and
> Flood mitigation structures protecting residential land.

Drainage or flooding issues reported by residents should be reviewed and assessed to identify if the issues are related to coastal processes or hazards.

Through the implementation of a complete stormwater and drainage GIS information system, assets noted as critical can be identified and linked to a maintenance regime, based on location of the assets, to address known issues. This will help develop maintenance planning for predicted SLR and increased inundation. Maintenance regimes will need to be reviewed and a gap analysis performed to ensure that maintenance planning will address adaptation options selected by the City.

7.5.5 Stormwater Modelling

R16: Stormwater and drainage system be reviewed for functional capacity should issues be reported.

As the town has over 40 drainage outlets discharging to the ocean, understanding the capacity of the drainage network will provide an indication of what catchments will be prone to failure due to coastal processes.

Up to 2030, should drainage assets be identified as underperforming (see **Section 7.4.4**), the drainage system should be reviewed for functional capacity and retrofication works undertaken to ensure performance is maintained.

Ultimately (i.e. beyond 2030), the City should undertake direct rainfall modelling of the coastal area. This assessment will provide the City with an understanding of the areas most prone to inundation due to rainfall. This modelling should be used to determine the impact of elevated water levels on the efficiency of the drainage network as part of the adaption measures assessment.

Direct Rainfall modelling applies an excess rainfall volume directly to a hydraulic model, thereby considering both flow capacity and volumetric storage. This is particularly important in considering drainage networks that flow to tidal boundaries, as exists in the City, as the capacity of the outlet can be constrained under high tidal levels, due to SLR or ocean inundation events, leading to the ponding of water in flood storage areas. These areas include low lying areas behind dunes and local depression storages that would normally flow under low tide conditions via the underground drainage network.

As part of the direct rainfall modelling, consideration should be given to include a joint-probability analysis of both coastal events and pluvial flooding along the entire coast line.

7.5.6 Lake Richmond

R17: Continue to undertake environmental surveys and monitor TDS levels for Lake Richmond.

The City currently and should continue to undertake environmental surveys (flora and fauna) alongside Total Dissolve Solid (TDS) monitoring to collect baseline information on Lake Richmond. This will ensure future adaptive measures will preserve the Lakes economic, environmental and social values.

Once substantial data is collected, i.e. 5 years of baseline data, trigger values and contingency measures should be derived. Trigger values will be monitored as part of the ongoing monitoring process and should trigger values be exceeded, contingency measures put in place. It is suggested trigger values are based on increases in TDS levels based on a review of the ability of flora and fauna to adapt to changes.

7.5.7 CHRMAP Revision

R18: Undertake a full revision of the City's hazard extents and CHRMAP, identifying and incorporating relevant new information.

As noted in the CHRMAP guidelines, the CHRMAP should be a living document and undergo regular revisions and monitoring.

> "…*risks arising from coastal hazards rarely remain static, especially as our understanding of coastal processes is improving and given the long timeframes associated with some types of coastal processes and types of land use and development in the coastal zone. It is also impacted by uncertainty on the degree of future climate change (i.e. what the future global greenhouse emissions will be), and climate change projections that are used in the vulnerability assessments. Monitoring and reviewing the CHRMAP ensure the management and adaptation to reduce risks, their likelihood and consequences and the risk priorities, remain the most suitable and effective, and timing and cost appropriate. Where possible principles of adaptive management should be applied which involves small, flexible, incremental changes based on regular monitoring and revision of plans based on the best information available at the time."*

The key changes to any future revisions of the CHRMAP should include an update of hazard estimates using more recent information, the findings of specialist investigations undertaken, changes to projected SLR and climate change effects and any changes to the use of the foreshore.

8 Key Recommendations

Key CHRMAP recommendations are collated and summarised in **Table 8-1**. These recommendations generally focus on actions that will or may require implementation prior to 2030. Recommendations for management actions beyond 2030 will be better informed by investigations undertaken and information collected over the next decade, which will be highlighted in the next review of the CHRMAP.

Table 8-1 Key CHRMAP recommendations

ID	Recommendation
R1	Engage the community to present the results of this CHRMAP and collect their feedback on the acceptability of adaptation options and pathways.
R2	A detailed economic assessment should be undertaken to establish the economic value/contribution of natural assets in key vulnerable areas.
R3	Investigate and establish a fund for ongoing coastal adaptation and management, and allocate funding sources.
R4	Existing and proposed structure plans should be reviewed to ensure they adhere to SPP2.6 and account for the risks identified in this CHRMAP.
R5	TPS2 should be amended to incorporate SPP2.6 and include vulnerable areas as SCAs.
R6	Landholders that may be affected by coastal hazards by 2110 should be notified directly and by the application of notification on Certificates of Title, where possible.
R7	Initiate/continue targeted beach nourishment in vulnerable areas.
R8	Undertake a detailed options assessment for management of coastal vulnerability in Sector 3, with a particular focus on ongoing erosion issues at Mersey Point.
R9	Undertake a detailed options assessment for management of coastal vulnerability in Sector 2A.
R10	Set up a coastal asset inventory and emergency/damage response plan to respond to potential coastal impacts.
R11	Initiate a long-term coastal monitoring program, incorporating *ad hoc* storm and metocean monitoring, and coastal asset condition assessments.
R12	Undertake a local water level and SLR rise analysis.
R13	Undertake a detailed sediment transport analysis to establish a detailed sediment budget for the City, focusing on Sectors 2 and 3.
R14	Undertake an investigation to identify suitable sediment sources and determine available volumes for use in ongoing beach nourishment.
R15	Update the City's Asset Management Plan to reflect adaptive measures selected by the City and develop a priority matrix to ensure assets nearer to the foreshore area are performing as expected.
R16	Stormwater and drainage system be reviewed for functional capacity should issues be reported.
R17	Continue to undertake environmental surveys and monitor TDS levels for Lake Richmond.
R18	Undertake a full revision of the City's hazard extents and CHRMAP, identifying and incorporating relevant new information.

8.2 Short-term Implementation Plan

A short-term implementation plan is presented in **Table 8-2**. The table describes actions recommended for implementation by 2030, their estimated costs and suggestions for timing. The cost estimates provided are based on commercial rates and do not assume work will be carried out by the City to complete the actions. Realistically a significant portion of the proposed works will be undertaken by City staff. The City should assess how it wishes to resource the proposed works, before estimating costs for the purpose of budgeting.

Table 8-2 Short-term implementation plan to 2030

Component	Annual cost estimate	Total cost estimate (to 2030)	Timing
Operational			
Review existing Structure Plans	-	-	2018
Amend TPS2	-	-	2018-19
Directly notify affected landholders	-	-	2018
Apply notifications to title	TBD	TBD	From 2018
	Sub-total	**TBD**	
Monitoring			
Shoreline monitoring manual	$25,000	$25,000	2018
Ongoing aerial imagery analysis	$5,000	$60,000	From 2018
Ongoing shoreline monitoring	$40,000	$480,000	From 2018
Storm monitoring	$15,000	$180,000	From 2018
Coastal asset condition assessments	$15,000	$180,000	From 2020
Metocean data collection	$25,000	$300,000	From 2019
	Sub-total	**$1,225,000**	
Implementation/ Management			
CHRMAP results community engagement	-	$25,000	2018
Ongoing community engagement	$10,000	$60,000	From 2019
Establish coastal adaptation fund	-	-	2019
Ongoing beach nourishment	$250,000	$3,000,000	From 2018
Coastal asset inventory update	-	$10,000	2018
Asset management plan update	-	$15,000	2018
Hazard response preparation	-	$15,000	2018
Management at Mersey Point	-	$500,000	2020-2025
	Sub-total	**$3,625,000**	
Special Investigations			
Detailed economic assessment	-	$150,000	By 2020
Detailed options assessment for Sector 3	-	$100,000	By 2020
Detailed options assessment for Sector 2	-	$100,000	By 2025
Water level / SLR analysis	-	$50,000	By 2030

Detailed sediment transport investigation	-	$120,000	By 2020
Nourishment sand source investigation	-	$20,000	By 2025
Storm water and drainage system review	-	$100,000	By 2030
Hazard line and CHRMAP revision	-	$150,000	By 2030
	Sub-total	**$790,000**	
	Grand Total	**$5,640,000**	

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APPENDIX
A
COASTAL HAZARD RISK MODELLING

Coastal Hazard Risk Modelling

City of Rockingham Coastal Hazard Risk Management and Adaptation Plan

59918065

Prepared for
City of Rockingham

1 March 2018

Contact Information

Cardno (WA) Pty Ltd
Trading as Cardno
ABN 77 009 119 000

11 Harvest Terrace
West Perth 6005
Australia

www.cardno.com
Phone +61 8 9273 3888
Fax +61 8 9486 8664

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Author(s):

Name: Colin Hart
Job title: Coastal Engineer

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Approved By:

Name: Chris Scraggs
Job title: Principal Coastal Engineer

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Rev B	18/12/2017	Client Comments Incorporated	CH	RD
Rev C	10/01/2018	Client Comments Incorporated	RD	CS
Rev 0	01/03/2018	Final	CH	DS

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1 Introduction

The City of Rockingham (herein referred to as ’the City’) is undertaking a Coastal Hazard Risk Management and Adaptation Plan (CHRMAP) for the Rockingham LGA coastline. Rockingham LGA is located approximately 38 km south-southwest of the Perth CBD (**Figure 1-1**).

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 Adaption 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 adaption 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 adaption plan.

This study utilises 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 a comprehensive CHRMAP for the study area. This CHRMAP will guide the ongoing development of the City and ensure coastal erosion and inundation hazards are accounted for.

There are a number of existing coastal studies that have been undertaken within the study area. Cardno has reviewed these existing studies and incorporated the results into this CHRMAP where relevant.

This report describes the ‘Coastal Hazard Assessment’ component of the CHRMAP, as per **Figure 1-2**. Specifically, this report describes the work undertaken as part of the coastal hazard assessment to develop the extents of the Coastal Foreshore Reserve.

Coastal vulnerability studies play an important role in identifying the development constraints and opportunities within the coastal zone, and provide a better understanding to developers and external agencies in regards to water management and investment decisions. This report summarises the coastal hazard assessment and risk identification elements within the ‘CHRMAP framework.

Figure 1-1 City of Rockingham CHRMAP Study Area and Locality Plan (Background image: Nearmap)

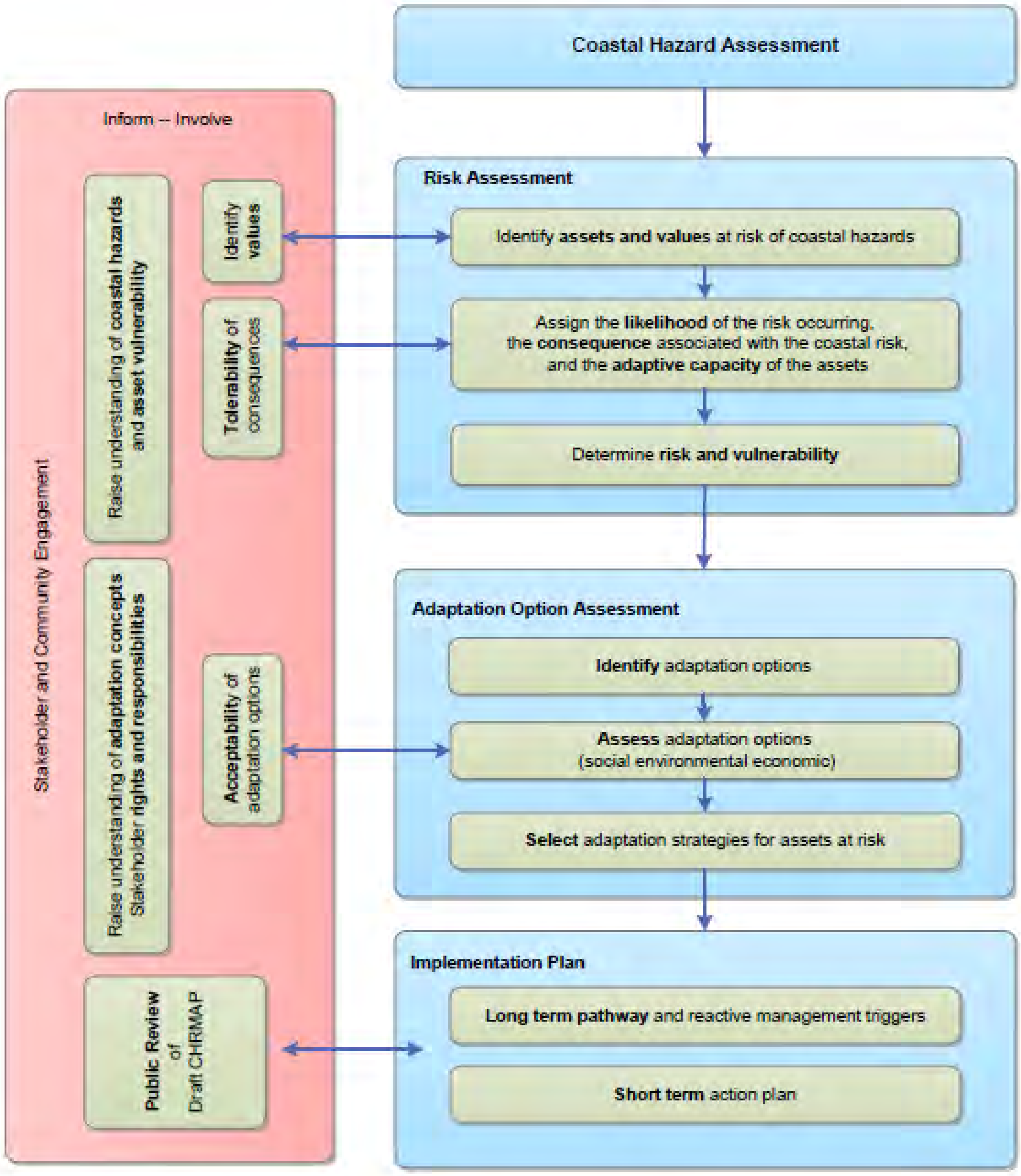

Figure 1-2 CHRMAP methodology flow chart (adapted from CHRMAP Guidelines (WAPC, 2014))

2 Study Approach

2.1 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 tide inundation. The coastal foreshore reserve should be determined on a case by case basis and include allowances for additional functions provided by the coastal foreshore region 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 adaption planning framework outlined in SPP 2.6. The assessment considers allowances for coastal erosion and storm surge inundation in parallel.

2.2 Coastal Erosion

The allowance for erosion on sandy coasts is calculated as the sum of the S1, S2 and S3 Erosion components, plus a 0.2 m per year allowance for uncertainty, and should be measured from the horizontal shoreline datum (HSD):

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

> (S2 Erosion) Allowance for historic shoreline movement trends

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

As stated above, the coastal foreshore reserve is applied from the HSD, a fixed line that is defined based on the type of coastline being assessed. As defined in SPP2.6, 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. The HSD level is determined based on the peak steady water level from the SBEACH simulation results. The peak steady water level (PSWL) is defined in SPP2.6 as being the highest average elevation of the sea surface caused by the combined effect of storm surge, tide and wave setup resulting from the storm events defined in Schedule One, Section 5 of SPP2.6.

Schedule One of SPP2.6 describes different areas for the definition of the storm event for use as the defined storm event in the assessment of inundation and erosion. The Rockingham LGA lies within Area 3 as defined in SPP2.6. Policy guidance for coastal erosion is that a mid-latitude depression or extra-tropical low storm event corresponding to the 100-year ARI ocean forces and coastal processes should be selected, tracking to maximise its erosion potential.

It should be noted that the existing coastal protection structures along the Rockingham coastline (see **Section 4.3.2.1**) were not factored into the derivation of the hazard allowances for coastal erosion for the various planning timeframes. The presence, condition and design life of the existing coastal structures is factored into the risk assessment which is the next stage of the CHRMAP. This approach was adopted as it identifies the underlying risk area which may be subject to coastal erosion hazards should the existing protection structures fail, not be maintained or be removed in the future. Factoring in existing coastal protection structures during the Risk Assessment phase allows their effect on the likelihood and consequence of coastal erosion hazards to be incorporated separately and for different assumptions to be adopted across the future planning timeframes.

2.3 Coastal Inundation

The allowance for current risk of inundation, according to SPP2.6, is calculated as the maximum extent of storm inundation, defined as the peak steady water-level plus wave run-up. Consideration must be given to the likelihood of breaching any manmade structure, e.g. seawall, or natural barriers, for example a dune system.

As discussed above, The City of Rockingham LGA falls in Area 3 as defined in SPP2.6. Policy guidance for coastal inundation is that a tropical low storm event corresponding to the 500-year ARI ocean forces and coastal processes should be selected, tracking to maximise its inundation potential.

As required by the City, this CHRMAP also considers storm events for coastal inundation with ARIs of 1, 10, 50 and 100 years in addition to the 500-year ARI event required under SPP2.6.

2.4 Sea Level Rise

Included in SPP 2.6 is the current policy relating to the Sea Level Rise (SLR) projection for the 100-year planning period. The current SPP2.6 policy requires the adoption of the following value for SLR:

> +0.9 m for a 100-year (~2110) planning period

This CHRMAP also considers additional interim planning timeframes of 2030 and 2070. The SLR projections for these shorter time periods are based on the recommendations of Department of Transport (2010) using 2017 as the base year and the adopted values are:

> +0.05 m for 2030 (13-year planning period); and

> +0.38 m for 2070 (53-year planning period).

2.5 Bathymetry and Survey Data

This stage of the CHRMAP utilised bathymetry and survey datasets comprising LiDAR survey data, feature surveys, nearshore hydrographic surveys, and beach profile surveys. Datasets and their respective survey dates are presented in **Table 2-1**. A Digital Elevation Model (DEM) was derived for the study using a combination of all the available datasets, with the most recent detailed survey data being applied.

There are large sections of the study area for which the only spatial survey data available was LiDAR which is from either 2008 (Department of Water and Environmental Regulation (DWER) LiDAR survey of land areas) or 2009 (Department of Transport Marine LiDAR survey). The LiDAR data is still very useful in areas where the land surface has not changed significantly since the survey date, however detailed analysis and comparison with recent vegetation lines provided by the Department of Transport revealed a number of sections of coastline within the study area that have changed significantly since the LiDAR surveys were captured. This presented challenges in spatially mapping the inundation and erosion hazards further described in **Section 4.6**.

Based on the above it is recommended that detailed area survey of the entire City coastline be captured prior to the next revision of this CHRMAP. This could be done either through collaboration with state or federal government agencies (e.g. the existing LiDAR surveys by DWER or DoT), collaboration with other local governments or associations (e.g. Cockburn Sound Coastal Alliance, Peron-Naturaliste Partnership or neighbouring local governments) or the City could independently commission a survey of its coastline.

Table 2-1 Bathymetry and survey datasets utilised in this study

Date	Source	Coverage Area
Nov 2017	City of Rockingham	20 shore-normal beach profiles spread across the study area surveyed specifically for this study to fill gaps in existing survey data
May 2017	City of Rockingham	Profiles covering the Tern Island Sandbar and beach to the east
May 2017	City of Rockingham	11 Beach profiles located between the Point Peron Boating Facility and NW end of Crystal Beach (~850m)
May 2017	City of Rockingham	17 shore-normal beach and hydrographic survey profiles and one shore-parallel profile in Safety Bay and Waikiki between Donald Drive and southern end of Warnbro Beach Road
May 2017	City of Rockingham	Profiles around universal beach access at Waikiki
May 2017	City of Rockingham	Mersey Point beach and nearshore hydrographic profiles and small feature survey

Sept 2016	City of Rockingham	Feature and nearshore hydrographic survey of Point Peron Boating Facility
May 2016	Department of Transport	Laser beach survey and nearshore hydrographic survey of Mangles Bay
April 2016	City of Rockingham	Feature and nearshore hydrographic survey of Tern Island Sandbar and surrounding area
Feb 2016	City of Rockingham	Feature survey of Palm Beach Boat Ramp
Apr-May 2009	Department of Transport	5m x 5m grid bathymetry LiDAR survey from Two Rocks to Cape Naturaliste covering up to 40m depth
2008	Department of Water and Environmental Regulation	LiDAR survey of entire Rockingham LGA land area

2.6 Study Area Sectors

The study area was delineated into six Sectors, numbered from north to south and covering the length of the Rockingham LGA coastline. Due to the presence of areas of rocky shoreline and multiple changes in coastline orientation and degree of sheltering, Sector 2 was separated into seven sub-sectors (2.1 to 2.7). The extent of the sectors is described below and shown in **Figure 2-1** to **Figure 2-6**. The sub-sectors within Sector 2 are shown in **Figure 2-7** to **Figure 2-10**.

- Sector 1 extends from the Northern Boundary of the City south to Wanliss Street, Rockingham;
- Sector 2 extends from Wanliss Street, Rockingham south to Boundary Road, Shoalwater;
  - Sub-sector 2.1 extends from Wanliss Street west to the Garden Island Causeway;
  - Sub-sector 2.2 extends from the sand trap at the entrance to the Point Peron Boating Facility west to the rocky shoreline approximately 250m south east of Cape Peron;
  - Sub-sector 2.3 extends from the rocky shoreline to Cape Peron;
  - Sub-sector 2.4 is the west facing section of beach south of Cape Peron down to the rocky headland;
  - Sub-sector 2.5 is the first south west facing section of beach where a carpark is located close to the beach;
  - Sub-sector 2.6 is the second south west facing section of beach to the south east of sub-sector 2.5;
  - Sub-sector 2.7 is the south east to west facing section of beach which extends south to Boundary Road, Shoalwater;
- Sector 3 extends from Boundary Road, Shoalwater south to Shelton Street, Warnbro;
- Sector 4 extends from Shelton Street, Warnbro south to Becher Point, Port Kennedy;
- Sector 5 extends from Becher Point, Port Kennedy south to Turtles bend, Secret Harbour; and
- Sector 6 extends from Turtles bend, Secret Harbour south to the southern Boundary of the City.

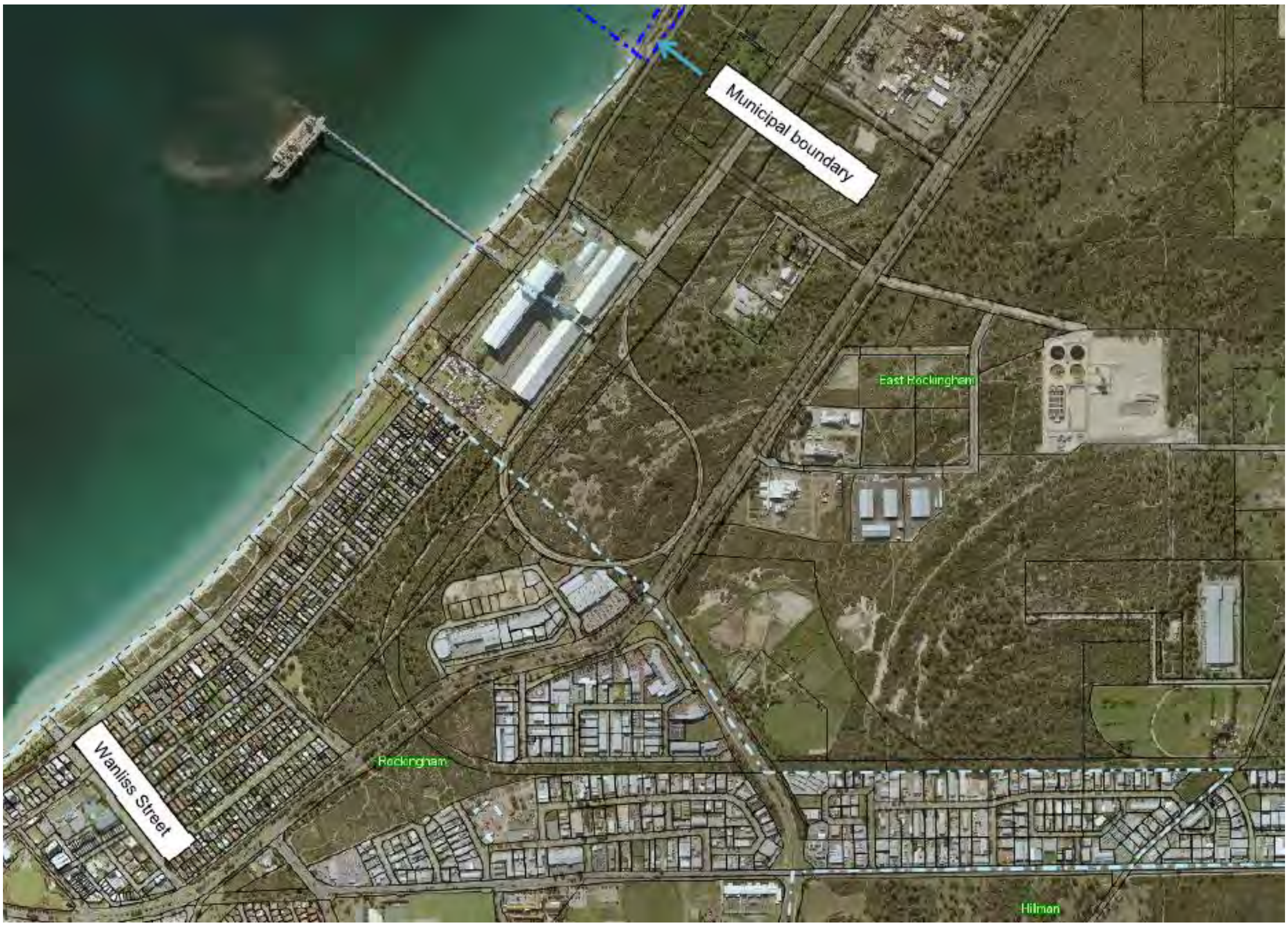

Figure 2-1 Sector 1: City of Rockingham Boundary to Wanliss St, Rockingham

Figure 2-2 Sector 2: Wanliss Street, Rockingham to Boundary Road, Shoalwater

Figure 2-3 Sector 3: Boundary Road, Shoalwater to Shelton Street, Warnbro

Figure 2-4 Sector 4: Shelton Road, Warnbro to Becher Point, Port Kennedy

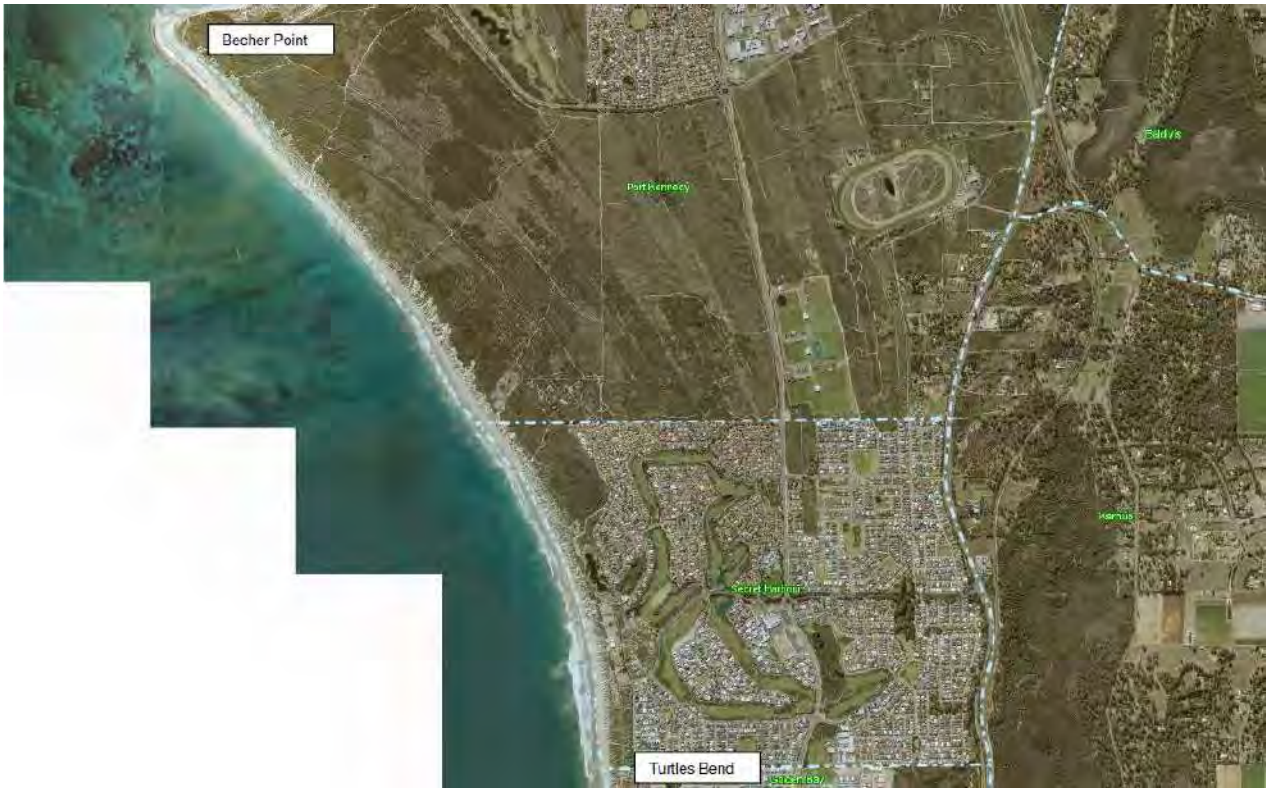

Figure 2-5 Sector 5: Becher Point, Port Kennedy to Turtles Bend, Secret Harbour

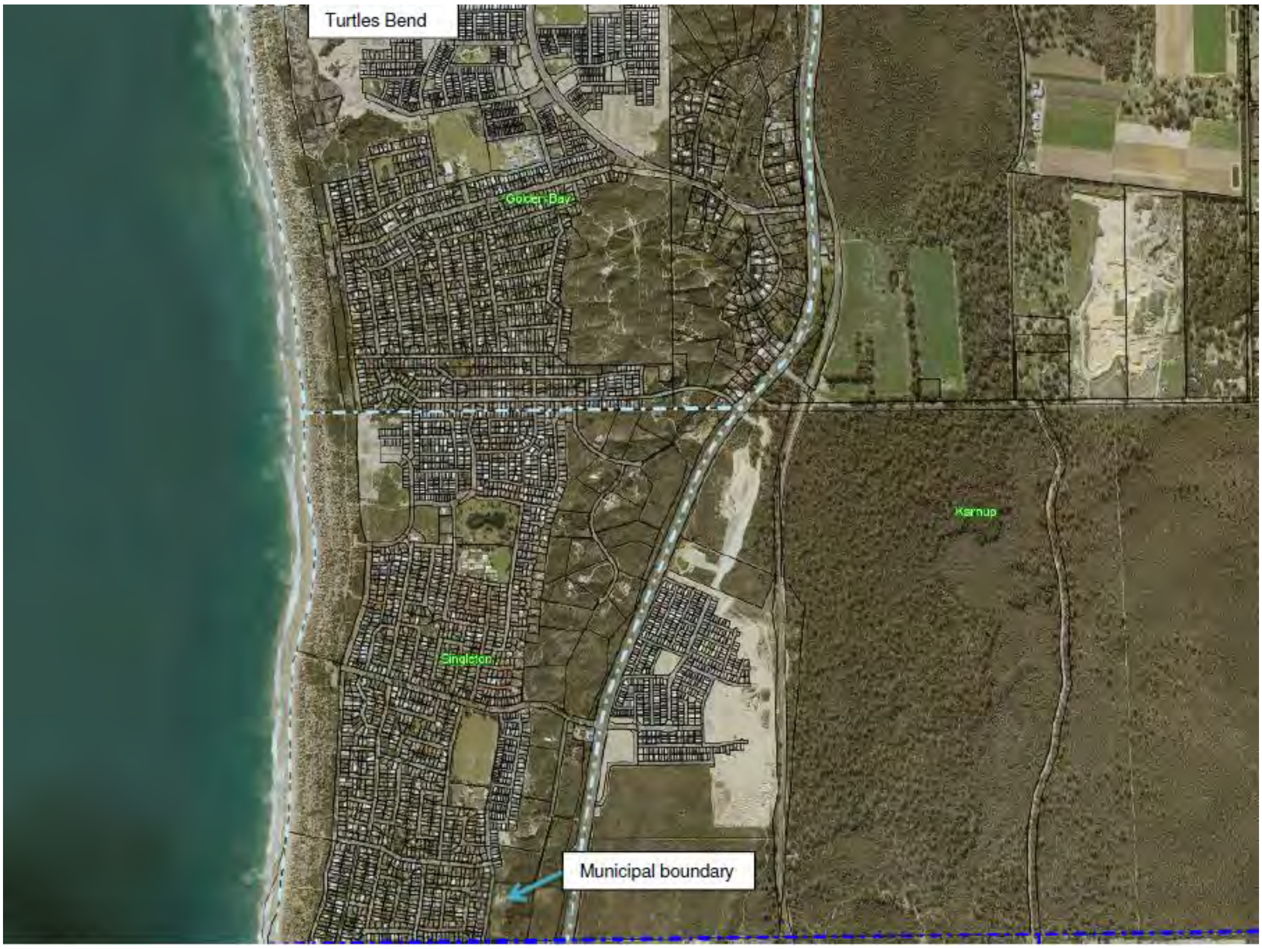

Figure 2-6 Sector 6: Turtles Bend, Secret Harbour to City of Rockingham Boundary

Figure 2-7 Sub-sector 2.1 within Sector 2

Figure 2-8 Sub-sectors 2.2 and 2.3 within Sector 2

Figure 2-9 Sub-sectors 2.4, 2.5 and 2.6 within Sector 2

Figure 2-10 Sub-sector 2.7 within Sector 2

3 Storm Surge Inundation Assessment (S4)

3.1 Modelling Approach

As described in **Section 2.3**, the area in which the City is located required the consideration of a 500-year ARI tropical cyclone storm event for coastal inundation as per SPP2.6. Tropical cyclones are very rare in the Rockingham area so there is minimal measured data available. Unfortunately, this means there is insufficient data to undertake a Monte-Carlo-type study for tropical cyclones in this area.

In order to estimate the 1, 10, 50, 100 and 500-year ARI coastal inundation levels across the study area based on available data, an Extreme Value Analysis (EVA) of the measured water level records from three different tide gauges was undertaken (Fremantle Fishing Boat Harbour, Mangles Bay and Mandurah (two locations). This analysis provided estimates of the extreme water levels for the different ARIs at each of the tide gauge locations. In addition to this, allowances for nearshore wave setup and future SLR were added to provide an estimate of the total still water level for each of the ARIs (1, 10, 50, 100 and 500) and planning timeframes (2017, 2030, 2070 and 2110). The resulting total still water levels were mapped across the study area using a combination of available survey and LiDAR data.

The analysis undertaken and the application of the coastal inundation levels are described in more detail in the following sub-sections.

3.2 Water Level Design Criteria

3.2.1 Measured Water Levels Analysis

In order to estimate the 1, 10, 50, 100 and 500-year ARI coastal inundation levels across the study area using the available data, an EVA of the measured water level data from three different tide gauges was undertaken as part of this study. The three tide gauges were Fremantle Fishing Boat Harbour (approximately 20km north of the study area), Mangles Bay (located within the study area just east of the Garden Island Causeway) and Mandurah (comprises two locations which are located approximately 9km south of the study area) which are all managed by the Department of Transport (DoT).

The measured water level records for the three locations were converted from their respective Chart Datums to Australian Height Datum (AHD) as per datum and benchmark information provided by DoT.

3.2.1.1 Fremantle Fishing Boat Harbour Tide Gauge

The tide gauge at Fremantle Fishing Boat Harbour is located approximately 20km north of the northern boundary of the study area. The measured water level record at Fremantle is one of the longest in Western Australia and is still operating, however DoT advised that the quality of the data recorded before 19/11/1986 cannot be assured. Accordingly, the measured water level record from 19/11/1986 to 30/09/2017 was analysed as part of this study, which represents a period of nearly 31 years and is essentially continuous with only a small gap in the record in mid-1987.

3.2.1.2 Mangles Bay Tide Gauge

The Mangles Bay tide gauge is the only tide gauge that is located within the study area, however it is an historical station that is no longer active. The period of record available from this location from DoT is 15/05/1991 to 31/12/2009 that is a period of approximately 18.5 years. The measured water level record is mostly continuous with three significant gaps in the record in 1998, 2003 and 2007.

3.2.1.3 Mandurah Tide Gauges

DoT has operated tide gauges at two different locations in Mandurah. The first was located at Fisherman's Jetty from 29/11/1990 to 07/02/2007 and the second has been located at Ocean Marina since 21/02/2007 and is still operating. The measured water level records from these two locations (which are less than 1km apart) were combined and converted to AHD using datum and benchmark information supplied by DoT.

Analysis of the combined measured water level record indicated a questionable period of data in 2007. This has been referred to DoT for further analysis and resolution. Due to this questionable period of data the tidal record from Mandurah was not considered further in this study but should be considered in future revisions to this CHRMAP once DoT has analysed the questionable period of data and provided a resolution.

3.2.2 Sea Level Rise

It is widely recognized in the scientific community that climate change is occurring, and as a result, its possible effects must be considered when planning for the future. For the Rockingham coast, the projected effects will most likely be an increase in mean sea level.

The measured water level record for each of the tidal gauges was modified to remove the historical sea level rise that is estimated to have occurred over the length of each record by applying a rate of 2mm/year. This was done such that the measured water level record was made relative to the end date of the record so that the levels from the EVA are relative to the present day.

In order to estimate the total still water levels for the future planning timeframes of 2030, 2070 and 2110, the future SLR estimates detailed in **Section 2.4** were incorporated into the values presented in **Section 3.2.5**.

3.2.3 Extreme Value Analysis

For both the Fremantle and Mangles Bay measured water level records, an extreme value analysis was conducted to provide an estimate of extreme water levels at each location. An EVA was conducted on the top 50, 40 and 30% of measured water levels above 0m AHD, with the values using the 40% threshold ultimately adopted. A 72-hour constraint (1.5 days either side of a peak water level) was applied to ensure all observations used in the EVA were independent. A Weibull EVA was conducted for each location and the results are presented in **Table 3-1** below.

Table 3-1 ARI Extreme Water Levels at Fremantle and Mangles Bay from EVA Analysis

ARI (years)	Extreme Water Level at Fremantle (m AHD)	95% Confidence Interval	Extreme Water Level at Mangles Bay (m AHD)	95% Confidence Interval
1	0.96	0.94 – 0.99	0.84	0.81 – 0.87
10	1.17	1.10 – 1.23	1.01	0.97 – 1.06
50	1.29	1.19 – 1.39	1.12	1.05 – 1.19
100	1.34	1.22 – 1.46	1.16	1.09 – 1.24
500	1.45	1.29 – 1.61	1.26	1.16 – 1.36

Based on a combination of the longer period of record providing greater confidence in the extrapolated results and as a conservative approach, the extreme water levels at Fremantle were adopted.

3.2.4 Wave Setup Allowance

Wave set-up is the increase in ocean water level near to the coast due to wave breaking and the onshore conservation of momentum flux. It is particularly important during extreme events where strong winds can generate large waves. The tide gauges which were analysed to get extreme water levels are located in protected locations (such as inside a harbour or marina) and so it is not expected that the measured water level records will include nearshore wave setup which occurs close to shore due to wave breaking. Thus, it is appropriate and conservative to include an additional allowance for nearshore wave setup on top of the extreme water levels in **Section 3.2.3**.

The results of the SBEACH modelling completed in this study for the 28 profiles spread across the study area (described in **Section 4.2.2**) were analysed to determine an estimate for nearshore wave setup at each profile location. Based on the spatial variation in these nearshore wave setup estimates, the study area was split into two areas with a different wave setup value adopted in each area. The division between the two areas was at Cape Peron, with one value applied east of this point and another south of this point. This division was based on the spatial variation in the nearshore wave setup estimates that clearly showed a greater degree of sheltering to the east of Cape Peron, consistent with the broad level of detail of a CHRMAP. The location of the division is shown in **Figure 3-1**. The wave setup values adopted are presented in **Table 3-2**.

Figure 3-1 Location of division point between the two wave setup areas (Background image: Nearmap)

Table 3-2 Wave setup values adopted in inundation assessment

ARI (years)	Wave setup applied east of Cape Peron (m)	Wave setup applied south of Cape Peron (m)
1	0.43	0.72
10	0.52	0.87
50	0.58	0.96
100	0.60	1.00
500	0.65	1.08

3.2.5 Water Level Design Criteria

The total still water levels for storm surge (S4) inundation adopted for this CHRMAP study, which combine extreme water level, nearshore wave setup and future sea level rise, are presented in the following tables for the different planning timeframes. Note that these levels do not include an allowance for the potential effects of wave run-up, which may need to be considered for assets and infrastructure located close to the back of the beach face. Wave run-up is defined in SPP2.6 as being the rush of water up a shoreline (or structure) on the breaking of a wave. It is thus only relevant on or immediately behind a beach (or structure) face upon which waves break, where wave run-up might cause water to rush up far enough to inundate an asset or infrastructure located close to the beach (or structure) face.

It should be noted that these coastal inundation levels are deliberately conservative, as per the approach of SPP2.6. The use of estimated extreme water levels from Fremantle (rather than the lower levels estimated from the historical Mangles Bay data) and the inclusion of a conservative estimate of wave setup result in coastal inundation levels for lower ARI events (e.g. 1 and 10-year ARI) which may not necessarily have been observed in recent history. These conservative levels are considered appropriate for a CHRMAP given that the purpose is for future planning and is consistent with the precautionary and conservative approach required in SPP2.6.

Table 3-3 S4 Storm Surge Inundation Levels for Present Day (2017)

ARI (years)	1	10	50	100	500
Extreme Water Level at Fremantle	0.96	1.17	1.29	1.34	1.45
Allowance for Wave Setup East of Cape Peron	0.43	0.52	0.58	0.60	0.65
Total Still Water Level East of Cape Peron (m AHD)	**1.39**	**1.69**	**1.87**	**1.94**	**2.10**
Extreme Water Level at Fremantle	0.96	1.17	1.29	1.34	1.45
Allowance for Wave Setup South of Cape Peron	0.72	0.87	0.96	1.00	1.08
Total Still Water Level South of Cape Peron (m AHD)	**1.68**	**2.01**	**2.25**	**2.34**	**2.53**

Table 3-4 S4 Storm Surge Inundation Levels for 2030

ARI (years)	1	10	50	100	500
Extreme Water Level at Fremantle	0.96	1.17	1.29	1.34	1.45
Allowance for Wave Setup East of Cape Peron	0.43	0.52	0.58	0.60	0.65
Allowance for Sea Level Rise	0.05	0.05	0.05	0.05	0.05
Total Still Water Level East of Cape Peron (m AHD)	**1.44**	**1.74**	**1.87**	**1.94**	**2.10**
Extreme Water Level at Fremantle	0.96	1.17	1.29	1.34	1.45
Allowance for Wave Setup South of Cape Peron	0.72	0.87	0.96	1.00	1.08
Allowance for Sea Level Rise	0.05	0.05	0.05	0.05	0.05
Total Still Water Level South of Cape Peron (m AHD)	**1.73**	**2.09**	**2.25**	**2.34**	**2.53**

Table 3-5 S4 Storm Surge Inundation Levels for 2070

ARI (years)	1	10	50	100	500
Extreme Water Level at Fremantle	0.96	1.17	1.29	1.34	1.45
Allowance for Wave Setup East of Cape Peron	0.43	0.52	0.58	0.60	0.65
Allowance for Sea Level Rise	0.38	0.38	0.38	0.38	0.38
Total Still Water Level East of Cape Peron (m AHD)	**1.77**	**2.07**	**2.25**	**2.32**	**2.48**
Extreme Water Level at Fremantle	0.96	1.17	1.29	1.34	1.45
Allowance for Wave Setup South of Cape Peron	0.72	0.87	0.96	1.00	1.08
Allowance for Sea Level Rise	0.38	0.38	0.38	0.38	0.38
Total Still Water Level South of Cape Peron (m AHD)	**2.06**	**2.42**	**2.63**	**2.72**	**2.91**

Table 3-6 S4 Storm Surge Inundation Levels for 2110

ARI (years)	1	10	50	100	500
Extreme Water Level at Fremantle	0.96	1.17	1.29	1.34	1.45
Allowance for Wave Setup East of Cape Peron	0.43	0.52	0.58	0.60	0.65
Allowance for Sea Level Rise	0.9	0.9	0.9	0.9	0.9
Total Still Water Level East of Cape Peron (m AHD)	**2.29**	**2.59**	**2.77**	**2.84**	**3.00**
Extreme Water Level at Fremantle	0.96	1.17	1.29	1.34	1.45
Allowance for Wave Setup South of Cape Peron	0.72	0.87	0.96	1.00	1.08
Allowance for Sea Level Rise	0.9	0.9	0.9	0.9	0.9
Total Still Water Level South of Cape Peron (m AHD)	**2.58**	**2.94**	**3.15**	**3.24**	**3.43**

3.3 Storm Surge Inundation Mapping

The spatial extent of coastal inundation caused by the storm surge inundation levels presented in the previous section were mapped for each planning timeframe using a bathtub modelling approach. It should be noted that only areas which were connected to the ocean via a flow path were included in the coastal inundation mapping. In addition, where a barrier dune was located between the ocean and an area which is below a particular inundation level, the approach set out in SPP2.6 was adopted which requires the dune to be assumed to be eroded (and thus ignored for the purposes of inundation mapping) where the cross-sectional volume of the barrier dune above a given inundation level is less than 100 m^3. The topographical DEM used to map the inundation extents was a composite surface comprised of all the area datasets listed in **Section 2.5**. It should be noted that the beach profile data was not incorporated into this DEM where it was not of sufficient spatial resolution to adequately interpolate between the profiles. As a result, large areas of the DEM are comprised entirely of LiDAR data from 2008 and 2009, including some areas where it is known that the coastline has significantly changed since those surveys. These areas are described in greater detail in **Section 4.6**. As the mapping of the inundation hazards was based on the best available survey data, the quality of the inundation mapping in these areas is lower than in the areas that have either not changed significantly since the LiDAR data was captured or more recent, detailed survey data was available. The variation in the quality of the inundation mapping largely depends on how much the coastline has changed since the best available survey data for that area was captured, which varies across the study area.

It is recommended that additional detailed area survey data, particularly of the areas that have changed significantly since the best available detailed area survey data was captured, is captured prior to the next revision of the City's CHRMAP to improve the quality of the mapping of coastal inundation risks.

Maps of the inundation for the four planning timeframes and three ARI levels, separated into the six sectors of the study area, are presented in **Appendix B**.

3.4 Depth and Duration of Inundation Mapping

In addition to the spatial extent of inundation, the depth of inundation as well as an estimate of the duration of inundation were calculated and spatially mapped. The depth of inundation was calculated by subtraction between the total still water level and the DEM. The duration of inundation was estimated by applying the water level time series for the S1 design storm provided by DoT (110 hours in duration) and adding a triangular surge component (which incorporated SLR for future timeframes) so that the peak water level reached the required level for each ARI/timeframe combination. The resulting water level timeseries was analysed to determine the duration at 0.1m elevation increments, this information was then used to spatially map the duration of inundation based on the DEM created for the study (**Section 2.5**). This estimate of the duration of inundation is an indicative estimate presented for information only and is not comparable to a flooding and drainage study as it does not include consideration of drainage, rainfall or stormwater flow, which is beyond the scope of this CHRMAP.

Spatial maps of the depth and estimated duration of inundation for the 500-year ARI event for each of the four planning timeframes in each sector are also included in **Appendix B**.

3.5 Assets at Risk from Coastal Inundation

The results of the inundation analysis indicate that the following assets (**Table 3-7**) are potentially at risk of coastal inundation over the planning timeframe.

Table 3-7 Assets at Risk from Coastal Inundation (extent of impact is for 500-year ARI event in 2110)

Sector	Assets at Risk	Extent of Impact
1	Beach	3.1 km
	Coastal/Dune Vegetation	
	Rockingham Foreshore Park	6,095 m^2
	Road – Rockingham Beach Rd	0.17 km

Sector	Assets at Risk		Extent of Impact
2	Beach		7.5 km
	Coastal/Dune Vegetation		
	DBCA-managed land at Point Peron		159,520 m^2
	Parks & Recreation Areas		96,460 m^2
	Boat Ramps (Catalpa Park)		
	Mangles Bay Fishing Club		46,680 m^2
	Rockingham Naval Club		1,025 m^2
	Point Peron Camp School		23,015 m^2
	Point Peron WWTP		
	Alfred Hines Seaside Home		12,105 m^2
	Residential Properties		985
	Roads		23.4 km
	Jetty Abutments (Val St and Fisher St)		
	Bell Park Carpark		2,140 m^2
	Samuel Street Carpark		440 m^2
	Catalpa Park Carpark		5,965 m^2
	Point Peron Boat Ramp Carpark		13,905 m^2
	Dual Use Path		10.0 km
	Department of Defence Land		15,405 m^2
3	Beach		7.4 km
	Coastal/Dune Vegetation		
	Parks & Recreation Areas		404,800 m^2
	Safety Bay Tennis Club		13,920 m^2
	Safety Bay Yacht Club		520 m^2
	Safety Bay Primary School		28,435 m^2
	Rockingham Wild Encounters (Mersey Point)		2,020 m^2
	Residential Properties		3,578
	Dual Use Path		27.5 km
	Roads		45.1 km
	Mersey Point Carpark		3,650 m^2
	Safety Bay Foreshore Carparks (6)	Carlisle St Watts Rd Safety Bay Yacht Club Waimea Rd Bent St Between June Rd and Donald Dr	7,395 m^2
4	Beach		6.4 km
	Coastal/Dune Vegetation		

Sector	Assets at Risk	Extent of Impact
	Port Kennedy Scientific Park	663,590 m^2
	Port Kennedy Boat Ramp	
	The Links Kennedy Bay Golf Course	14,865 m^2
	Residential Properties	28
	Roads	1.7 km
	Port Kennedy Foreshore Carpark	10,595 m^2
	Dual Use Path	2.1 km
5	Beach	6.1 km
	Coastal/Dune Vegetation	
	Port Kennedy Scientific Park	766,870 m^2
6	Beach	4.4 km
	Coastal/Dune Vegetation	

4 Shoreline Stability Assessment

4.1 Study Site Description

4.1.1 Geomorphological Setting

The coastline within the City that is included in the study area for this CHRMAP comprised approximately 35km pf coastline (note, Garden Island and Penguin Island were excluded). Using the sediment cells defined by Stul et al (2015), this length of coastline includes large areas of two primary sediment cells (R06C and R06D) and a small section of a third (R06E). Within these primary sediment cells, this coastline includes five entire secondary sediment cells (10 – 13 and 15) and parts of another three (10, 14 and 17) at the boundary of the study area and adjacent to Garden Island (Stul et al 2015). Within these secondary sediment cells, this coastline includes all of eight tertiary sediment cells and parts of another three at the boundary and adjacent to Garden Island (Stul et al 2015). It is worth noting that of the secondary sediment cells located within the study area, only secondary sediment cell 14 is separated into more than one tertiary sediment cell. Tertiary sediment cells are employed as a method of grouping sections of coastline within which the sediment movement is mostly constrained.

The 1:50,000 scale Geological Survey of Western Australia map of Rockingham shows that the vast majority of the study area is made up of Calcareous Sand – white, either fine to medium or medium-grained, sub-rounded or rounded quartz and shell debris, well sorted, of eolian (wind-blown) origin. Exception to this is the area around Cape Peron which contains some areas of Limestone (which are clearly visible on aerial imagery). In terms of geomorphological classification, the vast majority of the coastline and hinterland comprises relic foredune of high level from the Holocene. Exceptions to this are the area around Cape Peron (parabolic and nested parabolic dunes, Quindalup Dunes), the coastline of the first bay north of Mersey Point (Relic foredune of low level from the Holocene), most of the coastline of Warnbro Sound (also parabolic and nested parabolic dunes, Quindalup Dunes) and the coastline between Secret Harbour and Singleton (also relic foredune of low level from the Holocene).

4.1.1.1 Sediment Sampling

No Particle Size Distribution (PSD) results from sediment sampling were available within the study area. In order to fill this data gap, City staff undertook estimation of the sediment grain size at 31 locations across the study area (selected by Cardno) using sediment sizing cards. The estimates of sediment grain size are presented in **Table 4-1**.

Table 4-1 Preliminary sediment sizing undertaken as part of this study

Sample Name	Easting (MGA50)	Northing (MGA50)	Sediment size range (microns)
1	382669	6430868	250-350
2	382386	6430513	350-500
3	381926	6429985	710-1000
4	381477	6429395	350-500
5	381086	6429017	350-500
6	380509	6428519	350-500
7	379836	6428192	1000-1410
8	379320	6428229	710-1000
9	378899	6428325	350-500
10	378175	6428251	350-500
11	377600	6428452	250-350
12	376820	6428976	710-1000
13	376557	6429124	250-350

Sample Name	Easting (MGA50)	Northing (MGA50)	Sediment size range (microns)
14	376298	6428972	1000-1410
15	376481	6428659	1000-1410
16	376898	6428649	350-500
17	377542	6427917	500-510
18	377846	6426932	500-710
19	377913	6425829	177-250
20	377757	6425231	350-500
21	377816	6424994	250-350
22	378685	6424904	350-500
23	379188	6424577	350-500
24	379338	6424891	710-1000
25	379947	6424683	500-710
26	381096	6423843	350-500
27	381793	6421487	177-250
28	380559	6418301	250-350
29	380378	6416344	177-250
30	382029	6413474	350-500
31	382459	6410169	500-700

4.2 S1 Erosion: Allowance for the Current Risk of Storm 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).

4.2.1 Selection of Storm Event

As discussed in **Section 2.2**, SPP2.6 stipulates that a mid-latitude depression or extra-tropical low storm event corresponding to the 100-year ARI ocean forces and coastal processes should be selected for the simulation of erosion, tracking to maximise its erosion potential.

The DoT provided a synthetic time-series of wave and water level conditions which it has developed for the simulation of S1 erosion in southwest Western Australia as required under SPP2.6. This synthetic design storm was created after considered analysis of actual events recorded at the Rottnest Island Wave Buoy location which is in approximately 50m of water and located roughly 10km SW of Rottnest Island, offshore of the study area.

4.2.2 Storm Erosion Simulation

4.2.2.1 Simulation of Offshore Waves to Nearshore

The S1 design storm provided by DoT was simulated from offshore into the nearshore areas of the study area using the SWAN wave model. Wind was applied to the model from the Rottnest wind record to ensure nearshore waves were fully represented by the model

Five nested grids were utilised to simulate the offshore conditions into the nearshore. These five grids are shown in **Figure 4-1**.

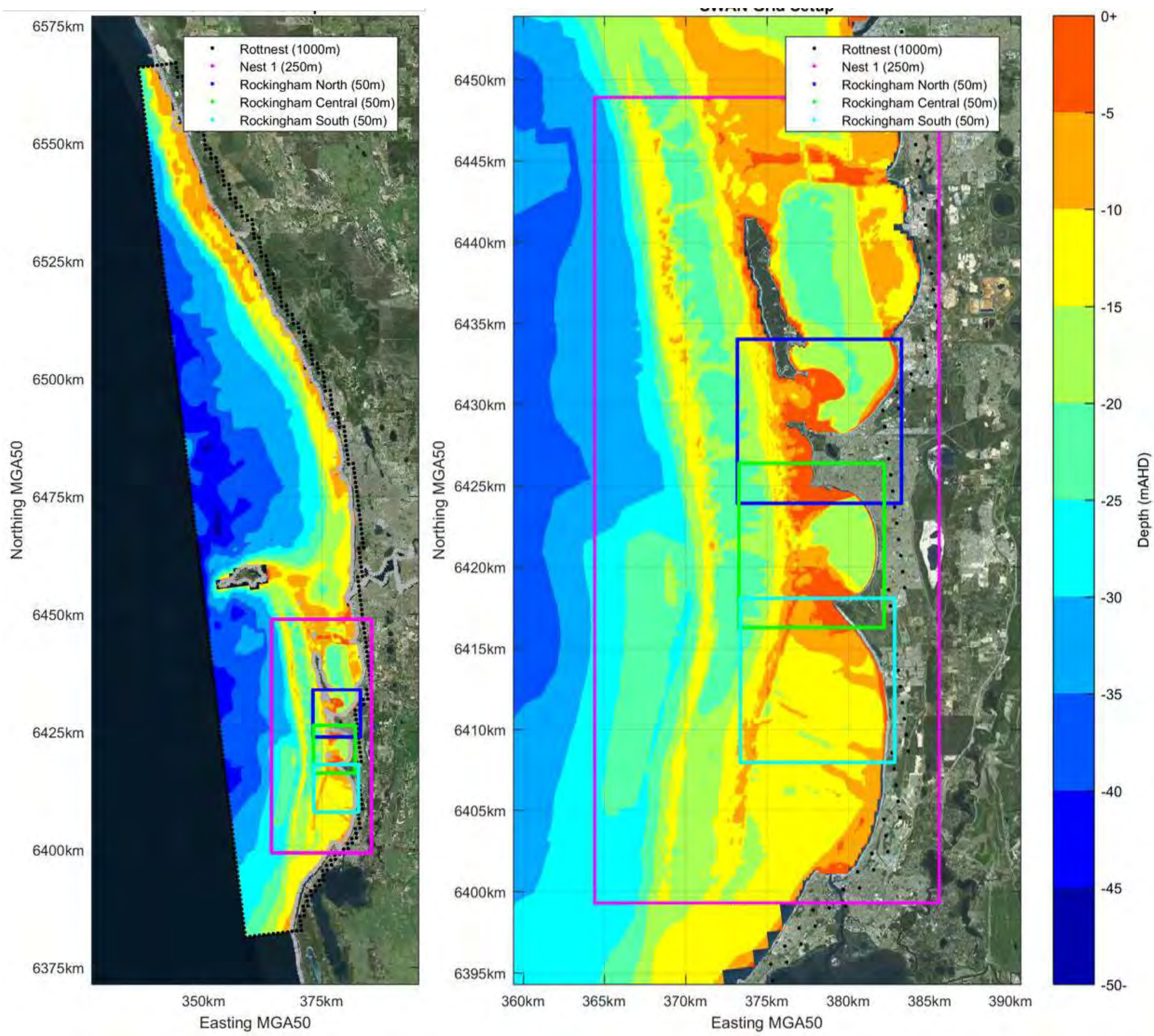

Figure 4-1 SWAN model setup. Regional scale (left), and zoomed to the Rockingham LGA (right)

As a conservative approach, the offshore S1 design storm was simulated with seven different offshore wave directions (SSW clockwise through to NNW) and the simulation that resulted in the largest significant wave height at the seaward end of each of the SBEACH profiles was applied for each profile.

4.2.2.2 Simulation of Storm Erosion of Beach Profiles

A total of 28 shore-normal beach profiles were applied in the simulation of S1 storm erosion. The location and length of each profile was based on an assessment of the study area, sediment cells, beach topography and nearshore bathymetry and the availability of detailed survey data. The locations of the 28 SBEACH profiles are shown in **Figure 4-2** to **Figure 4-5**.

Figure 4-2 SBEACH Profiles 1-8

Figure 4-3 SBEACH Profiles 9-17

Figure 4-4 SBEACH Profiles 18-23

Figure 4-5 SBEACH Profiles 24-26 (left) and 27-28 (right)

As mentioned in **Section 4.2.2.1**, the wave and water level conditions applied to each of the SBEACH profiles were from the SWAN simulations. As per the requirements of SPP2.6, the storm time series was applied to each profile three times in succession. The storm was applied as being perpendicular to the coast at each profile, which is a conservative, however not unrealistic, assumption. The results of the SBEACH simulation for each profile were analysed in order to determine the HSD elevation and the S1 storm erosion allowance for each profile as per SPP2.6. Plots showing the results of the SBEACH simulation for each profile are presented in **Appendix C**.

The SBEACH simulations for all of the profiles for which relatively large sediment sizes were estimated (see **Section 4.1.1.1**) showed minimal or no erosion along the profile during the SBEACH simulation. A sensitivity analysis was undertaken for these profiles by applying a range of smaller sediment sizes. The results of this sensitivity analysis showed significant larger amounts of storm erosion for smaller (but not unreasonably small) sediment sizes. As a conservative approach that aligns with the intent of SPP2.6, the results from SBEACH that applied the largest sediment size that still gave a plausible storm erosion value were selected.

It can be seen from the historical aerial photography that the Tern Island sandbar is a highly dynamic coastal feature. The current shape and extent of this sandbar has changed dramatically over recent decades (it has grown dramatically since 2000). There is anecdotal evidence that this feature has formed, disappeared and re-formed multiple times since the first recorded observations of the area. To account for the dynamic and uncertain nature of this feature, a conservative approach was adopted for the stretch of coast around the Tern Island sandbar with regard to storm erosion. The results for the SBEACH profiles on either side of the sandbar were applied to the area where the sandbar is presently. This means the results are conservative for the current shape and location of the sandbar but account for the possible disappearance of the sandbar over the 100-year planning timeframe. This is a prudent approach in line with the intent of SPP2.6.

4.2.3 S1 Storm Erosion Allowances

Based on the results of the SBEACH simulations described in **Section 4.2.2.2**, the following HSD elevations and S1 storm erosion allowances were adopted in accordance with SPP2.6.

Table 4-2 HSD elevations and S1 storm erosion allowances for each of the profiles in the study area

Profile Number	HSD Elevation (m AHD)	S1 Storm Erosion Allowance (m)
1	1.75	20
2	1.78	17
3	1.68	8
4	1.73	12
5	1.75	16
6	1.72	12
7	1.70	9
8	1.69	13
9	1.55	4
10	1.90	5
11	1.95	13
12	1.93	29
13	2.75	41
14	2.31	27
15	1.98	8
16	2.20	4
17	2.21	15
18	1.86	39

Profile Number	HSD Elevation (m AHD)	S1 Storm Erosion Allowance (m)
19	1.93	8
20	1.90	18
21	1.76	4
22	1.86	7
23	2.12	15
24	2.30	23
25	1.78	61
26	1.80	20
27	2.01	24
28	2.28	16

4.3 S2 Erosion: Allowance for Historic Shoreline Movement Trends

An analysis of historical vegetation lines based on aerial photography was undertaken in order to estimate the historical shoreline movement trends and thus an appropriate S2 allowance, in line with the requirements of SPP2.6. This analysis method assumes the vegetation line is a valid proxy for the shoreline.

4.3.1 Analysis of Historical Shoreline Movement

The DoT provided shapefiles of analysed vegetation lines based on historical aerial imagery for the following years: 1942, 1955, 1964, 1965, 1976, 1979, 1980, 1981, 1985, 1987, 1988, 1989, 1990, 1993, 1994, 1996, 1998, 2000, 2003, 2004, 2006, 2008, 2009 and 2016. The analysed vegetation line for each year covered varying proportions of the study area; some years covered the entire study area while many others covered only small sections. The position of the vegetation line for all of the years for which data was provided was analysed at 100m intervals along the length of the study area.

Based on an analysis of the spatial coverage of each vegetation line and the time period between the different lines, the vegetation lines from the following years were selected for detailed analysis: 1942, 1965, 1976, 1985, 1989, 1990, 2000 and 2016. These years were selected as they had the greatest coverage of the study area and they were spaced over the time period between the oldest and most recent years.

The change in shoreline position between each of the selected years and 2016 was analysed at each 100m interval along the length of the study area to estimate the long term average shoreline movement rate over each time period. As a secondary check, the change in shoreline position between each of the sequential years was also analysed to see how the average rate of shoreline change has changed between the different intervals.

For the Tern Island sandbar, the sandbar was only included in the historical shoreline movement trends when it was joined to the coast with no water in between i.e. the parts of the sandbar where there was water in between it and the coast (either because the whole sandbar was separated from the coast or, like it is presently, it is joined to the coast at one end) were excluded from the S2 analysis.

4.3.2 Historical Coastal Structures and Sand Nourishment

The analysis of the long term shoreline movement rates in the study area is complicated by two factors, the number of coastal structures that have been built along this coastline and the significant amount of sand nourishment that has been undertaken.

4.3.2.1 Coastal Structures

The coastal structures that have been constructed along the study area coastline and the year of construction/major modification is listed in **Table 4-3**. Some of these structures have led to significant long-term changes in the coastline and analysis of historical vegetation line changes suggests the coastline is still adjusting to the presence of many of these structures. The structure that has resulted in the most drastic changes is the Garden Island Causeway and the associated groynes that have dramatically changed the coastline in the area, particularly to the west of the Causeway. The analysis of historical shoreline movement trends in order to estimate an S2 erosion allowance ignored large changes in shoreline due to the construction of coastal structures that are unlikely to continue over the medium-long term.

Table 4-3 Coastal Structures constructed along the Rockingham coastline

Sector	Year	Structure
1	2007	2 Offshore Breakwaters
2.1	1950s (uncertain)	Palm Beach Jetty constructed
		Val St Jetty constructed
	2002	Palm Beach West Boat Ramp
	2002	Hymus St Timber Groyne
	2004	Rockingham Foreshore - GSC Seawall
	2007	Val St Jetty extended 40m
	2014	Val St Jetty 0-80m reconstructed
	2009	Palm Beach Jetty
	2010	Palm Beach East Boat Ramp
	Sept-Oct 2017	Palm Beach East Boat Ramp Rock Armour modified
		Palm Beach West Boat Ramp Rock Armour modified
2.1/2.2	1971	Garden Island Causeway
2.2	1973	200m groyne to west of Garden Island Causeway
	1986	65m long 90° groyne extension to west of Garden Island Causeway
	1987	Informal rock seawall west of camp school
	1990	Spur added to groyne west of Garden Island Causeway for sand trap
	2013	GSC Groyne at camp school
3	2003	South Mersey Point Rock Seawall (200m long)
	2004	Bent St Boat Ramp
	2010	Waikiki Rock Seawall
	2015	Bent St Boat Ramp Rock Armour modified
4	2010	Port Kennedy Boat Ramp

4.3.2.2 Sand Nourishment

The City has a unique situation relating to sand nourishment. The Point Peron Boating Facility, which is located immediately west of the Garden Island Causeway, is vulnerable to sedimentation as a result of sediment being transported in an easterly direction along the stretch of coast between Cape Peron and the facility. The rock sand trap that was constructed at the entrance to the facility in 1990 was constructed to help slow the sedimentation of the entrance to the facility and the regular removal of sediment from the sand trap is required to keep the facility in operational condition. The City regularly undertakes this removal of sediment from the sand trap and stockpiles it. For many years, the City has utilised this sediment source to undertake sand nourishment in areas experiencing erosion along its coastline. The City holds good records for nourishment volumes going back to 2008 but it is estimated that removal of sand from the sand trap has been occurring going back to at least 2000 (DoT 2009). DoT (2009) estimated approximate sand volumes which were removed from the sand trap based on discussions with the City, the then Department of Conservation (DEC) and M Radonich and Sons Contractors. These volumes are presented in **Table 4-4**.

Table 4-4 Estimated volumes of sand excavated from Sand Trap at Point Peron Boating Facility (DoT 2009)

Year	Excavated Volumes (m^3)
2000-2004	~44,000
2004	~7,000 – 10,000
2005	Unknown
2006	~10,000
2007	~10,000
2008	~10,000
2009 (to time of report)	~5,000

The City provided records of sand nourishment volumes that have been placed along its coastline since 2008. These volumes, separated into the six sectors of the study area, are presented in **Table 4-5**. The average volume of nourishment undertaken is approximately 9,600 m^3 per annum though there have been multiple instances of placement of larger volumes.

Table 4-5 Sand nourishment volumes placed by the City of Rockingham since 2008

Sector	Area	Nourishment Location	Date	Volume (m^3)
1	Kwinana Beach Headlands	-	16/06/2008	6,600
		-	20/02/2012	13,500
	Victoria Street	Beach Access Dune	Nov 2012	1,000
			Jan 2013	1,000
2.1	Rockingham Foreshore	Railway - Wanliss	Jan 2010	1,000
			June 2011	4,000
			Aug 2012	4,000
			Aug 2014	2,000
	Palm Beach Foreshore	Vista Ave/Bell St	06/07/2011	4,500
	Hymus St Foreshore	Corner of Hymus St and The Esplanade	08/04/2010	1,500
			20/05/2011	1,500
			05/07/2011	1,500
	Mangles Bay	Mangles Bay Fishing Club	01/01/2015	400
			12/08/2015	200
2.2	Point Peron	West of Camp School	12/03/2013	1,000
			31/03/2014	4,500
		West Compartment (GSC Groyne)	21/05/2013	15,000
2.7	Point Peron	Former Apex Camp	22/06/2015	5,000
			11/08/2015	800
		South-facing beach opposite WWTP	01/05/2016	11,000
3	Waikiki Foreshore	Malibu Rd to SE corner Warnbro Beach Rd	Apr 2009	3,000
			Jun 2010	6,000
			Dec 2012	2,000
		Donald Dr Boat Ramp to Warnbro Beach Rd	Nov 2014	5,000
		Donald Dr Boat Ramp to Malibu Road	Mar 2017	11,500

Sector	Area	Nourishment Location	Date	Volume (m^3)
	Warnbro Foreshore	Michael Rd Carpark (foredune adjacent to carpark)	Mar 2009	2,000
		Michael Rd/View St	14/06/2010	10,000
		View St Carpark (Warnbro Beach Rd, adjacent to View St)	Mar 2009	1,000
		View St Carpark (Warnbro Beach Rd, adjacent to View St)	Jul 2009	2,000
		View St Carpark (Warnbro Beach Rd, adjacent to View St)	Oct 2013	1,000
			TOTAL VOLUME	**123,500**

It is difficult to estimate the effect that the historical sand nourishment has had on the observed historical shoreline movement trends. The risk is, if sand nourishment has had a significant effect on the observed shoreline movement trends, simply analysing the observed trends will result in S2 erosion allowances which are less conservative (i.e. lower erosion or greater accretion) than natural trends. As most of the sand nourishment for which there are good records is post-2008, this recorded sand nourishment can only have influenced the most recent vegetation line which was analysed in detail (2016). The potential influence of this sand nourishment on the observed shoreline movement trends was factored into the selection of the S2 erosion allowances.

4.3.3 S2 Historical Shoreline Movement Allowances

The historical average shoreline movement rate between each of the historical years and 2016 measured at 100m intervals along the coastline of the study area is presented in **Figure 4-6**. The x value in **Figure 4-6** is the approximate chainage along the coastline from the northern boundary of the study area. The divisions between the different sectors of the study area are also shown as well as labels of areas of significant erosion or accretion.

As can be seen in the figure, there are multiple areas along the coastline within the study area which have experienced dramatic average rates of change over different time intervals, both of erosion and accretion. Some of these areas of large rates of change are associated with coastal features such as salients which can be highly dynamic, such as the Tern Island Sandbar and Becher Point, which can be misleading without the appropriate context.

Based on analysis of the average rates of shoreline change across the study area, an S2 rate of yearly shoreline movement was decided. The selection of this rate took into account the coastal structures that have been constructed along the coastline as well as the known sand nourishment that has been undertaken. As a conservative approach and in line with the recommendations of SPP2.6, the S2 erosion allowance was selected as zero for all areas where long-term accretion has been observed.

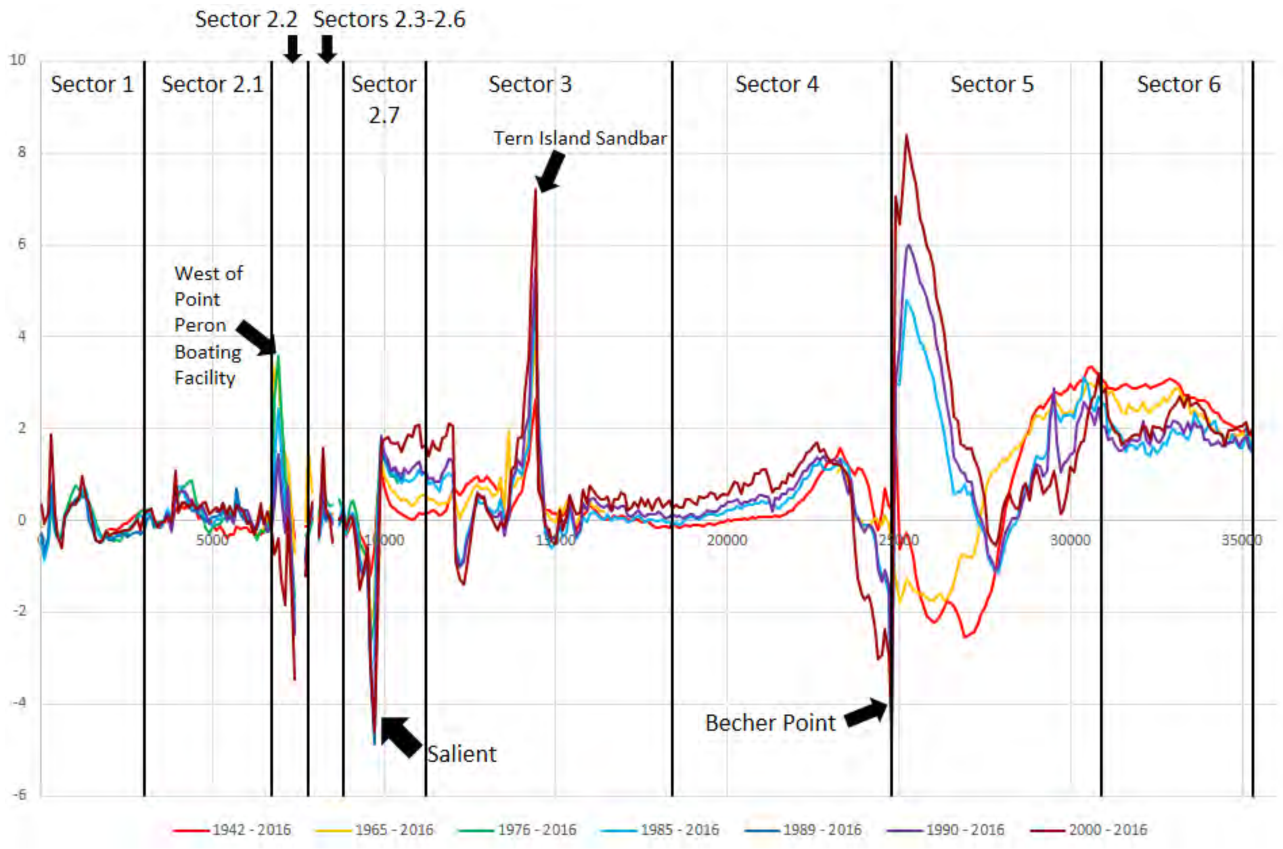

Figure 4-6 Average shoreline movement rate (m/year) between different years and 2016 (Negative values indicate erosion) over entire study area coastline

The S2 erosion allowance determined at each 100m chainage for each of the future planning timeframes is presented as part of the table in **Appendix E**.

4.4 S3 Erosion: Allowance for Erosion Caused by Future Sea Level Rise

In line with the requirements of SPP2.6, for the 2110 planning timeframe an S3 erosion allowance for erosion caused by future sea level rise of 90m (100 times the adopted sea level rise value of 0.9m) was adopted across the study area with the exception of a couple of areas of rocky shoreline around Point Peron. For the intermediate planning timeframes of 2030 and 2070, values of 5 and 38m, respectively, were adopted (100 times the adopted sea level rise value).

4.5 Coastal Processes Allowance Summary

The coastal foreshore reserve allowances for coastal erosion at 2017, 2030, 2070 and 2110 are summarised by Sector in **Table 4-6**. The full results with each component value are presented in **Appendix E**. The total allowances were calculated as the sum of the S1, S2 and S3 components plus the uncertainty allowance of 0.2 m/year as per SPP2.6. As can be seen in the table, there is a significant range in the total allowance for some sections. The range is due to differences in the S2 component that can, in places, vary significantly over relatively short distances along the coast, such as around dynamic coastal features such as points or salients (see full numbers in **Appendix E** for more detail).

Table 4-6 Coastal foreshore reserve allowance summary for coastal erosion

Sector	Chainages (m)	HSD Elev (m)	2017 Total (m)	2030 Total Range (m)	2070 Total Range (m)	2110 Total Range (m)
1	1 – 301	1.75	20	34 - 39	95 - 116	175 - 212
	401 – 801	1.78	17	25 - 32	66 - 97	126 - 181
	901 – 1601	1.68	8	16 - 22	57 - 83	117 – 163
	1701 – 2301	1.73	12	26	87	167
	2401 – 3001	1.75	16	28 - 29	81 - 88	153 – 166
2.1	1 – 1101	1.72	12	20 - 24	61 - 77	121 – 149
	1201 – 1901	1.7	9	17 - 21	58 - 74	118 – 146
	2001 – 2401	1.69	13	21 - 23	62 - 70	122 – 136
	2501 – 3101	1.55	4	12 - 17	53 - 74	113 – 150
	3201 – 3601	1.9	5	17 - 19	70 - 80	142 – 160
2.2	1 – 701	1.95	13	26 - 66	83 - 247	159 – 447
	801 – 1001	1.93	29	43 - 65	104 - 192	184 – 338
2.3	50	1.93	29	38	83	147
2.4	1 – 401	2.75	41	49 - 55	90 - 116	150 – 196
2.5	1 – 101	2.31	27	41	102	182
2.6	1 – 101	2.31	27	36	81	145
2.7	1 – 901	1.98	8	17 - 81	62 - 182	126 – 302
	1001 – 1901	2.2	4	12	53	113
	2001 – 2301	2.21	15	23	64	124
3	1 – 701	2.21	15	23	64	124
	801 – 1701	1.86	39	47 - 66	88 - 167	148 – 287
	1801 – 2101	1.93	8	16 - 20	57 - 75	117 – 149
	2201 – 2601	1.9	18	26 - 31	67 - 88	127 – 164
	2701 – 4001	1.76	4	12 - 19	53 - 84	113 – 168
	4101 – 5001	1.86	7	15 - 20	56 - 77	116 – 153
	5101 – 7101	2.12	15	23 - 25	64 - 74	124 – 142
4	1 – 3601	2.3	23	31 - 33	72 - 82	132 – 150
	3701 – 6301	1.78	61	69 - 134	110 - 375	170 – 635
5	1 – 3501	1.8	20	30 - 61	79 - 206	147 – 370
	3601 – 6001	2.01	24	32	73	133
6	1 - 1201	2.01	24	32	73	133
	1301 - 4301	2.28	16	24	65	125

4.6 Coastal Processes Allowance Mapping

The coastal foreshore reserve allowance for coastal erosion at 2017, 2030, 2070 and 2110 was spatially mapped in order to visually show the areas that have been estimated to be at risk from coastal erosion over the planning timeframe to 2110. For most of the study area, the coastal foreshore reserve allowances were applied from the HSD elevation (determined from the SBEACH modelling) which was located on the combined

DEM surface described in **Section 2.5**. However, as noted in **Section 2.5**, there are some areas of the coastline within the study area which are known to have changed significantly since the most recent detailed area survey data which was available was captured. These areas were:

1. Sector 2.2 - between the sand trap and the informal seawall (where the GSC groyne was built in 2013);
2. Sector 2.7 - where the salient has significantly changed since the LiDAR was captured;
3. Sector 3 - in the northern bay where the shoreline has changed significantly (Approximately Chainages 1 to 701);
4. Sector 3 – Chainages 2201 to 4001. In this area the erosion hazard allowances was applied from a combination of the 2016 vegetation line and the calculated HSD line based on where there was (and was not) recent survey data available;
5. Sector 4 - Chainages 3701 to 6301 where the coastline has changed significantly on the northern side of Becher Point; and
6. Sector 5 - Chainages 1 to 2901 on the southern side of Becher Point where there has been significant change.

In these areas (except for number 4 as noted), the coastal foreshore reserve allowance was applied from the 2016 vegetation line supplied by DoT rather than the HSD elevation calculated from the DEM. This was based on comparison of the 2008/2009 LiDAR survey data, the 2016 vegetation line and recent aerial photos, which showed that utilising the 2016 vegetation was likely to provide a better estimate of the “current” position of the HSD than that calculated from the DEM.

Again, it is recommended that additional detailed area survey data, particularly of the areas that have changed significantly since the most recent available detailed area survey data, is captured prior to the next revision of the City’s CHRMAP to improve the quality of the mapping of coastal erosion hazards.

Maps of the coastal foreshore reserve allowances for coastal erosion at 2017, 2030, 2070 and 2110 are presented in **Appendix F**.

4.7 Assets at Risk from Coastal Erosion

The results of the coastal erosion analysis indicate that the following assets are potentially at risk of coastal erosion over the planning timeframe.

Table 4-7 Assets at risk from coastal erosion over the planning timeframe

Sector	Assets at Risk	Extent of Impact
1	Beach	3.1 km
	Coastal/Dune Vegetation	
	Naval Memorial Park	29,900 m^2
	Rockingham Foreshore Park	27,125 m^2
	Residential Properties	102
	CBH Kwinana Grain Terminal	5,325 m^2
	Road – Rockingham Beach Road	4.1 km
	Dual Use Path	2.6 km
	Naval Memorial Park Carpark	1,620 m^2
	Governor Reserve Carpark	1,490 m^2
	Rockingham Road Conservation Reserve Carpark	2,960 m^2
	Phoebe Hymus Carpark	1,490 m^2
	Emerald Park Carpark	685 m^2
2	Beach	7.5 km

Sector	Assets at Risk	Extent of Impact
	Coastal/Dune Vegetation	
	DBCA-managed land at Point Peron	509,555 m^2
	Bell Park	14,775 m^2
	Churchill Park	12,350 m^2
	Commercial area (Rockingham Beach Rd)	2,4735 m^2
	Commercial area (Railway Tce)	5,990 m^2
	Alfred Hines Seaside Home	12,130 m^2
	Residential Properties	157
	Mangles Bay Fishing Club	67,295 m^2
	Jetty abutments (Val St and Fisher St)	
	Catalpa Park	19,995 m^2
	Rotary Park	11,680 m^2
	The Cruising Yacht Club	1,505 m^2
	Rockingham Naval Club	1,335 m^2
	Department of Defence Land	18,463 m^2
	Point Peron Boating Facility	340 m
	Point Peron Camp School	53,785 m^2
	Point Peron Wastewater Treatment Plant	
	L&S Recreation Centre	20,195 m^2
	Maritime Union of Australia Holiday Camp	8,255 m^2
	Rockingham Recreation Centre (Memorial Dr)	13,140 m^2
	Bell Park Carpark	2,140 m^2
	Flinders Lane Carpark	805 m^2
	Railway Terrace Carpark	1,760 m^2
	Samuel Street Carpark	440 m^2
	Rockingham Beach Road Parking	2,900 m^2
	The Cruising Yacht Club Carpark	1,430 m^2
	Catalpa Park Carpark	6,570 m^2
	Point Peron Boat Ramp Carpark	9,275 m^2
	Point Peron Foreshore Carpark (SW)	1,550 m^2
	Point Peron Foreshore Carpark (NE)	1,385 m^2
	Point Peron Foreshore Carpark (Central)	480 m^2
	Point Peron Dive Site Carpark	500 m^2
	Boat Ramps (Catalpa Park)	
	Road – Rockingham Beach Rd; Esplanade	11.3 km
	Dual use paths	8.0 km
3	Beach	7.4 km

Sector	Assets at Risk		Extent of Impact
	Coastal/Dune Vegetation		
	Shoalwater Foreshore Park		5,805 m^2
	Lions Park		5,895 m^2
	Safety Bay Foreshore Park		19,265 m^2
	Waikiki Foreshore Park		66,800 m^2
	Safety Bay Yacht Club		595 m^2
	Noel France Reserve (park)		1,075 m^2
	Rockingham Wild Encounters		2,020 m^2
	Commercial Area (Bent St)		1,830 m^2
	Residential Properties		520
	BP Petrol Station		3,535 m^2
	Dual use path		13.0 km
	Road - Arcadia Dr; Safety Bay Rd; Warnbro Beach Rd		7.4 km
	Shoalwater Foreshore Park Carpark		4,510 m^2
	Lions Park Carpark		1,120 m^2
	Mersey Point Carpark		4,070 m^2
	Safety Bay Foreshore Carparks (7 total)	Carlisle St	7,685 m^2
		Watts Rd	
		Safety Bay Yacht Club	
		Waimea Rd	
		Bent St	
		Between June Rd and Donald Dr	
		Corner of Safety Bay Rd and Warnbro Beach Rd	
	Waikiki Foreshore Carparks (5 total)	View Rd	5,200 m^2
		Viking Rd	
		Between Julia St and Michael Rd	
		Hilda Rd	
		Warnbro Beach Rd adjacent to Shelton St	
4	Beach		6.4 km
	Coastal/Dune Vegetation		
	Port Kennedy Scientific Park		173,935 m^2
	Port Kennedy Boat Ramp		
	Port Kennedy Foreshore Recreation Area (Park)		4,095 m^2
	Residential Properties		98
	Roads		1.0 km
	St Malo Cove Carpark		520 m^2
	La Seyne Crescent Carpark		990 m^2

Sector	Assets at Risk	Extent of Impact
	St Ives Cove Carpark	600 m^2
	Capella Pass Carpark	640 m^2
	Cote D'Azur Gardens Carpark	2,195 m^2
	Bayeux Avenue Carpark	675 m^2
	Port Kennedy Foreshore Carpark	9,325 m^2
	Dual use path	5.8 km
5	Beach	6.1 km
	Coastal/Dune Vegetation	
	Port Kennedy Scientific Park	734,000 m^2
	Lagoon Park	10,925 m^2
	Secret Harbour Surf Lifesaving Club	1,570 m^2
	Road - Siracusa Ct	0.1 km
	Secret Harbour Beach Carpark (Siracusa Ct)	1,535 m^2
	Secret Harbour Beach Carpark (Albenga Pl)	4,315 m^2
	Secret Harbour Beach Carpark (Palisades Bvd)	870 m^2
	Pedestrian Pathway	1.2 km
6	Beach	4.4 km
	Coastal/Dune Vegetation	
	Singleton Foreshore	1,105 m^2

5 Groundwater Rise Assessment

It is generally accepted that SLR will cause groundwater levels adjacent to the coast to increase the same i.e. 0.9m increase in MSL will result in a 0.9m increase in coastal groundwater levels. Inundation can also affect groundwater levels creating groundwater 'mounding' dependent on the aquifer properties.

Adapted from Timms, Anderson & Carly (2008), SLR can potentially affect groundwater resources by:

> Seawater intrusion – migration inland of the freshwater/saline water interface;

> Seawater inundation of unconfined aquifers;

> Contamination of production bores;

> Increased salinity in aquatic and wetland ecosystems; and

> Impact on infrastructure.

Within the City, the depth to groundwater will become shallower by varying amounts dependent on distance to the coast, geology and proximity to lakes and drains. The impact of this increase will vary dependent on the current depth to groundwater. Where groundwater is currently shallow, any increase would have more significant impacts than areas where the water table is deeper.

For the purposes of the assessment, Cardno utilised Department of Water and Environmental Regulation's (formally Department of Water) 1997 maximum groundwater level contours for the groundwater rise assessment. 2110 SLR was then added to the groundwater levels to provide groundwater elevations in 2110. Following this, the groundwater levels calculated were subtracted from the DEM to determine surface assets that would be impacted by sea level rise. Survey of drainage infrastructure inverts was compared to the predicted groundwater level to determine drainage assets that may be impacted by groundwater rise.

It should be noted that this is a simplistic approach to reviewing the impacts of coastal hazard risk but appropriate for a macro scale assessment. Groundwater levels near the coast can be greater during higher tides and during storm events as the sloping beach face fills (vertical infiltration) at a greater rate than it can drain (horizontal seepage) (Turner, Coates & Acworth, 1996).

The groundwater assessment has taken into account impacts on drainage infrastructure, open water bodies and groundwater production bores only. Footings of buildings and other underground services have not been considered.

5.1 Groundwater Rise Mapping

The spatial extent of groundwater rise was mapped for each sector using a bathtub modelling approach. The topographical DEM used to map the groundwater rise extent was a composite surface comprised of all the area datasets listed in **Section 2.5**. It should be noted that the beach profile data was not incorporated into this DEM where it was not of sufficient spatial resolution to adequately interpolate between the profiles. As a result large areas of the DEM are comprised entirely of LiDAR data from 2008 and 2009, including some areas where it is known that the coastline has significantly changed since those surveys. It is recommended that additional detailed area survey data, particularly of the areas that have changed significantly since the most recent available detailed area survey data, is captured prior to the next revision of the City's CHRMAP to improve the quality of the mapping of groundwater rise risks. Maps of the groundwater rise for each of the 6 sectors of the study area are presented in **Appendix G**.

5.1.1 Saltwater Intrusion Mapping

Not taking into account an increase or decrease in abstraction rates, the possibility of saltwater intrusion into production bores will increase with SLR. Smith and Hick (2001) noted groundwater monitoring of the superficial aquifer has shown that the saltwater-groundwater interface intrudes up to 1km inland from the coast. All bores within 1km of the coast have been identified as being at risk of saltwater intrusion. Maps of impacted bores for each sector are presented in **Appendix G**.

5.2 Assets at Risk from Groundwater Rise

The results of the groundwater rise analysis (**Table 5-1**) indicate that the following assets are potentially at risk of groundwater rise over the planning timeframe.

Table 5-1 Assets at risk from groundwater rise over the planning timeframe

Sector	Assets at Risk	Extent of Impact
1	Beach and Coastal/Dune Vegetation	
	Stormwater Pits	1
2	Beach and Coastal/Dune Vegetation	
	Stormwater Pits	76
	Stormwater Pipes	2,200 m
	Underground Storage	121 m^3
	Drainage Channels	1,700 m
	Residential Properties	3
	Rotary Park	
	Lake Richmond	
3	Beach and Coastal/Dune Vegetation	
	Stormwater Pits	220
	Stormwater Pipes	6,050 m
	Drainage Channels	1,400 m
	Apex Reserve Lake	
	Hawker Street Reserve Lake	
	Miscellaneous Lakes	4
4	Beach and Coastal/Dune Vegetation	
	Stormwater Pits	22
	Stormwater Pipes	400 m
5	Beach and Coastal/Dune Vegetation	
6	Beach and Coastal/Dune Vegetation	

5.2.2 Assets at Risk from Saltwater Intrusion

The results of the saltwater intrusion analysis indicate that the following assets are potentially at risk of saltwater intrusion over the planning timeframe.

Table 5-2 Assets at risk from groundwater rise over the planning timeframe

Sector	Assets at Risk	Extent of Impact
1	Groundwater Bores	1
2	Groundwater Bores	5
3	Groundwater Bores	11
4	Groundwater Bores	9
5	Groundwater Bores	3
6	Groundwater Bores	10

6 Stormwater Drainage Assessment

The City of Rockingham coastal strip is situated on Calcareous Sands, typically well suited for at source stormwater infiltration. However, topography and depth to groundwater along the coastal strip limits the ability to utilise this property and as such, the City has 40 ocean outfalls. The ability of these outfalls and the near coastal drainage system was assessed to determine its capacity to deal with coastal erosion and inundation for the planning timeframes set out in SPP 2.6.

Since urban drainage systems have a certain design capacity, more frequent inundation and subsequent water run-off will threaten the ability of these systems to cope with the discharge they were designed for. In addition, due to sea level rise and increasing aquifer salinity, subsurface structures, such as the pipe network and underground storage, will deteriorate at a faster rate.

A coarse survey of the drainage network was commissioned by the City to determine the impacts of SLR and coastal inundation on the drainage network. This survey was completed on drainage assets that were predicted to be subject to inundation by 2070. This was agreed due to a 50-year asset replacement lifespan of drainage assets. The stormwater drainage assessment and mapping however was completed until the 2110 timeframe utilising engineering judgement.

6.1 Stormwater Drainage Mapping

The extent of inundation impacts were assessed utilising a combination of inundation maps and erosion lines. Survey levels collected were compared to mapping levels to determine assets that would be impacted where available. While the probability of a critical rainfall event coinciding with an extreme coastal inundation event is remote, rising sea levels will cause more frequent inundation and will limit the capacity of the stormwater system to cope. While inundation will only be temporary, the duration and depth of inundation events will increase over the planning timeframe.

It is recommended that detailed surface water modelling which considers sea level rise and inundation is undertaken as a separate exercise prior to the replacement or upgrade of stormwater drainage assets in areas predicted to be impacted by inundation.

Maps of impacted stormwater assets for each of the 6 sectors of the study area are presented in **Appendix G**.

6.2 Stormwater Drainage Assets at Risk

The results of the stormwater drainage analysis indicate that the following assets are potentially at risk of coastal inundation over the planning timeframe.

Table 6-1 Stormwater Assets at risk from coastal inundation over the planning timeframe

Sector	Assets at Risk	Extent of Impact
1	N/A	
2	Stormwater Pits	202
	Stormwater Pipes	3,900 m
	Underground Storage	2520 m^3
	Drainage Channels	3,000 m
3	Stormwater Pits	455
	Stormwater Pipes	10,400 m
	Drainage Channels	5,300 m
4	Stormwater Pits	55
	Stormwater Pipes	600 m
5	N/A	
6	N/A	

7 Conclusions

Cardno has undertaken a coastal hazard assessment for the City of Rockingham LGA, in accordance with the requirements of SPP2.6 and the CHRMAP Guidelines, which forms the first part of the CHRMAP process for the City. Estimates of the coastal inundation and erosion hazards have been calculated and mapped across the study area. Coastal inundation hazards have been estimated for the 1, 10, 50, 100 and 500-year ARI event for four different planning timeframes, the present day (2017), 2030, 2070 and 2110. Coastal erosion hazards have been estimated based on a 100-year ARI storm event as per the requirements of SPP2.6 for the same four planning timeframes.

The results of the coastal hazard assessment indicate that the City is at risk to both coastal inundation and coastal erosion hazards now, and that these hazards are estimated to increase into the future, mainly due to sea level rise. These hazards need to be acknowledged, communicated to stakeholders and incorporated into planning for the future of the City.

The coastal inundation assessment shows that there are coastal inundation hazards along the length of the City's coastline, but there are four main areas of significant hazards:

1. The low-lying southern coastline of Cockburn Sound between approximately Wanliss Street and Cape Peron (Sectors 1 and 2);
2. The low-lying, west and south-facing sections of both Shoalwater and Safety Bay (Sector 3);
3. The low-lying areas of Safety Bay, Shoalwater, Peron and Rockingham between areas 1 and 2 above (Sectors 1, 2 and 3); and
4. The low-lying areas around Becher Point in Port Kennedy (Sectors 4 and 5).

The coastal erosion assessment shows that there are coastal erosion risks along the length of the City's coastline, but the following areas have significant hazards:

1. Almost the entire shorelines of Sectors 1, 2, 3 and 4 (East Rockingham around to Port Kennedy); and
2. The small developed area around the Port Kennedy Boat Ramp (Sector 4).

A detailed list of the assets which are projected to be affected by inundation and erosion over the planning timeframe is presented in the body of this report.

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APPENDIX

B

INUNDATION HAZARD MAPS

Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

Map produced by Cardno WA Pty Ltd
11 Harvest Terrace, West Perth WA 6005, Australia
Phone: +61 8 9273 3888
Web: www.cardno.com.au

Date
19/12/2017

Size
A3

Scale
1:15,000

0 0.1 0.2 0.3 0.4km

SECTOR 1 COASTAL INUNDATION 2017 HAZARD MAP

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING
CITY OF ROCKINGHAM

59918065-GS-001-SECTOR1_2017_INUNDATION 01

DATE PLOTTED:19/12/2017 10:11:43 AM BY: ANIN DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationHazardMaps\Sector 1\59918065-GS-001-Sector1_2017_Inundation.mxd

Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

Cardno

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Phone: +61 8 9273 3888
Web: www.cardno.com.au

City of Rockingham

Date
19/12/2017

Size
A3

Scale
1:15,000

0 0.1 0.2 0.3 0.4km

SECTOR 1 DEPTH OF COASTAL INUNDATION 2017 - 500 YEAR ARI

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING
CITY OF ROCKINGHAM

59918065-GS-001-SECTOR1_2017_500ARI_INUNDATIONDEPTH 01

DATE PLOTTED:19/12/2017 10:12:49 AM BY: ANIN.DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationDepthMaps\Sector 1\59918065-GS-001-Sector1_2017_500ari_InundationDepth.mxd

Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

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Date
19/12/2017

Size
A3

Scale
1:15,000

0 0.1 0.2 0.3 0.4km

SECTOR 1 DURATION OF COASTAL INUNDATION 2017 - 500 YEAR ARI

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING
CITY OF ROCKINGHAM

59918065-GS-001-SECTOR1_2017_500ARI_INUNDATIONDURATION 01

DATE PLOTTED:19/12/2017 10:16:07 AM BY: ANIN.DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationDurationMaps\Sector 1\59918065-GS-001-Sector1_2017_500ari_InundationDuration.mxd

Aerial imagery supplied by City of Rockingham (February 2017)
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City of Rockingham

Date
19/12/2017

Size
A3

Scale
1:15,000

0 0.1 0.2 0.3 0.4km

SECTOR 1 COASTAL INUNDATION 2030 HAZARD MAP

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING
CITY OF ROCKINGHAM

59918065-GS-001-SECTOR1_2030_INUNDATION 01

DATE PLOTTED:19/12/2017 10:11:41 AM BY: ANIN DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationHazardMaps\Sector 1\59918065-GS-001-Sector1_2030_Inundation.mxd

Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

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City of Rockingham

Date
19/12/2017

Size
A3

Scale
1:15,000

0 0.1 0.2 0.3 0.4km

SECTOR 1 DEPTH OF COASTAL INUNDATION 2030 - 500 YEAR ARI

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING
CITY OF ROCKINGHAM

59918065-GS-001-SECTOR1_2030_500ARI_INUNDATIONDEPTH 01

DATE PLOTTED:19/12/2017 10:12:26 AM BY: ANIN.DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationDepthMaps\Sector 1\59918065-GS-001-Sector1_2030_500ari_InundationDepth.mxd

DATE PLOTTED:19/12/2017 10:16:15 AM BY: ANIN.DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationDurationMaps\Sector 1\59918065-GS-001-Sector1_2030_500ari_InundationDuration.mxd

Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

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City of Rockingham

Date
19/12/2017

Size
A3

Scale
1:15,000

0 0.1 0.2 0.3 0.4km

SECTOR 1 DURATION OF COASTAL INUNDATION 2030 - 500 YEAR ARI

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING
CITY OF ROCKINGHAM

59918065-GS-001-SECTOR1_2030_500ARI_INUNDATIONDURATION 01

Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

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City of Rockingham

Date
19/12/2017

Size
A3

Scale
1:15,000

SECTOR 1 COASTAL INUNDATION 2070 HAZARD MAP

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING
CITY OF ROCKINGHAM

59918065-GS-001-SECTOR1_2070_INUNDATION 01

DATE PLOTTED:19/12/2017 10:11:20 AM BY: ANIN DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationHazardMaps\Sector 1\59918065-GS-001-Sector1_2070_Inundation.mxd

Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

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City of Rockingham

Date
19/12/2017

Size
A3

Scale
1:15,000

0 0.1 0.2 0.3 0.4km

SECTOR 1 DEPTH OF COASTAL INUNDATION 2070 - 500 YEAR ARI

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING
CITY OF ROCKINGHAM

59918065-GS-001-SECTOR1_2070_500ARI_INUNDATIONDEPTH 01

DATE PLOTTED:19/12/2017 10:12:41 AM BY: ANIN.DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationDepthMaps\Sector 1\59918065-GS-001-Sector1_2070_500ari_InundationDepth.mxd

DATE PLOTTED:19/12/2017 10:15:59 AM BY: ANIN.DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationDurationMaps\Sector 1\59918065-GS-001-Sector1_2070_500ari_InundationDuration.mxd

Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

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City of Rockingham

Date
19/12/2017

Size
A3

Scale
1:15,000

0 0.1 0.2 0.3 0.4km

SECTOR 1 DURATION OF COASTAL INUNDATION 2070 - 500 YEAR ARI

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING
CITY OF ROCKINGHAM

59918065-GS-001-SECTOR1_2070_500ARI_INUNDATIONDURATION 01

Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

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City of Rockingham

Date
19/12/2017

Size
A3

Scale
1:15,000

0 0.1 0.2 0.3 0.4km

SECTOR 1 COASTAL INUNDATION 2110 HAZARD MAP

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING

CITY OF ROCKINGHAM

59918065-GS-001-SECTOR1_2110_INUNDATION 01

DATE PLOTTED:19/12/2017 10:11:33 AM BY: ANIN.DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationHazardMaps\Sector 1\59918065-GS-001-Sector1_2110_Inundation.mxd

Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

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Web: www.cardno.com.au

City of Rockingham

Date
19/12/2017

Size
A3

Scale
1:15,000

0 0.1 0.2 0.3 0.4km

SECTOR 1 DEPTH OF COASTAL INUNDATION 2110 - 500 YEAR ARI

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING
CITY OF ROCKINGHAM

59918065-GS-001-SECTOR1_2110_500ARI_INUNDATIONDEPTH 01

DATE PLOTTED:19/12/2017 10:12:34 AM BY: ANIN.DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationDepthMaps\Sector 1\59918065-GS-001-Sector1_2110_500ari_InundationDepth.mxd

Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

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Web: www.cardno.com.au

City of Rockingham

Date
19/12/2017
Size
A3
Scale
1:15,000

0 0.1 0.2 0.3 0.4km

SECTOR 1 DURATION OF COASTAL INUNDATION 2110 - 500 YEAR ARI

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING
CITY OF ROCKINGHAM

59918065-GS-001-SECTOR1_2110_500ARI_INUNDATIONDURATION 01

DATE PLOTTED:19/12/2017 10:15:51 AM BY: ANIN.DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationDurationMaps\Sector 1\59918065-GS-001-Sector1_2110_500ari_InundationDuration.mxd

Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

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City of Rockingham

Date
19/12/2017

Size
A3

Scale
1:15,000

0 0.1 0.2 0.3 0.4km

SECTOR 2 COASTAL INUNDATION 2017 HAZARD MAP

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING
CITY OF ROCKINGHAM

59918065-GS-001-SECTOR2_2017_INUNDATION 01

DATE PLOTTED:19/12/2017 10:25:25 AM BY: ANIN DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationHazardMaps\Sector 2\59918065-GS-001-Sector2_2017_Inundation.mxd

Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

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Web: www.cardno.com.au

Date
19/12/2017

Size
A3

Scale
1:15,000

0 0.1 0.2 0.3 0.4km

SECTOR 2 DEPTH OF COASTAL INUNDATION 2017 - 500 YEAR ARI

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING
CITY OF ROCKINGHAM

59918065-GS-001-SECTOR2_2017_500ARI_INUNDATIONDEPTH 01

DATE PLOTTED:19/12/2017 10:23:35 AM BY: ANIN.DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationDepthMaps\Sector 2\59918065-GS-001-Sector2_2017_500ari_InundationDepth.mxd

Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

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Date
19/12/2017

Size
A3

Scale
1:15,000

SECTOR 2 DURATION OF COASTAL INUNDATION 2017 - 500 YEAR ARI

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING
CITY OF ROCKINGHAM

59918065-GS-001-SECTOR2_2017_500ARI_INUNDATIONDURATION 01

DATE PLOTTED:19/12/2017 10:26:11 AM BY: ANIN.DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationDurationMaps\Sector 2\59918065-GS-001-Sector2_2017_500ari_InundationDuration.mxd

Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

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City of Rockingham

Date
19/12/2017

Size
A3

Scale
1:15,000

0 0.1 0.2 0.3 0.4km

SECTOR 2 COASTAL INUNDATION 2030 HAZARD MAP

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING

CITY OF ROCKINGHAM

59918065-GS-001-SECTOR2_2030_INUNDATION 01

DATE PLOTTED:19/12/2017 10:25:01 AM BY: ANIN.DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationHazardMaps\Sector 2\59918065-GS-001-Sector2_2030_Inundation.mxd

Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

Cardno

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Web: www.cardno.com.au

city of Rockingham

Date
19/12/2017

Size
A3

Scale
1:15,000

0 0.1 0.2 0.3 0.4km

SECTOR 2 DEPTH OF COASTAL INUNDATION 2030 - 500 YEAR ARI

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING

CITY OF ROCKINGHAM

59918065-GS-001-SECTOR2_2030_500ARI_INUNDATIONDEPTH 01

DATE PLOTTED:19/12/2017 10:23:27 AM BY: ANIN.DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationDepthMaps\Sector 2\59918065-GS-001-Sector2_2030_500ari_InundationDepth.mxd

Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

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Web: www.cardno.com.au

Date
19/12/2017

Size
A3

Scale
1:15,000

0 0.1 0.2 0.3 0.4km

SECTOR 2 DURATION OF COASTAL INUNDATION 2030 - 500 YEAR ARI

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING
CITY OF ROCKINGHAM

59918065-GS-001-SECTOR2_2030_500ARI_INUNDATIONDURATION 01

DATE PLOTTED:19/12/2017 10:26:03 AM BY: ANIN.DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationDurationMaps\Sector 2\59918065-GS-001-Sector2_2030_500ari_InundationDuration.mxd

Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

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Web: www.cardno.com.au

Date
19/12/2017

Size
A3

Scale
1:15,000

0 0.1 0.2 0.3 0.4km

SECTOR 2 COASTAL INUNDATION 2070 HAZARD MAP

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING
CITY OF ROCKINGHAM

59918065-GS-001-SECTOR2_2070_INUNDATION 01

DATE PLOTTED:19/12/2017 10:25:01 AM BY: ANIN.DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationHazardMaps\Sector 2\59918065-GS-001-Sector2_2070_Inundation.mxd

Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

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Web: www.cardno.com.au

Date
19/12/2017

Size
A3

Scale
1:15,000

0 0.1 0.2 0.3 0.4km

SECTOR 2 DURATION OF COASTAL INUNDATION 2070 - 500 YEAR ARI

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING
CITY OF ROCKINGHAM

59918065-GS-001-SECTOR2_2070_500ARI_INUNDATIONDURATION 01

DATE PLOTTED:19/12/2017 10:26:38 AM BY: ANIN.DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationDurationMaps\Sector 2\59918065-GS-001-Sector2_2070_500ari_InundationDuration.mxd

Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

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Web: www.cardno.com.au

Date
19/12/2017

Size
A3

Scale
1:15,000

0 0.1 0.2 0.3 0.4km

SECTOR 2 DEPTH OF COASTAL INUNDATION 2070 - 500 YEAR ARI

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING
CITY OF ROCKINGHAM

59918065-GS-001-SECTOR2_2070_500ARI_INUNDATIONDEPTH 01

DATE PLOTTED:19/12/2017 10:23:41 AM BY: ANIN.DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationDepthMaps\Sector 2\59918065-GS-001-Sector2_2070_500ari_InundationDepth.mxd

Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

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City of Rockingham

Date
19/12/2017

Size
A3

Scale
1:15,000

0 0.1 0.2 0.3 0.4km

SECTOR 2 COASTAL INUNDATION 2110 HAZARD MAP

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING
CITY OF ROCKINGHAM

59918065-GS-001-SECTOR2_2110_INUNDATION 01

DATE PLOTTED:19/12/2017 10:25:05 AM BY: ANIN.DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationHazardMaps\Sector 2\59918065-GS-001-Sector2_2110_Inundation.mxd

Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

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City of Rockingham

Date
19/12/2017

Size
A3

Scale
1:15,000

0 0.1 0.2 0.3 0.4km

SECTOR 2 DEPTH OF COASTAL INUNDATION 2110 - 500 YEAR ARI

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING

CITY OF ROCKINGHAM

59918065-GS-001-SECTOR2_2110_500ARI_INUNDATIONDEPTH 01

DATE PLOTTED:19/12/2017 10:23:21 AM BY: ANIN.DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationDepthMaps\Sector 2\59918065-GS-001-Sector2_2110_500ari_InundationDepth.mxd

SECTOR 2 DURATION OF COASTAL INUNDATION 2110 - 500 YEAR ARI

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING
CITY OF ROCKINGHAM

Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

Date
19/12/2017

Size
A3

Scale
1:15,000

0 0.1 0.2 0.3 0.4km

59918065-GS-001-SECTOR2_2110_500ARI_INUNDATIONDURATION 01

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City of Rockingham

DATE PLOTTED:19/12/2017 10:26:51 AM BY: ANIN.DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationDurationMaps\Sector 2\59918065-GS-001-Sector2_2110_500ari_InundationDuration.mxd

Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

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Web: www.cardno.com.au

City of Rockingham

Date
19/12/2017

Size
A3

Scale
1:25,000

0 0.2 0.4 0.6 0.8km

SECTOR 3 COASTAL INUNDATION 2017 HAZARD MAP

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING
CITY OF ROCKINGHAM

59918065-GS-001-SECTOR3_2017_INUNDATION 01

DATE PLOTTED:19/12/2017 10:35:33 AM BY: ANIN.DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationHazardMaps\Sector 3\59918065-GS-001-Sector3_2017_Inundation.mxd

Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

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Web: www.cardno.com.au

City of Rockingham

Date
19/12/2017

Size
A3

Scale
1:25,000

0 0.2 0.4 0.6 0.8km

SECTOR 3 DEPTH OF COASTAL INUNDATION 2017 - 500 YEAR ARI

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING
CITY OF ROCKINGHAM

59918065-GS-001-SECTOR3_2017_500ARI_INUNDATIONDEPTH 01

DATE PLOTTED:19/12/2017 10:34:35 AM BY: ANIN.DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationDepthMaps\Sector 3\59918065-GS-001-Sector3_2017_500ari_InundationDepth.mxd

Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

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Web: www.cardno.com.au

City of Rockingham

Date
19/12/2017

Size
A3

Scale
1:25,000

0 0.2 0.4 0.6 0.8km

SECTOR 3 DURATION OF COASTAL INUNDATION 2017 - 500 YEAR ARI

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING
CITY OF ROCKINGHAM

59918065-GS-001-SECTOR3_2017_500ARI_INUNDATIONDURATION 01

DATE PLOTTED:19/12/2017 10:35:37 AM BY: ANIN.DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationDurationMaps\Sector 3\59918065-GS-001-Sector3_2017_500ari_InundationDuration.mxd

Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

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Date
19/12/2017

Size
A3

Scale
1:25,000

0 0.2 0.4 0.6 0.8km

SECTOR 3 COASTAL INUNDATION 2030 HAZARD MAP

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING
CITY OF ROCKINGHAM

59918065-GS-001-SECTOR3_2030_INUNDATION 01

DATE PLOTTED:19/12/2017 10:35:35 AM BY: ANIN.DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationHazardMaps\Sector 3\59918065-GS-001-Sector3_2030_Inundation.mxd

Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

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11 Harvest Terrace, West Perth WA 6005, Australia
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Web: www.cardno.com.au

Date
19/12/2017

Size
A3

Scale
1:25,000

0 0.2 0.4 0.6 0.8km

SECTOR 3 DEPTH OF COASTAL INUNDATION 2030 - 500 YEAR ARI

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING
CITY OF ROCKINGHAM

59918065-GS-001-SECTOR3_2030_500ARI_INUNDATIONDEPTH 01

DATE PLOTTED:19/12/2017 10:34:22 AM BY: ANIN.DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationDepthMaps\Sector 3\59918065-GS-001-Sector3_2030_500ari_InundationDepth.mxd

SECTOR 3 DURATION OF COASTAL INUNDATION 2030 - 500 YEAR ARI

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING

CITY OF ROCKINGHAM

Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

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City of Rockingham

Date
19/12/2017

Size
A3

Scale
1:25,000

0 0.2 0.4 0.6 0.8km

59918065-GS-001-SECTOR3_2030_500ARI_INUNDATIONDURATION 01

DATE PLOTTED:19/12/2017 10:59:49 AM BY: ANIN.DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationDurationMaps\Sector 3\59918065-GS-001-Sector3_2030_500ari_InundationDuration.mxd

Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

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Date
19/12/2017

Size
A3

Scale
1:25,000

0 0.2 0.4 0.6 0.8km

SECTOR 3 COASTAL INUNDATION 2070 HAZARD MAP

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING
CITY OF ROCKINGHAM

59918065-GS-001-SECTOR3_2070_INUNDATION 01

DATE PLOTTED:19/12/2017 10:35:32 AM BY: ANIN.DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationHazardMaps\Sector 3\59918065-GS-001-Sector3_2070_Inundation.mxd

Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

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City of Rockingham

Date
19/12/2017

Size
A3

Scale
1:25,000

0 0.2 0.4 0.6 0.8km

SECTOR 3 DEPTH OF COASTAL INUNDATION 2070 - 500 YEAR ARI

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING
CITY OF ROCKINGHAM

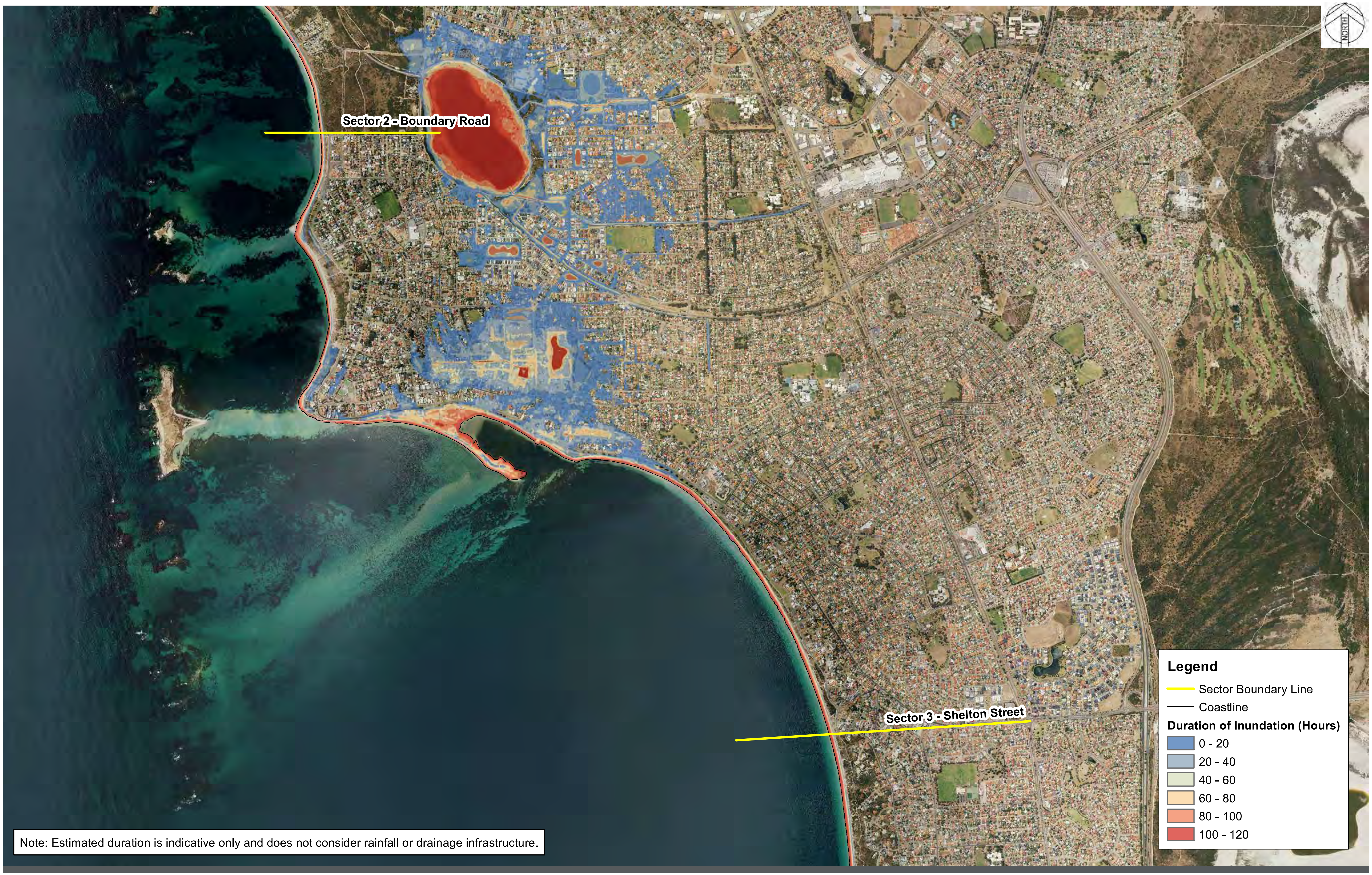
59918065-GS-001-SECTOR3_2070_500ARI_INUNDATIONDEPTH 01

DATE PLOTTED:19/12/2017 10:34:27 AM BY: ANIN.DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationDepthMaps\Sector 3\59918065-GS-001-Sector3_2070_500ari_InundationDepth.mxd

SECTOR 3 DURATION OF COASTAL INUNDATION 2070 - 500 YEAR ARI

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING

CITY OF ROCKINGHAM



Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

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Phone: +61 8 9273 3888
Web: www.cardno.com.au

Date
19/12/2017

Size
A3

Scale
1:25,000

0 0.2 0.4 0.6 0.8km

59918065-GS-001-SECTOR3_2070_500ARI_INUNDATIONDURATION 01

DATE PLOTTED:19/12/2017 10:35:57 AM BY: ANIN.DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationDurationMaps\Sector 3\59918065-GS-001-Sector3_2070_500ari_InundationDuration.mxd

Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

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Web: www.cardno.com.au

Date
19/12/2017

Size
A3

Scale
1:25,000

0 0.2 0.4 0.6 0.8km

SECTOR 3 COASTAL INUNDATION 2110 HAZARD MAP

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING
CITY OF ROCKINGHAM

59918065-GS-001-SECTOR3_2110_INUNDATION 01

DATE PLOTTED:19/12/2017 10:35:28 AM BY: ANIN.DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationHazardMaps\Sector 3\59918065-GS-001-Sector3_2110_Inundation.mxd

Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

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City of Rockingham

Date
19/12/2017

Size
A3

Scale
1:25,000

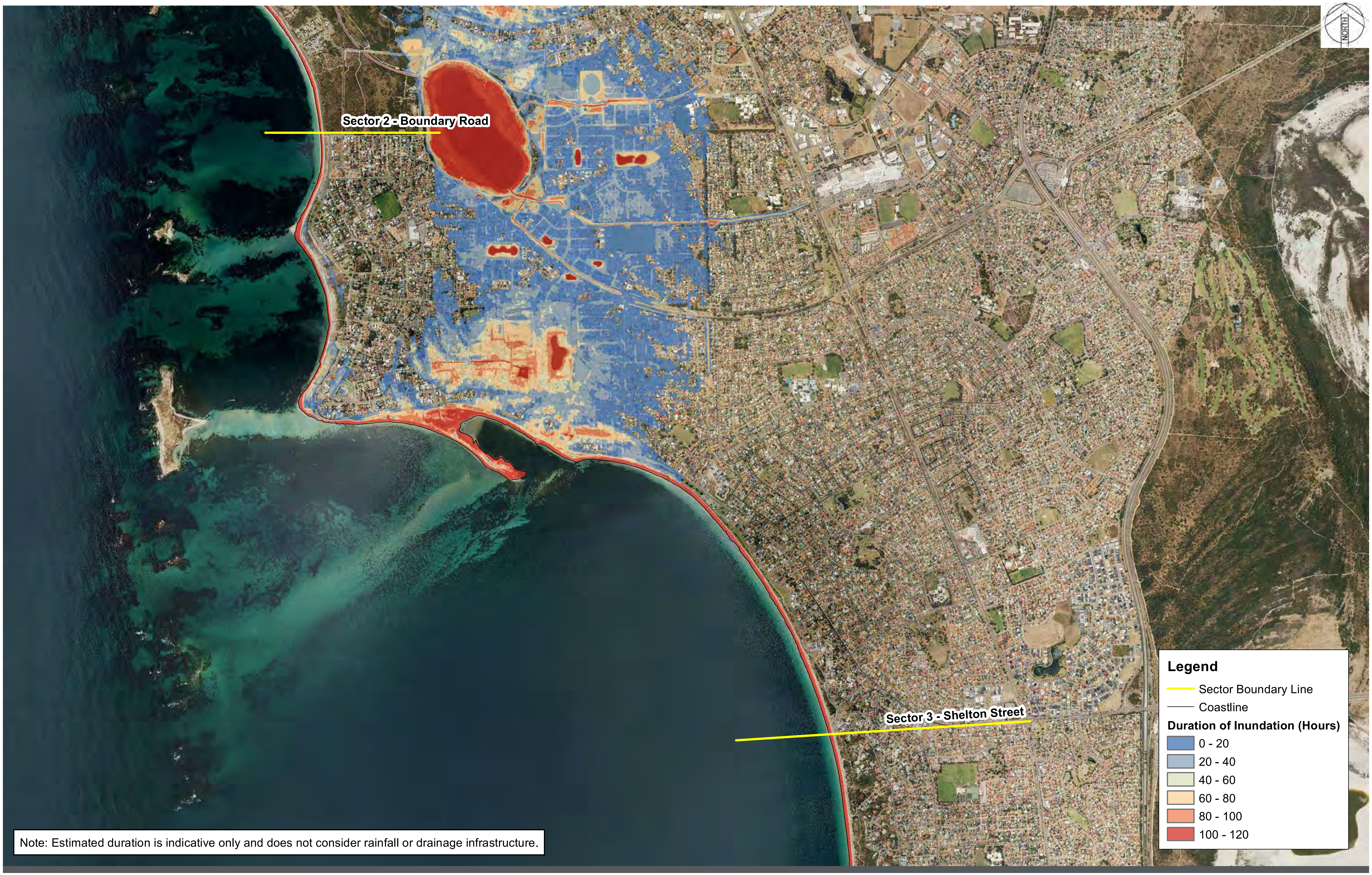
0 0.2 0.4 0.6 0.8km

SECTOR 3 DEPTH OF COASTAL INUNDATION 2110 - 500 YEAR ARI

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING
CITY OF ROCKINGHAM

59918065-GS-001-SECTOR3_2110_500ARI_INUNDATIONDEPTH 01

DATE PLOTTED:19/12/2017 10:34:43 AM BY: ANIN.DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationDepthMaps\Sector 3\59918065-GS-001-Sector3_2110_500ari_InundationDepth.mxd



Aerial imagery supplied by City of Rockingham (February 2017)
Coordinate System: GDA 1994 MGA Zone 50

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Web: www.cardno.com.au

City of Rockingham

Date
19/12/2017

Size
A3

Scale
1:25,000

SECTOR 3 DURATION OF COASTAL INUNDATION 2110 - 500 YEAR ARI

COASTAL HAZARD RISK MANAGEMENT AND ADAPTATION PLANNING
CITY OF ROCKINGHAM

59918065-GS-001-SECTOR3_2110_500ARI_INUNDATIONDURATION 01

DATE PLOTTED:19/12/2017 10:35:51 AM BY: ANIN.DHARMA
FILE: V:\Jobs\59918065_Rockingham_CHRMAP\Drawings\GIS\Workspaces\InundationDurationMaps\Sector 3\59918065-GS-001-Sector3_2110_500ari_InundationDuration.mxd