Cockburn Sound Coastal Vulnerability Values and Risk Assessment Study

1033_001/2_Rev1
November 2014

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Cockburn Sound Coastal Vulnerability Values and Risk Assessment Study

Prepared for

Cockburn Sound Coastal Alliance

Prepared by

BMT Oceanica Pty Ltd

In conjunction with

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Cover

Main image: City of Fremantle coastal infrastructure (BMT Oceanica Pty Ltd)
Minor images: Dune rehabilitation, Coogee Beach (BMT Oceanica Pty Ltd)
Risk Assessment Workshop, Coogee Beach Surf Life Saving Club (BMT Oceanica Pty Ltd)

Disclaimer

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Acronyms

AEP	annual exceedance probability
AHD	Australian Height Datum
ALARP	as low as reasonably practicable
AMC	Australian Maritime Complex
ARI	annual recurrence interval
AS/NZS	Australian Standards/New Zealand Standards
CAP	coastal adaptation and protection
CBA	cost-benefit analysis
CoC	City of Cockburn
CoF	City of Fremantle
CoK	City of Kwinana
CoR	City of Rockingham
CSCA	Cockburn Sound Coastal Alliance
CSMC	Cockburn Sound Management Council
CZM	Coastal Zone Management Pty Ltd
DoD	Department of Defence
DoT	Department of Transport
DPaW	Department of Parks and Wildlife
DPI	Department of Planning and Infrastructure
GIS	geographical information systems
ISO	International Organisation for Standardisation
LADS	laser airborne depth sounder
LGAs	local government areas
LiDAR	light detection and ranging
MSL	mean sea level
NPV	net present value
NSW	New South Wales
PWC	public watercraft
QLD	Queensland
RFT	request for tender
SLSC	surf life saving club
Stage 1 Assessment	Climate Change Vulnerability Assessment of the Coastal Zone of Cockburn Sound and Owen Anchorage
Stage 2 Assessment	Cockburn Sound Coastal Vulnerability Values and Risk Assessment
SPP2.6	Western Australian State Coastal Planning Policy 2.6
WA	Western Australia
WAMSI	Western Australian Marine Science Institution
WAPC	Western Australian Planning Commission

Executive Summary

Introduction

The Cockburn Sound Coastal Vulnerability Values and Risk Assessment documented herein (referred to as the 'Stage 2 Assessment') forms the second stage of the Cockburn Sound Coastal Vulnerability and Flexible Adaptation Pathways Project commissioned by the Cockburn Sound Coastal Alliance (CSCA). The CSCA comprises the Cities of Fremantle (CoF), Cockburn (CoC), Kwinana (CoK), Rockingham (CoR) and the Perth Region NRM. The Department of Defence (DoD), the Cockburn Sound Management Council (CSMC), Department of Transport, Department of Planning and the Department of Environment Regulation are key stakeholders.

The Cockburn Sound Coastal Vulnerability and Flexible Adaptation Pathways Project comprises four phases. The Stage 1 Climate Change Vulnerability Assessment of the Coastal Zone of Cockburn Sound and Owen Anchorage (hereafter referred to as the 'Stage 1 Assessment') identified areas exposed to erosion and inundation hazards with future sea level rise. The Stage 2 Assessment (this report) applies the outcomes of the Stage 1 Assessment to identify the cost of risk to the coastal assets and presents a first-pass adaptation approach to managing these coastal risks. Outcomes of the Stage 2 Assessment are to be reviewed and used in the upcoming Stage 3 Adaptation Plan Development to provide a strategy for coastal management of the Owen Anchorage and Cockburn Sound coastline, incorporating prioritised options to treat present and future coastal hazards.

The Cockburn Sound Coastal Vulnerability and Flexible Adaptation Pathways Project applies to the coastline between South Mole in CoF to Point Peron in CoR. The study area also includes the east coast of Garden Island on Department of Defence controlled land. The timeframes used were present-day, 2070 and 2110, as agreed with the CSCA, and are consistent with available projections and the State Coastal Planning Policy (SPP2.6; see Section 2.1.1).

The objectives of the Stage 2 Assessment and the approach adopted are summarised in Table ES.1.

Table ES.1 Approach to address project objectives

Facilitate understanding of coastal hazards and risk management among stakeholders	Communication with stakeholders occurred throughout the project and included direct discussion via phone calls and emails, presentations and workshops.
Prepare asset register	Available asset data were used to develop the asset register.
Determine the likelihoods of coastal hazards	Using a risk-based approach, the likelihood of impacts to coastal assets from coastal hazards (erosion and inundation as established in the Stage 1 Assessment) at each timeframe was determined taking into account the assumptions and limitations of the Stage 1 Assessment.
Identify the market, social and ecosystem values of assets at risk	An initial assessment of asset values was established using the existing datasets, which was informed by stakeholder consultation. This initial assessment was input into a more detailed economic valuation assessment to determine the market, social and environmental values of the assets based on the goods, services and functions they provide. This was used to establish the overall asset value (using a consistent metric of dollars).
Determine consequence	The consequences of coastal hazard impacts on the assets were determined based on the asset values. These consequences were then confirmed through stakeholder consultation (both direct liaison and via workshops).

Identify the 'cost of risk' of coastal assets for present day, 2070 and 2110	The 'cost of risk' was determined by analysing how an asset will be affected by the coastal hazard. It was assumed that an erosion hazard would result in total loss of an asset but inundation may only mean a partial loss or a reduction in value of an asset.
Quantify the coastal risks	The likelihood and consequence of the hazards (both erosion and inundation) were used to determine the level of coastal risk which was mapped and tabulated.
Identify and evaluate potential adaptation options for vulnerable areas	A range of potential coastal management options were considered and assessed for relevance to treat coastal risks along the Owen Anchorage and Cockburn Sound coastline. These options were reviewed in light of local knowledge from the stakeholders during the Risk Management Options Workshop, specifically relating to local issues and the effectiveness of management actions already in place. The efficacy of the management options and pathways were reviewed using a cost-benefit approach to provide an initial assessment of the optimal course of action for coastal adaptation and management.
Identify critical data gaps	Through the process of developing the asset inventory and values and risk assessments, data gaps were identified and documented.
Share best practices and lessons learnt	Through the completion of this Stage 2 Assessment, we have used methods for values and risk assessment that have been successful in a number of previous studies, incorporating both national and international best practice. We have documented these methods herein and thereby facilitate the sharing of best practice and lessons learnt from this and previous projects.

Stakeholder engagement

During the Stage 2 Assessment, the stakeholders were consulted for the purpose of gathering data and local knowledge vital to the success of this assessment and for informing the stakeholders about the Cockburn Sound Coastal Vulnerability and Flexible Adaptation Pathways Project and specifically the Stage 2 Assessment. The stakeholders were engaged during the assessment within the framework of the Team's Stakeholder Engagement Strategy (see Section 5) and in consultation with the Client.

The outcome of this engagement was the facilitation of understanding of coastal risk assessment and management among stakeholders. Specifically, the risk management approach, coastal assets at risk and potential coastal management options have been presented and discussion within and between LGAs, other government agencies and private land owners/managers. The key message broadcast to stakeholders is that for integrated strategic planning of coastal development to be effective, early engagement and public education is essential, and some degree of compromise is necessary, requiring protection of some assets and sacrifice of others.

Asset register

The Stage 2 Assessment has identified the coastal assets at risk along the Owen Anchorage and Cockburn Sound coastline. Asset data, as provided by the Client, were collated into an asset register (Appendix A). The assets at risk were identified by combining this asset dataset with the hazard mapping using a Geographic Information System. The economic, social and environmental values of the assets at risk were determined.

Values assessment

The quantitative values of these assets were assessed according to their value as market goods and services (for which fees or prices are applicable), social and cultural non-market goods and services (accessible for everyone for which no fee or price is applicable) and ecosystem services (as a result of applicable ecosystem functions).

The primary methods used for asset valuation in the Stage 2 Assessment were:

- Market price method, for market goods and services, including built assets such as residential and commercial properties.
- Benefit transfer method, mostly for social and cultural and ecosystem goods and services. This method can be applied to a wide range of social, cultural and ecosystem values, and is a cost-effective substitute for contingent valuation and choice methods. There are a number of national and international data banks containing valuations for a wide range of coastal assets and ecosystem values. For an effective transfer, it is important to consider and compare the study area on the basis of size, population and quality of assets.
- Replacement cost, for infrastructure assets.

Cost of risk

The cost of risk is the net present value (NPV) of the potential future damages due to erosion and inundation to assets. The cost of risk of the coastal assets is shown in Table ES.2.

Table ES.2 Cost[1] of erosion and inundation risk from 2015 to 2114

Beach	$129.6	$7.4	$41.8	$23.4	$56.9
Coastal structures	$7.1	$0.2	$4.0	$1.9	$1.0
Heritage	$47.0	$2.7	$27.5	$–	$16.9
Infrastructure	$4.6	$0.1	$3.2	$0.0	$1.3
Major industries	$14.2	$–	$–	$14.2	$–
Parks	$121.5	$10.1	$78.2	$4.8	$28.4
Utilities	$0.3	$0.1	$0.0	$0.0	$0.2
Urban area CoR	$0.9	$–	$–	$–	$0.9
Total	$325.2	$20.6	$154.7	$44.3	$105.7

Notes:
1. $million (NPV, 6% discount rate)
2. $– indicates no value
3. $0.0 indicates a very low value

The total cost of risk due to erosion and inundation for the 2015–2114 period is estimated to be ~$325 million for the entire study area. Most of this value is related to the beaches ($130 million) and parks ($122 million), which signifies the high economic (tourism), social (recreation use of the beaches and parks) and environmental (ecosystem services provided by the beaches, dune systems and parks) values held in these assets.

The valuation of many key industries located along the coastline was constrained due to data availability and the confidentiality that industries apply to disclosing information about their asset values. However, using the consequence table developed herein, these assets were determined (in consultation with the stakeholders) to have the highest consequence to represent the state-wide significance of some of these industries.

Risk assessment

The level of risk of coastal hazards for each asset was assessed using a combination of likelihood of impact and consequence of impact. The likelihood scale used was based on the Stage 1 Assessment data. The consequence scale used was based on economic, social and environmental values for the assets at risk in the coastal zone, as determined through this Stage 2 Assessment.

The likelihoods of impact, assigned consequences of the coastal hazard impacts and the resultant risk levels for each asset at each timeframe are tabulated as part of the asset register (Appendix A). Maps showing the likelihoods, consequences and risks of coastal hazard impact to the assets in the Owen Anchorage and Cockburn Sound coastline are presented in Appendix D to Appendix F.

A scale of risk tolerance was established to enable prioritisation of risk management. This 'risk tolerance' concept aligns with SPP2.6, and allows the cost of management actions to be allocated in proportion to the level of risk. Using this concept, present extreme and high risks and future extreme risks were deemed intolerable and therefore a priority for risk management.

Adaptation options

The adaptation options are generally considered to target one of the following:

i. **Avoid:** do not locate new development within an area identified to be affected by coastal hazards.
i. **Retreat:** relocate or remove assets within an area identified as likely to be subject to intolerable risk of damage from coastal hazards over the planning time frame.
ii. **Accommodate:** ensure design and/or management strategies render the risks from the identified coastal hazards acceptable.
iii. **Protect:** defend the assets from the hazard, when sufficient justification can be provided for not avoiding the use or development of land that is at risk from coastal hazards, and accommodation measures alone cannot adequately address the risks from coastal hazards.

There are a number of actions that represent good coastal management practice, which can be pursued by stakeholders without the need for compromise or significant capital-raising. Such actions can improve resilience and preparedness for coastal risks without limiting the ability to change a management approach and without negative long-term impact should risks change in the future. These actions include:

- monitoring
- land use planning and development controls (including new design criteria)
- continuing dialogue to promote integrated and consistent coastal management and planning
- dune rehabilitation
- audit and appropriate management of assets.

Pathways for coastal adaptation

Adaptation is a long-term process that can follow various pathways. Different adaptation pathways reflect different approaches to adaptation, generally with different strategic aims and objectives. Adaptation pathways mostly consist of a collection of adaptation options that are mutually reinforcing and/or complementary to each other.

There are three adaptation pathways that have been considered for this study:

i. Retreat Pathway, where climate change is permitted to take its course and development is progressively moved out of the way as it becomes impacted.
ii. Maintain Pathway, existing development rights are protected and continued into the future through redevelopment, but no additional development is permitted within high hazard areas.
iii. Intensify Pathway, where new coastal protection works are constructed that allow for additional coastal development and intensification of land use at isolated coastal nodes and infill areas.

Table ES.3 provides a summary of the results of a cost-benefit analysis (CBA) of the three adaptation pathways. More detailed results and a full listing of assumptions and rates used is provided in Appendix G.

Table ES.3 Cost-benefit analysis, the total NPV is cost of damage to assets less the cost of adaptation responses (NPV $million)

Retreat	CoF	high	$–	$–	$53	natural	no		$53
	CoC	high	$–	$–	$61	natural	no		$61
	CoK	extreme	$–	$4	$5	natural	no	--	$9
	CoR	high	$–	$–	$47	natural	no		$47
Maintain	CoF	medium	$–	$8	$2	modified	minimal		$10
	CoC	medium	$6	$8	$4	modified	minimal		$19
	CoK	medium	$2	$14	$0	modified	minimal	+	$17
	CoR	medium	$14	$8	$2	modified	minimal		$24
Intensify	CoF	low	$–	$11	$–	artificial	significant		$11
	CoC	low	$4	$16	$–	artificial	significant		$19
	CoK	low	$2	$28	$–	artificial	significant	++	$30
	CoR	low	$3	$30	$–	artificial	significant		$33

Notes.

1. LGA = local government areas
2. CoF = City of Fremantle
3. CoC - City of Cockburn
4. CoK = City of Kwinana
5. CoR = City of Rockingham
6. -- = significantly negative impact
7. + = positive impact
8. ++ = significantly positive impact

The Retreat Pathway results in no costs for adaptation works except the soft protection works for the Kwinana industrial area, vegetation management and removal of assets to allow for landward migration of natural areas such as beaches. This pathway does, however, result in significant costs to private landowners and community members by the loss of assets not reaching the end of their economic life, urban land (CoR), parklands (to let beaches move landward), heritage areas and importantly the loss of Bathers Beach which is projected to become permanently inundated over time. The total net present value of these costs is $170 million, if adopted consistently along the coastline.

The Maintain Pathway is likely to be the least costly adaptation pathway with a net present cost of $70 million, if adopted consistently along the coastline. The costs would predominantly involve coastal protection works for existing assets (beach nourishment) and the reconfiguration of infrastructure, at $40 million and $22 million, respectively. Although all assets would be allowed to reach the end of their economic life, there would be a loss of park, heritage and urban land by 2110.

The Intensify Pathway has a total net present cost of $94 million, if adopted consistently along the coastline. The most significant costs are the physical works, which include the construction of artificial beaches and seawalls, with a net present cost of $93 million. All the recreation and urban beaches would be maintained in their current locations. The character of these beaches would, however change significantly. The beaches would have artificial character and would be narrow compared to the Retreat Pathway and the Maintain Pathway.

The Owen Anchorage and Cockburn Sound coastline will evolve very differently under each of these pathways. It is anticipated that future integrated management of the coastline will likely adopt a patchwork of adaptation pathways, each section of the coastline being best suited to a particular pathway to protect the particular values at risk. The following broad pattern of adaptation pathways is suggested in the Stage 2 Assessment:

- The CoF coastline, South Beach and Bathers Beach, are suited to the Maintain Pathway or the Intensify Pathway.
- The CoC coastline is suited to the Maintain Pathway or the Intensify Pathway.
- The CoK coastline would be suited mostly to the Intensify Pathway.
- The CoR coastline would be suited to the Maintain Pathway.
- Small pockets of coastline (mostly within existing conservation areas) would be suited for the Retreat Pathway.
- Eastern shoreline of Garden Island would be suited for the Retreat Pathway (subject to further discussions with DoD).

To provide a greater level of detail on the application of the adaptation pathways, the Owen Anchorage and Cockburn Sound coastline was divided into management units based on coastal processes data from the Stage 1 Assessment, specific asset boundaries and LGA boundaries (Figure ES.1). Within these management units, appropriate adaptation pathways with specific management measures were proposed with consideration of the highest values at risk (Table ES.4). As part of this first-pass adaptation assessment, generic triggers for implementation of management actions were also identified (Table ES.4). These triggers determine the timeframe for adopting adaptation measures and allow the LGAs to incorporate adaptation planning into longer term strategic initiatives, while also addressing the most urgent risks.

Recommendations for Stage 3 Adaptation planning

It is important to note that the Stage 2 Assessment comprises a first-pass adaptation assessment only and it is necessary that the Stage 3 Adaptation Plan further develop these pathways and triggers to tailor them for each section of the coastline based on targeted stakeholder/community discussions and further in-depth shoreline studies and monitoring. Further work must also recognise the interactions between the adaptation pathways, assets and management units at a local scale.

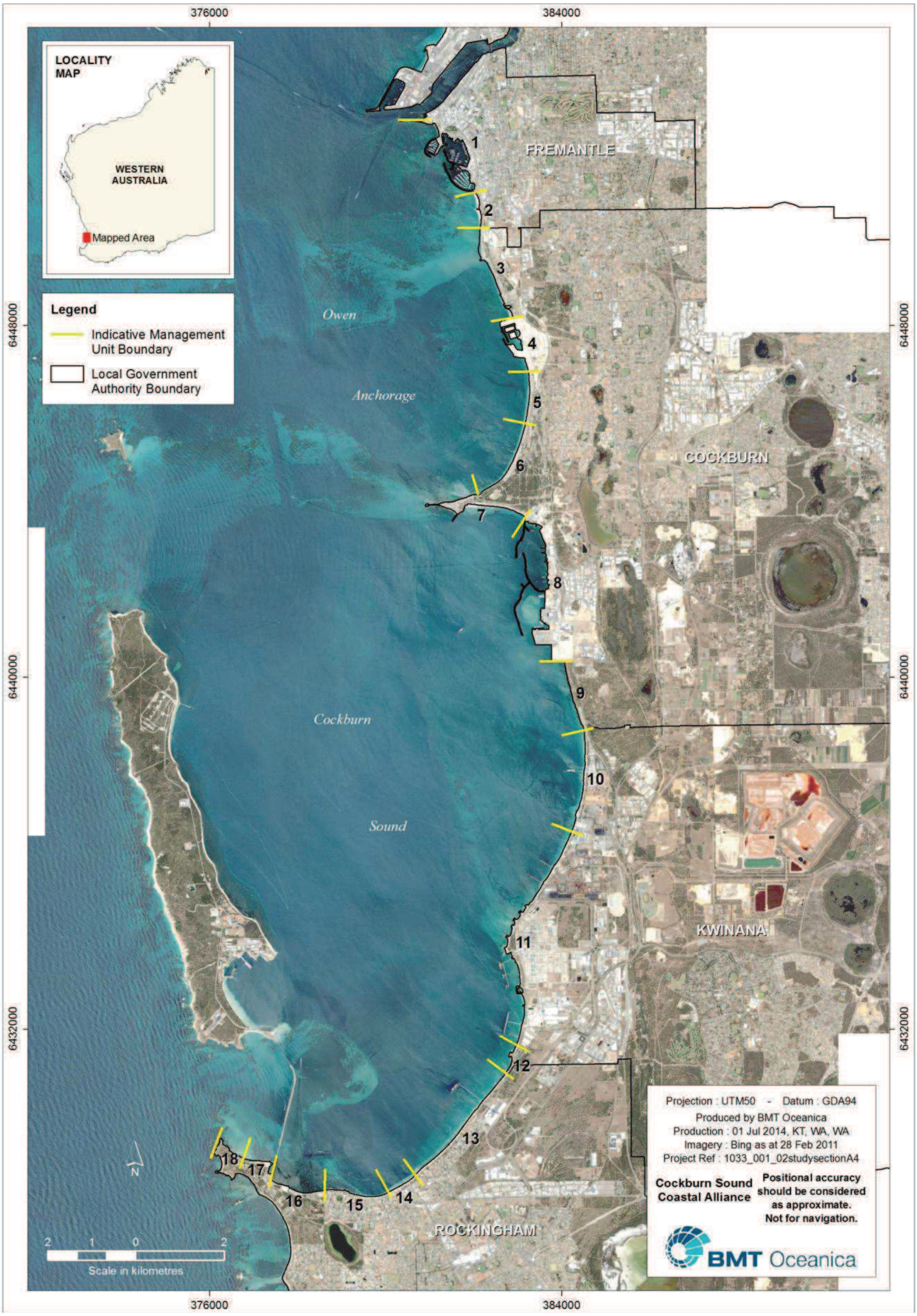


Figure ES.1 Indicative management units

Table ES.4 First-pass adaptation pathway assignment

1	South Mole	North boundary of South Beach	Boat Harbours and Heritage Areas	2 - Maintain	Increase height of breakwater	Breakwater overtopping >1/yr (average)	3 - Intensify	Initiation subject to development opportunities
2	North boundary of South Beach	North boundary Pickled Fig Café	South Beach and Heritage Areas	2 - Maintain	Sand nourishment, dune restoration	Net dune retreat >20 m	-	-
3	North boundary Pickled Fig Café	South extent of Robb Road	Power Station Redevelopment Site (Cockburn Coast), C. Y. O'Connor Reserve	2 - Maintain	Sand nourishment, dune restoration	Net dune retreat >20 m	3 - Intensify	Initiation subject to development opportunities
4	South extent of Robb Road	Socrates Road/Pelinte View intersection	Port Coogee	2 - Maintain	Increase height of breakwater	Breakwater overtopping or ocean inundation >1/yr (average)	3 - Intensify	Initiation subject to development opportunities
5	Socrates Road/Pelinte View intersection	South boundary of Coogee Beach Surf Life Saving Club	Coogee Beach Reserve	1 - Retreat	Dune management	Nil	2 - Maintain	Restore/maintain existing conditions when net dune retreat >20 m
6	South boundary of Coogee Beach Surf Life Saving Club	West boundary of Jervoise Bay Sailing Club	Woodman Point Regional Park	1 - Retreat	Decommissioning of structure	Asset compromised by erosion	2 - Maintain	Protect/maintain existing conditions when net dune retreat >20 m
7	West boundary of Jervoise Bay Sailing Club	West boundary of Woodman Point Facility	Woodman Point Regional Park, Cockburn Cement Washplant	1 - Retreat	Relocation of asset, sand nourishment, dune restoration	Asset compromised by erosion	2 - Maintain	Protect/maintain existing conditions when net dune retreat >20 m
8	West boundary of Woodman Point Facility	South boundary of Australian Maritime Complex	Woodman Point Facility and Australian Maritime Complex	3 - Intensify	Initiation subject to development opportunities		-	-
9	South boundary of Australian Maritime Complex	South boundary of Naval Base Shacks camp ground	Henderson Cliffs Reserve	1 - Retreat	Nil	Nil	-	-
10	South boundary of Naval Base Shacks camp ground	South boundary of Kwinana Power Station	Challenger Beach, Alcoa, Kwinana Power Station	2 - Maintain	Relocation or protection of asset, sand nourishment, dune restoration	Erosion within 10 m of asset	3 - Intensify	Initiation subject to development opportunities
11	South boundary of Kwinana Power Station	South boundary of Kwinana Bulk Jetty	Kwinana Industries	3 - Intensify	Initiation subject to development opportunities		2 - Maintain	Protect existing conditions when erosion within 10 m of asset
12	South boundary of Kwinana Bulk Jetty	Local govt boundary at coastline	Wells Park, The Wreck	2 - Maintain	Increase height of breakwater	Breakwater overtopping >1/yr (average)	-	-
13	Local govt boundary at coastline	Wanliss Street	Rockingham Beach, CBH Grain Terminal	2 - Maintain	Sand nourishment, dune restoration	Net dune retreat >20 m	-	-
14	Wanliss Street	Railway Terrace	Bell and Churchill Park	2 - Maintain	Sand nourishment, dune restoration	Asset (promenade) exposed by erosion	3 - Intensify	Initiation subject to development opportunities
15	Railway Terrace	Hymus Street	Palm Beach	2 - Maintain	Sand nourishment, dune restoration	Net dune retreat >20 m	3 - Intensify	Initiation subject to development opportunities
16	Hymus Street	Causeway	Causeway	2 - Maintain	Protection of asset, sand nourishment, dune restoration	Asset compromised by erosion	-	-
17	Causeway	Western boundary of Point Peron Recreational Camp	Point Peron Recreational Camp	1 - Retreat	Decommissioning or relocation of asset	Asset compromised by erosion	2 - Maintain	Protect/maintain existing conditions when net dune retreat >20 m
18	Western boundary of Point Peron Recreational Camp	End of peninsula	Point Peron – Rockingham Lakes Regional Park	1 - Retreat	Decommissioning or relocation of asset	Asset compromised by erosion	-	-

Note:

1. The scales of these triggers are generic and detailed shoreline studies and monitoring (as part of the Stage 3 Adaptation Plan) will be necessary in order to refine them for each management unit. Where triggers appear unfeasible e.g. there is less than 20 m of dune width available, this may be an indication that the management actions may already need to be undertaken.

1. Introduction

The Cockburn Sound Coastal Vulnerability Values and Risk Assessment documented herein (hereafter Stage 2 Assessment) forms the second stage of the Cockburn Sound Coastal Vulnerability and Flexible Adaptation Pathways Project, commissioned by the Cockburn Sound Coastal Alliance (CSCA). The CSCA comprises the Cities of Fremantle (CoF), Cockburn (CoC), Kwinana (CoK), Rockingham (CoR) and the Perth Region NRM. The Department of Defence (DoD), the Cockburn Sound Management Council (CSMC), Department of Transport, Department of Planning and the Department of Environment Regulation are key stakeholders.

The Cockburn Sound Coastal Vulnerability and Flexible Adaptation Pathways Project comprises four phases and is scheduled to be completed over the next 2 years. The Stage 1 Climate Change Vulnerability Assessment of the Coastal Zone of Cockburn Sound and Owen Anchorage (hereafter Stage 1 Assessment) (CZM et al. 2013) identified areas exposed to erosion and inundation hazards with future sea level rise (see to Section 3). The Stage 2 Assessment (herein) applies the Stage 1 Assessment hazard mapping to identify the cost of risk of the coastal assets and presents a first-pass adaptation approach. Outcomes of the Stage 2 Assessment are to be reviewed and used in the Stage 3 Adaptation Plan Development to provide a strategy for coastal management of the Owen Anchorage and Cockburn Sound coastline incorporating prioritised options to treat present and future coastal hazards.

1.1 The team

This Stage 2 Assessment was undertaken by BMT Oceanica Pty Ltd (BMT Oceanica), BMT WBM Pty Ltd (BMT WBM), Coastal Zone Management Pty Ltd (CZM), SGS Economics and Planning Pty Ltd (SGS) and Damara WA Pty Ltd (Damara)), hereafter collectively termed 'the Team'.

1.2 Study area

The study area is the coastal strip between South Mole, CoF, and Point Peron, CoR, and includes the eastern coastline of Garden Island between Beacon Point and the Causeway (Figure 1.1).

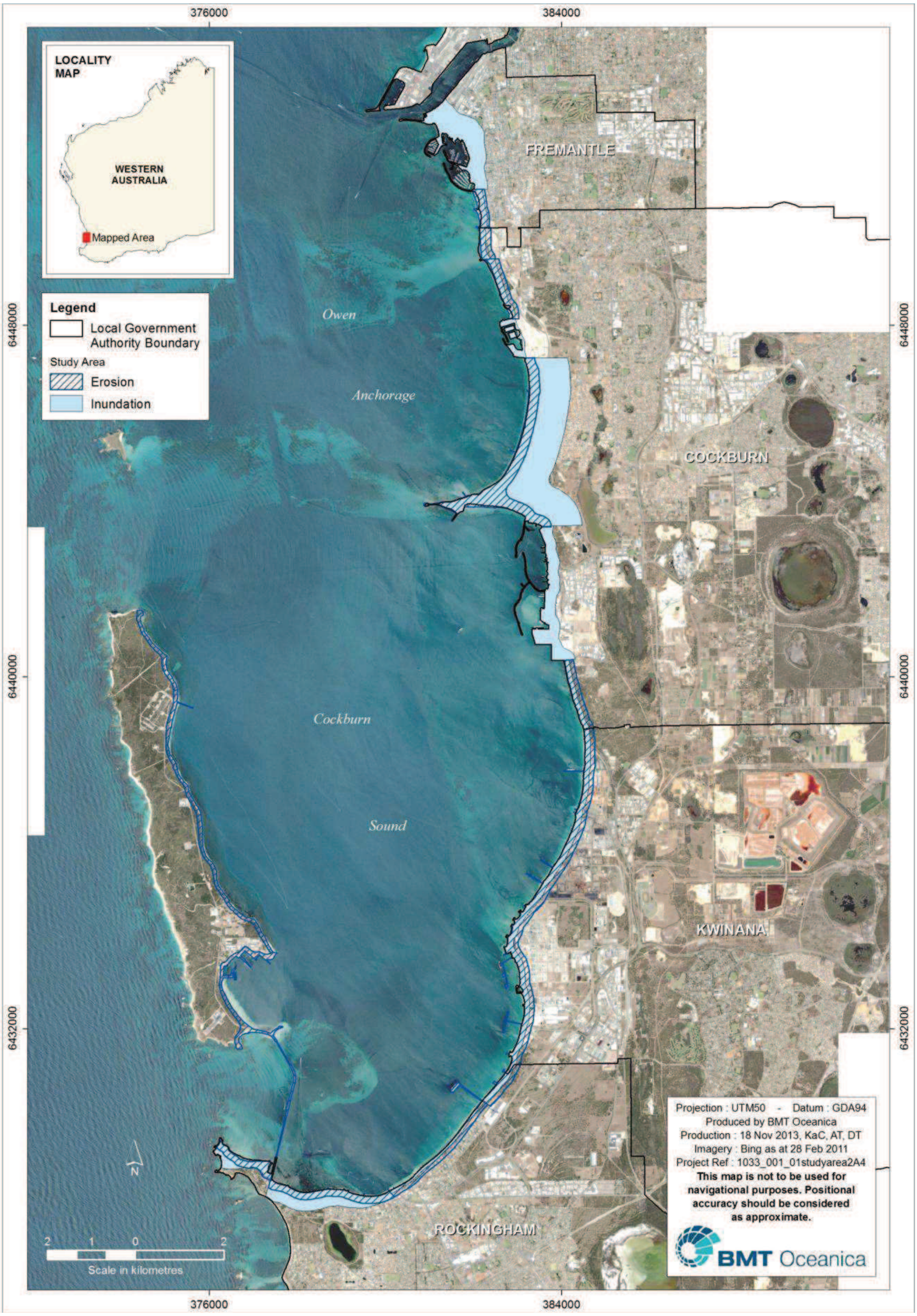


Figure 1.1 Study area

1.3 Motivation

The Owen Anchorage and Cockburn Sound coastline is complex, characterised by relatively low-energy, fetch-restricted, wave-impacted beaches as well as more exposed, rocky systems. Along this coastline there are a variety of land uses – including industrial, recreational, residential and commercial development – making the area vital to the local and state economies and to social values.

The four local government authorities (LGAs) in the study area and the DoD are responsible for coastal infrastructure such as coastal protection, buildings, recreational facilities, coastal roads, pathways and nearshore services. These infrastructure resources, and those of other government agencies and private interests along the coastal strip, are at the frontline in terms of coastal erosion and inundation hazards. The associated impact (in economic, social and environmental terms) of these coastal hazards is therefore potentially very high. With the future threat of anthropogenic climate change and the associated sea level rise, the occurrence and severity of coastal hazards will increase, enhancing the requirement for coastal management.

The CSCA was formed to facilitate cooperation and integration of management and adaptation along the shared coastline. The LGAs in the CSCA presently regulate development within their coastal zone with consideration of associated risks from coastal hazards. This largely occurs as a component of Town Planning Schemes, which are required to consider the State Planning Policies. The Royal Australian Navy also manage their assets with an awareness of shoreline change and water level fluctuations within their environmental sustainability programs, and are involved in planning strategies that address environmental concerns.

To effectively manage coastal assets, now and in the future, it is necessary to first understand the exposure and sensitivity of the surrounding coastline to the potential impacts of natural variability and climate-induced change and, second, to determine the value of the assets at risk to inform a framework for adaptation.

The Stage 1 Assessment (CZM et al. 2013) defined the areas at risk from coastal hazards (erosion and inundation) at present and into the future, incorporating both natural variability and climate change induced sea level rise. The Stage 2 Assessment (herein) has built on these outcomes to identify the assets (natural and built) at risk from these hazards and incorporates a values and risk assessment to provide a prioritisation for coastal adaptation. This assessment includes a first-pass assessment of adaptation options for assets identified as at high or extreme risk from coastal hazards.

1.4 Climate change scenarios

During the Stage 1 Assessment (CZM et al. 2013) climate change scenarios were defined, in conjunction with the CSCA, for the following timeframes: present day, 2070 and 2110. The scenarios were developed consistent with available projections and the State Coastal Planning Policy (SPP2.6; see Section 2.1.1). The associated sea level rise for each of the timeframes analysed were +0 m (present day), +0.5 m (2070) and +0.9 m (2110) (DoT 2010). For the Stage 1 Assessment, the CSCA requested that analysis include a sea level rise of +1.5 m to account for a high-end (worst-case) sensitivity for 2110. This approach recognises the sequential nature of coastal adaption. Please refer to Section 3.6.2 for further details.

1.5 Objectives

The objectives and approach for the Stage 2 Assessment is summarised in Table 1.1 below.

Table 1.1 Approach to address project objectives

Facilitate understanding of coastal hazards and risk management among stakeholders	Communication with stakeholders occurred throughout the project and included direct discussion via phone calls and emails, presentations and workshops.	5
Prepare asset register	Asset data (supplied by the CSCA) were used to develop the asset register.	6
Determine the likelihoods of coastal hazards	Using a risk-based approach, the likelihood of impacts to coastal assets from coastal hazards (erosion and inundation as established in the Stage 1 Assessment) at each timeframe was determined taking into account the assumptions and limitations of the Stage 1 Assessment.	8.1
Identify the market, social and ecosystem values of assets at risk	An initial assessment of asset values was established using the existing datasets, which was informed by stakeholder consultation. This was input into a more detailed valuation assessment to determine the market, social and environmental values of the assets based on the goods, services and functions they provide. This was used to establish the overall asset value (using a consistent metric of dollars).	7.1
Determine consequence	The consequences of coastal hazard impacts on the assets were determined based on the asset values. These consequences were then confirmed through stakeholder consultation (both direct liaison and via workshop).	8.2
Identify the 'cost of risk' of coastal assets for present day, 2070 and 2110	The 'cost of risk' was determined by analysing how an asset will be affected by the coastal hazard. It was assumed that an erosion hazard would result in total loss of an asset but inundation may only mean a partial loss or a reduction in value of an asset.	7.5
Quantify the coastal risks	The likelihood and consequence of the hazards (both erosion and inundation) were used to determine the level of coastal risk which was mapped and tabulated.	8.2
Identify and evaluate potential adaptation options for vulnerable areas	A range of potential coastal management options were considered and assessed for relevance to treat coastal risks along the Owen Anchorage and Cockburn Sound coastline. These options were reviewed in light of local knowledge from the stakeholders during the Risk Management Options Workshop, specifically relating to local issues and the effectiveness of management actions already in place. The efficacy of the management options and pathways were reviewed using a cost-benefit approach to provide an initial assessment of the optimal course of action for coastal adaptation and management.	5.3.4, 9
Identify critical data gaps	Through the process of developing the asset inventory and values and risk assessments, data gaps were identified and documented.	10.4.1
Share best practices and lessons learnt	Through the completion of this Stage 2 Assessment, we have used methods for values and risk assessment that have been successful in a number of previous studies, incorporating both national and international best practice. We have documented these methods herein and thereby facilitate the sharing of best practice and lessons learnt from this and previous projects.	Whole document

2. Coastal Management Framework in Western Australia

2.1 Coastal Zone Management Policy

The present and future vulnerability of Western Australia's coastline to erosion and inundation hazards is recognised in the *Coastal Zone Management Policy for Western Australia* (prepared by the Western Australian Planning Commission; WAPC 2001). This document details the State Government's policy of coastal planning and management and in doing so provides a framework and objectives for the management of the coastal zone and the assets within this zone. The coastal zone management objectives are categorised into environmental, community, economic, infrastructure and regional development objectives. This Policy emphasises the requirement for coherence and coordination between policies and plans for the implementation of an integrated approach to coastal zone management.

Operating under this Policy are the *State Coastal Planning Policy* (SPP2.6) (WAPC 2013) and the *Coastal Protection Policy* (prepared by Department of Planning and Infrastructure; DPI 2006).

2.1.1 State Coastal Planning Policy

The *State Coastal Planning Policy* (SPP2.6) is enacted under Part 3 of the *Planning and Development Act 2005* and was gazetted in July 2013 (WAPC 2013). SPP2.6 applies throughout Western Australia and is supported by other WAPC state planning policies, development control policies and guidelines relevant to the coastal zone.

The purpose of SPP2.6 is to provide guidance for decision-making within the coastal zone including managing development and land use change, establishment of foreshore reserves, and protecting, conserving and enhancing coastal values. The Policy provides a framework for coordinating agencies' activities with those of the private sector to ensure an integrated approach to coastal planning. Coastal hazard risk management and adaptation planning form a major part of the Policy's requirements. The Policy also provides guidance for private landowners wishing to undertake development in the coastal zone, specifically in relation to the calculation of setbacks.

From the consultation process for the Stage 2 Assessment, it is understood that the Department of Planning are developing coastal hazard risk management guidelines to provide additional assistance to development proponents and regulators in the interpretation of SPP2.6.

2.1.2 Coastal Protection Policy

The Coastal Protection Policy (DPI 2006) provides a framework for the appropriate allocation of funding for coastal adaptation works to mitigate the risks of coastal hazards and aims to build partnerships with local managers by facilitating the understanding of adaptation to coastal hazards. This is done through the Coastal Adaptation and Protection (CAP) grants scheme which is administered by the Department of Transport (DoT). In addition to financial assistance, the DoT also provides engineering and technical support, coastal data, guidance and advice.

2.2 Other planning guidelines

In addition to these state-wide policies, each of the LGAs have their own planning policies and coastal management plans for specific sections of the coast and/or specific developments. These have either been informed by, of are to be implemented alongside, SPP2.6. It is intended that the Cockburn Sound Coastal Vulnerability and Flexible Adaptation Pathways Project will set out a strategic framework that will guide and inform the future coastal management plans for this coastline and allow for an integrated response to present and future coastal hazard risks.

New federal guidelines were released in 2013 by the Commonwealth Department of the Environment in the form of a 'Climate Adaptation Outlook' for Australia. This document provides a national framework for the adoption of climate change risk assessments at the state and local level.

3. Overview of Coastal Processes and Hazards

The physical processes along the Owen Anchorage and Cockburn Sound coastline were assessed during the Stage 1 Assessment to provide an understanding of the coastal system in this area (CZM et al. 2013). This assessment was based on data and literature available at the time, including LiDAR (light detection and ranging) and LADS (Laser Airborne Depth Sounder) data. An overview of this assessment is detailed in the sections below and provides context for the Stage 2 values and risk assessment.

3.1 Geological and geomorphological setting

The geological setting of the Owen Anchorage and Cockburn Sound coastline has been described in detail by previous studies (Fairbridge 1950, Playford et al. 1976, France 1977, Searle & Semeniuk 1985, Cockburn 1986, Semeniuk & Searle 1987, Searle et al. 1988, DAL 1998, Skene et al. 2005, Oceanica et al. 2008). This coastline is characterised by a complex suite of submarine geological features. Overlying and interacting with these submarine features is a highly variable veneer of sedimentary features including sand banks, sand sheets, perched beaches and terraces (Figure 3.1).

There are four main rock ridges that have each played different roles in affecting the supply and distribution of sediment to the coastline. The outer two ridges (Five Fathom Bank, Garden Island Ridge) bound Sepia Depression and isolate the coast from the offshore shelf sediments (Figure 3.1). Gaps in the Garden Island Ridge have provided focal zones for the onshore movement of sediment, with influx south of Garden Island and at Success and Parmelia Banks. The Jervoise Bank Ridge has enabled retention of the wide flat basin in Cockburn Sound and has anchored the Kwinana coast south of James Point. The Spearwood Ridge has provided control for much of the modern coastline, with cliffs and perched beaches present at Spearwood and Henderson. These features effectively transfer fluctuations in sediment supply, which contribute to beach extension or contraction, along the line of the ridge. Success and Parmelia Banks are active sediment feeds for the coastline. The geological controls along the Owen Anchorage and Cockburn Sound coastline have constrained sediment availability and focused its distribution, such that present-day sedimentary features are still responding to previous episodes of sea level rise.

Much of the coastal plain close to the shoreline is composed of relatively modern sedimentary landforms, mainly foredune plains. This newer material is low-lying and will likely be more susceptible to reworking and modification than older material found at the northern extent of Cockburn Sound and in the vicinity of Fremantle. There are Tamala Limestone outcrops present along the coast at James Rocks in Owen Anchorage, from Russel Road to Naval Base, at Point Peron in Cockburn Sound; and at Cliff Point, Dance Head and Second Head on Garden Island.

Within the coastal plain there are a variety of coastal morphologies that have occurred in response to the varying aspects and exposures to locally relevant processes (winds, waves and water levels), the nature of sand supply (onshore or alongshore) and interaction with the rock features. In many cases, the morphology has been modified by the long history of active coastal management along the coast (Section 3.4). This diverse range of coastal landforms, with a number of landforms behaving differently to those found on more exposed open coasts, is of particular significance to the Stage 2 Assessment and will inform the range of management options that are potentially applicable to this coastline.

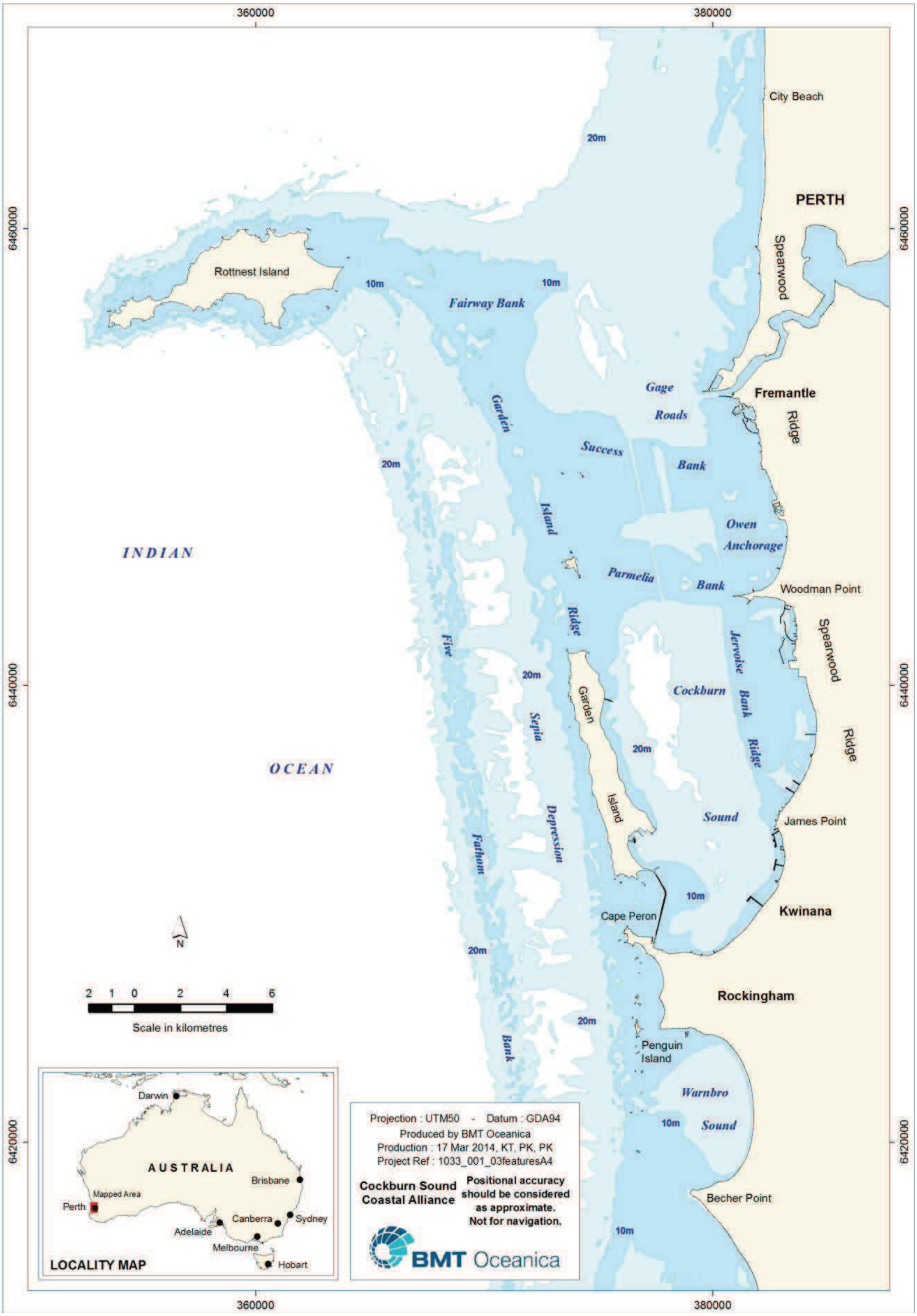


Figure 3.1 Key geological controls in Owen Anchorage and Cockburn Sound

3.2 Water levels

The Owen Anchorage and Cockburn Sound coastline is within a microtidal (mainly diurnal) tidal region (Easton 1970; NTF 2000). The very low tidal range experienced by the Owen Anchorage and Cockburn Sound coastline enables other (non-tidal) sea level processes to be comparable in scale, including seasonal and inter-annual mean sea level (MSL) variations, storm surge, continental shelf waves, seiching, meteotsunami and interannual tidal modulations (Eliot & Pattiaratchi 2007, Pattiaratchi & Eliot 2008). Furthermore, seasonal variations of tide, surge and MSL are almost coincident during May–July when high water levels can often occur (Eliot 2012).

A list of identified water level phenomena has been developed (Eliot & Pattiaratchi 2007; Pattiaratchi & Eliot 2008) and refined through further evaluation of individual processes and their interactions, with support through the WAMSI research program (Refer to Table 6 in the Stage 1 Assessment; CZM et al. 2013).

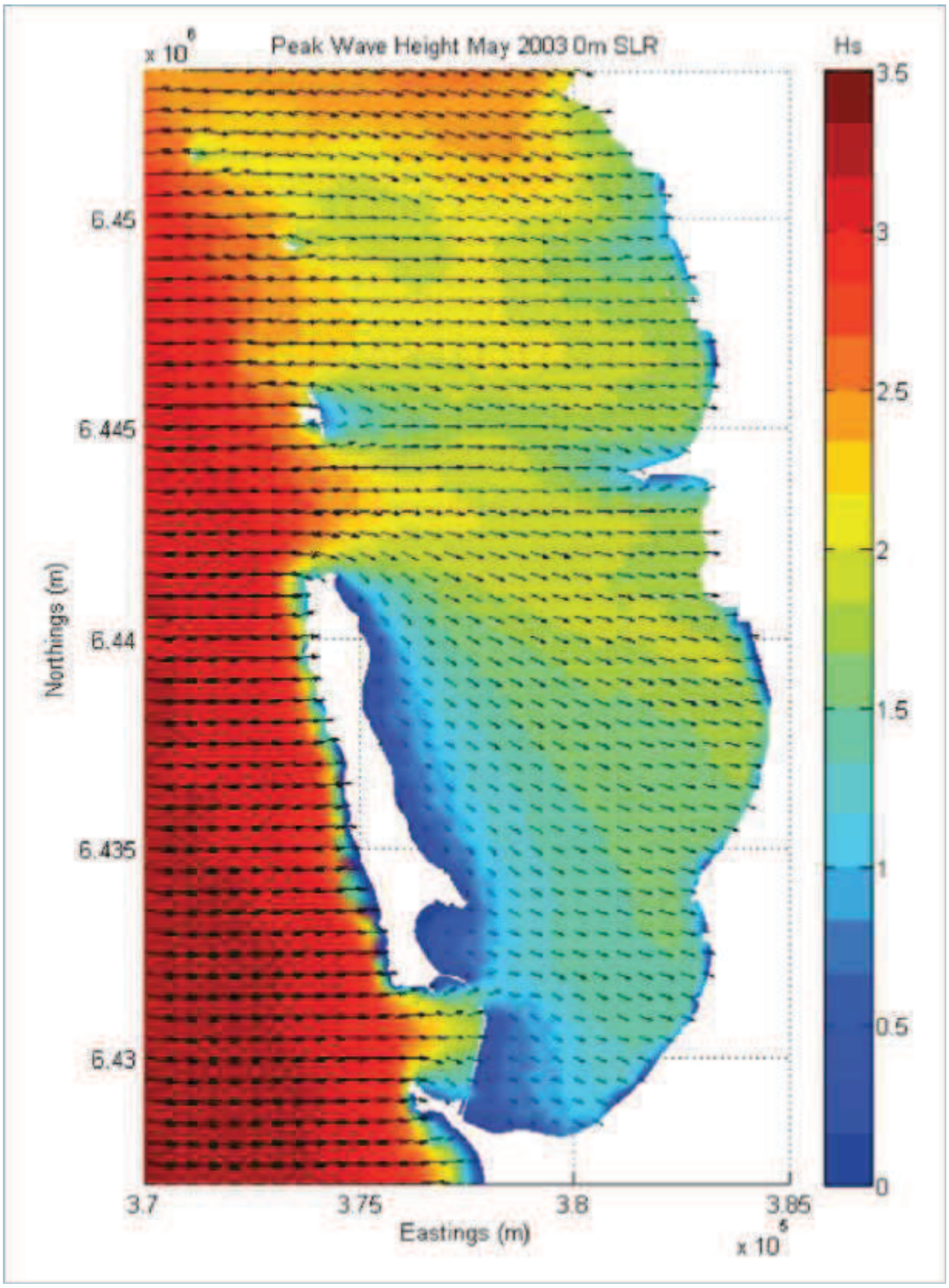
Overall, our existing knowledge of water level variability in the Owen Anchorage and Cockburn Sound suggests there is a high degree of uncertainty associated with the estimation of flood likelihood, whether generated by mid-latitude storms, tropical cyclones or other phenomena. The estimation of flood scenarios for the Stage 1 Assessment therefore made allowances for this uncertainty and recognised the limitations of nominating an event recurrence interval.

3.3 Wind and wave climate

The Owen Anchorage and Cockburn Sound coastline is within a temperate extra-tropical region, which experiences prevailing influence from diffuse high pressure systems, occasional influence from mid-latitude low pressure cells or fronts and the rare influence of tropical systems (Gentilli 1971). These synoptic conditions provide a distinct seasonal shift with a strong diurnal land-sea breeze cycle common during summer months and more variable conditions during winter months, typically swinging from mild north-east winds to intense westerlies associated with storm events (Steedman & Craig 1979; Masselink & Pattiaratchi 2001). Storms may occur at any time of year but are most prevalent during winter months.

Wave conditions affecting the broader south-west region are indirectly related to the observed wind patterns, with predominant waves generated by mid-latitude systems propagating from the south-west, resulting in a prevailing south-west swell offshore. Wave conditions outside the Garden Island ridge have been recorded using a permanent waverider buoy deployed offshore from Rottnest since 1994, which has also measured directional information since 2004 (Lemm et al. 1999, Li et al. 2009). Offshore wave conditions, as measured from the Rottnest waverider buoy, are typically 1–2 m median significant wave height (Hs) during summer, and 2–3 m Hs during winter, with higher conditions during westerly (south-west through north-west) storm events (Roncevich et al. 2009). The highest wave event recorded at this location was 8.44 m on 21 July 2009.

The offshore waves are modified before they reach the shore through interaction with the bathymetry, including diffraction around islands and breaking across the extensive limestone reef chains and platforms (e.g. Figure 3.2). Additional energy is introduced through local wind wave generation, of which the most distinct is produced by strong southerly sea breezes (Pattiaratchi et al. 1996). The Owen Anchorage and Cockburn Sound coastline has a variable wave climate as a result of the sheltering by Garden Island and the outer reefs. Owen Anchorage is generally more exposed to ocean waves and Cockburn Sound (including Garden Island east coast) is more exposed to wind waves. In Cockburn Sound the variable wave fetches provide local changes in prevailing and dominant wave conditions that vary around the Sound, with local divergences in the mean direction of incoming waves (Travers 2007).



Source: CZM et al. 2013

Figure 3.2 Distribution of peak wave energy though the study area, May 2013 storm, present sea level

One major effect of the sheltered coastal environment for the Owen Anchorage and Cockburn Sound coastline is the capacity for both seasonal and episodic changes in dominant wave direction. The balance between swell penetration (shifting from west through to northerly around the Sound) and wind waves from storms (westerly), sea-breezes (south-south-west) or easterly winds may be subtle, with fluctuations causing a large shift in the effective wave direction. The coastal response to such a change was dramatically and permanently illustrated at James Point whereby a net southward sediment flux occurred following construction of the Garden Island Causeway (CZM et al. 2013).

3.4 Existing structures

The Owen Anchorage and Cockburn Sound coastline has been extensively modified via numerous coastal structures including groynes, jetties, breakwaters, boat ramps and intakes/outfalls (Figure 3.3, Figure 3.4). The presence of these structures has an important influence on local sediment transport patterns and nearshore hydrodynamics to varying degrees over time (Oceanica 2010a,b). Structures typically modify longshore sediment transport pathways, particularly when they extend offshore, and hence their installation may affect shoreline stability within the surrounding sediment cell. In particular, large structures such as the Garden Island Causeway and Woodman Point groyne have isolated Cockburn Sound from significant longshore feeds from the north and south.

Many of the structures installed along the Owen Anchorage and Cockburn Sound coast were deliberately installed either to improve coastal stability or to isolate facilities that could be adversely affected by sedimentation.

Along the north of the Owen Anchorage coastline, around South Beach, sediment retention is apparent at the southern side of groyne-controlled sub cells, with a change of direction between the Bradken Seawall and Catherine Point Groyne (Figure 3.3). The groyne at Catherine Point is saturated on its northern side with episodic erosion occurring on its south side. Other old structures between Catherine Point and Port Coogee are completely smothered by sand. The more recently created ‘infill’ area between the South Fremantle Power Station and Port Coogee is actively accumulating sediment, at a forecast rate of 33,000 m^3/annum (Hamilton & Hunt 2011). The influence of recent reconstruction of Catherine Point groyne to its pre-existing length has not yet been established, although it is intended to increase the northward sediment supply and reduce the southward transport. Jetties along Coogee Beach do not apparently trap sediment in the present beach configuration.

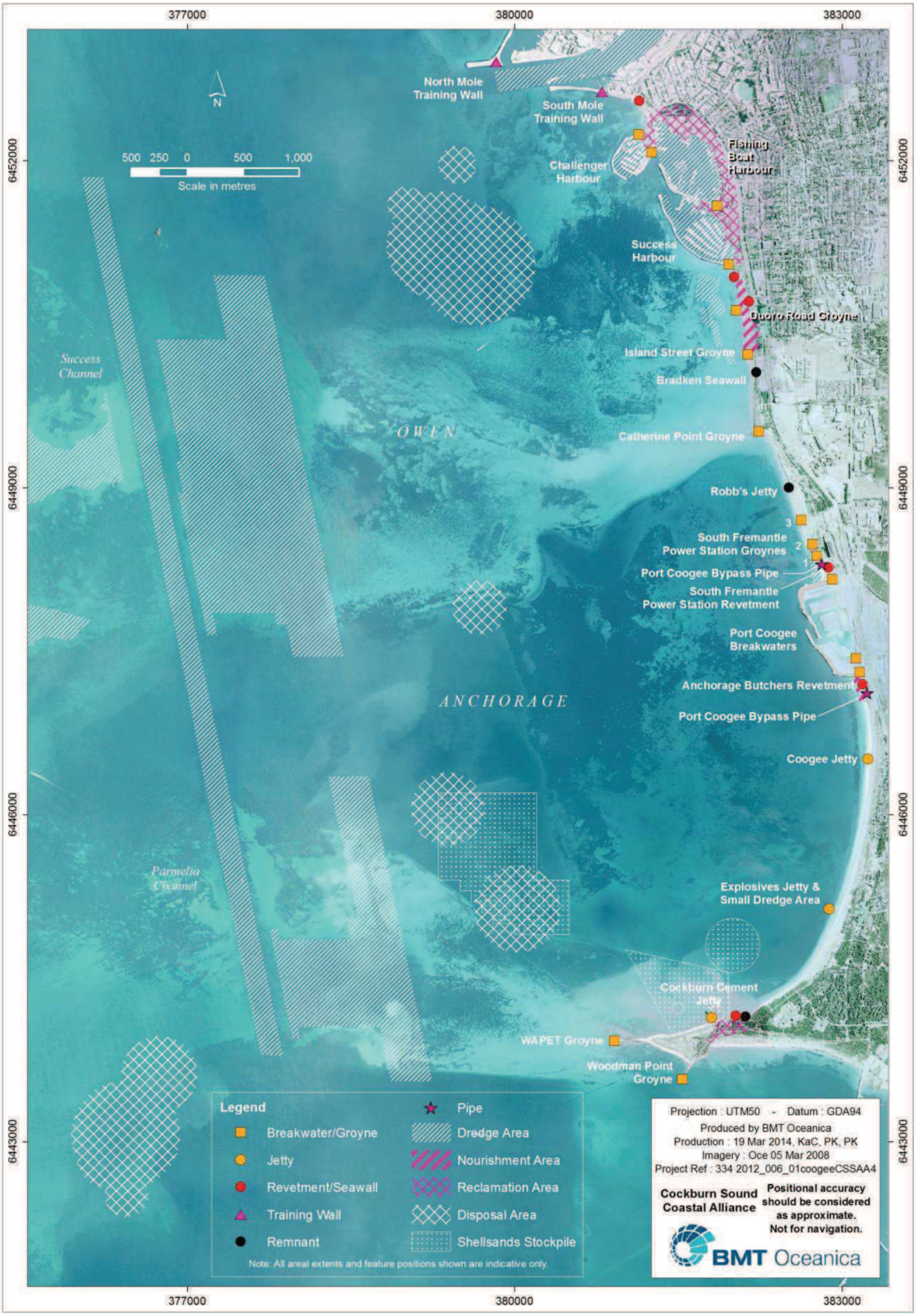


Figure 3.3 Coastal modifications in Owen Anchorage

Figure 3.4 Coastal modifications in Cockburn Sound

Woodman Point has been highly modified through groyne construction and reclamation activities (Figure 3.3). The reclaimer area at Woodman Point has a large influence on the coastal position, but is artificially managed and the coastal response is not considered a gauge of the response to active coastal processes. West Beach, between Woodman Point and Jervoise Bay Harbour, was originally developed in response to groyne construction. It has subsequently been subject to a short erosive episode, but has not recovered; this suggests a cut-off of supply as this area has the potential to be a sediment sink to any sediment bypassing the groyne. South of the Jervoise Bay Boat Harbours (Figure 3.4), the coastline in the Henderson area is controlled by natural rock formation up to the Alcoa Jetty area. From there to James Point, the jetties and other structures (generally short cross-shore length) presently have a minor influence on the shoreline alignment, with some accumulation apparent on the northern side of the Verve Cooling Canals.

Offshore breakwaters were installed at James Point to provide shore stabilisation following construction of Garden Island Causeway. It is understood that these will have a reduced effect under sea level rise scenarios, particularly when associated with coastal recession. South of James Point, sediment accumulation is apparent on both sides of BP's facilities. However, there is a general pattern of accumulation on the northern side of structures, the most significant being the Kwinana wreck, which required installation of two detached groynes to reduce the effect of downdrift erosion (DPI 2004). Structures in and around the southern part of the Sound are all short in extent and are generally saturated with sand on their western side. Some variation in transport directions has been identified in the Mangles Bay area, suggesting that it may have nearly a neutral direction of transport following installation of Garden Island Causeway (MP Rogers & Associates 2008, TABEC & JFA Consultants 2011).

The study area is highly modified by a wide variety of interventions that have caused a myriad of responses by the coastline at a local and regional level. There is a lag response to structural intervention and the system as a whole is likely to still be responding to some of the more significant previous works due to the low energy nature of this coastline. The Stage 1 Assessment assumed that future climate change impacts would arise from the combined influence of sediment supply, sediment transport and coastal management, including defences. To unravel these complexities, the Stage 1 Assessment assessed the distribution of climate-change driven erosion potential, or ‘stress' across the study area. A key simplifying assumption from the Stage 1 Assessment was that all existing coastal protection structures remain at current performance into the future.

3.5 Coastal change

During the Stage 1 Assessment, the major mechanisms of coastal change along the Owen Anchorage and Cockburn Sound coastline were determined via interpretation of aerial photographs, profile data and LADS bathymetry. Key determinants of coastal change include the:

- underlying geological framework that determines the coastal partitions (sediment cells) within which coastal change exhibits strong connectivity
- focused supply of sediment to the Owen Anchorage and Cockburn Sound coastline occurring at discrete locations, which include Catherine and Woodman Points, along with supply south of Garden Island that has been partly interrupted by construction of the Causeway
- significant anthropogenic modifications along the coast, including the massive deposition of dredged material, and installation of coastal structures (Section 3.4). In general, these works have acted to redistribute the alongshore sand supply, with larger structures such as the Garden Island Causeway, Catherine Point groyne and Port Coogee acting to modify the sediment cells

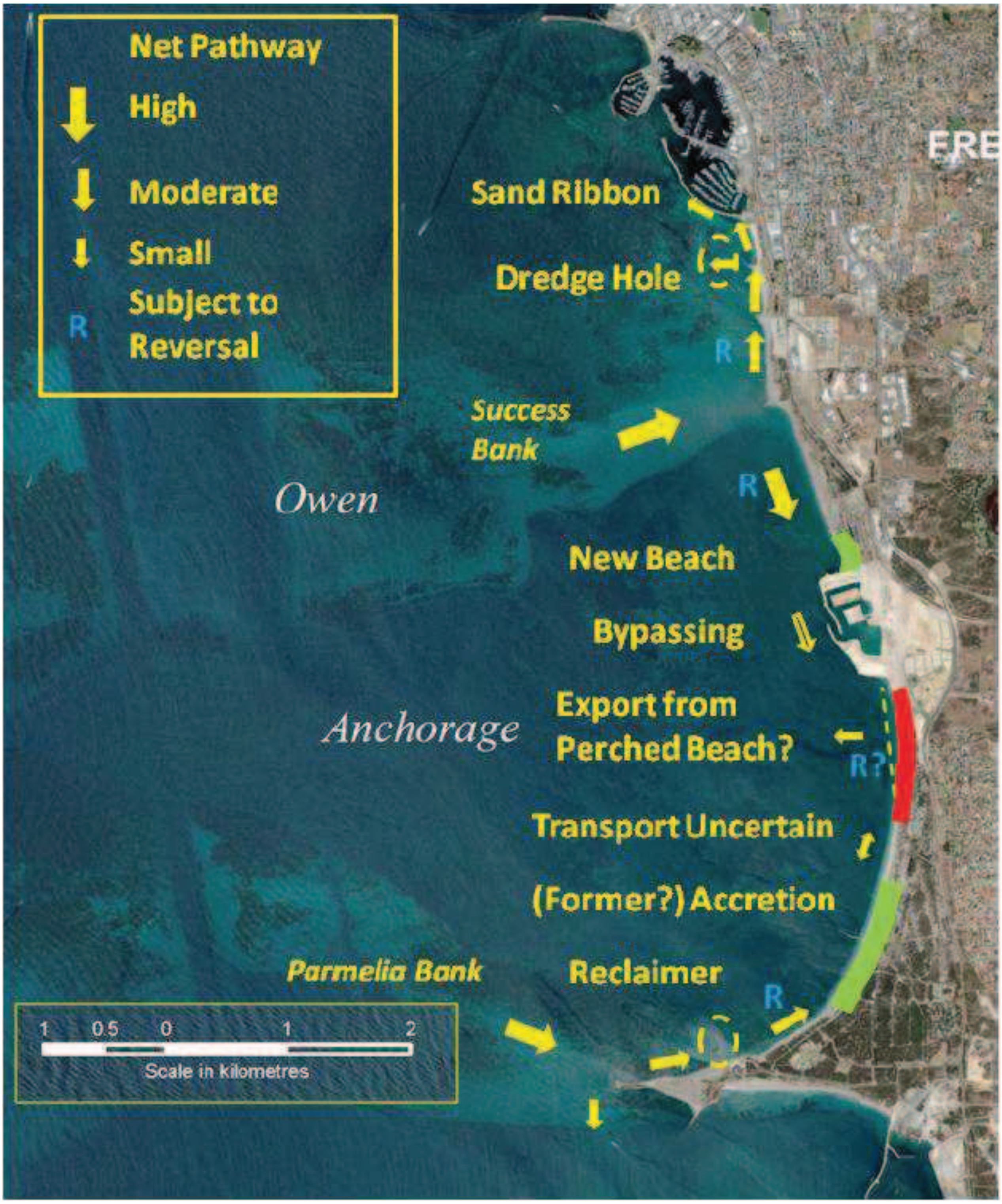
- infilling on Garden Island to the west of the Causeway and formation of the Careening Bay spit that provide evidence of supply to this area, with a sand ribbon adjacent to the north of the Causeway that also demonstrates the local sediment transport
- wave-driven longshore transport, the absence of tidal landforms (except the Careening Bay spit) suggests this is the dominant process with little contribution from currents
- relative balance of transport due to swell waves and locally-generated wind-waves. A portion of the observed coastal change relates to short- (storm) and medium- (1–5 year) term perturbations of this balance, resulting in erosion–recovery cycles
- terraced beaches that occur on Garden Island east coast and southern Cockburn Sound, which are characteristic of low-energy coast and may experience erosion–recovery imbalance. The sediment transport and associated coastal change may be discrete between the shore and the terrace margin.

Overall, there is a change in morphodynamics from the north to the south of the study area, shifting from swell-dominated conditions towards characteristic low-energy behaviour. Coastal change for the swell-dominated coast is more connected between the dune, beach and submerged parts of the profile. For the low-energy beaches, coastal change tends to be more episodic, and discrete between inner and outer margins of the terrace. Along the east coast of Garden Island, southward transport is dominant under swell, with apparently limited influence of wind waves, which are mainly from the east.

As part of the Stage 1 Assessment the pathways and relative rates of sediment supply into Cockburn Sound and Owen Anchorage were evaluated based on review and interpretation of existing information for the Owen Anchorage and Cockburn Sound coastline. Four major pathways of sediment supply are apparent, with two via the gaps in the Garden Island Causeway at Careening Bay and Point Peron. The other two onshore sediment feeds occur to the north of Garden Island across Parmelia and Success Banks. Sand supply south of Garden Island has not been quantified, but anecdotally has caused extensive infilling to the west of the Causeway over the last 40 years (Waterman et al. 2004). The interpretation was presented as indicative sediment pathways for Owen Anchorage (Figure 3.5) and Cockburn Sound (Figure 3.6). These pathways represent the likely net direction of transport of unconfined material were deposited at that location.

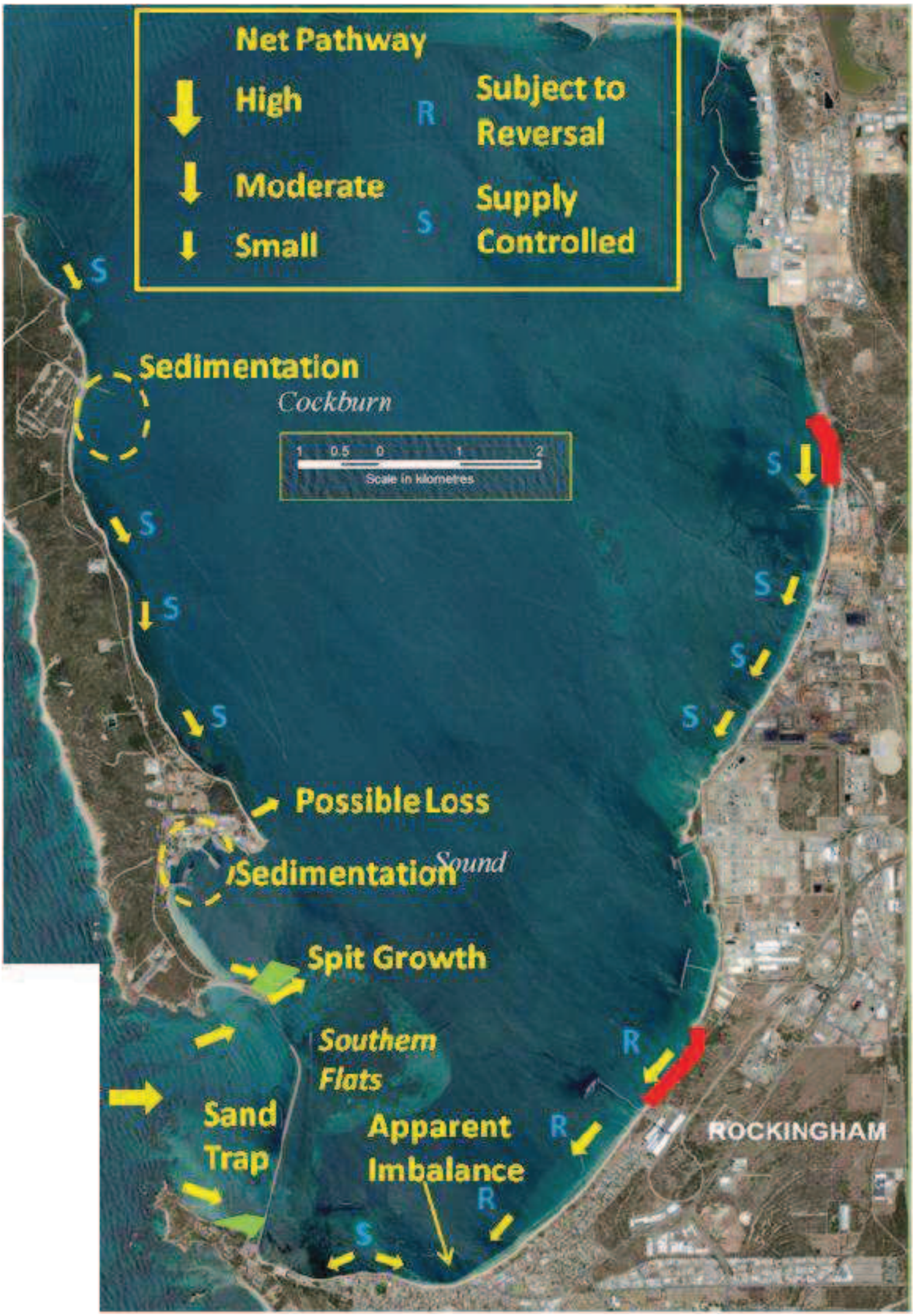
The Stage 1 Assessment concluded that overall, the sediment pathways identified within the Owen Anchorage and Cockburn Sound coastline are unlikely to change significantly as a result of elevated water levels (in the order of 1 m change). However, dramatic changes are likely to occur with respect to the rates at which sediment is supplied to particular areas. Sensitive locations are likely to occur where the sand presently feeds onshore (Catherine Point, Woodman Point), and towards the downdrift end of a compartmentalised beach sequence (James Point, Coogee Beach). There is some potential for erosion to shift to updrift areas in zones of high transport (e.g. south of Catherine Point).

The present-day coastal processes along the Owen Anchorage and Cockburn Sound coastline and the potential changes to these coastal processes are important in determining the possible coastal management and adaptation pathways for this coastline.



Source: CZM et al. (2013)

Figure 3.5 Indicative sediment pathways for Owen Anchorage



Source: CZM et al. (2013)

Figure 3.6 Indicative sediment pathways for Cockburn Sound

3.6 Hazard mapping

The coastal hazard modelling and mapping completed in the Stage 1 Assessment is summarised in the following sections. It is important to note that the impacts from the erosion and inundation will be fundamentally different: erosion will cause the total loss of land (and asset) while inundation will result in the damage of land (and asset), which could range from relatively minor to catastrophic depending on the level of inundation and the asset type.

3.6.1 Erosion hazard

During the Stage 1 Assessment the erosion hazard for the study area was assessed by considering the anticipated change in sediment availability at varying spatial scales and considering local controls (coastal infrastructure). The approach to the analysis was as follows:

- assessment of potential short-term (acute) erosion, due to both storm response and fluctuations of environmental conditions over typical intervention timescales (1–2 years)
- assessment of more gradual changes in shoreline position, including response to sea level rise
- evaluation of the amount of sediment removed from the shore, as calculated through the previous analysis steps, to project landward retreat of the shoreline.

In the Stage 1 Assessment the erosion hazard was presented as a series of lines where the anticipated coastal response to present and future erosive pressures had been converted into a horizontal distance of shoreline erosion. Reactive coastal management was excluded in this assessment because the cumulative impacts of any works should be considered across wider reaches of the coast and future works cannot be predicted. For mapping purposes, it was assumed that any existing coastal management will be maintained at current performance levels. A process for identifying the effects of additional structures or removing existing structures was outlined, and the reaches over which erosive pressures would be distributed defined.

Seven erosion scenarios produced in the Stage 1 Assessment were presented as lines buffered landward from a baseline of the +1 m AHD (Australian Height Datum) contour (2008 topography). Four of these scenarios represented: present-day acute erosion; long-term response for 2070 and 2110; and the high-end sensitivity for 2110 (2110+). Three additional scenarios represented the composite allowance for acute and chronic erosion for 2070, 2110 and 2110+ with the present-day allowance added to the three chronic scenarios.

Three areas identified with existing acute erosion were:

- Garden Island north of Colpoys Point
- Palm Beach
- Kwinana Bulk Terminal.

Three areas anticipated to experience the most severe long-term erosion were:

- North of Catherine Point
- Woodman Point
- Kwinana Industrial Area.

Areas where increased erosion due to sea level rise is expected were:

- south of Catherine Point groyne
- Woodman Point
- Kwinana Industrial Area
- southern end of Garden Island
- South Beach, potentially enhanced by the partitioning of the coast
- the cliff line of Spearwood Ridge, which will extend south to Challenger Beach as the coast erodes (Naval Base).

3.6.2 Inundation hazard

In the Stage 1 Assessment, the inundation hazard was evaluated for each of the three timeframes selected for this study (i.e. present day, 2070 and 2110) with corresponding projections for changes in mean sea level (i.e. 0 m [present day], +0.5 m [2070], +0.9 m [2110], +1.5 m [2110+]).

Coastal inundation mapping was based on tide gauge observation at Fremantle, from 1896 to 2011. Limitations of this database for extrapolation to future conditions have been previously identified and include the influence of tidal phase and modulation (Eliot 2012), non-tidal cycles (Haigh et al. 2011; Eliot 2012) and inter-annual variability of synoptic conditions (Haigh et al. 2010). Consequently, an extreme distribution based on historic data was modified to provide allowance for these additional sources of variability. Four inundation events relative to present day MSL were identified, covering the probabilistic range from 0.2% to 63% annual exceedance probability (AEP) (i.e. 1 to 500 year ARI; Table 3.1). Present-day 100 year ARI inundation scenarios are comparable to the observed total flood levels (including wave action) during 16 May 2003 event. The approach used for the coastal inundation mapping excluded the shift of the hydraulic zone (i.e. wave run-up) along the coast as the effect of wave run-up on inundation declines rapidly with landward propagation. As such the focus was specifically upon terrestrial areas below still water level. Future scenarios were then considered to result from the direct addition of the inundation events to the mean sea level rise allowances of +0.5, +0.9 and +1.5 m.

Table 3.1 Inundation scenarios

1 year ARI (63% AEP)	1.00 m AHD	1.50 m AHD	1.90 m AHD	2.50 m AHD
10 year ARI (10% AEP)	1.16 m AHD	1.66 m AHD	2.06 m AHD	2.66 m AHD
100 year ARI (1% AEP)	1.34 m AHD	1.84 m AHD	2.24 m AHD	2.84 m AHD
500 year ARI (0.2% AEP)	1.48 m AHD	1.98 m AHD	2.38 m AHD	2.98 m AHD

Notes:

1. ARI = annual recurrence interval
2. AEP = annual exceedance probability
3. The 100 year ARI was not used in the definition of the likelihood scale for the Stage 2 Assessment (refer to Section 8.1)

Source: CZM et al. (2013)

These inundation levels were applied to the Department of Water LiDAR high-resolution topography data from 29 February 2008, captured at 1 m spatial resolution with a +0.1 m vertical accuracy. Modifications to dune levels, seawalls or structures since 2008 are not captured in these maps; further inundation levels for Garden Island were not calculated due to the absence of adequate LiDAR data for this area. As part of this Stage 2 Assessment the inundation hazard mapping for the Port Coogee development was updated using proposed and as-constructed levels supplied by the CSCA.

The Stage 1 Assessment also analysed the Owen Anchorage and Cockburn Sound coastline to determine situations where the relative sediment transfer between connected landforms may occur, thereby changing the relative sensitivity to environmental change (i.e. 'tipping point' behaviour). The consequence of this in the study area was an increased transfer of sand from the beaches towards low coastal dunes. The Stage 1 Assessment identified this as potentially a key issue for many coastal cells (refer to Table 16 and Table 19 in the Stage 1 Assessment report; CZM et al. 2013) with particular impacts on Palm Beach, Rockingham to James Point (refer to Section 4.27 and Figure 50 in the Stage 1 Assessment report for further information; CZM et al. 2013).

The potential landward shift of inundation zones due to sea level rise along the study area will affect a relatively small area because along most of the coast the existing coastal dunes are above the 500 year ARI inundation scenario of +1.5 m SLR (2.98 m AHD in total). This would produce isolated areas of inundation in low-lying terrestrial areas. The following three areas of highest inundation 'hotspots' were identified in the Stage 1 Assessment:

- reclaimed land and the three harbours of CoF
- Woodman Point and small area of the Australian Maritime Complex (AMC).
- southern Cockburn Sound including large areas of CoR.

3.7 Stage 1 Assessment assumptions and limitations

The assumptions and limitations of the Stage 1 Assessment that have been carried forward in the Stage 2 Assessment are summarised in Table 3.2.

Table 3.2 Stage 1 Assessment assumptions and limitations

Stage 1 Assessment looks beyond the 2110 scenario and therefore uses an SLR of 1.5 m, greater than SPP2.6	The Stage 1 Assessment outlined the rationale for including a high-end scenario stating that the First Pass National Coastal Vulnerability Assessment (DCCEE 2009) used a 'high end' scenario of 1.1 m by 2100 that "considers the possible high end risk identified in the IPCC AR4 and includes some new evidence on ice-sheet dynamics published since 2006 and after the AR4". Further, DCCEE (2009) states that "very recent research also suggests that a 1.1 m scenario by the end of the century may not reflect the upper end of potential risk and that risk assessments could be informed by a higher level" (p.27). This conclusion was more recently echoed in the report entitled *America's Climate Choices: Panel on Advancing the Science of Climate Change*, Board on Atmospheric Sciences and Climate, Division on Earth and Life Studies, National Research Council of the National Academies (2010) (Chapter 7: Sea Level Rise and the Coastal Environment)[1]". This report concluded: "The 2007 IPCC projections are conservative and may underestimate future sea level rise because they do not include one of the two major processes contributing to sea level rise discussed in this chapter: significant changes in ice sheet dynamics (Rahmstorf, 2010[2])" (p. 243–244). In addition, the identification of adaptation pathways requires consideration of wider possible conditions.
The exclusion of areas where there is existing hard structures from the erosion hazard assessment (i.e. they will be maintained at their current performance into the future)	The study area is highly modified by various interventions that have caused a myriad of responses by the coastline at a local and regional level. It was assumed that future climate change impacts would be through the complex and combined result of sediment supply, sediment transport and coastal management, including defences. To unravel these complexities, Stage 1 Assessment took an approach of assessing the distribution of climate-change erosion potential, or 'stress' across the study area. In consultation with the CSCA it was decided to map this stress on the coastal segments with the existing coastal protection structures included.

[1] *http://www.nap.edu/openbook.php?record_id=12782*

[2] *http://www.nature.com/climate/2010/1004/full/climate.2010.29.html*

The exclusion of Bathers Beach from the erosion hazard assessment	The Department of Transport identified a block seawall at Bathers Beach constructed in 1872 as the abutment of the old jetty (ID S01) (Damara 2009). Given the assumption in the Stage 1 Assessment to exclude from the erosion hazard assessment areas where there are existing hard structures (i.e. they will be maintained at their current performance into the future), future coastal erosion was not considered at Bathers Beach.
South of Woodman Point is vulnerable, the Stage 1 Assessment considered this cell (19 a) as an 'artificial system'. As such, acute erosion only was considered.	It was recognised during Stage 1 that although the South of Woodman Point (cell 19 a) is potentially vulnerable to climate change impacts this cell was considered an 'artificial system' and did not respond to the imposed conditions. The method for erosion hazard assessment was therefore not valid for assessing the change along this section of the coastline and, as such, acute erosion only was considered.
Date of the LiDAR data (2008)	The use of LiDAR data in the Stage 1 Assessment was implied in the Request for Tender (RFT) that stated "Recent LIDAR information should remove many of the previously encountered barriers in gaining accurate topographical information for a vulnerability assessment" (RFT, p.56, Table 10.3). It was recognised during Stage 1 Assessment that the LiDAR data (Department of Water) represented a ‘snapshot’ of land height data captured 25–29 February 2008. Given the strategic nature of the study, and the ability to ensure that a regionally consistent dataset could be used, the use of the LiDAR data was considered appropriate for the Stage 1 Assessment and it was explicitly documented that "modifications to dune levels, seawalls or structures since 2008 are not captured in these [inundation] maps" (Stage 1 Assessment p.65).
No wave run-up was included in the inundation hazard assessment	The Stage 1 Assessment inundation mapping focused on those areas that could be subject to extensive and sustained flooding (i.e. not wave overtopping). The approach was focussed on identifying areas where adaptation actions may be meaningful to deal with inundation problems. The wave run-up zone is always encompassed in the erosion setback zone and therefore erosion exceeds the inundation hazard in terms of damage. The implication of the exclusion of these short-term factors was recognised during Stage 1. Consequently, the Stage 1 Assessment stated that "the maps and inundation values should not be used in design of coastal structures, determination of finished floor levels or consideration of overtopping or overwash hazard. Use of the inundation assessment outputs in this fashion would require the addition of further water level components" (Stage 1 Assessment p.20).
No inundation hazard assessment for Garden Island	The extent of the study area includes the eastern coastline of Garden Island. The Stage 1 Assessment states "Inundation levels for Garden Island will require mapping by Department of Defence using a detailed Digital Elevation Model because the Department of Water LiDAR does not cover Garden Island. The incomplete Digital Terrain Model from the Department of Planning LADS was not of sufficient accuracy to capture the inundation hazard" (Stage 1 Assessment p.65). Figure 33 of the Stage 1 Assessment demonstrates the constraints of the topographic data for Garden Island.
Changes in groundwater levels were not included as part of the scope of the Stage 1 Assessment.	The requirements of Stage 1 Assessment, as specified in the Request for Tender (RFT), were to undertake a focused study to "Determine vulnerability of each compartmentalised section of the coastline within the study area to erosion and/or inundation taking account of local geomorphologic and constructed features" (RFT, p.4). Consequently, potential impacts of sea level rise and other climate changes to groundwater levels (and also groundwater quality) were not included as part of the scope of the Stage 1 Assessment. Future assessment of potential groundwater impacts would be assisted by the Stage 1 Assessment, but would also require changes to other climate change drivers – particularly rainfall, temperature and runoff.

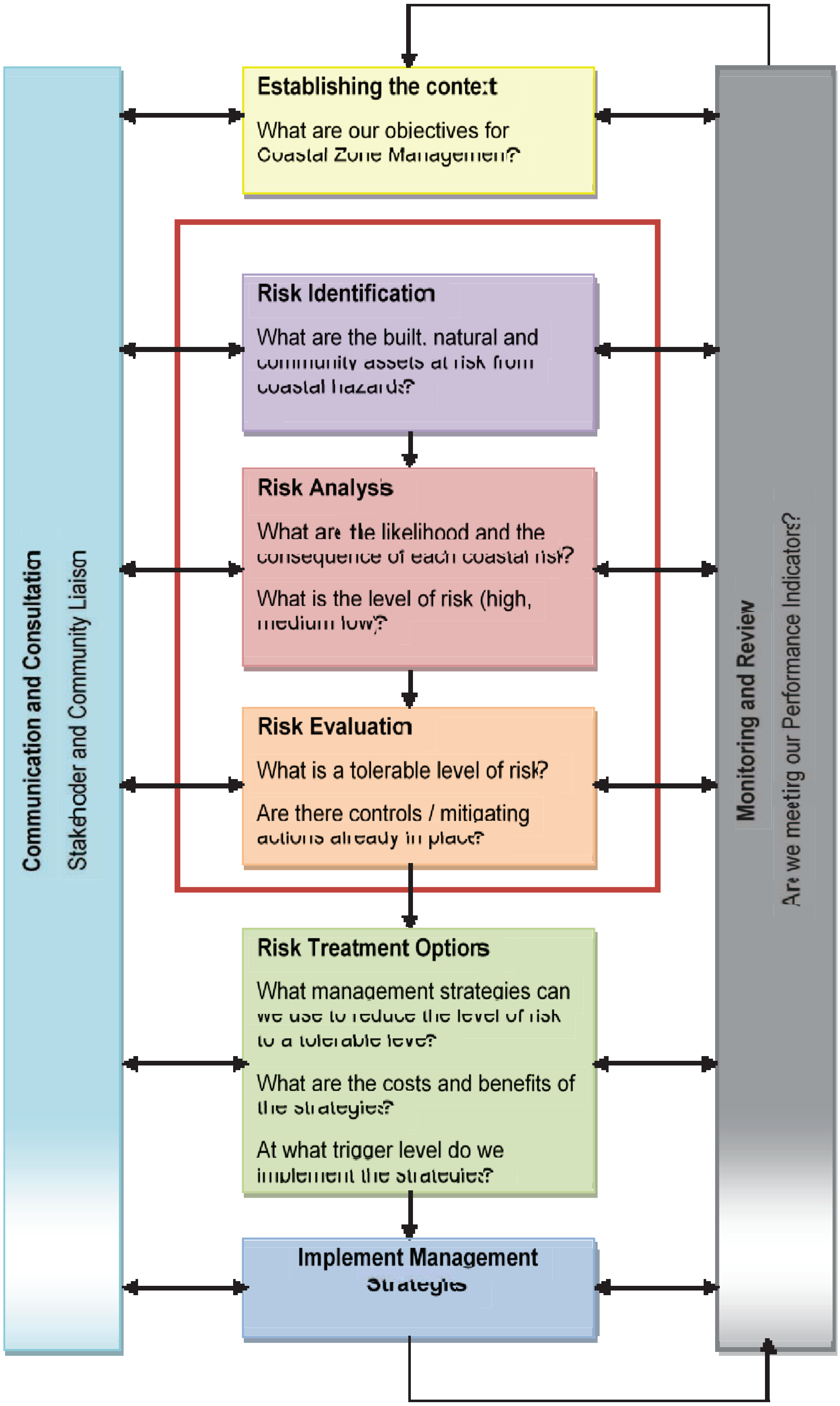
4. Risk Management Approach

The International Standard *Risk management – Principles and guidelines* (AS/NZS ISO 31000:2009) is a recognised and reliable method for the systematic application of procedures and practices to establish the context, and identify, analyse, evaluate and treat risks. Although this standard has been regularly implemented in various contexts, the more recent Australian Standard *Climate change adaptation for settlements and infrastructure – A risk based approach* (AS 5334-2013) has been developed to provide a systematic approach to planning for adaptation to risks specifically resulting from climate change hazards. Both AS/NZS ISO 31000:2009 and AS 5334-2013 have been applied in the context of this Cockburn Sound Coastal Vulnerability Values and Risk Assessment (refer to Figure 4.1).

This risk-based approach provides a systematic method for dealing with uncertainty in processes and information. Rather than providing a single answer, this approach allows managers to consider a range of events, their likelihood, consequence and thus the overall level of risk. The use of a risk-based approach for managing coastal hazards has become standard practice in Australia, and accords with current international best practice for natural resource management.

The International Risk Standard recommends risks be identified and analysed in terms of their likelihood and consequence. Management of risks can therefore focus on either reducing the recurrence of risks and/or reducing the detrimental impacts if and when they occur. For the Stage 2 Assessment, likelihood is based on the predicted occurrence of coastal erosion and inundation at selected time periods (present day, 2070 and 2110) recognising the expected coastal impacts of projected sea level rise. Consequences are based on the potential impacts to the economic, social and environmental values and the goods, functions and services provided by the land at risk and the associated assets on that land.

Coastal inundation and coastal erosion have been considered separately through this risk management approach as coastal erosion will result in a permanent loss of the land (and all improvements to that land, such as infrastructure and developments) whereas, coastal inundation will cause a temporary inconvenience for land user.



Adapted from AS/NZS ISO31000 (AS 5334-2013)

Figure 4.1 Generic risk management process applied to coastal management

The specific steps in the risk management process as they apply to coastal management are:

- **Establish the Context** – the context for coastal management is embedded in the state planning policies (Section 2.1). The objectives and motivation for this assessment are discussed in Section 1.
- **Identify the Risks** – the risks arise from the coastal hazards, namely, shoreline erosion and inundation. The hazards were determined during the Stage 1 Assessment (CZM et al. 2013), as summarised in Section 3.6. The risks impact upon coastal values, which include economic, social and environmental values, as identified during consultation with LGAs and other stakeholders. Coastal values are summarised in Section 7.
- **Analyse the Risks** – the risks were analysed (herein) considering the likelihood and consequence of the identified risks, to determine the overall level of risk (extreme, high, medium or low)
    - The likelihood of erosion and inundation at the present-day, 2070 and 2110 timeframes is summarised in Section 8.1. Assigning likelihoods to the hazards provides transparency regarding the uncertainties, limitations and assumptions used to assess hazards. The likelihood concept can also educate planners and the wider community that hazard lines are estimates only and not precise predictions of the future. The consequence and overall risk can then be more openly considered in context when determining a suitable management response.
    - The consequence of the risks is related to the degree of existing development and the values (e.g. aesthetic, recreational, ecological) associated with land and assets within the coastal zone. Information derived from consultation with stakeholders was used to assist in determining consequence of coastal risks, as described in Section 5.
    - The consequence and likelihood were combined to determine the level of risk for land (and assets) in the coastal zone. The level of risk was revised to include existing controls that may reduce the level of risk (Section 8.4). An Asset Risk Register is provided in Appendix A and considers risks over the present-day to 2110 timeframe.
- **Evaluate the Risks** – in consultation with the CSCA and other stakeholders, the level of risk that is deemed acceptable, tolerable and intolerable was agreed. The evaluation criteria determine the intolerable risks that must be treated as a priority and to which management efforts should be directed (refer to Section 8.3).
- **Treat the Risks** – the process of developing coastal management/adaptation options to treat the risks is directly related to reducing or eliminating intolerable risks where possible. Tolerable (low) risks can be flagged for monitoring, with no further resources necessary. Management options can be designed to reduce the likelihood of the risks (e.g. planning setbacks), or reduce the consequence of the risk (e.g. emergency management) or both. Management options first need to be technically viable for the study area. A cost-benefit analysis was used to determine which of the risk treatments will provide the greatest benefit in treating the highest priority risks. Preliminary management options are outlined and analysed in Section 9.
- **Implement Management Strategies** – the outcomes of the Stage 2 Assessment will be reviewed and used in the upcoming Stage 3 Adaptation Plan Development to provide a strategy for the implementation of coastal management incorporating the prioritised options to treat present and future coastal hazards identified in the Stage 2 Assessment. Stage 3 Adaptation Plan Development will also involve broader community consultation.

5. Stakeholder Engagement

Stakeholders were engaged throughout the Stage 2 Assessment for the purpose of gathering data and local knowledge vital to the success of this assessment and for informing the stakeholders about the Cockburn Sound Coastal Vulnerability and Flexible Adaptation Pathways Project and specifically the Stage 2 Assessment. The stakeholders were engaged during the assessment within the framework of the Team's Stakeholder Engagement Strategy (detailed in the Project Plan, BMT Oceanica 2013) and in consultation with the CSCA.

5.1 Stakeholder engagement activities

The Stakeholder Engagement Strategy was devised to target the different stakeholders and their key interests, and consisted of the activities listed in Table 5.1.

Table 5.1 Stakeholder engagement activities

Stakeholder liaison presentation The Team informed the stakeholders of the purpose of the Stage 2 Assessment, the proposed methods, and the intended outcomes. This ensured that the Team were informed early of any stakeholder comments or suggestions relating to the project
Direct contact with stakeholders/stakeholder representatives The Team achieved this via email and/or phone calls with the purpose of gathering specific information on the assets, asset values and the goods, service and functions of the assets
Risk Assessment Workshop The Team involved the stakeholders in determining the level of risk to assets, based on the scientific determination of the likelihood of coastal hazards combined with the perceived consequence to such assets
Management Options Workshop The Team engaged with the stakeholders regarding their experience in the day-to-day management of the Owen Anchorage and Cockburn Sound coastline to identify possible feasible risk mitigation responses for key locations/asset identified to be at risk
Presentation of the Draft Report The Team presented the project findings to the stakeholders in preparation for CSCA review of the draft report

Stakeholder engagement was initiated at the commencement of the Stage 2 Assessment and continued during the data verification and Asset Register phase, the value and risk assessment phase and first-pass adaptation assessment phase of the assessment.

5.2 Stakeholders and stakeholder categories

The stakeholders for the Stage 2 Assessment are listed in Table 5.2 with a description of why they were engaged regarding this assessment. The level of stakeholder engagement was determined from an understanding of each group's influence and interest in the assessment (Figure 5.1).

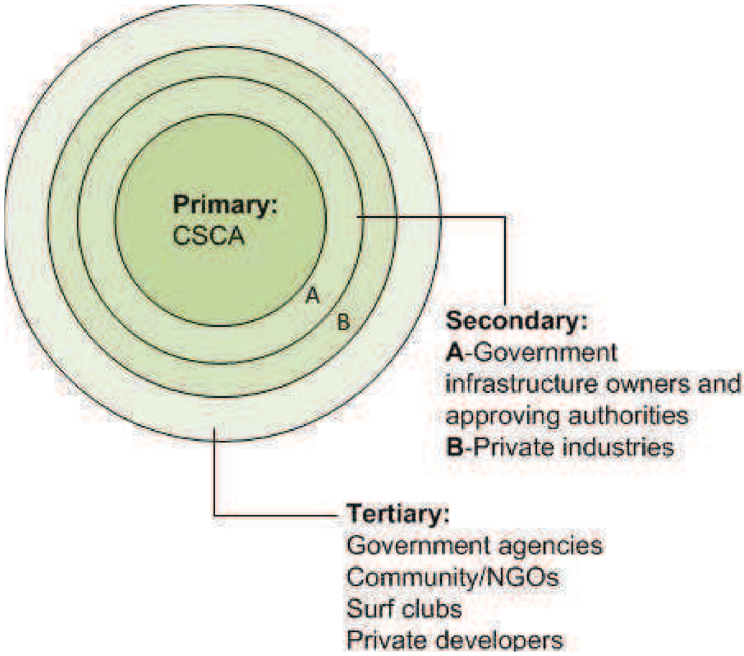


Figure 5.1 Stakeholder categorisation

These stakeholder categories were engaged as follows (also detailed in Table 5.2):

- The **Primary** stakeholder group were engaged via all the tasks listed in Table 5.1. Additionally, being the client, they were also kept informed of the assessment via monthly progress reports. Engagement with the Primary stakeholder group also included the dissemination of documents (monthly reports and draft/final reports) to the CSCA (which were distributed to the CSCA members by the CSCA representative for review; any CSCA comments for the Team were also coordinated by the CSCA representative
- The **Secondary** stakeholder group were engaged by the consultant via all the tasks listed in Table 5.1
- The **Tertiary** stakeholder group were engaged by the Team via communication of the project and its outcomes via the dissemination of the final report by the CSCA only.

Table 5.2 Stakeholder details and their level of engagement in the Stage 2 Assessment

Primary	**Cockburn Sound Coastal Alliance** City of Cockburn City of Kwinana City of Rockingham City of Fremantle Department of Defence Cockburn Sound Management Council Perth NRM	• Oversee preparation of the Cockburn Sound Coastal Vulnerability and Flexible Adaptation Pathways Project • Implement day-to-day management of community services, essential services (stormwater drainage, roadways and paths), land use planning and environmental systems in the coastal zone	• Input to assets, asset values, risk assessment process, past and present management approaches, known data sets, preferred management options, and feedback on Draft Plan report • Inform about Stage 2 Assessment outcomes	✓	✓	✓	✓	✓	✓	✓	
Secondary	**A—Government infrastructure owners and/or approving authorities:** Fremantle Ports Water Corporation Synergy Department of Planning Department of Transport Public Transport Authority Department of Parks and Wildlife Department of Environment Regulation	• Develop state legislation pertaining to planning and activities in the coastal zone, which includes Cockburn Sound • Implement transport operations and requirements for the State • Conduct scientific investigations (water quality, ecology, stormwater, minerals, fisheries, etc.) • Manage ecological habitats, cultural heritage sites and natural areas (parks and reserves) • Own (and manage some) public lands in the coastal zone • Oversee implementation of local coastal adaptation plans	• Input to assets, asset values, risk assessment process, past and present management approaches, known data sets and preferred management options • Inform about Stage 2 Assessment outcomes			✓	✓[1]	✓	✓		
	B—Private companies: Cockburn Cement Brookfield Rail KIC Alcoa BP BHP NickelWest CSBP CBH Australand LandCorp Stockland	• Conduct industrial operations and develop private residential (and commercial) real estate within the Owen Anchorage and Cockburn Sound coastal area, with significant industrial resources and operational assets • Aim to maintain profitable function of such industries, and achieve necessary environmental standards				✓	✓	✓	✓		
Tertiary	**Government Agencies:** Western Australian Local Government Association South West Group of Local Government Authorities Department of Industry and Resources South Metropolitan Regional Councils	• Oversee implementation of local coastal adaptation plans	• Inform about Stage 2 Assessment outcomes.								✓
	Community Groups: Coastcare Groups City of Cockburn Aboriginal Reference Group South West Aboriginal Land & Sea Council	• Implement dune rehabilitation and management • Manage ecosystems and habitats • Hold knowledge and meaning for the cultural heritage assets and values of the coastal zone									✓
	Surf Clubs	• Undertake life saving activities in the coastal zone and manage some public buildings									✓
	Mirvac	• Developers of private residential (and commercial) real estate in the coastal zone • Aim to maximise developable land based on existing land use planning legislation and policy									✓

Note:
1. Not all stakeholders in this category were contacted directly as this engagement was focused on asset valuation and therefore was targeted at land owners and managers

5.3 Outcomes of stakeholder engagement

5.3.1 Stakeholder liaison presentation

A Stakeholder Liaison Presentation was delivered by members of the Team to the CSCA at the CoR offices on 22 August 2013. Representatives from the DoT and the Department of Environment Regulation were also present.

During the presentation, the Stage 2 Assessment was introduced in the context of the Cockburn Sound Coastal Vulnerability and Flexible Adaptation Pathways Project. Also outlined were:

- the Team
- the intended approach to the values and risk assessment and adaptation planning
- the data inputs required from the CSCA and other stakeholders
- our proposed stakeholder engagement strategy.

5.3.2 Direct engagement with stakeholders

The Primary and Secondary stakeholder representatives were contacted via emails, phone calls and meetings with the purpose of requesting asset data and asset value data.

Asset data supply

- an asset data request letter was sent to the CSCA representative on 13 August 2013 to distribute to the other LGAs and the Department of Defence (Appendix B)
- a GIS data requirement meeting was held at the CoC offices on 15 August 2013. The Team met with GIS representatives from the each of the LGAs (with the exception of CoK and DoD) to discuss the timing and resourcing for the asset data provision, details of the sharing agreement and the nature of data requested
- the initial asset data supply was completed, with the exception of data from the DoD, on 3 December 2013
- the Team made direct contact with DoD requesting asset data but due to resourcing problems in DoD, no asset data for Garden Island were supplied

Asset replacement value data supply

Stakeholder meetings were held with the Primary and Secondary stakeholder representatives on 22–26 November 2013. Specifically, the Team met with representatives of each department or group of departments within each LGA and representatives of the Secondary stakeholders.

The objectives of these meetings were to:

- introduce the project and the project objectives
- present the draft likelihood and consequence scale to be used for the risk assessment
- present the maps showing the likelihoods of coastal hazards occurring at each timeframe
- discuss the values of the assets at risk with consideration of the economic, social and environmental values.

Stakeholders represented at these meetings were:

- CoC
- CoK
- CoR
- CoF
- Australand
- Department of Parks and Wildlife (DPaW)
- LandCorp
- Fremantle Ports.

Teleconference meetings with the same purpose were also held with representatives from:

- the Kwinana Industry Council
- DoT
- DoD.

These meetings were followed up with a letter to the LGA representatives, DPaW representatives and the DoT representatives on 28 November 2013 requesting information on asset replacement values (Appendix B). The asset value data requested were key to the asset valuation; following multiple follow-up requests for this data it was determined on 30 January 2014 to progress the study to meet the study timeframe. Following the workshops (detailed in Sections 5.3.3 and 5.3.4) the Team attempted to contact the absent stakeholder representatives as necessary (including DoD) to request further clarification on asset replacement values; this was met with limited response.

The asset valuation is detailed in Section 7.1.

Additional meetings

An additional stakeholder meeting was held between the Team, LandCorp and their consultant, MP Rogers, on 23 December 2013 to discuss the present study in the context of the Cockburn Coast development.

5.3.3 Risk Assessment Workshop

The Risk Assessment Workshop was held at the Coogee Beach Surf and Life Saving Club (Coogee Beach SLSC) on 4 February 2014. The stakeholders represented at this workshop are listed in Table 5.3.

Table 5.3 Risk Assessment Workshop invitees

City of Fremantle	Department of Defence
City of Cockburn	Cockburn Sound Management Council
City of Kwinana	Department of Parks and Wildlife
City of Rockingham	Fremantle Ports
Synergy	Water Corporation
LandCorp	Australand
Cockburn Cement	Stockland
Brookfield Rail	Kwinana Industry Council
Public Transport Authority	CBH
Department of Planning	CSBP
Department of Transport	BP
Department of Environment Regulation – Adaptation	Alcoa
Perth Region NRM	BHP Nickel West

Activities

At the start of this workshop the stakeholder representatives were briefed on the project background and objectives and the Team's risk management approach. This was followed by an overview of the erosion and inundation hazards and their likelihoods. The coastal Asset Register, which contained the assets within the maximum potential hazard extent, was presented to the stakeholders; this register comprised all relevant asset data provided to the Team. To prevent double counting of assets, it was necessary to merge and edit the asset data prior in the compilation of this Asset Register (see Section 6).

The stakeholder representatives (grouped by LGA and private/government asset owners/managers) then participated in confirming the assigned consequences of the erosion and inundation to their coastal assets (refer to Section 8.2 for further details on risk consequence). These grades were based upon a review of the economic, social and environmental consequences of the coastal hazard occurring. Stakeholder representatives then assigned an unmitigated risk level to their coastal assets based on the potential consequence of the loss or degradation of the asset resulting from the coastal hazard, combined with the likelihood of the particular coastal hazard occurring at present, in 2070 and in 2110 (refer to Sections 8.1 and 8.2 for further details on risk likelihood and risk evaluation, respectively).

This was followed by a whole group discussion during which the stakeholder representatives agreed on the level of risk that is deemed intolerable and should be treated as a priority within the context of the changing nature of the hazards at the different timescales up to year 2110.

Outcomes

- The Stage 2 Assessment and risk management approach was presented to the stakeholder representatives.
- The consequences of erosion and inundation hazards on the coastal assets were confirmed with each of the stakeholder representatives. This allowed the stakeholders to communicate to the Team, their local knowledge of the asset values and some adjustments to the assigned consequences were made. The risk assessment was then completed whereby each asset was assigned a risk rating. Refer to the Asset Register that details the assets, consequences and likelihoods and the risk assigned to each asset (Appendix A).
- The priority for risk management based on the risk ratings was confirmed with the whole stakeholder group. Refer to Table 8.6 for the agreed risk treatment priorities.
- The stakeholder representatives present at the workshop were made aware (if they were not already) of the coastal assets at risk from erosion or inundation hazards up to year 2110 and have an understanding of the project, the project objectives and our approach to achieve these and how the risk assessment was to be completed.

5.3.4 Risk Management Options Workshop

The Risk Management Options Workshop was held at the Darius Wells Resource Centre, CoK, on 6 February 2014. The workshop attendees are presented in Table 5.4.

Table 5.4 Risk Management Options Workshop invitees

City of Fremantle	Department of Defence
City of Cockburn	Cockburn Sound Management Council
City of Kwinana	Department of Parks and Wildlife
City of Rockingham	Fremantle Ports
Synergy	Water Corporation
LandCorp	Stockland
Australand	Kwinana Industry Council
Cockburn Cement	CBH
Brookfield Rail	CSBP
Public Transport Authority	BP
Department of Planning	Alcoa
Department of Transport	BHP Nickel West
Department of Environment Regulation – Adaptation	
Perth Region NRM	

Activity

At this workshop the stakeholder representatives were briefed on potential options for coastal management and adaptation that can reduce either the consequence or the likelihood of the coastal hazard occurring thereby reducing the risk—termed residual risk. The Team's coastal management options toolbox (Figure 9.1; Appendix C) was presented and then used as a basis for a whole group discussion to list all relevant existing management controls and actions along the study area coastline (see Section 8.4).

Using the existing controls as a basis, the stakeholder representatives (grouped by LGA and private/government asset owners/managers) assessed and discussed the effectiveness of these management measures by exploring whether the consequence or likelihood of the coastal hazard had been reduced by these measures and, if so, the residual risk was determined.

Following this, the stakeholder representatives (grouped by LGA and private/government asset owners/managers) discussed and explored potential new management options for those assets considered to be at an intolerable residual risk level. Discussions included present-day options as well as options that could be implemented into the future. Each group was provided with the coastal management options toolbox (Figure 9.1; Appendix C) as a starting point for discussion of the coastal management approaches appropriate to the various sections of coastline. The workshop concluded with a whole group discussion to share ideas between groups of potential new management options.

Outcomes

- Potential coastal management options and the concept of residual risk were presented to the stakeholder representatives.
- The management options currently in place along the coastline were listed against the specific assets and the residual risk was determined. This was an opportunity for stakeholders to discuss their knowledge of local issues and explore the effectiveness of historical and current actions in managing coastal hazards in the study area. Existing management measures that may no longer be effective, or will cease to be effective in the future, were also discussed. Refer to the Asset Register which details the residual risk ratings (Appendix A).
- Management concepts as listed in the management options toolbox provided (Figure 9.1; Appendix C) were explored and their appropriateness, practicality and feasibility for implementation in the local context were discussed. This initiated communication between stakeholder representatives regarding the appropriate approach(es) to coastal management within their LGAs and/or adjacent to their assets.
- It was communicated to the stakeholder representatives that early engagement and public education is key in this process and that according to the priorities determined during the risk assessment, the protection of some assets will result in the sacrifice of others.
- The final message delivered to the Stakeholder representatives was that management of the Owen Anchorage and Cockburn Sound coastline as a whole requires an integrated approach to coastal management and strategic planning for future development.

5.3.5 Workshop attendance

The stakeholder representatives were initially invited to the workshops verbally at the meetings held in November 2013. The dates were then confirmed in the Value Data Request Letter (Appendix B) sent to the Primary Stakeholder Representatives, DPaW representatives and the DoT representatives on 28 November 2013. By mid-January 2013, all formal invitations were sent to all invitees via email and included the details of the workshops and an information sheet detailing the subject and purpose of the workshops. In most cases this was followed up by a direct phone call to ensure receipt of the invitation and to ensure that the appropriate representatives had been contacted, where no response was received.

6. Asset Register

6.1 Compilation of coastal assets data

To undertake a values and risk assessment of coastal assets, it is necessary to compile a complete register of all the coastal assets within the study area (Figure 1.1). Asset data in a digital GIS format (for ArcGIS software) were requested from the CSCA via letter on 13 August 2013. This was followed by a meeting with the GIS representatives from each LGA (except CoK who were unavailable) to clarify the exact data requirements for the completion of the Stage 2 Assessment.

Comprehensive verification of the asset data provided identified that considerable data cleaning was required to meet the requirements of the assessment and to complete the Asset Register. Where obvious data flaws were identified these were corrected, in addition, it was necessary to manually digitise many assets to fill data gaps (Table 6.1). This verification and data cleaning ensured that all parcels of land potentially impacted by present and future coastal hazards were accounted for. Further, a number of assets were manually digitised following the Risk Assessment Workshop, where discussions highlighted assets in the coastal zone for which data had not been previously provided.

Table 6.1 Gaps in provided asset data

City of Cockburn	South Fremantle Redevelopment Area
City of Cockburn	South Fremantle Power Station
City of Cockburn	Port Coogee
City of Cockburn	Coogee Beach Surf and Life Saving Club
City of Cockburn	Woodman Point Regional Park
City of Cockburn	Jervoise Bay Yacht Club
City of Cockburn	Woodman Point Sewerage Outfall
City of Cockburn	Woodman Point Boating Facilities
City of Cockburn	Australian Marine Complex
City of Kwinana	Challenger Beach
City of Kwinana	Barter Road Beach
City of Kwinana	James Point
City of Kwinana	Kwinana Beach
City of Kwinana	Alcoa Refinery
City of Kwinana	Synergy Power Station
City of Kwinana	WaterCorp Desalination Plant
City of Kwinana	Kwinana Bulk Terminal
City of Kwinana	BP Refinery
City of Kwinana	CSBP Plant
City of Rockingham	CBH Grain Terminal and Silos
City of Rockingham	Wells Park Beach
City of Rockingham	Rockingham Beach
City of Rockingham	Bell and Churchill Parks
City of Rockingham	Bell and Churchill Parks beach-front
City of Rockingham	Palm Beach
City of Rockingham	Designated Dog Beach
City of Rockingham	PWC area
City of Rockingham	Crystals Beach
City of Rockingham	Cape Peron – Rockingham Lakes Regional Park
City of Rockingham	Point Peron Wastewater Treatment Plant
City of Rockingham	City of Rockingham residential area

All data supplied by the CoR was in GIS format for MapInfo software and required conversion in to ArcGIS format prior to the commencement of asset data verification. No data were received for Garden Island, which is managed by the DoD. It was agreed with the CSCA to proceed with the assessment in the absence of these data.

The cleaned and verified datasets were then combined to form the Asset Register and the assets were categorised into one of the following types:

- utilities
- infrastructure
- coastal infrastructure
- parks
- heritage areas.

6.2 Identification of assets at risk

To determine which assets in the data supplied by the CSCA LGAs are at risk from coastal hazards at present, in 2070 and in 2110, the Asset Register was intersected with the coastal hazard data at each timeframe in a GIS. Where only part of an asset would be at risk (i.e. a section of park or a length of road), the proportion of the asset at risk was also determined. The list of assets at risk (Appendix A) provided the basis for the asset values and risk assessment in accordance with the Team's risk management approach (Section 4).

Note that Naval Base Shacks was originally included in the Asset Register as this asset intersected with the inundation hazard lines in GIS. However, following CSCA advice that the current ground level of this asset is above the 2110+ inundation levels at 4–5 m AHD, this asset was removed from the Asset Register.

6.3 Outcome with no management actions

The expected impacts of projected climate change over the long-term if no measures are undertaken to manage the emerging risks are detailed in this section. Although doing nothing is unlikely to occur, the descriptions serve to demonstrate how the coastal area will change and the potential repercussions of these changes on existing natural and built environments.

6.3.1 Erosion

City of Fremantle

Erosion is not expected to affect Success Harbour, Fishing Boat Harbour or Challenger Harbour. However, it is noted that Bathers Beach to the north of these harbour areas may be impacted by erosion. The extent of the limestone walling behind this beach and the nature of the bedrock on which the beach is perched is unknown. However, since there is evidence of a hardened shoreline in this area it was assumed during the Stage 1 Assessment that this area will not be impacted by erosion.

The South Beach area in CoF is intensely used for recreational purposes. With sea level rise, the beach will move landward and the vegetation strip will narrow. By 2070, Ocean Drive may become impacted by erosion and some of the existing commercial uses across Ocean Drive may also be affected. There is a chance that some of the groynes would be outflanked by erosion on their downdrift sides.

City of Cockburn

The residential development west of the rail line (between Ocean Drive and Rollinson Road, which is part of the South Fremantle Power Station redevelopment site), is at minimal risk of erosion at present day. The walkways west of the estate may be affected and undermined by erosion events between present day and 2070. By 2070, erosion may start to impact some of these properties and by 2110 the area would be partially within an active erosion zone.

The foreshore from the C. Y. O'Connor Reserve to the LGA boundary with CoF consists of a park reserve with some parking facilities, amenities and walkways. It is backed by the freight rail line currently managed by Brookfield Rail and is a vital link between the Kwinana industries and Fremantle Ports. Existing groynes indicate that erosion is already an issue in this area. With sea level rise, the beach would move landward and by 2070, parts of walkways may become affected. By 2110, a section of Robb Road may be vulnerable to damage.

The South Fremantle Power Station is located close to the foreshore, with some of the shore hardened by a rock wall. As sea level rises, the shoreline may erode and diminish the buffer, causing significant erosion events and frequent overtopping of the structure. By 2110, the South Fremantle Power Station may be at significant risk of damage if the existing seawall loses structural integrity.

Woodman Point (Regional Park) and the Coogee Beach reserve are at risk of erosion under present-day conditions. This includes the Coogee Beach SLSC. With sea level rise, and if nothing further is done to manage the risks, the beach would move landward and reduce the area of the park lands. By 2070, the beach may migrate landward by 50 m or more. By 2110, pedestrian walkways along the foreshore may become affected. The jetties along these beaches may be impacted by erosion, most notably the access to the jetties. The John Graham Recreation Reserve may lose some of its amenities by 2110 and the western section of the Coogee Beach Holiday Park may be subject to erosion by 2110.

The shoreline of CoC south of Woodman Point (Regional Park) is not susceptible to erosion given its rocky morphology and the constructed breakwaters of the AMC harbour. Similarly, the Port Coogee development itself is protected by seawalls and breakwaters.

City of Kwinana

The foreshore of CoK is characterised by heavy industrial and maritime uses with a range of structures along the shoreline, including seawalls and jetties. There are also locally significant recreational areas in the northern and southern areas of the LGA (Challenger Beach, Barter Road Beach and Wells Park/Kwinana Beach).

Erosion has been an issue in the past, as evidenced by the existing rock walls, groynes and artificial headlands along the foreshores of the industrial estates. With sea level rise, the beaches would migrate landward where built structures do not impede this movement. The beaches in front of the heavy industries would become increasingly narrow over time until they are eventually lost. The rock walls would become increasingly overtopped, which may affect structural integrity.

If infrastructure associated with heavy industries is significantly damaged by erosion, the losses would be catastrophic, not just in economic terms but also in terms of social impacts (loss of employment and public health) and possibly environmental risks (leakage, pollution). Key heavy industrial operators include Alcoa (alumina refinery), Synergy (Kwinana Power Station), Water Corporation (Desalination Plant), Fremantle Port Authority (Kwinana Bulk Terminal and Kwinana Bulk Jetty), BP (oil refinery), and CSBP (chemical and fertiliser plant). The output of these industries is critical to the Western Australian economy – especially given that the BP refinery is the only refinery in the State. Some of the heavy industries may be at risk of erosion with some infrastructure likely to become unsafe for use by 2070 and substantial infrastructure affected by 2110.

Challenger Beach is backed by heavy industries and hard structures. Without appropriate management, Challenger Beach will lose substantial beach amenity as sea level rises, with a narrowing of width until eventually there would be little sand on the foreshore in front of coastal structures. Barter Road Beach and Wells Park/Kwinana Beach are backed by dunal systems, and as such will tend to recede landward under the influence of sea level rise. This erosion would result in loss of dune habitats and some infrastructure located immediately behind the beach areas.

In the south of CoK there is a heritage site, 'The Wreck', which is naturally degraded. With erosion this is likely to be lost over time. It is currently at risk of erosion and may have completely eroded away by 2070.

City of Rockingham

The CoR has an extensive coastline, parts of which are low-lying with a mixture of urban and recreational beaches which extend through to the southern end of the Study Area at Point Peron.

Erosion has been an issue in the past, as is evident from existing coastal structures along the foreshore at Rockingham Beach Road and the current need for periodic nourishment. Beaches that are nourished include the western end of Point Peron, Palm Beach (near Hymus Street), Rockingham Beach and Wells Park beach-front, with sand generally sourced from the sand trap at the eastern tip of Crystals Beach near the Point Peron boat ramp.

At present, the majority of the beach areas are susceptible to erosion. With sea level rise and if nothing further is done to manage the risks, significant loss of beach area may occur by 2070. Most of the beaches would be unable to migrate landward due to the existing built environment. The CBH grain terminal is located immediately behind Rockingham Beach. Although the facility itself is not at risk from erosion between now and 2110, bulk materials infrastructure is located between the facility and the loading jetty and may potentially be damaged during storm erosion events.

Some parkland along Rockingham Beach Road may also be susceptible as the shoreline moves landward. The same would likely occur at Governor Road Reserve, Naval Memorial Park, Rockingham Foreshore Reserve, Bell Park, Churchill Park and Catalpa Park. Footpaths and facilities in these park environments may to be subject to erosion, resulting in damage. In some locations, the Esplanade and the Rockingham Beach Road may be at risk of erosion and cause undermining of the roadways.

Although a large portion of the foreshore consists of beach and parkland, there are areas where residential and commercial uses are close to the beach with little buffer to protect from erosion. This is the case for the retail and commercial activity centre between Railway Terrace and Val Street, and the residential properties along the Esplanade west from this activity centre and the holiday park and community centre to the west of Hymus Street. This area would increasingly become subject to the risk of erosion, with private properties potentially affected by 2110 or earlier.

The Mangles Bay Fishing Club will most likely be subject to erosion between present day and 2070. The natural area of Point Peron would likely retreat as erosion affects parts of the foreshore. Some coastal structures may be damaged by storm conditions or may be outflanked and thus fail to provide design functionality.

6.3.2 Inundation

City of Fremantle

Parts of the harbour areas of Success Harbour and Fishing Boat Harbour are currently at risk of inundation from periodic events (typically occurring once a decade, on average). Inundation depths would generally be low, with areas affected largely used for parking and vessel storage. With sea level rise the depth of inundation of periodic events would potentially increase to between 0.4 and 0.9 m, which may impact on the use of the area during these times.

The inundation risk by 2070 may extend to a wider area, including the area between the Marine Terrace and Mews Road and the Esplanade park area. By 2110, inundation from periodic events (typically occurring once a decade, on average) would potentially impact on significant infrastructure, most importantly Mews Road, rail infrastructure, Marine Terrace, and parking and community facilities in the area. Other assets and facilities, including many heritage listed buildings and areas around the harbours, would also be affected at this time but generally with low-level inundation causing more disruption than damage.

City of Cockburn

With the exception of Woodman Point, the area potentially affected by future inundation would be restricted to the area also affected by shoreline erosion. Some low-lying lands at Woodman Point are at risk of periodic inundation at present day, although these do not yet extend far inland. By 2070, the area just south of the John Graham Recreation Reserve and including the Jervoise Bay Sailing Club may be periodically inundated (once a decade on average). Although the periodic inundation would initially be shallow, on-going sea level rise would see this depth potentially increase to about 50 cm by 2110.

City of Kwinana

The coastal areas within the CoK that would be affected by future inundation due to projected sea level rise would be restricted to the areas also subject to shoreline erosion and recession. There are, however, low-lying areas that would increasingly experience stormwater drainage issues, especially as a result of extreme rainfall events in combination with high tides and storm tides.

City of Rockingham

There are some low-lying areas in CoR beyond the projected shoreline erosion/recession areas that are likely to be affected by inundation events. Although the extent of these areas is limited under present-day conditions, sea level rise would significantly increase the area affected.

Based on projected values for sea level rise, the low-lying residential area behind the foreshore including Rotary Park to Fisher Street may be subject to inundation with a depth of about 40 cm or less on a periodic basis (typically occurring once a decade, on average) by 2110. As building floor heights of most modern homes are at least 30 cm above ground level, the expected damage from such an event would be limited. However, stormwater management may increasingly become an issue in these low-lying areas and the capacity of the infrastructure to manage runoff from extreme rainfall events may diminish, especially if these events coincide with high sea levels due to storm and/or (spring) tides.

Low-lying areas of the Point Peron Foreshore Park are already subject to annual flooding. With sea level rise, these areas may transform to saltmarsh. This may result in an increase of natural values in this reserve.

Towards 2110, there would is a potential for ocean inundation to penetrate into Richmond Lake. This lake provides habitat for thrombolites, which could suffer from saltwater incursions. The thrombolite communities have a very high environmental value.

7. Values Assessment

7.1 Economic, social and environmental values

Assets in coastal areas include both artificial and natural features that deliver goods and services to people and by doing so provide value. Assets include natural physical elements of the landscape (beaches, dunes, flora and fauna), formed or constructed assets such as roads and buildings, and archaeological and cultural heritage such as ruins and meeting places.

The goods and services these assets provide can be categorised as being: 1) market goods and services (for which fees or prices are applicable), 2) social and cultural non-market goods and services (accessible for everyone for which no fee or price is applicable), and 3) ecosystem services (as a result of ecosystem functions—23 ecosystem goods and services have previously been identified [Earth Economics 2012]). There is a potential overlap between these types of goods and services, and as part of the value assessment it is important to be explicit about how certain goods and services have been assessed to prevent duplication. The potential for overlap is greatest for cultural services generated by ecosystems such as, enjoyment of scenery, recreation, cultural and artistic interpretation and use, religious and historic interpretation, and use for education and science (e.g. school excursions).

7.2 Qualitative value assessment

The qualitative value assessment determined a generic value for each type of asset. Assets of high value were then identified based on the stakeholder consultation. The qualitative 'value' of each asset was used for the assignment of consequences (from 'insignificant' to 'catastrophic'). The consequences were assigned for the economic, social and environmental aspects of the asset value independently. These consequences were then confirmed, or adjusted as appropriate, via consultation at the Risk Assessment Workshop (Section 5.3.3). The outcomes of this qualitative valuation process are tabulated and documented in terms of the economic, social and ecosystem consequences of coastal hazard impact on the assets (refer to Section 8.2 for further details on the consequence scale and assignment and Appendix A for the Asset Register). This qualitative valuation was then extended through a quantitative economic valuation, which was based on other information on valuing assets and ecosystem services from similar local, national and international studies as outlined below.

7.3 Quantitative value assessment

Various methods are available to determine the value of the goods and services provided by an asset and many methods enable value to be expressed in dollar terms. Estimating the dollar value of intangible goods and services can require considerable effort, however, and may be best achieved using qualitative valuation methods.

7.3.1 Valuation of market goods and services (economic)

Goods and services in this category are usually traded in a market environment, and data on market prices are usually readily available. Assets for which the market value can be readily determined include houses and commercial properties. The market value of other assets (such as roads, paths, parks and other infrastructure, for which fees are paid via rates and taxes) can be determined on the basis of construction guides and/or local and state government data.

7.3.2 Valuation of social and cultural non-market goods and services (social)

There are many goods and services for which no fee is applicable, such as the recreation benefits of visiting a park. The value of the amenity benefits of visiting parks can be derived indirectly by, for instance, considering the travel costs (the travel time and costs visitors are willing to pay to visit the park).

In addition to these costs, coastal properties tend to have a premium on their price compared to similar properties located in non-coastal areas. This premium reflects the benefits of living in a high amenity environment with views and beaches. This premium can be used to value the amenity and recreation values of beaches; this value could also be considered an ecosystem service.

7.3.3 Valuation of ecosystem services (environmental)

An important element of values in coastal areas is likely to be generated by a range of ecosystem services. Ecosystem services are the beneficial outcomes (for the natural environment and/or people) that result from ecosystem functions. Some examples of ecosystem services are support of the food chain, harvesting of animals or plants, and the provision of clean water or scenic views (NOAA 2000). Several ecosystem value categories have been defined (Costanza et al. 1997):

- **Use value:** the value derived from the use of an ecosystem service by people, such as fishing, visiting the beach, swimming and hiking.
- **Option value:** the value that people place on having the option to enjoy, visit or use an ecosystem.
- **Bequest value:** the value that people place on knowing that their children or future generations will have the option to use an ecosystem.
- **Existence value:** the value that people place on knowing that an ecosystem exists, even if they never use it.

The total value of an ecosystem, from a human benefit perspective, is the sum of all of these categories.

All the above ecosystem values exist if there is some sort of appreciation by humans. They do not, however, reflect the intrinsic value of ecosystems and their functions, which are by definition impossible to value, let alone in dollar terms.

7.3.4 Quantitative valuation methods

A number of methods are commonly used for estimating each the economic, social and environmental values of assets (Table 7.1).

Table 7.1 Common valuation methods and their application

Market Price Method	Estimates values for products or services that are bought and sold in commercial markets.	✓		
Hedonic Pricing Method	Estimates values that directly affect market prices of another good. Commonly applied to housing price premiums that reflect the value of local ecosystems.		✓	✓
Benefit Transfer Method	Estimates known values by transferring existing benefit estimates from comparable case studies elsewhere.	✓	✓	✓
Productivity, Net Factor Income or Derived Value Method	Estimates values that contribute to the production of marketed goods.		✓	✓
Travel Cost Method	Estimates values based on how much people are willing to pay to travel to visit the site.		✓	✓
Damage Cost Avoided, Replacement Cost, and Substitute Cost Methods	Estimates values based on costs of avoided damages resulting from lost social, cultural or ecosystem services, costs of replacing services, or costs of providing substitute services.		✓	✓
Contingent Valuation Method	Estimates values based on peoples stated willingness to pay for specific services, based on a hypothetical scenario. Suitable for estimating non-use or 'passive use' values, but requires expensive primary research.		✓	✓
Contingent Choice Method	Estimates values based on people stated willingness to make trade-offs among sets of services or characteristics. Requires expensive primary research.		✓	✓

Source: based on NOAA (2000)

The primary methods used for asset valuation in the Stage 2 Assessment were:

- **Market price method**, for built assets such as residential and commercial properties.
- **Replacement cost**, for infrastructure assets (e.g. roads, paths, pipelines etc).
- **Benefit transfer method**, mostly for social and ecosystem goods and services. This method is a cost-effective substitute for contingent valuation methods. There are a number of national and international datasets containing valuations for a wide range of coastal assets and ecosystem values. For an effective transfer, it is important to consider the availability of data and the comparability of the study area such as size, population and quality of assets.

The valuation was constrained by the available data and therefore the following assets were either broadly valued, or not valuated:

- Residential and commercial land uses, not within heritage areas or the urban area of CoR. Capital improved values were provided for the whole study area (except CoK and Garden Island) but were not distinguished by land use type and the base land values were also not provided. Most of the capital improved values data overlapped with other asset data and so to prevent the double counting with the other asset categories, these values were not included. It is estimated that the cost of risk may therefore be undervalued by ~1–5%.

- Park areas: Limited data were available on the types of ecosystem services offered by the parks in the study area. Additionally there were limited data available on the recreational use levels of parks and open spaces.
- Beach areas: Limited data were provided about the beaches and in some cases the beach areas were included within adjacent parks (parks and beaches deliver quite different services). In these instances, beach assets were separated from the parks areas manually. An average beach width of ~25 m was estimated based on a number of samples in the study area, but acknowledging that beach widths vary between beaches and between seasons.
- Kwinana industrial area: No data were available about the value of the industries in the Kwinana industrial strip.

7.4 Asset valuation

The following sections detail the results of the asset valuation within each of the asset categories. All values herein are expressed in terms of 2013 Australian dollars unless otherwise specified.

7.4.1 Utilities and infrastructure

The replacement value of utilities and infrastructure assets were determined from rates indicated by the respective CSCA LGAs. Further explanation on the sources used for specific assets, for which generic values cannot be applied, is provided below.

Boat harbours

The study area contains three boat harbours: Challenger, Fishing and Success Boat Harbour, which include approximately 64, 200 and 300 public boat pens, respectively. The replacement values of these harbours were estimated by using the Shell Cove Harbour (berthing for 300 boats) on the south coast of New South Wales as a benchmark. The Shell Cove Harbour development is estimated to cost $25 million in preparation and design works with a forecast construction cost of around $133 million; this equates to a cost of $526 666 per boat berth (Table 7.2).

Table 7.2 Estimated boat harbour values

Challenger	64	$33.7 million
Fishing	200	$105.3 million
Success	300	$158.0 million

Groynes

The costs for groynes are typically between $2 000 and $5 000 per metre, depending on water depth and degree of wave exposure (similar to seawalls and breakwaters). This assessment has assumed a value per groyne of $500 000.

Coogee Beach Surf Lifesaving Club

The Coogee Beach SLSC facility was completed in 2013 and supports the provision of essential aquatic emergency and first aid services to the CoC coastal beaches. The construction of the club is estimated to have cost $10 million. The two-storey surf lifesaving club includes community facilities, a gymnasium, change rooms, meeting rooms, kitchen, public toilets and public kiosk. The community facilities allow use by various organisations for healthy lifestyle activities (e.g. sporting and social recreation, training, events, youth development, entertainment, fitness and gymnasium). The club also has public beach facilities and disabled persons access, including change rooms and showers, with beach wheelchairs for disabled persons.

Coogee Beach wheelchair ramp

In 2013 the Cooks Hill Surf Club, Newcastle, installed a wheelchair ramp and rubber matting for the value of $40 000. This value has been used to approximate the replacement value of the Coogee Beach wheelchair ramp

Centrelink building in Fremantle

Review of local commercial rents suggests that the CoF Centrelink building would have a Net Annual Value of approximately $250 000 per annum. The Net Annual Value is typically around 5% of the Capital Improved Value; therefore, the estimated Capital Improved Value for this building was $5 million. This is the estimated replacement value of the building.

Heritage items and areas

Assets listed as heritage were assumed to have a value that is 150% of the average land values in the study area, as heritage areas are generally valued at a premium compared to generic urban areas (Table 7.3). Government initiatives, such as the Sydney heritage floor space scheme (aimed at conserving heritage floor space in the City of Sydney), allocate public funds to the conservation of heritage floor space. This indicates the community's willingness to pay to have such assets conserved.

Table 7.3 Annual values of heritage areas

City of Fremantle	$ 5.13
City of Cockburn	$ 6.32
City of Rockingham	$ 7.09

Industrial land

The valuation of industrial land was constrained due to data availability. In the absence of these data, it has been assumed that industrial areas within the hazard areas represent an economic consequence of at least $20 million (based on the consequence scale used for this assessment, Table 8.3). It is likely that this represents an undervaluation of the actual values at risk. However, the use of $20 million ensures that the loss of this land will be assigned the highest consequence level as agreed by the stakeholders at the Risk Assessment Workshop (refer to Sections 5.3.3 and 8.2).

7.4.2 Beaches

Eighteen beach areas are defined within the study area.

Bathers Beach, in CoF, is a popular inner city beach, located between Fishing Boat Harbour and the Round House at Arthurs Head. It is a small beach in the oldest section of Fremantle and is popular with families with small children, particularly in the morning due to the sheltered waters. South Beach is the only beach of any significant size in CoF south of the river. It is located south of Success Harbour and has significant parking and a grassed area between the groynes. South Beach is also a family beach with views of Rottnest, Carnac and Garden islands. Recreational activities include picnics/barbeques, swimming and dining at the beachside café.

In CoC, the beach adjacent to C. Y. O'Connor Reserve runs from South Fremantle to McTaggart Cove. Facilities for this beach comprise car parks public toilets and picnic facilities. The beach at C. Y. O'Connor is also used as a horse exercise area. Coogee Beach has become more popular with the establishment of a new surf life saving club in 2013 in addition to the existing café. CoC has indicated that increased future residential population from the Port Coogee development (of up to 10 000 residents) is expected to increase the utilisation of Coogee Beach. The beach holiday park is equipped with camp grounds, chalets, family units, and powered caravan sites.

Beach areas affected by erosion or inundation are also found adjacent Woodman Point Regional Park.

Challenger Beach, in CoK, is located south of the Naval Base Shacks. This beach is backed by a 50 m wide grassy dune, which together front the Alcoa aluminium refinery. Facilities consist of a car park, toilets and a small boat launching ramp. Barter Road Beach to the south is often used for horse exercise and has a relatively low use by other recreational visitors. James Point is a low sandy foreland located in front of the BP oil refinery and as such James Point is inaccessible to recreational visitors. Wells Park Beach is surrounded by heavy industry, e.g. the BP oil refinery and the CSBP fertiliser plant. The northern area of the beach near these industries is generally closed to the public. Wells Park, located adjacent to the beach, is also popular with families.

Rockingham Beach, in CoR, is a recreational beach with shallow, calm water for swimming. Areas of this beach are also used as a horse exercise areas and dog walking. Bell and Churchill Parks beach-front is located adjacent to long established parks in the centre of CoR which have high recreational use and are also used as a venue for concerts and events. In these parks there are electric barbeques, change rooms and toilets. The shopping, commercial and restaurant precinct surrounded by a low to high density residential area is located across the road from the parks, beach reserves and boardwalk. Palm Beach is central and located in front of a prime real estate area. Crystals Beach, the PWC (Public Watercraft) Area and the Designated Dog Beach are more isolated beaches located along the peninsula of Point Peron.

All the beaches in the study area have been classified (Table 7.4) as:

- recreational: recreation beach in urban setting, utilised by a significant adjacent resident population and visited frequently by tourists
- urban: urban beach with some recreational values, utilised regularly by a significant nearby resident population
- remote recreational: recreation beach outside of urban setting visited frequently by tourists
- remote: low recreation value and outside of urban setting where access may be limited due to a nearby industrial development or natural barriers.

Table 7.4 Classification of study area beaches

Bathers Beach	Recreational
South Beach	Recreational
C. Y. O'Connor Reserve beach-front	Urban/partly remote[1]
South Fremantle Power Station	Remote
Coogee Beach	Recreational
Woodman Point Regional Park	Remote recreational
Henderson Cliffs Reserve	Remote
Challenger beach	Remote
Barter Road Beach	Remote
BP James Point	Remote
Wells Park Beach	Remote recreational
Rockingham Beach	Recreational
Bell and Churchill beach-front	Recreational
Palm Beach	Recreational
Designated Dog Beach	Remote recreational
PWC Area	Remote recreational
Crystals Beach	Remote

Note:

1. Sections far from current development may be considered remote.

Beaches are highly valued natural resources for both use and amenity and so provide a range of values to a wide variety of stakeholders. These values are discussed below.

Use values

A number of studies on beach values have been completed including Pitt (1992), Blackwell (2005, 2007) and Kirkpatrick 2011. Blackwell (2005) estimated the value for Australia's beaches based on peoples' willingness to pay to visit a beach. Analysis of this information shows that the beach values are dependent on the beach classification and can range from $3.80 for a remote beach to $23 for a recreational beach (Table 7.5).

Table 7.5 Beach values used for the Stage 2 Assessment

Recreational	$23.00
Urban	$21.00
Remote recreation	$12.80
Remote	$3.80

Note

1. * Based on Blackwell (2005)

Non-use values

Studies on the non-use values of beaches could not be found and as such have not been included herein. However, an extensive literature review (Rivers & Wills 2005) found that the non-use benefits of cultural and ecosystem assets can be significant and even exceed the use benefits as the number of users of such assets can be a small fraction of the number of people who know and care about them. The review concluded that the non-use values could comprise 70% (less iconic cultural assets) to 85% (internationally iconic cultural asset) of the total beach values.

7.4.3 Parks

The use (recreational) value of parks and open spaces has been estimated using the benefit transfer method using two source studies (Harnik & Welle 2009, Lockwood & Tracy 1995). For a number of parks no information was available regarding the visitation numbers. In those cases, the replacement value has been used as an approximation of the recreation value of parks.

Use value

A number of parks within the study area attract a large number of recreational visits; these parks are detailed below.

Arthur Head Reserve is on the edge of Fremantle's historic West End. It comprises the Round House and adjacent cottages, Bathers Beach, J Shed and Kidogo Arthouse. Annual visitation to the Round House and surrounding attractions is approximately 140 000 people per year.

Woodman Point Regional Park attracts approximately 400 000 visitors each year and Cape Peron – Rockingham Lakes Regional Park attracts 250 000.

Although no annual visitation data were available for Bell and Churchill Parks in CoR, event data suggest that visitation for Bell Park is well over 10 000 visitors per annum, possibly up to 100 000 visitors per annum. Churchill Park is used as a venue for a range of events and alone draws approximately 25 000 visitors, and visitation may be up to 250 000 visitors per annum.

To facilitate the benefit transfer, Woodman Point and Cape Peron – Rockingham Lakes Regional Parks were classified as 'general park use' while Arthur Head Reserve was classified as 'special uses' due to its heritage attractions. The average value per visit per category of park was then determined from data presented in (Table 7.6).

Table 7.6 Recreational value of direct use parks

General park use (playgrounds, trails, dog walking, picnicking, sitting, etc).	$3.07
Sports facilities use (tennis, team sports, bicycling, swimming, running, ice skating, etc.)	$12.55
Special uses (golfing, gardening, festivals, concerts, attractions, etc.)	$156.83

Source: Harnik and Welle (2009)

The value of urban parks has also been investigated using the travel cost method (Lockwood & Tracy 1995). The value of visiting Centennial Park, Sydney, was determined to be $12.45 per visit. This is considered an appropriate analogy for the iconic parks in the study area, including:

- Arthur Head Reserve (140 000 visitors)
- The Esplanade (no visitation data available, assumed ~250 000 visitors)
- South Beach Reserve (no visitation data available, assumed ~250 000 visitors)
- C. Y. O'Connor (no visitation data available, assumed ~100 000 visitors)
- Woodman Point Regional Park (400 000 visitors)
- Bell & Churchill Parks (only event visitor data, assumed ~350 000)
- Cape Peron – Rockingham Lakes Regional Parks (250 000 visitors).

Replacement value

No information on visitor numbers was available for several parks in the study area. In these instances the replacement value has been used as an approximation of the recreation value of parks. The replacement value shows what it would cost to develop a park including recreational infrastructure such as paths, shelters and playgrounds. It is reasonable to assume that the value the community gains from these parks would be at least equivalent to the replacement value, otherwise the investment would not have been made (Table 7.7).

Table 7.7 Replacement values of parks

Parks and open spaces in Fremantle, Cockburn and Rockingham	Medium public open space development cost	$3.00
Coogee Beach Reserve	High public open space development cost	$3.50

Note:

1. Assumes open space infrastructure and open space has an economic life of 20 years

Ecosystem value

At least two parks in the study area have significant value in terms of the role they play in supporting the natural ecosystems (Table 7.8).

Table 7.8 Parks with environmental significance

Woodman Point Regional Park	• significant tracts of undisturbed coastal vegetation including Tuart (*Eucalyptus gomphocephala*) woodland • vast area of a threatened ecological community consisting of Rottnest cypress (*Callitris preissii*) and Rottnest tea tree (*Melaleuca lanceolata*) • the significance of Woodman Point vegetation communities is recognised by its permanent listing of the Register of National Estate
Cape Peron – Rockingham Lakes Regional Parks	• small occurrence of threatened ecological community consisting of Rottnest cypress (*Callitris preissii*) and Rottnest tea tree (*Melaleuca lanceolata*) • significant surrounding marine environment, gazetted as Shoalwater Islands Marine Park • occurrence of a 'critically endangered' threatened ecological community: the thrombolites, at Richmond Lake. These are also listed as Endangered under the *Environment Protection and Biodiversity Conservation Act 1999*

One of the most complete studies of ecosystem services was undertaken by Costanza et al (1997) and this work has been applied in a number of Australian studies (including Kirkpatrick 2011 and Blackwell 2005, 2007) (Table 7.9). In the absence of another appropriate category, Woodman Point Regional Park was assigned the average environmental value for tidal marsh/mangroves and temperate/boreal forests ($0.53) and Cape Peron – Rockingham Lakes Regional Parks was assigned the environmental value for estuaries ($2.37). The park and reserve areas adjacent to beaches were assigned the environmental value for grass/rangelands ($0.02).

Table 7.9 Value of ecosystem services

Open ocean	$0.02
Estuaries	$2.37
Seagrass/algae beds	$1.87
Coral reefs	$0.63
Shelf	$0.17
Lakes/rivers	$0.88
Tropical forests	$0.21
Temperate/boreal forests	$0.03
Grass/rangelands	$0.02
Tidal marsh/mangroves	$1.04
Swamps/ floodplains	$2.03

Source: Costanza et al (1997)

Park value summary

The benefit transfer method was used to estimate the recreational values of parks in the study area. Where visitor numbers were known or could be approximated, recreation values were applied (based on Lockwood & Tracy 1995). Where these data were not available the annualised replacement costs of parkland were used to express recreation values. Finally, environmental values were added using values from Costanza et al (1997) for the study areas' known ecosystems. The resultant park values and associated area data are detailed in Table 7.10.

Table 7.10 Park values and total land area affected

City of Fremantle	Habitat areas (outside of named parks)	47 156	$3.00	n/a	$0.02	$3.02
	Arthur Head Reserve	28 124	n/a	$61.98	$0.02	$62.00
	Esplanade Reserve	35 243	n/a	$88.32	$0.02	$88.34
	South Beach	63 381	n/a	$49.11	$0.02	$49.13
	Wilson Park	3250	$37.50	n/a	$0.02	$37.52
City of Cockburn	Habitat areas (outside of named parks)	102 676	$3.00	n/a	$0.02	$3.02
	C. Y. O'Connor Reserve	166 686	n/a	$7.47	$4.57	$12.04
	Coogee Beach Reserve	106 177	$3.50	n/a	$0.02	$3.52
	Woodman Point Regional Park	1 663 003	n/a	$2.99	$4.57	$7.56
	Henderson Cliffs Reserve	171 545	$3.00	n/a	$0.02	$3.02
	Island Reserve	3021	$3.00	n/a	$0.02	$3.02
	Barrow Park	15 674	$3.00	n/a	$0.02	$3.02
	Lot 43701 (north of Port Coogee)	3246	$3.00	n/a	$0.02	$3.02
City of Kwinana	Challenger Beach	105 487	$3.00	n/a	$0.02	$3.02
	Barter Road Beach	20 233	$3.00	n/a	$0.02	$3.02
	BP James Point	67 548	$3.00	n/a	$0.02	$3.02
City of Rockingham	Parks (includes Wells Park)	706 405	$2.05	n/a	$0.02	$2.07
	Rockingham Beach	110 904	$2.05	n/a	$0.02	$2.07
	Bells and Churchill Parks	25 495	n/a	$170.92	$0.02	$170.94
	Palm Beach	65 334	$2.05	n/a	$0.02	$2.07
	PWC Area	6409	$2.05	n/a	$0.02	$2.07
	Crystals Beach	7659	$2.05	n/a	$0.02	$2.07
	Cape Peron – Rockingham Lakes Regional Park	2 678 045	n/a	$1.16	$2.40	$3.56

Notes:

1. LGA = local government area.
2. Excluding beach areas.

As with beaches, parks may also have significant non-use values and for iconic natural assets, the non-use value may even be greater than the use values. There were insufficient data available about the non-use values of parks to apply to the study area via the benefit transfer method. Nonetheless, it is important to note that people also place a value on knowing that parks, beaches and ecosystems are available (existence value) and will be available for future generations to enjoy (bequest value). In addition, it is worthwhile to note that natural ecosystems also have intrinsic values. By definition, these values cannot be expressed in dollar terms or other human terms as these values exist without delivering a good or service to people.

7.5 Cost of risk

Placing values on assets that may be at risk from erosion and inundation at some point in time over the 100-year planning timeframe is an important first step of the risk analysis. The next crucial step, which is generally overlooked in studies, is assessing the cost of risk. The cost of risk is the net present value (NPV) of the potential future damages due to erosion and inundation to assets and recognises:

- when and for how many years assets are at risk
- the likelihood of damages actually occurring
- the increasing levels of risk over time due to climate change
- in an appropriate way, the annual values of beaches and parks.

The values of parks and beaches mostly depend on recreation, protection, amenity and ecosystem service values, which are expressed in annual terms. Failing to consider the annual (loss) of values over a longer time will result in the under-representation of these values in the overall assessment.

If the cost of risk analysis is ignored, an asset at risk from a 1-in-10 year storm event (a 10% AEP) would be valued equally to a similar asset at risk from a 1-in-500 year storm event (a 0.2% AEP event). Further, ignoring the cost of risk analysis would result in valuing a risk that may occur in the future as being equal to a present day actual risk.

The cost of risk analysis has been undertaken as a 'discounted cash flow' analysis, expressing the projected costs over the 2014 to 2114 timeframe[3]. To allow for the depreciation of the value of money over time a discount rate of 6% per annum was used. Note that cost of risk calculations do not show actual damages of an extreme event occurring, rather they address the probability of an event occurring; the total cost of an extreme event occurring in a given year is significantly higher than the annual cost of risk.

For the cost of risk analysis the effects of erosion and inundation have been considered separately as the impacts of these hazards (and the resultant costs) will be different, erosion causing the permanent loss of land and inundation cause the temporary flooding of land, after the which the assets, although degraded will still exist. The assets (or proportion of the assets) that would be affected by erosion over time under the three likelihood categories – Almost Certain, Possible and Rare – have been identified and listed in the Asset Register (Appendix A). From that information it was assumed that:

[3] *While the hazard mapping extends to 2110, we have included an additional few years to allow for the potential damages to effectuate and to be considered as part of the analysis.*

- The cost of risk of the assets within the 'Almost Certain' category is assumed to increase by 90% of asset value per annum (i.e. after year 1, 90% of the assets value would be lost, in year 2, 90% of the remaining 10% asset value would be lost, etc.). For coastal structures, which are necessarily placed within a hazard zone, the cost of risk is assumed to be 10% as coastal structures were designed to accommodate erosion and inundation to some extent.
- The cost of risk of the assets within the 'Possible' category is assumed to increase by 5% of asset value per annum.
- The cost of risk of the assets within the 'Rare' category is assumed to increase by 1% of the asset value per annum.

Those items identified as being at risk of inundation were treated as follows:

- The cost of risk of the assets within the 'Almost Certain' category is assumed to increase by 90% of the asset value per annum. For coastal structures, which are necessarily placed within a hazard zone, the cost of risk is assumed to be 10% as coastal structures were designed to accommodate erosion and inundation to some extent.
- The cost of risk of the assets within the 'Possible' category is assumed to increase by 10% of the asset value per annum.
- The cost of risk of the assets at risk within the 'Rare' category are assumed to not be affected by inundation as the risk is well below what is generally regarded as an acceptable level of risk (1% AEP event).

In cases where an area would also be affected by inundation, only the additional units over and above those affected by erosion were included within the inundation assessment to prevent double counting the cost of risk.

Table 7.11 to Table 7.13 show the NPV of the cost of risk due to erosion, inundation and both coastal hazards by asset category and by LGA.

Table 7.11 Cost of erosion risk over timeframe from 2015 to 2114

Beach	$128.6	$6.5	$41.8	$23.4	$56.9
Coastal structures	$7.1	$0.2	$4.0	$1.9	$1.0
Heritage	$37.1	$0.6	$27.5	$-	$9.0
Infrastructure	$4.6	$0.1	$3.2	$0.01	$1.3
Major industries	$14.2	$-	$-	$14.2	$-
Parks	$67.8	$8.9	$31.0	$4.8	$23.1
Utilities	$0.3	$0.1	$0.01	$0.01	$0.2
Urban area CoR	$0.9	$-	$-	$-	$0.9
Total	$225.5	$16.5	$107.5	$44.3	$92.5

Note.
1. $million (NPV, 6% discount rate)
2. $- indicates no value
3. $0.00 indicates a very low value

Table 7.12 Cost of inundation risk (above and beyond areas at risk due to erosion) over timeframe from 2015 to 2114

Beach	$1.0	$1.0	$-	$-	$-
Coastal structures	$-	$-	$-	$-	$-
Heritage	$9.9	$2.0	$-	$-	$7.9
Infrastructure	$-	$-	$-	$-	$-
Major industries	$-	$-	$-	$-	$-
Parks	$53.7	$1.1	$47.2	$-	$5.3
Utilities	$-	$-	$-	$-	$-
Urban area CoR	$-	$-	$-	$-	$-
Total	$64.6	$4.1	$47.2	$-	$13.2

Note.
1. $million (NPV, 6% discount rate)
2. $- indicates no value
3. $0.00 indicates a very low value

Table 7.13 Cost of erosion and inundation risk over timeframe from 2015 to 2114

Beach	$129.6	$7.4	$41.8	$23.4	$56.9
Coastal structures	$7.1	$0.2	$4.0	$1.9	$1.0
Heritage	$47.0	$2.7	$27.5	$-	$16.9
Infrastructure	$4.6	$0.1	$3.2	$0.0	$1.3
Major industries	$14.2	$-	$-	$14.2	$-
Parks	$121.5	$10.1	$78.2	$4.8	$28.4
Utilities	$0.3	$0.1	$0.0	$0.0	$0.2
Urban area CoR	$0.9	$-	$-	$-	$0.9
Total	$325.2	$20.6	$154.7	$44.3	$105.7

Note.
1. $million (NPV, 6% discount rate)
2. $- indicates no value
3. $0.00 indicates a very low value

The total cost of risk due to erosion and inundation for the 2015–2114 period is estimated to be ~$325 million for the entire study area. Of the four LGAs, CoC has the most significant cost of risk to its assets at $150 million, followed by CoR at nearly $106 million. The two most significant cost of risk categories are the beaches ($130 million) and the parks ($122 million).

For CoK and CoR, the beaches are the most significant asset category at risk. The calculations as shown assume beaches are not allowed to move landward; however, beaches may often move landward under rising sea levels if there are no obstacles or sediment conditions that would prevent this. In most cases, where beaches would be allowed to move landward, this would occur at the expense of park land; consequently, the cost of risk for beaches would reduce at the expense of the cost of risk to park land. Note also that the majority of the beach values are associated with recreational and amenity values. If one beach would be lost, visitors and tourists may instead frequent a nearby alternative beach so that in recreational values terms, the loss of one beach may not result in a net loss of beach values in an area. In terms of coastal management it is therefore recommended to make informed and balanced decisions about which beaches to protect or to allow to move landward and which beaches to allow to be eroded away.

Parks are a key asset category at risk, especially for CoF and CoC which include a number of high visitation parks with intense usage patterns. The greatest cost of risk for parks is within the CoC which includes expansive park areas along the foreshores. These parks have both significant recreation values and ecosystem values.

8. Risk Assessment

The risk assessment approach utilised for this study is adapted from the Australian Standard Risk Management Principles and Guidelines ISO 31000:2009, as described in Section 4 and presented schematically in Figure 4.1.

8.1 Risk likelihood

The Stage 1 Assessment (CZM et al. 2013) provided the technical detail to define the likelihood or probability of occurrence of coastal hazards. This incorporated an analysis of local geomorphology and coastal processes, review of historical responses to storm events, and modelling to predict likely future response to sea level rise. Based on the Australian Standard for Risk Management (AS/NZS ISO 31000:2009) and its companion document (HB 436:2004), a scale of likelihood of occurrence for a hazard impact was developed for erosion (Table 8.1) and inundation (Table 8.2) for the following timeframes: present day (2014), 2070 and 2110 planning horizons. Maps showing the likelihood of coastal hazards along the Owen Anchorage and Cockburn Sound coastline at each timeframe are presented in Appendix D.

Table 8.1 Likelihood scale for erosion

		1 m AHD contour	present – acute (2003 storm)	2070 – acute (2003 storm)
Not used	Likely	–	–	–
		present – acute (2003 storm)	2070 – acute (2003 storm)	2110 – acute (2003 storm)
Not used	Unlikely	–	–	–
		2070 – acute (2003 storm)	2110 – acute (2003 storm)	2110+ – acute (2003 storm)

Note.

1. Based on Stage 1 Assessment (CZM et al. 2013).
2. Short-term (acute) erosion with the assessment of shoreline change due to sea level rise was used as the basis of the erosion hazard assessment at the study timeframes (Refer to Section 3.6.1).

Table 8.2 Likelihood scale for inundation

		present acute erosion line	present acute erosion line	1 yr ARI for 2070 (1.5 m AHD) or 2070 acute erosion, whichever the more landward
Not used	Likely	–	–	–
		10 yr ARI for present (1.16 m AHD) or present acute erosion, whichever the more landward	10 yr ARI for 2070 (1.66 m AHD) or 2070 acute erosion, whichever the more landward	10 yr ARI for 2110 (2.06 m AHD) or 2110 acute erosion, whichever the more landward
Not used	Unlikely	–	–	–
		500 yr ARI for present (1.48 m AHD) or 2070 acute erosion, whichever the more landward	500 yr ARI for 2070 (1.98 m AHD) or 2110 acute erosion, whichever the more landward	500 yr ARI for 2110+ (2.98 m AHD) or 2110+ acute erosion, whichever the more landward

Notes:

1. Likelihood scale for inundation is based on Table 10 in the Stage 1 Assessment (CZM et al. 2013).
2. The acute erosion lines appear in the likelihood scale for inundation because the nature of coastal hazards is such that inundation likelihoods must incorporate the erosion likelihoods because land that is predicted to be eroded at each probability will also, by definition, be inundated.

Although a typical risk assessment would include up to five likelihood descriptors, only three were considered practical for this study due to the limited amount of probabilistic information used in generating the Stage 1 Assessment coastal hazard mapping.

The understanding of coastal processes and climate change and the potential for impacts will continue to improve, allowing for improvements in the determination of likelihoods in the future. The CSCA is encouraged to continue to maintain and expand their data collection (e.g. monitoring of coastal erosion and inundation following significant storm events), to provide valuable ongoing datasets to inform future risk assessments.

8.2 Risk consequence

A consequence scale for economic, social and environmental values for the assets at risk in the coastal zone was developed (Table 8.3) consistent with the Australian Standard Risk Management Principles and Guidelines ISO 31000:2009 and existing enterprise risk frameworks already used by the four LGAs. The grades were appropriately weighted to ensure equivalence in impact severity across the economic, social and environmental categories and this was confirmed via the stakeholder consultation carried out as part of this project (refer Section 7.1). The consequence scale was designed such that it is appropriate to consider management actions for each asset as designated by the highest grade of consequence. The assigned consequences of the coastal hazard impacts on the assets are tabulated as part of the Asset Register (Appendix A). Maps showing the consequences of coastal hazard impact to the assets in the Owen Anchorage and Cockburn Sound coastline are presented in Appendix E.

Table 8.3 Consequence scale

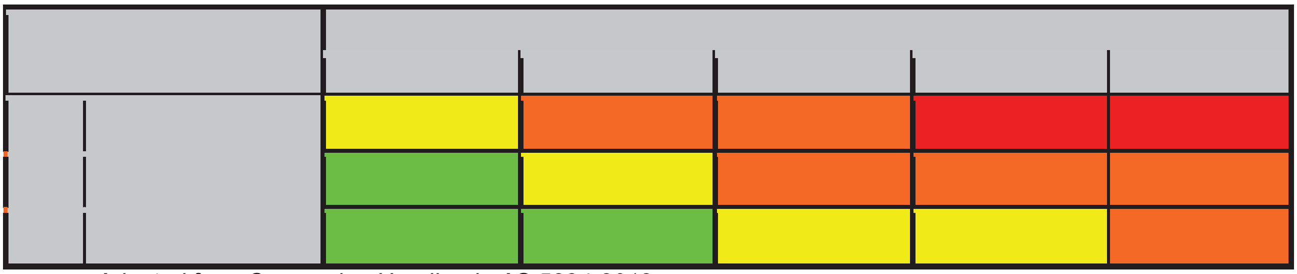
	Widespread major damage or loss of property or infrastructure with total value >$20 million. Regional economic decline, widespread business failure and impacts on state economy.	Widespread semi-permanent impact (~1 yr) to highly utilised community services, wellbeing, or culture of the community with no suitable alternatives. Loss of lives and/or permanent disabilities.	Severe and widespread, permanent impact on multiple regionally or nationally significant ecosystem services. Recovery unlikely.
	Major damage or loss of property or infrastructure with total value ~$5 million. Lasting downturn of local economy with isolated business failures and major impacts on regional economy	Major widespread long-term (~1 month) disruption to well-utilised services, wellbeing, or culture of the community with very few alternatives available. Widespread serious injuries/illnesses.	Severe and widespread semi-permanent impact on one or more regionally or nationally significant ecosystem services. Partial recovery may take many years.
	Major damage to property or infrastructure with total value ~$1 million. Significant impacts on local economy and minor impacts on regional economy	Minor medium- to long-term (~1 week) or major short-term disruption to moderately utilised services, wellbeing, or culture of the community with limited alternatives. Isolated serious injuries/illnesses and/or multiple minor injuries/illnesses.	Substantial impact on one or more locally significant ecosystem services. Full recovery may take several years.
	Substantial damage to properties or infrastructure with total value ~$200 000. Individually significant but isolated impacts on local economy	Small to medium short-term disruption (~1 day) to moderately utilised services, wellbeing, finances, or culture of the community with some alternatives available, or more lengthy disruption of infrequently utilised services. Minor and isolated injuries and illnesses.	Small, contained and reversible short-term impact on isolated ecosystem services. Full recovery may take less than 1 year.
	Minor damage to properties or infrastructure with total value ~$50 000. Minor short-term impact on local economy	Very small short term disruption (~1 hr) to services, wellbeing, finances, or culture of the community with numerous alternatives available. Negligible injuries or illnesses	Little to no environmental impact

8.3 Risk evaluation

Within a risk assessment approach, risk is defined as the combination of likelihood and consequence. For each asset potentially affected by coastal erosion and/or inundation, the combination of likelihood of occurrence and consequence of impact (adopting the highest grade of economic, social and environmental consequences) will determine the overall level of risk. Additionally, the risk rating (based on the highest consequence grade) informs the priority for risk treatments and the resultant adaptation pathway assignment is based on the asset/asset type identified as requiring risk treatment. As such the priorities for risk treatment are established in the same way but the risk treatment action may differ.

A risk matrix defining the level of risk from the various combinations of likelihood and consequence was developed for this assessment and largely adapted from AS 5334-2013 (Table 8.4).

Table 8.4 Risk matrix



Source: Adapted from Companion Handbook, AS 5334-2013

For each asset, likelihood values have been ascribed for both erosion and inundation hazards at the timeframes of present day (2014), 2070 and 2110 (Section 8.1). Consequence values for each asset have also been ascribed considering economic, social and environmental perspectives (Section 8.2). Based on the adopted likelihood and consequence values and the risk matrix presented in Table 8.4 above, each asset within the register has been assigned a risk level (low, medium, high or extreme) for the three timeframes. Maps showing the distribution of risk along the Owen Anchorage and Cockburn Sound coastline are presented in Appendix F.

The risks presented in the Asset Register and maps will help authorities and other stakeholders make appropriate decisions that aim to mitigate these risks based on the community's (and the Government's) tolerance for risk. In most cases it would be expected that low risks can simply be monitored, rather than demand valuable management resources, whereas extreme or high risks require more immediate management attention.

8.4 Existing coastal management

Many of the risks associated with existing and future coastal hazards (erosion and inundation) are currently being managed to some degree by a range of passive and active measures (refer to Section 3.4). Information provided by the LGAs and other stakeholders during the Risk Management Options Workshop (Section 5.3.4) helped identify what measures are currently in place and what risks these measures are addressing. Residual risks remaining after treatment by these coastal management measures were established based on how effective the measures are at reducing either the likelihood of risk or the consequence of risk. It is the residual risks after existing management controls are considered that should form the basis of future coastal management efforts.

The existing controls that have been adopted to date include a suite of structural and non-structural measures (Table 8.5). Details of the current risk management controls, as they apply to the various risks, and the level of risk remaining after consideration of these controls (i.e. the residual risk), are included in the Asset Register presented in Appendix A. The residual risks account for any existing controls and thus represent the present day need for management of coastal hazards that can occur at present and also in the future (in 2070 and 2110).

Table 8.5 Existing controls in the Owen Anchorage and Cockburn Sound coastline

Rock groynes	Several locations across the Cities of Fremantle, Cockburn and Rockingham. Treats the risk of erosion for areas behind the groyne by reducing likelihood of occurrence.	Generally results in accretion on one side and erosion on the other side depending on longshore drift. Effective for small areas only.
Timber groyne	Rockingham Palm Beach. Treats the risk of erosion for areas behind the groyne by reducing likelihood of occurrence.	Generally less effective and less robust than rock groynes.
Seawall/rock armouring	Several locations across the Cities of Fremantle, Cockburn, Kwinana and Rockingham. Treats the risk of erosion (and inundation) for areas behind the seawall by reducing likelihood of occurrence.	Depending on integrity of structure. Can cause erosion at ends and can lose beach in front. Generally effective for the land behind the seawall.
Harbour and breakwaters	Cities of Fremantle (boat harbours) and Cockburn (Port Coogee, AMC). Treats the risk of erosion for areas behind the breakwaters by reducing likelihood of occurrence.	Large and extensive structures. Very effective at reducing erosion, but not inundation.
Offshore/detached breakwater	BP oil refinery, James Point and Wells Park. Treats the risk of erosion for areas behind the offshore structure by reducing likelihood of occurrence.	Reduces wave impact, but is a low wave energy environment anyway. Reliant on salient formation behind structures. Limited effectiveness when considering impacts of sea level rise.
Dune stabilisation, revegetation and weed control	Across the Cities of Fremantle, Cockburn Kwinana and Rockingham. Treats the risk of erosion for areas behind the dunes by reducing likelihood of occurrence.	Helps retain sand in dunes and traps sand blown up from beachface. Limits loss of sand from the system. Limited effectiveness.
Sand nourishment	Selected locations within the Cities of Fremantle, Kwinana and Rockingham beaches. Treats the risk of erosion for areas behind the nourishment zone by reducing likelihood of occurrence.	Requires a source of sand and can be disruptive to beach amenity. Can be very effective for areas directly affected, but generally requires on-going renourishment as sand is transported away from site.
Sand bypassing	City of Cockburn (Port Coogee). Treats the risk of erosion for areas downdrift of Port Coogee by enabling sand supply to the beach and thus reducing likelihood of occurrence of erosion.	Manual transfer of sand across the development. Sporadic events driven by compliance to development conditions. Limited effectiveness in downdrift areas.

Induced accretion	Updrift (north) of Port Coogee. Treats the risk of erosion for areas adjacent to the accretion by reducing likelihood of occurrence.	Is not natural accretion but helps provide a buffer against erosion
Geotextile bags	Rockingham Palm Beach. Treats the risk of erosion for areas behind the geotextile bags by reducing likelihood of occurrence.	Good for temporary situations and can be removed relatively easily.
Setbacks	All Local Government Authorities e.g. City of Cockburn and LandCorp. Treats the risk of erosion and inundation by reducing (avoiding) likelihood of occurrence of impact.	Development buffer based on potential erosion (or inundation) over a given timeframe. The extent of buffer can reflect the tolerance for future risk.
Minimum ground levels	All Local Government Authorities e.g. City of Cockburn and Australand. Treats the risk of inundation for areas filled by reducing likelihood of occurrence.	Avoids inundation over a given timeframe. The extent of fill required reflects the tolerance for future risk.
Raised floor levels	All Local Government Authorities e.g. City of Fremantle. Treats the risk of inundation by reducing the consequence of impact (i.e. minimising damage if affected).	Typically incorporates a freeboard above minimum ground levels to provide an additional buffer.
Design standards	All Local Government Authorities e.g. Cockburn Cement wash plant and reclaimer jetty. Treats the risk of erosion by reducing the consequence of impact (i.e. minimising damage if affected).	Coastal engineering standards. Future climate conditions need to be considered.
SPP2.6 requirements	All Local Government Authorities e.g. LandCorp South Fremantle Power Station Redevelopment Site. Treats the risk of erosion and inundation by reducing the likelihood and/or consequence through legislated development requirements.	Compliance based approach only.
Asset relocation	City of Cockburn. Treats the risk of erosion or inundation of the asset by reducing likelihood of occurrence of impact.	Effective if there is an alternative location.
Asset replacement	City of Kwinana. Treats the risk of erosion or inundation of the asset by reducing consequence of impact (i.e. minimising damage if affected, assuming the replacement is more accommodating of impact than previous facility).	Replacing like-for-like may not be feasible in the same location given changing environmental conditions.
Asset repair/upgrade	City of Kwinana. Treats the risk of erosion or inundation of the asset by reducing consequence of impact (i.e. minimising damage if affected, assuming the upgraded asset is more accommodating than previous facility).	Retrofit of existing infrastructure to extend life.

8.5 Risk tolerability

It is impractical to mitigate all risk. Priority should be given to treating risks that are considered to be the most important. Section 4.1 of SPP2.6 "Coastal Hazard Risk Management and Adaptation Planning Process" states that coastal hazard risk management and adaptation planning should include risk evaluation criteria (i.e. tolerability) against which the coastal risks should be assessed. The application of tolerability concepts in coastal risk assessments helps to ensure alignment with SPP2.6 and innovation by applying emerging national best practice. This approach has been applied in a number of recent studies including Coffs Harbour Coastal Zone Management Study (WBM 2013) and the Coastal Settlements Adaptation Study – Middle Beach, South Australia (Western & Kellet 2013).

The tolerability concept has been applied based on the 'As Low as Reasonably Practicable (ALARP)' framework as adopted by the National Emergency Risk Assessment Guidelines (National Emergency Management Committee 2010). The ALARP framework has been adapted for this study to help prioritise risk treatment for critical areas or assets (Figure 8.1). This prioritisation was agreed by stakeholders to be appropriate for use during the Risk Assessment Workshop (Section 5.3.3). The ALARP framework outlines the action required for different levels of risk, and so determines those assets/areas that require risk treatment as a priority. The aim of this framework is to ensure adaptation methods are fit for purpose and economically efficient by scaling the treatment to the level of risk.

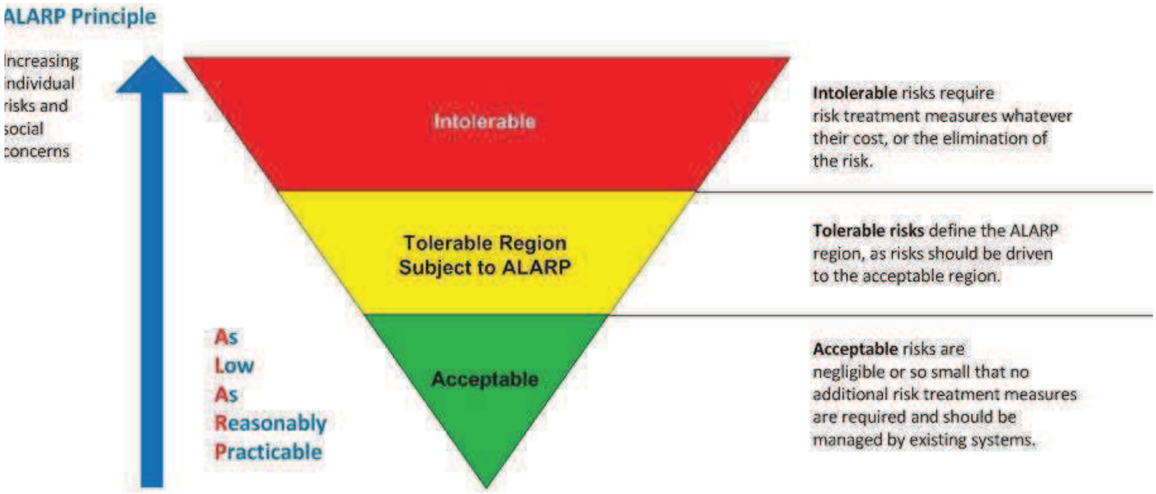


Figure 8.1 'ALARP' framework for risk tolerance scale and priorities for risk treatment

Table 8.6 Risk tolerance scale–priorities for risk treatment

Extreme risks, as determined through the risk evaluation process, are considered to be intolerable. Both extreme and high risks at the present-day timeframe are most critical, however, extreme risks at future timeframes are also very important as there is still considerable uncertainty regarding when these risks may manifest. A listing of the extreme intolerable risks (both now and in the future) are summarised in Table 8.7, while the present-day high risks are summarised in Table 8.8.

Table 8.7 Extreme intolerable risks (any timeframe)

Erosion of South Beach, foreshore and Wilson Park	Present
Erosion of electricity lines	2070
Inundation of the West End Conservation Area, heritage buildings and Manjaree	2110
Inundation of South Fremantle Heritage Area	Present
Erosion of roadways	2070
Erosion of public buildings	Present
Inundation of the freight rail line	2110
Erosion of water supply system	2070
Erosion of sewerage system	2070
Erosion of septic systems	2110
Erosion and inundation of Woodman Point Regional Park	Present
Erosion of C. Y. O'Connor Beach and Reserve	Present
Erosion of Coogee Reserve	2070
Erosion and inundation of South Fremantle Power Station redevelopment site	Present
Erosion of foundations and access to Coogee Beach jetty, Magazine Jetty, Swimming Jetty	2070
Erosion of roadways	2070
Erosion of Coogee Beach SLSC	Present
Erosion of Jervoise Bay Sailing Club	Present
Erosion of Woodman Point sewage outfall	Present
Erosion of Woodman Point boating facility	Present
Erosion of the freight rail line south of Catherine Point groyne	2110
Erosion of the Cockburn Cement wash plant	2110
Erosion of foundations and access to the Cockburn Cement reclaimer jetty	Present
Erosion of Challenger Beach	Present
Erosion of foundations and access to Kwinana Jetty	Present
Erosion of the Alcoa refinery	Present
Erosion of the desalination plant	2110
Erosion of foundations and access to the Kwinana Bulk Jetty	Present
Erosion of the BP oil refinery	Present
Erosion of foundations and access to the Kwinana Bulk Terminal jetty	Present
Erosion of the CSBP fertiliser storage	Present
Erosion and inundation of Wells Park	Present
Erosion of foundations and access to the CBH grain terminal jetty	Present
Erosion of Rockingham Beach	2070
Erosion of Bell and Churchill Park	2070
Erosion of Crystals Beach	2070
Erosion of Palm Beach	2070
Erosion of footpaths	Present
Erosion of roadways	Present
Erosion and inundation of buildings	2070
Erosion of Point Peron launching facility	Present

Table 8.8 Additional high intolerable risks at present timeframe

Erosion and inundation of stormwater
Inundation of habitat areas
Inundation of Arthur Head Reserve
Erosion and inundation of footpaths
Erosion and undermining of South Beach groynes
Inundation of Challenger, Fishing and Success Boat Harbours
Erosion and inundation of habitats
Erosion of Robb Jetty Camp
Erosion and inundation of footpaths
Inundation of the AMC facility
Erosion of street lights
Erosion of Barter Road Beach
Erosion of Kwinana Beach near Wels Park
Erosion of The Wreck near Wells Park
Erosion and undermining of Kwinana Beach seawall and tombolo
Erosion of Challenger Beach boat ramp
Erosion of Wells Park boat ramp
Erosion of Kwinana Power Station and associated infrastructure
Erosion of Western Power switch yard
Erosion of water supply
Erosion and inundation of Cape Peron – Rockingham Lakes Regional Park
Erosion of PWC area
Erosion of designated dog beach
Erosion and inundation of Rotary Park
Erosion of Palm Beach east boat ramp (Bell St)
Erosion of Palm Beach west boat ramp (Esplanade)
Erosion of Mangles Bay Fishing Club boat ramp
Inundation of Point Peron boat ramp

9. First-Pass Adaptation Options

This section presents the first-pass assessment of adaptation options for the study area. This first-pass assessment has been completed via the following steps:

- Determination of the assets at risk
- Assessment of risk
- Identification of three simple adaptation pathways
- Identification of key coastal process drivers within each management unit
- Determination of triggers based on the sensitivity of each asset (where each asset is treated in isolation)

Further work, beyond this first-pass assessment of adaptation options, will be required to recognise the interactions between the adaptation pathways, assets and management units at a local scale.

9.1 Overview of options

Coastal adaptation in Western Australia has long been linked to infrastructure planning, with development setbacks and easements identified to cater for future change (Town Planning Department 1974). Adaptation planning was informally encompassed within local coastal management plans, with forecasting relevant to local infrastructure and development (WAPC 2003). However, recognition that future coastal change may be greater than originally planned for has prompted a change in thinking, with more extreme and lower certainty scenarios considered. The corresponding planning approaches in a situation of high uncertainty are either to adopt a more conservative position or to ensure that there is adequate capacity to respond to change.

The Western Australian Coastal Zone Management Policy (WAPC 2001) acknowledges the practical benefits of avoiding development in the naturally dynamic zone immediately adjacent to the coast. This has typically been managed through the preferential use of development setbacks to avoid coastal hazards for a planning time frame of approximately 100 years, outlined in the State Coastal Planning Policy SPP 2.6 (WAPC 2003). Although these documents recognised the need for coastal adaptation, limited formal planning guidance was available at the time, except for recognition of infill development or the provision of coastal development nodes.

Recognition that a significant portion of existing coastal infrastructure may potentially be exposed to coastal hazard in the future led to revision of the coastal planning policy (WAPC 2013), incorporating information regarding adaptation and management of coastal hazards. Two key components of the policy are:

1. Where coastal hazards are identified as potentially occurring over the next 100 years, they should be managed through a Coastal Hazard Risk Management and Adaptation Plan (CHRMAP).

2. Definition of a preferred hierarchy of adaption options (for when the level of risk is unacceptable), following the sequence:
   i. **Avoid** the presence of new development within the area identified to be affected by coastal hazards.
   ii. **Retreat** – the relocation or removal of assets within the area identified as likely to be subject to intolerable risk of damage from coastal hazards over the planning time frame.

iii. **Accommodate** the hazard via design and/or management strategies that render the risks from the identified coastal hazards acceptable.
iv. **Protect** assets from the hazard, when sufficient justification can be provided for not avoiding the use or development of land that is at risk from coastal hazards, and accommodation measures alone cannot adequately address the risks from coastal hazards.

The suitability of the coastal adaptation approaches and management options depends on whether the assets are already in place or are planned for the future (Figure 9.1).

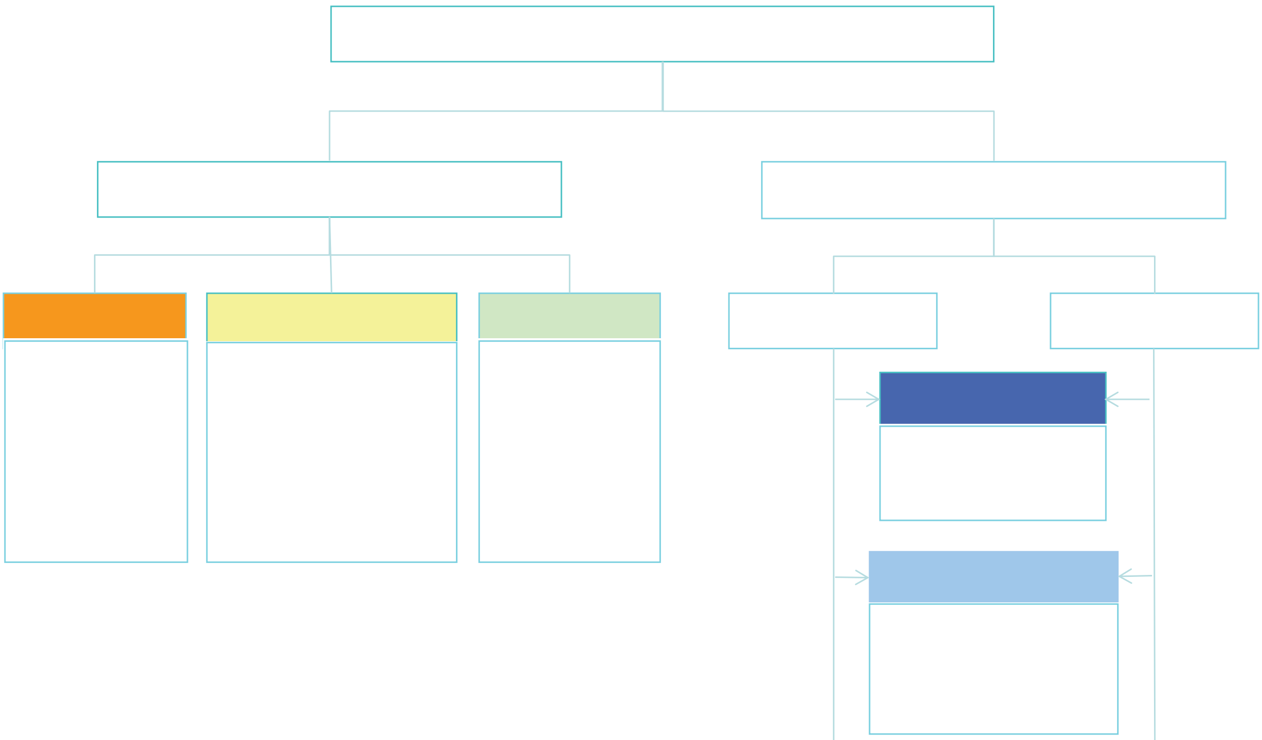


Figure 9.1 Coastal management options and adaptation approaches for existing and future development

These adaptation options are generally considered with a continuum of treatment approaches wherein avoiding the risk is the most ideal approach, but retaining the risk, or at least some component of the risk, is usually necessary in some form.

From a climate change adaptation perspective where risks are not expected to manifest for some time (and where there is uncertainty regarding both the impacts and the timing), there are a number of 'adaptation pathways' that can be explored that incorporate a suite of options to be implemented as risks materialise. This acknowledges that adaptation to climate-induced hazards and risks cannot be considered a one-off exercise. Rather, climate change adaptation needs an approach that involves consistent and integrated measures that are implemented continuously as the coastal environment responds and evolves in the future. This includes planning future works now, to prevent unnecessary costs and/or constraints emerging in the future.

A 'toolkit' of possible coastal management options has been compiled for consideration and use in this study. These options have been adapted from various sources including:

- The WA State Coastal Planning Policy (WAPC 2013)
- Climate Change Adaption Guidelines in Coastal Management and Planning (NCCOE 2012a)
- Guidelines for Responding to the Effect on Climate Change in Coastal and Ocean Engineering (NCCOE 2012b)

- First Pass National Assessment of Climate Change Risks to Australia's Coast (2009)
- NSW Coastal Planning Guideline: Adapting to Sea Level Rise (2009)
- NSW Coastline Management Manual (1990) and Guidelines for Preparing Coastal Zone Management Plans (DECCW 2010)
- QLD Guideline for Preparing a Coastal Hazard Adaptation Strategy (EHP 2013)
- QLD Coastal Hazard Adaptation Options – Compendium (GHD 2012)
- Other coastal zone management studies developed by the study team across Australia.

The full 'toolkit' of options is presented in Appendix C.

9.2 Good coastal management practice

There are a number of actions that represent good coastal management practice, which can be pursued by stakeholders without the need for compromise or significant capital-raising. Such actions can improve resilience and preparedness for coastal risks without limiting the ability to change a management approach and without negative long-term impact should risks change in the future. These actions are discussed in more detail below.

9.2.1 Monitoring

The general approach to management of risks to existing assets and infrastructure is to wait until the risks have materialised to a level that is no longer considered tolerable (i.e. risk reaches a 'trigger' level) before acting. Monitoring of key indicators is necessary to determine when this trigger has been reached. It is important that this trigger is reached before impacts to assets and infrastructure actually occur to enable sufficient prior-planning and the implementation of alternatives, especially in terms of community-dependent infrastructure.

Monitoring of triggers at specific critical assets should be reviewed regularly to determine when a trigger is reached. The results of monitoring should also be analysed and published, and incorporated into reviews of coastal management plans (e.g. every 5–10 years).

Monitoring should cover:

- frequency and depths/extents of coastal inundation
- erosion and recession of beach profiles, and dune condition
- condition of the existing revetments and coastal structures.

Assessment of monitoring results should involve trend analysis and proximity to pre-defined triggers. Monitoring results should also inform future re-analysis of hazards and risks as part of on-going risk management programs. Refer to Section 9.5.2 for further discussion regarding management triggers in the context of the Owen Anchorage and Cockburn Sound coastline.

9.2.2 Land use planning and development controls

Development controls simply apply controls as appropriate to the type of development and likely hazard over the expected life of the development. Development controls can apply to infill, greenfield and redevelopments. The existing development controls in SPP2.6 (WAPC 2013) require a coastal hazard risk management and adaptation planning for coastal development and management, with the primary requirement to 'avoid' the coastal hazard risk zone. This policy also includes guidelines for the calculation of setbacks that consider the erosion risks (S1), historic shoreline movements (S2), sea level rise (S3) and inundation (S4) for a variety of shoreline types (e.g. rocky, tidal, etc.) over a 100-year planning timeframe. These guidelines apply to any new development or land use change in the coastal zone. There is also provision in SPP2.6 for the development of 'coastal nodes' for a range of facilities on the coast that benefit the broader public and for surf life saving clubs for which location in the coastal zone is necessary. Guidelines for infilling development are also included as part of SPP2.6.

Other development controls may include:

- use of temporary or re-locatable structures in high hazard areas
- minimum floor levels maximum floor area for buildings and for alterations and additions
- adaptable building design, for structures to be temporary, sacrificial or relocatable, as considered suitable for the type of development
- time- (or distance-)based development approvals, which provide new developments or redevelopments with consent until the eroding shoreline (or wave overtopping height/frequency) reaches a certain distance to the property, at which point the development must be removed (to allow retreat). This may apply where the risk over the expected life is high, but development could be accommodated until that time. This would be ideal for areas where the timeframe for impact is unknown. The responsibility for monitoring could be tied to the landholder as part of the development consent, or otherwise fall to the LGAs
- restrictions on the expansion (or even reduction) of development footprints for existing sites in high development areas. These development controls do not prohibit existing landholders from remaining on their land until such time as an impact occurs. However, the development controls may specify that further expansion of the development footprint (e.g. extensions or renovations, subdivision, change of use) is restricted, thereby avoiding the intensification of asset values and therefore risk in high hazard areas over time
- planning controls and design guidelines to minimise the use of foreshore structures that restrict landward ecological migration/transition. A potential application of this development control (to the extent possible with existing development) could include development fringing important ecological habitats, such as Woodman Point Regional Park and Richmond Lake.

9.2.3 Integrated coastal management and planning

On-going dialogue between the CSCA, relevant government authorities and private stakeholders will be essential to achieving an integrated management solution for coastal planning along the coastline of Owen Anchorage and Cockburn Sound. Coastal processes act on a regional basis, and therefore, actions that disrupt updrift processes could affect downdrift shoreline response.

Between the councils it is important that coastal hazards and risks are consistently incorporated into local planning frameworks. This would facilitate a consistent approach to assessment of future developments that are potentially affected by coastal hazards, whether they are new developments, redevelopments of existing sites or subdivisions of land. It is also important that there is a consistent approach to coastal hazards by other consent authorities when councils are not the determining authority (e.g. state significant projects, development on defence land, etc).

9.2.4 Dune rehabilitation

Dune rehabilitation programs can be implemented in locations where vegetation is currently degraded, limited or overcome by weeds. This would primarily target areas where dunes can potentially afford protection of important areas behind (including social and environmentally valued areas). Examples of where dune rehabilitation would be worthwhile include South Beach, C. Y. O'Connor Reserve, Coogee Beach Reserve, Rockingham Beach and the Designated Dog Beach west of Palm Beach.

Dune revegetation allows for ongoing retention of sand; as the vegetation traps the sand that would otherwise blow over the dunes. With time, dunes can increase in height as vegetation adapts to the dune profile. Dune vegetation also provides ecological benefits that promote a functioning beach ecosystem.

This option would therefore also involve protection of native coastal vegetation by way of controlling access to dunes for walkers, horseback riders and four-wheel drive vehicles, for example using fencing, formalising and controlling pathways, signage, etc. Pilot projects could be encouraged for re-establishing coastal ecological communities.

9.2.5 Audit and appropriate management of assets

A detailed audit of assets located within potential hazard areas should be carried out. In general, assets should be considered in terms of the remaining functional life. The remaining life of the assets should then be managed in accordance with an asset plan that gives consideration to the most appropriate long-term alternative to the asset, including:

- 'Manage to fail', where the remaining life of the asset is approximately equivalent to the time before emerging hazards will affect the essential function of the asset. After this time the asset will need to be replaced and/or relocated to manage the risks associated with the hazards.
- 'Life extension', where retrofitting and on-going maintenance can extend the functional life of the asset to a timeframe equivalent to when the hazards will start to impact on asset function. Life extension can also consider protection works to delay the timeframe for impact of assets by future hazards.
- 'Replacement', where the impacts of hazards will not occur for some time, enabling replacement of existing assets with new assets in the same, or similar, locations with only minor changes in design criteria. This would be suitable for assets that have a relatively short functional life and are located in areas that are not subject to immediate hazards.

In the long term, most assets located within hazard areas will require protection, relocation, or significant redesign to accommodate the risks associated with the hazards. Thus, asset planning essentially involves managing the existing asset portfolio until such time that the assets are eventually protected, redesigned or relocated away from the hazards.

Within the asset management plans of the four councils and other stakeholders, all relevant assets should be notated with information regarding hazards. This would include details of the overall risk (low to high), type of hazard (inundation, erosion) and timeframes for impact (present day, 2070, 2110). For assets that are critical for community function (e.g. stormwater, sewer, water, telecommunications, gas, public buildings and amenities), effective asset management and planning will be essential for ensuring adequate services are maintained in the future as elements of the relevant systems are progressively replaced and updated. This will require sufficient planning and funding preparation.

9.3 Pathways for coastal adaptation

Adaptation is a long-term process that can follow various pathways. Adaptation pathways reflect possible approaches of adaptation with different strategic aims, and may vary from accommodating change and natural values to protecting community and amenity values to protecting private property.

Adaptation pathways generally consist of various adaptation options that are mutually reinforcing and/or complementary to each other, which are implemented over time as the need emerges. There is no single solution that represents best-practice climate change adaptation within the coastal zone. Rather, maintaining a balance between value perspectives (natural and built) and consideration of both existing and future demands on the coastal zone is essential to achieve a more climate-resilient coastal environment.

In broad terms there are three main pathways that have been considered for this study that illustrate the different approaches to adaptation that can be followed:

i. Retreat Pathway, where climate change is permitted to take its course and development is progressively moved out of the way as it becomes impacted;
ii. Maintain Pathway, existing development rights are protected and continued into the future through redevelopment, but no additional development is permitted within high hazard areas; and
iii. Intensify Pathway, where new coastal protection works are constructed that allow for additional coastal development and intensification of land use at isolated coastal nodes and infill areas.

The pathways are not predictions or recommendations, but ways of conceptualising different futures based choices of how to respond to climate change effects. Other variations are possible. In reality, the preferred approach may consist of a patchwork of pathways for different areas within the wider study area to provide the best solution at the local level.

The three pathways considered for this study are described in detail below.

9.3.1 The Retreat Pathway

This pathway aims to allow natural coastal processes to unfold as much as possible and with as little impediment from development as possible in the future. No new coastal structures would be constructed and any new development within the coastal zone would be prohibited within high risk areas. Where possible, dunes would be restored or enhanced to maintain or create a buffer against storm erosion.

As existing assets reach the end of their functional life (or if they are substantially damaged by a storm event), they would be removed, including any associated coastal protection structures (e.g. temporary protection works that extended the life of the asset). This pathway will result in the loss of public and private land as beach environments migrate landward. Beach amenity and environmental values of coastal habitats would be largely retained or enhanced. The shoreline will evolve in response to sea level rise. The existing coastal structures (groynes, seawalls, offshore breakwaters) will continue to influence this evolution until such time that these structures are removed (if at all).

What could the Retreat Pathway look like?

Most of the beaches and foreshore areas would be retained as beaches are allowed to move landward and built assets are removed to let natural values move landward. In some places saline ground water would lead to a change in vegetation. Salt intolerant terrestrial plants would become stressed and many trees and shrubs would die off and be replaced by more salt tolerant species. Significant foreshore community infrastructure would need to be relocated landward, including walkways, amenities and recreation areas. With sea level rise, some existing natural areas may change in character as they are inundated more often, until such time when they are (semi-)permanently under water. Increases in the area of saltmarsh may occur at Point Peron Foreshore Park and Woodman Point Regional Park.

Although this pathway assumes that climate change will take its course, in practical terms there are already many existing coastal protection structures that will continue to afford protection to coastal assets for some time. Under this pathway these structures would be removed as they deteriorate. Note that the hazard mapping for the Stage 1 Assessment was undertaken assuming that any existing coastal management infrastructure will be maintained at their current performance into the future. However, under the retreat pathway, this prior assumption would not be applicable, and as a result, predicted erosion and inundation extents determined from the Stage 1 Assessment may be worse than mapped.

City of Fremantle

Bathers Beach is essentially a closed coastal cell, meaning that future sea level rise will translate to a direct loss of beach as it cannot migrate landward. The boat harbours would be retained, so there would be little impact behind these structures other than more periodic inundation. For South Beach, the active beach area will migrate landward into the current reserve area. This will result in a net loss of reserve and car parking.

City of Cockburn

Landward retreat of the shoreline at the northern end of C. Y. O'Connor Reserve will mean that the recent major development north of Rollinson Road (part of the South Fremantle Power Station Redevelopment Site) may be affected. Dune restoration in front of the development could delay the impact, potentially providing enough time for the development to reach the end of its practical design life. Once impacted, this development would be removed.

Erosion immediately south of Catherine Point groyne would impact on Robb Road, and ultimately the freight rail line. Relocation of these important infrastructure elements would be required, potentially more eastward of their current locations.

Proposed development around the South Fremantle Power Station would not proceed given its potential for being impacted by coastal hazards, particularly if no new structures are to be constructed to protect the development.

The area of Coogee Beach Reserve and Woodman Point would be reduced as a result of landward retreat of the coastline. Existing minimal infrastructure within this section of the coast would be removed, ideally before it becomes derelict from coastal hazard impact. This includes the Coogee Beach SLSC which will require bolstering or removal in time due to the beach recession.

There would be little change in the AMC area and along the rocky shoreline adjacent to the naval shacks.

City of Kwinana

At the northern end of Challenger Beach erosion would occur at the southern end of the cliff, which would potentially impact on Sutton Road. There is a significant amount of industrial development along the CoK coastline, from Alcoa to the Kwinana Bulk Jetty, much of which has statewide significance and operates under a state agreement. Based on feedback provided by industry operators and the Kwinana Industry Council, it is considered that this existing development would be protected if threatened by erosion and/or inundation. Therefore, given the high value of these assets this pathway assumes that the existing facilities would be protected for the duration of their current functional life. Additionally, retreating from this area would result in high costs in terms of loss of economic activity and decommissioning/environmental costs to address contamination.

In keeping with the aspiration of this pathway and to maintain the beaches, this would be achieved by soft protection measures such as periodic beach nourishment to maintain a buffer of sand in front of the facilities, or temporary sandbag walls or similar. However, this is not a feasible long-term solution. Existing coastal structures around James Point may also help to limit the erosion of the shoreline in front of the BP refinery.

City of Rockingham

This pathway would result in a significant loss of coastal reserve shoreward of Rockingham Beach Road. This would include the important recreation areas of Bell Park and Churchill Park as well as parking facilities. The extent of retreat could be limited by dune restoration and revegetation, especially post-storms. Retreat would also likely involve the relocation of Rockingham Beach Road just south of Wells Park.

Shoreline retreat would also impact on the Esplanade roadway and potentially on waterfront properties along the Esplanade. There is a narrow parkland around Catalpa Memorial that could be used for dune restoration to provide a greater buffer for these properties. It is expected that the Esplanade would eventually require either rerouting or significant protection. The Esplanade provides important access to private properties, as well as a services corridor for various municipal services (water, sewerage, power, telecommunications, etc.). Protection of the Esplanade would come at the expense of existing recreational amenity of the beach and parkland in front of the roadway. The existing timber groyne, jetties and boat ramps on the Esplanade would provide minimal resistance to future shoreline migration. Future retreat from existing shoreline development west of Hymus Street would be required, including the Holiday Park and the Mangles Bay Fishing Club.

Some low-lying properties would be susceptible to periodic inundation, with frequency of inundation increasing in the future. This includes areas around Rotary Park and Fisher Street. Where not addressed through routine stormwater management works, these areas may need to be abandoned in the future.

9.3.2 The Maintain Pathway

This pathway aims to 'hold the line' of current coastal properties and development. That is, where there is development now, this will be permitted to continue in the future in its current footprint only. For currently undeveloped areas, the shoreline would be permitted to retreat, thus maintaining coastal ecosystem and community values. This pathway aims to provide a balance between existing and future development values and sustainable natural values and ecosystem services.

Existing development (private and public assets) would be maintained and repaired as required to maximise functional life. If there are existing coastal protection works in front of existing development, then these works would be upgraded/enhanced to allow for continuing use of the land in the future. If there are no existing coastal protection works, then such works would be permitted to be constructed to maintain existing land use privileges providing these works are carried out on private land. Replacement of existing development would involve rebuilding in the current location but with alternative design criteria (and additional coastal protection as required) to better withstand new coastal environment conditions.

Beach amenity and valued environmental areas may be diminished in areas surrounding existing development (due to 'coastal squeeze', i.e. the natural environment wants to migrate landward but fixed infrastructure prevents this from happening, resulting in a net narrowing of the natural area). Shoreline response would be significantly impacted by the existing, and future, coastal protection structures in place along the coastline.

What could the Maintain Pathway look like?

The most important beaches from a community perspective (Bathers Beach, South Beach, C. Y. O'Connor Reserve Beach, Coogee Beach, Challenger Beach, a section of Rockingham Beach, the Bell and Churchill Parks beach-front and Palm Beach) will be protected by measures such as beach nourishment. These measures would also protect the foreshore reserves including community infrastructure for at least some decades into the future. Over time, as the sea level continues to rise, the need to nourish the beaches will increase. At some point, the costs of re-nourishment may outweigh the benefits and the beaches would be allowed to erode and move landward.

City of Fremantle

For this pathway all existing development is currently protected by coastal structures. Therefore this pathway will be essentially the same as the retreat adaptation pathway with the possible exception of stormwater drainage works and/or low levees around the harbours that would be required to prevent infrequent coastal inundation.

Areas of South Beach would be permitted to retreat into existing reserves. If the erosion extends as far as the freight rail line, then this infrastructure would be protected by a seawall or similar.

As Bathers Beach would essentially disappear under high sea levels, beach nourishment would be required to maintain existing recreational amenity of the beach environment.

City of Cockburn

The recent development just south of South Beach would be protected by a seawall or similar. With such a structure in place there is a high potential for loss of beach environment and associated amenity in front of the development unless extensive nourishment is carried out. Given its importance as a local recreational beach, nourishment is included for this pathway.

Potential erosion of the shoreline immediately south of Catherine Point groyne would require seawall construction along a 200 m section of Robb Road.

The proposed development at the South Fremantle Power Station Redevelopment Site, Port Coogee and the existing AMC facilities would be largely compatible with this pathway as these developments are already in the late planning stages and can be considered as existing.

Coogee Beach and the beach fronting Woodman Point Regional Park would be maintained by beach nourishment and dune rehabilitation in the short- to medium-term, to preserve beach amenity until a time when such measures become unfeasible. At this time the Coogee Beach SLSC, the holiday club and café will be protected. However there will be a point where this infrastructure and other coastal infrastructure will require decommissioning. Similarly the Woodman Point Regional Park land area would be reduced as a result of landward retreat of the coastline.

City of Kwinana

There is extensive existing development stretching from Sutton Road, south of the Naval Base Shacks, to Wells Park, south of James Point. It is expected that seawalls would be progressively constructed on private lands in front of existing infrastructure as it becomes increasingly threatened by coastal erosion. Existing coastal structures will provide the basis for more intensive defence works, which may be required over a 100-year timeframe. There are limited sections of CoK that are not currently developed, and as such, there is limited scope for allowing natural retreat of the coastline as sea level rises. The only significant exception to this is the open space area on the southern side of Barter Road, north of the Kwinana Bulk Terminal.

The extensive 'hardening' of the CoK shoreline would result in a loss of sandy beach environment and associated amenity that is currently afforded in front of the existing industrial development, although it is not extensively used at present due to restrictions on access. There may be some opportunity to maintain beach amenity over parts of this shoreline through beach nourishment, which indeed may be a substituted for a seawall for a period of time.

City of Rockingham

Rockingham Beach Road between Wells Park and Railway Terrace may require protection as the shoreline retreats under higher sea levels. The need for protecting the roadway could be deferred by undertaking nourishment in the short to medium term, particularly for the section of beach north of the CBH grain terminal where the road is located just behind the beach.

Rockingham Beach would generally be permitted to retreat with an overall loss of the reserve behind as the active beach environment moves landward. Bell and Churchill Parks and the residential development behind Palm Beach, would be protected by a seawall or similar. Beach nourishment in front of the seawall would also be used in the short to medium term to maintain recreational amenity of the Bell and Churchill Parks beach-front and Palm Beach. In the long term, however, it is expected that the beach amenity would be substantially lost.

Beach nourishment would also be carried out on the Designated Dog Beach west of Palm Beach to limit the erosion and consequent loss of infrastructure associated with the AIW Recreation Centre, the RSL holiday reserve and the Mangles Bay Yacht Club. This would be feasible in the short to medium term only. After this time beaches and foreshore areas would be allowed to move landward.

9.3.3 The Intensify Pathway

This pathway aims to maximise potential future development of the coastal zone through providing additional protection of land from coastal hazards to facilitate more intensive land use. New coastal protection works would be designed to withstand future coastal conditions, thus ensuring value to new developments. The result would be a heavily 'engineered' coastline. Development would need to be of regional or state-wide significance in order to justify the substantial cost of the engineering works.

Future development would be subject to the design standard of protection measures. Intensification of development would be permitted providing that hazards and other planning constraints are addressed. Development may involve raising of land to avoid inundation or construction of levees/dykes to prevent wave and storm surge overtopping.

Coastal protection measures may include significant beach nourishment and dune creation. This may have ancillary benefits for beach amenity and ecological habitats. Notwithstanding, most new and existing coastal structures would result in a loss of beach amenity unless 'engineered' beaches are incorporated into the design objectives. This could be done at selected prime locations, with groynes holding in place narrow beaches, which are maintained periodically by sand nourishment. Natural values associated with these 'engineered' sections of coastline would be limited, with minimal provision of significant ecosystem services.

What could the Intensify Pathway look like?

This pathway would allow for walls to be erected along much of the foreshore where significant property values are at risk of erosion and inundation. This includes walls along several prime beaches that have considerable existing recreational amenity for the community. Although beach nourishment may maintain some of the existing amenity for a period of time, the beaches will eventually become narrower until they are permanently inundated. Well-designed promenades could be incorporated into seawall designs, providing a vastly different but also potentially appealing community infrastructure.

City of Fremantle

Bathers Beach would be nourished to maximise recreational amenity in this part of the coastline. Similarly, nourishment would be carried out on South Beach to ensure it maintains a regional recreational function. Low-lying levees and stormwater drainage works would be required around the urban area of CoF to prevent backwater inundation into some of the more low-lying sections of the LGA.

City of Cockburn

As for the Maintain Pathway, the existing development south of South Beach would be protected by a seawall along with extensive beach nourishment. A new groyne structure may be required to help keep nourished sand in place. There is potential for further intensification of the land to the north of Catherine Point groyne on the basis that beach nourishment and coastal structures can protect the site in the future.

The South Fremantle Power Station area immediately north of Port Coogee is a prime location for further intensive residential development. This could involve a similar harbour and canal estate configuration as Port Coogee, as well as reclamation behind extensive breakwaters to expand the developable footprint. The northern section of this part of the coastline, immediately south of Catherine Point groyne, could be utilised for recreational amenity, with reclamation and extensive sand nourishment.

The current AMC site would also be ideal for redevelopment in the longer term. The site is protected by offshore breakwaters and the shoreline is currently hardened as wharfs. No further coastal infrastructure would be required to pursue redevelopment opportunities at this site. Development would need to comply with a minimal fill level and finished floor level to mitigate the impacts of coastal inundation in the future.

City of Kwinana

This pathway allows for significant intensification of development along the CoK coastline through the construction of extensive seawalls along the shoreline (approximately 6 km). The seawall should be a continuous structure, with the alignment determined to maximise land use potential. Reclamation could be a component of this pathway as well as additional harbour facilities.

If a new port were developed at James Point then ancillary development to the north and south of the site could utilise the coastal protection offered by the port facilities if it was planned and designed in an integrated manner. This pathway aims to offer an integrated solution for advancing with intensification of the coastal industrial land in this section of Cockburn Sound.

City of Rockingham

Land to the immediate north of the CBH grain terminal could be used for additional industrial development. Although there are a couple of small offshore breakwaters in front of the shoreline of this land, this pathway would require the construction of a more substantial seawall or similar along the back of Rockingham Beach to protect this land and make it suitable for future development. Such a seawall would need to minimise impacts on the adjacent sections of Rockingham Beach and, as such, a groyne and extensive nourishment would also be likely.

Bell and Churchill Parks in CoR are highly valuable parklands that are utilised extensively by the community. This pathway includes 'engineering' of these parks and associated beach areas to retain their recreational amenity in the short- to medium-term as sea level rises. This would include substantial nourishment as well as a groyne or similar structure to retain the sand on the beach. Nourishment would extend to Palm Beach in front of the Esplanade and the Catalpa

Memorial. At the back of the beach would be a seawall, as a last line of defence to protect the parklands and the Esplanade roadway. This seawall would likely be designed as a promenade to enhance the amenity of the foreshore.

This pathway includes additional development in the area along the current Designated Dog Beach west of Palm Beach. Hard protection of this shoreline via a seawall or similar, combined with nourishment and additional structures to retain the nourished sand, would maximise the social and recreational amenity offered by this part of the coastline.

9.4 Cost-benefit analysis of adaptation pathways

The cost-benefit analysis provides a first-pass broad assessment of the expected costs of the three pathways. It is important to note that this assessment excludes the urban area of CoF that is already heavily modified and protected, the Port Coogee development and the AMC in CoC. The coastlines here have already been heavily modified, and irrespective of the pathway, these areas will continue to be protected and the costs associated with this do not impact on the comparative costs of the three pathways. For the Kwinana industrial area it is assumed the area will also be protected irrespective of the pathway, however the level of protection and the duration for which the area will be protected for varies by pathway.

9.4.1 The Retreat Pathway

Vegetation management

Vegetation management is the main adaptation option available to protect the study area from erosion and inundation. Vegetation management would be applicable to areas where there are risks to existing development including most of the Bathers Beach, South Beach, the northern section of the C. Y. O'Connor Reserve (near Rollinson Road), the South Fremantle Power Station Redevelopment Site and the Rockingham foreshore.

Assets not reaching end of asset life

This pathway would result in a number of assets not being able to reach the end of their economic life, resulting in a loss. The economic lifetime of houses and most infrastructure such as roads, paths and stormwater infrastructure is between 40 and 60 years. Assuming most infrastructure has been maintained adequately so far, and that on average most infrastructure has been in place for ten years since the last major upgrade, the broad overall remaining lifetime of assets is assumed to be 40 years, to approximately 2050.

In CoC, significant assets not expected to reach the end of their asset life include the South Fremantle Power Station Redevelopment Site, Coogee Beach surf lifesaving club and the Woodman Point Boating Facility that will be subject to inundation. In CoK some footpaths and the boat ramps at Challenger Beach and Wells Park would also not reach the end of their asset lives. In CoR, approximately 1 km of footpaths and close to 1 km of road would be eroded before reaching the end of the asset's life in addition to the low-lying residential uses in CoR subject to inundation. Lost assets in both CoF and CoR would also include public buildings (or at least the land associated with public buildings).

Loss of land

With this pathway considerable areas of privately owned, often developed, land and public land would be lost over time. This includes the loss of land and assets whose values are not subject to depreciation over time, such as heritage assets and parks. The areas of land lost also include residential, commercial, open spaces and other land uses. It was not possible to identify the value of land lost as the land values, separate from the capital improved values, were not provided; instead, an indication of the land areas lost is provided.

Total areas of land lost due to erosion towards 2110 are as follows:

- **CoF**: The main loss of land comprises approximately 4 ha at Arthurs Head Reserve and South Beach Reserve. The area including the three harbours is currently heavily developed with no significant natural values remaining. The area will continue to be protected even with this pathway.
- **CoC**: The loss of land comprises between 117 and 176 ha by 2110. This consists of loss of 70–77 ha of parkland (specifically at Woodman Point Reserve, habitat areas (not in parks), C. Y. O'Connor Reserve and Coogee Beach Reserve), and 44–50 ha of heritage areas (South Fremantle Power Station, Limestone Office on Bradken Site, Robb Jetty Camp). The Port Coogee development and the AMC facilities remain heavily modified shorelines and are expected to be protected in the future and are therefore not included in these estimations.
- **CoK**: The shoreline in front of the major industries has been modified in the past and the industries are expected to be protected even with this pathway. There would be ~31 ha of beach areas lost by 2110, mostly consisting of Challenger Beach, Barter Road Beach and BP James Point beach.
- **CoR**: The loss of land comprises between 35 and 46 ha by 2110, excluding Point Peron and parkland west of CBH grain terminal. Of this, between 18 and 19 ha is parkland in Bell and Churchill Parks, as well as beach areas of Crystals, Palm, Wells Park Beaches and the Designated Dog Beach. Between 16 and 18 ha of this land lost is heritage area, comprising Rotary Park and John Point. In addition, 2–5 ha of urban area (residential and commercial use) would be lost to erosion by 2110 and an additional 9 ha would be subject to frequent inundation.

Removal of assets

Part of active retreat would be the need to remove (remnants of) assets in zones designated for retreat. The costs for the removal depend on the types of assets as well as a range of other factors, these costs may be significant.

Reconfiguration of infrastructure

Some infrastructure will need to be relocated or reconfigured to ensure the continued servicing and accessibility of residential, commercial, industrial and other areas. Key infrastructure that would require reconfiguration to continue to service assets and properties not at risk include:

- sections of the freight rail line between CoK and CoF. Sections of this line (just south of Catherine Point groyne) would be exposed to erosion where the line is close to the foreshore
- sections of the Esplanade in CoR, to continue to offer access to assets that are continued to be used to the end of the study timeline (2110).

Loss of economic activity

There is a likely loss of some economic activity in foreshore areas. Although many beach-related activities are expected to move landward over time with the beaches, this is not likely to be true for:

- economic activity around Bathers Beach and Arthurs Head, as the beach will likely disappear over time
- the commercial activity behind Palm Beach in CoR.

Most beaches will be maintained, except for Bathers Beach which will be inundated as it has insufficient opportunity to move landward.

Although total park areas may decrease (depending on how actively retreat is managed and parks are allowed to move landward), there would be some increases in natural values such as increased saltmarsh and wetland areas at Woodland Point and Cape Peron – Rockingham Lakes Regional Parks. This pathway would result in the degradation and eventual loss of the thrombolites in Lake Richmond after 2070.

Adaptation works in the Kwinana industrial area

The Kwinana industrial area would be protected by soft protection works including beach nourishment and temporary groynes to extend the period the area can be used for industrial purposes. This should enable the industry assets to reach the end of their economic life.

Costs and benefits in the Kwinana industrial area

The Kwinana industrial area would be enabled to continue to operate until the industrial assets reach the end of their economic life. After that, there would be a strategy of retreat. This involves loss of land and probably significant costs in decommissioning assets and decontamination of the soil. These costs may be extremely high, possibly making this pathway significantly more costly than the other pathways, at least when considering the study's timeframe to 2110.

The benefit of this pathway in the Kwinana industrial area firstly is that it prevents the loss of assets, as they would have been written off by the time retreat would be required. Secondly, it retains levels of economic activity for some time.

9.4.2 The Maintain Pathway

Adaptation works

Beach nourishment would be applicable to all urban and recreational beaches in the area, most notably: Bathers Beach, (parts of) C. Y. O'Connor Reserve, (parts of) Rockingham Beach, Bell and Churchill Parks beach-front and Palm Beach. Beaches currently subject to erosion in CoR are on average renourished twice per annum at a total cost of approximately $100 000. It is assumed a similar cost would apply to beaches in CoF and CoC. Over time, the frequency for beach nourishment will increase. Further, existing sources for sand will likely become depleted and new sources may need to be found, which may become more difficult with time. The costs of beach nourishment vary greatly with frequency and the source of sand (location, type etc.). Although alternative sand sources will likely be required, it is assumed the cost per cubic metre remains stable (which is a low-cost estimate). It is important to note that these costs might be expected to increase as additional sources for nourishment become necessary, with increasing distance from site and/or extraction methods. However, there are many variables to consider when predicting the potential future cost of sand nourishment and a detailed technical feasibility assessment to derive the potential future cost is outside the scope of the present assessment.

Vegetation management will be used to minimise the impacts of erosion on dunes and vegetated foreshores. To manage erosion there will also be a need to upgrade existing coastal structures including groynes, offshore headlands, boat ramps and breakwaters. Jetties and boat ramps would be replaced or upgraded at the end of the assets' lifetime, possibly in a different location to ensure new assets last. Since the assets are allowed to reach the end of their economic life, there are no net costs associated with this[4].

The modified hardened foreshores of harbours and industries are assumed to be maintained as with any other pathways and so this presents no additional costs under this pathway.

[4] *The assets would be replaced by then anyway because they have reached the end of their economic life.*

Raising and hardening (including seaward protection structures such as rock revetments or seawalls) of road infrastructure would occur when infrastructure is due for significant maintenance. Hardened and raised roads will also protect assets at the landward side of the infrastructure. Key infrastructure that would need to be raised and hardened are:

- Robb Road (from Rollinson Road to Mc Taggart Cove) would enable to road to be used to the end of the study timeframe. It would also act as a protective buffer for the rail line at the section where it is most susceptible to erosion (Catherine Point), enabling it to be functional at least to 2110
- Sutton Road from the Naval Base Shacks south to and adjacent to Alcoa.
- Rockingham Beach Road from Wells Park to Railway Terrace in CoR. This will protect the road in the long term and would not be required until after 2070.
- The Esplanade (CoR). This is likely not required until after 2070, once beach nourishment may become less cost effective. It would ensure the road to be used until the end of the study timeline and protect low lying residential uses landward from the road to be protected from erosion and inundation from the sea.
- Adaptation works in front of the Kwinana industrial area, which would include the construction of a seawall to protect the existing development and to enable the industrial use of the area at least to the end of the study timeframe of 2110.

Raising of low-lying land and stormwater drainage

Low-lying residential land would need to be raised while allowing for improved stormwater drainage infrastructure. Filling of land would occur gradually, and redevelopment of existing assets would be allowed to be at a raised level to withstand inundation events. Raising of land would not be allowed in areas reserved for drainage. Raising of land would primarily be required in the low-lying residential area in CoR. This could be an option for parts of CoF, however, much of land at risk from inundation within this LGA is within the heritage area and therefore redevelopment of these areas is considered unlikely.

Loss of land

Remote beaches are assumed to not be nourished as the increasing costs of nourishment would exceed the benefits enjoyed by a limited number of visitors. Beaches would move landward and where significant development and/or industries are present, the shoreline would be hardened for protection resulting in the eventual loss of the beach. The more remote beaches in the study area, which will move landward under this pathway, are:

- Woodman Point Regional Park
- Challenger Beach[5]
- Barter Road Beach and James Point[5]
- Kwinana Beach
- Crystals Beach
- PWC Area and CoR Designated Dog Beach

Benefits Kwinana industrial area

The Maintain Pathway allows for the existing industrial uses and future redevelopment of the area for change of uses to continue operating for the long term, beyond the study timeframe of 2110. Existing levels of production and employment will be maintained and growth will be in line with average productivity improvements that apply for these sectors of industries as would be the case for similar industries elsewhere.

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5 *These beaches are bordered on the landward side by development and/or industrial assets and will therefore be lost in favour of these assets.*

In the extended term, beyond 2110 and with sea levels continuing to rise, there would still be a need to retreat from this area, resulting in similar costs as mentioned in the Retreat Pathway that would involve the removal of assets and decommissioning of some industries.

9.4.3 The Intensify Pathway

Adaptation works

Adaptation works with this pathway include hard protection works such as seawalls, artificial beaches, promenades and stormwater management upgrades. It also includes the construction of engineered, artificial beaches in front of seawalls. Some seawalls may become promenades with high amenity values.

The costs for this pathway consist of:

- seawalls
- engineered beaches including nourishment and groynes or similar to retain the sand
- loss of land
- stormwater management upgrades
- change of character of beaches (loss of natural amenity)
- loss of community values

Seawalls would be constructed along areas with significant existing development, areas currently under development and proposed future developments. These areas include:

- South Beach in CoF
- the South Fremantle Power Station Re-development site
- Rockingham Beach east from the CBH Grain Terminal, to accommodate any future development plans. It is assumed that the industrial precinct of Kwinana may expand into this area
- Palm Beach and Bell and Churchill Parks beach-front

Bathers Beach would likely become an engineered, artificial beach but without a seawall as there is a natural limestone rock wall that separates the Arthurs Head reserve from the urban foreshore area.

In front of the seawalls, engineered beaches would be likely maintained by significant beach nourishment (raising the beach) and groynes or similar. The character of the beaches would change significantly, but amenity values would largely be maintained. Along the Esplanade, behind Palm Beach, a promenade on top of the seawall would add some amenity values, while some of the beach-front houses (while protected) may have decreased views. The height of the seawall would be approximately 1 m higher than the current vegetation line at the beach.

The values of the engineered beaches would continue to be substantial due to the increased levels of development (residential and mixed uses) and the resulting higher visitation by residents (more residents).

The adaptation works for the Kwinana industrial area consist of extensive protection of the shoreline beyond the existing industrial area, allowing for future expansion and intensification of industrial uses in the area.

Upgrading existing coastal structures

Existing coastal structures (excluding the works for the artificial beaches) would need to be upgraded over time to withstand increasing erosion risks due to sea level rise.

Raising infrastructure

Key infrastructure that would need to be raised and hardened are those sections that would not be protected by seawalls. These are:

- Robb Road between (from Rollinson Road to McTaggart Cove) would enable the road to be used to the end of the study timeframe. It would also act as a protective buffer for the freight rail line at the section where it is most susceptible to erosion, enabling it to be used at least to 2110
- Sutton Road from the Naval Base Shacks south to and adjacent to Alcoa
- Rockingham Beach Road from Wells Park to the CBH grain terminal. This will protect the road in the long term and would not be required until after 2070.

Loss of beach and parkland

It is assumed that more remote beaches will not become engineered. Those beaches would move landward, where parkland is adjacent to the beaches, or be lost where protection works are in place (e.g. Bathers Beach under the Maintain Pathway). In addition areas of parkland are likely to be lost where future protection works are built behind these. Areas where beaches and/or parklands are likely to be lost are:

- South Beach
- C. Y. O'Connor Reserve (especially northern section)
- Foreshore at South Fremantle Power Station
- Coogee Beach Reserve
- Rockingham Beach including Rockingham Foreshore Reserve, Naval Memorial Park and Governor Road Reserve

Stormwater management

Low-lying areas would become increasingly susceptible to stormwater drainage issues. Improved drainage, possible retention basins and higher capacity pipes and outlets would be required in CoF, parts of the AMC in CoC and in the low-lying CoR area behind Palm Beach.

Loss of natural values/amenities at urban and recreational beaches and foreshores

The natural look/character and values at engineered beaches would be lost, and they will typically become narrow. There are currently no threatened or rare species at these beaches and therefore the loss in natural values would be considered small. The value of these beaches from a recreational perspective ($ value per visit) would decrease but will likely be offset by the intensification of development and subsequent higher visitation numbers.

Loss of community values

The character of the coastal communities may change dramatically with the intensification of development. This would especially be true for existing residential areas that would be protected in the future and where intensification of development would be required to have a sufficient base to afford the expensive protection works (CoR). This issue does not affect newly developed areas or areas that are still in development such as the South Fremantle Power Station Redevelopment Site and the Port Coogee development which is being developed with protection works irrespective of any of the pathways described herein.

The loss of community values would be greater than with the Maintain Pathway and possibly less than the Retreat Pathway, which could affect the community quite drastically.

Benefits for Kwinana industrial area

The industrial estate can develop and grow into the future allowing for higher levels of production and employment, which are significant economic benefits to the region.

9.4.4 Evaluation of costs and benefits

Cost-benefit analysis (CBA) is a tool that enables evaluation of economic and non-economic costs and benefits into a single framework. It mutually compares different possible scenarios of the future based on different policy decisions. The CBA method has been applied to a range of infrastructure and policy instrument projects in the past. The application of the method to various scenarios for coastal adaptation comprising of a range of adaptation options is considered relatively unique and represents advanced practice for coastal climate change management. The CBA provides an understanding of the different types of costs and benefits and also the receptor who may have to bear these costs and benefits. Although this CBA is a broad assessment based on first-pass assessment data, it provides a solid starting point for a more detailed assessment to be carried out as part of the next stage assessment (Stage 3 Adaptation Plan).

The adaptation pathway approach provides scenarios of how areas may adapt over a period of time, from present day to 2110. It is based on the understanding that adaptation is not a one-off exercise and that it is an ongoing process that needs to be integrated in everyday decision making in areas such as planning and development, infrastructure planning, economic development and importantly governance and funding.

The CBA method expresses expected costs and benefits in NPV (for monetary values) and in qualitative values for other costs and benefits that are not easily expressed in dollar terms. Net present values express future costs and benefits in present-day dollar terms and puts a time value on money taking future inflation, interest and risk into account. The discount rate used is 6% and is equal to the discount rate used for the cost of risk analysis (refer Section 7.5).

As this is a first-pass assessment, the values should be interpreted as such and more detailed investigations would be required to guide final decision making. This analysis aims to provide a better understanding of the likely types of impacts of the three alternative adaptation pathways, Table 9.1 provides a summary of the results of the CBA. More detailed results and a full listing of assumptions and rates used is provided in Appendix G.

Table 9.1 Cost benefit analysis, the total NPV is cost of damage to assets less the cost of adaptation responses (NPV $million)

Retreat	CoF	high	$–	$–	$53	natural	no		$53
	CoC	high	$–	$–	$61	natural	no		$61
	CoK	extreme	$–	$4	$5	natural	no	--	$9
	CoR	high	$–	$–	$47	natural	no		$47
Maintain	CoF	medium	$–	$8	$2	modified	minimal		$10
	CoC	medium	$6	$8	$4	modified	minimal		$19
	CoK	medium	$2	$14	$0	modified	minimal	+	$17
	CoR	medium	$14	$8	$2	modified	minimal		$24
Intensify	CoF	low	$–	$11	$–	artificial	significant		$11
	CoC	low	$4	$16	$–	artificial	significant		$19
	CoK	low	$2	$28	$–	artificial	significant	++	$30
	CoR	low	$3	$30	$–	artificial	significant		$33

Notes.
1. LGA = local government areas
2. CoF = City of Fremantle
3. CoC - City of Cockburn
4. CoK = City of Kwinana
5. CoR = City of Rockingham
6. -- = significantly negative impact
7. + = positive impact
8. ++ = significantly positive impact

The Retreat Pathway results in no costs for adaptation works except the soft protection works for the Kwinana industrial area, for vegetation management and for removal of assets to allow for landward migration of natural areas such as beaches. This pathway does, however, result in significant costs to private landowners and community members by the loss of assets not reaching the end of their economic life and loss of urban land (CoR), parklands (to let beaches move landward), heritage areas and, importantly, Bathers Beach which is projected to become permanently inundated over time. The total NPV of these costs is $170 million.

Beaches have a significant value to communities, visitors and tourists. The annual value of recreation beaches in urban areas is estimated at $21 per m^2 of beach (Blackwell 2005). With the Retreat Pathway, Bathers Beach would be lost within the timeframe of the study (2110) and the net present cost of this loss is a major cost of this pathway.

The other beaches, not including beaches in front of the large industrial uses in and around CoK, will all be maintained as assets are being cleared away and parklands are sacrificed to let the beaches move landward.

Although not possible at this stage to estimate the costs of removing remnants of industrial assets and the decommissioning of sites in the Kwinana industrial area, it is reasonable to assume that these costs may be very high and beyond the total costs of the other pathways. So based on the monetised costs, the Intensify Pathway may appear most affordable for CoK with the costs of retreat being far greater.

For the CoR, the loss of assets and land would be substantial. The total net present cost for the Retreat Pathway is lower than the costs associated with the other pathways, but the costs of retreat (clearing removal of assets and actively managing natural values to move landward) may be substantial and have not been expressed in dollar values.

The Maintain Pathway is likely to be the least costly adaptation pathway with a net present cost of $70 million. The costs would predominantly involve coastal adaptation works (beach nourishment) and the reconfiguration of infrastructure, at $40 million and $22 million, respectively. Although all assets would be allowed to reach the end of their economic life, there would be a reasonable loss of park, heritage and urban land by 2110. The NPV of this cost would be close to $4 million, most of which is within CoC.

All the beaches in the study area would be maintained although the character of the urban and recreation beaches would be modified as a result of beach nourishment. The amenity value would likely be maintained. This is a relative benefit for CoF, which would lose Bathers Beach with the Retreat Pathway. CoC would also be more suited to the Maintain Pathway as it prevents the loss of significant areas of parkland.

Although the monetised costs of the Maintain Pathway exceed those of the Retreat Pathway for CoK, this pathway maintains the levels of economic activity in the Kwinana industrial area. Importantly, this pathway also prevents the need to retreat which could result in significant costs in terms of removal of assets and decommissioning.

The Intensify Pathway is the second most affordable option. The total net present cost is $93 million. The most significant costs are the adaptation works, which include the construction of artificial beaches and seawalls at $86 million net present cost. All the recreation and urban beaches would be maintained in their current locations but their character would change significantly. The beaches would have artificial character and the beaches would be narrower compared to the Retreat Pathway and the Maintain Pathway.

For CoF, this pathway would protect the recreation areas of Bathers Beach and South Beach and would allow for more economic and residential uses in this already urbanised area. This is likely to outweigh the additional costs of protection. The Intensify Pathway may therefore be the most desirable option.

In CoC, this pathway has net present costs that are close to the Maintain Pathway. The key difference between the Maintain Pathway and the Intensify Pathway is whether it is preferred by the community and other stakeholders to significantly intensify residential and economic land use in the area, especially in the northern area near Rollinson Road, the South Fremantle Power Station and Coogee Beach.

For CoK, the Intensify Pathway may be most attractive. Although the costs of coastal protection exceed those for the Maintain Pathway, this pathway would allow the economic activities in the Kwinana industrial estate to increase significantly, generating economic benefits for the region.

For CoR, the costs for the Intensify Pathway are significant compared to the other two pathways. The potential loss in the character of the community due to intensification and the construction of artificial beaches may not be seen as a preferred way forward by the community.

9.5 Assignment of adaptation pathways

The study area is extensive and the patterns of land use vary significantly including natural areas, recreation areas, industrial/commercial areas and urban uses. In reality, it is unlikely that a single pathway approach would be adopted for the entire study, or even an entire LGA. More likely, areas with significant natural coastal values could follow the Retreat Pathway approach. This may also include Garden Island on the western side of Cockburn Sound. Lower density, high amenity coastal areas would likely adopt the Maintain Pathway approach that protects the existing amenity, functions and services, while also retaining existing property values. Highly developed and built-up areas with high economic values would probably be identified as key areas for protection and future on-going development and adopt a the Intensify Pathway approach.

Future integrated management of the Owen Anchorage and Cockburn Sound coastal area would therefore likely adopt a patchwork of adaptation pathways.

9.5.1 Management units

An assessment of the application of the adaptation pathways along the Owen Anchorage and Cockburn Sound coastline was undertaken using a series of management units along the coastline (Figure 9.2). These ‘management units’ are discrete comparatively homogeneous sections of coastline and were defined based on the transect zone boundaries identified in the Stage 1 Assessment (see Figures 28 and 29 of the Stage 1 Assessment report; CZM et al. 2013), key assets/asset types and the LGA boundaries. Assets in the Asset Register (Appendix A) have been divided into these management units where possible. Some assets such as roads, paths, and heritage areas extend over more than one management units.

9.5.2 Adaptation pathways for management units

Within each of the management units there is a unit-specific asset(s), these are the assets which are most highly valued in, and in most cases define the character of, that section of the shoreline (Appendix A). For each unit-specific asset, the level of priority for risk treatment (based on the intolerable coastal risks, due to erosion and/or inundation, resulting from the risk assessment and evaluation–Section 8) was assessed with consideration of stakeholder preferences, confirmed during the meetings and workshops. The priority for risk management and the nature of the unit-specific assets was then the basis for the assignment of adaptation pathways to each management unit. The broad impacts of pathways on adjacent areas has not been specifically included, but would need to be considered as and when specific actions are developed for management units. The assignment of adaptation pathways to the management units is detailed in (Table 9.2, Appendix A).

In addition to the adaptation pathways, potential management measures consistent with the assigned pathway have been suggested based on the nature of the coastline and assets within the management units. Alternative pathways have also been suggested for some management units where the stakeholder/community preference may differ from the Team's perspective.

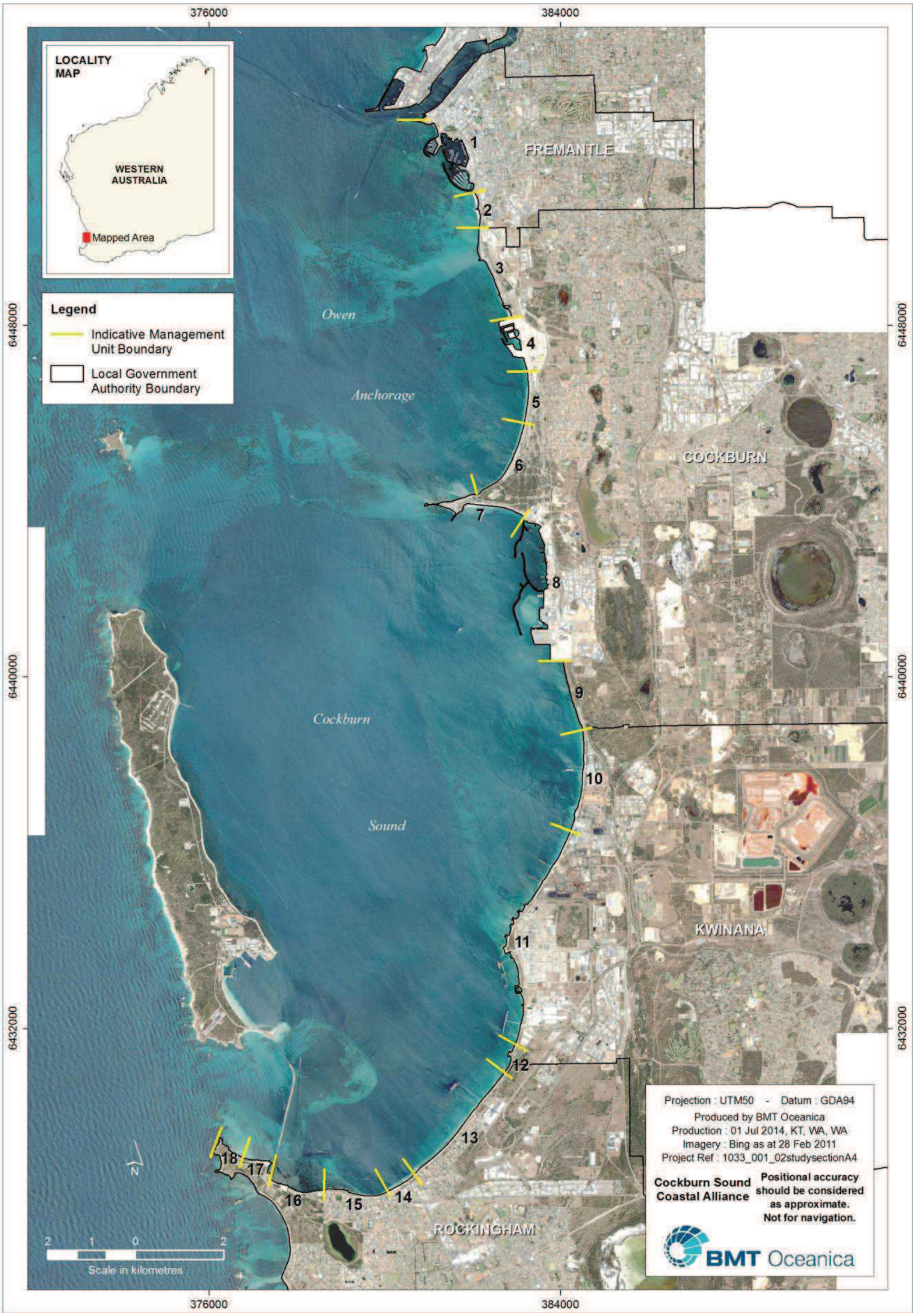


Figure 9.2 Indicative management units

Table 9.2 First-pass adaptation pathway assignment

1	South Mole	North boundary of South Beach	Boat Harbours and Heritage Areas	2 - Maintain	Increase height of breakwater	Breakwater overtopping >1/yr (average)	3 - Intensify	Initiation subject to development opportunities
2	North boundary of South Beach	North boundary Pickled Fig Café	South Beach and Heritage Areas	2 - Maintain	Sand nourishment, dune restoration	Net dune retreat >20 m	-	-
3	North boundary Pickled Fig Café	South extent of Robb Road	Power Station Redevelopment Site (Cockburn Coast), C. Y. O'Connor Reserve	2 - Maintain	Sand nourishment, dune restoration	Net dune retreat >20 m	3 - Intensify	Initiation subject to development opportunities
4	South extent of Robb Road	Socrates Road/Pelinte View intersection	Port Coogee	2 - Maintain	Increase height of breakwater	Breakwater overtopping or ocean inundation >1/yr (average)	3 - Intensify	Initiation subject to development opportunities
5	Socrates Road/Pelinte View intersection	South boundary of Coogee Beach Surf Life Saving Club	Coogee Beach Reserve	1 - Retreat	Dune management	Nil	2 - Maintain	Restore/maintain existing conditions when net dune retreat >20 m
6	South boundary of Coogee Beach Surf Life Saving Club	West boundary of Jervoise Bay Sailing Club	Woodman Point Regional Park	1 - Retreat	Decommissioning of structure	Asset compromised by erosion	2 - Maintain	Protect/maintain existing conditions when net dune retreat >20 m
7	West boundary of Jervoise Bay Sailing Club	West boundary of Woodman Point Facility	Woodman Point Regional Park, Cockburn Cement Washplant	1 - Retreat	Relocation of asset, sand nourishment, dune restoration	Asset compromised by erosion	2 - Maintain	Protect/maintain existing conditions when net dune retreat >20 m
8	West boundary of Woodman Point Facility	South boundary of Australian Maritime Complex	Woodman Point Facility and Australian Maritime Complex	3 - Intensify	Initiation subject to development opportunities		-	-
9	South boundary of Australian Maritime Complex	South boundary of Naval Base Shacks camp ground	Henderson Cliffs Reserve	1 - Retreat	Nil	Nil	-	-
10	South boundary of Naval Base Shacks camp ground	South boundary of Kwinana Power Station	Challenger Beach, Alcoa, Kwinana Power Station	2 - Maintain	Relocation or protection of asset, sand nourishment, dune restoration	Erosion within 10 m of asset	3 - Intensify	Initiation subject to development opportunities
11	South boundary of Kwinana Power Station	South boundary of Kwinana Bulk Jetty	Kwinana Industries	3 - Intensify	Initiation subject to development opportunities		2 - Maintain	Protect existing conditions when erosion within 10 m of asset
12	South boundary of Kwinana Bulk Jetty	Local govt boundary at coastline	Wells Park, The Wreck	2 - Maintain	Increase height of breakwater	Breakwater overtopping >1/yr (average)	-	-
13	Local govt boundary at coastline	Wanliss Street	Rockingham Beach, CBH Grain Terminal	2 - Maintain	Sand nourishment, dune restoration	Net dune retreat >20 m	-	-
14	Wanliss Street	Railway Terrace	Bell and Churchill Park	2 - Maintain	Sand nourishment, dune restoration	Asset (promenade) exposed by erosion	3 - Intensify	Initiation subject to development opportunities
15	Railway Terrace	Hymus Street	Palm Beach	2 - Maintain	Sand nourishment, dune restoration	Net dune retreat >20 m	3 - Intensify	Initiation subject to development opportunities
16	Hymus Street	Causeway	Causeway	2 - Maintain	Protection of asset, sand nourishment, dune restoration	Asset compromised by erosion	-	-
17	Causeway	Western boundary of Point Peron Recreational Camp	Point Peron Recreational Camp	1 - Retreat	Decommissioning or relocation of asset	Asset compromised by erosion	2 - Maintain	Protect/maintain existing conditions when net dune retreat >20 m
18	Western boundary of Point Peron Recreational Camp	End of peninsula	Point Peron – Rockingham Lakes Regional Park	1 - Retreat	Decommissioning or relocation of asset	Asset compromised by erosion	-	-

Note:

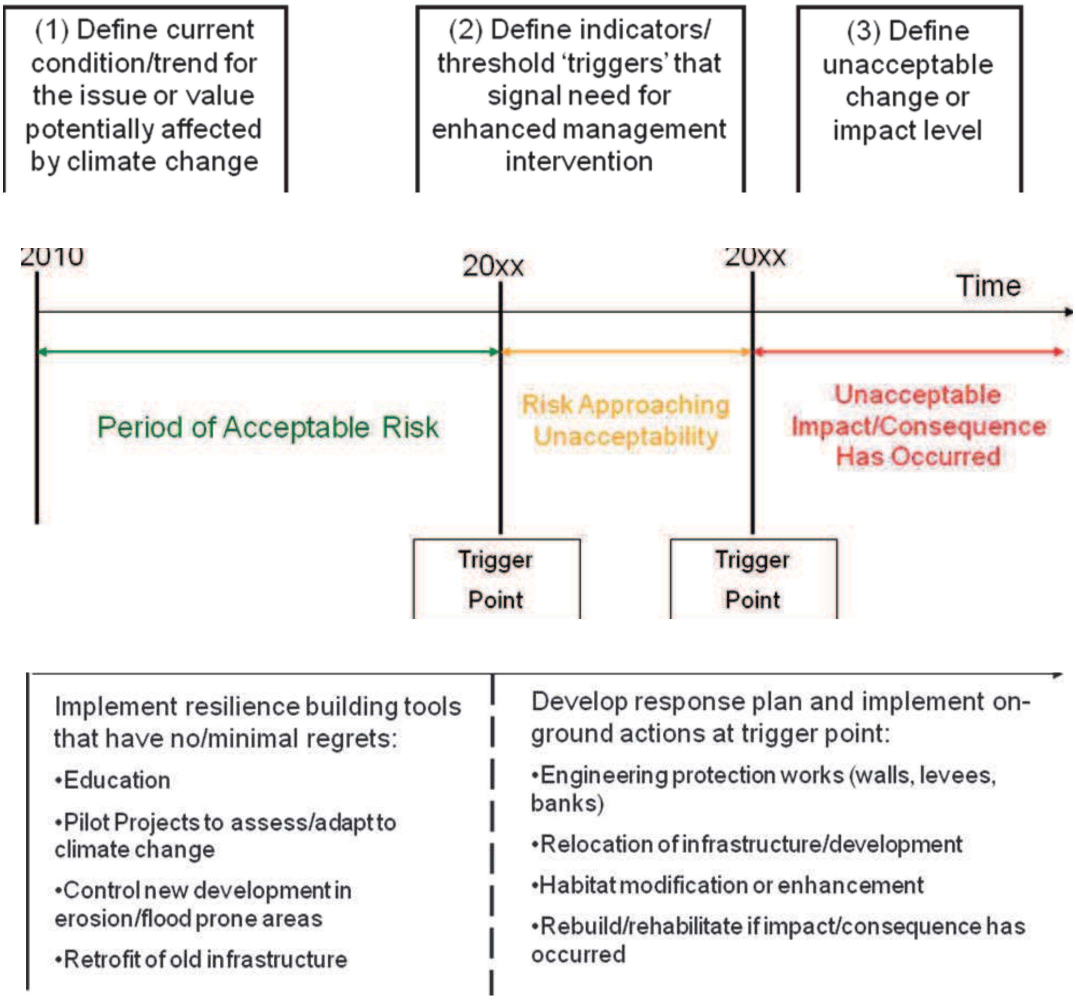
1. The scales of these triggers are generic and detailed shoreline studies and monitoring (as part of the Stage 3 Adaptation Plan) will be necessary in order to refine them for each management unit. Where triggers appear unfeasible e.g. there is less than 20 m of dune width available, this may be an indication that the management actions may already need to be undertaken.

9.5.3 Triggers and timeframes for action

The approaches to coastal risk management will require a high degree of adaptation given the uncertainties regarding when impacts of climate change will start to manifest. To avoid undesirable impacts it is important to identify issues as they emerge and implement measures in a timely manner. It is equally important to avoid implementing measures prematurely as they may be excessively costly or unattractive to the community. Fisk and Kay (2010) provide a method for setting triggers for climate change adaptation actions along a time continuum. The trigger points are set to flag the ‘level of acceptable change’ where more assertive or decisive actions must be implemented to avoid an undesirable impact (Figure 9.3). The use of triggers therefore sets the timeframe for action such that coastal management can be planned on an as needed basis, covering the urgently required and strategic actions.

The coastal risks associated with erosion and inundation will increase over time; hence the intervening time before detrimental impact occurs can be used to implement resilience-building measures, particularly where the action may be costly or difficult for community to accept or implement. This lead time can also be used to source funding and prepare approvals and designs. This approach also recognises that some hazard or climate change impacts may not eventuate as projected. If this is the case, the trigger-based approach for adaptation means that the community has not been unnecessarily burdened by costly management responses.

To appropriately define these triggers for each of the indicative management units, detailed shoreline studies will be necessary to determine the envelope of historic shoreline change, the scale of shoreline erosion/inundation from seasonal 'normal' storm events and the level of recovery from such storm events. Such detailed analysis is outside of the scope of this assessment. However, generic triggers, have been assigned to each of the indicative management units to provide an indication of the nature and scale of shoreline change/impact expected before risk management is to be implemented and also the nature of the shoreline monitoring required moving forward (Table 9.2, Appendix A). These generic triggers represent the first trigger point in Figure 9.3 at which point action must be taken to prevent the risks from becoming intolerable. When further work is undertaken to define triggers at a local scale, the evidence of damage to an asset should not be used as the basis for a local trigger, as the management action should ideally be triggered before this occurs.



Note:

1. Terminology used in this figure (i.e.' acceptable' and 'unacceptable') correspond to the terminology used in this report (i.e. 'tolerable' and 'intolerable').

Source: Fisk & Kay (2010)

Figure 9.3 Continuum model for climate change adaptation

10. Discussion

10.1 Summary of Stage 2 Assessment and first-pass adaptation assessment

Coastal hazards, including beach erosion and storm surge inundation already affect a considerable area along the coastline of Owen Anchorage and Cockburn Sound. With sea level rise, these coastal hazards will be exacerbated and the areas affected by the hazards will move further landward. The land potentially affected by coastal hazards includes natural habitats, urban lands and industrial/employment precincts. Some of the industries potentially affected by coastal hazards are of state significance, including the BP oil refinery and Kwinana terminals. The total cost of risk to land and assets potentially at risk from coastal erosion and inundation hazards is at least $325 million; this total only includes conservative estimates for industrial land uses (in the absence of data).

A number of intolerable coastal risks, due to erosion and/or inundation, were found to affect a broad range of natural and built assets that provide extensive economic, social and environmental values. These intolerable risks were prioritised for management taking into account both the level of risk and the timeframe of impact. The highest priority was assigned to those extreme intolerable risks that are presently occurring, followed by extreme risks at future timeframes and high risks at present day.

The Stage 2 Assessment has identified the following priority assets for consideration during adaptation planning:

i. Highest cost of risk: the amenity of a number of high value beaches (namely Bathers, South, Rockingham, Bell and Churchill Parks, and Palm Beaches) should be preserved for as long as possible. The adaptation for these amenities will require the preservation of the beach environment through future nourishment and associated works.
ii. Highest value parklands: Woodman Point, C. Y. O'Connor Reserve and the Cape Peron – Rockingham Lakes Regional Park. The value of these parklands in particular should be preserved; therefore adaptation needs to allow for the continuation of the critical values (both recreational and environmental) of these parklands.
iii. High value existing key infrastructure. Whilst the Kwinana infrastructure has not been included in the valuation process, it can be considered in line with other existing infrastructure. To ensure that value of infrastructure is not compromised by a truncated functional life, adaptation must include the protection (or accommodation) of infrastructure to allow for continued use through to the end of the design life.

Adaptation is an ongoing process that can follow various pathways that reflect possible management approaches with different strategic aims. Three potential adaptation pathways have been identified for the management of the Owen Anchorage and Cockburn Sound coastline:

i. Retreat
ii. Maintain
iii. Intensify

The Maintain Pathway of adaption has been identified to have the lowest net present cost at $65 million for the study timeframe (present day–2110); although a number of cost categories could not be expressed in dollar value terms. This pathway essentially involves maintaining the existing development and the coastline, while also actively maintaining the environmental and recreational values and amenity of the existing beaches through extensive beach nourishment.

However, the Intensify Pathway, which is about 45% more costly than the Maintain Pathway over the same timeframe, would allow for substantially more development in the coastal zone including residential development and heavy industrial/maritime development. This additional development would increase the number of stakeholders and land owners benefiting from the adaptation works, who may also be able to subsidise many of the works required to implement this adaptation pathway over time. However additional development could increase the number of properties and/or landholders at risk should the adaptation works fail.

A patchwork of adaptation pathways will likely be required for the management of the Owen Anchorage and Cockburn Sound coastline to ensure appropriate management measures are applied to accommodate the significantly different land uses which include natural areas, recreation areas, industrial/commercial areas and urban uses.

Based on this first-pass assessment, the Maintain Pathway is considered the most appropriate for most of the management units within this coastline although the nature of the adaptation measure will vary according to the specific asset type and the character of the shoreline (refer to Table 9.2, Appendix A). The pathways presented in this assessment provide a tool to further engage with stakeholders and communities to determine the specific preferences of adaptation in various locations. Adaptation is a long-term process and decisions made today may impact on how to adapt in the future. Though difficult, for the purposes of long-term planning, it will be necessary for some decisions to be made early otherwise options may become limited in the future. It is important to have a proper understanding of the possible impacts of such decisions and the adaptation pathways approach will help by creating a better understanding of these long-term implications and whether these are acceptable and preferred by the community.

10.2 Funding for adaptation

The costs associated with the various management approaches, ranging from coastal adaptation works to loss of land, will vary considerably between pathways. The loss of land and assets are costs that would primarily affect land owners and users of land, such as home owners, infrastructure providers and visitors. The costs of maintaining and reconfiguring infrastructure would mostly affect infrastructure providers while coastal adaptation works are mostly borne by local and state government or private landowners if undertaken on private lands. With the Retreat Pathway of adaption, loss of beaches[6], park and heritage areas, urban land and assets not reaching their economic lives are the most significant costs. This would primarily affect the wider community/visitors of beaches, parks and heritage areas, property owners in urban areas affected and infrastructure providers (including local government). With the Maintain Pathway or the Intensify Pathway of adaption, the parties most affected will be infrastructure providers and (local) government providing coastal adaptation works.

There is a need to establish mechanisms to ensure equitable contributions from those who benefit from the adaptation works, and to communicate clearly and consistently about the developing risks and the associated pathways of adaptation. Effective adaptation responses will also need considerable coordination in terms of governance and funding, including:

- the management of developing risks in a timely and integrated manner; and;
- no subsidy for those who choose to occupy hazardous locations

These two principles indicate that ‘doing nothing’ and letting risks increase over time may not be an effective option. Current property owners may not have been aware of the coastal risks due to climate change when they invested in their properties. So in the short term (e.g. 10 years) there is a case of providing protection to private property. This allows sufficient time for property

[6] *Note that the full beach amenity may not necessarily be lost as the beaches migrate landwards*

owners to reconsider their investment decisions. Thereafter, if people decide to invest in an area that is known to be at risk, it would be poor public policy to continue to subsidise these property owners. Additionally, with climate change affecting increasingly large areas around Australia (and the world), it would be beyond the capacity of the wider community to continue to compensate financially those who choose to invest in areas at risk. There is a need to set up equitable funding mechanisms; special rates and levies are among the possible mechanisms that could be applied.

10.3 Recommendations for Stage 3 Adaptation Plan

The Stage 3 Adaptation Plan will formulate an adaptation strategy for the Owen Anchorage and Cockburn Sound coastline. The development of this strategy will involve the identification and further assessment of coastal risk management actions, including detailed shoreline studies to refine the pathway assignment and triggers presented herein, and it will define the responsibilities and timeframes for coastal management.

It is recommended that the Stage 3 Adaptation Plan should build on the following elements:

- the values and risk assessment presented herein and the appropriate adaptation pathway for each section of the coastline (management unit) should be confirmed through consultation with the relevant managers within each LGA as well as through wider community engagement
- specific actions (with triggers/timeframes) to manage these individual sections of coastline should be confirmed through more in-depth studies, shoreline monitoring and wider community engagement
- holistic coastal planning approaches that recognise the integrated nature of impacts and adaptive responses to neighbouring sections of coast should be acknowledged and incorporated
- regionally important environmental areas should be protected where possible
- areas for habitat migration (for regionally important habitats) should be managed appropriately
- potential sources of sand for nourishment should be identified
- potential areas for suitable intensification of development (residential, commercial and/or industrial) should be identified. This may involve adopting a regional land-use planning approach to ensure that these areas are targeted and meet regional demands
- beach management zoning should be applied according to the present and proposed future beach use, including their regional economic benefits

Based on the above, recommended pathways can be confirmed for different parts of the coastline. Importantly, if beaches continue to be viewed as highly valued then ‘engineered’ beaches (i.e. the Intensify Pathway) may be appropriate to ensure these amenities continue to be provided. The Stage 2 Assessment has found that engineered beaches at Bathers, South, northern C. Y. O'Connor and Bell and Churchill Park beach-front would be required to service the communities across all CSCA LGA areas.

The parklands that provide environmental value (Woodman Point, C. Y. O'Connor Reserve and Cape Peron – Rockingham Lakes Regional Parks) should be permitted to retreat (i.e. the Retreat Pathway of adaption) as sea level rise occurs to maintain the beach environment and associated values. A similar approach may also be appropriate for Garden Island (subject to discussion and confirmation with DoD). In general, infrastructure protection can be achieved via the Maintain Pathway, but from a regional planning perspective it may be worthwhile considering the Intensify Pathway providing it does not compromise the values of beaches and parklands. Importantly, these parks are high-value existing assets and should be protected from the potential impacts of future intensification of development as much as possible.

10.4 Post study evaluation

10.4.1 Data gaps

During this Stage 2 Assessment several important data gaps were identified and addressed during this study (Table 10.1).

Table 10.1 Data gaps

No asset data were available for Garden Island.	Given lack of asset data for Garden Island and the poor state of the LiDAR data for this area, a detailed coastal risk assessment was not possible for Garden Island.
All data was not available for all the key assets of the Owen Anchorage and Cockburn Sound coastline. This included data on the beach areas, coastal infrastructure, the South Fremantle Power Station redevelopment site and all Kwinana industries. Refer to Table 6.1 for a full list.	The spatial extent of these assets was captured via manual digitisation so that they could be included in the Asset Register.
A number of asset data overlapped in GIS space.	Overlapping data were identified and manually edited by isolating the relevant shapefiles for analysis.
Spatial land zoning/uses (residential and commercial) data was not available for all LGAs.	Capital improved values were provided for the whole study area (except CoK and Garden Island) but were not distinguished by land use type and the base land values were also not provided. Most of the capital improved values data overlapped with other asset data and so to prevent the double counting with the other asset categories, these values were not included. These assets were not considered at critical risk as many of these areas were only impacted by inundation in the possible and rare 2110 scenarios and damage will therefore likely be minimal. It is estimated that the cost of risk may therefore be undervalued by ca. 1–5%.
Value data were not available for the Kwinana industries and many of these industries were not represented at the stakeholder meetings and workshops. As such the values of their assets were not adequately discussed to allow a more detailed value assessment beyond the broad consequence categorisation.	The value of the major industries in Kwinana are significantly underestimated at $20 million NPV at risk over the next 100-year period. A conservative estimate of the asset cost of risk was derived from the economic consequence scale which identified whether the expected damage to the assets was smaller than $50 000, $50 000 to $200 000, $200 000 to $1 million, $1 million to $5 million or greater than $20 million. The maximum value of the consequence scale was therefore used. Given their statewide importance as strategic assets, it was recommended that these assets be protected into the future.
Value data were not available for Water Corporation infrastructure (wastewater treatment plants, outfalls, water pipes).	The values for the water pipes were estimated using values for stormwater pipes provided by the CSCA LGAs. The wastewater treatment plant and outfall were only impacted by inundation in the 2110 scenario when they may be at the end of their asset life. Further, these assets were not considered at critical risk and were omitted from the cost of risk calculation.
Economic valuation.	Contingent valuation and choice methods are useful for estimating the recreation and bequest values. However these methods consist of extensive primary research and were not feasible within the resource allocation of this project. The values assessment has instead identified sources for the benefit transfer based on information about the assets that was collected as part of the consultation process. The values derived using the benefit transfer method should be considered to be indicative as the quality of the outcomes depends on the comparability of the assets in the study and the assets where the values are transferred from.
Limited data were available on the ecosystem services offered by the parks in the study area.	Reserve and park areas for which no ecosystem data were available have been assigned a value of $0.02 to reflect their environmental value.

Limited data were available on the recreational use levels of parks and open spaces.	Where no information on park visitation were available, the replacement value has been used as an approximation of the recreation value of parks. The replacement value shows what it would cost to develop a park including recreational infrastructure such as paths, shelters and playgrounds. It is reasonable to assume that the value the community gains from these parks would be at least equivalent to the replacement value, otherwise the investment would not have been made.
Limited data were available for the beaches and in some cases the beach areas were included within adjacent parks (parks and beaches deliver quite different services).	In these instances, beach assets were separated from the parks areas manually. An estimated an average beach width of approximately 25 m was estimated based on a number of samples in the study area, but acknowledging that beach widths vary between beaches and between seasons.
Presence of coastal structures or bedrock at Bathers Beach is undetermined therefore this section was not included in the erosion hazard assessment during Stage 1.	This section was only assessed for inundation.

10.4.2 Lessons learned

The lessons learned during the completion of the Stage 2 Assessment are outlined in Table 10.2.

Table 10.2 Lessoned learned during the Stage 2 Assessment

Data supply	The Stage 2 Assessment was fundamentally constrained by the availability of data. Further, sourcing, collation, editing, cleaning and verifying the available data took a very significant amount of time. In future it would be advisable if this compilation is undertaken prior to commencing of the risk assessment phase. This would allow for a more efficient risk assessment in which critical data gaps are acknowledge from the inception and methods could be tailored towards the data in advance. Further, commencing the risk assessment work with a comprehensive data set would allow stakeholder meetings to better target key areas of discussion. Within the context of the present study data gaps were regularly identified and this required continued review of the appropriate methods.
Data supply	Obtaining data from existing local sources (i.e. local councils) than obtaining data from external sources (i.e. LandGate) proved to be a much cheaper option.
Stakeholder meetings	Given the paucity of appropriate data available to complete the values and risk assessment more stakeholder meetings were required than were originally scoped for. The provision and compilation of the data prior to the scoping for such works would have allowed appropriate project/meeting planning to allow for the level of data availability.
Stakeholder meetings	In addition to the number of meetings, prior knowledge of the data availability would have initiated engagement with the stakeholders to fill the asset and value data gaps.
Engagement of private stakeholders	Many of the Kwinana industries were not present at the stakeholder meetings and workshops; this highlights the need to carefully consider how the industrial coastline in Kwinana is managed relative to the rest of the Cockburn Sound coastline.
Communication of Stage 1 Assessment	It is noted that the Stage 1 Assessment had not been released to the stakeholders prior to the commencement of Stage 2. Therefore, the workshops were the first opportunity for stakeholders to provide feedback on the hazard mapping. If the Stage 1 Assessment had been circulated to stakeholders via an appropriate communications strategy prior to the inception of the Stage 2 Assessment, any feedback could have been incorporated prior to presentation of the Stage 2 risk assessment process to the stakeholders. As it was feedback regarding the Stage 1 Assessment served to disrupt the stakeholder engagement for the Stage 2 Assessment.
Methods for values assessment	Prior knowledge of the data availability would have allowed for appropriate scoping of the methods for asset valuation, in addition determining the costs of risks and how they develop over time is an innovative area of research which is an integral part of the risk analysis and would have benefited from an expanded scope to fully explore the analytical uncertainties.
Methods for values assessment	Scope for undertaking local studies to further tailor the benefit transfer method for parks and beaches to the study areas would have strengthened the valuation of these assets.

10.4.3 Valuation methods evaluation

The valuation methods and assumptions used for the economic valuation of the assets at risk in the Stage 2 Assessment are listed in Table 10.3 and Table 10.4.

Table 10.3 Economic valuation methods used

Beaches	Benefit transfer method based on Blackwell (2005)
Parks	Council usage data and benefit transfer method
Heritage areas	Benefit transfer method
Public buildings	Benefit transfer method
Coastal structures	Council replacement values and benefit transfer from the one Council to another
Public facilities e.g. public toilets and surf lifesaving clubs	Council replacement values and benefit transfer from the one Council to another
Private stakeholder assets	Broad estimate based on consequence scale

Table 10.4 Economic assumptions

Future development	Only the value of the existing land and assets were considered and the value of any future development has not been included in this assessment, including that of the South Fremantle Power Station Redevelopment Site (Cockburn Coast) and the Port Coogee development.
Heritage assets	Assets listed as heritage were assumed to have a value of that is 150% of the average land values in the study area as heritage areas are generally valued at a premium compared to generic urban areas.
Industrial land	The valuation of industrial land was constrained due to data availability. In the absence of these data, it has been assumed that industrial areas within the hazard areas represent an economic consequence of at least $20 million. This ensures that the loss of this land will be assigned the highest consequence level as agreed by the stakeholders at the Risk Assessment Workshop. However, it is likely that this represents an undervaluation of the actual values at risk.
Benefit transfer method	The values derived using the benefit transfer method should be considered to be indicative as the quality of the outcomes depends on the comparability of the assets in the study and the assets where the values are transferred from. The values assessment has identified sources for the benefit transfer based on information about the assets that was collected as part of the consultation process. The benefit transfer method can only be applied to values in the study area that are known; if it is unknown what the levels of visitation are, or what ecosystems are present, then it is impossible to place a value on the unknown service or product.
Beach valuation	The Blackwell (2005) study concluded that the beach values therein do not capture social and cultural values other than peoples' willingness to pay to visit/use a beach of beaches.
Non-use values, parks and beaches	Studies on the non-use values of parks and beaches could not be found and as such have not been included herein. It has been noted that people also place a value on knowing that parks, beaches and ecosystems are available (existence value) and will be available for future generations to enjoy (bequest value). This issue can only be addressed by undertaking primary research to establish the values directly through methods such as the Contingent Valuation Method and the Contingent Choice Method. These were not within the present scope as the cost of undertaking this type of research is high and would be more applicable as part of a more detailed adaptation assessment (not a first-pass assessment). In addition, it is worthwhile to note that natural ecosystems also have intrinsic values. By definition, these values cannot be expressed in dollar terms or other human terms as these values exist without delivering a good or service to people.

Beach valuation	Beaches also have protection values where they act as a buffer between the ocean and the built environment. Protection values are location specific and depend on the nearby urban context and built environment. The more development, the more important the protective value of beaches, and the stronger the case to implement works to protect the beach at its current location. However, other protection works, such as seawalls, would deliver similar if not higher protection values, and may provide an alternative solution to protecting the built environment. This aspect of the beach value has not been included in the values assessment.
Park valuation	The park valuation does not include the benefits associated with physical activity (i.e. preventative public health costs), community cohesion, and avoided costs of managing urban stormwater or the removal of air pollution by vegetation.
Park valuation	The ecosystem dataset for park areas was not complete; therefore for those parks where these data were not available an environmental value for grass/rangelands ($0.02) was assigned.
CBA	Costs for adaptation measures used in the CBA were assumed based on current generic costs. Specific costs and how they might change with time have to be determined by local technical assessments. It is important to note that the costs will be different in different locations and also change over time e.g. sources of beach nourishment will change over time and depending on how suitable the material is to the beach being nourished.
CBA	The CBA has assumed that the cost of nourishment remains stable into the future, but for the Fremantle and Cockburn areas, these costs may increase over time as it becomes more difficult to source nourishment material. There are many variables to consider when predicting the potential future cost of sand nourishment and a detailed technical feasibility assessment to derive the potential future cost was outside the scope of the present assessment.
CBA	The CBA does not account for the potential increase in the cost of coastal management as coastal mobility (i.e. with beach retreat) or artificial beach maintenance increases. For example, the erosion rate on an engineered and renourished beach can be far higher than on a natural beach.
CBA	The cost of maintaining or replacing coastal defences has not been included the CBA.

11. Conclusions

The Stage 2 Cockburn Sound Coastal Values and Risk Assessment has identified the coastal assets at risk along the Owen Anchorage and Cockburn Sound coastline. The values of these assets were determined and used in a risk assessment to delineate the priorities for risk treatment and a first-pass adaptation plan for this coastline.

The available asset data were collated into an Asset Register (Appendix A). The assets at risk were then identified by combining this dataset with the hazard mapping using a Geographic Information System. The economic, social and environmental values of these assets were then determined.

The total cost of risk to the land and assets (considering both erosion and inundation over 100 years) is greater than $325 million. The majority of this value is in the beaches ($130 million) and parks ($122 million), which signifies the high economic, social and environmental values held in these assets.

The risk levels of the assets were evaluated using the combination of the asset values (consequence) with the likelihood of the coastal hazard occurring. The risks are presented in the Asset Register and Risk Maps (Appendix A and Appendix F). As it is impractical to manage all risk it was necessary to establish a risk tolerance to enable prioritisation of risk management. This 'risk tolerance' concept aligns with SPP2.6 allows the cost of management actions to be allocated in proportion to the level of risk. Using this concept, present extreme and high risks and future extreme risks (Table 8.7 and Table 8.8) were deemed intolerable and therefore a priority for risk management.

The following three adaptation pathways were considered in this study:

i. Retreat Pathway, where climate change is permitted to take its course and development is progressively moved out of the way as it becomes impacted;
ii. Maintain Pathway, existing development rights are protected and continued into the future through redevelopment, but no additional development is permitted within high hazard areas; and
iii. Intensify Pathway, where new coastal protection works are constructed that allow for additional coastal development and intensification of land use at isolated coastal nodes and infill areas.

The Owen Anchorage and Cockburn Sound coastline will evolve very differently under each of these pathways. It is anticipated that future integrated management of the coastline will likely adopt a patchwork of adaptation pathways, each section of the coastline being best suited to a particular pathway to protect the typical values. The following broad pattern of adaptation pathways is suggested in the Stage 2 Assessment based on this analysis:

- The CoF coastline covering South Beach and Bathers Beach is suited to the Maintain Pathway or the Intensify Pathway.
- The CoC coastline is suited to the Maintain Pathway or the Intensify Pathway. The preferred direction may differ by location and on preferences from the community and other stakeholders.
- The CoK coastline would be suited mostly for the Intensify Pathway. The coastline is already heavily modified and the industrial uses are of regional and possibly state significance.

- The CoR coastline would be suited for the Maintain Pathway, but this will depend on whether the community and other stakeholders aspire for significant intensification in the area or prefer the community and amenity values to be largely maintained as they currently are.
- Small pockets of coastline (mostly within existing conservation areas) would be suited for the Retreat Pathway.
- Eastern shoreline of Garden Island would be suited for the Retreat Pathway (subject to further discussions with Department of Defence).

The Owen Anchorage and Cockburn Sound coastline was divided into management units based on coastal processes data from the Stage 1 Assessment, specific asset boundaries and LGA boundaries. Within in these management units, appropriate adaptation pathways with specific management measures were proposed with consideration of the highest values at risk, namely, the beaches, certain parklands and the high values infrastructure (Kwinana industries). As part of this first-pass assessment, generic triggers for management were also identified. These triggers determine the timeframe for implementation of the adaptation measures and allow the LGAs to plan adaptation whilst also treating urgent risks.

It is recommended that the Stage 3 Adaptation Plan further develop these pathways and triggers to tailor them for each management unit along the coastline based on targeted stakeholder/community discussions and further in-depth shoreline studies and monitoring.

The Stage 2 Assessment has involved the facilitation of understanding of coastal risk assessment and management among stakeholders through presentations, meetings and workshops. Specifically, the risk management approach, coastal assets at risk and potential coastal management options have been presented and discussed within LGAs, other government agencies and private land owners/managers. A key message to these stakeholders was that to ensure effective coastal management and adaptation requires an integrated approach and strategic planning for future development. This should also include early engagement and education of the public on the requirements to protection some assets and sacrifice others.

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