



Our Coastal Future **Port, Leighton and Mosman** **Beaches**

Coastal Adaptation Plan



APPENDICES

Appendix A – Community Engagement

The following information describes the activities and tasks undertaken by the project team to engage with the local community in the development of the coastal adaptation plan.

Community engagement is vital in the coastal hazard risk management and adaptation planning (CHRMAP) process; the level of risk presented to coastal areas is strongly influenced by the value of the area. The appropriate adaptation decision is also dependent on the values of coastal assets and areas. The community's feedback to determine values and consider the relative contribution of those values – including social, environmental and economic – to decision-making is important to ensure the right decisions are made.

The function of community and stakeholder engagement during the project was to:

- Inform the community and stakeholders about the risk associated with coastal processes at work in the study area;
- Collaborate with the community and stakeholders to determine the level of risk tolerance, community values of coastal assets and to identify potential adaptation options;
- Involve the community and stakeholders in assessing the adaptation options presented; and
- Consult with the community and stakeholders on the draft CHRMAP through a public consultation process.

To deliver the required function, objectives of the engagement strategy were:

- To identify key stakeholders and the required level of engagement required at different stages of the project in line with the International Association of Public Participation's (IAP2) Public Participation Spectrum,
- To provide a means for engaging and educating the community and other stakeholders
- To inform the community and other stakeholders on opportunities to participate in the delivery of an effective CHRMAP;
- To establish criteria for evaluating the efficacy of ongoing management.
- To consult with government agencies to ensure relevant issues are captured in the CHRMAP;
- To encourage informed comment on the CHRMAP; and
- To assist the project team in developing appropriate mitigation measures in response to key issues raised as part of the engagement process.

Phases of engagement

The engagement methodology involved a number of key activities to identify stakeholders, inform them about the project process, provide opportunities for comment and document feedback for consideration by the project team.

The consultation process was undertaken in three key phases:

- Community dialogue - to inform and educate the community about the CHRMAP project and to obtain feedback related to community and stakeholder values.
- Community awareness campaign - to inform the community of the results of the vulnerability and risk assessment and to obtain feedback in respect of values weightings.
- Formal advertising – to present the draft adaptation plans and encourage formal, written feedback.

Community dialogue

The community dialogue phase of consultation commenced on 15 July 2016, and concluded on 15 August 2016. The community dialogue included:

- Informing the community about the project through a project website hosted by the City of Fremantle, media release, social media posts, information sheets, and project signs located along Port, Leighton and Mosman Beaches; and
- Obtaining feedback from the community regarding values of the coast through a survey.

Whilst much of the community dialogue occurred through online sources, this was augmented through physical engagement opportunities through signs on site – leading community members to online information – and an onsite engagement morning to provide in person opportunities and information about the project.

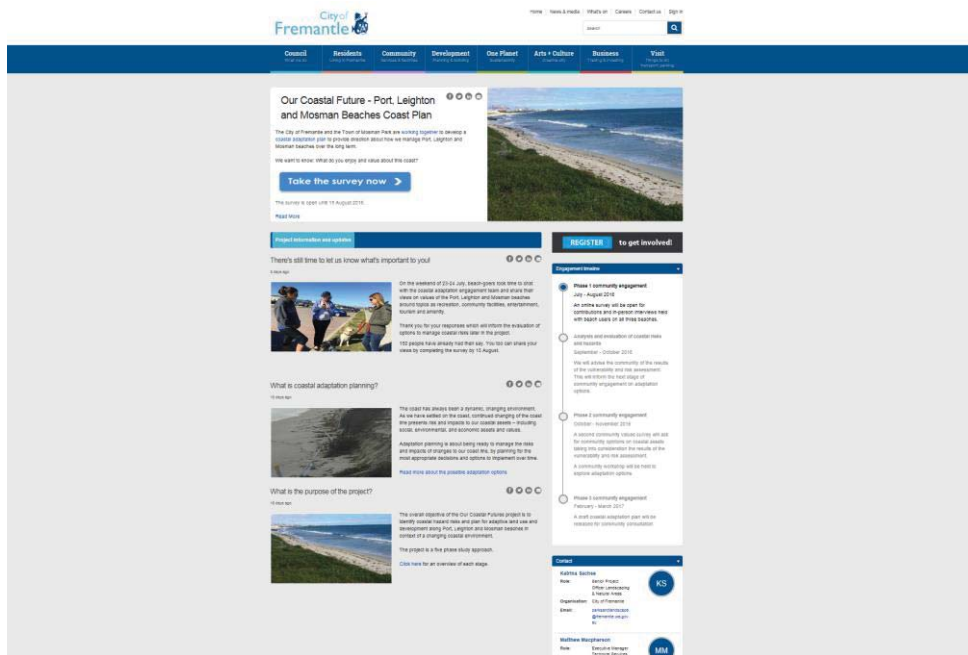
The timing of the community consultation activities was influenced by the funding timeline's for this project. The project had to begin in winter 2016 and the first stage in the process is understanding community values. Ideally the timeframe for this stage of consultation would be held over a summer period. As a result, consultation participants and therefore results may have been biased toward local representation and values, as regional users may not have visited the area during the consultation phase. The consultation outcomes were considered in light of this potential bias.



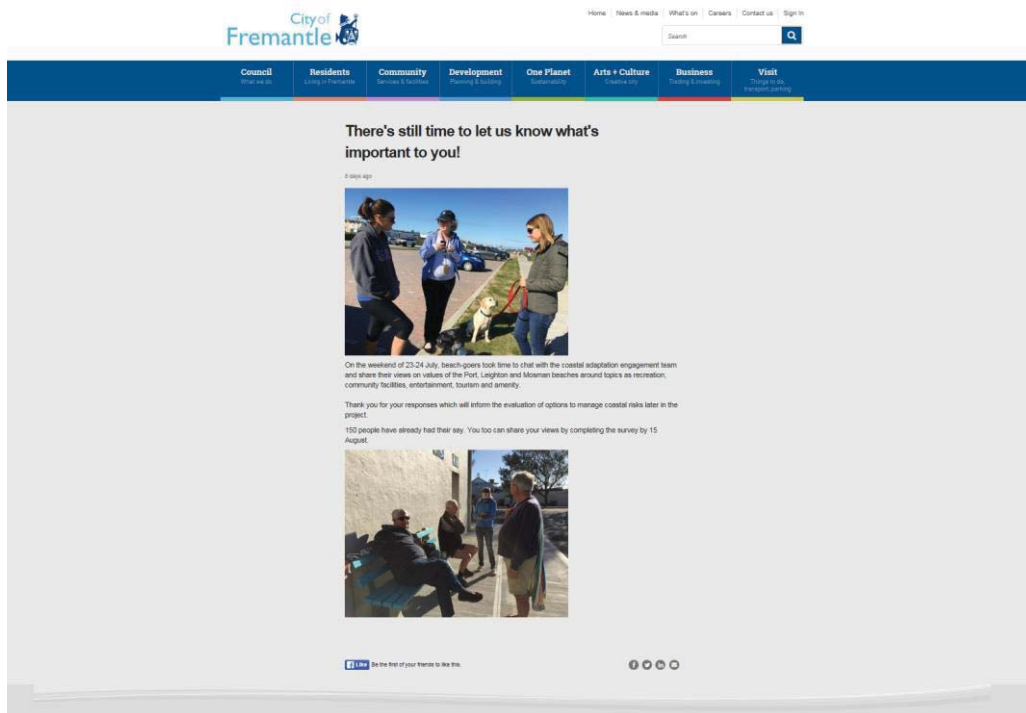
Signs within the coastal study area directed community members to online information



Social media posts provided an innovative platform to direct community members to the project website, survey, and engagement morning, and start a dialogue through sharing across Facebook and Twitter.



The project “MySay” website provided clear information about the project and opportunities for the community to be engaged.



Updates to the project website shared progress with the community, such as sharing information about the engagement morning

Our Coastal Future Port, Leighton and Mosman Beaches

Coastal Hazard Risk Management and Adaptation Planning Project

The City of Fremantle and the Town of Mosman Park are collaborating to identify the vulnerability of Port, Leighton and Mosman Beaches and adjacent land to coastal processes through a Coastal Hazard Risk Management and Adaptation Planning (CHMAP) project.

The overall objective of the project is to identify coastal hazard risks and to properly plan for adaptive land use and development along the Port, Leighton and Mosman Beach coast in light of a changing coastal environment.

The project is a five phase study approach.

Phase 1 is to establish the context of the coastal environment and to establish community values for the Port, Leighton and Mosman Beaches and surrounding area.

Phase 2 is to identify and quantify the coastal hazards, including erosion and inundation. Coastal hazards will be assessed at present and future predicted sea levels to determine what built and natural assets, and their cultural, social, environmental and economic values, are at risk over time. This phase will prepare maps of the hazards, showing what areas may be impacted by erosion and/or inundation.

Phase 3 analyses coastal hazard risks against community and stakeholder values to give a range of tolerable coastal risks. Phase 4 will develop a plan for the most appropriate coastal adaptation responses based on multiple social, cultural, environmental and economic criteria.


The final phase, Phase 5, will prepare a project report which collates all the outcomes of the project.

The project will provide a clear and easily understood framework for the future management along the Port, Leighton and Mosman Beaches coast.

Be Involved



Contribute to the project by highlighting the key things you enjoy and value about the coast in our community survey located on the project website by 15 August 2016.

Regular updates will be provided during the project through website updates, social media and community events.



This project is funded by the Western Australian Planning Commission through the Coastal Management Plan Assistance Program.

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Our Coastal Future Port, Leighton and Mosman Beaches

What are the available options?



Above, erosion in front of a sea wall has resulted in a loss of beach area.



Below, groynes and offshore breakwaters are interim protection options that can assist in alleviating erosion for a time.



There are four key coastal adaptation options available when making decisions about managing coastal risks. These are:

- **Avoid** development in the area of risk
- **Retreat** (relocate) assets and development away from the risk
- **Accommodate** the risks (e.g. occasional flooding) through retrofitting
- **Protect** the assets through coastal engineering works.

The most appropriate adaptation option may differ based on the values to be protected in a certain location.

For example, land protection measures (sea walls) can exacerbate erosion and severely affect beach amenity, compared to retreat which enables retention of a natural beach environment.

Interim protection options can help, but may not be permanent or appropriate in all situations.

Groynes and offshore breakwaters are examples of passive interim protection measures. This groyne example (left) is made from geotextiles. Groynes can also be constructed from rocks to extend their design life. Offshore breakwaters can interrupt open views of the ocean, and groynes can create a barrier along the beach.

Sea walls are an example of active interim protection measures. Designed well, they can integrate well into the development of beach amenities, although they can exacerbate erosion (beach loss) in front of the wall over time if ongoing sand nourishment is not undertaken.

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Information flyers provided additional detail regarding the project and increased awareness about coastal hazards and coastal adaptation planning

The engagement morning occurred on Sunday 24 July between 9am and 1pm. This was a sunny day in the winter season, therefore a number of people were out and about. The engagement included a “roving” information display of posters and flyers, with team members undertaking “intercept” surveys with community members. Cards with project and survey links were also handed out to community members who, whilst interested in the project, did not want to stop and talk at the time.

The engagement team commenced at Port Beach, adjacent to the change rooms and car park. After about an hour, the team relocated to the Mosman Beach area where a manned information stand was set up within a gazebo, and two team members walked along the coastal path to engage with community members. The engagement team concluded at the local park within Leighton Beach with a manned information stand.



Roving information stand during the engagement morning

Engagement Levels

During the onsite engagement morning, approximately 50 to 60 survey information cards were distributed. 12 surveys were completed on the spot by community members with the engagement team.

The survey received total of 306 responses. The survey opened on 15 July 2016 and closed on 15 August 2016, Figure 1 below outlines response volume across the period the survey was open.

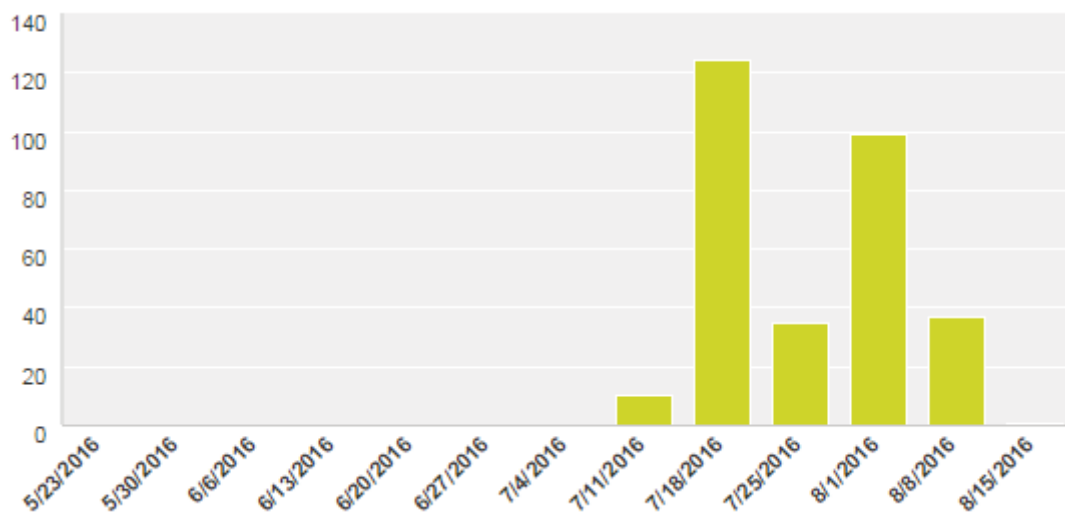


Figure 1 Responses to survey (by week)

Engagement Outcomes

The values survey comprised 16 questions, a summary of responses is outlined below.

Question 1: Which of these recreational aspects at Port, Leighton and/or Mosman Beaches are important to you?

Overall, recreation in the ocean was the most important recreational aspect of the beaches, with 87 percent of respondents valuing activities such as swimming, snorkelling, diving, and stand up paddle boarding, and 32 percent of respondents selecting surfing, kite surfing, and wind surfing as important (Figure 2). Exercise opportunities (running/walking/cycling/fitness classes along the beach and parkland) and access to bike and pedestrian pathways were also valued, with 76 percent and 72 percent of respondents rating these recreational aspects as important, respectively.

Boating, fishing and access to fixed exercise equipment were valued as important by the least percentage of respondents, at 5 percent, 9 percent and 12 percent, respectively.

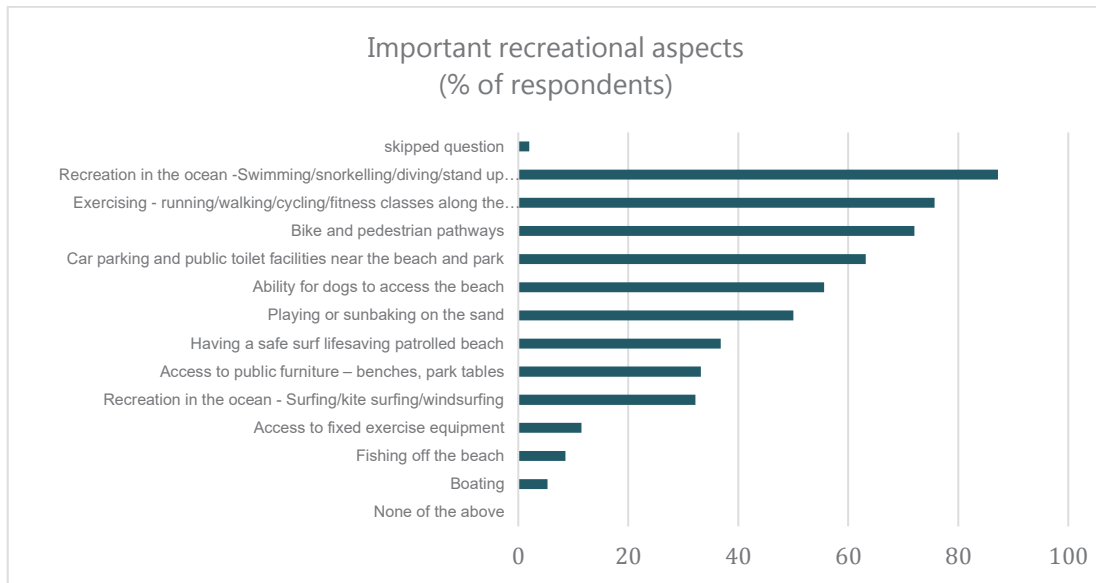


Figure 2 Important recreational aspects at Port, Leighton and/or Mosman Beaches

Question 2: Which of these coastal amenity aspects at Port, Leighton and/or Mosman Beaches are important to you?

Access to the beach was the most important coastal amenity aspect at Port, Leighton and/or Mosman Beaches, with 91 percent of respondents (see Figure 3). 86 percent of respondents place importance on cleanliness of the beach, and 69 percent value coastal vegetation and habitat. Shark patrols and safety were the least valued coastal amenity, with 38 percent of respondents marking the aspect as important. Quality of the surf was an aspect unearthed by the ‘Other (please specify)’ option as important to respondents.

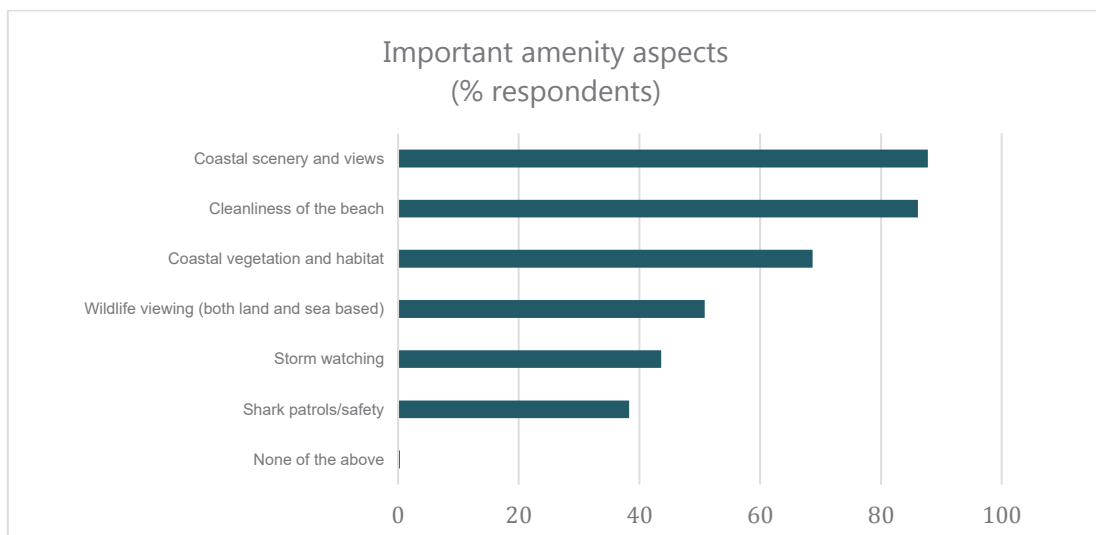


Figure 3 Important coastal amenity aspects at Port, Leighton and/or Mosman Beaches

Question 3: Which of these community facilities and services at Port, Leighton and/or Mosman Beaches are important to you?

Universal access to the beach and facilities, as well as access to changerooms, toilets and showers were regarded as equally important community facilities, with 70 percent of respondents selecting these aspects (see Figure 4). The footbridge from Leighton across the railway lines was a recurring aspect noted as important to respondents in the 'Other' field.

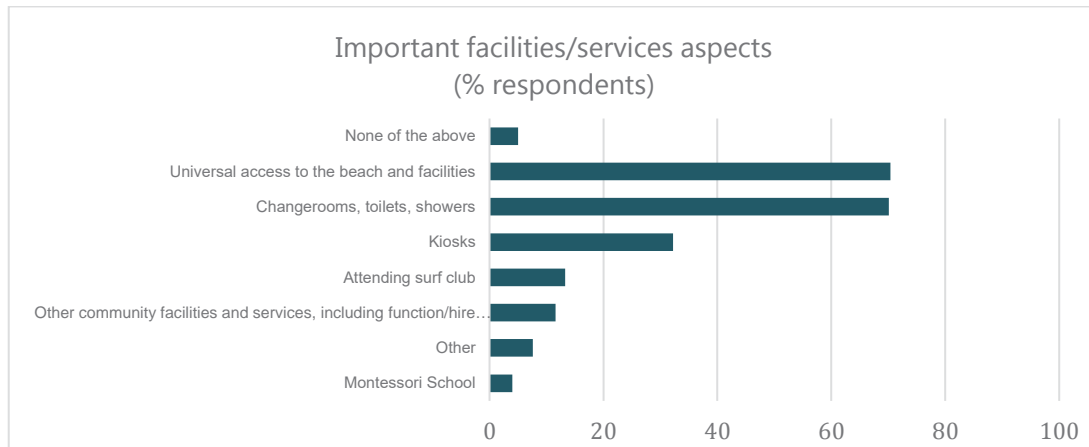


Figure 4 Important community facilities and services at Port, Leighton and/or Mosman Beaches

Question 4: Which of these entertainment and socialising aspects at Port, Leighton and/or Mosman Beaches are important to you?

63 percent of respondents regarded picnicking/barbecuing in the park as an important entertainment and socialising aspect, and 61 percent of respondents noted dining at cafes and restaurants adjacent to the beach as important (Figure 5).

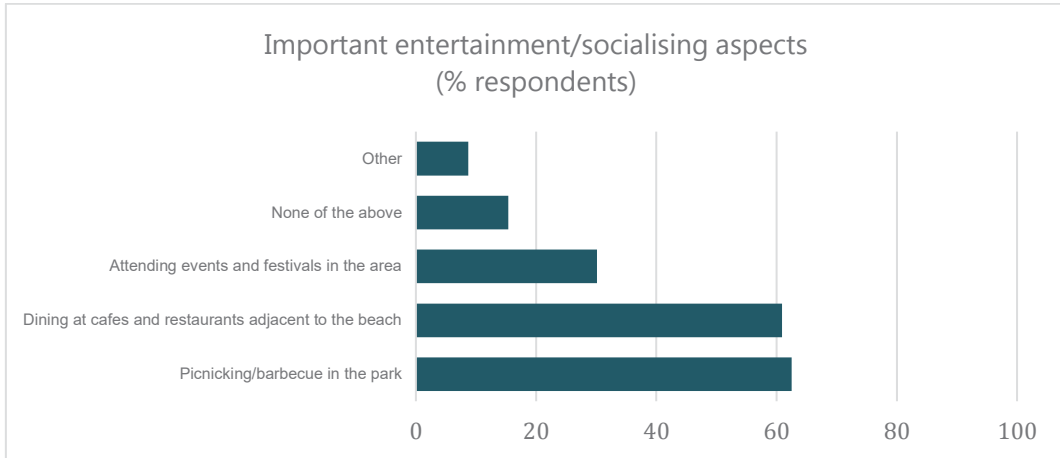


Figure 5 Important entertainment and socialising aspects at Port, Leighton and/or Mosman Beaches

Question 5: Which of these private benefits at Port, Leighton and/or Mosman Beaches are important to you?

Less respondents placed importance on the value of their property due to proximity of the beach/ocean (20%) than living close to or next to the beach (44%) (Figure 6).

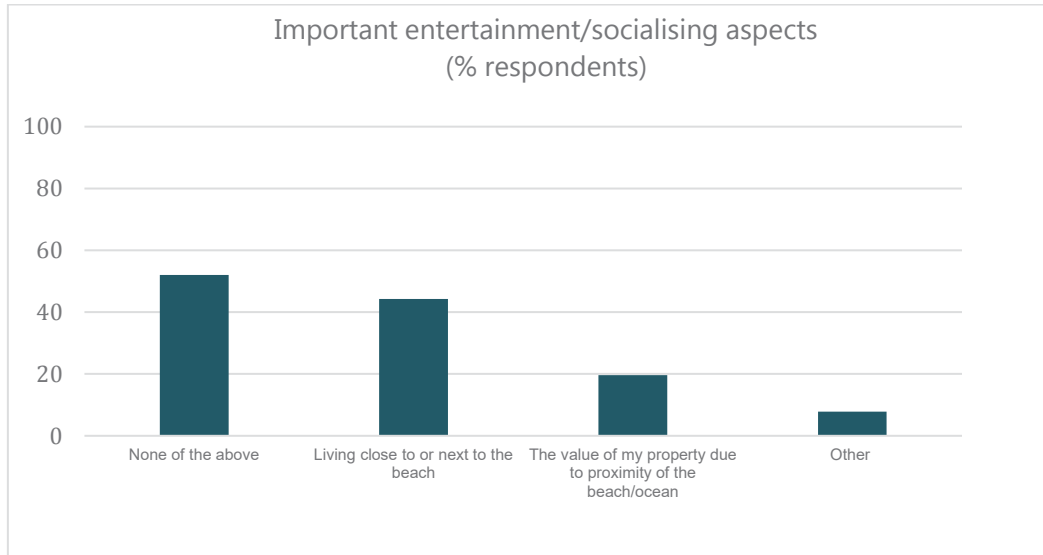


Figure 6 Important private benefits at Port, Leighton and/or Mosman Beaches

Question 6: Which of these employment and economic benefits at Port, Leighton and/or Mosman Beaches are important to you?

The ability to run a small business in the area and were both valued as important by 36% of respondents, while 48% of respondents indicated that none of the options provided were important to them (Figure 7).

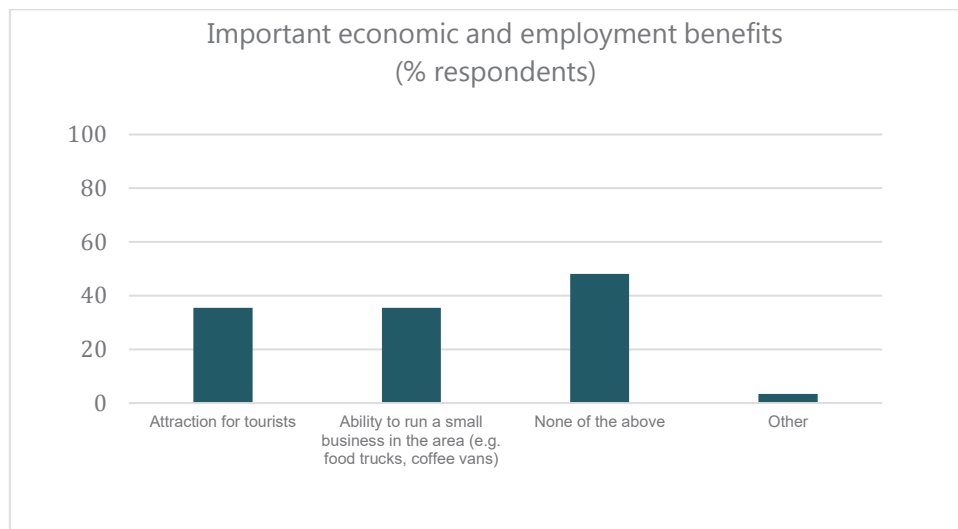


Figure 7 Important employment and economic benefits at Port, Leighton and/or Mosman Beaches

Question 7: Is there anything else you enjoy or value about the area around Port, Leighton and Mosman Beaches?

Question 7 was an opportunity for respondents to include important aspects of the Port, Leighton and/or Mosman Beaches that had not been addressed in previous questions. The majority of responses to this question expanded on aspects already listed. Nevertheless, several unique values emerged, including:

- The quiet, calm aspect of the beaches, in particular the lack of crowds;
- Lack of development along the foreshore;
- A strong sense of community, in particular social and community groups such as the Polar Bears, a local swimming group;
- Longer groyne area allowing for kitesurfing safe landing zones;
- The beaches being part of a larger coastal network; and
- Quality of the water.

Question 8: How important is it to you to be able to access the following aspects at Port, Leighton and Mosman Beaches?

Recreation opportunities were selected as the most important aspects of Port, Leighton and Mosman Beaches, with 86 percent of respondents unable or preferring not to conveniently access this aspect elsewhere. Coastal amenity closely followed with 85 percent of respondents unable or preferring not to conveniently access this aspect elsewhere. Conversely, employment and economic benefits were unimportant to, or easily accessed elsewhere by 71 percent of respondents.

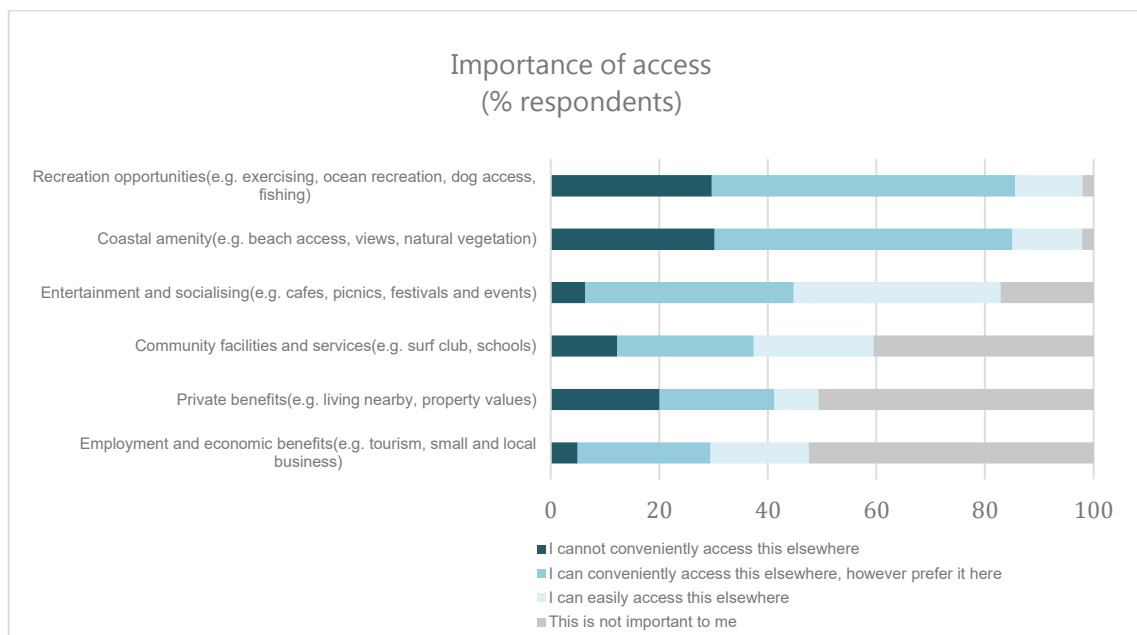


Figure 8 Importance of access to Port, Leighton and Mosman Beaches

Question 9: How much would the loss of these experiences/ opportunities impact on your way of life?

The loss of recreation opportunities would impair 91 percent of respondents' way of life, with 71 percent of respondents noting their way of life would be *significantly* impaired. The loss of coastal amenity would impair 90 percent of respondents' way of life, with 69 percent of respondents noting their way of life would be *significantly* impaired. The loss of employment and economic benefits would impact the least amount of respondents' way of life, with 63 percent selecting that it was not important or would not impair their way of life (Figure 9).

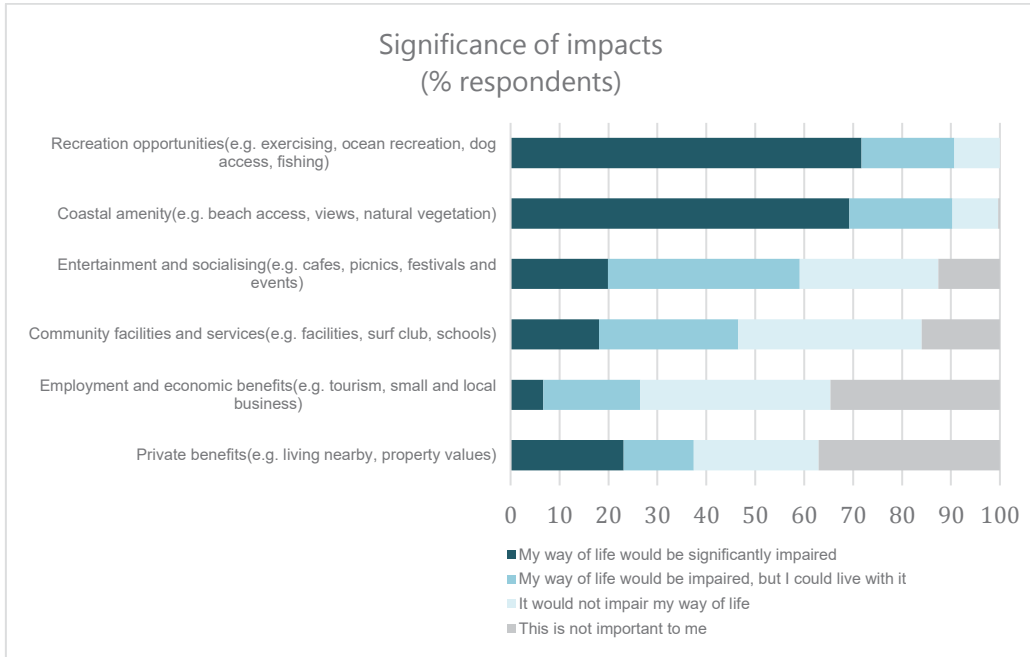


Figure 9 Significance of loss of aspects at Port, Leighton and Mosman Beaches

Question 10: Which local government area do you live in?

Figure 10 outlines the percentage of respondents living in the Town of Mosman Park (11 percent), City of Fremantle (58 percent), Town of Cottesloe (5 percent) or elsewhere (26 percent)

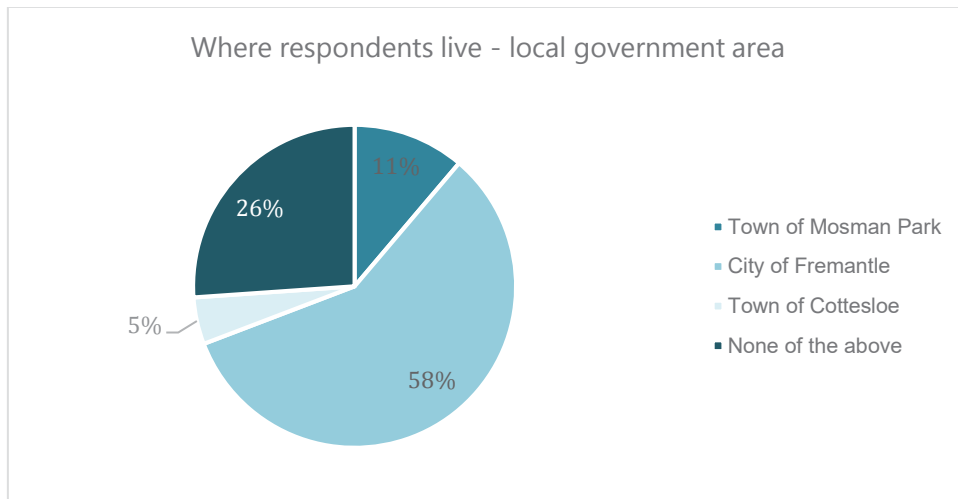


Figure 10 Location of respondents

Question 11: Do you live in the local area (within a 10 to 15-minute drive)?

Figure 11 outlines whether respondents lived within a 10 to 15-minute drive from the site area, 94 percent of whom live in the local area.

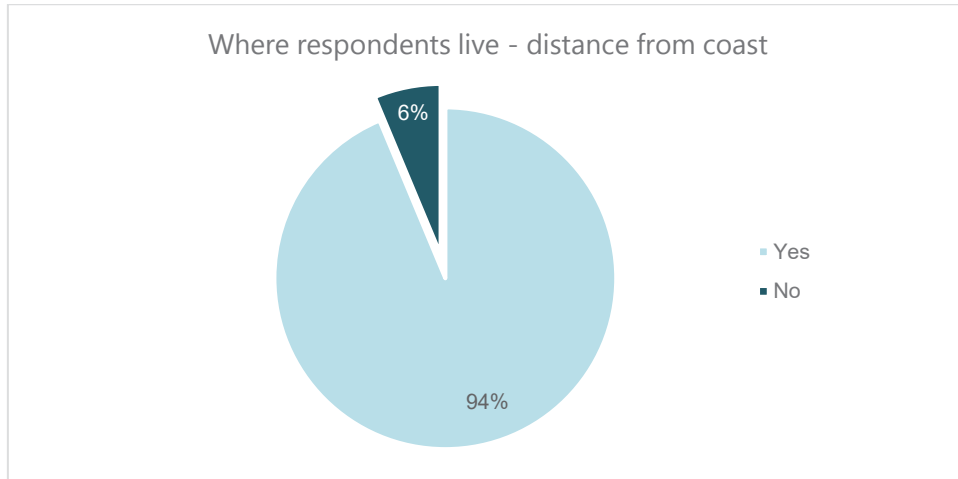


Figure 11 Distance of respondents to Port, Leighton or Mosman Beaches

Question 12: How would you usually get to Port, Leighton or Mosman Beaches?

The majority of respondents (59 percent) drove to access Port, Leighton or Mosman Beaches, and public transport was the least used form of transport with only 2 percent of respondents catching a train or bus (Figure 12). The majority of responses submitted under 'Other' noted the use of more than one form of transport to access the beaches.

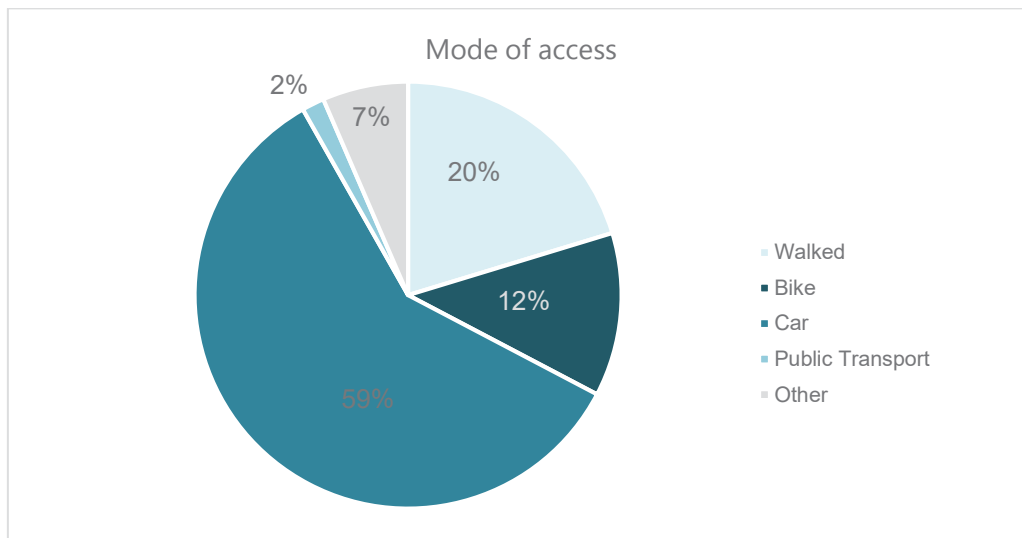


Figure 12 Form of transport to Port, Leighton or Mosman Beaches

Final Questions – Demographic Information

Figure 13 and 14 present key demographics that responded to the survey.

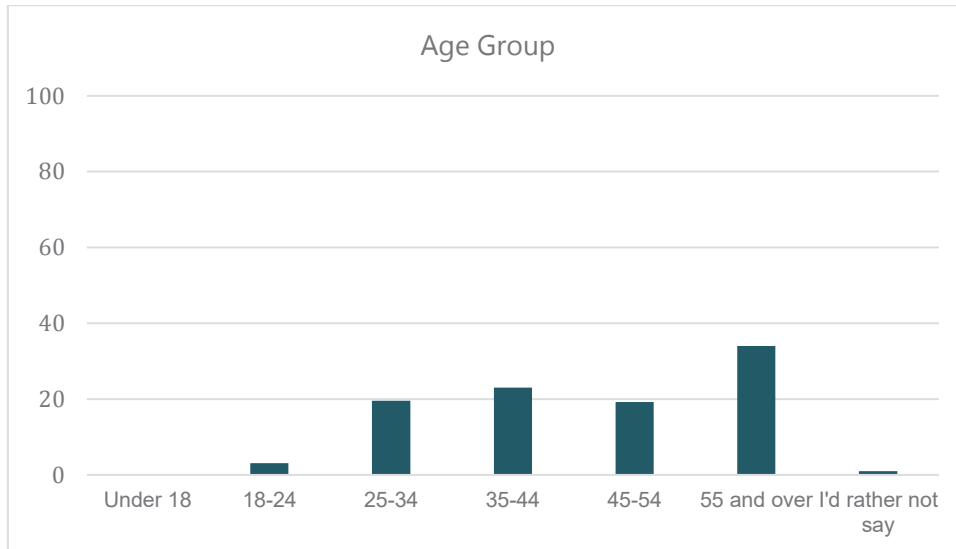


Figure 13 Respondent age groups

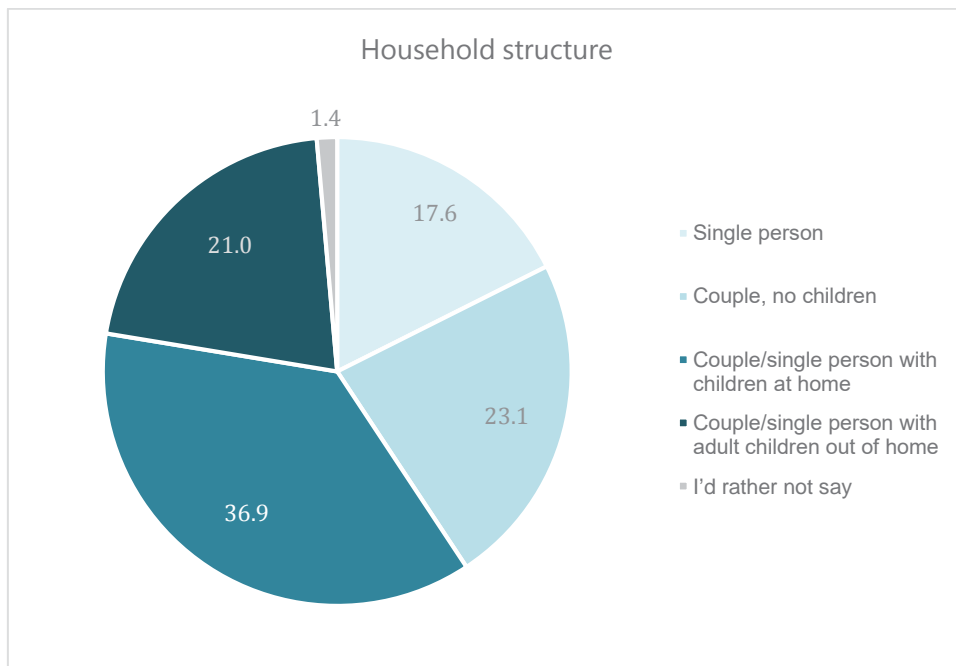


Figure 14 Respondent living situation

Community awareness campaign

The community awareness campaign phase of consultation commenced on 2 February 2017 and concluded on 27 February 2017. The community awareness campaign included:

- Informing the community about the project through a project website hosted by the City of Fremantle, information sheets and project signs located along Port, Leighton and Mosman Beaches.
- Informing the community about outcomes of the community values survey undertaken in the community dialogue phase.
- Informing the community about coastal hazards in the area.
- Presenting the results of the coastal hazard risk assessment
- Obtaining feedback and confirmation of the outcomes of the community values survey.

The outcomes of the community values survey were provided on the project website and the community were asked to respond to a survey to confirm whether the results correctly reflected their values. The MySay survey was available online between 2 February and 27 February 2017.

The online consultation was augmented with an in-person drop in session at Leighton Beach Park on Saturday 25 February between 9.00am and 12.00pm. The session was attended by two of the project team members. The drop in session provided the community with an opportunity to obtain project information and ask questions of the project team. The outcomes of the community values survey were also available on the day for community members to review.



There were eight responses to the MySay survey, all which indicated that the survey was reflective of the community's values.

The following material was provided online.

Our Coastal Future Port, Leighton and Mosman Beaches

Community Values Survey

What we've done so far
The project has included two key components that have been running in parallel – a technical analysis to understand the coastal hazards and risks and a community values survey to understand what aspects of the beach and coastal environment are valued by the community within the project area.

The community values survey examined a range of aspects to determine how the beach is used, understand the unique qualities of the project area and determine what is it about the area that is most valued by the community.

The community values survey was undertaken in July and August 2016. The survey was available for completion online via the City of Fremantle's website. In addition, members of the project team were available on site within the project area on 24 July 2016 to discuss the project and complete surveys with the community.

What was said in the survey?
The community values survey sought feedback from the community particularly in relation to recreation, coastal amenity, community facilities, entertainment and social aspects, private benefits and employment and economic benefits.

Generally, the survey indicated that the community valued the ability to access and use the beach for recreation and leisure activities and that there is a strong sense of community in the area. There was a positive response to the ability to use and access facilities and amenities in the area, however many respondents noted the desire to keep the area relatively undeveloped. Dog access to the beach was also highly valued.

Undertaking recreational activities in the ocean or along the beach were highly valued by the community. The coastal amenity was highly valued in particular with over 85% respondents noting that they value the ability to access the beach, the coastal scenery and views and beach cleanliness. This highlights the importance for the community to be able to access and enjoy the beach. Universal access to the beach and facilities was also highlighted as an important community service.

Changerooms, toilets and showers were noted as important community facilities, highlighting the value of physical infrastructure for beach goers. Picnicking and barbecuing in

the park as well as dining at adjacent cafes and restaurants were noted as important.

Generally private benefits were less valued, as indicated by the lower response rate compared with other values. Living close to the beach was important to a large proportion (44%) of respondents and a number of comments generally noted the desire of keeping the area relatively simple with little development.

Respondents were asked to determine the level of importance of each of the elements by determining how they access these things. The Figure 1 below indicates that the recreational opportunities and coastal amenity are preferred within the study area compared to other locations. This highlights that this area is unique to the community and convenience and preference to access this area for recreation and amenity was more valued to the community than the other social, economic and infrastructure values.

To further understand the importance of the beach and coast, respondents were asked to determine how their way of life would be impacted if certain aspects were lost (Figure 2). The loss of recreation opportunities and coastal amenity were seen to be significant. This aligns with the community's preference to access this area, rather than other coastal areas.

Where did this information come from?
A positive response was received from the local community with a total of 506 surveys completed. Of those respondents who indicated where they lived, 56% were from the City of Fremantle, 11.2% from Mosman Park, 4.7% from the Town of Cotswold and 26.1% were from another area. The majority of respondents (93.8%) lived within a 10-15 minute drive.

What will the survey results be used for?
The next phase of the project will be looking at the most appropriate options for coastal adaptation. This will involve a detailed assessment using the community values identified in the survey and the outcomes of the technical risk assessment.

For project updates and information, visit fremantle.wa.gov.au/coastplan

This project is funded by the Western Australian Planning Commission through the Coastal Management Plan Assistance Program.

City of Fremantle MOSMAN PARK

Our Coastal Future Port, Leighton and Mosman Beaches

Community Values Survey

How important is it to you to be able to access the following aspects at Port, Leighton and Mosman Beaches?

Figure 1: Importance of beach elements

Aspect	I can't conveniently access this elsewhere (%)	I can easily access this elsewhere (%)	I can conveniently access this elsewhere, however prefer to live here (%)	This is not important to me (%)
Recreation opportunities (e.g. swimming, ocean recreation, dog access, fishing)	~15	~45	~35	~5
Coastal amenity (e.g. beach access, views, natural vegetation)	~10	~55	~25	~10
Entertainment and socialising (e.g. cafes, picnic, facilities and events)	~15	~40	~25	~20
Community facilities and amenities (e.g. surf club, schools)	~10	~45	~25	~20
Private benefits (e.g. living nearby, property values)	~10	~35	~25	~30
Employment and economic benefits (e.g. tourism, retail and local business)	~10	~35	~25	~30

How much would the loss of these experiences/opportunities impact on your way of life?

Figure 2: Impact of loss of experiences/opportunities

Aspect	My way of life would be significantly impacted (%)	I would not impact my way of life (%)	My way of life would be impacted, but I could live with it (%)	This is not important to me (%)
Recreation opportunities (e.g. swimming, ocean recreation, dog access, fishing)	~15	~10	~55	~20
Coastal amenity (e.g. beach access, views, natural vegetation)	~10	~10	~60	~20
Entertainment and socialising (e.g. cafes, picnic, facilities and events)	~10	~10	~40	~40
Community facilities and amenities (e.g. surf club, schools)	~10	~10	~40	~40
Private benefits (e.g. living nearby, property values)	~10	~10	~30	~50
Employment and economic benefits (e.g. tourism, retail and local business)	~10	~10	~30	~50

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City of Fremantle MOSMAN PARK

Our Coastal Future Port, Leighton and Mosman Beaches

Coastal Hazard Risk Assessment

Purpose of estimating coastal hazards
The purpose of estimating the coastal hazards of erosion and inundation was to assess the future risks to coastal assets and values which will assist in the analysis of coastal adaptation solutions. The results and maps of this study are not to be used for the purpose of determining coastal setback distances for development.

Likelihoods and timeframes for coastal hazards
The coastal hazards of erosion and inundation were estimated at short (to 2020), medium (to 2070) and long term (to 2110) to align with coastal planning timeframes and at three likelihoods: Almost Certain, Possible and Rare.

The erosion hazard accounts for a combination of short term and long term erosion factors in combination with increased sea level rise over time. Inundation considers risk of temporary storm inundation combined with sea level rise over time. The short term results are presented below, as these are the primary consideration for immediate adaptation planning.

Short term results
In general, the impacts of inundation to the beaches at Mosman, Leighton and Port Beaches was identified to be insignificant when compared to the potential impacts of erosion due to the elevation of the dune system along the foreshore.

Risk assessment
A risk assessment was undertaken to determine whether assets, their associated values and functions within a given area are at risk of being impacted by coastal hazards. Conducting a risk assessment is an important step in selecting the most appropriate adaptation and management options. The risk assessment is guided by community values, modeling and evidence-based research.

The risk assessment involved examining the assets within Mosman, Leighton and Port Beach areas and determining the level of risk (low, medium or high) over the short, medium and long term. There are four categories of assets:

- Social: Elements facilitate access to the coast.
- Infrastructure: Physical items that service the population (e.g. roads, rail, utilities).
- Environment: Natural elements and open spaces.
- Economic: Items that have a financial component and/or may support and/or generate employment.

By understanding the level of risk on the assets in the area, we are able to investigate management and adaptation measures that are appropriate to minimise the risks to a more acceptable level.

Generally the risks identified were of an acceptable or tolerable level, however some were identified as 'intolerable/unacceptable' in either the short, medium and/or long term for the different beaches.

Mosman Beach
Erosion in the short term at Mosman Beach will be caused by sea level rise and a slow but consistent erosion of the dune/cliff base causing slope erosion. While this erosion hazard area identified was significantly less than at Leighton and Port Beach, the width of the dune system and the elevation of the land behind mean that this section of the coast has a reduced capacity to buffer and repair from erosion events. The short term erosion hazard at 2020 for Mosman Beach is shown in Figure 1.

The areas identified at risk were beach access points (short, medium and long term), coastal paths (medium and long term) and off-street parking (long term).

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City of Fremantle MOSMAN PARK

Our Coastal Future Port, Leighton and Mosman Beaches

Coastal Hazard Risk Assessment

Leighton Beach
The Leighton Beach foreshore is an accreting sandy foreshore. The processes identified to be contributing to the erosion hazard areas were short term storm erosion and sea level rise. In the short term, the almost certain erosion hazard area for Leighton Beach was maintained within the dune system, except near the northern extent of the City of Fremantle boundary. The possible and rare erosion hazard areas however extended into the Leighton Parklands and change rooms facilities as shown in Figure 2.

The areas identified at risk were Fremantle Surf Life Saving Club (medium and long term), Port Beach Road Reserve (long term), coastal paths (long term) and off-street parking (long term).

Port Beach
The coastal processes used to calculate erosion hazard areas in the future included storm erosion, a long term (23 year) trend of erosion and sea level rise. Hazards maps presented for Port Beach assume that the Port Beach Road sea wall does not contribute to beach protection to indicate the potential extents of erosion. If the seawall was not included in future coastal adaptation solutions.

In the short term the almost certain erosion hazard for Port Beach extended across a significant portion of carpark and dune areas as well as across Port Beach Road at the southern end of the site as shown in Figure 3.

The areas identified at risk were Port Beach Road Reserve (medium and long term), Freight Rail (medium and long term), Fremantle Port Land (long term) and Beach access points, Coastal paths, Off-street Parking, Public coastal facilities, Kiosk and changerooms and Public furniture (short, medium and long term).

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City of Fremantle MOSMAN PARK

MYSAY FREO

The following text will be placed on the MySay Freo page

Question: Do you think the survey results correctly reflect your values?

- Yes
- No
- I am unaware of the survey results

If you answered no, please provide your comments below.

If you were not aware of the survey results, click here for the results and project information.

Local government engagement

On 19 July, local government representatives from the City of Fremantle and the Town of Mosman Park were engaged through a series of intensive interviews. These interviews asked the internal stakeholders to comment on the key values and challenges for the project from the point of view of the local government administration.

Key outcomes of the interviews included:

- Many local government representatives had no specific knowledge of coastal risk and adaptation planning and had not worked within the area to date. Of those that had come across it previously, the Cockburn Sound Coastal Alliance Coastal Vulnerability and Flexible Adaptation Pathways Project was noted as a key example.
- Significant concerns were raised regarding coastal hazards and risks, including the potential for contamination related to ex-landfill sites within the Town of Mosman Park, managing community and business perception relating to private infrastructure and the impacts of erosion on coastal assets (including the natural dune system).
- Management orders and lease agreements were another area of concern, with interviewees deliberating on how future coastal adaptation will impact lease agreements.
- Funding responsibility for adaptation planning between local and state government.
- Parking facilities are a strongly valued asset, with almost all local government representatives mentioning the importance of parking assets to the community.
- Loss of ratepayer base due to constraints on residential development, loss of investment into new facilities and assets, and commercial income from properties were significant areas of concern for many local government representatives.
- A general concern was raised for any loss of existing infrastructure that would impact the community's enjoyment and access to the beach and recreational opportunities.
- The potential for this project to guide future planning and business strategies and asset management was identified by local government representatives as an opportunity. Access to more and better quality information to support decision-making was highlighted by some interviewees as a benefit of the project.
- Natural and soft adaptation actions were of the most interest to local government representatives. Several interviewees stated that the options to retreat and avoid were not viable with residential and commercial assets, particularly as it was contrary to infill planning policies.
- While most local government representatives noted that elected members were well educated on the matter, they noted that budgeting and costs would be an issue as well as dealing with long-term adaptation.

Interviewees highlighted the vested interests of specific community groups, while observing that the wider community had varying levels of interest and understanding of the matter. Loss of amenity and the desire to retain the natural state of the site are expected responses from community members to risk and adaptation.

Appendix B – Asset and Values Register

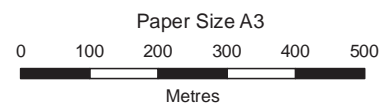
Asset Register - Port, Leighton and Mosman Beaches CHRMAP

Coastal Planning Unit	Asset	Asset Type	Description	Asset manager	LGA
Mosman Beach	Mosman Beach Reserve	Public park	Public beach and coastal foreshore	Town of Mosman Park	Town of Mosman Park
Mosman Beach	Curtin Avenue Reserve	Road	Single carriageway local road Distributor A (MRWA)	Main Roads WA	Town of Mosman Park
Mosman Beach	Beehive Montessori School	Community building	220+ students aged 3-15 (beehive.wa.edu.au) - inc. approx 20 car bays	Private asset owner	Town of Mosman Park
Mosman Beach	Beach access points	Recreational access	Two public stairways to beach	Town of Mosman Park	Town of Mosman Park
Mosman Beach	Coastal path	Recreational access	Principal shared path along coast	Town of Mosman Park	Town of Mosman Park
Mosman Beach	Off-street Parking	Public parking	Three public parking areas	Town of Mosman Park	Town of Mosman Park
Mosman Beach	Public furniture	Street furniture	Picnic tables, bins, gazebos	Town of Mosman Park	Town of Mosman Park
Mosman Beach	Wire fencing, wooden posts	Fencing	Wire fencing running along entirety of beach and foreshore	Town of Mosman Park	Town of Mosman Park
Leighton Beach	Leighton Beach Reserve	Public park	Public beach and coastal foreshore	City of Fremantle	City of Fremantle
Leighton Beach	Vlamingh Parklands	Public park		City of Fremantle	City of Fremantle
Leighton Beach	Curtin Avenue Reserve	Road	Single carriageway local road Distributor A (MRWA)	Main Roads WA	City of Fremantle
Leighton Beach	Curtin Ave off street parking	Public parking		City of Fremantle	City of Fremantle
Leighton Beach	Leighton Beach parkland area	Public park		City of Fremantle	City of Fremantle
Leighton Beach	Leighton Beach Changerooms	Community building		City of Fremantle	City of Fremantle
Leighton Beach	Fremantle Surf Life Saving Club	Community building		City of Fremantle	City of Fremantle
Leighton Beach	Leighton Beach Boulevardde Reserve	Road	Local access road.	City of Fremantle	City of Fremantle
Leighton Beach	Port Beach Road Reserve	Road	Local access road. Provides access to Fremantle Port.	City of Fremantle	City of Fremantle
Leighton Beach	Fremantle Passenger Railway Reserve	Rail		Public Transport Authority	City of Fremantle
Leighton Beach	Beach access points	Recreational access	Beach paths, including universal access path	City of Fremantle	City of Fremantle
Leighton Beach	Coastal path	Recreational access	Principal shared path along coast	City of Fremantle	City of Fremantle
Leighton Beach	Off-street Parking	Public parking	Public parking areas	City of Fremantle	City of Fremantle
Leighton Beach	Public coastal facilities - Kiosk	Public facilities	Public change rooms and toilet facilities	City of Fremantle	City of Fremantle
Leighton Beach	Public furniture	Street furniture	Picnic tables, bins, gazebos	City of Fremantle	City of Fremantle
Leighton Beach	Wire fencing, wooden posts	Fencing	Wire fencing running along entirety of beach and foreshore	City of Fremantle	City of Fremantle
Leighton Beach	Residential development	Residential	High density residential development including apartments.	Private asset owner	City of Fremantle
Leighton Beach	Vacant residential land	Residential		Private asset owner	City of Fremantle
Leighton Beach	Vacant industrial land	Industrial	Proposed MRS scheme amendment to rezone to urban development.	Private asset owner	City of Fremantle
Leighton Beach	Commercial development - Within Foreshore	Commercial	Bib and Tucker café; The Shipping Lane Cage, Elemental Surf lessons, hire and sales	Private asset owner	City of Fremantle
Leighton Beach	Bus stops	Public Transport	Transperth bus stops	Public Transport Authority	City of Fremantle
Port Beach	Port Beach Reserve	Public park	Public beach and coastal foreshore	City of Fremantle	City of Fremantle
Port Beach	Port Beach Road Reserve	Road	State Highway	Main Roads WA	City of Fremantle
Port Beach	Tydemans Road Reserve	Road	National Highway	Main Roads WA	City of Fremantle
Port Beach	Freight Rail	Rail	Freight rail access to Fremantle Port	Fremantle Port Authority	City of Fremantle
Port Beach	Fremantle Port Land	Ports	Fremantle Port land and infrastructure	Fremantle Port Authority	City of Fremantle
Port Beach	Beach access points	Recreational access	Beach paths	City of Fremantle	City of Fremantle
Port Beach	Coastal path	Recreational access	Principal shared path along coast	City of Fremantle	City of Fremantle
Port Beach	Off-street Parking	Public parking	Two public parking areas	City of Fremantle	City of Fremantle
Port Beach	Public coastal facilities-kiosk and changerrooms	Public facilities	Public change rooms and toilet facilities	City of Fremantle	City of Fremantle
Port Beach	Public furniture	Street furniture	Picnic tables, bins, gazebos	City of Fremantle	City of Fremantle
Port Beach	Wire fencing, wooden posts	Fencing	Wire fencing running along entirety of beach and foreshore	City of Fremantle	City of Fremantle
Port Beach	Industrial land	Industrial	Industrial land and infrastructure	Private asset owner	City of Fremantle
Port Beach	Commercial development	Commercial	Salt on the Beach (under refurbishment); Kiosk	Private asset owner	City of Fremantle
Port Beach	Bus stops	Public Transport	Transperth bus stops	Public Transport Authority	City of Fremantle

Values Register - Port, Leighton and Mosman Beaches CHRMAP

Coastal Planning Unit	Value	Value Type	Description
Port Beach	Freight industry	Economic	Freight within Fremantle port presents significant economic and employment value
All	Boating	Social	Supports quality of life of the community
All	Fishing off the beach	Social	Supports quality of life of the community
Leighton Beach\ Port Beach	Recreation in the ocean - Surfing/kite surfing/windsurfing	Social	Supports health, wellbeing and quality of life of community through access to natural environment
All	Access to public furniture – benches, park tables	Social	Provides spaces for community to socialise and rest - supports wellbeing
Leighton Beach	Having a safe surf lifesaving patrolled beach	Social	Supports the safety of the community
All	Playing or sunbaking on the sand	Social	Supports quality of life of the community
Leighton Beach	Ability for dogs to access the beach	Social	Supports socialisation and promotes health and wellbeing for community
All	Car parking and public toilet facilities near the beach and park	Social	Enables access for community to the beach and provides services to support health
All	Bike and pedestrian pathways	Social	Supports health, wellbeing and quality of life of community
All	Exercising - running/walking/cycling/fitness classes along the beach and parkland	Social	Supports health, wellbeing and quality of life of community through access to natural environment
All	Recreation in the ocean - Swimming/snorkelling/diving/stand up paddle boarding	Social	Supports health, wellbeing and quality of life of community through access to natural environment
All	Shark patrols/safety	Social	Supports the safety of the community
All	Storm watching	Social	Supports ability to enjoy natural environment
All	Wildlife viewing (both land and sea based)	Social	Supports ability to enjoy natural environment
All	Coastal vegetation and habitat	Environmental	Supports ecology, provides natural buffer zone and supply of sand to beach
All	Cleanliness of the beach	Environmental	Supports natural resources
All	Coastal scenery and views	Environmental	Natural resources
All	Ability to access and enjoy the beach setting	Social	Supports health, wellbeing and quality of life of community
Leighton Beach	Attending surf club	Social	FSLs Club provides social value to its members and visitors to the beach
Port Beach\ Leighton Beach	Kiosks	Economic	Supports employment and social interaction
All	Changerooms, toilets, showers	Social	Support health, wellbeing and quality of life of community
All	Universal access to the beach and facilities	Social	Supports health, wellbeing and quality of life of community
Leighton Beach	Picnicking/barbecue in the park	Social	Supports health, wellbeing and quality of life of community
All	Dining at cafes and restaurants adjacent to the beach	Economic	Support quality of life of community and employment
Leighton Beach\ Mosman Beach	Attending events and festivals in the area	Economic	Supports quality of life and social interaction between community members
Leighton Beach\ Mosman Beach	The value of properties due to proximity of the beach/ocean	Economic	Economic implications for property values
All	Attraction for tourists	Economic	Supports tourism industry
Port Beach\ Leighton Beach	Ability to run a small business in the area (e.g. food trucks, coffee vans)	Economic	Supports employment and industry

Appendix C – Coastal Hazard Maps



Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50



LEGEND

- Almost Certain
- Possible
- Rare
- Local Government Boundary

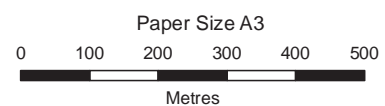
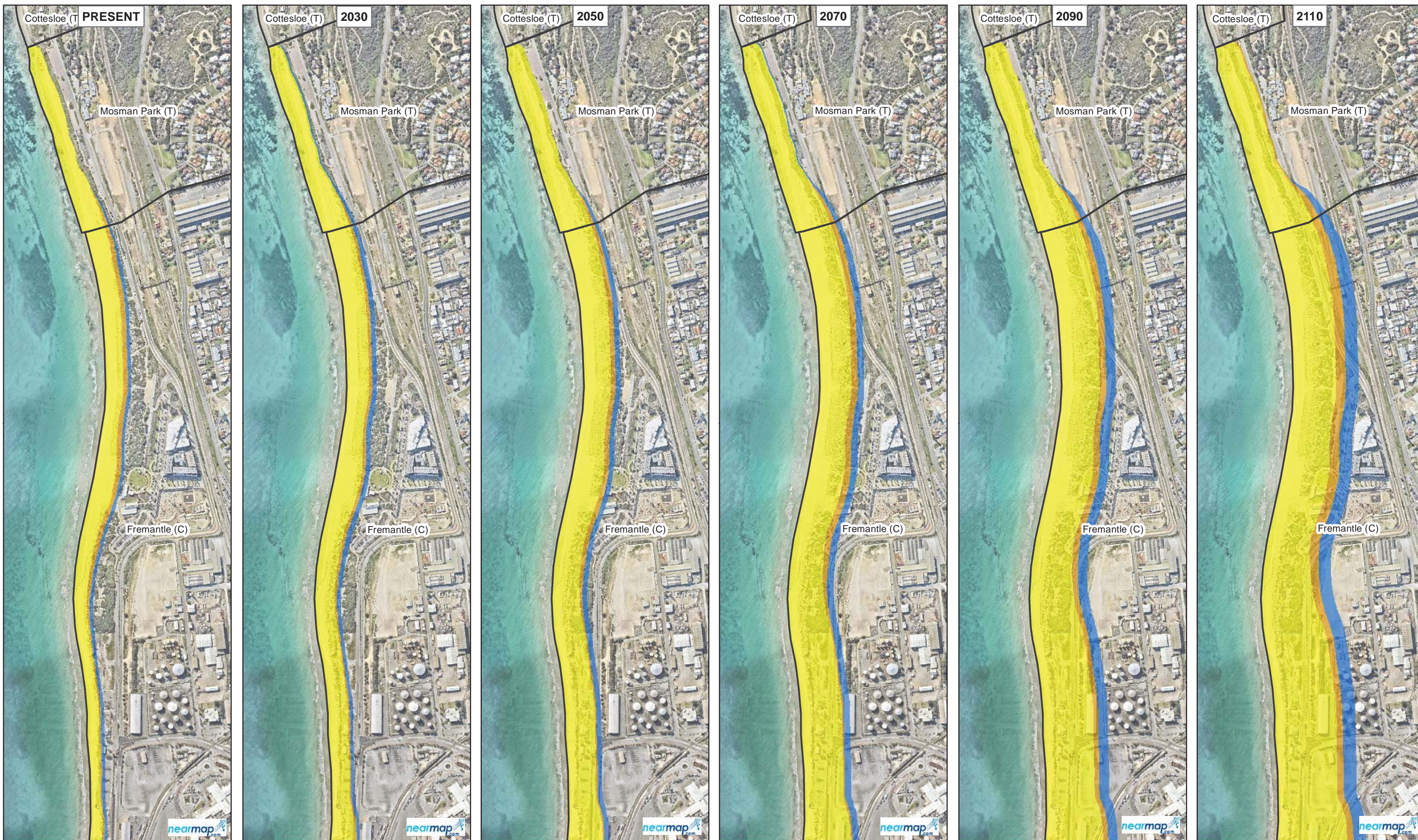
These maps are to be read in conjunction with the assumptions and limitations as detailed in section 1.6 of the GHD Physical Processes Report (August 2016) found in Appendix D of the Coastal Adaptation Plan.



City of Fremantle/Town of Mosman Park
Coastal Adaptation Plan

Job Number	61-34650
Revision	0
Date	24 Aug 2016

Mosman Beach - Erosion Hazard Figure 1



Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50



LEGEND

- Almost Certain
- Possible
- Rare
- Local Government Boundary

These maps are to be read in conjunction with the assumptions and limitations as detailed in section 1.6 of the GHD Physical Processes Report (August 2016) found in Appendix D of the Coastal Adaptation Plan.



City of Fremantle/Town of Mosman Park
Coastal Adaptation Plan

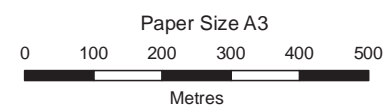
Job Number	61-34650
Revision	0
Date	24 Aug 2016

Leighton Beach - Erosion Hazard Figure 2

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Data source: Neamap; Imagery 12th July 2016 - 20160802; Landgate; Local Government Boundary; GHD; Erosion Levels - 20160802. Created by:afeeny



Map Projection: Transverse Mercator
 Horizontal Datum: GDA 1994
 Grid: GDA 1994 MGA Zone 50



LEGEND

- Almost Certain
- Possible
- Rare
- Local Government Boundary

These maps are to be read in conjunction with the assumptions and limitations as detailed in section 1.6 of the GHD Physical Processes Report (August 2016) found in Appendix D of the Coastal Adaptation Plan.



City of Fremantle/Town of Mosman Park
 Coastal Adaptation Plan

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Date	24 Aug 2016

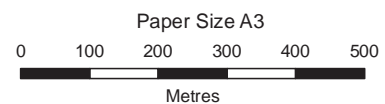
Port Beach - Erosion Hazard

Figure 3

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Data source: Neimap: Imagery 12th July 2016 - 20160802; Landgate: Local Government Boundary; GHD: Erosion Levels - 20160802. Created by:afeeny



Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50



LEGEND

- Almost Certain
- Possible
- Rare
- Local Government Boundary

These maps are to be read in conjunction with the assumptions and limitations as detailed in section 1.6 of the GHD Physical Processes Report (August 2016) found in Appendix D of the Coastal Adaptation Plan.

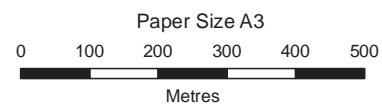
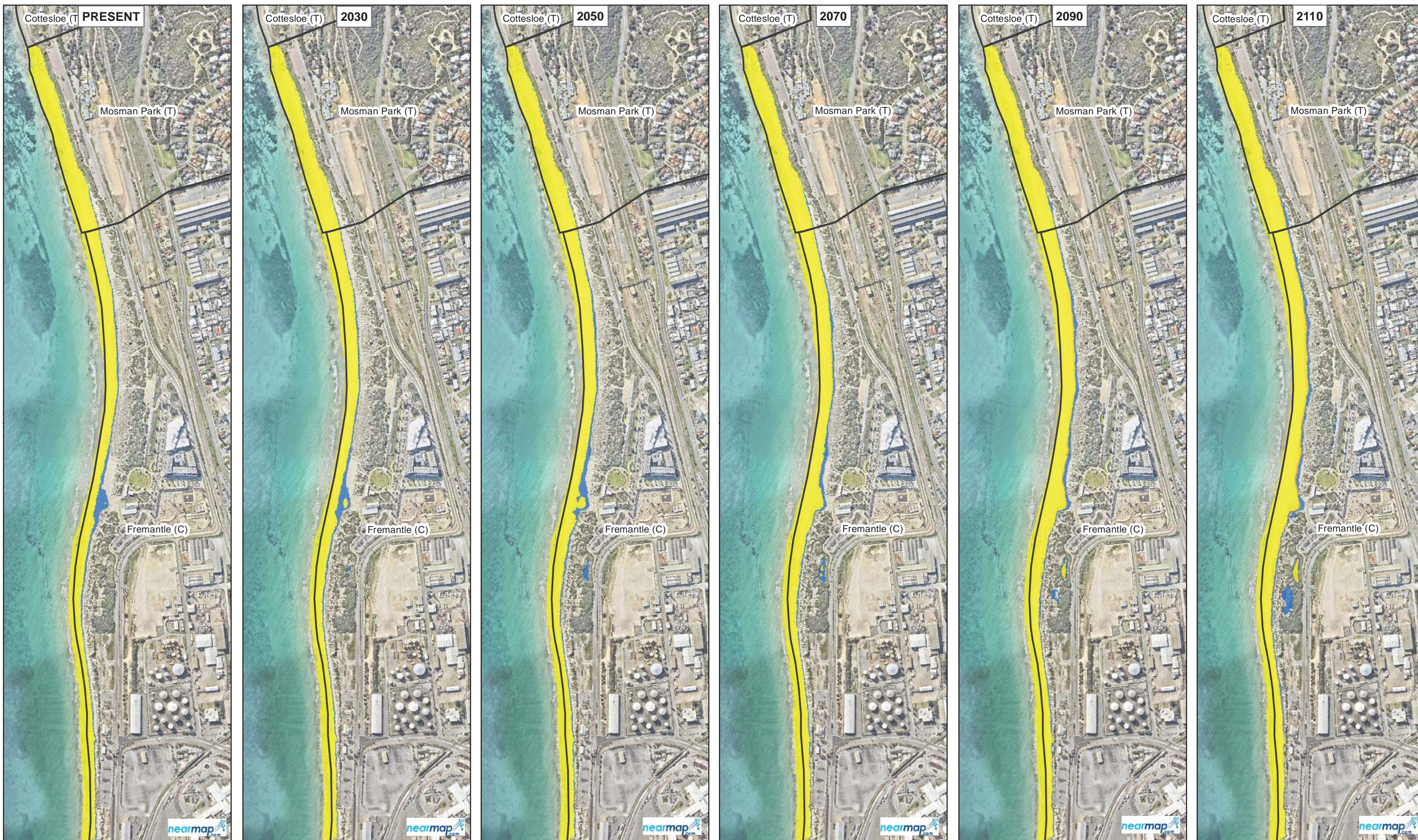


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Date	24 Aug 2016

**Mosman Beach
Inundation Hazard**

Figure 4



Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 54



LEGEND

- Almost Certain
- Possible
- Rare
- Local Government Boundary

These maps are to be read in conjunction with the assumptions and limitations as detailed in section 1.6 of the GHD Physical Processes Report (August 2016) found in Appendix D of the Coastal Adaptation Plan.

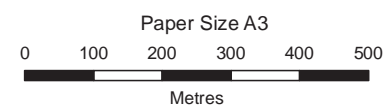
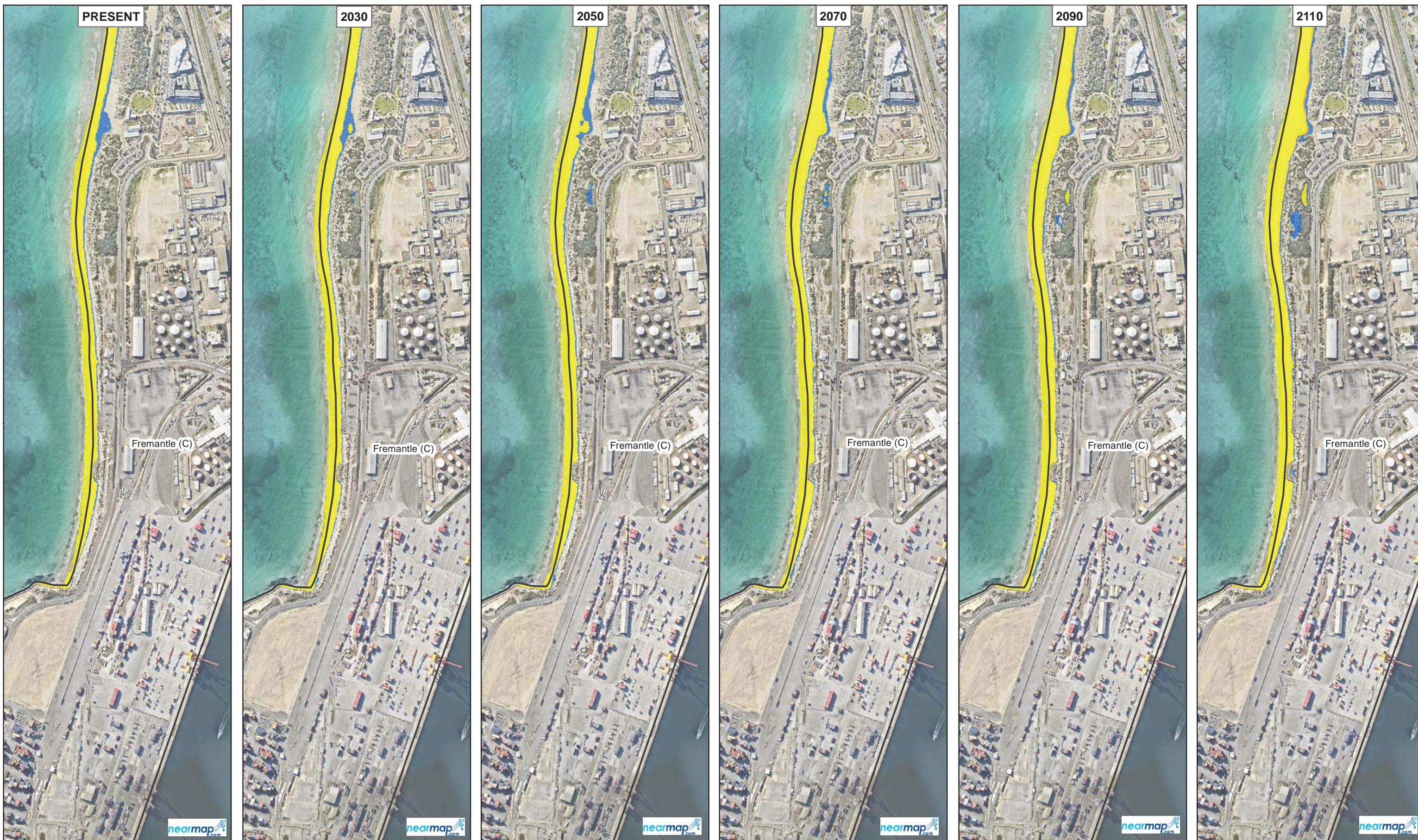


City of Fremantle/Town of Mosman Park
Coastal Adaptation Plan

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Revision 0
Date 24 Aug 2016

**Leighton Beach
Inundation Hazard**

Figure 5



Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50



LEGEND

- Almost Certain
- Possible
- Rare
- Local Government Boundary

These maps are to be read in conjunction with the assumptions and limitations as detailed in section 1.6 of the GHD Physical Processes Report (August 2016) found in Appendix D of the Coastal Adaptation Plan.



City of Fremantle/Town of Mosman Park
Coastal Adaptation Plan

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Date	24 Aug 2016

**Port Beach
Inundation Hazard**

Figure 6

Appendix D – Coastal Hazard Assessment



City of Fremantle & Town of
Mosman Park
Coastal Adaptation Plan - Appendix D
Coastal Hazard Assessment

January 2017

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Appendices

Appendix A - Erosion Hazard Line Components

1. Introduction

1.1 Purpose of this report

This report has been prepared to support the Port, Leighton and Mosman Beaches Coastal Adaptation Plan by providing details on the assumptions, technical details and results of the coastal vulnerability assessment.

1.2 Objectives

Prepare coastal hazard maps which will allow stakeholders and community to make informed decisions about assets and foreshore values in the future including how these assets and values may be protected.

Results of the coastal modelling and hazard mapping will be used to develop and assess appropriate adaptation options.

1.3 Scope and limitations

- Collate and review all relevant coastal plans, studies and data sets previously completed, and emerging data sets such as Western Australian Integrated Marine Observing System (WAIMOS) based at University of Western Australia (UWA) Oceans Institute.
- Analyse current and future behaviour of the coastal system under climate change scenarios,
- Provide physical process report and maps on risk and vulnerability at different timeframes (present day, 2030, 2050, 2070, 2090, 2110).

1.4 Deliverables

- Coastal hazard likelihood maps of erosion and inundation for different likelihood levels and timeframes, including effects of sea level rise, at present (2016), 2030, 2050, 2070, 2090, 2110).

1.5 This Report

This report: has been prepared by GHD for City of Fremantle & Town of Mosman Park and may only be used and relied on by City of Fremantle & Town of Mosman Park for the purpose agreed between GHD and the City of Fremantle & Town of Mosman Park as set out in section 1.1 of this report.

GHD otherwise disclaims responsibility to any person other than City of Fremantle & Town of Mosman Park arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared this report on the basis of information provided by City of Fremantle & Town of Mosman Park and others who provided information to GHD (including Government authorities)], which

GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

Climate change is a significant current and future issue and effects, such as sea level rise, are at this stage difficult to quantify to a high degree of certainty. The following assumptions have been made during the preparation of this report:

The sole purpose of the reports are for evaluating coastal hazard risks and developing adaptation plans associated with coastal hazards and sea level rise for the City of Fremantle and Town of Mosman Park.

The reports are produced for use by the City of Fremantle and Town of Mosman Park, and are not for use by any third party person or organisation. The information and recommendations are to be read and considered holistically, and content is not to be used selectively for purposes other than coastal hazard risk management (e.g. design) as this may misrepresent the data and processes herein and provide erroneous project or decision outcomes.

The data and processes herein are to be used for coastal hazard risk assessment and adaptation planning purposes, approved by the City of Fremantle and Town of Mosman Park, and based on Australian and state government guidelines:

- *Western Australian Planning Commission and Department of Planning (2014). Coastal hazard risk management and adaptation planning guidelines, Perth, Australia.*
- *Western Australian Planning Commission (2013). State Planning Policy No. 2.6 State Coastal Planning Policy.*

These guidelines have been considered as per the requirements of the brief. This information has not been independently verified. Assumptions and recommendations that need further testing are noted in the text of the report.

The establishment of the sea level rise aspects of the project uses data and scenarios based on publicly available information by the International Panel on Climate Change, summarised by the Western Australian Department of Transport:

- *Bicknell (2010). Sea Level Change in Western Australia: Application to Coastal Planning, prepared by the Department of Transport, Fremantle, WA.*

Climate change and coastal hazard assessment by its nature is a dynamic and ongoing process. As the sea level rise projections used are uncertain by nature, it is possible that the effects that actually occur may not be as assumed and stated in this exercise. Therefore, it is recommended that City of Fremantle and Town of Mosman Park routinely incorporate the latest climate change science and sea level rise cause and effect knowledge into all future planning.

1.6 Assumptions and Limitations

Sea Level Rise is based on the results of the IPCC Fifth Annual Report RCP scenarios as described in the report.

Extreme water levels from present used in this study are based on water levels used and reported on by the Cockburn Sound Coastal Alliance in the Cockburn Vulnerability Assessment.

SBEACH modelling was conducted at three locations considered representative of the larger beach unit. Alongshore variations in storm erosion response are likely but has not been modelled as it is beyond the scope and scale of this study.

Tertiary man-made controls on sediment transport and erosion (eg seawalls and groynes) have not been considered in the hazard assessment as it is unknown whether they will be maintained in the future. Nonetheless, presence of these controls would act as mitigating measures and do not influence the likelihood of coastal hazards on an unprotected coast. Primary man-made controls such as the Fremantle dredge channel and Rous Head Extension are assumed to exist throughout the study timeframes.

Erosion and accretion rates measured in the historical shoreline analysis are calculated at the time periods described within the report. The rates of shoreline movement are dependent on the shoreline response to changes in the coastline such as the construction of infrastructure like the Rous Head Extension. Unless otherwise noted, historical shoreline movement rates have been assumed to continue at the calculated rate over the timeframes in line with the requirements of SPP2.6, however this may be an exaggeration as shoreline response is likely to stabilise over time.

It has been assumed that the long term stability of Mosman beach has been provided by a layer of Tamala limestone which acts as a foundation to the high elevation dune system at Mosman Beach. Whilst no detailed geotechnical data is available for this section of the coast, adjacent geotechnical information from Cottesloe and GHD's previous review of dune stability at Mosman Beach (2014) has been used to support the assumption that the dunes of this section of the coastline will resist cross shore storm erosion. In the erosion hazard mapping, the transition between the southern extent of the Town of Mosman Park and the northern extents of the City of Fremantle at north Leighton beach has been smoothed.

It is noted that estimation of erosion and inundation likelihood is undertaken to review risks of exposure of the assets to various coastal hazards. The inundation and erosion risks lines shown are not indicative of setback lines. Identification of development set back lines is not an objective of this study.

Table 1 Abbreviations

Abbreviation	Definition
AEP	Annual Exceedance Probability
AHD	Australian Height Datum
CD	Chart Datum
DPI	Department of Planning and Infrastructure
HSD	Horizontal Setback Datum.
IPCC	International Panel on Climate Change
RCP	Representative Concentration Pathway
SBEACH	Storm induced BEACh CHange
SPP2.6	State Planning Policy 2.6

2. Literature Review

2.1 Existing reports for study area

There have been a number of coastal management plans and studies undertaken along the Port, Leighton and Mosman Park beaches. These documents and other relevant sources of information relating to coastal processes have been summarised and important information for this study highlighted. A large amount of the available information on this section of the coast is focussed on Port Beach where erosion has been an ongoing management issue. The amount of available information for Mosman and Leighton beaches is considerably less. In addition, the literature review results also include study information from Cottesloe as the metocean conditions are very similar at the two sites and Cottesloe is also part of the primary and secondary sediment cell that may be influenced by changes to Port, Leighton and Mosman Beaches.

2.1.1 Review of Reports

Port and Leighton Beaches Coastal Management Plan (Ben Carr and Associates 1996)

The Port and Leighton Beaches Coastal Management Plan was prepared in 1996 to develop a beach access and dune maintenance program (Ben Carr and Associates 1996). Information was obtained from a survey of beach access paths and used to identify areas requiring dune rehabilitation and pathway requiring maintenance. The plan provides a brief background of coastal processes and the beach environment. It identifies that whilst generally this section of coast was stable, the stability at the southern end of Port Beach was “upset” and had experienced net erosion of the beach and dune line. A review of coastal process in the plan identified a late winter storm in 1995 that eroded the foredune of Port beach by 3m, destroyed the majority of the foredune and destroyed beachfront dune fencing (Ben Carr and Associates 1996). It also described that within the study area, the volume of annual sand movement was described as large and could result in changes of the position of the mean water line of up to 20m.

The plan included a dune rehabilitation strategy and specifications to repair the dunes, access paths and associated infrastructure including prioritisation of works according to safety, stability, usage and reducing ongoing maintenance. The intention of the dune rehabilitation works was to improve the stability of foredune areas and provide beach access for beach users into the future (Ben Carr and Associates 1996).

Port and Leighton Beaches Management Study (Tingay 1999)

The Port and Leighton Beaches Management Study was prepared after handover of the Port and Leighton Beaches from the Fremantle Port to the City of Fremantle in 1995 (Tingay 1999). The purpose of the study was to collate background information and to identify a community vision to facilitate the development of a coastal management plan to enable effective planning and evaluate future development scenarios. The study provided a thorough background of the biophysical and social environment of the beaches, a summary of existing facilities, infrastructure and land uses, a description of existing management issues and community vision for the future from stakeholder consultation.

A review of the coastal processes identified that erosion observed in 1995 and 1996 was a result of severe storm activity and that local erosion at the southern end of Port Beach may have been a result of the construction of the Rous Head extension in 1995 (Halpern Glick Maunsell 1997 in Tingay 1999). The study concluded that this erosion may be a result of southward moving sediment in winter being deposited further offshore in deeper water as a

result of the Rous Head extension, and that sheltering effects of the extension may have prevented swells during the summer from replenishing the lost winter sediment. HGM recommended construction of a spur groyne to the northern end of the Rous Head extension (Tingay 1999).

The study also includes a section on beach erosion modelling which summarised the results from Halpern Glick Maunsell (HGM) study in 1997 and further work done by MP Rogers in 1998 to assist in determining setback distances. The beach erosion modelling by HGM using SBEACH of a 100 year average recurrence interval event indicated a retreat of the vegetation line of between 20 to 25m applicable to Leighton and Port Beach. Additional profiles to the southern end of Port Beach were modelled by MP Rogers at the Sand Tracks car park and adjacent Tydeman Road. The results indicated that retreat of the vegetation line of approximately 5 to 10m would be expected for a 100 year ARI event and a retreat of the beach berm between 20 to 25m (Tingay 1999).

Aerial photography analysis identified a general trend of accretion from 1965 to 1998 for the majority of Port and Leighton beaches except the southern area of Port Beach (Rudderham Drive) which followed the accretion trend (40m) from 1965 to 1989 followed by recession of 6m to 1998 (Tingay 1999).

A key issue identified in the study was the impact and sustainability of development in close proximity to the beach and enhancing dune development. Setback recommendations in the study identified that infrastructure within 25 m of the 1998 vegetation line was at high risk of being lost in a 100 year ARI event and that new infrastructure should be setback no closer than 65m from the 1998 vegetation line based on a 30-year estimate of sea level rise.

Site contamination west of Port Beach Road between Leighton and Port Beaches was reported as a result of bulk fuel storage facilities in operation in the 1960's including the Former Golden Fleece site, the Mid West Fodder Site and the Ampol Terminal Storage. Tingay reports in detail on the investigations and remediation works that have been undertaken at each site. Contamination was reported in both soil and as hydrocarbon plumes. Further details on site remediation are recommended in the management section of the report which identified that at the Former Golden Fleece and Mid-West Fodder sites that there is residual soil contamination present in the water table fluctuation zone beneath the vegetated foredunes along the former western margin of the fuel terminal and that if remediation of this soil was attempted, extensive excavation would be required. The extent and potential to impact on sensitive marine receptors by the dissolved hydrocarbon plumes is unknown and could be addressed through monitoring and modelling, but risks to human health were assessed as likely to be negligible (Tingay 1999).

Port and Leighton Beaches Management Plan (City of Fremantle 2001)

Continuing from the Tingay (1999) Port and Leighton Beaches Management Study, the Port and Leighton Beaches Management Plan was prepared by the City of Fremantle (CoF 2001) to guide ongoing maintenance as well as future planning and development of Port and Leighton beaches. "The overall aim of this plan is to create a sustainable coastal reserve in a natural dune setting, with native species, catering to the community's recreational needs while minimising annual maintenance costs." The principles and guidelines for each of the following management issue are detailed including erosion, vegetation, access, parking, recreation, commercial development, site contamination and environmental issues, visual amenity, landscape character and implementation of regional guidelines.

The report included concept design and nodal action plans for Sandtracks node, Port Beach node, South Leighton node, surf lifesaving club node and North Leighton node and included an implementation strategy and field specification for coastal reserve facilities and infrastructure.

Of specific interest to the current study, a review of the history of the site identified that the dunes along Leighton Beach were flattened between 1946 and 1972 for new industrial development and new railway alignments.

The Leighton Regional Planning Guidelines (2000), relevant for Leighton beach north of Walter Place, concluded a coastal reserve width of 95m was required in line with the Western Australian Planning Commission Policies DC2.3 and DC 6.1 requirements. When incorporating coastal recreation demand, a width of up to 150m was recommended for the coastal reserve (CoF 2001).

Port Beach Coastal Management (MP Rogers & Associates 2000)

This study provided a review of beach monitoring transects and a thorough summary of coastal processes and coastal management activities from previous reports including the 1997 Halpern Glick Maunsell Port and Leighton Beaches Coastal Study, as well as the MP Rogers & Associates (MPRA) previous study from 1998 and others. The report provides a range of coastal management options for the area including realigning Port Beach Road.

Reviews of shoreline monitoring surveys from beach transects between 1991 and 1997 highlighted that storage of sediment in an offshore sand bar occurred between 1995 and 1997 of potentially 100,000 to 150,000m³ (MPRA 2000).

SBEACH model results undertaken by MPRA were reported to indicate that the position of the vegetation line could retreat between 10 and 25 meters as a result of a modelled extreme event.

Four management options including realignment of the Port Beach Road to metropolitan region scheme (MRS) designated alignment or an alternate alignment with a seawall upgrade or with construction of a spur groyne and nourishment were investigated in this report.

Port Beach Coastal Erosion Study (DPI 2004)

Significant beach erosion occurred at Port Beach during a severe winter storm in May 2003 that highlighted concerns about the Port Beach road realignment planned for the area in 2004 and prompted the Port Beach Coastal Erosion Study by the Department of Planning and Infrastructure (DPI) (2004).

Six coastal management options were identified based on the construction of the seawall to protect the Port Beach road realignment going ahead, which was constructed after the DPI (2004) study in 2004/2005. The options considered were

- sand nourishment;
- upgrade and extending seawalls with sand nourishment;
- spur groyne and sand nourishment;
- headlands, spur groynes and sand nourishment;
- offshore breakwaters with spur groyne and sand nourishment; and
- groynes with spur groyne and sand nourishment.

The study reviewed the capital, annual maintenance and net present value costs of the options over 20 years but recommended further investigation of the social and environmental issues.

The study recommended 6 monthly beach surveys and short term sand nourishment and continued removal of rocks from the surf zone because of potential delays to permanent coastal management of Port Beach. No recommendations on preferred options were made.

The study provides a good review of past literature in particular on environmental, geomorphological and metocean conditions. The study highlighted that in 2000 the erosion rate

of southern end of Port Beach was about 2 metres per year and was described as a long-term trend, not a seasonal variation. Shoreline movement at the main Port Beach car park was also eroding but at a more 'mild' rate of 0.8 m per year. Results of shoreline movement and erosion rates are reported in Figure 1 and Figure 2. Results of sediment sampling analysis at Port Beach were also reported on and details are provided in Figure 3.

Notable historical construction works that affected the coastal zone at Port and Leighton Beaches were the construction of the Rous Head harbour from 1989 to 1990/91 and the Rous Head Extension seawall that was constructed in 1995.

The report also indicates that during 2003 storm, the vegetation line (+2.0mCD) eroded an average of 5 to 10m along Port Beach and up to 25m at Leighton Beach.

Based on shoreline movement and average erosion volumes from beach survey data, DPI (2004) developed a conceptual model of littoral transport of contemporary years, refer to Figure 4.

PERIOD/CHAINAGE	MOVEMENT OF VEGETATION LINE (m)										
	LEIGHTON BEACH					PORT BEACH					
	A 2,120m	B 1,920m	C 1,720m	D 1,520m	E 1,320m	F 1,120m	G 920m	H 720m	I 520m	J 320m	K 120m
1945 – 1955	8.0	24.0	10.0	29.0	44.0	25.5	23.5	27.0	22.5	41.5	46.5
1955 – 1963	9.5	20.5	36.0	16.0	6.0	-3.5	24.5	-15.0	7.5	3.0	2.0
1963 – 1974	3.0	12.5	34.5	-0.5	11.0	1.5	-40.5	-1.0	-14.0	-6.0	5.0
1974 – 1983	2.0	10.5	7.0	19.0	6.0	-1.0	24.0	-2.0	12.5	6.0	18.0
1983 – 1993	7.0	6.5	9.0	-4.0	10.5	11.0	12.5	19.0	0.5	3.0	-3.5
1993 – 2000	5.5	10.0	2.5	12.0	3.5	3.5	-9.0	-2.0	-5.0	-7.5	-20.5

Note : Chainage is distance north of Rudderham Drive. Letter refers to the profile number (Fig 5.5)
+ve: accretion, -ve: erosion

Figure 1 Summary of shoreline movement over time at Port and Leighton Beaches (DPI 2004).

LOCATION	CHAINAGE (m)	CONTEMPORARY SHORELINE MOVEMENT TREND 1993 TO 2000
Southern End of Beach	0 - 300	2.2 m/ year erosion
Port Beach main	300 – 900	0.8 m/ year erosion
Northern End of Port Beach	900 -1300	Stable
Leighton	1300 – 2100	1.0 m/ year accretion

Note : Chainage is the distance north of Rudderham Drive seawall

Figure 2 Summary of beach erosion rates from 1993 to 2000. (DPI 2004)

	NATIVE BEACH MATERIAL	NOURISHMENT MATERIAL
Description	Moderately well sorted medium to coarse mixed quartz/carbonate sand with both mineral populations displaying a similar particle morphology.	Well sorted medium to coarse quartz sand.
Roundness	Sub rounded	Rounded to Sub rounded
Sphericity	Spherical to sub prismatic	Spherical to sub prismatic
Surface Texture	Smooth, quartz grains clear (non-frosted)	Smooth with frosted surface.
Mineralogy	Mixed quartz and calcium carbonate	Quartz
Calcium carbonate	19.2 %	0 %
Grain size	d ₁₅ = 0.32mm; d ₅₀ = 0.45mm; d ₈₅ = 0.62mm	d ₁₅ = 0.38mm; d ₅₀ = 0.50mm; d ₈₅ = 0.65mm
Settling Velocity	W ₁₅ = 2.8 cm/s; W ₅₀ = 4.2 cm/s; W ₈₅ = 5.6 cm/s	W ₁₅ = 5.8 cm/s; W ₅₀ = 8.0 cm/s; W ₈₅ = 10.0 cm/s

Source: UWA School of Earth and Geographical Sciences

Figure 3 Port Beach sand characteristics. (DPI 2004)

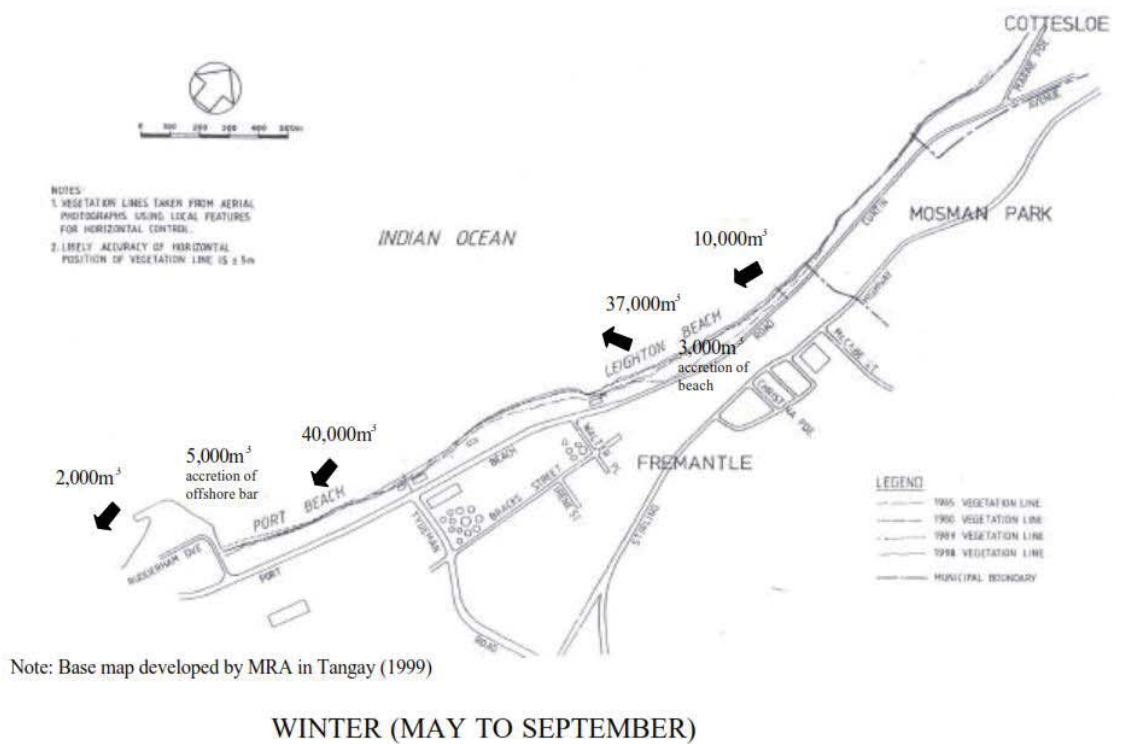
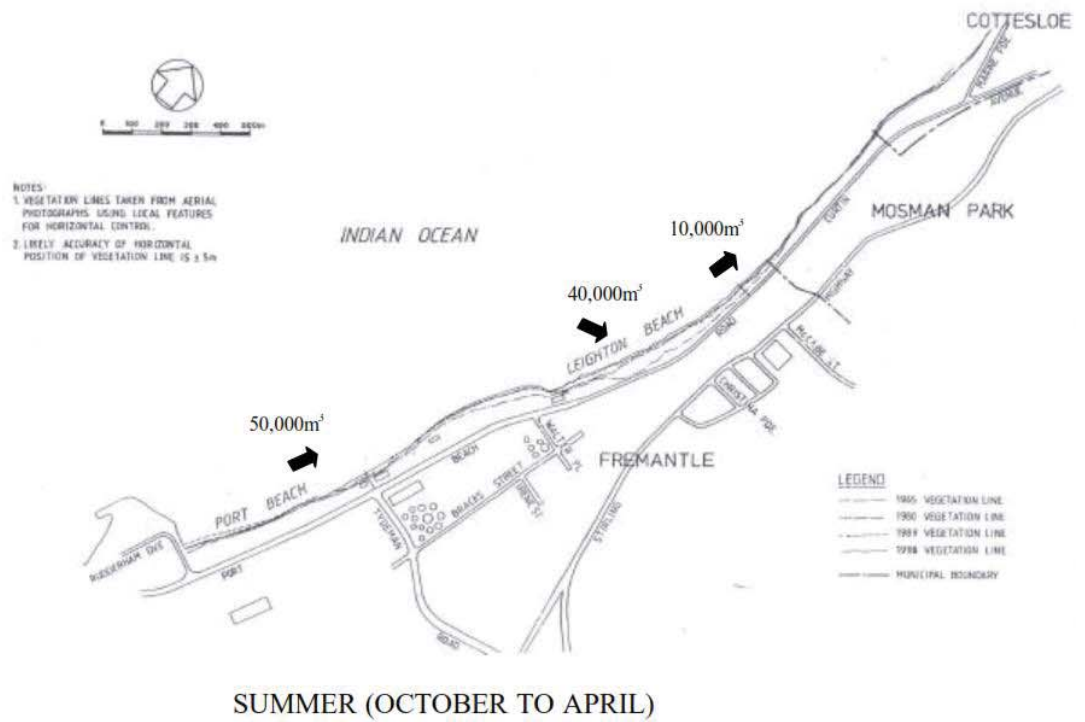


Figure 4 Conceptual contemporary model of sediment transport at Port and Leighton Beach (DPI 2004)

Port Beach Wave and Shoreline Modelling (MPRA 2007)

MPRA conducted detailed numerical wave and shoreline modelling of three proposed management options for Port Beach as well as an additional scenario of the final Rous Head Ultimate Extension to identify impacts on shoreline position. The management options investigated were no further works, a spur groyne off the Rous Head Extension and two artificial headlands. Typical and severe weather conditions were modelled. Modelled shoreline impacts were restricted to Port Beach, with very little impacts on Leighton Beach.

“The model predicted that the shoreline along most of Port Beach may accrete by between 10 and 20m under typical weather conditions, with the largest accretion at the southern end of the beach. Under the severe weather conditions, it is possible that Port Beach will still accrete, but to a reduced magnitude of between 0 to 10m.

The accretion predicted along Port Beach following the construction of the Rous Head Ultimate Extension is likely to be caused by the extended structure partly sheltering the south westerly sea breeze events that would otherwise move the sediment north away from Port Beach. Furthermore, the new structure would prevent the loss of sand to the south around the existing Rous Head Extension where it becomes trapped and removed from the system.

This modelling indicates that the Rous Head Ultimate Extension may result in accretion of the shoreline along Port Beach. However, the long term impacts of the structure on the onshore feed of sediment and the accuracy of the data that was used to calibrate the model may result in different outcomes.”

Port Beach Monitoring 2010 (MPRA 2010)

MPRA were engaged by the Fremantle Port to prepare a monitoring report of shoreline changes at Port Beach after the construction of the Rous Head Extension because of their ongoing commitment to understanding the impacts of the construction on the coastal environment.

Review of hydrographic survey indicated that between 2004 and 2009 Port Beach was relatively stable. On a seasonal scale, MPRA reported that Port Beach exhibited a pattern of northward movement of sediments during summer and southward movement of sediments during winter storms. Cross-shore dynamics were also reported with the beach berm eroding during storms to form an offshore bar and the berm rebuilding during swell conditions (MPRA 2010).

The report provides no estimate of storm induced or long-term erosion or accretion of the shoreline, it only looks at bathymetric changes offshore.

Port Beach Monitoring 2013 (MPRA 2014)

Following on from the 2010 monitoring report, MPRA were engaged again by Fremantle Port to update the study based on additional data collated by the port since 2010.

The report reviewed additional aerial images from 2009 to 2013 and drew some general conclusions on general trends including:

- “The movement of sediment into offshore banks during winter storms and return to the beach face during summer swell.
- Movement of sediment north during summer seabreeze events. At the end of summer there is a relatively wide beach at the northern end of the study area, but at the end of winter this beach is very narrow with rocks exposed along the shoreline.
- Movement of sediment south during north-westerly winter storms. The width of the beach at the southern end of Port Beach is greater following the winter months when sand is transported from the north to the south during storm events”

Review of hydrographic survey from April 2011 to October 2013 indicated that beyond the -3 mCD to -4 mCD contour there was minimal changes to the seabed. Between April 2013 and October 2013, accretion of sediment was observed in the surf zone off Port Beach and erosion of the sediment off Mosman Beach indicating cross-shore movement of sediment during winter.

Long-term difference plots were also prepared and assessed. Between May 2008 (before the construction of the Rous Head Extension) to April 2012 “a large amount of accretion along Leighton Beach and a small amount of erosion of the offshore bank at Port Beach. The shoreline along Port Beach shows little change with some minor accretion (0.25 to 0.5m).”

The report provides no estimate of storm induced or long-term erosion or accretion of the shoreline, it only looks at bathymetric changes offshore.

Mosman Beach Management Plan (ToMP 2003)

The Mosman Beach Management Plan, prepared by the Town of Mosman Park (ToMP) was developed “to provide a series of principles to manage future planning and development along the Mosman coastline”. The document provides a historical and cultural context, briefly describes the geomorphological context.

“The soils are typically fine to coarse leached sands.” Beach sand “overlays the submarine Tamala limestone shelf known as the Cottesloe Fringing bank to a depth of 1.5m, however in winter much of the shelf is exposed”. (ToMP 2003)

Coastal management issues relating to coastal processes, vegetation, access, infrastructure, recreation, development, site contamination and existing management plans are discussed and brief management strategies for these issues made.

Cottesloe Coastal Monitoring (BMT Oceanica 2015)

The Town of Cottesloe (ToC) undertook a two year long coastal monitoring project to assist in coastal decision making and management of the Cottesloe coastline and to ‘facilitate improved planning for the future coastal protection and adaptation’ (BMT 2015).

The study involved collection of hourly remote imagery at Cottesloe main beach and north Cottesloe beach from 19/11/2014 to 13/05/2015 as well as two beach profile campaigns at 39 cross shore transects at the start and end of the photo monitoring period.

“The results of the remote imagery and beach profile monitoring showed that the general pattern of beach morphology change along the Cottesloe coastline during summer 2014/2015 was erosion of the beaches north of Cottesloe Groyne/Mudurup Rocks, and accretion of the beaches south of Cottesloe Groyne/Mudurup Rocks (with the exception of a small area of erosion directly north of Beach Street Groyne). Erosion generally occurred via a reduction in beach width and increase in beach face steepness, with an increase in berm crest height along some profiles.

Accretion generally occurred via an increase in beach width and an increase in berm crest height along some profiles. The longshore pattern of erosion and accretion at Cottesloe is likely attributable to the net northward longshore sand transport in summer (driven by predominant south-south-westerly winds) being interrupted by cross-shore features such as groynes and rocky outcrops, causing accumulation of sand updrift (i.e. to the south) and erosion of sand downdrift (i.e. to the north) of these features. Remote imagery indicated that periods of accelerated or slowed erosion at Cottesloe Main Beach and North Cottesloe during summer 2014/2015 may have been linked to variations in sea breeze activity, storm direction, water levels and long-range swell.

As the general pattern of beach change at Cottesloe over summer 2014/2015 was mainly related to seasonal northward sediment transport direction, it is likely that a sediment transport

direction reversal during winter will result in some accretion in previously eroded areas. However episodic beach erosion may also occur in these areas during winter due to offshore sediment transport during more frequent and/or intense winter storms.”

“Cottesloe lies on the western part of the Swan Coastal Plain, which extends from the north of Perth to Dunsborough in the south, and from the Darling Scarp in the east to the Indian Ocean in the west (WAPC 1999). The local geology consists mainly of Holocene sands overlying Pleistocene Tamala Limestone, which rests on older sandstone, siltstone, claystone and shales. The Tamala Limestone is calcarenite and forms small rocky headlands and nearshore reef platforms (Searle & Semeniuk 1985; Sanderson & Eliot 1999).”

Cottesloe Coastal Monitoring (Cardno 2016)

Cardno (2016) undertook the continuation of the Cottesloe Coastal Monitoring Report, from April 2015 to March 2016 assessing remote imagery, beach surveys and comparing observed changes to metocean records of weather, waves and water level.

A significant wave run up event observed in the remote imagery record occurred during the monitoring period from the 15 to 18th May 2015 during a long duration storm event where waves reached a significant wave height of greater than 2.5m. The peak observed runup was coincident with the highest annual water level of 1.8mCD, but not with the peak of the wave height which occurred later on the same day. Cardno noted that other large wave height events during the observation period did not impact on the beach in the same manner as this event due to lower water levels.

Extreme analysis of water levels undertaken by Cardno from recorded water level at Fremantle is summarised in Table 2.

Table 2 Extreme analysis of Fremantle recorded water level (adapted from Cardno 2016).

Annual Exceedance Probability	Average Recurrence Interval (years)	Water Level (m LWM*)	Water Level (m AHD)
20%	5	1.1	0.3
10%	10	1.9	1.1
5%	20	1.9	1.1
2%	50	2.0	1.2
1%	100	2.1	1.3

*Low Water Mean. The vertical datum (or chart datum) used for water level recordings at Fremantle Port is referenced to the Low Water Mean mark from 1949.

2.1.2 Summary

A range of studies conducted between 1996 and 2016 were reviewed. There are several studies evaluating storm response and long-term erosion and accretion patterns along Port and Leighton Beach.

Storm erosion estimates at Port and Leighton beach generally suggest a recession of 20 to 25m at the vegetation line (Tingay 1999, MPRA 2000, DPI 2004). Development setback values recommended vary in different report and range from 25m to 150m (COF 2004, including recreational requirements).

Annual change in shoreline position varies significantly along the study area and vary over time with the gradual development of Rous Head industrial area. While a pattern of accretion was dominant before 1990, erosion of the shoreline has been persistent in more recent years. Erosion rates are estimated between 0.6m to 2.2m per year and are predominant estimated response in the southern stretches of the study. Accretion is more likely towards the northern parts of the Leighton Beach.

There is no specific shoreline movement or storm response report for the Mosman Beach area however, available reports suggest an Tamala limestone rock at the base of the cliff and a wave cut platform along Mosman Beach foreshore which is often exposed during winter time but is recovered with sand during the summer times, which is supported by aerial imagery review undertaken by GHD (2014). See section 2.5 for further description on beach geology and geomorphology..

2.2 Vulnerability and CHRMAP studies

2.2.1 Review of individual Studies

Vulnerability of Cottesloe foreshore to the potential impacts of climate change (Damara & Coastal Zone Management 2008)

In 2008 Damara & Coastal Zone Management (CZM) undertook a study with the aim “to establish the potential risk to existing key coastal infrastructure under a range of future climate scenarios”. The study included three phases. Phase 1 provided background information including establishing consequence scales and how these were measured, dividing the study area and setting the scenarios for Phase 2. Phase 2 was a risk assessment of the coastal change, analysing the impacts of predicted change on key elements and evaluating the risks posed to the Town of Cottesloe. Phase 3 assessed the options available to treat the phase 2 risks, the risk treatments were grouped and implementation considered at four timeframes. The iterative approach to treatment options was highlighted and as a result a plan was developed which was used to align sequencing of immediate adaptation options with key risk treatment options over a twelve-month period.

Assessment of historical changes noted that the least amount of shoreline change was observed in areas that had a rocky shoreline or were backed by engineering structures, “however, these areas were prone to extensive beach lowering and shunting of sediment on, off and alongshore in response to high-energy events.” Southern transects were identified to be in net erosion, yet the rate was noted as gradual and not influenced by sporadic shoreline changes unlike other locations (Damara 2008). Severe erosion events affecting Cottesloe foreshores were characterised by water levels greater than 1.6mCD (0.9mAHD) (Damara 2008). Damara and CZM described the summer (September to April) sediment transport to be mainly northwards and the winter (June and July) sediment transport to be predominantly southwards, with the resultant net sediment transport over a year to the north.

Coastal Vulnerability Study: Erosion and inundation hazard assessment report. (Cockburn Sound Coastal Alliance 2013)

In this Coastal Vulnerability Study (CSCA 2013) the hazards of erosion and inundation were quantified for the Owen Anchorage and Cockburn Sound (OACS) coasts from Point Peron in the City of Rockingham to South Mole in the City of Fremantle. The timeframes for hazards were assessed at present, 2070 (+0.5m of Sea Level Rise) and 2110 (+0.9 m and 1.5m of Sea Level Rise). A summary of the water levels used to assess the inundation hazard at present day levels is summarised in Table 3. In the CSCA study, “wave runup was not included in the analysis, as due to its near-coast nature, its effect upon inundation declines very rapidly with landward propagation.”

Table 3 Inundation scenario, present day water levels (CSCA 2013).

Annual Exceedance Probability	Average Recurrence Interval (years)	Water Level (m AHD)
63%	1	1.00
10%	10	1.16
1%	100	1.34
0.2%	500	1.48

2.3 Sea level rise

The Department of Transport's (DoT) recommended allowance for sea level rise application to coastal planning in WA (Bicknell 2010) is based on the 95th percentile of the A1F1 scenario from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report. Since 2010, the Fifth Assessment Report (AR5) has been released by the IPCC with confidence in the projections of global mean sea level rise increasing (IPCC 2013). The IPCC has developed four representative concentration pathway (RCP) scenarios that demonstrate different population size, economic activity, lifestyle, energy use, land use patterns, technology and climate policy pathways and their possible resulting emissions. The sea level rise scenarios are referred to as RCP2.6, RCP4.5, RCP6.0 and RCP8.5 with the number being indicative of the W/m² reached by the trajectory in 2100 and are used to represent likelihood of sea level rise magnitude and are used in this study, see Figure 5.

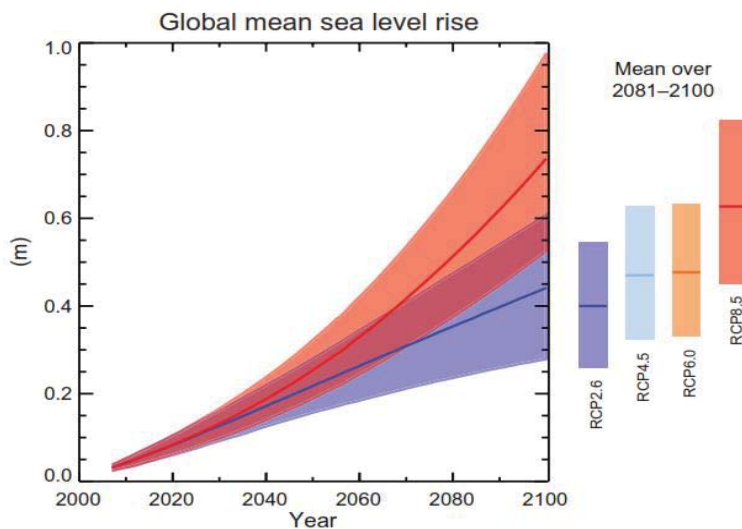


Figure 5 Fifth Annual Report global mean sea level rise predictions * (IPCC 2013)

* "Projections of global mean sea level rise over the 21st century relative to 1986–2005"

In the assessment of sea level rise for this study, GHD have used the values from the 2013 IPCC report as these are considered to reflect the latest research. The relevant values are provided in Table 4 alongside the 2010 DoT recommended values for ease of reference and comparison.

Table 4 Sea Level Rise Scenarios referenced from 2010

Scenario	2016	2030	2050	2070	2090	2110
DOT 2010 (4AR A1F1)	0.02	0.09	0.22	0.41	0.64	0.90
RCP 2.6 (5AR)	0.02	0.08	0.20	0.33	0.46	0.6
RCP 6.0 (5AR)	0.02	0.08	0.20	0.35	0.55	0.75
RCP 8.5 (5AR)	0.02	0.09	0.24	0.46	0.74	1.04

2.4 Coastal data sources including emerging data sets

Integrated Marine Observing System (IMOS) is a national system to integrate observations of physical, chemical and biological variables at the ocean-basin and regional scales (IMOS, 2016). Research undertaken by the WA node of the Integrated Marine Observing System (WAIMOS) is focused around five key questions relating to:

- “Multi-decadal variation, it's regional structure, mechanisms, impact on the Leeuwin Current and ecosystems,
- Interannual climate variation and weather extremes (such as Ningaloo Niño), local versus remote forcing of the marine environment and ecosystems and regional feedback-dynamics, if it exists,
- Dynamical studies of the Leeuwin Current, its relationship to El Niño Southern Oscillation, its eddy-field and connectivity to inter-basin flows (Indonesian Throughflow and the Indo-Pacific supergyre),
- Continental shelf and coastal processes, the relationship of shelf waters to offshore circulation (Holloway Current, Ningaloo Current, Capes Current, continental shelf waves and tides),
- Ecosystem studies focussed on key species linked to exotic higher trophic level biota (e.g. krill in Perth canyon linked to Blue whales; small prey near Abrolhos Islands linked to nesting birds; larvae in the Leeuwin Current linked to juvenile bluefin tuna), drivers of water quality and benthic ecology, and their impacts of iconic fisheries and ecosystems” (IMOS, 2016)

Improved understanding of current dynamics and the influence of inter-annual cycles such as El Niño Southern Oscillation on water level is of particular importance to water levels off Perth and continued studies in these fields may assist to improve the accuracy of the water level exceedance likelihoods in the future.

2.5 Geology and geomorphology

The study area 'lies on the western part of the Swan Coastal Plain, which extends from the north of Perth to Dunsborough in the south, and from the Darling Scarp in the east to the Indian Ocean in the west (WAPC 1999). The local geology consists mainly of Holocene sands overlying Pleistocene Tamala Limestone, which rests on older sandstone, siltstone, claystone and shales. The Tamala Limestone is calcarenite and forms small rocky headlands and nearshore reef platforms (Searle & Semeniuk 1985; Sanderson & Eliot 1999)' (BMT Oceanica 2015).

Geophysical Investigation for Subsurface Lithology along the foreshore of Cottesloe Beach (GBG Maps 2010)

Geophysical survey was conducted along Marine Parade in Cottesloe in two project stages. The investigations used ground-penetrating radar (GPR), multi-channel analysis of surface waves (MASW) and cone penetrometer testing (CPT) to assess the depth to bedrock as well as sand cover depth and sand density. GPR was used to assess the depth to the boundary between sand and limestone parallel to Marine Parade and was used to collect longitudinal profiles in stage 1 and in stage 2 cross sectional profiles were collected. MASW data collection was limited to grassed and some asphalted areas. GPR survey was able to detect features to a maximum of 7m below the ground surface. CPT points were collected to calibrate results of the MASW and GPR surveys.

A longitudinal survey profile at the southern end of the site, parallel to Marine Parade in phase 1 indicated a strongly reflective layer at 5m below the ground surface. The phase 1 study concluded, "that much of the limestone bedrock along the foreshore is highly undulating and exhibits pinnacle features' (GBG Maps 2010). GPR profiles taken perpendicular to Marine Parade from the southern end of the Cottesloe survey area, indicate sandy material over limestone bedrock sloping toward the ocean with an interface varying from 8m to 6m below the surface (GBG Maps 2011). The phase 2 study found that "the interface between the limestone and overlying sand was generally well defined in the data with the top of the limestone bedrock being identified in the majority of the profiles. At some locations the bedrock was poorly resolved and may represent areas of weak or weathered limestone."

Town of Mosman Park Beachfront: Preliminary Slope Stability Assessment Report (GHD 2014)

In 2014, GHD undertook a visual site inspection of the Mosman Park foreshore to assess geomorphological features of the slopes, assess the engineering condition of the rock mass and identify any evidence of slope instability. No detailed morphological mapping was undertaken. The study site was the foreshore within the Town of Mosman Park boundary.

The report notes that the Mosman Park foreshore was used as a municipal tip from the early 20th century to the 1950's. and that in 1959 the construction of the marshalling yards resulted in cut material being located to Mosman Beach. "This material is generally referred to as "construction and non-industrial waste" and there is up to 5m of overburden over the tip site from the marshalling yard cut" material. During the site inspection this material "was observed to comprise sand with construction material such as with brick, concrete rubble and asphalt" (GHD 2014).

"Major seasonal changes in beach levels and erosion occur along the Perth coastline. Some of the seasonal changes are evident from the Google Earth Imagery. In general, deposition of sand occurs along the beaches with the prevailing south-westerly winds during the summer months. During winter months, with the occurrence of storm events and increased wave action,

there is increased erosion, degradation and undercutting of sea cliffs along the coastline” (GHD 2014).

“There is evidence of development of a wave cut notch at the toe of the slope, which implies ongoing undercutting and erosion of the toe of the slope by wave action. This is particularly evident in the north of the study area, where wave action is concentrated at the base of the slope during winter months, and reduces to the south. This erosion leads to collapse of the toe of the slope and debris slides to occur up slope” (GHD 2014).

The foreshore was divided into 6 zones based on geological features and susceptibility to hazards (GHD 2014). A map of the beach zones and hazard assessment is shown in Figure 6.

Zone 1 in the north has high slopes of Tamala Sand overlying Tamala Limestone which outcrops at the base of the slopes. The Tamala Limestone contains pinnacles with root casts, and has a cap rock layer. It is locally undercut by wave action with overhangs to a maximum height of 0.8 m and small cavities in the limestone up to approximately 0.5 m across. The sand above the limestone slopes at a gradient of approximately 20°, less than the angle of repose.

Zone 2 comprises around 9m of municipal fill overlying Tamala Limestone rock at the base of the cliff. The Tamala Limestone is described as up to 2.5m high forming a sub-vertical cliff and it is undercut with root casts acting as pillars supporting overhangs The fill material at the top of the face slope at 30° to 40°.

Zone 3 slopes are formed of municipal fill material and dune sands. The slopes stand at about 35°, the approximate angle of repose of the material. The slopes are generally well vegetated. Minor local outcrop of Tamala Limestone up to 1m high occurs at the base of the slope.

Zone 4 slopes are formed within municipal fill material overlying Tamala Limestone. The limestone is locally exposed at the base of the slopes up to a height of 1.3 m in the northern section and 2.5 m in the southern section. The slopes within Zone 4 are relatively steep, sloping between 30° to 50° and with overall heights ranging from 6 m to 9 m. The slopes within the northern section of Zone 4 are the steepest (45° to 50°).

Zone 5 slope(s) consists of black-red metallic slag material. The slope has an angle of approximately 60° and is only partially vegetated. There are indications that the slope is being undercut at the base by periodic wave action, particularly during storm events. This is causing the slope to erode back in an easterly direction. There is some reworked slag material at the toe of the slope as a result of the erosion process.

Zone 6 is a transition zone into natural beach dunes which slope at 20° and are 5 to 7m high. The beach in front of the slope is broader than the beaches to the north and continues to widen to the south. The slope is well vegetated.”

The foreshore zones were classified into four slope hazard descriptions based on the zone’s hazard susceptibility. Zones 1,4 and 5 were classified as having a low susceptibility to undercutting by wave action, erosion, slumping and debris slides. Zone 3 was classified as having a very low susceptibility to landslide hazard. Zone 2 was classified as having moderate susceptibility to landslide hazards and Zone 6, at the southern end of the site was classified as having no slope hazards being observed (GHD 2014).

2.5.1 Summary

The thickness and extents including the elevation of the Tamala limestone is not accurately known along this section of the coast, however as described by GHD in 2014, Tamala Limestone outcrops are evident at the base of dunes and an indicative height at locations is provided.

Based on GHD's assessment (2014) the southern end of the site (zone 6) transitions to more typical beach dunes and is therefore more susceptible to erosion by wave action.



Figure 6 Mosman Park Stability Assessment (GHD 2014).

2.6 Sediment cells

Coastal Sediment Cells for the Vlamingh Region between Cape Naturalists and Moore River (Stul et al 2015)

Sediment cells are lengths of coastline, which are spatially discrete from adjacent areas in that interruptions or changes to the movement of sediment along the coast do not significantly alter the sediment transport and beaches within adjacent cells. Sediment cells are connected by sediment exchange. Sediment budgets can be defined for sediment cells, which include areas of sand supply (sources), sand losses (sinks) within the cells as well as the transport into and out of the cell (Stul et al 2015).

The definition of sediment cells provides a useful context for coastal evolution, can be used to assist coastal management decision-making and natural resource management and provide guidance when considering jurisdictional boundaries, such as boundaries between local government areas (Stul et al 2015).

Port, Leighton and Mosman Beaches fall within the below sediment cell classifications detailed in Table 5.

Table 5 Sediment cell classification (Stul et al 2015)

Beach	Primary Cell	Secondary Cell	Tertiary Cell
Port Beach	R06F	25	a
Leighton Beach	R06F	25	a/b (division at salient)
Mosman Beaches	R06F	25	b

The southern boundary of secondary cell 25 is defined by the manmade rock structures of South mole and the dredged harbour channel. It is a fixed point and considered a closed boundary (Stul et al 2015). The northern extent is defined by the fixed point of the Mudurup Rocks outcrop and the Cottesloe engineered groyne, which restricts sediment transport on an annual scale but on longer time scales acts as an open boundary (Stul et al 2015).

Secondary cell 25 is divided into two tertiary sediment cells 25a which extends from the South Mole at Fremantle to the Leighton salient and the 25b that runs from the Leighton salient to Mudurup Rocks (Stul et al 2015). The Leighton salient boundary is described as an ambulatory zone that is open thus allowing transport of sediment across it. The offshore boundary of the tertiary cells is the -7m AHD isobath (Stul et al 2015). This indicates that changes in sediment transport in tertiary cell 25a over annual time scales are unlikely to influence tertiary cell 25b and vice versa.

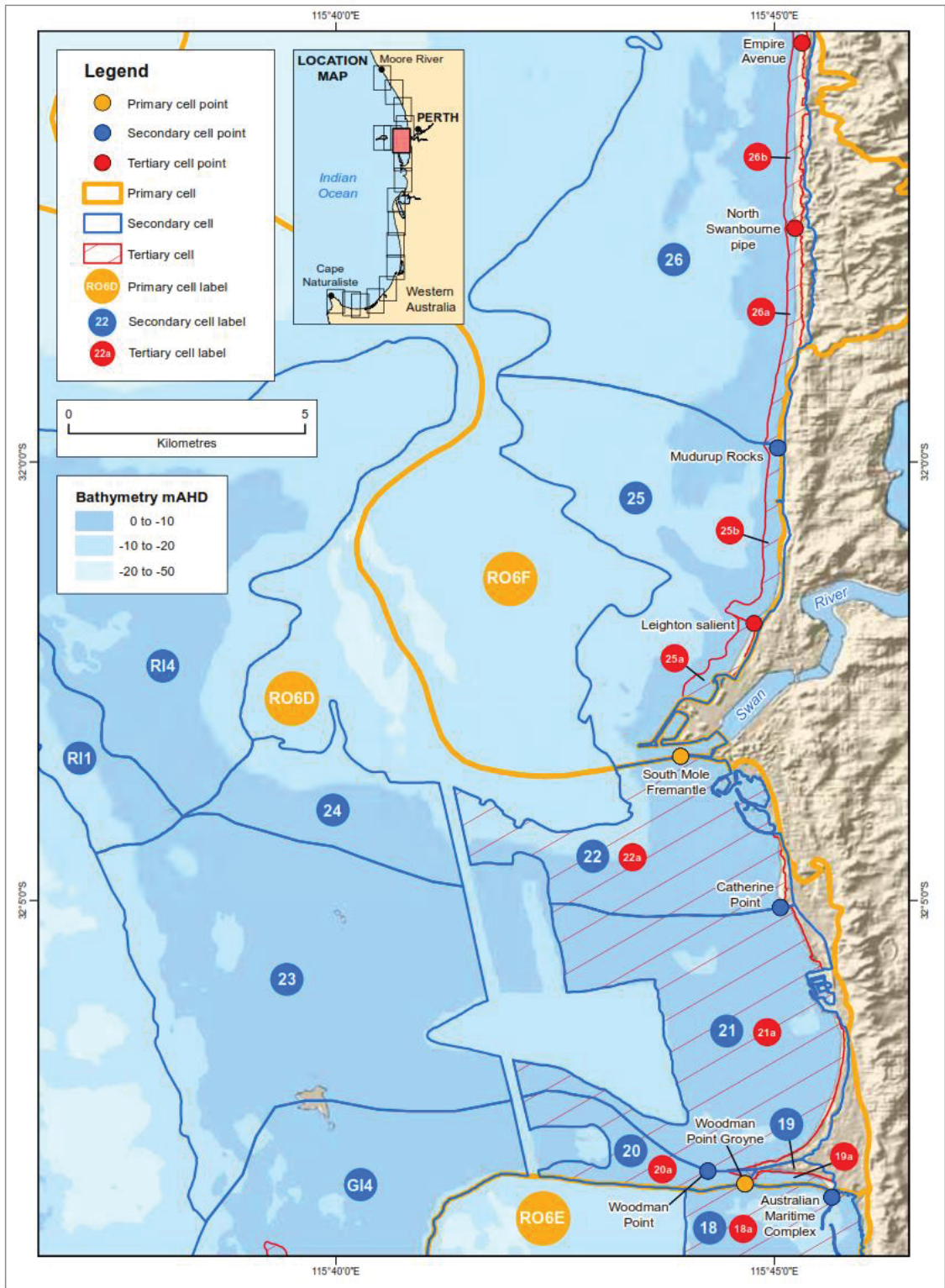


Figure 7 Secondary and tertiary sediment cells along the Perth coastline.

2.7 State Planning Policy

Schedule one of the state coastal planning policy (SPP2.6) (2013) was written with the intent to define the recommended setbacks required for new development along the coastline in regions not already developed or that are not considered infill development in response to the hazards of erosion and inundation on sandy coasts.

It is noted the latest revision of SPP2.6 provides a more conservative approach to estimation of the setback values and therefore it is expected that new estimates indicate larger set back values than those estimated in the previous years and with reference to other methods or policies now obsolete.

2.7.1 Inundation

According to SPP2.6, the allowance for the current risk of inundation is the maximum extent of inundation caused by the peak steady water level plus wave run-up. If the cross sectional area of the dune above the peak steady water level is less than 100 m³ then the dune is assumed to be removed during the storm and inundation extents are calculated without the dune. According to SPP2.6 the peak steady water level for the Perth area is defined by the 0.2% annual exceedance probability (1 in 500 year average recurrence interval event) caused by a mid-latitude depression or an extra tropical low storm.

2.7.2 Erosion

Schedule one of the State Planning Policy 2.6 stipulates that the following allowances be made for shoreline movement, with the combined values of these allowances equating to the required total physical setback distance from the horizontal shoreline datum:

Total erosion setback distance = S1 + S2 + S3 + Safety Factor + Landform Instability.

S1 Allowance for the current risk of storm erosion

The distance is calculated by modelling the impact of an extreme storm event sequence on the shoreline, at the development site. In the absence of modelling this value shall be set to 40m for cross shore erosion for the 100 ARI event on a typical sandy coast.

State Planning Policy 2.6 recommends that the storm event used to model movement in coastal alignment from erosion should be an event with a 1% annual exceedance probability of occurring in any given year during the planning timeframe.

S2 Allowance for historic shoreline movement trends

The allowance for historic shoreline movement should be based on a review of the available shoreline records. The allowance for historic shoreline movement trends should generally be calculated as 100 times the historic annual rate of erosion.

Shorelines with a long term accretion rate of less than 0.2 m per year, the setback allowance for historic shoreline trends should be zero.

Shorelines where the long term accretion rate is found to be in excess of 0.2 m per year, with compelling evidence that accretion is likely to continue at the same rate for at least the next 50 years, the allowance for historic shoreline movement trends should be calculated as minus 50 times the historic longer term annual rate of accretion.

The main limitation to historical shoreline movement is that historical rates of erosion may not reflect current and future changes in long term erosion forces and processes. Therefore, a degree of caution must be used when applying rates of erosion to long time periods.

S3 Allowance for erosion caused by future sea level rise

Allowance for sea level rise should be 100 times the adopted sea level rise value for the scenario being assessed.

Safety Factor

Schedule one of SPP2.6 requires setback calculations to include a 0.2m per year allowance for uncertainty.

Allowance for consideration of landform instability and sediment cell system dynamics

In addition to the three setback components and safety factor, consideration of landform instability, the net long shore sediment transport, structures in the area which may affect longshore transport and offshore sand bars that may input sand to the system, should be considered on a sediment cell scale.

3. Methodology

Below is an overview of the methodology undertaken to assess the erosion and inundation hazards at the time frames of present (2016), 2030, 2050, 2070, 2090 and 2110. These horizons were selected based on the request from the client and are in line with previous methodologies adopted for similar studies.

- Use calibrated regional wave model forced with Rottnest Island wave records at present sea levels to estimate nearshore waves.
- Extract modelled wave time series at approximately -10m to -15 CD (boundary of cross shore beach response model). Combine transformed wave conditions with recorded sea levels.
- Utilise SBEACH to: transfer wave and water levels from the extraction point nearshore, model beach storm erosion response and estimate nearshore extreme water levels. Inundation levels estimated using SBEACH will therefore include sea level rise, storm surge and wave setup.
- Summarise the results combined with other factors influencing erosion (such as historic and long-term effects) and geomorphology to develop erosion estimates for the study horizons.

3.1 Scenarios Definition

Definition of extreme water levels in this study follow an approach similar to that of the Cockburn Sound Coastal Alliance (CSCA) Coastal Vulnerability Study (2013). In this study, consideration of sea level rise scenarios is in line with the maximum of the likely range of the IPCC FAR estimates for the RCP scenarios as summarised in Table 6.

Table 6 Definition of inundation modelling scenarios.

Year Likelihood	2016	2030	2050	2070	2090	2110
Almost Certain	1 year ARI storm level (63% AEP) from the Mild Sea Level Rise Scenario (RCP2.6)					
Likely	Not Used					
Possible	10 year ARI storm level (10% AEP) from the Medium Sea Level Rise Scenario (RCP6)					
Unlikely	Not Used					
Rare	500 year ARI storm level (0.2% AEP) from the Severe Sea Level Rise Scenario (RCP8.5)					

The present day extreme water levels reported in CSCA Coastal Vulnerability Study (2013) are referenced in this study as, aside from wave setup nearshore, (which have been estimated using SBEACH), the levels are unlikely to vary substantially along the Perth coastline. The more exposed nature and straighter length of coastline of the Port, Leighton and Mosman Park beaches results in the setup component contributing more significantly to water levels. The levels to be used for the inundation modelling shown in Table 7, were adjusted to consider the RPC scenarios sea level rise described in Table 4.

Table 7 Input water levels for inundation modelling (mAHD). Storm surge + Sea Level Rise.

Year Likelihood	2016	2030	2050	2070	2090	2110*
Almost Certain	1.0	1.1	1.2	1.3	1.5	1.6
Likely	Not Used					
Possible	1.2	1.2	1.4	1.5	1.7	1.9
Unlikely	Not Used					
Rare	1.5	1.6	1.7	1.9	2.2	2.5

*2110 is based on a linear extrapolation of the sea level rise gradient for each RCP between 2090 and 2100.

Values are rounded to 1 decimal place

Definition of extreme wave scenarios will be based on repetition of selected historic storms. Two storms are used, namely a 2003 and a 1996 storm, both reported and evaluated in previous DoT publications such as Li and Ilich (2009) paper on storm waves and their temporal and directional distribution, Perth, 1994-2008. The 2003 storm has been previously used in CSCA to represent storm conditions in Perth. The 1996 storm is currently recommended by DoT as a base for estimation of minimum storm response set-back for use in planning purposes. The rare scenario represents that of 100 ARI storm event State Coastal Planning Policy (SPP 2.6) (WAPC 2013).

The scenarios for use in estimation of erosion hazards are summarised in Table 8 below. The peak of tide is adjusted to have an offset of 2 to 3 hours with the peak of offshore wave height to avoid unrealistic joint probability effects. The water level used in this assessment represented the actual recorded storm (varying between 0.9 and 1.2m AHD).

Table 8 Scenarios for storm erosion modelling

Likelihood Year	2016	2030	2050	2070	2090	2110
Almost Certain	1 occurrence of 2003 Storm at a tide signal reaching Almost Certain storm levels at each horizon					
Likely	Not Used					
Possible	1 occurrence of DoT 1996 Storm at a tide signal reaching Possible storm levels at each horizon					
Unlikely	Not Used					
Rare	3 consecutive occurrence of DoT 1996 Storm at a tide signal reaching Possible storm levels at each horizon					

3.2 Regional Wave Model

GHD had previously developed and validated a regional model to transfer extreme offshore wave conditions from Rottnest Island wave rider buoy to nearshore locations near Garden Island. The model had been used in studies of a number of projects near Garden Island and was calibrated using ADCP data collected near the Garden Island Causeway. The model was used to transfer recorded wave time series from the Rottnest Island wave rider buoy to the end

of representative SBEACH profiles for Mosman Beach, Leighton Beach and Port Beach. Given the extraction of the model results were intended at depths outside the surf area, the modelling of offshore waves was undertaken at a constant water level representing present conditions. It is noted that in transferring the extracted time series from the point offshore surf zone to the beach, the actual water levels associated with the storm and horizon were used and influence of tidal fluctuations is considered. The setup of the regional wave model is therefore as per Table 9.

Table 9 Definition of storm event for regional wave modelling

Likelihood Year	2016	2030	2050	2070	2090	2110
Almost Certain	1x2003 Storm					
Likely	Not Used					
Possible	1x1996 Storm					
Unlikely	Not Used					
Rare	3x1996 Storm					

The extent of the regional model and extraction points are shown in Figure 8. The results were extracted at 12 selected points as time series of wave height, period and directions for each of the 3 offshore wave scenarios shown above.

3.3 Beach controls and properties

Analysis of the February 2008 Fugro Light Detecting and Ranging (Lidar) survey of the Perth Metropolitan area within the study site and aerial imagery (Landgate Perth 2016 Mosaic) was used to gain an understanding of beach properties at Port, Leighton and Mosman beaches important for use in erosion analysis. Table 10 includes a summary of beach type and dune elevation features and Table 11 includes a summary of natural and manmade controls along Port, Leighton and Mosman beaches which influence sediment transport and beach stability. We note that previous reports suggest a vegetation line of approximately +2.0mCD. The continuous erosion of the shoreline at Port and Leighton beach could have contributed to a higher estimated level of vegetation line in this study.

Table 10 Summary of beach properties.

Location	Beach description	Approx. Foreshore vegetation line elevation	Average dune barrier elevation
Port Beach	Sandy beach, reflective, reef-protected.	3.0 to 3.5m AHD	4.0m AHD (maximum of 5.5m AHD)
Leighton Beach	Sandy beach, reflective, reef-protected.	2.0 to 2.5m AHD (Vlamingh Parkland) 2.5 to 3m AHD (South & Mid Leighton)	4.0 to 4.5m AHD (maximum of >6m AHD)

Location	Beach description	Approx. Foreshore vegetation line elevation	Average dune barrier elevation
Mosman Beach	Mixed sandy and rocky, reflective, reef-protected beach. Dunes are founded on a variable rocky layer of unknown thickness and extents. The beach is perched with an intertidal platform that is often exposed in winter after storms.	3.0 to 3.5m AHD	10 to 11m AHD
South Cottesloe Beach	Mixed sandy and rocky, reflective, reef-protected.	3.0 to 3.5m AHD	10m AHD

Table 11 Description of beach controls and engineered features.

Area / common name	Chainage from Rous Head/South Beach	Control points and engineered features
South Port Beach/ Sandtracks	0m	Rous Head Extension rock revetment
	0m to 270m	Seawall from Rous Head Extension to southern end of Sandtracks carpark.
	385m to 450m	Rock revetment at northern entrance to Sandtracks carpark
Port Beach	560m to 635m	Rock revetment at southern end of Port Beach carpark
Leighton Beach	2730m	N/A
Mosman Beach	3135m	Rocky shoreline north of Mosman Reserve Beach carpark
		Rock outcrop
		Artificial reef
Cottesloe Beaches	N/A	Beach Street Rock Groyne

3.4 SBEACH Modelling

The SBEACH modelling was undertaken for 3 different profiles, 3 different likelihood scenarios and 6 timeframes (54 Scenarios). The profiles were extracted from DoT Lidar at the model extent and the location of the profiles are shown in Figure 8 and cross sections are shown in Figure 9. A typical tide profile was used as a base to generate input water level signal. The peak of the tide was adjusted to represent the recorded water level during the selected 1996 or 2003 storms.

Figure 8 Model Extent

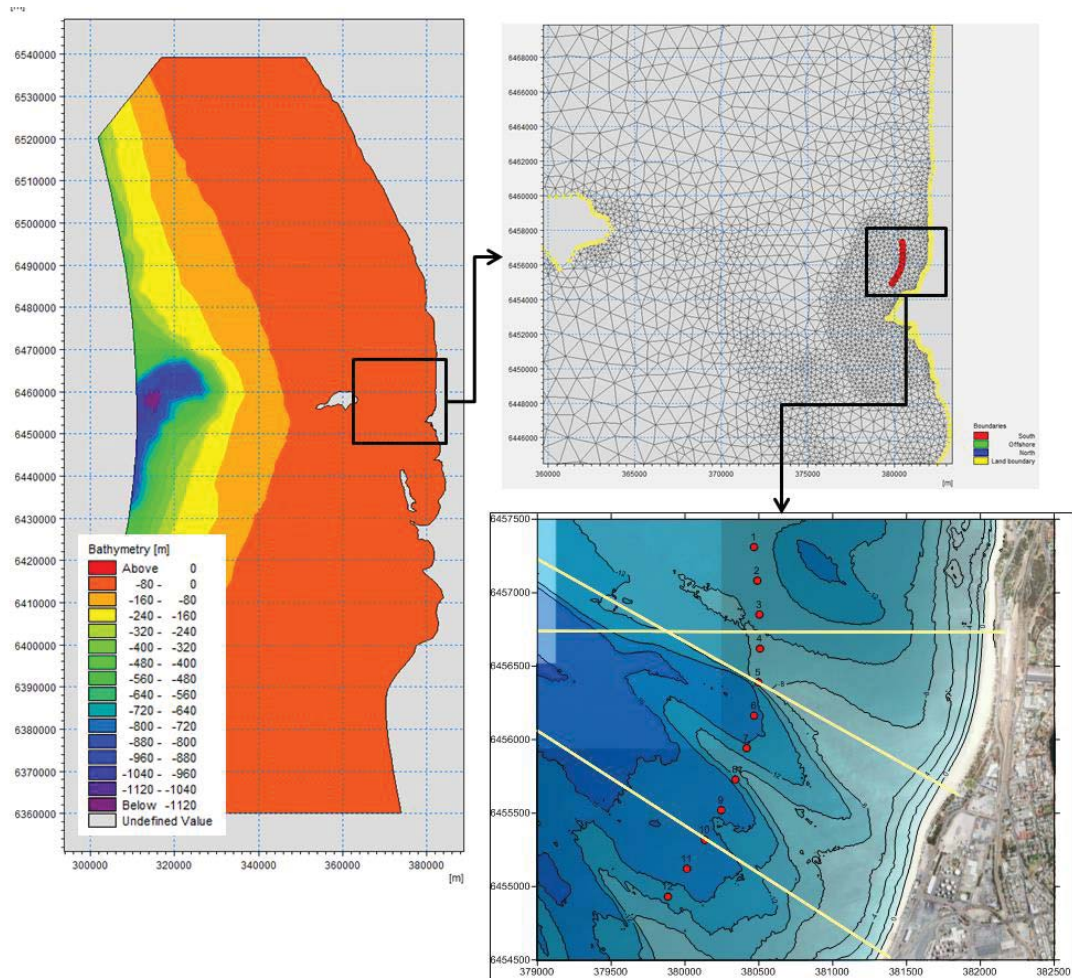
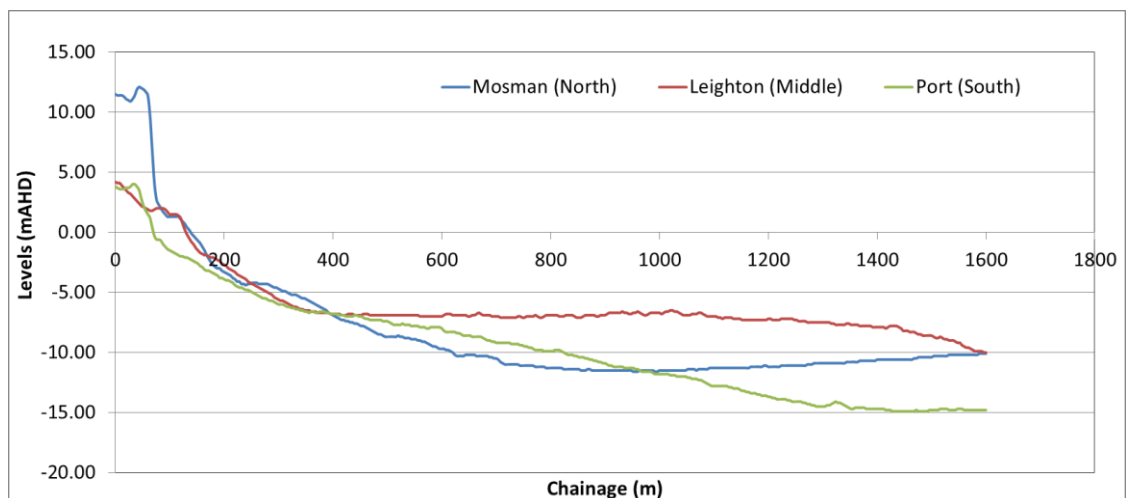


Figure 9 Beach Profiles



3.5 SBEACH Parametrisation

Parametrisation used in the SBEACH model was based on the mean recommended parametrisation from Ilich (2009). Sensitivity testing was also undertaken to understand the sensitivity of the storm erosion at each profile to grain size and water level. A conservative grain size of 0.35mm equivalent was used in the estimates. It is noted that the recorded D50 at this site is likely to be larger than the number used in the modelling however the selected D50 along

with other parameters provides reasonable estimates of erosion comparable with other studies undertaken for this or other similar regions of the coastline.

The seawall at Port Beach was also noted and not included, to highlight the potential risk if this structure is not maintained. Mosman beach has been excluded from the S1 assessment due to:

- vegetation/cliff line at Mosman Beach exhibiting a gradual historical erosion in response to wave climate as opposed to event based dune erosion seen on the adjacent sandy beaches at Leighton and Port Beach in response to severe storm events; and
- the presence of the Tamala Limestone along base of the foreshore slopes which withstands wave erosion better than adjacent sandy dunes.

3.6 Inundation Results

The peak water levels from SBEACH account for the combined sea level rise, tide, storm surge and wave setup effects. The results are summarised in Table 12 below and shall be used for evaluation of the extent of inundation events across the study area.

Table 12 Inundation Levels. (Storm surge + wave setup + sea level rise)

Likelihood	2016	2030	2050	2070	2090	2110
Almost Certain	1.8	1.9	2.0	2.2	2.3	2.4
Possible	1.8	1.9	2.0	2.2	2.4	2.6
Rare	2.1	2.2	2.4	2.6	2.9	3.2

3.7 Erosion Results

Allowance for erosion for each scenario has been calculated by addition of the below described components. To assist in classifying the erosion properties along the study site, the site has been divided into erosion groups based on trends in historical shoreline.

3.7.1 Allowance of Acute Storm Erosion

Erosion was assessed at two levels, at the mean water level input into the SBEACH scenario and at the HSD (classified as the mean elevation of the vegetation line which varied between 2 to 3.0m AHD at Leighton Beach to 3 to 3.5m AHD at Mosman Beach and Port Beach.

The S1 estimates are generally in line with previous records or estimated values by other studies except that the Rare estimate at Leighton beach (30m) is 5m more than the estimates made by MPRA or DPI in the previous studies. Given the planning horizon associated with this study, the newly estimated values are found to be reasonable and will be referenced in the evaluation of erosion hazards.

Table 13 Possible S1 Storm erosion distances (+/- 5m accuracy).

Site	Almost Certain	Possible	Rare
Mosman	0m	0m	0m
Leighton	5m	20m	30m
Port	10m	15m	25m

3.7.2 Allowance for long-term shoreline response to sediment supply

Historical shoreline movement was assessed using the Digital Shoreline Analysis System (DSAS) (Theiler et al 2009) from historical vegetation lines provided by DoT from 1945 to 2009, plus digitisation of the 2016 vegetation line.

From 1945 to 1983, Sandtracks Beach accreted approximately 60 to 70m. The construction of the Rous Head Harbour in 1989 however had a significant influence on sediment transport patterns, shifting to erosion as observed from historical shorelines from 1993 onwards. As such estimates of erosion rates for Port Beach have been assessed before and after construction of the Rous Head Harbour, whereas, Leighton and Mosman Beach include the full data set provided from 1945 to 2016. Other events such as dredging and nourishment activities may also influence the results and have not been accounted for in this analysis due to lack of a detailed information and accuracy.

The estimated shoreline movement numbers are in line with the previous estimates made by DPI (2004) but in some areas are more than the values reported by MPR (2000). It is noted that use of more recent aerial imagery results in larger estimated erosion rates. Given that the shoreline movement rates are to be used for a planning horizon of 100 years and that some of the recent erosion events are likely to be linked to completion of the Rous Head development, the measured rates at Port Beach could be considered too conservative. As such, the values used for calculation into the future have been summarised alongside the measured rates in Table 14.

Table 14 Results from historical shoreline analysis using DSAS.

Erosion Group	Area Name	Chainage from South end of Port Beach	Annual Shoreline Movement Rate (m/year)	Value used in S2 calculation (m/year)	Trend
1	Sandtracks/ Southern Port Beach	0 to 500	+1.50 (1945 to 1983) -2.00 (from 1993 to 2016)	-2.0 (from present to 2030) -1.0 (from 2030 to 2110)	Eroding
2	Port Beach Main	500 to 1200	-0.80	-0.8	Eroding
3	South of Leighton SLSC	1200 to 1400	+0.20	0	Transitional
4	North Leighton, Vlamingh Parklands	1400 to 2500	+0.3 to +2.0 (+1.2 mean)	0	Accreting
5	Mosman Dog Beach	2500 to 2700	-0.10	-0.1	Stable Rock
6	Mosman (Beehive Montessori)	2700 to 3000	-0.10	-0.1	Gradual erosion Perched beach

The erosion rates are in line with the previous estimates made by DPI (2004) but in some areas are more than the values reported by MPRA (2000). It is noted that use of more recent aerial imagery results in larger estimated erosion rates. Given that these rates are to be used for a planning horizon of 100 years, historical evidence for periodical accretion at the sites and that some of the recent erosions are likely to be linked to completion of the Rous Head development,

the estimates (especially use of 2m/year for the southmost area of the study) could be considered conservative. As a result the shoreline movement rate used for erosion group 1 in the short term was -2.0m/ year, and in the medium and long term a reduced shoreline movement rate of -1.0m/ year (average of the contemporary and long-term values).

In line with the State Coastal Planning Policy (SPP2.6), the allowance for each section has been calculated as the time period by the erosion rate for eroding shorelines and 0 for shorelines accreting at less than 0.2m per year. The only other difference other to that stated above is that for the accreting shoreline at Leighton Beach an allowance of 0m per year has been used to account for uncertainty about future sediment supply see section 3.7.3.

3.7.3 Allowance for landform instability

The only alongshore boundary within the study region is the Leighton Beach salient which is classified as a tertiary sedimentary feature. DPI (2004) speculated that the accretion trend at Port and Leighton beach were a result of dredging and reclamation works associated with the port development in the last century. Review of aerial imagery and bathymetry from Lidar indicates a sand spit feed which is shallower with less seagrass coverage. Due to the highly dynamic nature of tertiary landforms such as this sedimentary salient and the uncertainty of future sediment supply from this feature, a historical shoreline movement rate of 0 m/year has been used for Leighton Beach (erosion groups 3 and 4).

3.7.4 Allowance for gradual change in shoreline caused by sea level rise

SPP2.6 Schedule One recommends application of Brunn multiplier of 100 times the vertical component of sea level rise for sandy coasts to estimate sea level rise induced shoreline retreat. The Brunn Rule equation (Mariani et al 2012):

$$R = \frac{1}{\tan\theta} S$$

Where R is the horizontal extent of landward retreat, θ is the cross shore slope and S is the sea level rise. The Brunn multiplier of 100 in indicates a $\tan\theta$ of approximately 0.01. For a steeper beach slope such as Mosman where the slope is approximately 0.04 a Brunn multiplier in the vicinity of 25 times the sea level rise would be the outcome of the Brunn Rule equation.

The Brunn Rule equation (Schwartz 1967, in Mariani et al 2012) is based on a number of assumptions which result in limitations to its applications. The main limitation of the application of the Brunn rule to locations such as Mosman beach is that the rule does not accommodate variations in sediment properties across the profile such as substrate geology or adjacent engineered structures (Mariani et al 2012). The Tamala sand dunes at Mosman beach are underlain by outcropping Pleistocene Tamala Limestone, which has an increased ability to buffer erosion over a purely sand dune and as such the Brunn multiplier, indicating the horizontal retreat of the beach due to sea level rise in this area has been reduced to 10.

Due to the variable nature of the onshore boundary within the tertiary sediment cells from sandy beaches at Port and Leighton Beach to high elevated dunes founded on Pleistocene Tamala Limestone and perched beaches in Mosman Park, the approach to assess sea level change on future shoreline position has been summarised in Table 15. The horizontal component calculated using the relative Brunn multiplier for each scenario is summarised in Appendix A.

Table 15 Review of landforms and approach to address sea level rise.

Location	Landforms	Approach to Sea level change
Mosman (CH2550 to 3000)	Rock at back of beach	Limited by rock, shoreline erosion limited. Brunn multiplier of 10.
Leighton (CH1200 to 2550)	Sandy open beach	Brunn model, Brunn multiplier of 100.
Port Beach (CH0 to CH1200)	Sandy open beach	Brunn model, Brunn multiplier of 100.

3.7.5 Allowance for uncertainty

In line with SPP2.6, a 0.2m/year allowance has been incorporated into each scenario.

3.7.6 Combined erosion results for each timeframe

A summary of the combined erosion hazard setback distances for each erosion group, erosion likelihood and timeframe is summarised in Table 16 and the breakdown of each component is included in Appendix A.

Table 16 Combined Erosion Hazard Likelihoods

Location			Combined Erosion Setback					
Erosion Group	Area Name	Chainage from South end of Port Beach	2016	2030	2050	2070	2090	2110
Almost Certain								
1	Sandtracks/ Southern Port Beach	0 to 500	10	50	85	125	160	200
2	Port Beach Main	500 to 1200	10	35	65	100	130	165
3	South of Leighton SLSC	1200 to 1400	5	20	35	50	70	85
4	North Leighton, Vlamingh Parklands	1400 to 2500	5	20	35	50	70	85
5	Mosman Dog Beach	2500 to 2700	0	5	15	20	30	35
6	Mosman (Beehive Montessori)	2700 to 3000	0	5	15	20	30	35
Possible								
1	Sandtracks/ Southern Port Beach	0 to 500	15	55	90	130	175	220
2	Port Beach Main	500 to 1200	15	40	70	105	145	185
3	South of Leighton SLSC	1200 to 1400	20	35	50	70	90	115
4	North Leighton, Vlamingh Parklands	1400 to 2500	20	35	50	70	90	115
5	Mosman Dog Beach	2500 to 2700	0	5	15	20	30	40
6	Mosman (Beehive Montessori)	2700 to 3000	0	5	15	20	30	40
Rare								
1	Sandtracks/ Southern Port Beach	0 to 500	25	65	105	150	205	260
2	Port Beach Main	500 to 1200	25	50	85	125	175	225
3	South of Leighton SLSC	1200 to 1400	30	45	65	90	120	155
4	North Leighton, Vlamingh Parklands	1400 to 2500	30	45	65	90	120	155
5	Mosman Dog Beach	2500 to 2700	0	10	15	25	30	40
6	Mosman (Beehive Montessori)	2700 to 3000	0	10	15	25	30	40

4. Results

A discussion on the results of the erosion and inundation assessment can be found in the Coastal Adaptation Plan under the section titled “An evolving coastline: Erosion Hazard and Inundation Hazard”.

Estimation of hazard lines are based on the method described in WA Coastal Planning Policy, SPP2.6. Several assumptions are made in estimating various components as described within the methodology. The results are compared and benchmarked against previous studies summarised below in Table 17. This comparison indicates that the results of this study for S1 storm erosion and S2 historical shoreline movement align well with other existing studies. The main factor which contributed to the difference in setback previously reported on and this study is due to the S3 sea level rise component and the increase in available predictions on sea level rise included in the revision of SPP 2.6 in 2013 and in Bicknell 2010.

Table 17 Comparison of setback results.

Report	Location	S1 Storm Erosion of Vegetation line(m)	S2 Historical Shoreline Movement Rate (m/year)	S3 Sea Level Rise to 2110 (m)	Safety Factor (m)	Combined (m)
This study (2110 Rare)	Mosman, Leighton, Port	0	-0.1	10.4	20	40
		30	0	104	20	155
		25	-2.0 (to 2030 and -1 to 2110)	104	20	260
Tingay 1999	Leighton	20 to 25	0	20 by 2030	20	65
MPRA 1998	Port	5 to 10	n/a	n/a	n/a	n/a
MPRA 2000	Port	10 to 25	n/a	n/a	n/a	n/a
WAPC 2002	Leighton	41	0	34 * to 2100	20	95
DPI 2004	Sandtracks Port (main) Port (north) Leighton	25 for Port and Leighton	-2.2 -0.8 0 +1 (1993 to 2000)	n/a	n/a	n/a
SPP2.6 (WAPC 2013)	n/a	varies	varies	90	20	n/a

4.1 Maps

The results of the erosion and inundation mapping can be found in Appendix C of the Coastal Adaptation Plan.

4.2 Recommendations

Based on the review of the available literature and the results of this study the following recommendations are made which could be used to improve the accuracy of the estimation of erosion and inundation hazards.

Undertaking beach monitoring surveys including seasonal beach transects and regular photo monitoring could improve understanding of beach dynamics along the Port, Leighton and Mosman Park foreshore.

Ongoing beach and hydrographic survey data at Port Beach has been collected on and reported on (DPI 2004, MPRA 2010 and 2013) however this information could be combined and further developed to improve the conceptual sediment transport model at Port and Leighton. This would improve understanding of likely beach response to future changes in sediment transport pathways for adaptation options.

Continued slope and vegetation monitoring of the Mosman Beach Foreshore, as noted in GHD 2014 should continue.

Assessment of the risk of exposure of contaminated materials from the Mosman municipal tip and from the historical Fuel Tanker stores between Port and Leighton Beach should be further investigated as the potential erosion highlighted to the foreshore in this study could increase the exposure risk.

Geotechnical survey of the Mosman and North Leighton foreshore is strongly recommended to reduce the uncertainty in the potential erosion hazard lines for this section of the coast. The type of survey recommended should be similar to the geophysical surveys undertaken for the City of Cottesloe completed by GPGMAPS Pty Ltd in 2010 and 2011 with the addition of referencing of ground and bedrock levels to a vertical datum (preferably to AHD). This type of survey will provide information on the extents, depth and density of the different layers (overlying sand and rock) and will provide more certainty in assessing the foreshore's potential resistance to erosion. It is recommended that as new information becomes available and predictions about sea level rise are amended, that the coastal hazards to Port, Leighton and Mosman beach should be reviewed, after no more than ten years.

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Appendix A - Erosion Hazard Line Components

Location			2016						2030						2050					
Erosion Group	Area Name	Chainage from South end of Port Beach	S1	S2	S3	SF	Combined	Rounded	S1	S2	S3	SF	Combined	Rounded	S1	S2	S3	SF	Combined	Rounded
Almost Certain			Almost Certain						Almost Certain						Almost Certain					
1	Sandtracks/ Southern South Beach	0 to 500	10	0	0	0	10	10	10	28	8	2.8	48.8	50	10	48	20	6.8	84.8	85
2	South Beach Main	500 to 1200	10	0	0	0	10	10	10	11.2	8	2.8	32	35	10	27.2	20	6.8	64	65
3	South of Leighton SLSC	1200 to 1400	5	0	0	0	5	5	5	0	8	2.8	15.8	20	5	0	20	6.8	31.8	35
4	North Leighton, Vlamingh Parklands	1400 to 2500	5	0	0	0	5	5	5	0	8	2.8	15.8	20	5	0	20	6.8	31.8	35
5	Mosman Dog Beach	2500 to 2700	0	0	0	0	0	0	0	1.4	0.8	2.8	5	5	0	3.4	2	6.8	12.2	15
6	Mosman (Beehive Montessori)	2700 to 3000	0	0	0	0	0	0	0	1.4	0.8	2.8	5	5	0	3.4	2	6.8	12.2	15
Possible			Possible						Possible						Possible					
1	Sandtracks/ Southern South Beach	0 to 500	15	0	0	0	15	15	15	28	8	2.8	53.8	55	15	48	20	6.8	89.8	90
2	South Beach Main	500 to 1200	15	0	0	0	15	15	15	11.2	8	2.8	37	40	15	27.2	20	6.8	69	70
3	South of Leighton SLSC	1200 to 1400	20	0	0	0	20	20	20	0	8	2.8	30.8	35	20	0	20	6.8	46.8	50
4	North Leighton, Vlamingh Parklands	1400 to 2500	20	0	0	0	20	20	20	0	8	2.8	30.8	35	20	0	20	6.8	46.8	50
5	Mosman Dog Beach	2500 to 2700	0	0	0	0	0	0	0	1.4	0.8	2.8	5.0	5	0	3.4	2	6.8	12.2	15
6	Mosman (Beehive Montessori)	2700 to 3000	0	0	0	0	0	0	0	1.4	0.8	2.8	5.0	5	0	3.4	2	6.8	12.2	15
Rare			Rare						Rare						Rare					
1	Sandtracks/ Southern South Beach	0 to 500	25	0	0	0	25	25	25	28	9	2.8	64.8	65	25	48	24	6.8	103.8	105
2	South Beach Main	500 to 1200	25	0	0	0	25	25	25	11.2	9	2.8	48	50	25	27.2	24	6.8	83	85
3	South of Leighton SLSC	1200 to 1400	30	0	0	0	30	30	30	0	9	2.8	41.8	45	30	0	24	6.8	60.8	65
4	North Leighton, Vlamingh Parklands	1400 to 2500	30	0	0	0	30	30	30	0	9	2.8	41.8	45	30	0	24	6.8	60.8	65
5	Mosman Dog Beach	2500 to 2700	0	0	0	0	0	0	0	1.4	0.9	2.8	5.1	10	0	3.4	2.4	6.8	12.6	15
6	Mosman (Beehive Montessori)	2700 to 3000	0	0	0	0	0	0	0	1.4	0.9	2.8	5.1	10	0	3.4	2.4	6.8	12.6	15
Location			2070						2090						2110					
Erosion Group	Area Name	Chainage from South end of Port Beach	S1	S2	S3	SF	Combined	Rounded	S1	S2	S3	SF	Combined	Rounded	S1	S2	S3	SF	Combined	Rounded
Almost Certain			Almost Certain						Almost Certain						Almost Certain					
1	Sandtracks/ Southern South Beach	0 to 500	10	68	33	10.8	121.8	125	10	88	46	14.8	158.8	160	10	108	60	18.8	196.8	200
2	South Beach Main	500 to 1200	10	43.2	33	10.8	97	100	10	59.2	46	14.8	130	130	10	75.2	60	18.8	164	165
3	South of Leighton SLSC	1200 to 1400	5	0	33	10.8	48.8	50	5	0	46	14.8	65.8	70	5	0	60	18.8	83.8	85
4	North Leighton, Vlamingh Parklands	1400 to 2500	5	0	33	10.8	48.8	50	5	0	46	14.8	65.8	70	5	0	60	18.8	83.8	85
5	Mosman Dog Beach	2500 to 2700	0	5.4	3.3	10.8	19.5	20	0	7.4	4.6	14.8	26.8	30	0	9.4	6	18.8	34.2	35
6	Mosman (Beehive Montessori)	2700 to 3000	0	5.4	3.3	10.8	19.5	20	0	7.4	4.6	14.8	26.8	30	0	9.4	6	18.8	34.2	35
Possible			Possible						Possible						Possible					
1	Sandtracks/ Southern South Beach	0 to 500	15	68	35	10.8	128.8	130	15	88	55	14.8	172.8	175	15	108	75	18.8	216.8	220
2	South Beach Main	500 to 1200	15	43.2	35	10.8	104	105	15	59.2	55	14.8	144	145	15	75.2	75	18.8	184	185
3	South of Leighton SLSC	1200 to 1400	20	0	35	10.8	65.8	70	20	0	55	14.8	89.8	90	20	0	75	18.8	113.8	115
4	North Leighton, Vlamingh Parklands	1400 to 2500	20	0	35	10.8	65.8	70	20	0	55	14.8	89.8	90	20	0	75	18.8	113.8	115
5	Mosman Dog Beach	2500 to 2700	0	5.4	3.5	10.8	19.7	20	0	7.4	5.5	14.8	27.7	30	0	9.4	7.5	18.8	35.7	40
6	Mosman (Beehive Montessori)	2700 to 3000	0	5.4	3.5	10.8	19.7	20	0	7.4	5.5	14.8	27.7	30	0	9.4	7.5	18.8	35.7	40
Rare			Rare						Rare						Rare					
1	Sandtracks/ Southern South Beach	0 to 500	25	68	46	10.8	149.8	150	25	88	74	14.8	201.8	205	25	108	104	18.8	255.8	260
2	South Beach Main	500 to 1200	25	43.2	46	10.8	125	125	25	59.2	74	14.8	173	175	25	75.2	104	18.8	223	225
3	South of Leighton SLSC	1200 to 1400	30	0	46	10.8	86.8	90	30	0	74	14.8	118.8	120	30	0	104	18.8	152.8	155
4	North Leighton, Vlamingh Parklands	1400 to 2500	30	0	46	10.8	86.8	90	30	0	74	14.8	118.8	120	30	0	104	18.8	152.8	155
5	Mosman Dog Beach	2500 to 2700	0	5.4	4.6	10.8	20.8	25	0	7.4	7.4	14.8	29.6	30	0	9.4	10.4	18.8	38.6	40
6	Mosman (Beehive Montessori)	2700 to 3000	0	5.4	4.6	10.8	20.8	25	0	7.4	7.4	14.8	29.6	30	0	9.4	10.4	18.8	38.6	40

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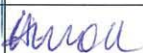

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Appendix E – Risk Assessment

The risk assessment undertaken for Port, Leighton and Mosman Beach follows the framework outlined in the WAPC 2014 Coastal Hazard Risk Mapping and Adaptation Guidelines (CHRMAP Guidelines). Risk is assessed by combining the “likelihood” of a coastal hazard impacting an asset with the “consequence” of that impact. To determine this, a likelihood scale and consequence scale were developed in the context of the Port, Leighton and Mosman Beach sites.

Analysis of the coastal hazards (see report section Coastal Hazard Likelihoods and Appendix D) found inundation to pose an insignificant risk to assets within the three zones of Port, Leighton and Mosman Beach. As a result, the risk assessment is significantly influenced on the likelihood and consequence of erosion on existing and future assets.

Likelihood

Likelihood is defined as the chance of a coastal hazard occurring and how often it may impact an asset. Table 0-1 identifies the hazard likelihood for erosion based on the technical inputs developed by the Coastal Hazards Assessment. Further information on how the likelihood scale was established is detailed in Appendix D – Coastal Hazard Assessment.

Table 0-1 Likelihood of Scale

Hazard Likelihood	Erosion
Almost Certain	1 occurrence of moderate erosion event + mild sea level rise scenario* + historical erosion trend
Possible	1 occurrence of severe erosion event + medium sea level rise scenario* + historical erosion trend
Rare	3 occurrences of severe erosion event + high sea level rise scenario* + historical erosion trend

*for timeframe

Consequence

Consequence is the impact of coastal hazards on assets and their values. Consequences relate not only to the direct impact or damage to an asset but also the effect on related social, economic and environment values (WAPC 2014). The scale identifies levels of consequence, from insignificant to catastrophic, across a range of categories depending on the defined impact of a coastal hazard to an asset. Where an asset relates to more than one category, the category with the highest scale of

consequence will be selected. Community values, as outlined in the survey summary (see Appendix A) and the Values Register (see Appendix B) have been taken into consideration when defining the level of consequence the coastal hazard will have on an asset.

The risk assessment defined consequences for the value types that had been identified in the study area: Social, economic, environment and infrastructure. Based on literature review of other consequence scales, safety was also included as a key consequence type. The scale of consequence for the different categories were selected to represent the range of potential consequences relevant to the context of the study area. For example, the social consequence scale ranges from local to regional as both local residents and people across the Perth metropolitan area use and value social services and experiences unique to the area. Setting the consequence levels to cover the expected scale of potential impacts is important as it assists decision makers to prioritise risks requiring mitigation. Use of state-wide or national scales for some categories, would not allow identification of risks appropriate to the scale of this project.

The environmental scale was based on the potential damage to the local environment, the ability for the environment to recover, for damage to be of offset and identification of alternate habitat areas. For example erosion of a small area of foredune vegetation in an area with a wide dune habitat is not going to impact on all of the dune habitat and through natural processes dune vegetation has the ability to recover from small amounts of damage so consequence is less critical than if it could not recover.

The infrastructure impact scale was developed based on the proportion of infrastructure impacted, whether the asset was sensitive to gradual versus a threshold response to coastal hazards and its adaptive capacity, in line with the Coastal hazard risk management and adaptation planning guidelines (WAPC 2014).

When considering coastal hazard likelihoods in the present planning period, existing erosion controls such as the seawalls along Port Beach Road were not considered due to varying engineered quality of the implemented structures. Risk levels of existing erosion structures quality and expected design life were taken into consideration in the adaptation planning phase.

The scale in Table 0-2 identifies unmitigated risk. In locations where existing erosion controls are in place, such as the seawall along Port Beach Road adjacent the Rous Head Extension, they will be taken into consideration in the adaptation planning phase.

The social consequence scale was defined through the community survey. The importance of social values in a particular place were measured by two key elements – access and impact. The impact that value/experience has on someone's quality or way of life, and their ability to access that value/experience.

The importance of (or the level of consequence of the loss of) these two elements of access and impact was directly questioned in the community survey, and directly

reflected in the consequence scale. The development of economic, environment and safety were informed by literature review of similar scales. The development of the infrastructure consequence scale was informed by professional opinion of infrastructure engineers.

Access

- Very important – cannot be conveniently accessed elsewhere
- Somewhat important – can be conveniently accessed elsewhere, with a preference to access it in this location
- Not important – can conveniently accessed elsewhere

Impact

- Very important (significant impact) – the loss of the value/experience would significantly impair my way of life
- Somewhat important (some impact) – the loss of the value/experience would impair my way of life, but I could live without it
- Not important (negligible impact) – the loss of the value/experience would not impair my way of life

To undertake the risk assessment, a consequence level was selected in line with the consequence scale for each asset in the study area affected by coastal hazards. For most consequence types, this definition was quantifiable. For social values, the consequence level was determined based directly on survey responses in relation to “ability to access” and “impact on way of life” for the value most influenced by the particular asset.

Table 0-2 Scale of Consequence

		Category				
		Social	Economic	Environment	Infrastructure	Safety
5	Catastrophic	Loss of social or heritage values of regional significance; no alternative exists	Damage to local economy, public infrastructure or loss of land value greater than \$20 million	Irreversible damage to local environmental asset that would compromise its viability, no alternate habitats exist.	Damage to majority or all of infrastructure (Greater than 75%). Asset with step change sensitivity and no adaptive capacity.	Loss of life and serious injury
4	Major	Loss of social services and experiences that would significantly impair quality of life of the local community; no convenient alternative exists	Damage to local economy, public infrastructure or loss of land value \$5 million to \$20 million	Irreversible damage to local environmental asset that would compromise its viability, local alternate habitat exists.	Damage to significant portion of infrastructure (50% - 75%) or asset with step change sensitivity. Asset with step change sensitivity and some adaptive capacity.	Serious injury
3	Moderate	Loss of social services and experiences that would somewhat impair quality of life of the local community; no convenient alternative exists	Damage to local economy, public infrastructure or loss of land value \$500,000 to \$5 million	Environmental damage to local environmental asset that could be reversed or offset, no alternate habitats exist.	Damage to no more than half of the infrastructure (25% - 50%). Asset with step change sensitivity with adaptive capacity.	Minor injury
2	Minor	Loss of social services and experiences that would somewhat impair quality of life of the local community; alternative sites exist	Damage to local economy, public infrastructure or loss of land value \$50,000 to \$500,000	Environmental damage to local environmental asset that could be reversed or offset, local alternate habitat exists.	Minor damage to infrastructure (10% - 25%)	No injury
1	Insignificant	Loss of social services and experiences that would have limited impact on quality of life; many alternative sites exist	Damage to local economy, public infrastructure or loss of land value less than \$50,000	Minimal damage to local environmental assets; recovery may take less than six months	Little or no damage to infrastructure (Less than 10%)	No injury

Risk Evaluation

Risk levels enable decision-makers to prioritise actions based on the likelihood and consequence of a hazard on existing assets. Four risk levels have been identified for the assessment and follow the scale set out in the CHRMAP Guidelines:

- Extreme – risks are unacceptable/intolerable, requiring immediate management and adaptation action.
- High – risks are the most severe that can be tolerated and need monitoring in the short-term as management and adaptation action is likely to be needed in the short-term.
- Medium – risk can be tolerated and need monitoring in the short to medium-term.
- Low – risk can be accepted; no actions will be required in the short to medium-term.

The matrix in Table 0-3 below defines the risk level based on “likelihood” x “consequence”.

Table 0-3 Risk Evaluation Matrix

Likelihood	Risk Level				
A Almost certain	Medium	High	High	Extreme	Extreme
C Possible	Low	Medium	High	High	Extreme
E Rare	Low	Low	Medium	High	High
	1 Insignificant	2 Minor	3 Moderate	4 Major	5 Catastrophic
	Consequence				

Tolerance Level

The varying levels of risk must then be defined in terms of their acceptability that is the expected need and timeframe for adaptation. The As Low As Reasonably Practicable (ALARP) Framework identifies required actions based on whether a risk is acceptable, tolerable or intolerable/unacceptable (CSCA 2014). Table 0-4 presents the tolerance for each risk level and the corresponding required actions.

Table 0-4 Tolerance Level Matrix

Risk Level	Action Required	Tolerance
Extreme	Risk treatment required	Intolerable/ Unacceptable
High	Eliminate or Reduce the risk or Accept the risk provided residual risk level is understood	Tolerable
Medium	Reduce the risk or Accept the risk provided residual risk level is understood	Tolerable
Low	Accept the risk and manage through existing risk management systems	Acceptable

Risk Assessment

Table 0-5 presents risk levels for the assets based on risk analysis results. Results indicate the majority of assets over a short-term have a low risk with the exception of those within Port Beach. Note, risk levels presented are the unmitigated risk levels. Therefore the risk levels reported here for Port Beach assume that the Port Beach Road seawalls do not contribute to beach protection. Protection provided by the existing seawalls will be considered in the implementation plan. The risk profile for each zone assumes no management or adaptation efforts and due to changing likelihoods, significantly increases when looking across all planning horizons. Further details of the risk assessment are discussed in section 3.8 of the Coastal Adaptation Report.

Where the coastal hazards of erosion and inundation do not impact upon the asset within the timeframe, the risk is considered not applicable (NA) For example at Leighton Beach at Present (2016) and 2030 shown in Figure 2 and Figure 5 of Appendix C, Fremantle Surf Life Saving Club is outside the area of coastal hazards for both erosion and inundation and as such the risk level at these times does not need to be assessed. Assets not identified as at risk within the short, medium or long-term planning period are not included.

Table 0-5 Unmitigated Asset Risk

Asset	Category	Risk Level								
		Short-term (to 2030)			Medium-term (to 2070)			Long-term (to 2110)		
		Consequence	Likelihood	Risk	Consequence	Likelihood	Risk	Consequence	Likelihood	Risk
Mosman Beach										
Mosman Beach Reserve	Social	3	A	High	3	A	High	3	A	High
Curtin Avenue Reserve	Social	4	NA		4	C	High	4	A	Extreme
Beach access points	Social	4	A	Extreme	4	A	Extreme	4	A	Extreme
Coastal path	Social	2	E	Low	4	A	Extreme	4	A	Extreme
Off-street parking	Social	1	E	Low	1	A	Medium	4	A	Extreme
Public furniture	Social	1	E	Low	3	A	High	3	A	High
Wire fencing, wooden posts	Environment	1	E	Low	1	A	Medium	1	A	Medium
Leighton Beach										
Leighton Beach Reserve	Social	3	A	High	3	A	High	3	A	High
Vlamingh Parklands	Environment	3	C	High	3	A	High	3	A	High
Curtin Avenue Reserve	Social	4	NA		4	C	High	4	A	Extreme
Curtin Ave off street parking	Social	2	E	Low	2	A	High	2	A	High
Leighton Beach parkland area	Social		NA		3	A	High	3	A	High
Leighton Beach Changerooms	Infrastructure	5	E	High	5	A	Extreme	5	A	Extreme
Fremantle Surf Life Saving Club	Infrastructure		NA		5	A	Extreme	5	A	Extreme

Asset	Category	Risk Level								
		Short-term (to 2030)			Medium-term (to 2070)			Long-term (to 2110)		
		Consequence	Likelihood	Risk	Consequence	Likelihood	Risk	Consequence	Likelihood	Risk
Leighton Beach Boulevard Reserve	Infrastructure		NA			NA		5	E	High
Port Beach Road Reserve	Social	4	NA		4	NA		4	C	High
Fremantle Passenger Railway Reserve	Infrastructure		NA			NA		1	E	Low
Beach access points	Social	3	C	High	3	A	High	3	A	High
Coastal path	Social	2	E	Low	2	C	Medium	4	A	Extreme
Off-street parking	Social	2	E	Low	2	C	Medium	4	A	Extreme
Public coastal facilities - Kiosk	Social		NA		1	C	Low	3	A	High
Public furniture	Social	1	E	Low	1	C	Low	3	A	High
Wire fencing, wooden posts	Environment	1	E	Low	1	A	Medium	1	A	Medium
Residential development	Infrastructure		NA			NA		1	E	Low
Vacant residential land	Infrastructure		NA			NA		1	E	Low
Vacant industrial land	Economic		NA			NA		2	C	Medium
Commercial development - within foreshore	Economic		NA		3	A	High	3	A	High
Bus stops	Social		NA		2	A	High	2	A	High

Asset	Category	Risk Level								
		Short-term (to 2030)			Medium-term (to 2070)			Long-term (to 2110)		
		Consequence	Likelihood	Risk	Consequence	Likelihood	Risk	Consequence	Likelihood	Risk
Port Beach										
Port Beach Reserve	Social	3	A	High	3	A	High	3	A	High
Port Beach Road Reserve	Economic	5	A	Extreme	5	A	Extreme	5	A	Extreme
Tydeman Road Reserve	Economic	5	NA		5	A	Extreme	5	A	Extreme
Freight Rail	Economic	5	NA		5	A	Extreme	5	A	Extreme
Fremantle Port Land	Economic	5	A	Extreme	5	A	Extreme	5	A	Extreme
Beach access points	Social	4	A	Extreme	4	A	Extreme	4	A	Extreme
Coastal path	Social	4	A	Extreme	4	A	Extreme	4	A	Extreme
Off-street Parking	Social	4	A	Extreme	4	A	Extreme	4	A	Extreme
Public coastal facilities- Kiosk and changerooms	Infrastructure	4	A	Extreme	4	A	Extreme	4	A	Extreme
Public furniture	Social	4	A	Extreme	4	A	Extreme	4	A	Extreme
Wire fencing, wooden posts	Environment	1	A	Medium	1	A	Medium	1	A	Medium
Industrial land	Economic		NA		1	C	Low	4	C	High
Commercial development	Economic	3	A	High	3	A	High	3	A	High
Bus stops	Social		NA		2	A	High	2	A	High

*NA refers to a likelihood rating that does not fall within the likelihood matrix

Appendix F –Planning Framework Literature Review

The text below provides a broad summary of the existing state and local government planning documents which influence land use and development in this area of coast.

Perth and Peel at 3.5 Million – Central Sub-regional Strategy (Draft)

Perth and Peel at 3.5 Million is the strategic planning document prepared by the Western Australian Planning Commission (WAPC) to guide the future planning for Perth and the Peel region with a population of 3.5 million. The strategic framework is divided into four sub-regional strategies. The Central sub-regional strategy applies to the Port, Leighton and Mosman Beaches. Typically the spatial framework (Figure 0-1) aligns with the existing Metropolitan Region Scheme zonings and reserves.

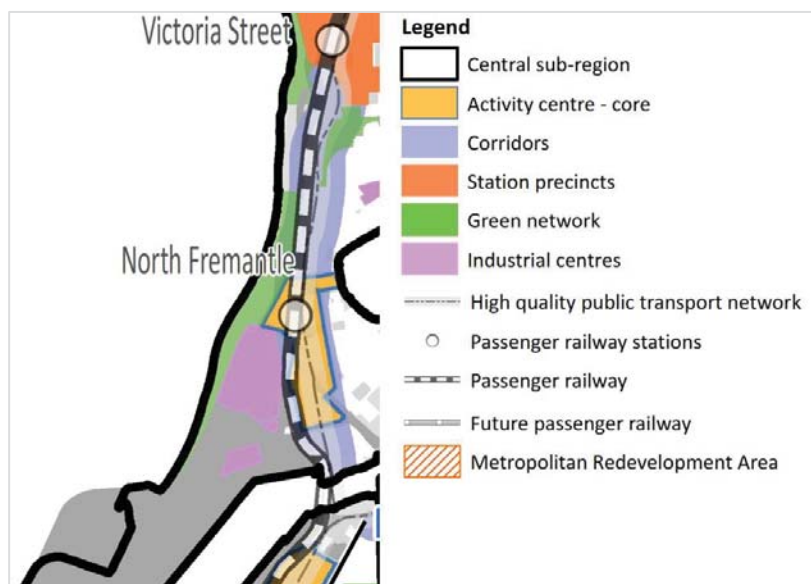


Figure 0-1 Draft Perth and Peel at 3.5 Million – Central Sub-regional Strategy extract (source: WAPC, 2015)

The framework provides a vision and direction for how the Perth and Peel will develop. It has the ability to recommend appropriate broad land use categories on the spatial plan and key strategies for development.

Whilst the Central Sub-regional Strategy does not have any discussion around coastal planning, the overarching Perth and Peel at 3.5 Million document acknowledges that changing climatic conditions are affecting our coastline which will have impacts on coastal communities, infrastructure and ecosystems. The framework notes that ‘Perth has an enviable system of coastal reserves which provide protection as well as biodiversity and recreation values...’

Metropolitan Region Scheme

The MRS is the overarching statutory planning framework for land uses within the Perth metropolitan area. The MRS identifies areas of reserved and zoned land and provides the framework for how the land is to be used.

The majority of the land within the study area is reserved for the purpose of 'parks and recreation'. There are only small areas of zoned land within the study area, these being urban where the Leighton high density mixed use area is and an area of industrial land adjacent to the Fremantle Port.

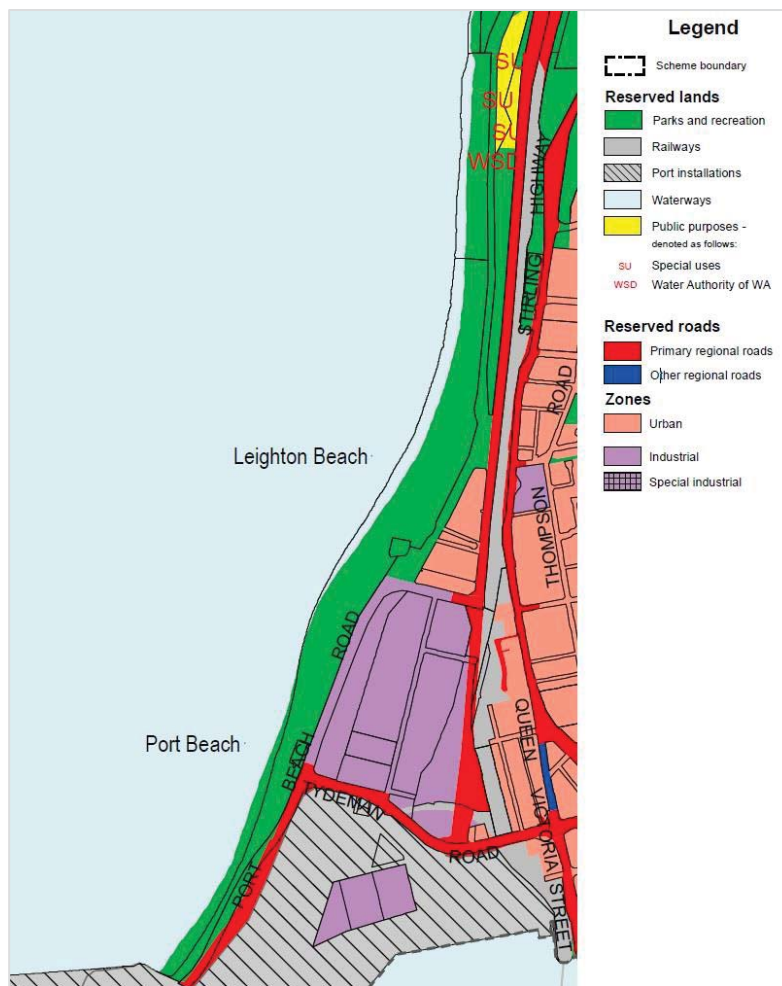


Figure 0-2 Metropolitan Region Scheme extract (source: WAPC, 2015)

State Planning Policy No. 2.6 State Coastal Planning Policy

State Planning Policy 2.6 (SPP2.6) provides the decision-making framework within the coastal zone across Western Australia, including:

- Managing development and land use change
- Establishment of foreshore reserves
- Protect, conserve and enhance coastal values

SPP2.6 provides the framework for undertaking ‘coastal hazard risk management and adaptation planning’ and has been used to guide this project.

City of Fremantle Local Planning Strategy (2001)

Local planning strategies are a strategic document which outline the vision for future development within a local government area. They are used to inform the preparation of local planning schemes. The City of Fremantle’s local planning strategy was adopted by Council in 2001 and provided the strategic planning framework to inform City Planning Scheme No. 4.

The strategy identifies a number of objectives and includes strategies to provide mechanisms to determine how the objectives can be met. The objective and corresponding strategy outlined below are the most applicable to this project.

Objective	Strategy
‘B7.1 - To ensure an adequate distribution of open space.’	‘B7.1.3 The following foreshore reserves are required: A minimum of 100 metre wide coastal foreshore reserve for land abutting a coastal foreshore. This shall be measured from the beginning of the accepted permanent vegetation line. This coastal reserve may also be required to be increased depending on other environmental and recreational requirements. (b) A minimum of 30m foreshore reserve for land abutting the Swan River.’

The identification of the coastal foreshore reserve is typically shown as a reserve in the local planning scheme. While most of the foreshore reserve under the scheme within the project area is approximately 100m, there are areas that are less than 100m.

The strategy identifies one of the key planning issues for the North Fremantle – Local Planning Area, is the Leighton Marshalling Yards Redevelopment. The Fremantle Regional Strategy included a number of proposed changes to the Leighton Peninsula including:

- *relocation of the fuel tanks west of Port Beach Road*
- *narrowing of Stirling Highway (connecting to the FEB south of High Street)*
- *the extension of Curtin Avenue through to a realigned Tydeman Road*
- *realigned rail access to the port (south of Tydeman Road)*
- *redevelopment of the Leighton Marshalling Yards for residential and tourist uses*
- *the retention of the petroleum bunkering facilities off Bracks Street*

The Fremantle Regional Strategy was reviewed by the WAPC who then released the *Leighton Regional Planning Guidelines* (discussed below).

City of Fremantle Local Planning Scheme No. 4

The City’s Local Planning Scheme No. 4 provides the statutory framework for managing land use and development within the City of Fremantle. The MRS reserves are reflected

in the local planning scheme. In addition, there are areas of industrial zoned land and development zone.

Land use and development within the development zone is to be in accordance with the *Leighton Marshalling Yards Planning Guidelines Development Area Structure Plan, December 2003* and the provisions of Development Plan 17 – Leighton North Fremantle.

Town of Mosman Park Local Planning Strategy (2013)

The Town's Local planning Strategy has been prepared as part of the review of Town Planning Scheme No. 2. The local Planning Strategy does not propose any changes to the coastal area. The area is depicted similar to that shown on the MRS. The local planning strategy does not have any specific aims, strategies or actions relating to the coastal foreshore, however broadly those specified in the strategy could be applied to the coastal reserves.

Town of Mosman Park Town Planning Scheme No. 2

The Town's Town Planning Scheme No. 2 provides the statutory framework for managing land use and development within the Town of Mosman Park. The portion of land within the study area for this project are all reserved under the MRS as parks and recreation, public purpose, primary regional road and railways. The MRS reserves are reflected in the local planning scheme. The provisions of the MRS would apply to these reserves.

City of Fremantle Port and Leighton Beaches Management Plan (October 2001)

The Port and Leighton Beaches Management Plan applies to reserve 43311 that is vested in the City of Fremantle. *'The aim of this management plan is to make the coastal reserve a natural dune setting, with native species, catering to the community's recreational needs while minimising annual maintenance costs.'*

The management plan includes recommended setbacks for major and minor infrastructure as a result of coastal processes.

Town of Mosman Park Mosman Beach Management Plan

The Mosman Beach Management Plan applies to Reserve 18016 which was vested in the Town of Mosman Park in 1984. The management plan was prepared to *'...provide a series of principles to manage future planning and development along the Mosman coastline.'*

The management plan provides a concept plan for the coastline and includes a series of recommendations for the coastline.

Leighton Regional Planning Guidelines

The Leighton Regional Planning Guidelines were prepared by the WAPC and endorsed by State Cabinet in 2000. The guidelines provide broad planning parameters to guide

future decision-making. The guidelines proposed a widening of the parks and recreation reserve which is now reflected in the MRS. Only one small area of urban land was maintained and some land uses were reserved for public purpose.

Vlamingh Parklands Report

It is noted that this document was not publically accessible through online mediums, therefore the information below is a summary from other documentation rather than a review of the document itself.

The WAPC published the Vlamingh Parklands Report in 1998 which, '*...proposed the establishment of integrated parklands comprising a series of Regional Park and Recreation Reserves and open space areas throughout the Leighton peninsular linking the Swan River and the coast*' (Leighton Regional Planning Guidelines, WAPC).

The Leighton Regional Planning Guidelines have superseded the Vlamingh Parklands Report as well as the Fremantle Regional Planning Strategy.

City of Fremantle Leighton Marshalling Yards Redevelopment Area (D.G.N12)

This policy provides a framework to guide the land use and development of the former Leighton Marshalling Yards. The guidelines designate a large portion of the policy area as proposed coastal reserve with only a small portion proposed for urban. The policy provides provisions for the coastal reserve including objectives, regional guidelines, local requirements, coastal reserve requirements, setbacks and dune management.

The policy provides setback requirements for Port Beach Road and the relocation of existing buildings. It also specifies that no major new infrastructure should be within 65 metres of the 1998 vegetation line. The policy acknowledges that some minor infrastructure may be within that area but the Council should recognise that there is a risk of it being lost.

Other policy provisions include procedures for implementation, recreation planning, car parking, public transport, vehicle, pedestrian and cyclist access, local requirements, views and landscape character, environmental management.

City of Fremantle Leighton Development Area Design Guidelines (D.G.N14)

The Leighton Development Area Design Guidelines apply to the roughly bounded by Walter Place, Curtin Avenue and Leighton Bach Boulevard. The guidelines state that '*The vision for the Leighton Development Area is an accessible village of contemporary design, with high quality landscape and buildings that address the streets and parks.*'

The guidelines contain a provision for coastal considerations, suggesting that proposal should consider '*...views; lifestyle opportunities; likelihood of strong sea breezes and storm events; air borne sand and salt water; and sun glare.*'

Appendix G – Adaptation Options Compendium



City of Fremantle & Town of Mosman Park
Coastal Adaptation Plan - Appendix G
Adaptation Options Compendium

October 2017

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Appendices

Appendix A – Coastal Management Units

1. Introduction

1.1 Project Background

The City of Fremantle on behalf of the City of Fremantle and Town of Mosman Park engaged GHD to deliver the Port, Leighton and Mosman Beaches Coastal Hazard Risk Assessment and Management Adaptation Plan. This project is supported by the Department of Planning's Coastal Management Plan Assistance Program Grant.

The overall objectives of the project are to identify coastal hazard risks and to properly plan for adaptive land use and development along the Port, Leighton and Mosman Beach coast in light of a changing coastal environment, through a coastal adaptation plan.

1.2 Purpose of this report

This options compendium has been prepared to provide a listing of local adaptation options relevant to each coastal management unit of the study area. The compendium provides a strategic adaptation pathway, localised listings of interim protection and planning options, and a summary description of all adaptation options.

1.3 Scope and limitations

The scope of this document is to identify suitable options that may be applied to the coastal management units along Port, Leighton and Mosman Beaches to address coastal hazards as described in Stage 1 and Stage 2 of the Coastal Hazard Risk Assessment and Management Adaptation Plan.

This report: has been prepared by GHD for City of Fremantle & Town of Mosman Park and may only be used and relied on by City of Fremantle & Town of Mosman Park for the purpose agreed between GHD and the City of Fremantle & Town of Mosman Park as set out in section 1.2 of this report.

GHD otherwise disclaims responsibility to any person other than City of Fremantle & Town of Mosman Park arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared this report on the basis of information provided by City of Fremantle & Town of Mosman Park and others who provided information to GHD (including Government authorities)], which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

Climate change is a significant current and future issue and effects, such as sea level rise, are at this stage difficult to quantify to a high degree of certainty. The following assumptions have been made during the preparation of this report:

The sole purpose of the reports are for evaluating coastal hazard risks and developing adaptation plans associated with coastal hazards and sea level rise for the City of Fremantle and Town of Mosman Park.

The reports are produced for use by the City of Fremantle and Town of Mosman Park, and are not for use by any third party person or organisation. The information and recommendations are to be read and considered holistically, and content is not to be used selectively for purposes other than coastal hazard risk management (e.g. design) as this may misrepresent the data and processes herein and provide erroneous project or decision outcomes.

The data and processes herein are to be used for coastal hazard risk assessment and adaptation planning purposes, approved by the City of Fremantle and Town of Mosman Park, and based on Australian and state government guidelines:

Western Australian Planning Commission and Department of Planning (2014). Coastal hazard risk management and adaptation planning guidelines, Perth, Australia.

Western Australian Planning Commission (2013). State Planning Policy No. 2.6 State Coastal Planning Policy.

Western Australian Planning Commission (2013), State Coastal Planning Policy Guidelines.

These guidelines have been considered as per the requirements of the brief. This information has not been independently verified. Assumptions and recommendations that need further testing are noted in the text of the report.

The establishment of the sea level rise aspects of the project uses data and scenarios based on publicly available information by the International Panel on Climate Change, summarised by the Western Australian Department of Transport:

Bicknell (2010). Sea Level Change in Western Australia: Application to Coastal Planning, prepared by the Department of Transport, Fremantle, WA.

Climate change and coastal hazard assessment by its nature is a dynamic and ongoing process. As the sea level rise projections used are uncertain by nature, it is possible that the effects that actually occur may not be as assumed and stated in this exercise. Therefore, it is recommended that City of Fremantle and Town of Mosman Park routinely incorporate the latest climate change science and sea level rise cause and effect knowledge into all future planning.

2. Adaptation Pathways

2.1 Adaptation Principles

In developing a pathway to adapt to changing coastal processes, and to guide decisions that are appropriate for the community, the following principles should underpin the adaptation planning process. These principles were initially developed by GHD for the Cockburn Sound Coastal Adaptation Plan and have been further refined since that project.

Principle 1 Adaptation planning in the current planning horizon does not impede the ability of future generations to respond to risk beyond the current planning horizons.

The preparation of erosion and inundation risk mapping to inform this plan considers possible scenarios for sea level rise to 2110. These hazard risks include projections for sea level rise that are dependent on the global action taken to mitigate climate change impacts through greenhouse gas emission reductions. The modelled scenarios considered by the Intergovernmental Panel on Climate Change (IPCC) give rise to a range of predictions of sea level rise, which show increasing variability in sea level estimates with increasing time into the future.

Therefore:

- the implementation of adaptation solutions should, where possible, not be tied to specific time frames, but tied to trigger points in coastal hazard risks due to uncertainty about the timing of when and if risks may be realised.
- the implementation of short and medium term coastal adaptation measures should not adversely impact upon coastal adaptation measures implemented in the medium and long-term.

Principle 2 Adaptation requires a decision-making framework that enables the right decision to be made at the right time, in line with the values and circumstances of the time.

The dynamic nature of community needs and values requires a flexible approach when considering adaptation options. The effects of climate change on the coast, and changes to our beaches from erosion and engineered changes have been identified as potential concerns for some in the community. The interest and values of the community will change over time as more information becomes available, and impacts of climate change become more apparent. Our approach to coastal adaptation will likely evolve as new technology and information opens up new approaches to manage risk.

Making decisions based on community values that are likely to change can be considered short-sighted, and may potentially prevent achieving the best possible outcome when considering short, medium and long-term measures to adapt to changing coastal processes. Adaptation planning should provide opportunity for future action to utilise new technologies and reflect community values at the time of the decision.

Principle 3 Adaptation planning reflects the public’s interest in the social, environmental, and economic value of the coast.

Western Australia is renowned for its extensive coastline and beaches. Social and recreational use of these features form an integral part of Western Australian culture. Continued public access to the coast and beaches is an iconic part of Western Australia’s lifestyle, contributing to the high quality of public spaces enjoyed by the community. Our economy and quality of life is supported by coastally dependent infrastructure and industries. In addition the coast might support future projects critical to the development of the Western Australian economy. The coast also provides important environmental values, with a unique ecology that includes marine, intertidal, and dune habitats.

Adaptation planning should respect the inherent value of the coast that is ingrained in the state’s social, environmental and economic interests.

Principle 4 Alternative adaptation measures should consider the full range of land uses and values.

The objectives of State Planning Policy (SPP) 2.6 include the retention of coastal areas for a range of public and private uses including economic uses, coastal foreshore access and social and environmental uses and values, including:

- housing, tourism, recreation, ocean access, maritime industry, commercial and other activities;
- public coastal foreshore reserves and access to them; and
- landscape, biodiversity and ecosystem integrity, indigenous and cultural significance.

Principle 5 The full life-cycle benefits, costs and impacts of coastal interim protection works should be evaluated when considering adaptation options.

Coastal engineering works have the potential to provide protection to nearshore coastal assets over their design life, dependent on the rate of future sea level rise. There are two broad categories of protection with potential for use along the Port, Leighton and Mosman Coast. These are:

- Engineering (hard) measures: seawalls, revetments, levees, groynes/breakwaters

- Regenerative (soft) measures: beach nourishment and dune restoration

Seawalls and revetments, if implemented in response to persistent erosion but without ongoing beach nourishment, will eventually lead to a loss of beach and coastal habitat seaward of the structures. Nourished beaches require ongoing maintenance to offset sediment losses incurred from storm-related erosion events and sea level rise. Coastal protection measures taken in a specific location may also influence adjacent coastal cells.

Interim protection measures also bring cost impacts. Engineering works can have a high capital cost, and require ongoing investment in maintenance. The cost impact of coastal engineering works should also consider decommissioning costs. Engineering options are designed to mitigate against a particular level of risk and have a discrete design life. However, the presence of protection works can set expectations for asset owners, and can potentially limit future decision-making flexibility.

SPP 2.6 includes a presumption against coastal protection measures unless “all other options ... have been fully explored”.

Adaptation principles recognise that the most appropriate adaptation decision may differ based on the specific site and the values to be protected. As illustrated in Figure 2-1, land protection measures (seawalls) can exacerbate erosion and severely affect beach amenity compared to retreat or natural recession.



Figure 2-1 Restricted amenity of a protected beach vs a natural beach.

2.2 Adaptation Measures

There are four key coastal adaptation options available when making decisions about managing coastal risks. These are:

- Avoid development in the area of risk
- Retreat (relocate) assets and development away from the risk
- Accommodate the risks (e.g. occasional flooding) through retrofitting
- Protect the assets through coastal engineering works.

The most appropriate adaptation option may differ based on the values to be protected in a certain location.

2.2.1 Avoid

Avoid measures involve avoiding the location of new development in an area of coastal vulnerability. This does not preclude the use and enjoyment of the coast, however, it avoids locating future development in an area that would experience intolerable risk, at some stage during the life of that development.

2.2.2 Managed retreat

Managed retreat means relocating assets outside the area of risk, to allow land at risk to naturally experience erosion and/or inundation. Retreat can be on a small scale, for example relocating a car park within a large foreshore reserve to an area outside immediate risk. In the long-term, retreat strategies can occur on a significant scale, for example the expansion and remediation of the foreshore reserve, which requires the relocation of infrastructure (such as road, rail, and sewer) and acquisition of private land within the expanding foreshore reserve. Large-scale strategic retreat will require coordination and partnership across state and local government.

2.2.3 Accommodation measures

Accommodation measures are asset specific activities that enable an asset to continue to operate whilst being affected by coastal impacts. In the face of erosion, this includes measures to accommodate increased risk, such as dune revegetation to reduce the immediate impact of wave erosion. In relation to inundation, this includes measures to enable an asset to manage occasional flooding, such as raising of habitable floor levels and emergency management plans.

2.2.4 Interim protection measures

The role of coastal interim protection is to reduce the risks associated with the coastal hazards of erosion and inundation to land and assets. Engineering measures suitable to protect against these hazards can involve either soft or hard and passive or active

engineering approaches. Descriptions and examples of these approaches are shown in Table 2-1.

Table 2-1 Interim protection measures

Approach	Description	Examples
Soft – Passive	Foreshore protection works that offer benefits to mitigate against erosion and inundation but do not involve construction of structures and do not directly affect coastal processes.	Sand nourishment and dune stabilisation
Hard – Passive	Foreshore protection works that involve the construction of structures that alter the coastal processes that act on the land/beach with the intention to maintain or improve beach amenity through retention of sand.	Groynes and offshore breakwaters
Hard – Active	Works that involve the construction of structures that offer a source of protection to landside assets in proximity to the foreshore. The construction of hard active engineering measures can alter the way coastal processes act on the land/beach interface. These changes to the shape of the land (e.g. erosion of a beach in front of a seawall) can have implications on land use (e.g. loss of beach amenity).	Seawalls and Levees



Figure 2-2 Top: offshore breakwater. Bottom: geotextile sand container groyne.

Offshore breakwaters and groynes are examples of hard passive interim protection measures. This groyne example, Figure 2-2 bottom picture, is made from geotextile

containers filled with sand. Groynes can also be constructed from rocks to extend their design life. Offshore breakwaters can interrupt open views of the ocean, and groynes can create a barrier along the beach.



Figure 2-3 Limestone rock seawall left and block work retaining seawall right.

Sea walls are an example of hard active interim protection measures, Figure 2-3. Designed well, they can integrate well into the development of beach amenities, although they can exacerbate erosion (beach loss) in front of the wall over time if ongoing sand nourishment is not undertaken.

2.1 Adaptation pathways

In line with adaptation principles, the most appropriate adaptation pathway is one that enables decision-making on adaptation measures to be made at the right time, in line with the values of that time.

Decisions must be made as the risk to assets increases from tolerable to intolerable. The points in time when decisions are required become trigger points for adaptation planning.

The Coastal Hazard Risk Management and Adaptation Planning Guidelines (WAPC, 2014) set out coastal adaptation options available when making decisions about managing coastal risk (Figure 2-4). The options shown in Figure 2-4 and Table 2-2 should be considered as a hierarchy – the further down the hierarchy, the less flexibility there is to consider alternative adaptation measures. Effectively, these

options become decisions for government and the community to make when planning for the future of coastal assets and land.



Figure 2-4 Hierarchy of risk management and adaptation options (WAPC, 2014)

Table 2-2 Levels of risk mitigation

Adaptation Option	Description	Type of Development	Applicable Hazard
Avoid	Avoiding development in areas at risk	New development	Erosion & Inundation
Planned or Managed Retreat:	In the face of intolerable risk, eliminate the risk through relocation, demolition or removal of existing asset.	Existing development	Erosion & Inundation
Accommodate:	Design and / or management measures that reduce the risk to a tolerable level		Inundation*
Protect	Where there is a need to preserve the foreshore reserve, public access and public safety, property and infrastructure that is not expendable.		Erosion & Inundation

Is accommodate a suitable mitigation measure for Port, Leighton and Mosman Beaches?

In the context of the Port, Leighton and Mosman Beaches coastline, the dominant coastal hazard identified in the risk assessment (refer to Appendix E of the Coastal Adaptation Plan) that triggers the need for risk mitigation and adaptation is erosion.

Erosion hazards, in areas without natural ongoing sediment supply, have a higher risk profile compared to temporary storm induced inundation hazards, or areas without sediment supply, because extreme erosion hazards from storm events result in the permanent loss of land or permanent damage to assets and values without the ability for dunes and beaches to recover. Accommodation of risks is only appropriate when adaptation measures are able to reduce risks to tolerable levels. The higher risk profile for erosion hazards means that it is harder to develop accommodation measures to mitigate erosion risks. This is particularly applicable to areas of Port Beach where sediment supply to the system is limited due to the Primary sediment cell barrier of the Fremantle Harbour dredged shipping channel and North Mole.

In areas prone to erosion hazards, but with natural sediment supply, such as Leighton beach, the question transitions to how long will it take the beach to recover from an event and what is a reasonable length of time to allow before risk mitigation needs to be considered.

As such accommodate is only a suitable adaptation option when the risk profile for a coastal management unit is tolerable.

Are interim protection measures a permanent adaptation solution?

Interim protection measures typically have life spans in the range of 30 to 50 years. The life span of interim protection measures can be extended, with additional works near the end of the design life such as upgrades, increasing the levels or extending structures. The choice to extend the design life is an active management decision point between continuing protection and decommissioning. Therefore, any coastal protection works that are undertaken are considered to have a finite lifespan despite having the ability to extend, as the protection afforded may not be permanently suitable.

Is retreating from current land and asset uses a more feasible long-term option?

Appropriately planned for retreat from current land and asset uses may be an effective option in the very long-term considering environmental, social and economic costs. As a result, managing long-term sea level rise requires adaptation options that compliment an underlying retreat approach strategically identified in initial project stages. This does not necessarily mean that retreat will be the most appropriate option in the current planning horizon, however, mechanisms should be in place to allow for this adaptation option to be implemented should future risk be heightened.

How can we maintain a flexible management approach to coastal hazard management?

In the absence of interim protection and accommodation measures, as sea levels rise, the shoreline, beaches and dune systems will adjust to the changes in coastal processes. In the case where there is sufficient sediment supply and room for the coast to move, the beach will seek to gradually move landwards, refer to Figure 2-5. Accordingly, the risk to nearshore coastal assets will increase, initially leading to loss of land through erosion (of sandy areas) and leading to occasional and then eventually permanent inundation.

In the case where there is insufficient sediment supply, the coast may retreat, but the beach dunes, an important structure to buffer and moderate the effects of erosion, maybe lost. In the situation where there are natural barriers such as fringing rocky cliffs and a lack of supply of sediment, beaches may be lost altogether with the ocean lapping at the base of rock cliff landforms.

As this sequence of events unfolds, the options available in any specific location depend on the likelihood and consequence of the risk at that time. The decision made will be informed by values of the coast, coastal assets and community. Values will change over time – as they have in the area over the last 100 years – therefore it is important that decisions are made at the time of the trigger point.

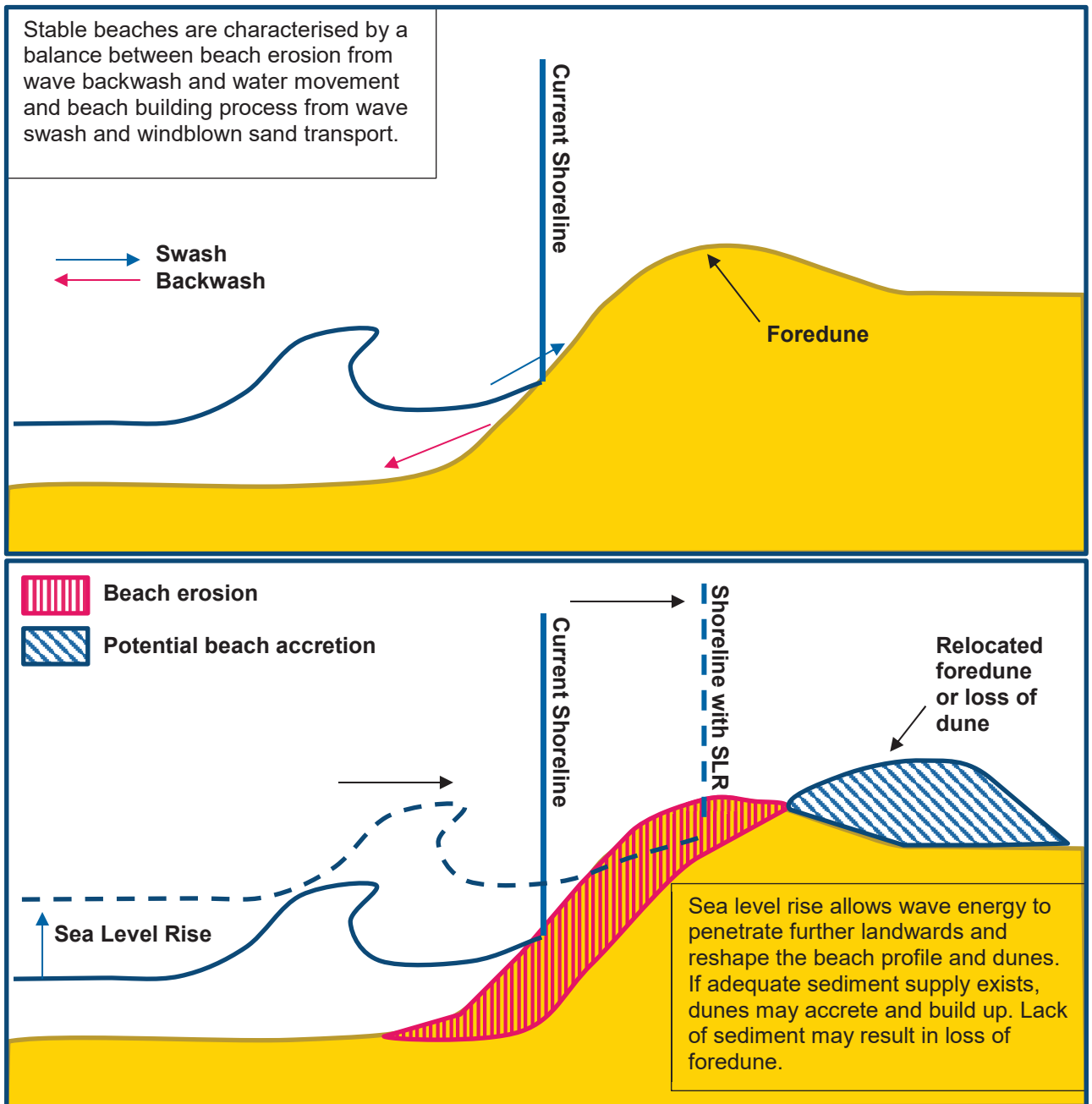


Figure 2-5 Simplified schematic of a sandy beach response to sea level rise

What does successful adaptation look like?

A successful adaptation pathway is achieved when decisions made now, in 20 years or in 50 years do not prevent other courses of action being chosen later, retaining ongoing flexibility in decision-making consistent with the hierarchy of options. For example, at the end of the life cycle of interim protection structures, the hierarchy of adaptation options should be reassessed and the adaptation measure most appropriate for that point in time progressed. There may be a point when the viability of less flexible measures (such as interim protection) is compromised due to social or economic costs. This requires ongoing strategic planning to retain the full flexibility of adaptation options for future decisions, even when other options are employed in the shorter-term.

The recommended flexible adaptation pathway combines decision-making at trigger points on specific adaptation measures (avoid, retreat, accommodate, interim protection) with an ongoing strategic planning process that plans for, and therefore maintains, all adaptation options for subsequent trigger points over time. In this way, by choosing to accommodate or protect in early horizons, future communities are not bound to the long-term cost of that decision beyond the design life of the infrastructure or asset. The pathway and decision points are illustrated in Figure 2-6. More detailed description of the trigger points for Port, Leighton and Mosman Beach are provided in the Coastal Adaptation Plan.

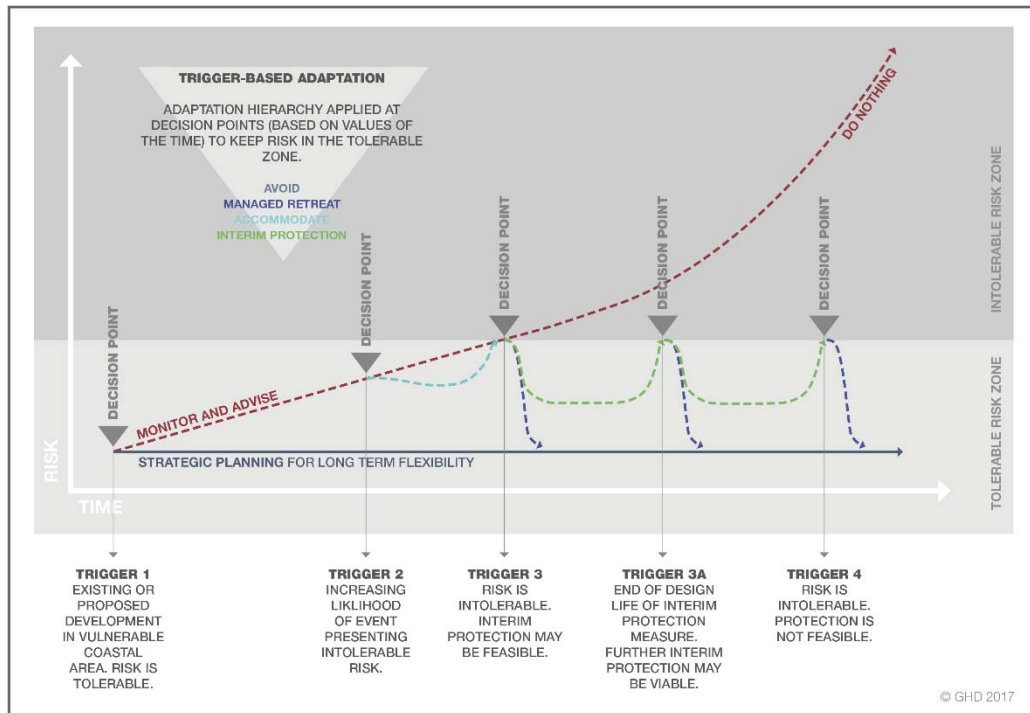


Figure 2-6 Flexible adaptation pathway

The flexible pathway provides a framework to enable retreat measures on the most vulnerable coastal land in the long-term. The pathway also facilitates responsible interim adaptation measures that continue land uses where those measures are justified on social, economic and environmental grounds. For assets on vulnerable land, a decision to accommodate and/or undertake interim protection or retreat is dependent on a wide range of factors, including:

- the consequences of taking no action;
- the feasibility and social/environmental/economic costs associated with accommodation/protection compared to the residual values, risks and design life of the asset;
- the disruption and costs involved with relocation.

There are parallel pathways for government and private asset owners. Whether government decides to facilitate interim protection measures on certain sections of coast, or allow the shoreline to recede, private asset owners retain their ability to determine the pathway that reflects their own circumstances (where it is not incompatible with or less flexible than a government decision). In order for this approach to be workable and provide certainty to asset owners, it is recommended that the following principles apply to government decisions about coastal protection works:

- Decisions about the appropriateness of coastal protection measures are made and implemented/facilitated by government alone, and occur on coastal reserves, notwithstanding whether or not private landowners contribute to costs;
- Any such measures are designed for a finite life, after which a new decision is required as to whether further, finite protection is justified or the coast is then allowed to naturally recede; and
- Advice is provided to private asset owners about government decisions to protect or otherwise, and the likely residual risk associated with those decisions.

Adaptation measures need to be considered at all times for land identified as being within the vulnerable coastal area, (i.e. at all times after trigger 1 is reached). The nature, extent and suitability of accommodation measures will change over time as risks increase. Accommodate is an appropriate adaptation option when risks are tolerable to delay the need to undertake retreat or interim protection, but when the erosion risk level has reach intolerable, accommodate is no longer a suitable option.. All protection options are designed for a certain set of circumstances (e.g. a 1% Annual Exceedance Probability (AEP) event), and there is a residual risk that either these circumstances will be exceeded or that the protection measure does not perform to expectations.

3. Local Adaptation Options

The dynamic nature of the coast brings risks of inundation and erosion, and the realisation of these risks over time changes the nature, shape, and location of our coastline. The coastline of North Fremantle has changed throughout history, particularly over the last 50 to 100 years due to significant human influences. This is likely to continue to change into the future. The risks of coastal erosion and inundation for the coastline have been modelled, looking at current risk, year 2070 risk, and year 2110 risk (short, medium and long-term risk). The realisation of erosion and inundation risks will change the coast, the way we use it, and the nature (and location) of development along and in the vicinity of the coast.

As the coastline responds to erosion and inundation, there are a range of planning and interim protection options available to manage how the changes impact on our coastal use and experience. Options range from interim protection measures that will delay coastal hazards impacts on assets through to the retention of natural coastal environments (retreat) that respond naturally to coastal processes. The latter approach may require strategic planning interventions and decommissioning of assets at risk.

Determining the most appropriate option for a certain location along the coastline requires consideration against social, economic, and environmental values. The Port, Leighton and Mosman Beach Coastal Hazard Risk Management and Adaptation Plan engaged community and stakeholders through a values survey to:

- identify important values and assets along the coast
- understand whether there are locally available alternatives to these assets or values
- and to understand how loss of these values of assets would impact on their way of life.
- This information will guide the requirements for adaptation options suitable for the local area. The key decision will be to identify those sections of coastline where protection is considered necessary, and those areas where the retention of natural beaches and coastlines is appropriate (retreat).

Irrespective of the decisions made, proactive coastal management (including dune management and revegetation) is important to avoid poor quality environments accelerating natural erosion processes. Beach nourishment, in the short to medium term (subject to the availability of materials) is one management tool available to replenish beaches, and slow down the loss of land from erosion processes. These management techniques are listed in the following table of options, however they are not standalone climate change adaptation options, but are best employed in combination with retreat or engineered protection options to delay interim protection and planning responses.

3.1 Coastal Management Units

To aid the selection of the most appropriate adaptation options, sections of foreshore have been grouped into areas of similar risk profile and type of foreshore properties. Table 3-1 below summarises the risk levels identified for each coastal management unit which have further divided up the beaches areas at Port, Leighton and Mosman Beach. In all coastal management units and for all time frames, erosion is the dominant hazard, resulting in the below risk profile. The extents of these coastal management units are indicated in Appendix A.

Table 3-1 Summary of risk assessment for coastal management units

Management Unit	Short	Medium	Long
1. Mosman Beach	Extreme	Extreme	Extreme
2. North Leighton	High	High	Extreme
3. Leighton Beach-Vlamingh Parkland	High	High	Extreme
4. Leighton Beach - Surf Club Precinct	High	Extreme	Extreme
5. Leighton & Port Beach Dunes	High	Extreme	Extreme
6. Port Beach North	Extreme	Extreme	Extreme
7. Port Beach South - Sandtrax	Extreme	Extreme	Extreme

3.2 Management Unit 1 – Mosman Beach

3.2.1 Risk Profile

Short to medium term extreme risks at Mosman Beach indicate that coastal paths and beach access points have an extreme risk of erosion. Due to the difference in elevation between shore parallel coastal paths and the beach, beach access ways such as piled timber framed stairs are less adaptable to changes in beach levels over the long-term when compared to sandy or paved pathways through dunes. In the long-term, off the street parking at Mosman Beach also becomes exposed to extreme risk.

The values impacted by these risks are predominantly social, with the potential to impact on the community's ability to access and enjoy beach settings and use beach areas for a variety of active recreation and passive uses.

Table 3-2 Management Unit 1 -Risk Profile Summary

Timeframe	Risk Level	Asset Triggering Risk	Value Triggering Risk Level
Short	Extreme	Beach Access Points	Social
Medium	Extreme	Beach Access Points, Coastal Path	Social
Long	Extreme	Beach Access Points, Coastal Path, Off Street Parking	Social

3.2.2 Existing Controls

The only existing controls to manage coastal hazards at Mosman Beach are natural. There is a small artificial surfing reef located at the northern extent of the site; however, this is expected to have limited protective influence in its current form, particularly as sea levels progressively rise.

3.2.3 Recommended Adaptation Measures

A mixture of soft and hard engineered approaches with planning approaches have been considered suitable for Mosman Beach, due to the effectiveness of the approaches currently being undertaken to date to stabilise and maintain the elevated dune system.

Measures not considered suitable for coastal protection at Mosman Beach include:

- **Seawalls.** Due to the high potential for loss of beach area and therefore recreational amenity and environmental habitat of the foreshore, developing seawalls at this location is not considered appropriate.
- **Dune maintenance, revegetation and monitoring.** This option may be appropriate along small sections of the Mosman foreshore where the limestone foundation is stable, however revegetation alone is unlikely to be able to maintain dunes in areas where the limestone cliff is failing and receding.
- **Sand nourishment** alone is not expected to be a suitable option as it is unlikely to be able to sustainably stabilise the limestone cliffs at the base of the dunes for the required design life. Renourishment rates would be expected to be high due to the high longshore sediment transport rates and the presence of the submerged beach rock platform which restricts wave infiltration and promotes sediment erosion.

Recommended adaptation measures to manage erosion risks include:

- **Engineered cliff stabilisation, in combination with dune revegetation and nourishment with annual beach monitoring and maintenance**

Sections of the limestone cliffs at the base of the dunes along the Mosman foreshore in areas are degrading and prone to collapse, which has resulted in slumping and therefore retreat of the sand dunes. Reinforcing this rock with engineering techniques, sand nourishment and associated rehabilitation and ongoing maintenance of the dunes could potentially prevent further retreat and maintain beach area in the short to medium-term. Annual beach monitoring to monitor need for nourishment.

- **Groynes, nourishment and dune rehabilitation with annual beach monitoring and maintenance**

- Development of a series of groynes with associated nourishment may assist to maintain a greater beach width in front of the dunes. Downdrift impacts are likely as the net northward sediment transport will be restricted. Maintaining the groynes in a “filled” state will minimise these downdrift impacts. Ongoing nourishment is likely to be required following storm events to maintain beach amenity. An individual groyne is unlikely to provide the required level of protection and would have to be considerably longer than if used in combination with more frequently spaced groynes. Annual beach monitoring to monitor need for nourishment.

- **Offshore or submerged breakwaters and nourishment with annual beach monitoring and maintenance**

Implementation of a series of offshore or submerged breakwaters along North Leighton, Mosman and potentially into south Cottesloe Beaches could be used to provide interim protection against erosion from north-westerly storm waves as well as south-westerly swell waves. Nourishment is required with this protection to allow the beach shape to reform, to provide a buffer and maintain beach amenity. This measure will reduce the wave energy reaching the beach area, reducing the effects of erosion, but will not provide protection against inundation. Annual beach monitoring to monitor need for nourishment.

- **Retreat and relocation of constructed assets such as beach access points and stairs, coastal paths, off street parking and roads**

Retreating at risk assets and land uses to alternative locations beyond the coastal hazard risk zones will allow the continuation of natural coastal processes acting on the Tamala limestone and dune system. Some loss of beach amenity may result.

3.3 Management Unit 2 – North Leighton

3.3.1 Risk Profile

Short to medium-term risk levels at north Leighton are high, due to potential for social impacts from loss of the beach and dune areas, affecting social values of the area. In the long term, the risk increases to extreme due to the potential for coastal erosion to impact on the Curtin Avenue Reserve, impacting social and infrastructure values.

The social values impacted by these risks are people’s ability access and enjoy beach settings, use beach areas for a variety of active recreation and passive uses as well as access to car parking and facilities near the beach.

Table 3-3 Management Unit 2 -Risk Profile Summary

Timeframe	Risk Level	Asset Triggering Risk	Value Triggering Risk Level
Short	High	Leighton Beach Reserve, Vlamingh Parkland	Social
Medium	High	Leighton Beach Reserve, Vlamingh Parkland, Curtin Ave Reserve, Curtin Ave off street parking	Social
Long	Extreme	Curtin Ave Reserve	Social

3.3.2 Existing Controls

There are no known constructed controls to mitigate erosion. The only natural control is a vegetated sandy dune system.

3.3.3 Recommended Adaptation Measures

Recommended adaptation measures to manage erosion risks include:

- Dune stabilisation and nourishment with annual beach monitoring and maintenance**

Stabilisation of dunes using erosion fencing, coir matting, planting, combined with beach nourishment can be used to increase the buffering capacity of the dune system. Sand nourishment and associated rehabilitation and ongoing maintenance of the dunes could potentially prevent further retreat and maintain beach area in the short to medium-term. This adaptation measure is not as effective as some engineered options at reducing the risk level. Annual beach monitoring to monitor need for nourishment.
- Groynes, nourishment, dune rehabilitation with annual beach monitoring and maintenance**

Development of a series of groynes with associated nourishment may assist to maintain a greater beach width in front of the dunes. Downdrift impacts are likely as the net northward sediment transport will be restricted. Maintaining the groynes in a “filled” state will minimise these downdrift impacts. Ongoing nourishment is likely to be required following storm events to maintain beach amenity. An individual groyne is unlikely to provide the required level of protection and would have to be considerably longer than if used in combination with more frequently spaced groynes. Annual beach monitoring to monitor need for nourishment.

- **Offshore or submerged breakwaters and nourishment with annual beach monitoring and maintenance**

Implementation of a series of offshore or submerged breakwaters along North Leighton, Mosman and potentially into south Cottesloe Beaches could be used to provide interim protection against erosion from north-westerly storm waves as well as south-westerly swell waves. Nourishment is required with this protection to allow the beach shape to reform, to provide a buffer and maintain beach amenity. This measure will reduce the wave energy reaching the beach area reducing the effects of erosion, but will not provide protection against inundation. Annual beach monitoring to monitor need for nourishment.

- **Retreat and relocation of constructed assets such as beach access points and stairs, coastal paths, off street parking and roads**

Retreating at risk assets and land uses to alternative locations beyond the coastal hazard risk zones will allow the continuation of natural coastal processes acting on the dune system. Some loss of beach amenity may result.

3.4 Management Unit 3 – Leighton Beach – Vlamingh Parkland

3.4.1 Risk Profile

The short and medium term risk profiles for this area of Leighton Beach are high due to impacts on the beach reserve and Vlamingh Parklands. This risk increases to extreme in the long-term due to impacts on coastal paths and off street parking.

Environmental values affected by the risk in the short and medium-term are the result of loss of coastal dunes, vegetation and habitat – which provides a supply of sand to the beach during storm events provide a natural buffer zone to coastal processes and supports ecology. Social values at risk in the long-term include the ability to access and enjoy beach areas which may further impinge on people’s ability to undertake a variety of passive and active recreation and other social values.

Table 3-4 Management Unit 3 -Risk Profile Summary

Timeframe	Risk Level	Asset Triggering Risk	Value Triggering Risk Level
Short	High	Leighton Beach Reserve, Vlamingh Parklands	Environment
Medium	High	Leighton Beach Reserve, Vlamingh Parklands	Environment
Long	Extreme	Coastal path, off street parking	Social

3.4.2 Existing Controls

There are no known constructed controls to mitigate erosion. The only natural control is a vegetated sandy dune system.

3.4.3 Recommended Adaptation Measures

Recommended adaptation measures to manage erosion risks include:

- **Dune stabilisation and nourishment with annual beach monitoring and maintenance**

Stabilisation of dunes using erosion fencing, coir matting, planting, combined with beach nourishment can be used to increase the buffering capacity of the dune system. Sand nourishment and associated rehabilitation and ongoing maintenance of the dunes could potentially prevent further retreat and maintain beach area in the short to medium-term. This adaptation measure is not as effective as some engineered options at reducing the risk level. Annual beach monitoring to monitor need for nourishment.

- **Groynes, nourishment, dune rehabilitation with annual beach monitoring and maintenance**

Development of a series of groynes with associated nourishment may assist to maintain a greater beach width in front of the dunes. Downdrift impacts are likely as the net northward sediment transport will be restricted. Maintaining the groynes in a “filled” state will minimise these downdrift impacts. Ongoing nourishment is likely to be required following storm events to maintain beach amenity. An individual groyne is unlikely to provide the required level of protection and would have to be considerably longer than if used in combination with more frequently spaced groynes. Annual beach monitoring to monitor need for nourishment.

- **Offshore or submerged breakwaters and nourishment with annual beach monitoring and maintenance**

Implementation of a series of offshore or submerged breakwaters along North Leighton, Mosman and potentially into south Cottesloe Beaches could be used to provide interim protection against erosion from north-westerly storm waves as well as south-westerly swell waves. Nourishment is required with this protection to allow the beach shape to reform, to provide a buffer and maintain beach amenity. This measure will reduce the wave energy reaching the beach area, reducing the effects of erosion, but will not provide protection against inundation. Annual beach monitoring to monitor need for nourishment.

- **Retreat and relocation of constructed assets such as beach access points and stairs, coastal paths, off street parking and roads**

- Retreating at risk assets and land uses to alternative locations beyond the coastal hazard risk zones will allow the continuation of natural coastal processes acting on the dune system. Some loss of beach amenity may result.

3.5 Management Unit 4 -Leighton Beach – Surf Club Precinct

3.5.1 Risk Profile

In the short-term, the risk level at Leighton Beach is high due to risks to environmental and social values. In the medium-term, a number of assets including the Fremantle Surf Life Saving Club and the Leighton Beach Change room facilities are at extreme risk of erosion. In the long-term, there is an extreme risk of erosion to the off street car parking area and coastal paths.

Environmental values at risk in the short-term are the result of loss of coastal dunes, vegetation and habitat – which provides a supply of sand to the beach during storm events, provide a natural buffer zone to coastal processes and supports ecology. In the medium term, social values at risk are access to public toilet facilities near the beach and park, and having a safe surf-lifesaving patrolled beach. In the long term, social values at risk also include access to car parking which may impinge on the community’s access to the beach for a variety of passive and active recreation and other social values.

Table 3-5 Management Unit 4 -Risk Profile Summary

Timeframe	Risk Level	Asset Triggering Risk	Value Triggering Risk Level
Short	High	Leighton Beach Reserve, Vlamingh Parklands, Leighton Beach Changerooms	Environment, Social
Medium	Extreme	Leighton Beach Changerooms, Fremantle Surf Life Saving Club	Social
Long	Extreme	Leighton Beach Changerooms, Fremantle Surf Life Saving Club, Curtin Ave Reserve, coastal path, off street parking	Social

3.5.2 Existing Controls

There are no known constructed controls to mitigate erosion. The only natural control is a vegetated sandy dune system.

3.5.3 Recommended Adaptation Measures

Recommended adaptation measures to manage erosion risks include:

- **Dune stabilisation and nourishment with annual beach monitoring and maintenance**

Stabilisation of dunes using erosion fencing, coir matting, planting, combined with beach nourishment can be used to increase the buffering capacity of the dune system. Sand nourishment and associated rehabilitation and ongoing maintenance of the dunes could potentially prevent further retreat and maintain beach area in the short to medium-term. This adaptation measure is not as effective as some engineered options at reducing the risk level. Annual beach monitoring to monitor need for nourishment.

- **Groynes, nourishment, dune rehabilitation with annual beach monitoring and maintenance**

Development of a series of groynes with associated nourishment may assist to maintain a greater beach width in front of the dunes. Downdrift impacts are likely as the net northward sediment transport will be restricted. Maintaining the groynes in a “filled” state will minimise these downdrift impacts. Ongoing nourishment is likely to be required following storm events to maintain beach amenity. An individual groyne is unlikely to provide the required level of protection and would have to be considerably longer than if used in combination with more frequently spaced groynes. Annual beach monitoring to monitor need for nourishment.

- **Offshore or submerged breakwaters and nourishment with annual beach monitoring and maintenance**

Implementation of a series of offshore or submerged breakwaters along North Leighton, Mosman and potentially into south Cottesloe Beaches could be used to provide interim protection against erosion from north-westerly storm waves as well as south-westerly swell waves. Nourishment is required with this protection to allow the beach shape to reform, to provide a buffer and maintain beach amenity. This measure will reduce the wave energy reaching the beach area, reducing the effects of erosion, but will not provide protection against inundation. Annual beach monitoring to monitor need for nourishment.

- **Buried seawall with beach nourishment**

Establishment of a buried seawall at the back of the beach combined with nourishment could be used to protect important values supplied to the community by the foreshore infrastructure and assets. Development of traditional, exposed, high seawall in this area would not be complimentary to the existing uses and values of this foreshore, as it is one of the few wide, sandy beaches in the area, and a seawall may increase the potential for loss of beach amenity due to the increased erosion potential from wave energy reflected off the less permeable structures.

- **Retreat and relocation of constructed assets such as beach access points and stairs, coastal paths, off street parking and roads**

- Retreating at risk assets and land uses to alternative locations beyond the coastal hazard risk zones will allow the continuation of natural coastal processes acting on the dune system. Some loss of beach amenity may result.

3.6 Management Unit 5 -Leighton & Port Beach dunes

3.6.1 Risk Profile

In the short-term the risk level at Leighton and Beach dunes is high due to risks to environmental and social values of the Port Beach Reserve. In the medium to long-term, there are extreme risks to coastal paths and the Port Beach Road reserve, affecting social values.

Environmental values triggering the risk in the short term are coastal vegetation and habitat – which support ecology, provide a natural buffer zone to coastal processes and provide a supply of sand to the beach during storm events. In the medium to long-term, social risks relate to the potential impacts on accessing the foreshore reserve by road or coastal paths due to risk to the road reserve.

Table 3-6 Management Unit 5 -Risk Profile Summary

Timeframe	Risk Level	Asset Triggering Risk	Value Triggering Risk Level
Short	High	Port Beach Reserve	Environment
Medium	Extreme	Port Beach Road Reserve	Social
Long	Extreme	Port Beach Road Reserve	Social

3.6.2 Existing Controls

There are no known constructed controls to mitigate erosion. The only natural control is a vegetated sandy dune system.

3.6.3 Recommended Adaptation Measures

Recommended adaptation measures to manage erosion risks include:

- **Dune stabilisation and nourishment with annual beach monitoring and maintenance**

Stabilisation of dunes using erosion fencing, coir matting, planting, combined with beach nourishment can be used to increase the buffering capacity of the dune system. Sand nourishment and associated rehabilitation and ongoing maintenance of the dunes could potentially prevent further retreat and maintain beach area in the short to medium-term. This adaptation measure is not as effective as some engineered options at reducing the risk level. Annual beach monitoring to monitor need for nourishment.

- **Groynes, nourishment, dune rehabilitation with annual beach monitoring and maintenance**

Development of a series of groynes with associated nourishment may assist to maintain a greater beach width in front of the dunes. Downdrift impacts are likely as the net northward sediment transport will be restricted. Maintaining the groynes in a “filled” state will minimise these downdrift impacts. Ongoing nourishment is likely to be required following storm events to maintain beach amenity. An individual groyne is unlikely to provide the required level of protection and would have to be considerably longer than if used in combination with more frequently spaced groynes. Annual beach monitoring to monitor need for nourishment.

- **Offshore or submerged breakwaters and nourishment with annual beach monitoring and maintenance**

Implementation of a series of offshore or submerged breakwaters along North Leighton, Mosman and potentially into south Cottesloe Beaches could be used to provide interim protection against erosion from north-westerly storm waves as well as south-westerly swell waves. Nourishment is required with this protection to allow the beach shape to reform, to provide a buffer and maintain beach amenity. This measure will reduce the wave energy reaching the beach area reducing the effects of erosion, but will not provide protection against inundation. Annual beach monitoring to monitor need for nourishment.

- **Retreat and relocation of constructed assets such as beach access points and stairs, coastal paths, off street parking and roads**
- Retreating at risk assets and land uses to alternative locations beyond the coastal hazard risk zones will allow the continuation of natural coastal processes acting on the dune system. Some loss of beach amenity may result.

3.7 Management Unit 6 –Port Beach North

3.7.1 Risk Profile

The risk profile for Port Beach North is extreme across all time periods due to the impact to economic, social and infrastructure values from erosion hazards to assets identified in Table 3-7. These risks represent a substantial economic cost due to the potential impacts to the Fremantle Port, ability to run a small coastal business, and industry related businesses east of Port Beach Road.

The social values impacted by erosion include impact on the community’s ability to access and enjoy beach settings, use beach areas for a variety of active recreation and passive uses, access public toilet facilities near the beach and park, have a safe surf-lifesaving patrolled beach and access the region by road.

Table 3-7 Management Unit 6 -Risk Profile Summary

Timeframe	Risk Level	Asset Triggering Risk	Value Triggering Risk Level
Short	Extreme	Port Beach Road Reserve, Fremantle Port Land, Beach access points, coastal paths, off street parking, Public Coastal Facilities – Kiosk and Change Rooms	Economic, Social, Infrastructure
Medium	Extreme	Port Beach Road Reserve, Tydeman Road Reserve, Fremantle Port Land, Freight Rail, Beach access points, coastal paths, off street parking, Public Coastal Facilities – Kiosk and Change Rooms	Economic, Social, Infrastructure
Long	Extreme	Port Beach Road Reserve, Tydeman Road Reserve, Fremantle Port Land, Freight Rail, Beach access points, coastal paths, off street parking, Public Coastal Facilities – Kiosk and Change Rooms	Economic, Social, Infrastructure

3.7.2 Existing Controls

Existing controls along the northern length of Port Beach, chainage 500 to 870 as described by DPI (2004) and shown in Table 3-8, are a mixture of Type B (Seawalls without engineering design) and Type C (Poorly founded concrete block seawalls).

Table 3-8 Existing controls along Port Beach (DPI 2004).

CHAINAGE (m)	LENGTH OF SECTION (m)	COASTAL ASSET	DISTANCE FROM HSD (m)	EXISTING EROSION PROTECTION
0m to 200m	200	Road Realignment	15 to 20	Sand dune Seawall (Type A)
200m to 300m	100	Road Realignment	30	Sand dune Seawall (Type A & B)
300m to 500m	200	Road Realignment & Existing Road	40	Sand dune Seawall (Type B)
500m to 560m	60	Car Park	5	Seawall (Type B)
560m to 650m	110	Car Park	10	Nourished sand dune
650m to 670m	20	Fremantle SLSC Port Beach Annex building (10m frontage)	10	Nourished sand dune Seawall (Type B)
670m to 690m	20	Change rooms (20m frontage)	15	Nourished sand dune Seawall (Type C)
690m to 730m	40	Car Park	5	Nourished sand dune Seawall (Type C)
730m to 800m	70	Oyster Bar Café building (70m frontage)	10	Vegetated sand dune Seawall (Type C)
800m to 870m	70	Car Park	15	Natural sand dune Seawall (Type C)

3.7.3 Recommended Adaptation Measures

A number of options were discounted for the following reasons:

- Groynes are not considered to be feasible in this area as they will not substantially affect cross shore transport, which from review of the bathymetry change maps is the dominant erosion force at this site. The construction of groynes may disrupt and reduce sediment supply to the area from the north and may promote the need for sand nourishment.
- Offshore breakwaters or submerged breakwaters are not suitable for this site presently due to the popularity of this beach as a surf beach. Construction of offshore breakwaters or submerged breakwaters would have a significant impact on the local wave climate and may pose a safety risk to people trying to use the submerged breakwater as an artificial surf reef.

Adaptation measures to manage erosion risks include:

- **Dune stabilisation and nourishment with annual beach monitoring and maintenance**

Stabilisation of dunes using erosion fencing, coir matting, planting, combined with beach nourishment can be used to increase the buffering capacity of the dune system. Sand nourishment and associated rehabilitation and ongoing maintenance of the dunes could potentially prevent further retreat and maintain beach area in the short to medium-term. This adaptation measure is not as effective as some engineered options at reducing the risk level. Annual beach monitoring to monitor need for nourishment.

- **Seawalls with nourishment**

Existing seawalls in this area are poorly founded and have limited capacity to withstand severe wave action. Replacement or upgrade of these structures with properly engineered seawalls with deeper foundations will increase protection to landward assets,

but may increase the potential for loss of beach due to the increased erosion potential from wave energy reflected off the less permeable structures. Nourishment of seawalls after construction and throughout their design life is required to prevent undermining of the toe to maintain structural stability. Annual beach monitoring to monitor need for nourishment.

- **Retreat and relocation of constructed assets such as beach access points and stairs, coastal paths, off street parking and roads**
- Retreating at risk assets and land uses to alternative locations beyond the coastal hazard risk zones will allow the continuation of natural coastal processes acting on the dune system. Some loss of beach amenity may result.

3.8 Management Unit 7 –Port Beach South – Sandtrax

3.8.1 Risk Profile

The risk profile for Port Beach South is extreme across all planning periods due to potential impact to social assets including parking, beach access, coastal paths, kiosks and infrastructure assets including the North Quay Rail Terminal and Port Beach. These risks represent a substantial economic cost within the area due to the potential impacts to the Fremantle Port and businesses associated with the Rous Head precinct due to potential risks to the Port Beach Road Reserve and the Freight Rail line.

Table 3-9 Management Unit 7 - Risk Profile Summary

Timeframe	Risk Level	Asset Triggering Risk	Value Triggering Risk Level
Short	Extreme	Port Beach Road Reserve, Fremantle Port Land, Beach access points, coastal paths, off street parking	Economic, Social, Infrastructure
Medium	Extreme	Port Beach Road Reserve, Fremantle Port Land, Freight Rail, Beach access points, coastal paths, off street parking	Economic, Social, Infrastructure
Long	Extreme	Port Beach Road Reserve, Fremantle Port Land, Freight Rail, Beach access points, coastal paths, off street parking	Economic, Social, Infrastructure

3.8.2 Existing Controls

Existing controls along the southern length of Port Beach, chainage (CH) 0 to CH 500, are summarised in Table 3-8 and include a mixture of Type A (Seawalls with engineering design) and Type B (Seawalls without engineering design) (DPI, 2004). The first 200m of the southern end of the shoreline, adjacent the Rous Head Extension, is protected by a Type A seawall, constructed in 2004-2005 after the realignment of Port Beach Road, and is expected to have a design life of 50 years. The remaining section of seawall between CH 200 and CH 500 is predominantly type B. The exact age of the seawall is not known, but it is likely to have been constructed around 1968. A small sand dune has formed seaward of this seawall; however periodic erosion of the dune has resulted in seawall exposure after storm events (MPR 2000). Recommendations to remove the seawall were made prior to the realignment of Port Beach Road.

3.8.3 Recommended Adaptation Measures

Only engineered options have been considered as appropriate short-term solutions at South Port Beach due to the consequence rating to assets and values, and the immediacy of the risk level. The options considered for this area include groynes, seawall maintenance and upgrade, submerged breakwaters and nourishment with monitoring. In the short-term, retreat is not considered to be an acceptable option at this site due to the status of Port Beach Road as a critical transport link to coastally dependent infrastructure at Rous Head.

A number of options were discounted for the following reasons:

- Groynes are not considered a feasible option in this area as they will not prevent cross short transport at this site which from review of the bathymetry change maps is the dominant erosion force at this site. Construction of groynes may disrupt and reduce sediment supply to the area from the north and may promote the need for sand nourishment.
- Offshore breakwaters or submerged breakwaters are not suitable options at this site presently due to the popularity of this beach as a surf beach. Construction of offshore breakwaters or submerged breakwaters would have significant impact on the wave climate and pose a safety risk to people trying to use the submerged breakwater as an artificial surf reef.

Recommended adaptation measures to manage erosion risks include:

- **Dune stabilisation and nourishment with annual beach monitoring and maintenance**

Stabilisation of dunes using erosion fencing, coir matting, planting, combined with beach nourishment can be used to increase the buffering capacity of the dune system. Sand nourishment and associated rehabilitation and ongoing maintenance of the dunes could potentially prevent further retreat and maintain beach area in the short to medium-term. This adaptation measure is not as effective as some engineered options at reducing the risk level. Annual beach monitoring to monitor need for nourishment.

- **Seawalls with nourishment**

Some of the existing seawalls in this area are poorly founded and have limited ability to resist against a severe erosive event. Replacement or upgrade of these structures with properly engineered seawalls with deeper foundations will increase protection to assets behind, but may increase potential for loss of beach amenity due to the increased erosion potential from wave energy reflected off the less permeable structures. Nourishment of seawalls after construction and throughout their design life is required to prevent undermining of the toe to maintain structural stability. Annual beach monitoring to monitor need for nourishment.

- **Retreat and relocation of constructed assets such as beach access points and stairs, coastal paths, off street parking and roads**

- Retreating at risk assets and land uses to alternative locations beyond the coastal hazard risk zones will allow the continuation of natural coastal processes acting on the dune system. Some loss of beach amenity may result.

4. Summary of Adaptation Options

4.1 Interim Coastal Protection

The role of interim coastal protection measures is to reduce the risks associated with the coastal hazards of erosion and inundation to land and assets. There is a variety of options suitable to protect against these hazards involving either soft or hard engineering approaches. Some forms of coastal protection can provide protection against both hazards, but coastal protection works are generally designed to protect against either erosion or inundation and not both.

The development of interim protection measures can have implications for coastal processes and sediment transport at updrift and downdrift locations from the protection works. The development of interim protection measures therefore needs to consider scales larger than the area being protected as effects can be felt many kilometres away, particularly if there is a disruption to the pathways or quantities of longshore sediment transport.

The State Coastal Planning Policy (SPP 2.6) only permits the development of coastal protection works where all other options (Avoid, Planned or Managed Retreat and Accommodate) have been considered as part of a Coastal Hazard Risk Management Process.

Interim protection works are often expensive, require ongoing maintenance and therefore require ongoing funding to guarantee ongoing functionality of the protection over the design life.

The construction of interim protection measures alters how coastal processes act on the land/beach and can therefore affect the shape of the land. These changes to the shape of the land (e.g. erosion of a beach in front of a seawall) can have implications on usage of the land (e.g. loss of beach amenity). As a result, the associated effects of interim protection measures and the future desired land use need to be assessed when deciding on adaptation options as the implications of a particular interim protection measures itself may contradict the initial purpose of the coastal protection.

The following sections describe a variety of interim protection measures that that could be used along the Port, Leighton and Mosman Beaches. A background to how each protection functions, their general purpose and the main negatives associated with the style of protection are detailed.

4.1.1 Beach nourishment

Beach nourishment is the artificial addition of sand to a beach system. It increases the buffer against erosion and is used to maintain and/or advance the shoreline position in an area which has a sediment deficit or inadequate buffer zone. Beach nourishment is commonly carried out in response to long-term shoreline erosion trends and can be planned for whereas emergency works to cope with erosion from extreme storms is event based cannot be planned for.

Beach nourishment reduces the risk of storm tide inundation when combined with the creation and vegetative stabilisation of an elevated dune system. It is important to note that beach nourishment does not halt erosion, but simply provides sediment from an external source in the form of a natural beach, upon which wave and current forces will continue to act.

Beach nourishment is undertaken for the following purposes:

1. To control erosion and create a buffer for settlements and infrastructure (a wider beach system can reduce storm damage to coastal structures by dissipating energy across the surf zone, protecting settlements and infrastructure from extreme events); and

- To broaden beaches for recreational purposes (beaches are valuable assets for tourism, recreation and economic drivers for coastal communities).

Beaches unable to naturally migrate landward will require additional sand volumes to counterbalance beach recession caused by sea level rise (refer Figure 4-1).

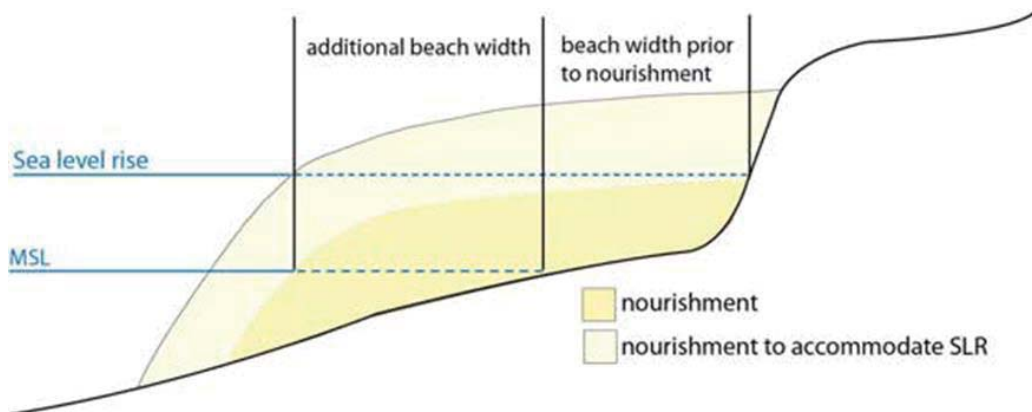


Figure 4-1 Diagram of typical beach nourishment cross-section (Linham et al 2010)

Beach nourishment can require large amounts of sand. For example, creating a 100m wide beach requires approximately 500m³ per linear metre of coastline, depending on the beach slope and grain size. The identification of accessible and sustainable sand deposits is therefore critical to inform long-term strategies, especially in the light of the possible impacts of climate change.

Sand nourishment alone, without other forms of protection, will not prevent erosion and the nourishment material will be transported offshore or longshore over time. As such, beach nourishment should only be regarded as a short-term option feasible for short time scales of 1 to 5 years maximum depending on the wave climate and nourishment material used.

4.1.2 Artificial Reefs

Artificial reefs are submerged structures designed to reduce wave energy by causing waves to break or be disrupted at a suitable distance away from the shoreline in order to reduce the severity of erosive processes on the shoreline. This reduction in wave energy can also encourage sediment deposition in the lee of the structure. In some instances artificial reefs can be designed to enhance recreational amenity opportunities such as surfing and diving. However it is difficult to create an artificial reef that offers coastal protection and surfing amenity at the same time (due to different water depth requirements) an artificial surfing reef is not likely to be suitable to address coastal hazards along Port, Leighton and Mosman Beaches.

Artificial reefs can be effective as localised erosion control, however issues related with design and sea level rise exist because sea level rise will progressively impair the ability of the structure to reduce wave energy reaching the coast. Artificial reefs can also change beach alignment and erosion patterns.

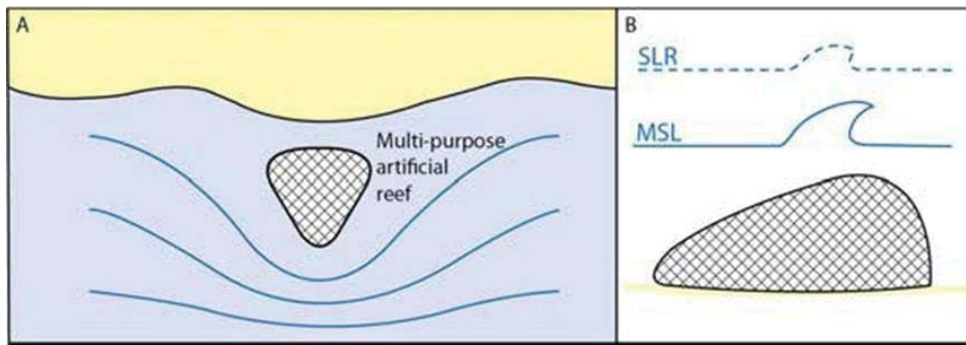


Figure 4-2 Typical diagram of a multi-purpose artificial reef (Linham et al 2010)

Sea level rise and changes in the wave climate can affect the efficiency and stability of artificial reefs, in the same way it can affect the efficiency of other emerged or submerged structures on wave energy reduction such as detached breakwaters. A rise in sea level or substantial changes in wave energy and direction can alter the reef's role in beach and shoreline stabilisation. Substantial changes in the wave climate can require expensive changes in the design of the structure (e.g. orientation). Artificial reefs can therefore be seen as a measure to control the shoreline position in the medium-term (5 to 20 years), but their efficiency as a long-term strategy to maintain the current shoreline configuration is limited.

4.1.3 Detached breakwaters

Detached breakwaters are erosion control structures. They are most frequently placed parallel to the coast to reduce wave energy and increase beach stability. Detached breakwaters can create salients (accretion of sand behind the structure) and stabilise the shoreline position against erosion.

They can be effective in defending the current shoreline position against erosion; however their effectiveness depends on the detailed design of the structure. Detached breakwaters can be used to reduce extreme and chronic storm erosion by reducing wave energy and sand movement and allowing for sand accumulation. They are not effective for protection against storm tide inundation.

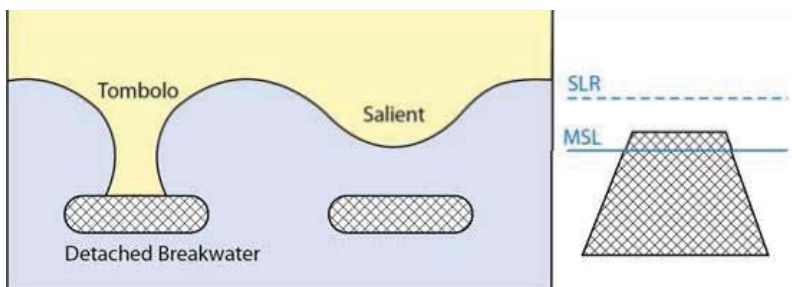


Figure 4-3 Typical detached breakwaters Note: MSL = mean sea level; SLR = sea level rise (Linham et al 2010)

Their purpose is to reduce wave energy transmission, long shore currents and therefore reduce cross-shore and longshore transport and, as a consequence, reduce erosion and increase the beach width. However by reducing the longshore transport of sand, offshore breakwaters may cause or significantly increase erosion in nearby unprotected down drift beaches.



Figure 4-4 Detached breakwater (bottom right) forming a tombolo in Geraldton, Western Australia, as part of a coastal protection and harbour configuration (Source: Google Earth Pro)

While breakwaters can be efficient in the short-term, a rise in sea level or substantial changes in wave energy and direction can alter their role in beach and shoreline stabilisation. The crest height of the structure can be submerged by rising sea levels, requiring further intervention to maintain functionality. Changes in the wave climate can require expensive changes to the design of the structure (e.g. orientation). Detached breakwaters can therefore be seen as a measure to control the shoreline position in the medium-term (5 to 20 years) but their efficacy as a long-term strategy to maintain the current shoreline configuration is questionable.

4.1.4 Groynes and artificial headlands

Groynes are structures built perpendicular to the shoreline that trap sand moving along the coast, causing sand build up on the downdrift side of the structure. A variant of a groyne is an artificial headland, which acts in the same manner but has a larger footprint. They can be effective in controlling coastal erosion, particularly due to a deficit in the supply of longshore sediment transport.

Groynes and artificial headlands can be effective in defending the current shoreline position against erosion. They are not effective for protection against storm tide inundation. As such, they should be combined with sand nourishment to mitigate the adverse effects on coastal processes. They can be used to reduce extreme storm erosion by reducing longshore sand movement.

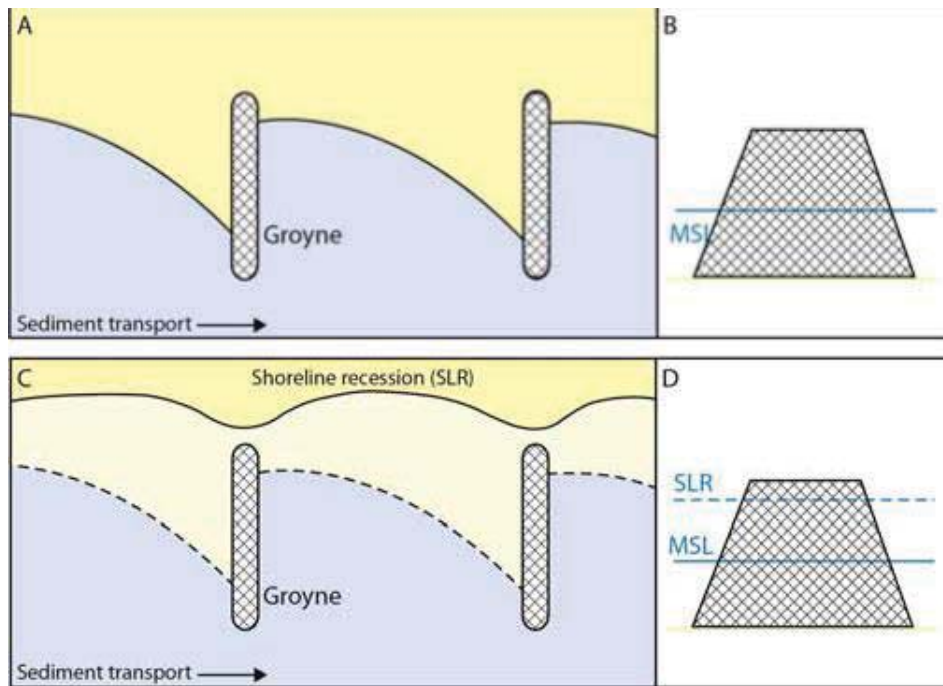


Figure 4-5 Groynes can be used to control longshore transport and facilitate beach accretion. Sea level rise can affect groynes functionality in the future (Linham et al 2010)

The primary negative impact includes coastal erosion on the lee side of the structure. In the case of a group of groynes (a groyne field), the above effect appears on the lee side of each structure within the system. Therefore it is recommended that sand nourishment is undertaken at the time of groyne construction to effectively “fill” the groyne and mitigate immediate adverse downdrift effects. The erosion is also observed in direct vicinity of the structures, particularly when waves approaching the shore are predominantly perpendicular.

Sea level rise and changes in the wave climate can affect the efficiency and stability of groynes. While groynes can be efficient in the medium-term (up to 50 years), a rise in sea level or substantial changes in wave energy and direction can alter their role in beach and shoreline stabilisation. These changes could require the implementation of adaptation measures to ensure that the groynes remain fit for purpose.

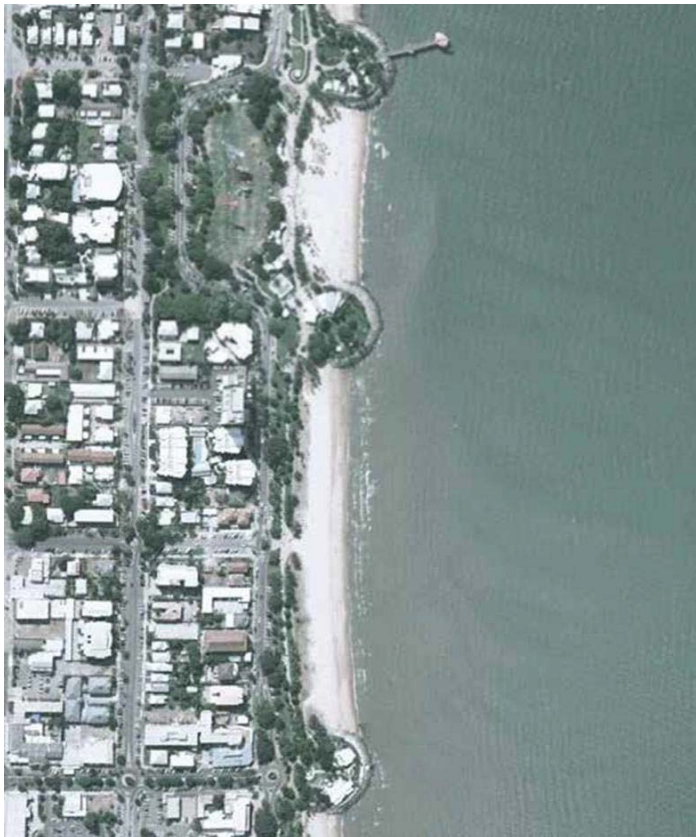


Figure 4-6 Artificial headlands along the Townsville esplanade

4.1.5 Sea dykes

A sea dyke or levee is an artificially constructed fill or wall commonly designed to regulate water levels and to avoid inundation from storm tides to low-lying land. It is usually earthen, covered with vegetation and parallel to the shoreline of low-lying coastlines. Sea dykes can be used to control extreme water levels associated with storm tides and in conjunction with sea level rise. They can also be used to defend low-lying areas from the risk of erosion provided that they are appropriately armoured on the seaward face.

Sea dykes require high levels of maintenance where extreme storms or rising sea levels challenge their efficiency and performance.

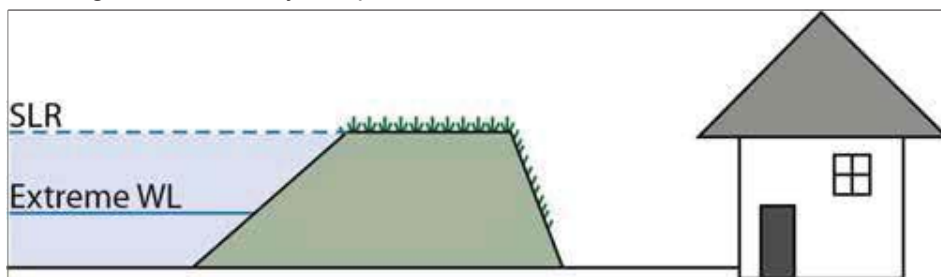


Figure 4-7 Typical sea dyke configuration Note: Extreme WL = extreme water level; SLR = sea level rise (Linham et al 2010)

Sea dykes can be used to protect human settlements from storm surge floods and sea level rise. However, sea level rise can threaten their efficiency and reshaping and upgrading may be required in the future if not adequately designed.

Sea dykes and levees can be an effective measure to reduce the risks of storm tides under sea level rise and could be designed with a 100 year or more design life, if adequate land and funding is available. However, raising sea dykes in response to sea level rise can cause the

area of land required for dyke construction to increase if slope gradients are maintained. The construction and maintenance costs are likely to increase into the future; caused by increases in water depth in front of the structure, which in turn causes increased wave heights and wave loadings on the structure. Therefore the design life needs to be considered with a long-term view in order to ensure the structure meets the needs and capabilities of future stakeholders.

4.1.6 Seawalls

Seawalls are structures separating land and water areas designed to prevent erosion of land and other damage due to wave action. Seawalls can be very large structures on the open coast as they are designed to resist the full force of waves and storm surges. Seawalls are effective in defending the current shoreline position against erosion. They are not effective for protection against storm tide inundation unless designed to be as they can be limited in height and may be porous. They should also be combined with sand nourishment to reduce beach loss in front of the wall due to wave reflection.

Seawalls are put in place to protect the land and associated land-based amenities behind them. While these structures are usually termed coastal protection structures, they effectively serve as land protection mechanisms as opposed to aiding in reducing coastal erosion. In many instances seawalls accelerate erosion on their seaward side, which ultimately results in a loss of the beach. In addition, these structures can be aesthetically unappealing and may hinder access to the beach.

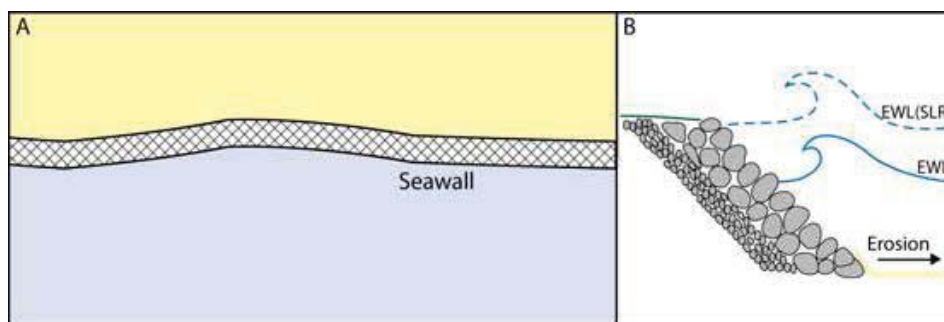


Figure 4-8 Typical seawall and the effect of sea level rise and erosion (Linham et al 2010)

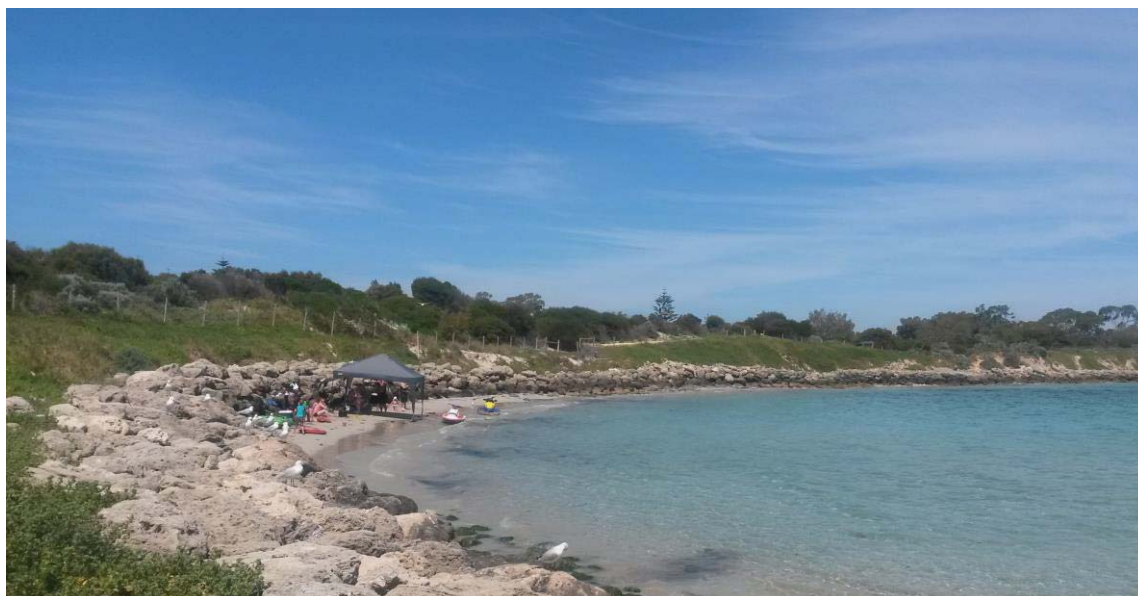


Figure 4-9 Example of a seawall at Wells Park in the City of Kwinana.

It is desirable for seawalls to cover the full length of the sediment cell within which they are located in order to prevent down-coast effects. In some instances this is not practical or feasible,

in which case the potential for erosion to occur around the ends of the wall needs to be considered to ensure that the structure does not collapse adjacent to the unprotected coast, or accelerate erosion of the adjacent unprotected shoreline.

Seawalls do not typically require continuous maintenance, however, extreme storms can damage the structures and occasional maintenance can be required.

Seawalls on the open coast are typically designed with a 50 year design life, if adequate land and funding is available. However, it is important that the design life is considered with a long-term view in order to ensure the structure meets the needs and capabilities of future stakeholders. To address sea level rise, seawalls will either need to be designed and constructed to meet future requirements or planned for height increases to be undertaken periodically. However this will only be practical if the foundations of the wall have been built sufficiently robustly to allow the extra load. Otherwise the wall may need to be rebuilt or augmented.

4.2 Planning and Development Options

Planning adaptation responses are designed to reduce the risk of coastal hazards on human settlements by controlling development in high hazard risk areas and reducing the current urban footprint in high hazard risk areas. Planning responses ultimately contribute to strategic retreat pathways, however can also provide a framework for shorter term use and enjoyment of the coast prior to the realisation of coastal risks. Planning responses can also provide for intensification of coastal development, where community, economic and social values support the long-term (interim) protection of coastal developments.

Planning decisions made in short and medium term horizons should not pre-empt or restrict future planning decisions. This is supported by the WAPC's SPP 2.6 *State Coastal Planning Policy and Guidelines* which recommend that more favourable risk adaptation options will allow for a "wide range of potential future risk management options". For this reason, planning responses are most effective when considering the "avoid" and "planned or managed retreat" risk mitigation levels set out in the *Coastal Hazard Risk Management and Adaptation Planning Guidelines* (WAPC) and in Figure 2-4.

Relevant planning mechanisms in Western Australia include the *Environment Protection and Biodiversity Act 1999* (Commonwealth); the *Planning and Development Act 2005* (WA); *Planning and Development (Local Planning Schemes) Regulations Act 2015*; State Planning Policy 2.6 *State Coastal Planning Policy* and *State Coastal Planning Guidelines*; local planning schemes and local planning strategies; structure plans; local area plans; foreshore management plans and coastal management strategies. These are mechanisms that can deliver/implement planning responses, however do not operate as the discrete response themselves.

For future development, risks can be avoided by policy approaches that restrict vulnerable development in high-level coastal hazard risk areas. There is scope to accommodate risks through a range of planning policy mechanisms by providing warning to landowners, educating the community, government intervening to secure future vulnerable land, and reducing the consequences of impacts (e.g. development styles, construction techniques). Alternatively, there is an opportunity to accept the risk of development in vulnerable areas where the design life of the development aligns with the expected timeframe until a certain risk level is reached.

As comprehensive infrastructure and works are already in place in settlements within coastal hazard risk areas, it is much more difficult to manage existing development as there may be limited opportunity to avoid or accommodate the risk using planning responses alone. Risk management options, therefore, are mainly concerned with protecting the land or asset through

redevelopment, rezoning and land acquisition to utilise land and development in the most efficient way in providing protection from high coastal risk.

State Planning Policy 2.6 provides an effective planning tool in Western Australia, and provides development control and strategic planning guidance for new coastal development and land use. The limitations of SPP 2.6 in managing coastal risks in the long-term relate to the capacity of decision makers to understand and implement the policy, and the ability and precedence of the (non-statutory) policy to be varied in response to political outcomes. The focus of the SPP on new development and land use change limits its applicability to existing development within coastal risk areas.

The following planning options are described within this compendium. This information discusses the planning policy response to manage risks rather than the mechanisms in the Western Australia planning system that might be used to implement them. The mechanisms will be analysed and explored in the development of the adaptation plan:

- Coastal Development Control
 - Restriction of development in vulnerable areas
 - Coastal development setbacks
 - Temporary development
 - Managed redevelopment
 - Design standards to manage risk
- Strategic Planning
 - Rezoning land (density/land use)
 - Development incentives and split codings
 - Foreshore reserve expansion and retention
 - Intensification planning
- Retreat Strategies
 - Strategic withdrawal of utilities/infrastructure
 - Land acquisition (voluntary and compulsory, leaseback) and impermanent land tenure
 - Notifications on title

4.2.1 Coastal Development Control

Restriction of Development in Vulnerable areas

Prevention of further development within coastal areas at high risk, including primary and foredunes and low-lying coastal areas, is an effective policy tool to avoid future hazard issues with coastal development.

Restriction policy, using scheme provisions, special control areas, local or state planning policy, can be implemented by local and state government to avoid the need to provide longer-term interim protection for development in vulnerable locations.

The use of planning policy to restrict development on the basis of coastal vulnerability can be subject to challenge by developers and applicants, particularly where (interim) protection measures are seen to manage the risk in the current planning horizon. The use of statutory mechanisms (including scheme provisions and special control areas) can remove some level of discretion for such decisions.

Coastal development setbacks

Development setbacks establish fixed distances from a designated boundary (i.e. the high water mark, a hazard risk line, a defence line, or another specific line determined by the legislative framework) to the property line in which development is restricted, prohibited or regulated by specific design requirements to provide a safety buffer against extreme storms and future sea level rise.

Coastal development setbacks provide protection to properties and infrastructure against coastal flooding and erosion by ensuring that buildings are not located in an area susceptible to these hazards and that those structures which are susceptible are appropriately designed to mitigate against the risk. Coastal development setbacks can also be imposed to specify locations in which existing developments may not be rebuilt or improved following damage.

In general two types of setback can be implemented:

- Elevation setbacks to deal with flooding; and
- Lateral setbacks to deal with erosion.

Setback distances are determined either as:

- A fixed setback, which prohibits development for a fixed distance landward of a reference feature; or
- A floating setback, which uses dynamic, natural phenomenon to determine these distances case by case.

Building setbacks allow coastal processes, such as erosion, to continue naturally along strategic sections of the coast while ensuring that intensification of development in at-risk areas is restricted. Setback boundaries can be adopted on the basis of historical erosion rates, extreme water level rise predictions and sea level rise figures¹.

A limitation of development setbacks is their relevance only for a single planning horizon; land outside the defined setback will (in a future planning horizon) become land at risk. Therefore setbacks require ongoing regular review, alongside the use of other planning mechanisms to provide for retention of foreshore environments/retreat of development over subsequent planning horizons.

Temporary development

Where coastal areas are identified for retreat or interim protection (to delay retreat), their use and enjoyment by the community does not dissipate with that decision. Many vulnerable coastal areas (outside areas currently at risk) will be available for appropriate use and development for 50 and 100 years. There is opportunity to enjoy economic and social benefits of the vulnerable coast before the risks are realised, through appropriate temporary development.

Temporary development can include:

- Structures and development that have an asset design life that will expire prior to physical processes affecting their location; and
- Structures and development that are transportable, enabling their relocation as physical processes (and the coast) move toward their location.

With appropriate planning policy and design guidelines, temporary development can create distinct 'pop up' communities and facilities along the coast under the stipulation that these communities will be relocated in the future, as the coast moves further inland. This option is a temporary measure to maximise (temporary) land use opportunities along coastal locations with the ultimate aim of a planned retreat.

Temporary development can also assist in generating greater awareness of the temporary nature of our current beaches, in their current form/location. Design guidelines that require the physical built form to appear temporary can assist the community in understanding that coastal environments are dynamic and will change.

Modular architecture is an effective sustainable building technique that should be considered for development along the coast. Structures at a low cost or that can readily be repaired at low cost following likely impacts of coastal erosion are ideal for sites within the vulnerable area.

Temporary development policy can be very effective when planning for public recreational facilities in coastal areas, or private development on leased land. Challenges in land tenure for private development can arise where private investment prefers long-term or permanent land tenure.

Managed redevelopment

Conventional coastal development control policies have limited relevance to planning for existing freehold land located in vulnerable coastal areas. Existing policies in Western Australia tend not to be retrospectively applied to existing developed and zoned areas as decision makers are reluctant to remove existing development rights. The current policy framework and mechanisms do not facilitate adaptive planning and development in vulnerable coastal areas that can respond to changing conditions. Instead the current framework assumes an interim protection approach for the development and redevelopment of assets along the coast.

Planning policy that manages redevelopment of coastal processes can rely on the natural decommissioning and relocation of private assets at the end of their design life *prior* to coastal risks affecting the property and/or private asset through private redevelopment.

Alongside managed redevelopment policy, notifications can be placed on Certificate of Title that state that assets cannot be redeveloped beyond a certain date/risk level. This will enable freehold land to be developed now, but prevents redevelopment should the development exist within an identified coastal risk zone.

Design standards to manage risk

Increasing or changing asset design standards is one coastal adaptation option that can be used to withstand the impacts of coastal processes within coastal hazard zones. This measure should only be considered where avoiding risk or relocating an asset is not an option. This option is best implemented for new assets are considered at risk due to the pressing coastal risk line to ensure reduced cost in mitigating the impacts with initial design outcomes. Retrofitting of existing assets can be undertaken through redesign and renovations; however this would be at an increased cost to the proponent.

A design approach can inform developments sensitive to the unique natural coastal characteristics. When addressing both new and existing redevelopment, this option can be initiated through built form design controls that appropriately address the coastal impacts presented to a coastal asset. Design guidelines can include ways to 'live' with the effects of coastal inundation, including vertical building design, reducing or shifting the building footprint, locating the development on the least hazardous portion of the site, and using appropriate building materials. Guidelines can be updated according to changes in the risk line.



Figure 4-10 An example of retrospective design requirements: flood wall/gates and doors added to a dwelling to protect existing property from storm related flooding in United Kingdom

4.2.2 Strategic Planning

Our continued, long-term enjoyment of coastal environments and public beaches requires fundamental different approaches to planning of coastal settlements. Current practices, which result in intensive development adjacent to coastal foreshore due to the market and amenity value of these locations, are not conducive to natural retreat of the coast, and therefore retention of the beach asset that creates the market and amenity value. Strategic planning measures therefore relate to changing settlement patterns, moving development away from the receding coastline, to retain public ownership of the beach and coast in the long-term.

Changes in land-use, for example from residential to recreational purposes, can be considered as part of a strategy to mitigate future development from exposure to risks from coastal erosion and storm tide inundation. Changes to land-use designation should be considered as a preventative mechanism to ensure that the distribution and intensity of future uses are compatible with identified risks in high coastal hazard and erosion prone areas.

Changes in land-use can be carried out to reduce the intensification within coastal hazard areas. Exposure of coastal settlements to coastal hazards can be reduced through a gradual land-use transition. Conversely, where social and economic values allow, changes in land use might intensify development in coastal areas to better justify the cost-benefit of coastal protection works.

Proposals for land-use change should be supported by a broad stakeholder consultation process. This could be a challenging process, particularly considering the loss of value of land that may be caused by land use planning changes.

There are several ways in which land use planning can mitigate the risks of high-level coastal hazard risks through local planning scheme mechanisms, primarily to encourage the provision of better land uses that are more naturally appropriate to the coastal hazards risk levels.

Rezoning land

Rezoning strategies enable planning decision makers to restrict and discourage development on residential, commercial and industrial areas along the coast, particularly in high-risk areas exposed to coastal hazards in the future. Rezoning forms a part of retreat strategies, effectively reducing and removing development potential in vulnerable locations to remove the need to protect private land from erosion over time.

Changes in land use – for example from intense commercial activities, to lower scale temporary activities – reduces the future cost of purchasing, compensating, and decommissioning private assets in vulnerable areas. Changing zones from intense residential and commercial zones to special use zones that restrict the nature of use and development can prepare private land and communities for eventual retreat.

On residential lots, rezoning to change density of development and redevelopment can ensure that intense, high-density areas are planned for outside vulnerable coastal locations. For example, increasing residential density in the Rockingham city centre, and lowering density on the immediate coast can enable the coastline to recede naturally over time, with fewer properties/dwellings at risk, and without impacting on the overall supply of dwellings in the area. The decline in value of coastal land (from the reduced density) is offset by the increase in value of higher density land elsewhere. Whilst restriction and down coding of coastal land may result in claims for compensation due to injurious effect on land values on the coast, these costs may be offset by the avoidance of interim protection measures and/or the social benefit of retaining public beaches which are otherwise lost where interim protection of private land is undertaken (through seawalls and other engineering structures).

As coastal locations are currently considered of high market value, a comprehensive change in community perceptions would be required regarding the risks of coastal hazards to land, land use and property to ensure community outrage over reducing density/perceived loss of land values is managed. Stakeholder and community engagement will be important to engage the community in decisions related to changing the structure of coastal settlements, to provide ongoing public benefit.

Development incentives

Development incentives provide a softer approach than rezoning to shift coastal development patterns. Opportunities to incentivise the ceding of private property at risk over time, through increased development potential elsewhere, can remove some of the angst felt by coastal landholders, and also alleviate compensation costs where land values are affected by rezoning policies.

Split coding (which tie increased development potential on a 'safe' lot to the ceding of a lot at risk) is an example of development incentives. These allow for more efficient land use along the coast as higher density development is encouraged outside of the hazard risk area, which could be used as public open space, community gardens or other public uses as the natural coastline continues to recede naturally. This option would make it appealing to developers and landowners who would likely benefit from the more flexible higher density coding.

The non-mandatory nature of developer incentives requires that private landholders choose to give up their coastal assets; in the context of the Port, Leighton and Mosman Beaches, many of these assets which are at risk are public infrastructure such as roads, paths, beach access points and the Fremantle Port. . Developer incentives alone may not adequately shift large private assets such as the Fremantle Port. Similarly, there is unlikely to be a development incentive that would encourage the shifting of public infrastructure assets. Developer incentives are most applicable to those land uses that are not coastal dependent such as residential and commercial properties. These development incentives may be more applicable to properties in the long-term as the risk increases.

Foreshore reserve expansion and retention

For some time, Western Australia has had a policy of public ownership and foreshore reserve along the coast and waterways. In line with this policy, the State Government has acquired land over time and requires ceding of land to provide public foreshores. This practice supports the principle that, in Western Australia, the coast and beaches are a public asset for community benefit.

Foreshore reserves along the Port, Leighton and Mosman Beaches are threatened by three key processes:

- Coastally dependent port assets;
- Erosion of the coast; and
- Road reserves

Where erosion extends beyond the foreshore reserve, or if no foreshore reserve exists, the ability to retain public beaches and foreshore reserves is entirely removed unless private land is relocated/acquired and land is reserved. The use of reserves also enable greater control of development in vulnerable areas, as private land use and development is subject to lease and approval, with no as of right development potential that exists in many zones.

In some areas of the study area, the existing foreshore reserve is insufficient to provide a beach and associated open space along the coast, particularly for Port Beach. Parts of the Port Beach area outside the foreshore reserve become impacted by erosion hazards in the short-term. .

Expanding the foreshore reserve to include all vulnerable land and some adjacent land, is the only planning response that enables retention of public beaches and coastal reserves in the long-term. Ensuring that the existing foreshore reserve is retained (i.e. not rezoned for private development) will avoid introduction of new development and assets within vulnerable areas, and therefore avoid the costs of acquisition/compensation/interim protection being borne by future communities.

Where expansion of the foreshore reserve impacts currently developed properties, existing land uses can continue to operate under non-conforming use rights; once those rights expire – or the land is purchased, the land on the coast shall form part of a foreshore reserve. A staged approach according to risk levels is appropriate in determining which lots should be rezoned and at what time. Reservation of public land will require compensation and/or purchase.

Intensification planning

Planning for intensification of coastal development may be a necessary planning strategy for development types that are dependent on coastal locations. This includes:

- Coastal dependent industrial development (e.g. access to import/export facilities and ocean outfalls); and
- Boating and marina facilities

Intensification of development may also be used in existing coastal settlements where social or economic values (e.g. value of private land, heritage values) provide justification for interim protection works. In such instances, intensifying development (and therefore the cost benefit of interim protection) can assist to offset the costs of interim protection measures over long (50+ years) planning horizons. In commercial/residential examples, increasing density and intensity can increase the number of users (e.g. residents) that benefit from the infrastructure, therefore reduce the cost per user (and share these costs through local area rates/special levies to fund the construction, maintenance and upgrading of the necessary temporary protection).

As population increases within a hazardous coastal zone, it is assumed that the intensification would support the ongoing protection of the land. Similar approaches have been undertaken in the Netherlands, where the high population density in vulnerable locations makes it viable to systematically protect in the long-term as the assets become too valuable to lose or to retreat. This is particularly relevant for state significant industrial development that is dependent on coastal access and infrastructure. The intensification option is effectively a high cost, high reward option. However, the extreme investment of costs in assets and services within a vulnerable zone means that there is a high cost associated with protection. Essentially, ever increasing seawalls would be required to protect the development from ever relocating. For this to be financially viable, it requires significant density and a critical mass of people/economic development potential to support the protection elements in the infinite term.

An issue emerges as, despite the proviso that protection will continue in the long-term, future climate change and evolving coastal processes are unknown. As such, future ways to protect the area, its land and assets, are also constantly changing. Despite the influx of communities and infrastructure through intensification making the land worthwhile to protect, as future climate change is unknown, it is unsustainable to protect in the long-term and as a result, should only be considered as a long-term, but still an impermanent measure.

4.2.3 Retreat Strategies

Once a strategic decision to retreat has been made, additional responses are necessary to manage the infrastructure and financial impacts. Some preliminary responses may include the following options dependent on the primary issue/s relevant to the location:

- Strategic withdrawal of utilities/infrastructure
- Land acquisition (voluntary and compulsory, leaseback)
- Notifications on title

Strategic Withdrawal of Utilities/Infrastructure

Over time, strategic planning for utilities and infrastructure can identify ways to relocate and decommission infrastructure in areas at risk as assets become ready for renewal. With sufficient lead in, infrastructure providers are able to consider the level of maintenance, upgrade, and renewal that is appropriate in areas of coastal risk.

New infrastructure should be located outside areas of coastal risk, commensurate with asset lifetimes. Alternative servicing strategies for coastal developments, such as design and installation of infrastructure perpendicular to the coast, can enable staged decommissioning of infrastructure assets over time, as risks are realised.

For infrastructure that may already be located within an identified future retreat location, not allowing for any future upgrading or installation of new infrastructure. The installation of infrastructure is to be limited to outside the identified risk zone, and preferably perpendicular to the coast, as opposed to parallel, where possible. .

Land acquisition and impermanent land tenure

There may be potential for compensation claims to be made where private land will be affected by erosion and inundation.

Acquisition of land, through compulsory acquisition or market purchase can be explored for private land located within an identified area where a retreat strategy applies. Where land is acquired ahead of coastal risks being experienced, there is opportunity to lease these landholdings to provide income streams, and continue the use and enjoyment of coastal land.

In new coastal development areas, the release of private land should consider leasehold rather than freehold sale, to avoid future pressures and costs to protect private coastal land.

Notification on Title

In all instances, an effective and appropriate planning response is to place a notification on title on all affected landholdings, informing landholders of the status of the land being located within a vulnerable coastal area which has a retreat strategy applicable to it. This ensures all land holders and potential land purchases are aware of the risks, and assists to avoid an assumption that the land value will be retained in perpetuity through coastal protection works.

5. References

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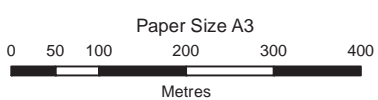
Appendices

Appendix A – Coastal Management Units



LEGEND

- Coastal Management Units
- Local Government Boundary



City of Fremantle
Coastal Adaptation Plan

Job Number | 61-34650
Revision | B
Date | 26 Oct 2017

Coastal Management Units

Figure 1

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		Name	Signature	Name	Signature	Date
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Appendix H – Adaptation Options Evaluation Report



City of Fremantle & Town of Mosman Park Coastal Adaptation Plan - Appendix H Adaptation Options Evaluation Report

October 2017

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Appendices

Appendix A – Coastal Management Unit Risk Maps

Appendix B – MCDA Results

1. Introduction

1.1 Background

The City of Fremantle on behalf of the City of Fremantle and Town of Mosman Park engaged GHD to deliver the Port, Leighton and Mosman Beaches Coastal Hazard Risk Assessment and Management Adaptation Plan. This project is supported by the Department of Planning's Coastal Management Plan Assistance Program Grant.

The overall objectives of the project are to identify coastal hazard risks and to properly plan for adaptive land use and development along the Port, Leighton and Mosman Beach coast in light of a changing coastal environment, through a coastal adaptation plan.

An Adaptation Options Compendium has been developed which outlines the coastal hazard risk profile for the Port, Leighton and Mosman Coast, identifies existing controls to manage erosion and identifies the suite of suitable adaptation measures that can be implemented along the coast to mitigate these risks.

In this phase of the study, Phase 4 – Coastal Adaptation Planning, evaluation of the adaptation options developed in the Adaptation Options Compendium has been undertaken to assess the potential benefits and impacts to social, environmental and economic values in line with the adaptation pathways approach.

1.2 Overview of options evaluation approach

To evaluate the benefits and impacts of the different adaptation options, a multi criteria analysis approach (MCA) has been used. The purpose of the MCA is to compare and assess different options designed to reach the same objectives, when options are best assessed by considering a variety of criteria. An important factor when comparing materially different options is to make sure that the options are in general capable of achieving the overall objective. This can at times be difficult because different options may achieve the desired objectives to different extents and in adaptation planning the options are not equal. In the context of the Port, Leighton and Mosman Beach CHRMAP, the options being assessed in the MCA process are the different coastal adaptation measures.

While the study is not encompassing the whole of secondary sediment cell 25, Figure 1-1, it is a requirement that any coastal measures be considerate of their impacts on the remainder of the cell. Therefore the coastal adaptation measures will be developed for the whole tertiary sediment cell (whole of coast approach), with a focus on Port, Leighton and Mosman Beaches and may include a variety of different localised measures.

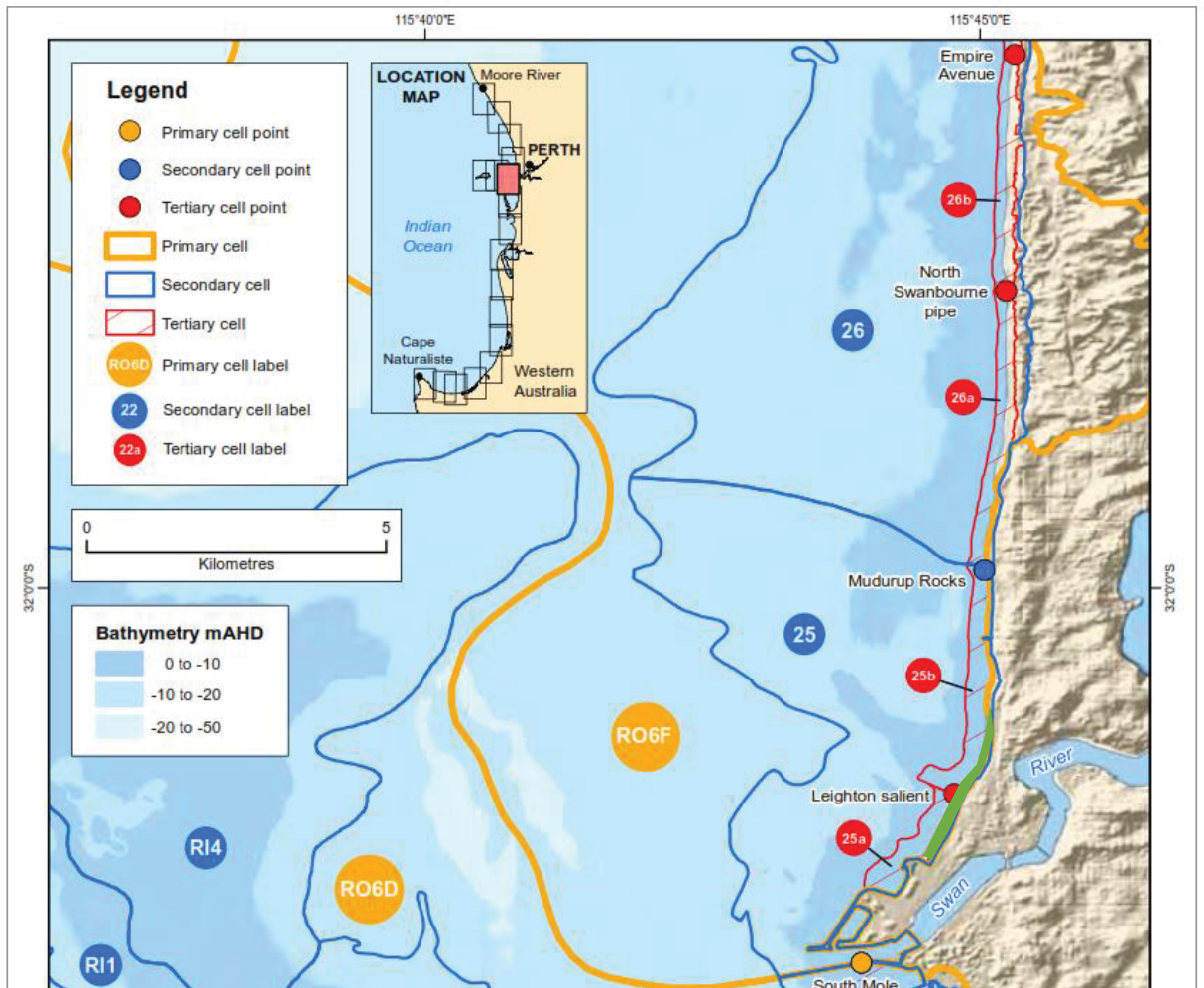


Figure 1-1 Sediment cells and study area (Green).

In line with GHD's trigger based flexible adaptation pathway employed in this study, we have assessed the short term adaptation options based on the tolerability levels and trigger points for each coastal management unit. For the adaptation planning process, the coast was broken down into coastal management units to assist in adaptation planning process for areas with common risk profiles. The extents of the coastal management units for adaptation planning are illustrated in Figure 1-2.

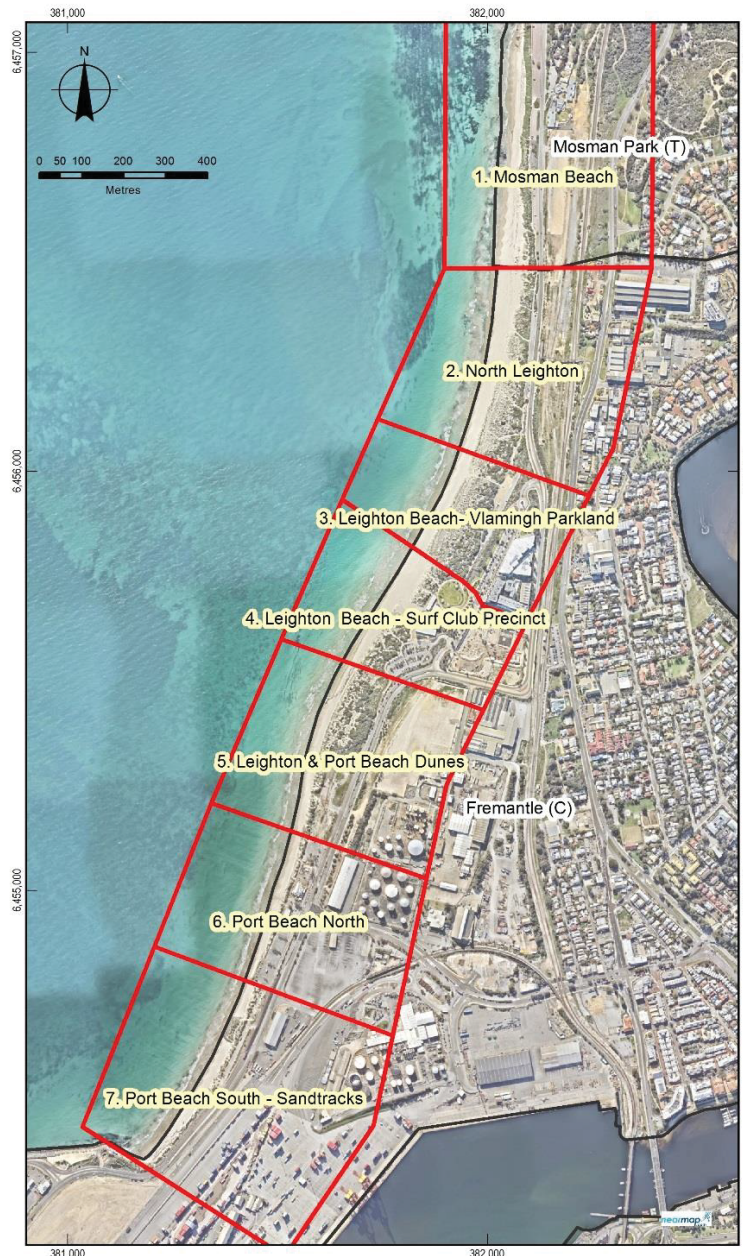


Figure 1-2 Coastal management units for adaptation planning

1.3 Approach to Multi Criteria Assessment

There are numerous methodologies that can be used to undertake a MCA. Amongst the most common are Multi Criteria Decision Analysis (MCDA) and Cost Benefit Analysis. In this study a MCDA approach has been used to undertake the MCA. The MCDA approach has been chosen as it uses measurable criteria which effectively considers the values and services which differentiate between the options. A benefit of the MCDA approach is that it does not monetise non-financial, intangible values or non-economic impacts/benefits when comparing different options. This reduces the uncertainty when attempting to evaluate the economic value of intangible values and services. In comparison, the cost benefit analysis process aims to estimate in dollars the benefit or impacts of different options on services and values. Due to the large number of values and services provided in this study area and the lack of quality processes to monetise impacts or benefits to these values and services, cost benefit analysis has not been used in this study.

1.4 Process overview

GHD has used the following MCDA process is informed by the Department for Communities and Local Government: London (2009) proposed methodology when developing the MCDA process for this project:

1. Establish the decision context
 - Define the project objectives
 - Establish aims of the MCDA Process
 - Define the context of the appraisal
2. Identify the options to be appraised
3. Identify the objectives and criteria
 - Identify criteria for assessing the consequences of each option
4. 'Score' each option in respect of each criteria.
5. 'Weight' the criteria to reflect their relative importance to the decision
6. Combine the scores and weights to derive an overall weighted score and rank the options
7. Review results and
8. Sensitivity testing – Assessing how sensitive the final scoring or ranking of the options is to changes in the weightings assigned to the criteria.

1.5 Limitations of the Multi Criteria Decision Assessment process

The MCDA process assists decision makers to build a mental model of the options when there are numerous criteria. It is a tool to help simplify complex issues.

A key understanding required of the outcomes of the MCDA process is that the MCDA does not necessarily include an assessment of feasibility. Thus the options assessed through an MCDA process must be adequately developed and refined, possibly through multiple MCA rounds to identify the preferred ranking of the options.

Ultimately, the MCDA process only ranks the performance of the options in achieving the stated objectives. The best practice is to limit options to those which would not be considered to have passed an initial feasibility test.

1.6 Purpose of this report

This document is not a standalone report and is to be read in conjunction with the Adaptation Options Compendium and the Coastal Adaptation Plan. The purpose of this report is to assess the adaptation options identified in the Adaptation Options Compendium and develop a whole of coast adaptation solution for Port, Leighton and Mosman Beaches. The adaptation options have been assessed against their respective benefits and impacts to social, environmental and economical values and services.

1.7 About limitations of this report

This report: has been prepared by GHD for City of Fremantle & Town of Mosman Park and may only be used and relied on by City of Fremantle & Town of Mosman Park for the purpose agreed between GHD and the City of Fremantle & Town of Mosman Park as set out in section 1.6 of this report.

GHD otherwise disclaims responsibility to any person other than City of Fremantle & Town of Mosman Park arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared this report on the basis of information provided by City of Fremantle & Town of Mosman Park and others who provided information to GHD (including Government authorities), which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

Climate change is a significant current and future issue and effects, such as sea level rise, are at this stage difficult to quantify to a high degree of certainty. The following assumptions have been made during the preparation of this report:

- The sole purpose of the reports are for evaluating coastal hazard risks and developing adaptation plans associated with coastal hazards and sea level rise for the City of Fremantle and Town of Mosman Park.
- The reports are produced for use by the City of Fremantle and Town of Mosman Park, and are not for use by any third party person or organisation. The information and recommendations are to be read and considered holistically, and content is not to be used selectively for purposes other than coastal hazard risk management (e.g. design) as this may misrepresent the data and processes herein and provide erroneous project or decision outcomes.
- The data and processes herein are to be used for coastal hazard risk assessment and adaptation planning purposes, approved by the City of Fremantle and Town of Mosman Park, and based on Australian and state government guidelines:
 - Western Australian Planning Commission and Department of Planning (2014). Coastal hazard risk management and adaptation planning guidelines, Perth, Australia.
 - Western Australian Planning Commission (2013). State Planning Policy No. 2.6 State Coastal Planning Policy.

These guidelines have been considered as per the requirements of the brief. This information has not been independently verified. Assumptions and recommendations that need further testing are noted in the text of the report.

- The establishment of the sea level rise aspects of the project uses data and scenarios based on publicly available information by the International Panel on Climate Change, summarised by the Western Australian Department of Transport:
 - Bicknell (2010). Sea Level Change in Western Australia: Application to Coastal Planning, prepared by the Department of Transport, Fremantle, WA.

- Climate change and coastal hazard assessment by its nature is a dynamic and ongoing process. As the sea level rise projections used are uncertain by nature, it is possible that the effects that actually occur may not be as assumed and stated in this exercise. Therefore, it is recommended that City of Fremantle and Town of Mosman Park routinely incorporate the latest climate change science and sea level rise cause and effect knowledge into all future planning.

GHD has prepared the indicative order of magnitude costs set out in sections 4.3 and 4.3.1 of this report using information reasonably available to the GHD employee(s) who prepared this report; and based on assumptions and judgments made by GHD based on capital and maintenance costs of similar foreshore stabilisation projects in Western Australia.

The Cost Estimate has been prepared for the purpose of comparing the feasibility of the different adaptation options in the Multi Criteria Decision Analysis and must not be used for any other purpose.

The Cost Estimate is a preliminary estimate only. Actual prices, costs and other variables may be different to those used to prepare the Cost Estimate and may change. Unless as otherwise specified in this report, no detailed quotation has been obtained for actions identified in this report. GHD does not represent, warrant or guarantee that the works can or will be undertaken at a cost which is the same or less than the Cost Estimate.

Where estimates of potential costs are provided with an indicated level of confidence, notwithstanding the conservatism of the level of confidence selected as the planning level, there remains a chance that the cost will be greater than the planning estimate, and any funding would not be adequate. The confidence level considered to be most appropriate for planning purposes will vary depending on the conservatism of the user and the nature of the project. The user should therefore select appropriate confidence levels to suit their particular risk profile.

2. MCA Process

2.1 Project objectives

The objectives used for identifying the coastal adaptation options for the Port, Leighton and Mosman Beaches have been informed by the values of the community and stakeholders and the implications of the short-term options for the medium and long-term options. The key objectives include:

- Maintain sufficient areas to allow for provision of the social and environmental values such as providing beach access, beach recreational amenity and healthy vegetated dune and beach areas. Specifically this includes maintaining space in the foreshore reserve that allows for the provision of public infrastructure and coastally dependent assets such as beach access paths, footpaths, cycle paths, local roads, carparks, toilet blocks and other infrastructure such as surf lifesaving clubs, which contribute to access and amenity of the coastal areas.
- Provide protection of coastally dependent economic values and functions that provide important contributions to the Western Australian economy such as the economic value provided to the state by port and port related industries and assets, freight rail and regional transport roads.

It is important to note that these two objectives are based on the present day values, and in the future, changes in the community and stakeholder's values and proposed uses of the land in the Port, Leighton and Mosman Beaches areas may influence and alter the medium and long term objectives of the coastal adaptation options.

The process of developing short or medium-term coastal adaptation options should not restrict the selection of medium and long-term options by future coastal managers. First pass assessment using the MCDA approach should be used to assess short-term adaptation options for individual Coastal Management Units (CMU). Following development of the short-term adaptation options for each CMU, whole of coast solutions should be developed and assessed based on compatibility of options and risk tolerability levels.

2.2 Appraisal context

2.2.1 Adaptation context and assumptions

The ultimate objective of the study is to identify the most feasible long term coastal adaptation options for the Port Leighton and Mosman coast when considering social, economic, environmental and infrastructure impacts over the 100 year planning period.

The adaptation pathways approach include a transition from short to medium term measures to long term retreat which will be used to compare to the option of retreating now (for further details refer to Adaptation Options Compendium).

While the time-period for comparison of the adaptation options will be the next 100 years, the focus of costing is based on short to medium term measures only.

Therefore in essence, the MCDA process is being undertaken to identify the best of the options between the adaptation measures and retreating at the time of the trigger. These options are called Interim protection measures.

Interim protection measures have been developed based on the assumption that they will provide a 50 year design life, after which retreat will occur (unless future triggers recommend further interim protection).

2.2.2 Coastal management unit tolerability profiles

Decisions must be made as the risk to assets increases from tolerable to intolerable. The points in time when decisions are required become trigger points for adaptation planning and are summarised in Table 2-1.

Table 2-1 Trigger and decision points.

Trigger	Tolerability	Decision	Implication/action
Trigger 1: Assets or values in coastal zone reach high risk level	Tolerable risk	Avoid and monitor	Avoid through strategic planning measures Ongoing monitoring
Trigger 2: Assets or values in coastal zone will reach extreme risk level in next planning period	Increasing likelihood of intolerable risk	Accommodate and monitor	Accommodate through asset specific activities Ongoing monitoring
Trigger 3: Assets or values in coastal zone reach extreme risk level	Intolerable risk	Interim protection may be viable, retreat or protect	Evaluate whether interim protection is justifiable on social, environmental, and economic grounds. Where interim protection is justifiable, determine the nature of the works based on social, environmental and economic grounds.
Trigger 4: Assets or values in coastal zone continue to be extreme	Intolerable risk	Protection is not viable, retreat	Actively plan for retreat in a coordinated manner. This should be led by state government, as the tier of government with the jurisdiction to change land use.

The coastal hazard risk levels and tolerability ratings from the risk assessment in Appendix E of the Coastal Adaptation Plan has been used to establish the tolerance profile for each CMU in the short, medium and long-term and is shown below in Table 2-2. A summary map of the coastal hazard risks is shown in Appendix A of this report.

Table 2-2 Summary of coastal hazard risk tolerance levels and trigger points per CMU.

Management Unit	Short	Medium	Long
1. Mosman Beach	Intolerable Trigger 3	Intolerable Trigger 3A	Intolerable Trigger 3A
2. North Leighton	Tolerable Trigger 1	Tolerable Trigger 2	Intolerable Trigger 3
3. Leighton Beach- Vlamingh Parkland	Tolerable Trigger 1	Tolerable Trigger 2	Intolerable Trigger 3
4. Leighton Beach - Surf Club Precinct	Tolerable Trigger 2	Intolerable Trigger 3	Intolerable Trigger 3A
5. Leighton & Port Beach Dunes	Tolerable Trigger 2	Intolerable Trigger 3	Intolerable Trigger 3A
6. Port Beach North	Intolerable Trigger 3A	Intolerable Trigger 3A	Intolerable Trigger 3A
7. Port Beach South - Sandtrax	Intolerable Trigger 3A	Intolerable Trigger 3A	Intolerable Trigger 3A

3. Short-Term Adaptation Options

The adaptation options developed in the Adaptation Options Compendium have been assessed to identify the highest ranked options in the short term for each individual CMU.

3.1 Assessment criteria

The criteria to assess the coastal adaptation options have been adapted from the MCDA criteria developed for the South Fremantle Coast - Coastal Adaptation Plan (GHD 2016) prepared for the Cockburn Sound Coastal Alliance and reflects the different land use composition and values which are specific to this region. Erosion is the dominant coastal hazard in all the coastal management units of Port, Leighton and Mosman Beaches, so the criteria used reflect the potential impact that the different coastal adaptation options have on social, economic and environmental values.

A summary of the criteria, what they are a measurement of, and the specific purpose of inclusion of the criteria in the MCA process is shown in Table 3-1.

3.2 Adaptation options

The adaptation options are detailed further in the adaptation options compendium but are summarised below:

- Retreat
- Dune stabilisation, revegetation & nourishment (Dune S,R&N)¹
- Offshore breakwaters and nourishment
- Groynes and nourishment or
- Seawall and nourishment².

Across the study area, dune stabilisation and revegetation alone without ongoing nourishment is not considered a suitable option in areas where risk levels are extreme. This option is considered to be an accommodation level option, and is only a suitable option in areas where the risk levels are tolerable, assisting to delay the timeframe when implementation of a higher level of risk remediation is required. Because accommodation measures do not meet the same risk mitigation objectives as interim protection measures, they have not been considered alongside the above adaptation options. In an MCDA process only options which meet the same objectives should be compared.

¹ Dune stabilisation, revegetation & nourishment for Coastal Management Unit 1 is engineered cliff stabilisation with revegetation and nourishment.

² For Coastal Management Unit (CMU) 4, Interim Protect 3 is a buried seawall

Table 3-1 MCDA Criteria summary

Criteria	units	Measure	Purpose
Beach area (habitat and recreational amenity area)	%	Potential beach area lost from coastal erosion hazards with adaptation measure in place.	To identify if the adaptation option reduces or promotes erosion and loss of beach area between the mean water line and dune vegetation.
Dune vegetation area (habitat area)	%	Potential dune area lost from coastal erosion hazards with adaptation measure in place.	Beach dunes are important to maintaining beach areas as they trap windblown sand, act as a source for sand in storm events and provide habitat area. Dunes area also protect the hinterland from direct storm action.
Length of road	%	Of road impacted by coastal erosion hazards with adaptation measure in place.	The length of road impacted indicates if access to the area may be impacted for road-based transport. And is also indicative of the length of cycle and footpath impacted as well.
Area of carpark	m ²	The area of carpark impacted by the residual hazard zone for the planning horizon.	The area of car parking is a value itself, providing access to the area for the community, but also a proxy to other values such as beach side facilities of showers, bins, shelters.
Number of residential lots	#	Number of residential lots within the residual hazard zone.	To understand the potential number of residential lots that may be impacted by coastal hazards.
Number of non-residential lots	#	Number of (non-residential) commercial lots within the residual hazard zone.	To understand the potential number of non-residential lots that may be impacted by coastal hazards.
Residual risk to assets	Risk Scale (1 to 4)	Highest residual risk from asset register within the coastal management unit after implementation of adaptation solution.	To identify if adaptation reduces the coastal hazard risk profile to assets and values.
Cost of implementation	\$M	Cost of implementation of the adaptation solution measured over the next 100 years considering implementation, maintenance costs and decommissioning costs. Maintenance costs have been included for existing erosion protection structures such as the Port Beach Road South Buried seawall which was upgraded during the road realignment.	To understand the whole of life costs of the adaptation solution.

3.3 Scoring and assumptions

Given that detailed coastal hazard assessment is not revisited for each of the proposed adaptation options, it is necessary to make assumptions to define the residual hazard area (and hence criterion score) associated with each of the adaptation options. This was required for all criterion, except for the cost of implementation criterion that are independent of changes to the hazard zones.

First, an assessment was made on how the hazard risk zones would change in light of implementation of each adaptation option:

- Retreat – This adaptation option will have no impact on the hazard zones. Scoring of dune, beach and car park areas at risk in the short term assume that these areas will be lost or retreated from, and not be relocated elsewhere as in the short term there will be no changes to the coastal reserve.
- Engineered cliff stabilisation with revegetation and nourishment (Applicable to CMU 1 at Mosman Park only)- This adaptation option is assumed to act like a seawall such that the rare risk zone will only impact assets and land in front of the stabilised dune/cliff. It has therefore been assumed that 100% of beach area and 0% of dune area will be lost during a rare erosion event.
- Dune SR&N- Does not physically stop erosion, but provides an increased buffer zone. It has therefore been assumed that 75% of beach area at risk of erosion during a rare event and that 75% of dune area at risk of erosion during a rare erosion event will be lost.
- Offshore breakwaters and nourishment- Have a significant effect on reducing the nearshore wave environment and erosive effects. It has therefore been assumed that only 25% of beach area at risk of erosion during a rare event will be lost and that 0% of dune area at risk of erosion during a rare erosion event will be lost. There is also an increased buffer zone.
- Groynes and nourishment- Act to stabilise foreshores by providing an increased buffer zone
- Seawall and nourishment- act to protect assets and land behind, them but offer little protection to the land or assets in front of them. It has therefore been assumed that 100% of beach area and 0% of dune area behind the seawall will be lost during a rare erosion event. At Port Beach, where the dune is located in front of the seawall, it is assumed that 100% of dune in front of the seawall will be lost during a rare erosion event.
- Buried seawall and nourishment – acts to protects assets and land behind to a lesser extent than a normal seawall and attempts to maintain a greater beach area in front of the seawall with a better opportunity to recover. It has therefore been assumed that 75% of beach area at risk of erosion during a rare event and that 75% of dune area at risk of erosion during a rare erosion event will be lost.

Residual risk - Given the above-described changes to the hazard likelihood zones, for each coastal management unit the risk rating was reassessed and the risk level revised to the highest remaining risk after implementation of the adaptation solution. Retreat was assessed to have no change to the risk rating for social risks tied to loss of an area or value as it has been assumed under this retreat scenario that in the short-term services and values provided by areas and assets retreated from will not be replaced.

Implementation costs-are based on net present value calculation of capital (commissioning), decommissioning and annual maintenance costs required for the adaptation option. For interim protection measures, adaptation options have been costed based on high-level engineering

design costs per linear meter of foreshore. Capital costs have been considered for implementation in 2020, the engineering design life of these structures is assumed to be 50 years with decommissioning costs occurring in year 51. The implementation cost for the retreat scenario are assumed to be nil. Realistically, in the longer term there will be a cost to implement the retreat option, but the magnitude of these costs is very difficult to assess. Instead, these costs are considered by using the proxy criterion of the beach area, dune vegetation area and carpark area.

It should be noted that whilst decommissioning costs have been included in the implementation costs, it is not anticipated that interim protection measures will have to be decommissioned at the end of the short or medium-term as the amount of sea level rise, based on current predictions over the next 100 is not expected to make interim protection measures unfeasible. Implementation costs have been estimated based on net present value with a discount rate of 2.1%³.

3.4 Criteria weightings

The weightings of the individual criteria vary between each coastal management unit and are dependent upon the difference between the calculated criterion values for the different adaptation options and the relative importance of the remaining values. Weighting of values was determined by the steering committee in an MCDA workshop with weightings assessed based on the results of the community consultation and steering committee understanding of issues. Weightings of the criteria used in the MCDA are summarised in Table 3-2. CMU's with criteria weightings of zero (blank in Table 3-2) indicates that the criterion scores of all the adaptation options being compared are equivalent, and therefore this criterion is not required in the cumulative scoring to differentiate between the options.

Table 3-2 Distribution of criteria weighting for each CMU.

Criterion	1. Mosman Beach	2. North Leighton	3. Leighton Beach - Vlamingh Parkland	4. Leighton Beach - Surf Club Precinct	5. Leighton & Port Beach Dunes	6. Port Beach North	7. Port Beach South - Sandtrax
Length of road							0.13
Dune vegetation area	0.31	0.31	0.35	0.25	0.35	0.06	
Beach area	0.31	0.31	0.35	0.25	0.35	0.39	0.25
Area of carpark						0.22	0.25
Number of non-residential lots				0.13		0.11	0.13
Residual risk to assets	0.13	0.13	0.12	0.13	0.12	0.11	0.13
Implementation Cost	0.25	0.25	0.18	0.25	0.18	0.11	0.13
TOTAL	1.00	1.00	1.00	1.00	1.00	1.00	1.00

³ Based on Garnaut Climate Review figure for GNP growth in 21st century (Garnaut, 2008).

3.5 Options ranking

With individual scores and weighted criteria defined for each CMU, the weighted scores are calculated and used to rank the adaptation options. Table 3-3 below shows the ranking of the weighted scores from the MCDA process for each CMU. For a detailed breakdown of the scoring results for each CMU, refer to Appendix B.

Table 3-3 Adaptation options ranking per CMU.

	Retreat	Dune or Engineered Cliff Stabilisation with R&N	Offshore breakwaters and nourishment	Groynes and nourishment	Seawall and nourishment
1. Mosman Beach ⁴	4	2	1	3	NA
2. North Leighton	4	3	1	2	NA
3. Leighton Beach-Vlamingh Parkland	4	3	1	2	NA
4. Leighton Beach - Surf Club Precinct	5	4	1	2	3
5. Leighton & Port Beach Dunes	4	3	1	2	NA
6. Port Beach North	3	2	NA	NA	1
7. Port Beach South - Sandtracks	3	2	NA	NA	1

3.6 Sensitivity of options

Sensitivity assessment for each coastal management unit was undertaken to assess the percentage change required to each criteria to result in a shift in the first ranked option. Sensitivity assessment was undertaken using Hiview3 software by Catalyze, a decision-modelling tool that is used to appraise and evaluate options.

Table 3-4 indicates for each criteria which direction a cumulative point score needs to shift in, which option the shift is towards and the sensitivity level of the shift required is indicated by the colour:

- Red indicates a shift of < 5%
- Orange indicates a shift of 5-15%
- Green indicates a shift of >15%
- Greyed out cells indicate criteria which was equivalent between each option and therefore not assessed in the scoring and weighting.

⁴ Cumulative weighted scores for Mosman beach options engineered cliff stabilisation with revegetation and nourishment and offshore breakwaters and nourishment were ranked equal first as described in section 3.5.

Table 3-4 Adaptation options sensitivity testing results.

CMU	# Ranked Option	Direction of Cumulative Weight Change	Length of road	Dune vegetation area	Beach area	Area of carpark	Number of non-residential lots	Residual risk to assets	Implementation Cost
1	Offshore Breakwater and Nourishment	Decrease			Engineered Cliff SR&N				
		Increase							Engineered Cliff SR&N
2	Offshore Breakwater and Nourishment	Decrease							
		Increase							Retreat
3	Offshore Breakwater and Nourishment	Decrease							
		Increase							Retreat
4	Offshore Breakwater and Nourishment	Decrease		Groynes and nourishment					
		Increase					Seawall and nourishment		Groynes and nourishment
5	Offshore Breakwater and Nourishment	Decrease							
		Increase							Retreat
6	Seawall and nourishment	Decrease							
		Increase							Retreat
7	Seawall and nourishment	Decrease							
		Increase			Dune SR&N				Dune SR&N

The results of the sensitivity analysis have been used to confirm the ranking and the recommendation of the adaptation options for each CMU. Based on the results in Table 3-4 it can be seen that CMU 1- Mosman Beach, CMU 4 –Leighton Beach – Surf Club Precinct and CMU 7 – Port Beach South - Sandtrax have a higher degree of sensitivity to the combined scoring of the adaptation options.

The results for CMU 1 - Mosman Beach, identified that the ranking of this cell was particularly sensitive to the weighting of implementation cost, which would result in a shift of the first ranked option to engineered cliff stabilisation with revegetation and nourishment.

In CMU 4 –Leighton Beach – Surf Club Precinct the offshore breakwater and nourishment interim protection option was identified to be sensitive to changes in the weighting to criteria of dune vegetation area and implementation cost, which would result in a shift of the first ranked option to groynes and nourishment.

In CMU 7 – Port Beach South - Sandtrax the seawall and nourishment interim protection option was identified to be particularly sensitive to changes in the weighting to the beach area criteria, which would result in a shift of the first ranked option to dune stabilisation with revegetation and nourishment.

Now that the prioritised adaptation options have been assessed and ranked in the short term, the next stage is to develop the whole of coast, long term adaptation options pathways, which is developed in section 4.

4. Long Term Adaptation Pathways

Long term adaptation pathways have been developed for the whole of coast based on two different risk mitigation pathways.

- The first adaptation pathway, Option 1, is based on implementing adaptation options where a trigger point 2 or higher has been reached in the short-term. Eg in locations where risk is presently intolerable or going to become intolerable in the medium-term.
- The second adaptation pathway, Option 2, uses a risk based trigger point pathway, where risks are only mitigated with adaptation options once an areas risk profile is identified as becoming intolerable, reaching trigger 3.

The two different risk adaptation pathways have been developed and assessed as detailed below.

4.1 Option 1: Mitigate tolerable and intolerable risks

Principle: Implement interim protection to all coastal management units with intolerable and tolerable risks, (trigger 2 or higher) for any given planning period, reducing the overall risk levels to low or medium.

Table 4-1 Mitigate tolerable and intolerable risks adaptation pathway.

CMU	Short		Medium		Long	
	Present	2030	2050	2070	2090	2110
1. Mosman Beach	Interim Protection			Interim Protection or Retreat	Interim Protection or Retreat	Interim Protection or Retreat
2. North Leighton	Interim Protection			Interim Protection or Retreat	Interim Protection or Retreat	Interim Protection or Retreat
3. Leighton Beach-Vlamingh Parkland	Interim Protection			Interim Protection or Retreat	Interim Protection or Retreat	Interim Protection or Retreat
4. Leighton Beach - Surf Club Precinct	Interim Protection			Interim Protection or Retreat	Interim Protection or Retreat	Interim Protection or Retreat
5. Leighton & Port Beach Dunes	Interim Protection			Interim Protection or Retreat	Interim Protection or Retreat	Interim Protection or Retreat
6. Port Beach North	Interim Protection			Interim Protection or Retreat	Interim Protection or Retreat	Interim Protection or Retreat
7. Port Beach South - Sandtracks	Interim Protection			Interim Protection or Retreat	Interim Protection or Retreat	Interim Protection or Retreat

4.1.1 Interim protection measures

To achieve a whole of coast adaptation solution to meet the above mitigate tolerable and intolerable risks pathway requires complimentary interim protection measures that will work together. The short-term interim protection measures ranking from section 3 in this report indicates that offshore breakwaters with nourishment is the number one solution for CMUs 1 (Mosman Park) to 5 (Leighton & Port Beach Dunes) and seawall and nourishment recommended for CMUs 6 and 7 (Port Beach North and South). Dune stabilisation with revegetation and nourishment whilst being considered a suitable adaptation option for CMU 7 – Port Beach South -Sandtrax, the risk profile for this option does not meet the guiding principles for option 1.

4.2 Option 2: Mitigate intolerable risks

Principle: Implement interim protection only to coastal management units with intolerable risks for the given planning periods to maintain flexibility of future adaptation pathways.

4.2.1 Option 2 Mitigate intolerable risk adaptation pathway

The mitigate intolerable risk adaptation pathway is summarised below in Table 4-2.

Table 4-2 Option 2 Mitigate intolerable risk adaptation pathway.

CMU	Short		Medium		Long	
	Present	2030	2050	2070	2090	2110
1. Mosman Beach	Engineered dune stabilisation with revegetation and nourishment.			Interim Protection or Retreat	Interim Protection or Retreat	
2. North Leighton	Accommodate		Accommodate		Interim Protection or Retreat	
3. Leighton Beach-Vlamingh Parkland	Accommodate		Accommodate		Interim Protection or Retreat	
4. Leighton Beach - Surf Club Precinct	Accommodate		Interim Protection or Retreat		Interim Protection or Retreat	
5. Leighton & Port Beach Dunes	Accommodate		Interim Protection or Retreat		Interim Protection or Retreat	
6. Port Beach North	1. Seawall or 2. Dune stabilisation, revegetation & nourishment			Interim Protection or Retreat	Interim Protection or Retreat	
7. Port Beach South - Sandtracks	1. Seawall or 2. Dune stabilisation, revegetation & nourishment			Interim Protection or Retreat	Interim Protection or Retreat	

4.2.2 Interim protection measures

Given that the two regions requiring protection in the short term are at distinct ends of the project area, the protection options need to work in isolation and cannot be dependent upon protection properties provided by the adjacent CMU's which are accommodating the risks, and needs to minimise the impacts on adjacent areas. As such Table 4-2 includes the suitable interim protection measures for option 2, mitigate intolerable risk adaptation pathway.

Considering a whole of coast adaption solution, offshore breakwaters and nourishment is not an appropriate solution for CMU 1, Mosman Beach, anymore as implementation of offshore breakwaters in this area is likely to impact sediment transport and subsequently neighbouring CMUs for which accommodation pathways are selected.

4.2.3 Accommodate measures

Accommodation measures recommended to support the mitigate intolerable risk adaptation pathway for CMU's 2- North Leighton to CMU 5 – Leighton and Port Beach Dunes include:

- Annual beach monitoring and reporting as an extension of the current annual beach monitoring already underway for Port Beach.
- Dune stabilisation through a combination of sand traps, erosion matting and revegetation and ongoing maintenance to promote healthy dune vegetation to minimise loss of dunes during storm events.

4.3 Outcomes of the different adaptation pathways

The budget estimates provided in this section are indicative only. The estimates are based on average typical cross sections and do not consider specific physical conditions of each site. As a result, further investigation could show that costs vary significantly from values shown in this section. These estimates were initially prepared for reference in the multi criteria decision making process and are not produced specifically for the implementation plan and budgeting purpose.

When comparing the overall implementation budget estimates between the two presented adaptation option pathways, the total budget estimate of option 1 is \$87.5M in comparison to \$33.8M for option 2, as detailed in Table 4-3. The accommodate operating costs included have been calculated assuming maintenance over a 50 year period, to 2070, in line with the design life of the interim protection options. The capital budget estimates included in Table 4-3 are for implementation of new structures, but the cumulative operating costs include maintenance costs for both new and existing structures.

Table 4-3 Estimated total order of magnitude budget estimates to 2070

Adaptation Pathway		Capital (\$M)	Decommissioning (\$M)	Operating (\$M)	Whole of Life (\$M)
Option 1 – Mitigate tolerable and intolerable risks	Interim protection costs	\$49.3	\$5.3	\$32.9	\$87.5

Option 2 – Mitigate intolerable risk	Interim protection costs	\$16.3	\$1.81	\$11.8	\$29.9
	Accommodate costs	\$2.4	n/a	\$1.9	\$3.9
	Total	\$18.3	\$1.81	\$13.7	\$33.8

4.3.1 Recommended adaptation pathway

The current state coastal planning policy supports maintaining flexibility of options and accepting some level of risk as it only allows for protection when all other options for a section of a coast have been explored. As such the recommended approach for the adaptation plan is the implementation of Option 2, the trigger based, mitigate intolerable risk adaptation pathway. Table 4-4 and Table 4-5 provide a summary of the anticipated costs with this adaptation pathway. As described in section 1.7 About limitations of this report, the below implementation costs are costings that were prepared for the purpose of comparing the feasibility of the different adaptation options in the Multi Criteria Decision Analysis and must not be used for any other purpose.

Table 4-4 Implementation budget estimate per planning period for the recommended adaptation pathway.

Short-term (to 2030)	Medium-term (to 2070)	Long-term (to 2110)
\$ 20.7 M	\$ 13.1 M	To be assessed in future adaptation plans.

Table 4-5 Estimated Total Costs to 2070 per CMU.

Coastal Management Unit	Adaptation Option	Whole of Life Estimated Discounted Cash Flow Budget Estimate to 2070 (\$M)
1.0 Mosman Beach	Engineered Cliff Stabilisation & Revegetation	
	- capital costs	3.7
	- operating costs	1.6
	- decommissioning costs	0.4
	Total costs	5.7
2.0 North Leighton /Vlamingh	Dune Stabilisation + Revegetation	
	- capital costs	0.7
	- operating costs	0.6
	- decommissioning costs	0.0
	Total costs	1.3
3.0 Leighton - Vlamingh Parkland	Dune Stabilisation + Revegetation	
	- capital costs	0.4
	- operating costs	0.4
	- decommissioning costs	0.0
	Total costs	0.8
4.0 Leighton - Surf Club Precinct	Dune Stabilisation + Revegetation	
	- capital costs	0.4
	- operating costs	0.5
	- decommissioning costs	0.0
	Total costs	0.9
5.0 Leighton/ Port Parkland	Dune Stabilisation + Revegetation	
	- capital costs	0.6
	- operating costs	0.5
	- decommissioning costs	0.0
	Total costs	1.1
6.0 Port Beach North	Hard Passive Protection and Nourishment	
	- capital costs	5.8
	- operating costs	4.3
	- decommissioning costs	0.6
	Total costs	10.7
7.0 Port Beach South - Sandtrax	Hard Passive Protection and Nourishment	
	- capital costs	6.5
	- operating costs	6.0
	- decommissioning costs	0.8
	Total costs	13.3
	Mosman Park Total	5.7
	City of Fremantle Total	28.1
	Grand Total	33.8

5. Conclusions and Recommendations

This report provides a high-level assessment of the short term and long-term adaptation pathways that have been assessed using a multi-criteria decision analysis process to assess the ranking of the options based on specific quantified criterion. The results of this assessment do not necessarily indicate acceptability of the proposed options and these results are recommended to guide the City of Fremantle and Town of Mosman Park to identify the timing and recommended nature of upcoming projects. Implementation of the specific preferred options shall be based on engineering feasibility assessments and engineering designs.

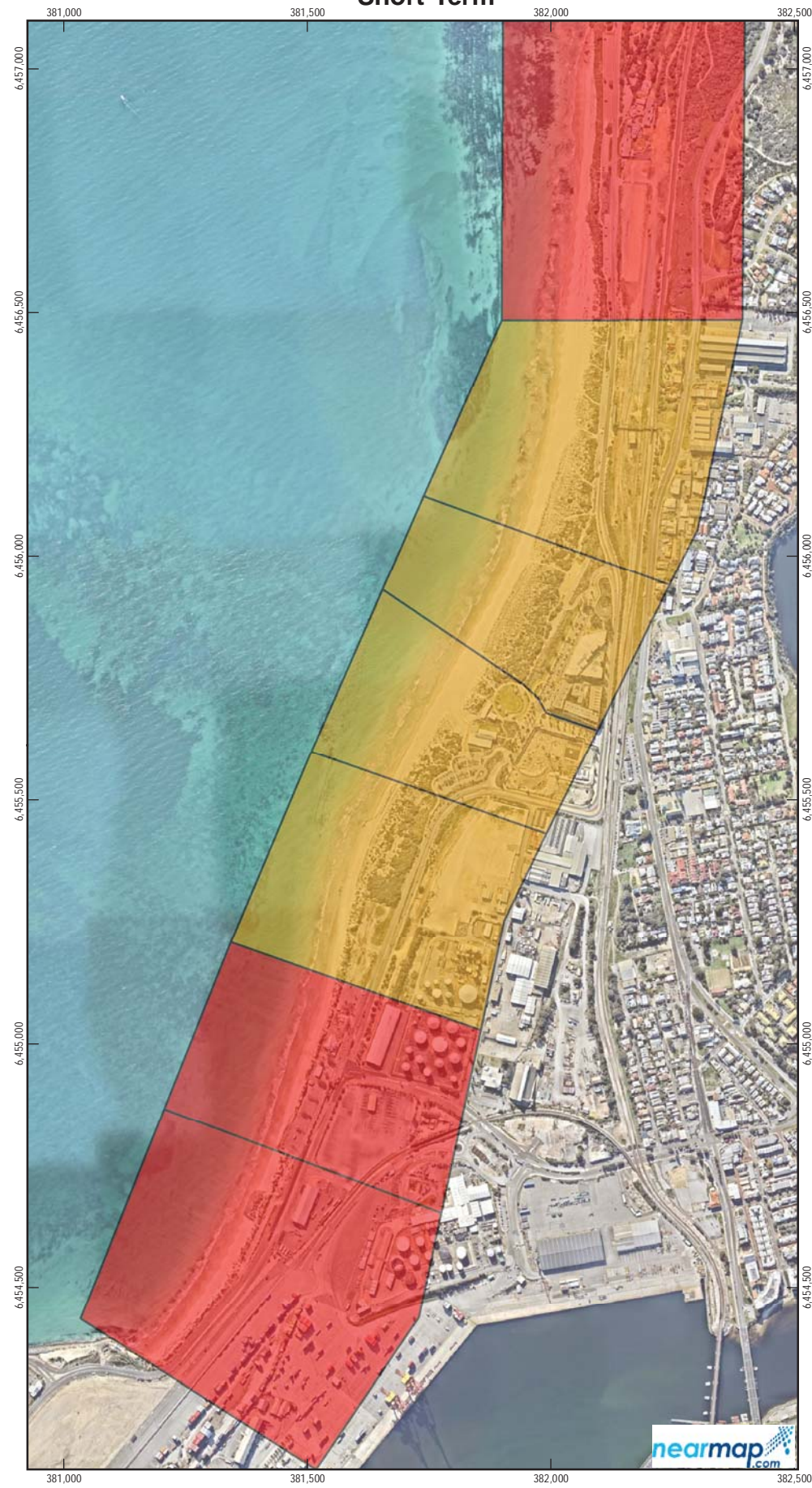
Although the MCDA process includes an assessment based on potential benefits and impacts to a variety of criteria, it is noted that this is not the equivalent of undertaking an engineering feasibility study. It is therefore recommended that engineering feasibility studies to assess the interim protection options in more detail and to assess localised implications to coastal processes and sediment transport pathways for all interim protection measures of the preferred adaptation pathway are undertaken

The recommended adaptation pathway for the Port, Leighton and Mosman Beach is Option 2, the mitigate intolerable risk, trigger based adaptation pathway. This pathway will allow flexibility for future coastal adaptation planning decisions and only recommends interim protection in locations and times when risks become intolerable. The implementation costs of this pathway, are estimated to be in the order of \$34M over the next 50 years.

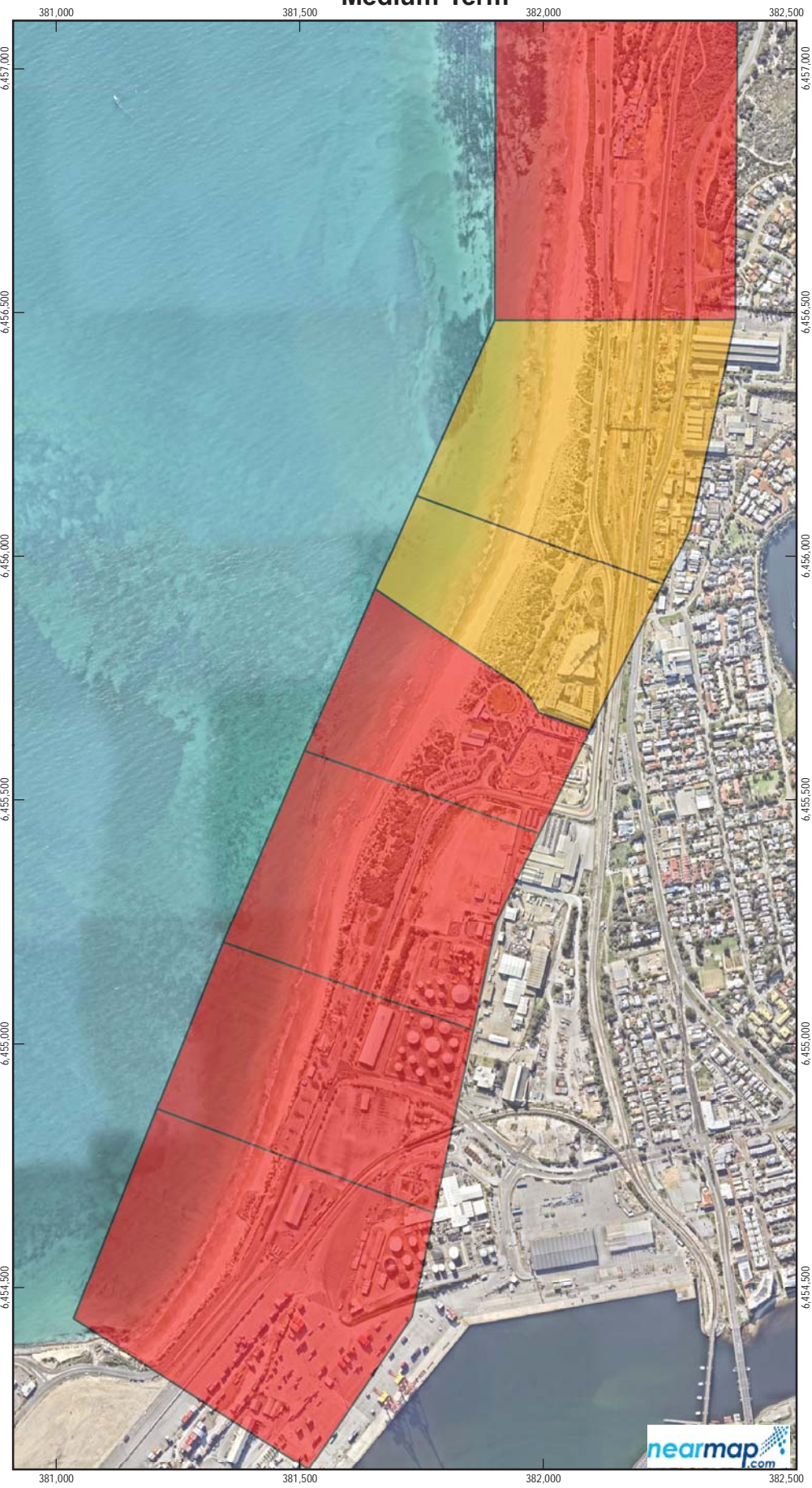
Appendices

Appendix A – Coastal Management Unit Risk Maps

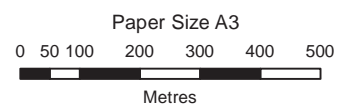
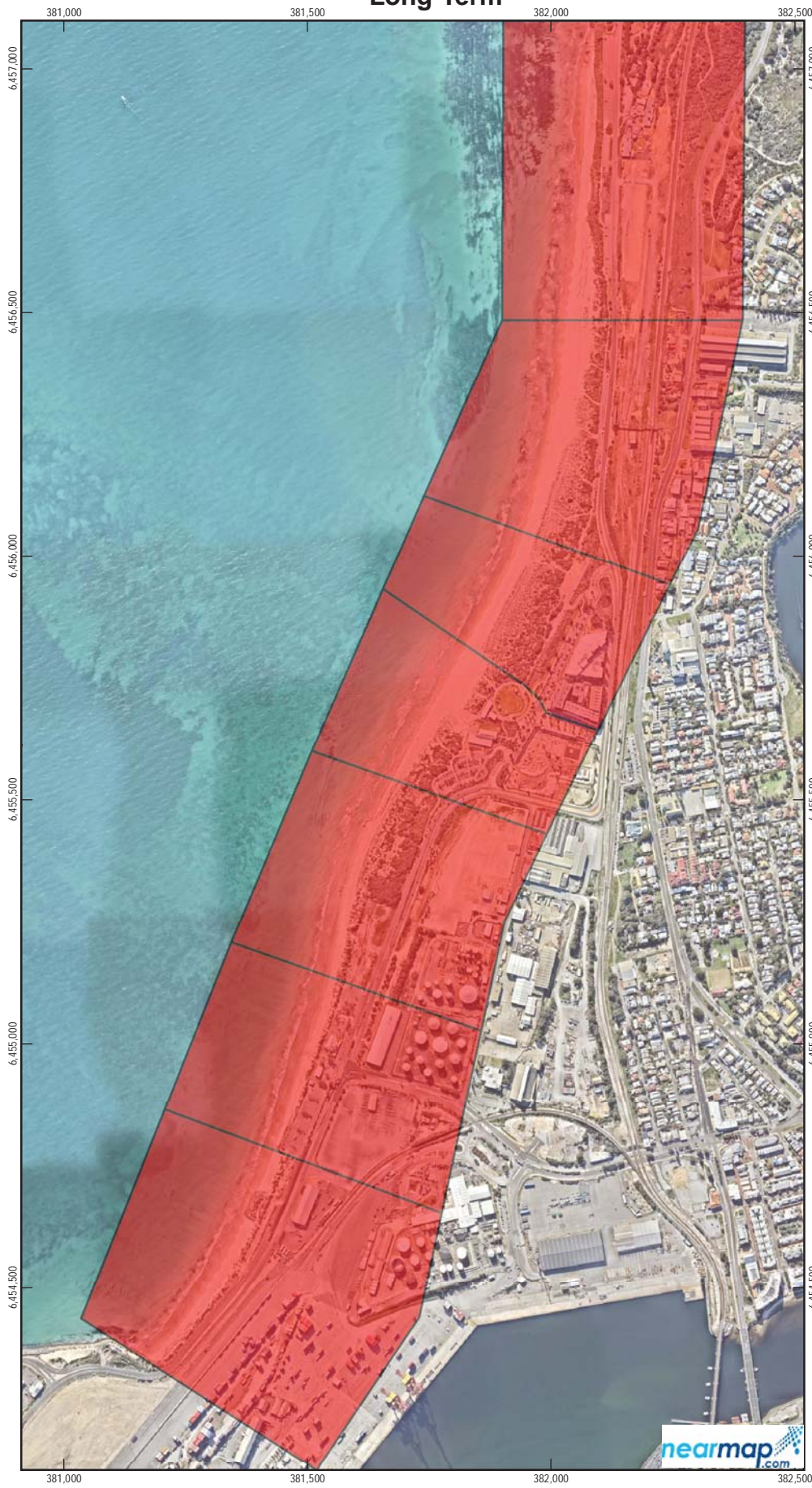
Short-Term



Medium-Term







Long-Term



Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50



Legend

- | | |
|--|---|
|  Low |  High |
|  Medium |  Extreme |



City of Fremantle
Coastal Adaptation Plan

Job Number | 61-34650
Revision | A
Date | 13 Jun 2017

Coastal Management Units Coastal Hazard Risk Levels Appendix A

Appendix B – MCDA Results

1.0 Mosman Beach			Short Term Adaptation Options - Criteria Scores				Normalised Criteria				
Value Type	Criteria	unit	Retreat	Engineered Dune Stabilisation & Revegetation & Nourishment	Offshore Breakwater and Nourishment	Groynes and Nourishment	Retreat	Engineered Dune Stabilisation & Revegetation	Offshore Breakwater and Nourishment	Groynes and Nourishment	Criteria Weight
ENV	Dune vegetation habitat area	%	40%	0%	0%	20%	100%	0%	0%	50%	0.31
SOC/ENV	Beach area (Habitat and Recreational Amenity)	%	100.0%	100.0%	25.0%	75.0%	100%	100%	0%	67%	0.31
RISK	Residual Risk	scale	4	3	1	1	100%	67%	0%	0%	0.13
ECON	Cost of implementation	\$M	\$ -	\$ 5.71	\$ 17.65	\$ 17.65	0%	32%	100%	100%	0.25
			Sum				3.00	1.99	1.00	217%	1.00
			Weighted				0.75	0.47665854	0.25	0.61458333	
			Rank				4	2	1	3	

2.0 North Leighton /Vlamingh			Short Term Adaptation Options				Normalised Criteria				
Value Type	Criteria	unit	Retreat	Dune Stabilisation, Revegetation & Nourishment	Offshore Breakwater and Nourishment	Groynes and Nourishment	Retreat	Dune Stabilisation, Revegetation & Nourishment	Offshore Breakwater and Nourishment	Groynes and Nourishment	Criteria Weight
ENV	Dune vegetation habitat area	%	40.0%	30.0%	0%	15%	100%	75%	0%	38%	0.31
SOC/ENV	Beach area (Habitat and Recreational Amenity)	%	100.0%	75.0%	25.0%	50.0%	100%	67%	0%	33%	0.31
RISK	Residual Risk	scale	3	3	1	1	100%	100%	0%	0%	0.13
ECON	Cost of implementation	\$M	\$ -	\$ 9.47	\$ 15.56	\$ 15.56	0%	61%	100%	100%	0.25
			Separated costs				3.00	3.02	1.00	1.71	1.00
			Sum				0.75	0.71975825	0.25	0.47135417	
			Weighted				4	3	1	2	
			Rank								

3.0 Leighton - Vlamingh Parkland			Short Term Adaptation Options				Normalised Criteria				
Value Type	Criteria	unit	Retreat	Dune Stabilisation, Revegetation & Nourishment	Offshore Breakwater and Nourishment	Groynes and Nourishment	Retreat	Dune Stabilisation, Revegetation & Nourishment	Offshore Breakwater and Nourishment	Groynes and Nourishment	Criteria Weight
ENV	Dune vegetation habitat area	%	30.0%	22.5%	0%	11%	100%	75%	0%	38%	0.35
SOC/ENV	Beach area (Habitat and Recreational Amenity)	%	100.0%	75.0%	25.0%	50.0%	100%	67%	0%	33%	0.35
RISK	residual risk	scale	3	2	1	1	100%	50%	0%	0%	0.12
ECON	Cost of implementation	\$	\$ -	\$ 5.21	\$ 9.62	\$ 9.62	0%	54%	100%	100%	0.18
			Sum				3.00	2.46	1.00	1.71	1.00
			Weighted				0.82352941	0.65443119	0.17647059	0.42647059	
			Rank				4	3	1	2	

4.0 Leighton - Surf Club Precinct			Short Term Adaptation Options					Normalised Criteria					
Value Type	Criteria	unit	Retreat	Dune Stabilisation, Revegetation & Nourishment	Offshore Breakwater and Nourishment	Groynes and Nourishment	Buried Seawall and Nourishment	Retreat	Dune Stabilisation, Revegetation & Nourishment	Offshore Breakwater and Nourishment	Groynes and Nourishment	Buried Seawall and Nourishment	Criteria Weight
ENV	Dune vegetation habitat area	%	50.0%	37.5%	0%	25%	38%	100%	75%	0%	50%	75%	0.25
SOC/ENV	Beach area (Habitat and Recreational Amenity)	%	100.0%	75.0%	25.0%	50.0%	75.0%	100%	67%	0%	33%	67%	0.25
ECON	# of non residential lots	#	1	1	0	0	0	100%	100%	0%	0%	0%	0.13
RISK	residual risk	scale	3	2	1	1	2	100%	50%	0%	0%	50%	0.13
ECON	Cost of implementation	\$	\$ -	\$ 4.42	\$ 8.18	\$ 4.42	\$ 7.64	0%	54%	100%	54%	93%	0.25
			Sum					4.00	3.46	1.00	1.37	2.85	1.00
			Weighted					0.75	0.68	0.25	0.34	0.65	
			Rank					5	4	1	2	3	

5.0 Leighton/ Port Parkland			Short Term Adaptation Options				Normalised Criteria				
Value Type	Criteria	unit	Retreat	Dune Stabilisation, Revegetation & Nourishment	Offshore Breakwater and Nourishment	Groynes and Nourishment	Retreat	Dune Stabilisation, Revegetation & Nourishment	Offshore Breakwater and Nourishment	Groynes and Nourishment	Criteria Weight
ENV	Dune vegetation habitat area	%	50.0%	37.5%	0%	19%	100%	75%	0%	38%	0.35
SOC/ENV	Beach area (Habitat and Recreational Amenity)	%	100.0%	75.0%	25.0%	50.0%	100%	67%	0%	33%	0.35
RISK	residual risk	scale	3	2	1	1	100%	50%	0%	0%	0.12
ECON	Cost of implementation	\$	\$ -	\$ 6.67	\$ 12.34	\$ 12.34	0%	54%	100%	100%	0.18
Sum							3.00	2.46	1.00	1.71	1.00
Weighted							0.82352941	0.65419376	0.17647059	0.42647059	
Rank							4	3	1	2	

6.0 Port Beach North			Short Term Adaptation Options			Normalised Criteria			
Value Type	Criteria	unit	Retreat	Dune Stabilisation, Revegetation & Nourishment	Seawalls and Nourishment	Retreat	Dune Stabilisation, Revegetation & Nourishment	Seawalls and Nourishment	Criteria Weight
ENV	Dune vegetation habitat area	%	100.0%	75.0%	0%	100%	75%	0%	0.06
SOC/ENV	Beach area (Habitat and Recreational Amenity)	%	100.0%	75.0%	25.0%	100%	67%	0%	0.39
SOC	Car Park Area	%	71%	71%	0%	100%	100%	0%	0.22
ECON	# of non residential lots	#	100%		0%	100%	0%	0%	0.11
RISK	Residual Risk	scale	4	3	1	100%	67%	0%	0.11
ECON	Cost of implementation	\$	\$ -	\$ 5.80	\$ 10.68	0%	54%	100%	0.11
Sum						5.00	3.63	1.00	1.00
Weighted						0.8888	0.65754845	0.1111	
Rank						3	2	1	

7.0 Port Beach South - Sandtrax			Short Term Adaptation Options			Normalised Criteria			
Value Type	Criteria	unit	Retreat	Dune Stabilisation, Revegetation & Nourishment	Seawall and Nourishment	Retreat	Dune Stabilisation, Revegetation & Nourishment	Seawall and Nourishment	Criteria Weight
SOC	Length of Road total	m	523	261.5	0	100%	50%	0%	0.13
SOC/ENV	Beach area (Habitat and Recreational Amenity)	%	100.0%	75.0%	100.0%	100%	0%	100%	0.25
SOC	Car Park Area	%	100%	50%	0%	100%	50%	0%	0.25
ECON	# of non residential lots	#	1	1	0	100%	100%	0%	0.13
RISK	Residual risk		4	3	1	100%	67%	0%	0.13
ECON	Cost of implementation	\$	\$ -	\$ 11.54	\$ 13.49	0%	86%	100%	0.13
				Sum		5.00	3.52	2.00	1.00
				Weighted		0.88	0.50	0.38	
				Rank		3	2	1	

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Document Status

Revision	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
A	G Bertrand	S Hosseini	On File	S Hosseini	On File	15/06/2017
B	G Bertrand	S Hosseini	On File	S Hosseini	On File	05/09/2017
0	G Bertrand	S Hosseini		S Hosseini		26/10/2017

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